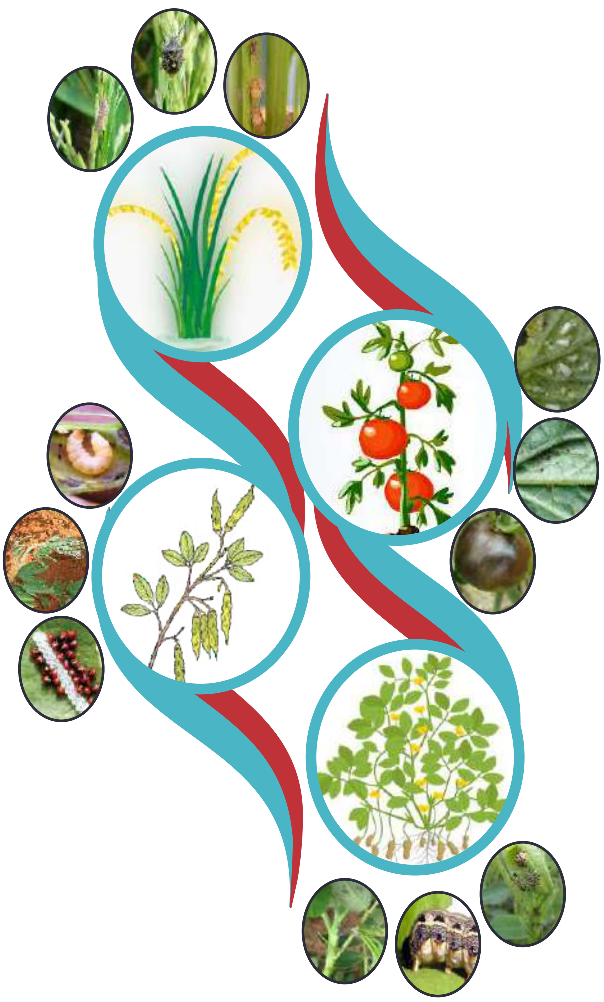
NCIPM

NICRA
National Innovations in Climate Resilient Agriculture

A TREATISE ON IMPACT OF CLIMATE VARIABILITY AND CHANGE ON INSECTS AND DISEASES



ICAR - National Research Centre for Integrated Pest Management
New Delhi

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A Treatise on
Impact of Climate Variability and Change on Insects and Diseases

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Foreword

Climate change effects are manifested on crop production, ecosystem services, food price, nutrition and hunger. Synergies and trade-offs between mitigation, adaptation and sustainable development needed to cope with impacts of 1.5°C global warming above pre-industrial levels ushered in the sixth annual report of International Panel of Climate Change require enabling actions accounting geophysical, environmental, technological, economic, socio-cultural and institutional dimensions. All components of agriculture are impacted by changing climate effects of increasing temperature, rising atmospheric carbon di oxide and changing precipitation not to exclude the perils of weather extremes such as drought, floods, cyclones, hailstorms frost and forest fires.

Insects and diseases are biotic perils of agricultural production and are associated with weather and climate change on ecological and evolutionary scales, respectively. Species adaptations determine the potential of insect populations, their damage and disease progressions to respond to environmental changes. Research studies under controlled conditions using growth cabinets, open top chambers, free air temperature enrichment, free-air carbon dioxide enrichment and carbon dioxide temperature gradient chamber facilities at global and national levels have clearly brought out direct as well as host mediated effects of increasing temperature and elevated carbon di oxide, respectively on the intrinsic life history features of insects and developmental characters of diseases. However, crop production happens amidst complex natural resource endowments and anthropogenic interventions. Hence, assessment of impact of climate change in field set up considering ecosystem characteristics is essential.

Indian Council of Agricultural Research launched the flagship scheme of 'National Initiative on Climate Resilient Agriculture' in February 2011 and was subsequently renamed 'National Innovations in Climate Resilient Agriculture'. Spread over two plan periods (XI & XII) of the Government of India, the mega scheme brought multiple sectors of agriculture on a common platform with three pronged objectives of climate change research, technology demonstrations and capacity building in the face of changing climate. The thematic institutions of National Research Centre for Integrated Pest Management, New Delhi and Central Research Institute for Dryland Agriculture, Hyderabad together put forth the needful research agenda for crop protection with selection of target crops and study locations from the diverse agro climatic zones.

Implementation pathway of project has been comprehensive with holistic information collection at field level with scientific surveillance plan and sampling procedures for insects and diseases adopted involving a network of researchers of varied disciplines. Database on agronomic practices, seasonal dynamics of insects, diseases, management interventions and meteorological variables developed using web server and their retrieval for the multiple crops/locations/seasons had offered visualization and analysis of data over short and long periods and across parameters of interest with the current reporting being on the field level impact of climate change on insect and disease spectrum of rice, pigeonpea, groundnut and tomato. The report has provided a methodological approach to assess the impact of climate change on time series data sets reflecting seasonal dynamics. Species specific responses to climate change deduced and reported would not only serve as bench mark for future comparison in respect of crops and agro ecologies but also assists in prioritization of candidate insects/diseases against which adaptive management strategies need to be developed and implemented in crop fields.

Although annual reports of NCIPM and NICRA over 2011 till 2021 contain some findings of the project, the current consolidated report titled '*A Treatise on Impact of Climate Variability and Change on Insects and Diseases*' is expected to bring visibility and utility by readers in the coming days. I appreciate the sincere and continued efforts of project team members from different parts of the country. I also congratulate the authors who with their sustained zeal for research in crop protection could bring out this valuable publication.

16/3/2022

[Subhash Chander]

March, 2022 **Director, ICAR-NCIPM, New Delhi**

PROLOGUE

Universe operates on the law of change, and changes are always challenging. Weather of today becomes the climate over periods. Weather, or climate variability and climate change do not operate in isolation but are intertwined and the impacts are cumulative. In agricultural production systems, the component of crop protection contributes to reduction of pestilence. Crop-insect-disease-weather interactions are a continuum over time and space. Assessment of impact of climate change on these interacting variables requires simultaneous quantifications of their states and rates. The 'National Innovations in Climate Resilient Agriculture (NICRA)' of the 'Indian Council of Agricultural Research (ICAR)' prioritised the assessment of climate change impact on insects and diseases of select crops *viz.*, rice, pigeonpea, groundnut and tomato in addition to development of forewarning models as resilient tools for pest management. Current report '*A Treatise on Impact of Climate Change on Insects and Diseases*' is an output of NICRA implemented by ICAR- National Research Centre for Integrated Pest Management, New Delhi co-opting a strong project team.

Field level data on crop, weather, climate, insect/disease dynamics and their management provide ample and immediate scope of understanding effects of climate change and to implement adaptive pest management strategies. Since systematic and quantified reporting and repository on the status of insects and diseases were lacking, a framework of database development on insects and diseases together with all other cropping system variables including simultaneous documentation of weather constituted the basic step of the project. Availability of information and communication tools (ICT) has made it possible to create a centralized database of multi seasons for crops-insects-diseases-weather for multiple locations. A total of 24 study locations from 10 agro climatic zones of 12 agro ecological regions across 11 States of India were co-opted for four target crops *viz.,* rice, pigeonpea, groundnut and tomato. Development and implementation of surveillance plan and procedures for insects and diseases *vis a vis* weather were made through formulation of standard data recording formats, guidelines and manuals facilitated by web based tools. Data reporting system enhanced the analyses of insect/disease/weather dynamics and interrelations amongst them. The long term average in respect of climatic variables of temperature and rainfall for the study locations obtained from ICAR-Central Research Institute for Dryland Agriculture (CRIDA) aided in quantifying the magnitude of climate variability and change. Use of deviations based on the actual and normal values alongside of seasonal dynamics of insects and diseases in respect of study locations and crops brought out the impact of individual climatic variables. However, the highlight has been the development and testing of scale neutral tool of 'species - climate change association index (SAI)' accounting the magnitude of climate change. SAIs portray the impact of climate change integrated qualitatively (+ or -) with or without quantitative significance. Although deciphered impacts of climate variability and change in respect for insects, diseases and agro ecologies for target crops are expected to change over time with farming situations, the current status would serve as a baseline for future works. The report would have done its duty if it propels further testing and use of study approach of SAI with use of dynamic long term normals of climatic variables. The logical and simple approach of SAI determining adaptive or vulnerable response of insects and diseases to the climate variability and change used in this report should set precedent for its replication in other crops and locations notwithstanding the fact that database offers additional scope for further and future analyses using advanced analytical tools. Report is also an important data resource book on weather, climate, insects and diseases. We fervently hope that the report would be of immense use for students, scientists, research managers and policy makers.

We sincerely acknowledge all project team members of the co-opted partner institutions under NICRA for their meticulous contribution to the comprehensive database on insects, diseases, and weather and production practices. The contributions by the project staff engaged as research associates, senior research fellow, young professionals, and pest scouts and data entry operators at different time periods are thankfully acknowledged.

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AB	:	*Alternaria* Blight
ACZ	:	Agro Climatic Zone
AEZ	:	Agro Ecological Zone
AICRPAM	:	All India Coordinated Research Project on Agrometeorology
ALS	:	*Alternaria* Leaf Spot
A-MaxT	:	Actual Maximum Temperature
A-MinT	:	Actual Minimum Temperature
ANOVA	:	Analysis of Variance
AP	:	Andhra Pradesh
APH	:	Aphids
APHI	:	Aphid Infestation
APHS	:	Aphid Severity
A-RF	:	Actual Rainfall
BB	:	Blackbug (Rice)
BB	:	Blue Butterfly (Pigeonpea)
BB	:	Bud Blight (Tomato)
BBtl	:	Blister Beetle
BCI	:	Bacterial Canker Incidence
BCS	:	Bacterial Canker Severity
BPH	:	Brown Plant Hopper
BSI	:	Bacterial Spot Incidence
BSS	:	Bacterial Spot Severity
CA	:	Crop Age
CB	:	Cow Bugs
CC	:	Climate Change / Coccinellids (Rice, Pigeonpea, Groundnut, Tomato)
CD	:	Critical Difference
CG	:	Chhattisgarh
CLS	:	*Cercospora* Leaf Spot
CR	:	Collar Rot
CRIDA	:	Central Research Institute for Dryland Agriculture
CV	:	Climate Variability/ Cucumo Virus (Tomato)
CW	:	Caseworm
DAT	:	Days After Transplanting
DHB	:	Dark Headed Borer
D-MaxT	:	Climatic Deviation: Maximum Temperature
D-MinT	:	Climatic Deviation: Minimum Temperature
DMRT	:	Duncan's Multiple Range test
D-RF	:	Climatic Deviation: Rainfall
DRR	:	Dry Root Rot
DSPS	:	Diagnosis and Sampling for Pest Surveillance
EBI	:	Early Blight Incidence

EBS	:	Early Blight Severity
ELS	:	Early Leaf Spot
ETL	:	Economic Threshold Level
FAO	:	Food and Agricultural Organisation
FW	:	*Fusarium* Wilt
GJ	:	Gujarat
GLH	:	Green Leaf Hopper
GM	:	Gall Midge
GMB	:	Green Mirid Bug
HAF	:	*Helicoverpa armigera* Fruit Damage
HAN	:	*Helicoverpa armigera* Larval Number
ICT	:	Information and Communication Technology
IMD	:	Indian Meteorological Department
ICAR	:	Indian Council of Agricultural Research
IPCC	:	Intergovernmental Panel on Climate Change
IPM	:	Integrated Pest Management
JDI	:	Jassid Infestation
JDN	:	Jassid Number
JS	:	Jassids
KA	:	Karnataka
LBI	:	Late Blight Incidence
LBS	:	Late Blight Severity
LF	:	Leaf Folder
LLPB	:	Lablab Pod Borer
LLS	:	Late Leaf Spot
LM	:	Leaf Miner
LMI	:	Leaf Miner Infestation
LMN	:	Leaf Miner Number (mines with live larvae)
LPB	:	Legume Pod Borer (*Maruca*)
MaxT	:	Maximum Temperature
MB	:	Mealybug
MH	:	Maharashtra
MinT	:	Minimum Temperature
MIT	:	Mites
MLP	:	Multiple Linear Regression
MP	:	Madhya Pradesh
MSC	:	*Macrophomina* Stem Canker
NICRA	:	National Innovations in Climate Resilient Agriculture
NS	:	Not Significant / Non Significant
PB	:	Punjab/Pod Borer *H. armigera* (Tomato)
PBlt	:	*Phytophthora* Blight
PBND	:	Peanut Bud Necrosis Disease
PCR	:	Polymerase Chain Reaction
PDW	:	Powdery Mildew (Tomato)

PH	:	*Phyllody*
PLM	:	Plume Moth
PM	:	Powdery Mildew (Pigeonpea)
PSB	:	Pink Stem Borer (Rice)/ Pod Sucking Bug *Clavigralla* (Pigeonpea)
PSND	:	Peanut Stem Necrosis Disease
RCP	:	Representative Concentration Pathway
RD	:	Rainy Day
RF	:	Rainfall
RHE	:	Relative Humidity - Evening
RHM	:	Relative Humidity - Morning
RST	:	Rust
RTPD/RTPS	:	Real Time Pest Dynamics / Real Time Pest Surveillance
RW	:	*Ralstonia* Wilt
SAI	:	Species – Climate Change Adaptation Index
SAS	:	Statistical Analysis System
SL	:	*Spodoptera litura* (Tomato)
SLS	:	*Septoria* Leaf Spot
SMD	:	Sterility Mosaic Disease
SMW	:	Standard Meteorological Week
SP	:	Spiders
SPDI	:	*Spodoptera* Infestation (Groundnut)
SPDN	:	*Spodoptera* Larval Number (Groundnut)
SQL	:	Structured Query Language
SR	:	Stem Rot
SS	:	Sun Shine/Sun Scald (Tomato)
SSB	:	Striped Stem Borer
SW	:	*Sclerotium* Wilt
TLC	:	Tomato Leaf Curl
TM	:	Tomato Mosaic
TN	:	Tamil Nadu
TRP	:	Thrips
TRPI	:	Thrips Infestation
TRPN	:	Thrips Number
TS	:	Telangana State
UP	:	Uttar Pradesh
WAP	:	Weeks After Planting
WAS	:	Weeks After Sowing
WB	:	West Bengal
WBPH	:	White Backed Plant Hopper
WF	:	Whiteflies
WLH	:	White Leaf Hopper
WSB	:	White Stem borer
YSB	:	Yellow Stem Borer

Note: Symbols and units mentioned in the report not expanded

LIST OF TABLES

LIST OF ANNEXURES

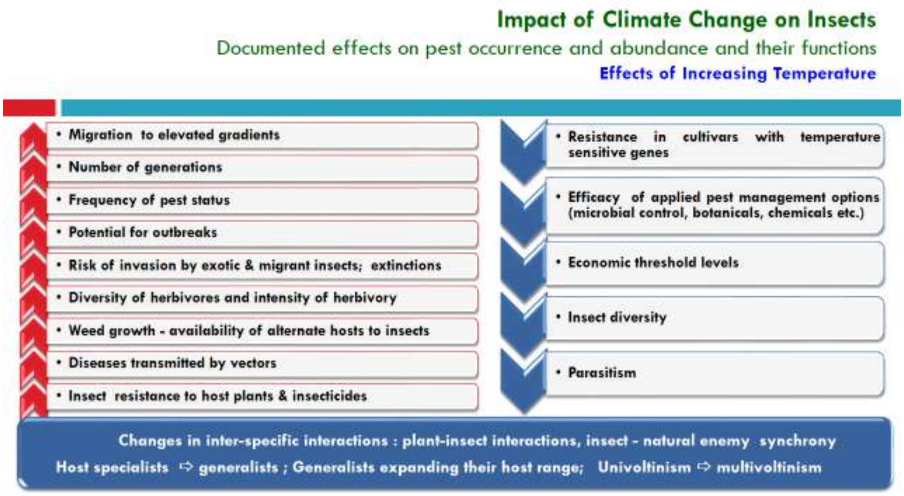
CONTENTS

INTRODUCTION

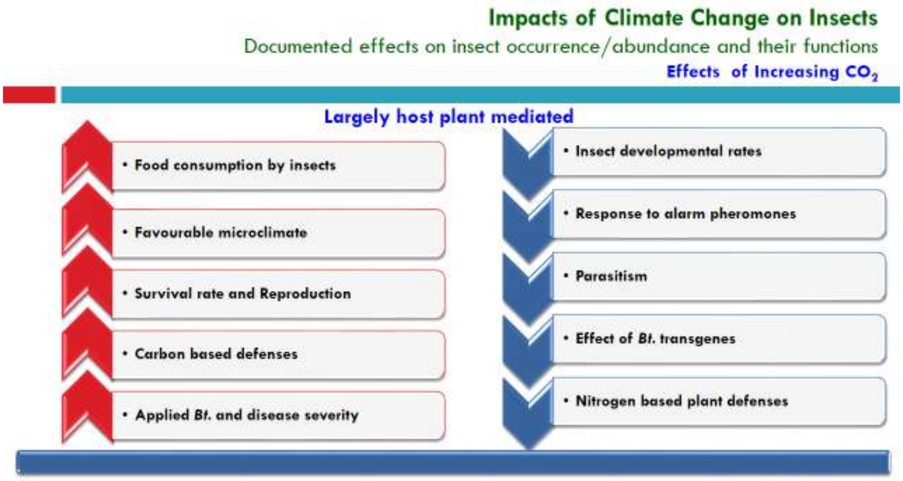
Climate change causing significant shifts in weather patterns threatens food cum nutritional security besides livelihoods of millions of people across the world and in India (IPCC, 2014). It is very clear that the climate variables relevant to food production and nutritional systems are predominantly temperature and precipitation dependent although integrated metrics that combine other variables such as solar radiation, wind and humidity in addition to extreme weather and climate events are included (Jia *et al*., 2019). Increased temperatures, changed rainfall patterns and more frequent and intense floods and droughts will affect the food production (Lobell *et al*., 2012; Schellnhuber *et al*., 2013; Rosenzweig *et al*., 2014). The impacts of climate change on crop yields indicate that yield losses may be up to 60 % by the end of the century depending on crop, location, and future climate scenario (Rosenzweig *et al*., 2014; Challinor *et al*., 2014; Asseng *et al*., 2015). Increasing climatic variability further complicates agricultural production and food security as almost one-third of yield variations is related to climatic variability (Ray *et al*., 2019).

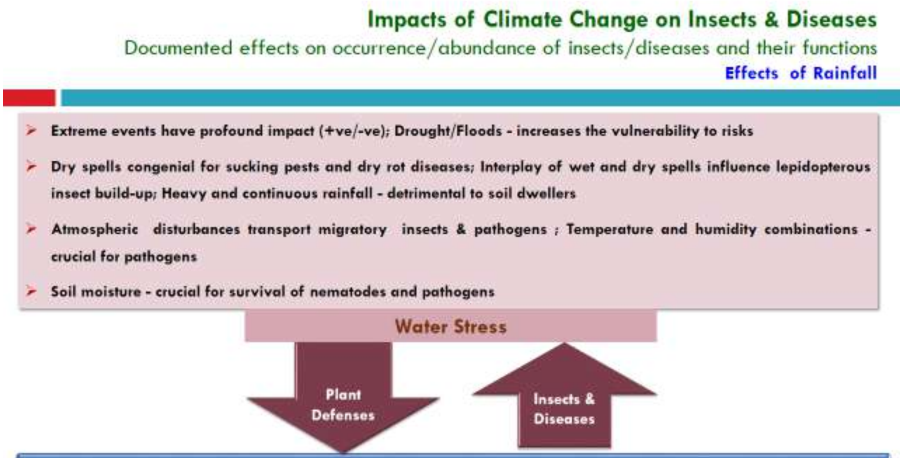
Climate change projections made up to 2100 for India indicate an overall increase in temperature by 2 to 4°C with no substantial change in precipitation quantity. Analysis of data for the period 1901 to 2005 by Indian Meteorological Department (IMD) suggested that annual mean temperature for the country as a whole increased by 0.51°C. Climate change projections in India over the baseline period of 1976-2005 indicated a rise in minimum over maximum temperature with the magnitude higher during *rabi* (October-April) over *kharif* (June-September). During *kharif,* an increase in minimum and maxiumum temperature of 0.95 - 4.07°C, 0.74 - 3.53°C was reported for 2020 to 2080 with increased rainfall of 2.3 - 3.3 % and 4.9 - 10.1% in respect of 2020 and 2050 (Naresh Kumar *et al*., 2019). Higher rise in temperature in northern than southern parts of India also was projected. With the sea-surface temperature already risen by almost one degree over the last century the occurrence of extreme events including unseasonal rainfall, droughts and floods throughout the country was highly obvious (Anonymous, 2019a) besides an anticipated increase in tropical cyclones along the coastline of India (FAO, 2021).

Impacts and responses are a continuum in all spheres of the universe with spatial and temporal variations. Climate change impacts on living organisms and adaptations of species of terrestrial ecosystems vary depending on multitude of interacting factors (Vennila *et al*., 2018a). Climate change has the potential to affect the behavior and biology of crop pests both direct and indirect ways. Increased populations of insects and severity of diseases with associated impact on their management, crop yields, food quality cum safety and environmental health are the major concerns. Increasing temperature, altered precipitation and humidity, increased frequency of extreme weather events (frost, variable and unseasonal rainfall, drought, cyclones *etc*.) and increasing carbon di oxide (CO_2) levels are the major climate change factors that influence the insect and disease scenario. Insects and diseases attain pest status when they impinge on crops causing yield losses that assume economic significance interms of increased cost of protection as well as reduced income to growers. Effects of climate change are: increasing species diversity and geographical distribution, increased abundance manifested through emerging pests and pest outbreaks and reduced efficacy of applied pest management options. The following paragraphs furnish the expected effects of climate change on insects & diseases and their natural enemies in addition to some of the documented evidences of changing pest scenario on selected crops in India where climatic variability and change have played a role.



Changing geographic range of species, timing of their lifecycles and population dynamics are some direct effects of climate change on the ecology of animals including insects and diseases of crop plants. Diversity, distribution and behavior of insects and diseases and their response to changing climate could range from geographical shifts, increased or decreased populations to extinctions or explosions. While higher temperatures could reduce the reproductive potential of key agricultural pests, increasing winter temperatures would increase the density of insects and winter mortality would be less besides the reduction of hibernating insects, which means additional generations, increased pestilence and greater economic loss to farmers. Bioclimatic studies on insect hosts and their natural enemies have confirmed potential physiological limitation for their geographical spread. Higher temperature, humidity and greater precipitation, on the other hand, are likely to result in the spread of plant diseases, as wet vegetation promotes the germination of spores and proliferation of bacteria and fungi, and influences the lifecycle of soil nematodes. Higher levels of CO_2 could stimulate the growth of crops and some weed species. Higher temperatures will favour parasitoids than their hosts. For those insects and their parasitoids with lower developmental threshold, their relationship might not be affected dramatically under global warming. Species that do feed longer to compensate the decreased nitrogen may become more vulnerable to natural enemies. As the climate change would affect crop phenology and associated crop production practices, the implications that the insect phenology and disease progession would change with changes in their management as well as effectiveness of protection practices. New environmental insects and diseases could emerge through invasion of new ones into ecosystems. The negative influences associated with CO_2 rise such as extreme variation in temperature and rainfall, natural disasters such as floods and droughts could nullify the positive impacts. Changes in rainfall pattern and the amounts have implications for insect survival and disease progressions. The long dry spells and intense rainfall could have reducing impact on small insects and their stages that directly feed on plant canopy. While excessive rainfall leading to water stagnation in long periods prevent the adult emergence from immature stages of insects, floods act as carrier for spread of insects and diseases in larger areas. Changes in rainfall, temperature and relative humidity also readily contaminate harvested crop commodities like groundnut, wheat, maize, rice and coffee with fungi that produce potentially fatal mycotoxins affecting food safety.





Geographical variations in rainfall, temperature, crops cum cropping systems, soils and management practices. Magnitude of climate change is variable on spatial and temporal scales. Living organisms continually evolve not only in response to their living and feeding habitats, but also to alterations happening in whole of the environment. Hence, attempt to assess climate change impact needs to be dealt with the purpose and relevance kept in focus. As plant protection specialists, we feel there would be space and time for the natural mortality factors including parasitoids, predators and microbials that could bring equilibrium in agro ecosystems through their beneficial services. The climate change altering the susceptibility or resistance of host plants - tri trophic interactions and management options under the integrated pest management (IPM) umbrella would be the scenario in a world of changing socio-economic and environmental milieu (Vennila *et al.,* 2015a). Present report dwells on some findings on the climate variability and change affecting insects and diseases at the fields of growers of specific crops.

STUDY APPROACH

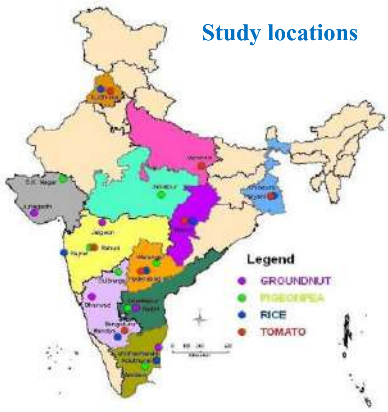
Target crops and study locations

Strategic Research for "Pest (Insect) and Disease Dynamics in relation to Climate Change" was one of the identified thematic areas of the scheme on "National Initiative on Climate Resilient Agriculture (NICRA)" under XI Plan (2010-11 and 2011-12) under the ICAR-Division of Natural Resources management operated through ICAR-Central Research Institute for Dryland Agriculture, Hyderabad. Pre-launch workshop of NICRA held in February 2011 at New Delhi recommended ICAR-NCIPM, New Delhi and ICAR-CRIDA, Hyderabad to develop collaborative linkages for Strategic Research on "Insect and Disease Dynamics in relation to Climate Change" through a national workshop involving ICAR institutes and State Agricultural Universities. Selection of target crops *viz.,* rice, pigeonpea, groundnut and tomato was done considering importance of crops from national food and livelihood security perspective in addition to considerations on profile of pest spectrum.

Target crops

Selection of study locations representing different climatic zones and agro eco regions was made involving researchers from disciplines of Agricultural Entomology, Plant Pathology, Agricultural Meteorology, Microbiology, Plant Breeding, Genetics, Plant Physiology, Computer Science and Agricultural Statistics. The expertise of the ICAR-NCIPM, in implementing information and communication technology (ICT) based pest surveillance was harnessed to build database on insect and disease dynamics and weather through web based portals. Group meetings in respect of rice, pigeonpea, groundnut and tomato crops involving researchers of identified study locations (refer map) aided in finalising technical, financial and administrative framework for implementation of the plant protection research programme (*https://ncipm.icar.gov.in/nicra2015/index.aspx*). Twenty-four locations (refer map) from 12 agro climatic zones belonging to 11 States were co-opted for the four target crops (Annexure I & II).

Study locations

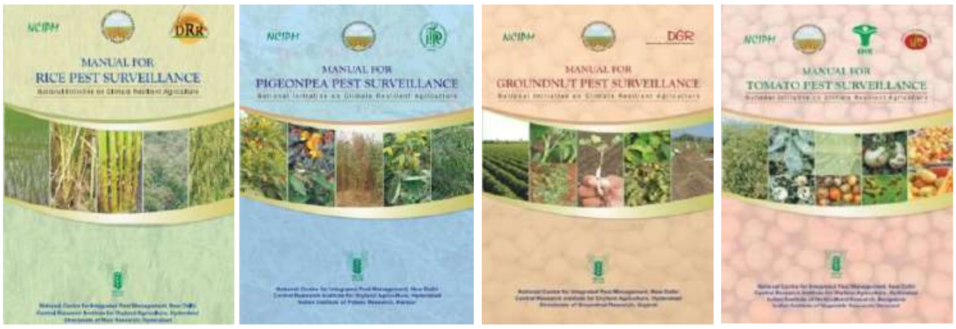


Surveillance plan and procedures

Implementation of web based pest surveillance amongst co-opted locations was conceptualised to capture data on insect and disease dynamics along with weather during project period for crop seasons (*kharif/rabi/*summer) as applicable to target crops. Foundations and methodologies were visualised to (1) facilitate uniformity in sampling methodology for insect pests and diseases of target crops; (2) understand their status in relation to climatic variability and change at field level and (3) generate long-term database for developing forecast models.

Surveillance plan included surveillance in experimental station and farmer's fields. List of insects and diseases along with their sampling methods and weather variables to be collected were incorporated to design data recording formats. Insect and disease surveillance was carried out at two fixed fields (protected and unprotected) of experimental station and at two fixed (farmer) fields per village across ten villages in each study location. Pest scouts (two) and data entry operator (one) were engaged at each location to assist researchers in surveillance. The data sheet formats have general information *viz.,* geographical, cropping system and agronomic details to be recorded once per crop season and crop specific insect and disease surveillance data sheets to record observations on weekly basis from all fixed fields. The period of crop season(s) in respect of study locations for the same crop varied and are specified in Annexure III. Manuals of pest surveillance for each target crop was developed including diagnosis and sampling of insect pests and diseases, monitoring tools, data sheets and guidelines. Specific proforma for recording new pests (Annexure IV) through explorative surveys and pest outbreaks (Annexure V) when noticed were also developed for reporting. Insects/diseases documented as new during the study period are furnished under Annexure VI. All documents have been made accessible at: *https://ncipm.icar.gov.in/nicra2015/datasheetsmanuals.aspx*

Manuals on pest surveillance



The surveillance parameters in respect of target crops to cover the study locations are summarized in Table 1&2.

Table 1. Frequency profile of insect and disease surveillance parameters

Crop	Insects	Diseases	Beneficial insects	Production & protection practices	Destructive sampling	Trap records	Total
Rice	17	8	6	8	5	$1^{\#}+17^{*}$	62
Pigeonpea	10	8	2	8	4	$1^{\#}$	33
Groundnut	8	11	2	8	-	$2^{\#}$	31
Tomato	8	15	2	10	-	$2^{\#}$	37
$^{\#}$: pheromone & *: light trap observations							

Collection of daily data on weather factors was done from meteorological observatory of each study location.

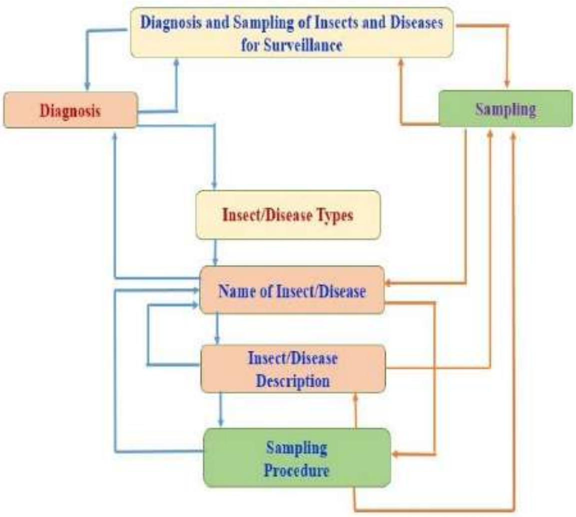
Table 2. Parameters of weather data

Date	Maximum temperature	Minimum temperature	Relative humidity (%)		Rainfall	Sunshine	Wind velocity
(dd/mm/yy)	(°C)	(°C)	Morning	Evening	(mm)	(h/day)	(km/h)

Information system for *e*-surveillance

Standalone information system on 'Diagnosis and Sampling for Pest Surveillance (DSPS)' for Rice, Pigeonpea, Groundnut and Tomato have been developed as a window based application using *asp.net* with C# with descriptions and images of plant parts, insects, diseases and beneficial insects sampled *vis a vis* sampling procedures. It also contains features of data sheets along with user manual. DVDs are available in addition to software downloads possible at: *https://ncipm.icar.gov.in/nicra2015/Softwaretools.aspx*.

Flow chart of DSPS and information system



DVD on DSPS

Implementation of ICT based surveillance

Web hosting of NICRA home page

Dedicated web page for "Pest Dynamics in relation to Climate Change" was constructed and hosted under NCIPM home page (*https://www.ncipm.gov.in)*. As a dynamic web page, it offers project background, details of surveillance locations and team in addition to links to all outputs developed including the software tools.

e- pest surveillance system for database accrual and reporting

An information and communication technology (ICT) (electronic-*e*) supported web based pest surveillance system (*e-pest surveillance*) consisting centralized database, offline client data capture, admin panel, and data reporting and analysis was designed. Developed web application is working in two modules (1) Client and (2) Reporting applications integrated with each other to have user-friendly interface. Login page is created to provide authenticated user based sessions for web application access. The credentials are system generated based on crop and study locations. A separate console is developed for administrator to authenticate web application accessibility. Client software installations and problem solving are done through remote access using open source remote access softwares.

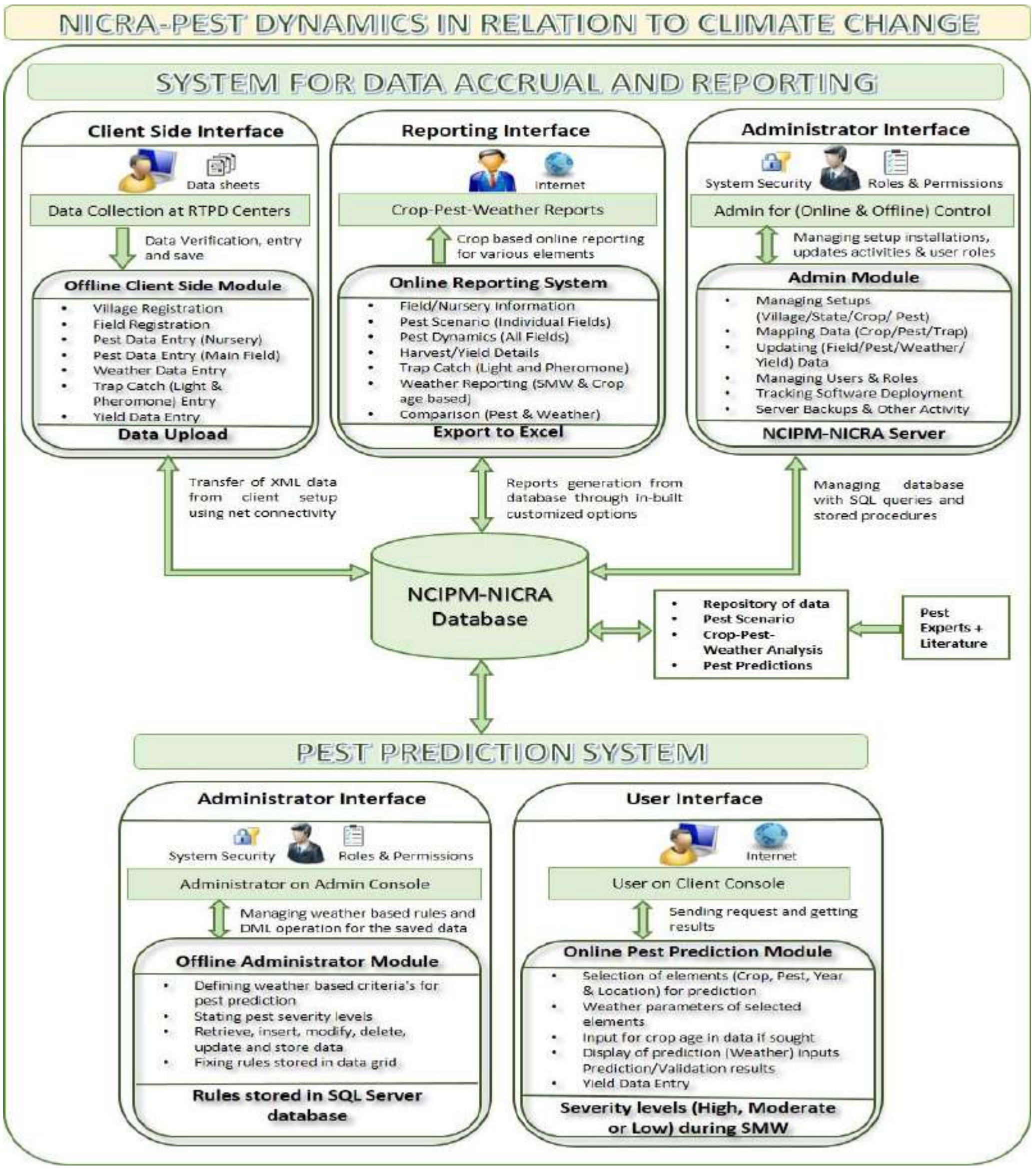
NICRA home page

Client application: XML based and installed in computer system of project co-opted centers to accrue information *viz.*, field, crop, insect pest and disease details, weather observations, crop yields etc. All the relevant data of insect, disease and field surveillance are collected by pest scouts and saved/uploaded in client application by data entry operator. Software is a standalone program developed using ASP.net technology for capturing pest surveillance data of designated locations and crops *viz.,* rice, pigeonpea, groundnut and tomato besides weather entries. The application works in offline mode with uploads to the server database in online mode. Setup files for client software installation by real time pest dynamic study (RTPD)/real time pest surveillance (RTPS) centers were generated using admin panel configuring software applicable for the target surveillance center. NICRA client software user manuals were made available online in addition to facilitating needful open source software such as Teamviewer© and Anydesk© (for window upgradations and for establish remote access between NCIPM server and RTPD/RTPS computer systems for installation and problem solving).

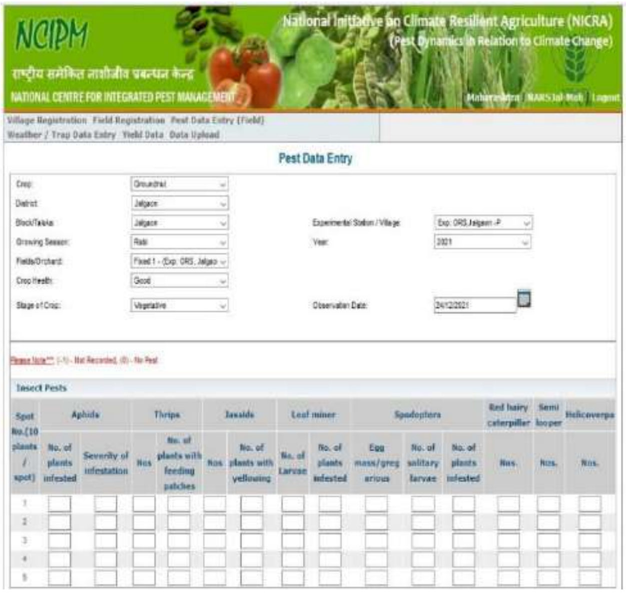
Reporting application: The reporting system has been developed to make available the details and data accrued through the pest surveillance from the fields and received at the server through uploads from the client side application. Reporting application consisting admin panel is functional and available on website links: *https://ncipm.icar.gov.in/nicra2015/NICRAPanel2012Onwards/rvLogin.aspx;https://ncipm.icar.gov.in/nicra2015/NICRAAdminPanelNew/rvLogin.aspx of https://ncipm.icar.gov.in/nicra2015/index.aspx.* Reporting systems for 2011 and later from 2012 onwards were developed and hosted due to mid-course modification in data sheets and reporting enhancements. Reporting modules have options to retrieve data sets in the desired formats and units that could serve researchers to work on various ecological models analyzing within/ between field variations, multispecies associations, and crop yield loss assessment by pests besides crop-pest-weather/climatic analysis across seasons or locations. Data stored in the server database are used further for viewing and downloading different customized reports in online mode *viz.,* (1) Crop pest weather reporting; (2) Comparison [weather, light and pheromone traps, insect and disease scenario across locations] and (3) Spatial [pest-weather (graphical)]. The queries serve as data provider for web applications from SQL server. Experts make queries and analyze data for intra and inter-center pest-weather dynamics. These optimized reports can be downloaded to MS excel for display, print and additional analytical purposes.

Software architecture: The architecture of the client (for data accrual and upload) and reporting appilcations and sample screen shots are presented below.

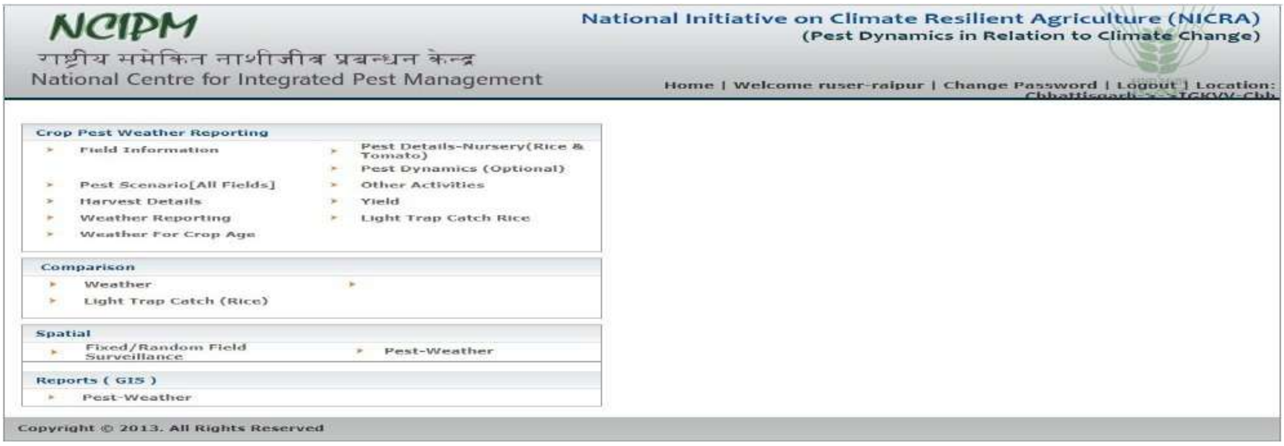
Architecture of e-surveillance for database accrual and reporting under NICRA

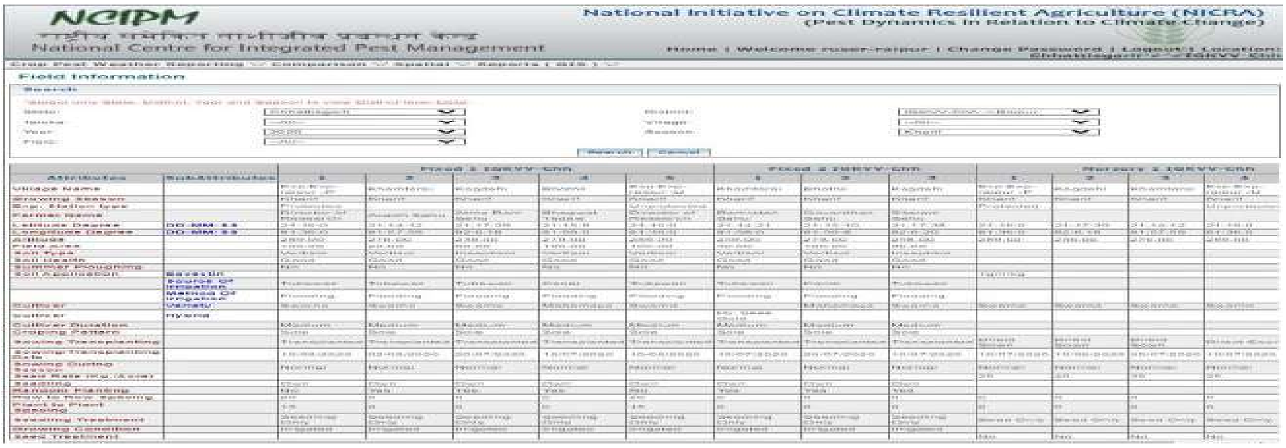


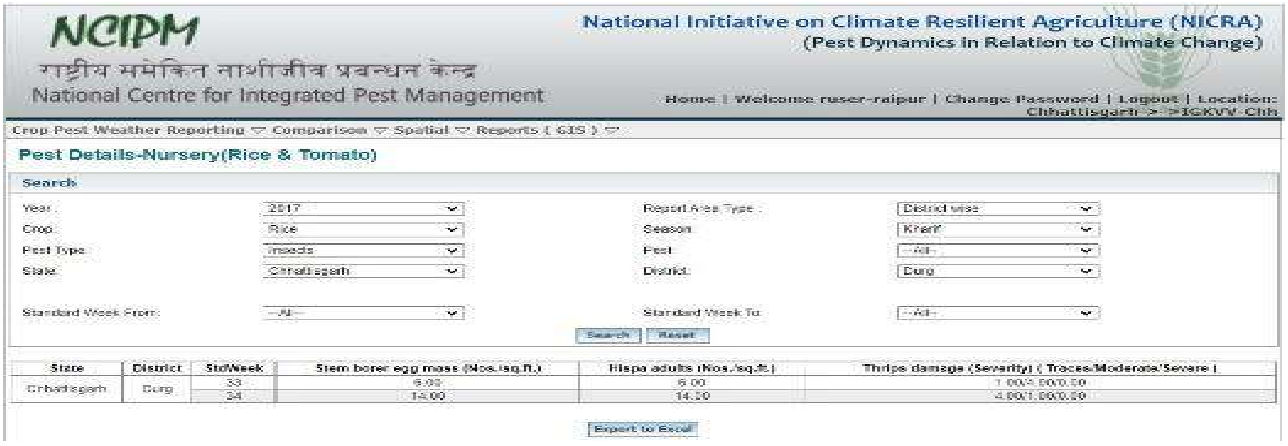
Screenshots of NICRA client software



Screenshots of NICRA reporting system







Screenshots of NICRA reporting system

NCIPM
राष्ट्रीय समेकित नाशीजीव प्रबन्धन केन्द्र
National Centre for Integrated Pest Management

National Initiative on Climate Resilient Agriculture (NICRA)
(Pest Dynamics in Relation to Climate Change)

Home | Welcome ruser-raipur | Change Password | Logout | Location: Chhattisgarh->->IGKVV-Chh

Crop Pest Weather Reporting ▽ Comparison ▽ Spatial ▽ Reports (GIS) ▽

Pest Scenario [All Fields]

Search

Year: 2020 | Crop: Rice
Season: Kharif | Pest: Insects
State: Chhattisgarh | District: IGKVV-Chh-->Raipur
Report Option: SWM Month Year

Search Reset

Taluka	Village	FieldName	Year	SWM	Latitude	Longitude	SoilType	Cultivar_Hybrid	Cultivar_Variety	CultivarDuration	GrowingCondition	SowingDate	CropAgeInD
Aarang	Bhothli	Fixed 1	2020	35	21:15:9	81:59:5	Vertisol		Mahamaya	Medium	Irrigated	15/07/2020	46
			2020	36	21:15:9	81:59:5	Vertisol		Mahamaya	Medium	Irrigated	15/07/2020	51
			2020	37	21:15:9	81:59:5	Vertisol		Mahamaya	Medium	Irrigated	15/07/2020	57
			2020	38	21:15:9	81:59:5	Vertisol		Mahamaya	Medium	Irrigated	15/07/2020	65
			2020	39	21:15:9	81:59:5	Vertisol		Mahamaya	Medium	Irrigated	15/07/2020	72
			2020	40	21:15:9	81:59:5	Vertisol		Mahamaya	Medium	Irrigated	15/07/2020	78
			2020	41	21:15:9	81:59:5	Vertisol		Mahamaya	Medium	Irrigated	15/07/2020	85
			2020	42	21:15:9	81:59:5	Vertisol		Mahamaya	Medium	Irrigated	15/07/2020	92
			2020	43	21:15:9	81:59:5	Vertisol		Mahamaya	Medium	Irrigated	15/07/2020	99
			2020	44	21:15:9	81:59:5	Vertisol		Mahamaya	Medium	Irrigated	15/07/2020	106
			2020	45	21:15:9	81:59:5	Vertisol		Mahamaya	Medium	Irrigated	15/07/2020	114
			2020	46	21:15:9	81:59:5	Vertisol		Mahamaya	Medium	Irrigated	15/07/2020	120
			2020	47	21:15:9	81:59:5	Vertisol		Mahamaya	Medium	Irrigated	15/07/2020	128
		Fixed 2	2020	36	21:15:10	81:59:8	Vertisol		Mahamaya	Medium	Irrigated	20/07/2020	41
			2020	36	21:15:10	81:59:8	Vertisol		Mahamaya	Medium	Irrigated	20/07/2020	46
			2020	37	21:15:10	81:59:8	Vertisol		Mahamaya	Medium	Irrigated	20/07/2020	52
			2020	37	21:15:10	81:59:8	Vertisol		Mahamaya	Medium	Irrigated	20/07/2020	57
			2020	38	21:15:10	81:59:8	Vertisol		Mahamaya	Medium	Irrigated	20/07/2020	60
			2020	40	21:15:10	81:59:8	Vertisol		Mahamaya	Medium	Irrigated	20/07/2020	73
			2020	41	21:15:10	81:59:8	Vertisol		Mahamaya	Medium	Irrigated	20/07/2020	80
			2020	42	21:15:10	81:59:8	Vertisol		Mahamaya	Medium	Irrigated	20/07/2020	87
			2020	43	21:15:10	81:59:8	Vertisol		Mahamaya	Medium	Irrigated	20/07/2020	94
			2020	44	21:15:10	81:59:8	Vertisol		Mahamaya	Medium	Irrigated	20/07/2020	101
			2020	45	21:15:10	81:59:8	Vertisol		Mahamaya	Medium	Irrigated	20/07/2020	108
	Kagdehi	Fixed 1	2020	35	21:17:39	82:5:18	Inceptisol		Swarna	Medium	Irrigated	20/07/2020	42

1 2 3 4

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Home | Welcome ruser-raipur | Change Password | Logout | Location: Chhattisgarh->->IGKVV-Chh

Crop Pest Weather Reporting ▽ Comparison ▽ Spatial ▽ Reports (GIS) ▽

Yield Comparison

Search

Crop: Rice | Year: 2020
Season: Kharif
State: Chhattisgarh | District: IGKVV-Chh-->Raipur

Search Cancel

Taluka	Village	FieldName	Season	Yield (Kg./Acre)
Aarang	Bhothli	Fixed 1	Kharif	2300.00
		Fixed 2	Kharif	1900.00
	Kagdehi	Fixed 1	Kharif	2300.00
		Fixed 2	Kharif	2000.00
	Khamtarai	Fixed 1	Kharif	2100.00
		Fixed 2	Kharif	2400.00
Raipur	Exp:Exp-raipur -U	Fixed 1	Kharif	2500.00
	Exp:Exp-raipur -P		Kharif	2800.00

Export to Excel

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Home | Welcome ruser-raipur | Change Password | Logout | Location: Chhattisgarh->->IGKVV-Chh

Crop Pest Weather Reporting ▽ Comparison ▽ Spatial ▽ Reports (GIS) ▽

Weather Reporting

Search

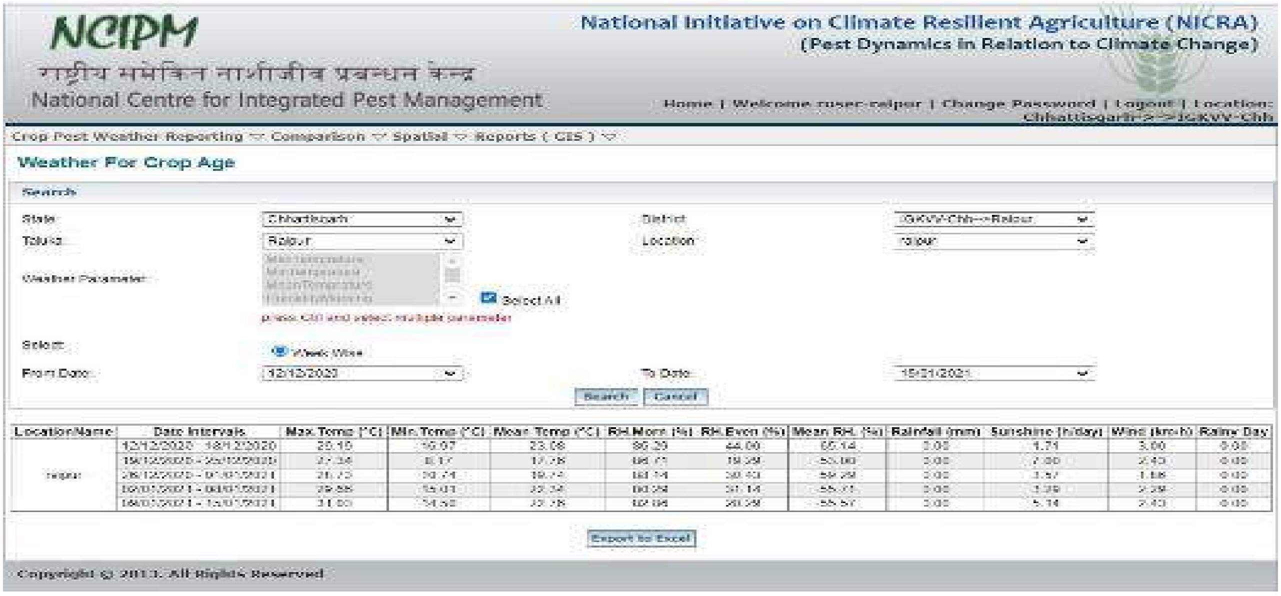
State: Chhattisgarh | District: IGKVV-Chh-->Raipur
Taluka: Raipur | Location: raipur
Weathe Parameter: MaxTemprature, MinTemprature, MeanTemprature, HumidityMorning ☑ Select All
press Ctrl and select multiple parameter
Select: Date Wise SMW Wise Month Wise Year Wise
From Date: 25/12/2020 | To Date: 05/01/2021

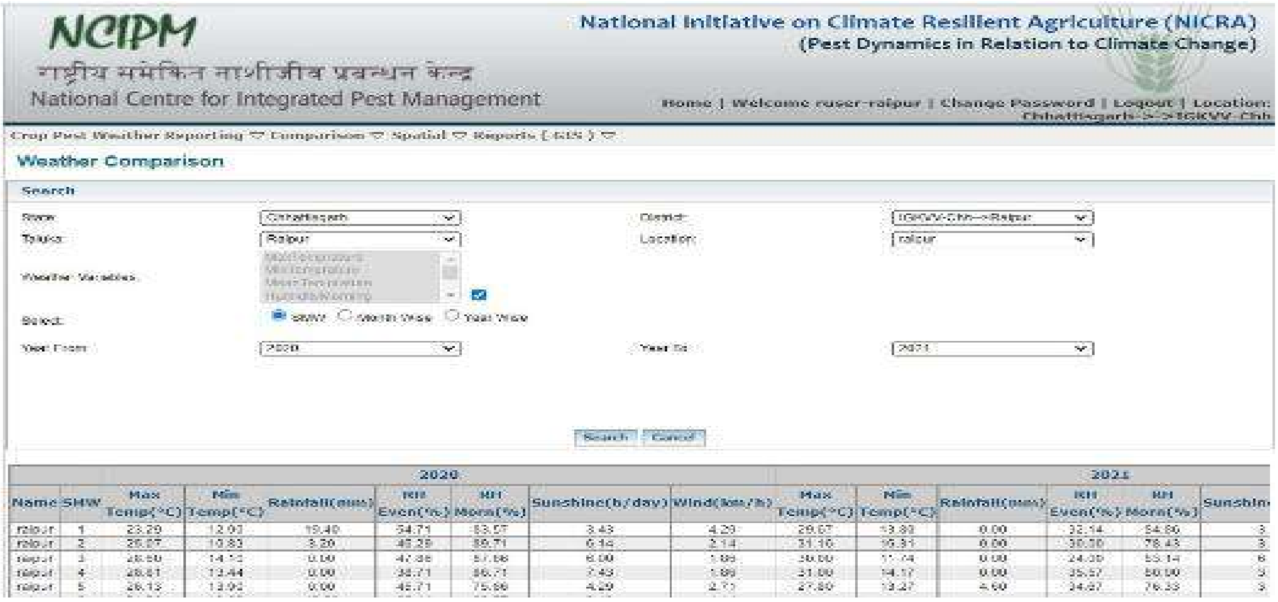
Search Cancel

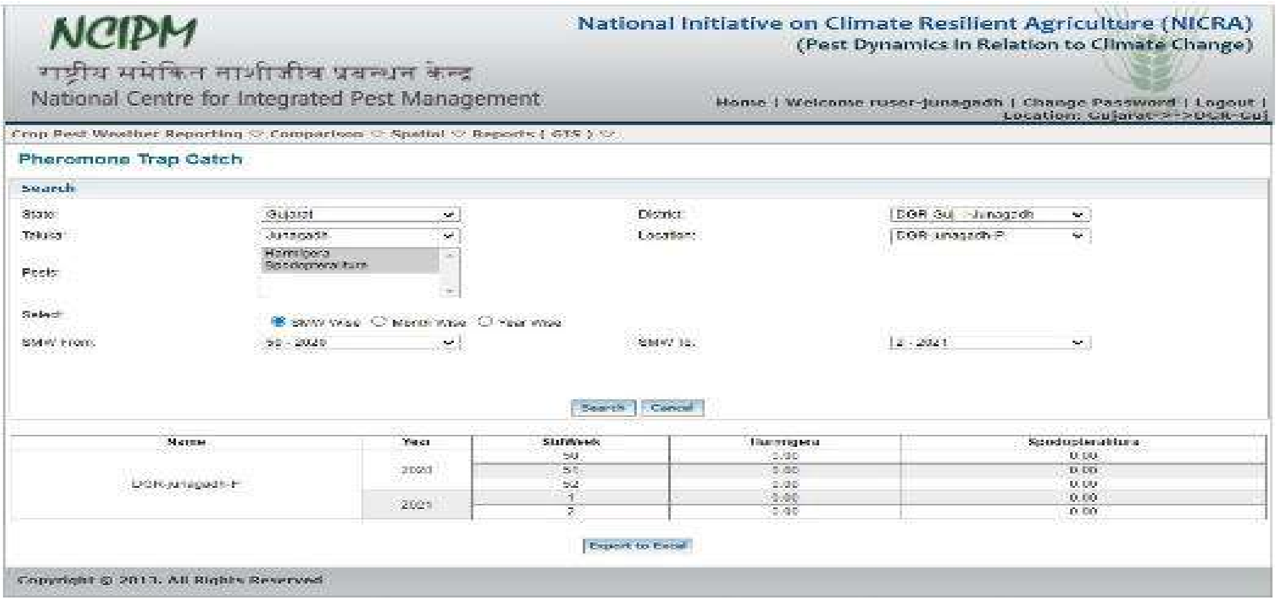
LocationName	ObservationDate	Max.Temp (°C)	Min.Temp (°C)	Mean Temp (°C)	RH.Morn (%)	RH.Even (%)	Mean RH. (%)	Rainfall (mm)	Sunshine (h/day)	Wind (km/h)	Rainy Day
raipur	25/12/2020	27.80	8.00	17.90	89.00	22.00	55.50	0.00	7.00	2.00	0
	26/12/2020	27.50	8.00	17.75	92.00	27.00	59.50	0.00	7.00	3.00	0
	27/12/2020	28.00	8.20	18.10	89.00	24.00	58.50	0.00	8.00	2.00	0
	28/12/2020	29.00	10.20	19.60	83.00	29.00	56.00	0.00	6.00	1.00	0
	29/12/2020	30.00	12.00	21.00	86.00	28.00	57.50	0.00	4.00	2.00	0
	30/12/2020	30.00	12.80	21.40	85.00	36.00	60.50	0.00	2.00	1.00	0
	31/12/2020	28.00	12.00	20.00	88.00	33.00	60.50	0.00	0.00	2.00	0
	01/01/2021	28.80	12.00	20.30	93.00	38.00	64.50	0.00	0.00	2.00	0
	02/01/2021	28.80	12.00	20.40	88.00	35.00	61.50	0.00	0.00	3.00	0
	03/01/2021	28.50	10.60	19.55	90.00	29.00	59.50	0.00	0.00	2.00	0
	04/01/2021	30.00	13.80	21.90	83.00	32.00	57.50	0.00	7.00	2.00	0
	05/01/2021	29.50	13.00	21.25	89.00	22.00	55.50	0.00	4.00	3.00	0

Export to Excel

Screenshots of NICRA reporting system







While trainings were held for installation of NICRA client software, data entry and upload to researchers of all study locations, further trainings to data entry operators were facilitated through remote access of computer systems or through personal visits by project team.

Graphics on weather cum climatic normals, insects and diseases

Database on population dynamics of insects and diseases of occurrence in respect of seasons and locations along with weather parameters assimilated over study periods using ICT based surveillance and reporting served as the repository for data extraction and analyses. Data on actuals of weather on standard meteorological week (SMW) basis in respect of study locations were taken from the online database of project web portal of NICRA at ICAR-NCIPM, New Delhi. Data on 'normals' (long term average of 40 years:1970-2010) along SMWs for MaxT, MinT and RF (1-52 SMW) were obtained from ICAR- AICRPAM at ICAR-CRIDA, Hyderabad relevant to each study location. All the graphical representations of the prevalent weather for all study calendar years along with 'normals' are given for all study locations [Annexure VII-X] in respect of target crops [Annexure VII (Rice); Annexure VIII (Pigeonpea); Annexure IX (Groundnut) & Annexure X (Tomato)] to have a visual glimpse and understanding the interannual variations.

The database on insects and diseases in respect of individual fields of surveillance of each study location was extracted from the server along dates of observations attributed to SMWs and curated before analysis. The data reporting featute of population dynamics of insects and progression of diseases along crop age calculated by the software considering the date of sowing/planting of crops in respect of each field facilitated expression and comparison of seasonal dynamics across years on a standard scale. The study periods between 2011 and 2016 were common for all target crops in respect of identified locations. A few locations (maximum of two) in each target crop were continued for the insect, disease and weather surveillance till 2020. Later years beyond 2016 had reduced locations (six) across the four target crops. Scientific names of the insects, beneficials and diseases under surveillance with their standard reporting units in respect of rice, pigeonpea, groundnut and tomato are given in Annexure XI, Annexure XII, Annexure XIII and Annexure XIV, respectively. The frequency of insects (including predators) and diseases that were part of field observations for studies on the impact of climate variability and change in respect target crops are given in Annexure XV &. XVI.The seasonal dynamics of insects and diseases for study locations and crop seasons as applicable to target crops are furnished in Annexures that are referred under each target crop again to showcase the enormous seasonal fluctuations happening. While study period of 2011-16 was common for all target crops in respect of their locations, for locations that continued to be part until 2020 or where data sets for additional years were obtained (esp. for rice locations), the graphs include weather, insect and disease dynamics for those additional years.

Data analyses

Trends of climate variability-common analysis

Daily data on weather variables *viz*., maximum and minimum temperature (MaxT & MinT in ^{0}C), morning and evening humidity (RHM & RHE in %), sunshine hour (SS in h/day), wind velocity (wind in km/h), total rainfall (RF in mm), and rainy days (RD) recorded at meteorological observatory of each study location for study periods (2011-2016) were accrued online through web portal. Reporting system of the NICRA software had provisions of weather calculations on standard meteorological weeks (SMW), monthly and annual basis. Since temperature and rainfall are the major factors of climate change, non-parametric Mann-Kendall test estimating Sen's slope to detect significance of upward or downward trends in data series of weather parameters *viz.*, maximum temperature (MaxT), Minimum temperature (MinT) and Rainfall (RF). The trends were analysed for the annual variability using SMW (1-52) and monthly (12) data sets in addition to analysis for seasons of *kharif* (22-44 SMW), *rabi* (45-13 SMW) and summer (1-25 SMW) for the period of 2011-2016. Linear trends using simple linear regressions and Sen's slope estimators were used to examine the rate of change of weather parameters. Based on the trends and their significance, the study locations were grouped under annual and seasonal trends.

Seasonal variations of insects, diseases, actual weather and climatic deviations

Inter seasonal variations of insects/diseases were analysed based on the database of insect/disease dynamics after appropriate transformations using one-way ANOVA. The study also involved statistical quantifications of interseasonal climatic variability using one-way ANOVA for (1) 'actual' weather *per se* and (2) 'climatic deviations' worked out as the difference between 'actual' and 'normal' values in respect of MaxT, MinT and RF along SMWs corresponding to individual crop seasons (2011-16) in respect of locations.

Magntiude of climate change

The common study period for all study locations of different target crops was between 2011 and 2016. Hence, the magnitude of climate change was worked out over six years relevant to crop seasons of each location for the variables *viz.,* MaxT, MinT, and RF. The mean difference between actuals and normals over 2011-16 and its significance was deciphered employing student 't' test. The specific periods of crop seasons (on SMW basis; Annexure III) in respect of target crops and seasons (*kharif/rabi/*summer as applicable; Annexure III) for study locations were accounted for analysis. The rainfall data was subjected to log (X+1) transformation before analysis.

Species-climate change association index

A tool for determining the impact of changing climate on insect pests and diseases was developed and named it as species climate change association index (SAI). Assessment of the impact of climate change on insects and diseases was restricted to overall periods of 2011-16 considering the commonality in study periods. The climatic deviations (D) in respect of MaxT, MinT and RF for individual crop seasons over study periods (2011-16) and corresponding abundance of insects/diseases/damage/incidence/severity on SMW basis were subjected to Kendall's correlative analysis with significance of coefficients tested to assess the impact of climate change on field population dynamics of insects and diseases. The correlation coefficients tau (τ) between population dynamics of insects /diseases /damage /severity and the deviations of the individual climatic variables indicated the type (positive or negative) and significance on the impact in relation to individual climatic variables. Further, a methodology was evolved to have a cumulative index for assessing the overall impact of climate change. The climate change impact on population dynamics of insects and progression of diseases was done through species adaptaion index (Anonymous, 2020) later renamed as species climate change association index (SAI). The species association index (SAI) to climate change involves the following steps.

(1) Working out the magnitude of climatic deviations for weather variables of maximum temperature, minimum temperature and rainfall; (2) Obtaining coefficients of associations (Kendall's tau (τ)) between the climatic deviations of weather variables and the corresponding population abundance of period under consideration (values always range between -1 to +1); (3) Calculation of products of the coefficients with the magnitude of climate change of individual weather variables (variable specific index) (step 2 and step 1) and (4) Arriving at a cumulative index (single value) by summing up the indices relevant to three weather variables (MaxT, MinT and RF) calculated in step 3 (referred as SAI).

While a positive association of the cumulative index indicates the species adaptation to the changing climate, the negative values point to the species vulnerability equivalent to the increased and reduced insect abundance/damage/disease incidence/severity as the case may be, respectively (in general terms). The SAIs can be positive or negative and take values dependent on both the sign and quantum of the magnitude of climate change (CC) and the coefficients between climatic deviations and dynamics of insects/diseases for a given season. The SAIs can be ordered to understand the adaptation of different species for a given season within a given location and between locations. The cumulative index (SAI) calculated for each insect and disease in respect of locations for corresponding crop seasons can be positive or negative, wherein the magnitude of climate change was significant for at least for one or any two or for all three climatic variables (MaxT, MinT and RF) was considered to indicate the significant/definitive impact of climate change (in significant terms). The index is scale neutral, and even the comparisions of adaptability/vulnerability of each insect across locations can also be ranked. SAIs should essentially use data sets of weather-pest dynamics over multiple years to infer the impact of climate change and of a few years or even an individual seaon/year for knowing the effect of climatic variability. SAIs attempted for a single season or many seasons along other factors such as cultivars/sowing dates/other production and protection practices would allow to derive an indication of evolving response or otherwise of insects and diseases to climate change and variability. The deviations of SAIs of individual over multiple seasons would imply the inclusiveness of weather extremes/abberations and other dominant biotic factors influencing population dynamics of insects/diseases.

TRENDS OF CLIMATE VARIABILITY

Establishment of climate variability (CV) and change (CC) as a happening phenomenon in general and during the standard crop seasons (*kharif*/*rabi* and summer) at study locations was the prerequisite and premise towards assessment of impact of CC on insects and diseases. The analysis based on six-year (2011-16) data sets (Anonymous, 2018) of weather for annual and seasonal trends for 23 locations and the summary on the commonalities change in climate at a single location among seasons or otherwise and across locations are furnished.

Trends analyzed for 23 locations (Table 3) using climatic deviations for weather variables of maximum and minimum temperature and rainfall indicated that significance at least for anyone of the variable for anyone of the study seasons signified that climate change is a happening phenomenon at all locations. Between the analysis performed for annual change using data series on SMW and monthly basis, former data series had brought out the significance of trends more effectively. Sixteen of the 23 locations had the similar trends that were significant. Monthly data series showed no change at five locations [(Kadiri AP), Karjat (MH), Ludhiana (PB), S.K. Nagar (GJ) & Warangal (TS)] for MaxT and one each for MinT [Chinsurah (WB)] and RF [Aduthurai (TN)] which otherwise had a significant trend when analysed using SMW data series. The only deviation had been with Karjat (MH) where monthly series had brought out a significantly decreasing trend for MinT, which was not shown by SMW based annual trend analysis. The higher number of observations that SMW over monthly data series have brought out the significance better. While Dharwad (KA) and Bengaluru (KA) belonging to two different agro climatic zones had all three seasonal trends, Chinsurah (WB) had *rabi* and summer trends similar to that of annual trend. Twelve and 17 locations in respect of *kharif* and summer had trends reflected annually. Similar trends of both *kharif* and summer seasons represented annual trends at Jabalpur (MP), Jalgaon (MH), Kadiri (AP), Mandya (KA), Raipur (CG) and Varanasi (UP). Variations in trends of 20 of locations were different in any one of the three variables (MaxT, MinT & RF) from that of annual trends during *rabi*. Trends varied for their significance amongst all seasons, only at Rahuri (MH) and Vamban (TN) (Anonymous, 2018).

Trends along climatic variables

Maximum temperature: Analysis of trends for 23 locations based on SMW based data sets had indicated significance for maximum temperature to be exclusively negative at Kadiri (AP), Vamban (TN) and Virudhachalam (TN). While the trends of annual MaxT was not significant for eight locations, twelve locations had significantly increasing trends. Annual trends analysed based on monthly values indicated differences in significance for the locations namely Junagadh (GJ), Kadiri (AP), Karjat (MH), Ludhiana (PB), S.K. Nagar (GJ) and Warangal (TS) indicating that mean values and less number of cases mask the statistical significance. Summer>*kharif* >*rabi* for MaxT and Summer>*rabi*>*kharif* for MinT was the order of increasing trends (Table 4). Eight, five and 14 locations had significantly increasing trends of MaxT during *kharif, rabi* and summer, respectively. MaxT had decreasing trends (Table 5) in the order of *rabi* (five locations)>summer (4)> *kharif* (2). While five [Bengaluru (KA), Chinsurah (WB), Kalyani (WB), Kampasagar (TS) and Karjat (MH)] of the 23 locations had increasing trends of MaxT, two locations [Kadiri (AP) and Vridhachalam (TN)] had decreasing trends during all three seasons. Aduthurai (TN), Dharwad (KA), Rajendranagar (TS), Jabalpur (MP), and Jalgaon (MH) are the only five locations that did not show change during summer. Similarity for unchanging climate between *kharif* and *rabi* existed for 11 locations (Table 6). Gulbarga (KA) and Vamban (TN) had decreasing trends during *rabi* and summer and no change during *kharif*. Warangal (TS) has only increasing trend of MaxT in summer and not in *kharif* and *rabi*. Varanasi (UP) had increasing trend during *kharif* and summer and not during *rabi*. No locations had shown opposite trends between seasons (Table 3, 4, 5 & 6).

Minimum temperature: Eighteen, three and two locations had increasing, decreasing and unchanging trends as against 17, four and two noted in respect of analysis done based on SMW and month based data sets. Thirteen, 17 and 19 locations had increasing trends in respect of *kharif, rabi* and summer (Table 4). Eleven locations had increasing MinT during all three seasons. While Jabalpur (MP) had increasing MinT in *kharif* and summer, no change was observed for *rabi.* Vamban had increasing MinT during *kharif* and *rabi* with no change in summer. Karjat (MH) had declining MinT during *kharif* and no change during *rabi* and summer. Warangal (TS) did not show change during *kharif* but declining MinT in *rabi* and summer (Table 5). Rajendranagar (TS) also did not show change during *kharif* but had increasing MinT in *rabi* and summer. Kalyani (WB) had increase in MinT during summer alone. Junagadh (GJ) had declining, unchanging and increasing MinT in respect of *kharif*, *rabi* and summer. Mandya (KA) had declining trend in all three seasons.

Four each for significantly declining (Karjat, Mandya, Warangal and Junagadh) and increasing (Bengaluru, Varanasi, Gulbarga and Virdhachalam) trends for minimum temperature was noted during *kharif*. *Rabi* had increasing minimum temperature among 15 of 23 locations *viz.,* Ludhiana (PB), Raipur (CG), Dharwad (KA), Chinsurah (WB), Hyderabad (AP), Kadiri (AP), Varanasi (UP), Jalgaon (MH), Rahuri (MH), Anantapur (AP), Gulbarga (KA), S.K. Nagar (GJ), Bengluru (KA), Kampasagar (TS) and Virudhachalam (TN). Mandya (KA) alone had declining minimum temperature that was significant. Summer season had twenty and one location showing significantly increasing and decreasing trends for minimum temperature, respectively but for Warangal (TS) and Junagadh (GJ) (Table 3, 4, 5 & 6).

Rainfall: Only Aduthurai had showed significantly declining trend of rainfall on the basis of SMW based data sets, however no change in trend noted for annual trend analysis based on monthly data sets. None of the locations showed any significant change for summer and fifteen of them had no significance for trends during other two seasons also. Increasing RF was seen only during *rabi* at seven locations [Aduthurai (TN), Jalgaon (MH), Kadiri (AP), Karjat (MH), Rahuri (MH), Vamban (TN) and Virudhachalam (TN)] and decreasing trend only in *kharif* at three locations [Aduthurai(TN), Kampasagar (TS) and Virudhachalam (TN)]. Aduthurai and Virudhchalam of Tamil Nadu had increasing RF in *rabi* and decrease during *kharif* with no change in summer. While Kampasagar (TS) had declining trend in *kharif*, change of RF for other two seasons is non significant. Virudhachalam (TN) had declining RF in *kharif* and increasing during kharif with no change in summer (Table 3, 4, 5 & 6).

Table 3. Annual and seasonal trends of climate variability

Location	Annual (based on SMWs)			Annual (based on months)			*Kharif*			*Rabi*			Summer		
	Max.T	Min.T	Rain	Max.T	Min.T	Rain	Max.T	Min.T	Rain	Max.T	Min.T	Rain	Max.T	Min.T	Rain
Aduthurai (TN)	-	↑	↓	-	↑	-	-	↑	↓	-	↑	↑	-	↑	-
Anantapur (AP)	↑	↑	-	↑	↑	-	-	-	-	-	↑	-	↑	↑	-
Bengaluru (KA)	↑	↑	-	↑	↑	-	↑	↑	-	↑	↑	-	↑	↑	-
Chinsurah (WB)	↑	↑	-	↑	-	-	↑	-	-	↑	↑	-	↑	↑	-
Dharwad (KA)	-	↑	-	-	↑	-	-	↑	-	-	↑	-	-	↑	-
Gulbarga (KA)	-	↑	-	-	↑	-	-	↑	-	↓	↑	-	↓	↑	-
Rajendranagar (AP)	-	-	-	-	-	-	-	-	-	-	↑	-	-	↑	-
Jabalpur (MP)	-	↑	-	-	↑	-	-	↑	-	-	-	-	-	↑	-
Jalgaon (MH)	-	↑	-	-	↑	-	-	↑	-	-	↑	↑	-	↑	-
Junagadh (GJ)	-	↓	-	-	↓	-	-	↓	-	-	-	-	↑	↑	-
Kadiri (AP)	↓	↑	-	-	↑	-	↓	↑	-	↓	↑	↑	↓	↑	-
Kalyani (WB)	↑	↑	-	↑	↑	-	↑	-	-	↑	-	-	↑	↑	-
Kampasagar (TS)	↑	↑	-	↑	↑	-	↑	-	↓	↑	↑	-	↑	↑	-
Karjat (MH)	↑	-	-	-	↓	-	↑	↓		↑	-	↑	↑	-	-
Ludhiana (PB)	↑	↑	-	-	↑	-	-	↑	-	-	↑	-	↑	↑	-
Mandya (KA)	↑	↓	-	↑	↓	-	↑	↓	-	-	↓	-	↑	↓	-
Rahuri (MH)	-	↑	-	-	↑	-	-	-	-	-	↑	↑	↑	↑	-
Raipur (CG)	↑	↑	-	↑	↑	-	↑	↑	-	-	↑	-	↑	↑	-
S.K. Nagar (GJ)	↑	↑	-	-	↑	-	-	↑	-	-	↑	-	↑	↑	-
Vamban (TN)	↓	↑	-	↓	↑	-	-	↑	-	↓	↑	↑	↓	-	-
Varanasi (UP)	↑	↑	-	↑	↑	-	↑	↑	-	-	↑	-	↑	↑	-
Virudhachalam (TN)	↓	↑	-	↓	↑	-	↓	↑	↓	↓	↑	↑	↓	↑	-
Warangal (TS)	↑	↓	-	-	↓	-	-	-	-	-	↓	-	↑	↓	-

Symbols indicate significance for their trends [upward (↑)/downward (↓)] based on Mann-Kendall test; - indicates the non-significance

Seasonal trends

Among seasons, significance for climate change was summer>*rabi*>*kharif*. While trends of rains that were of significance showed decrease during *kharif,* increase was noticed for *rabi* and summer. The locations categorized based on the singnificance of trends for the variables of MaxT, MinT and RF as increasing (Table 4) or decreasing (Table 5) or no change (Table 6) are furnished based on Table 3.

Kharif: MinT>MaxT>RF had been the order of significance for trends amongst location. Thirteen and eight locations had increasing trends of MinT and MaxT, respectively with no location having change for RF. Three [Karjat (MH), Mandya (KA) and Junagadh (GJ)] for MinT, two [Kadiri (AP) and Virudhachalam (TN)] for MaxT and three [Aduthurai (TN), Kampasagar (TS) and Vridhachalam (TN)] locations had declining trends. Bengaluru (KA), Raipur (CG) and Varanasi (UP) are the only locations that had increasing trends of both MaxT and MinT. Twenty of the 23 locations did not show any change for RF.

Rabi: The order of increasing climatic trends was MinT (17)>RF (7)>MaxT (5) and that of decreasing trends was MaxT (5)>MinT (2). MaxT increase alone at Chinsurah (WB) and Kalyani (WB) and and that of MinT alone at Anantapur (AP), Dharwad (KA), Gulbarga (KA), Jalgaon (MH), Rahuri (MH), Vamban(TN) and Vridhchalam (TN) was noticed. Increased MaxT as well as MinT was seen only at Bengaluru (KA) and Kampasagar (TS) and that of decreasing trend was noted only at Mandya (KA). Warangal (TS) had declining MinT with no change for MaxT and RF. While increasing trend of MaxT and RF was seen only with Karjat (MH), increasing MinT and RF was noted at Aduthurai (TN), Jalgaon (MH), Kadiri (AP), Rahuri(MH), Vamban (TN) and Vridhachalam (TN) wherein increasing temperature (either MaxT or MinT) with increased RF was associated. However, increasing MinT as well as MaxT with no change of RF was noticed at Bengaluru (KA), Chinsurah (WB) and Kampasagar (TS).

Summer: Fourteen and nineteen locations had increasing trends in respect of MaxT and MinT with 12 of them common for both variables. While Karjat (MH) and Mandya (KA) had increase for only MaxT, Aduthurai (TN), Dharwad (KA) Gulbarga (KA), Jabalpur (MP), Jalgaon (MH), Kadiri (AP) and Rajendranagar (TS) had only MinT increasing. Decreasing MaxT at Gulbarga (KA), Kadiri (AP), Vmban (TN) and Vridhchalam (TN) and of MinT at Mandya (KA) and Warangal (TS) was seen. Karjat (MH) and Vamban (TN) did not show change for MinT. None of the locations had RF increase or decline in recent periods.

Table 4. Seasonal climate variability: increasing trend

Variable	*Kharif*	*Rabi*	Summer
Maximum temperature	Bengaluru (KA), Chinsurah (WB) Kalyani (WB), Kampasagar (TS), Karjat (MH), Mandya (KA), Raipur (CG), Varanasi (UP) **(8)**	Bengaluru (KA), Chinsurah (WB), Kalyani (WB), Kampasagar (TS), Karjat (MH) **(5)**	Anantapur (AP),Bengaluru (KA), Chinsurah (WB), Junagadh (GJ), Kalyani (WB),Kampasagar (TS), Karjat (MH), Ludhiana (PB), Mandya (KA), Rahuri (MH), Raipur (CG), S.K. Nagar (GJ), Varanasi (UP), Warangal (TS) **(14)**
Minimum temperature	Aduthurai (TN), Bengaluru (KA), Gulbarga (KA), Dharwad (KA), Jabalpur (MP), Jalgaon (MH), Kadiri (AP) Ludhiana (PB), Raipur (CG), S.K. Nagar (GJ), Vamban (TN), Varanasi (UP), Virudhachalam (TN) **(13)**	Aduthurai (TN), Anantapur (AP), Bengaluru (KA),Chinsurah (WB), Dharwad (KA), Gulbarga (KA), Jalgaon (MH), Kadiri (AP), Kampasagar (TS), Ludhiana (PB), Rahuri (MH),Raipur (CG), Rajendranagar (TS), S.K. Nagar (GJ), Vamban (TN), Varanasi (UP), Virudhachalam (TN) **(17)**	Aduthurai (TN), Anantapur (AP), Bengaluru (KA),Chinsurah (WB), Dharwad (KA),Gulbarga (KA), Jabalpur (MP),Jalgaon (MH), Junagadh (GJ), Kadiri (AP), Kalyani (WB), Kampasagar (TS), Ludhiana(PB), Rahuri(MH), Raipur(CG), Rajendranagar (TS), S.K. Nagar (GJ), Varanasi (UP), Virudhachalam (TN) **(19)**
Rainfall	-	Aduthurai (TN), Jalgaon (MH), Kadiri (AP), Karjat (MH), Rahuri (MH), Vamban (TN) Virudhachalam (TN) (7)	-

Locations common to all seasons indicated in purple fonts had similar trend across seasons of *kharif, rabi* and summer

Table 5. Seasonal climate variability: decreasing trend

Variable	*Kharif*	*Rabi*	*Summer*
Maximum temperature	Kadiri (AP), Virudhachalam (TN) **(2)**	Gulbarga (KA), Kadiri (AP), Mandya (KA), Vamban (TN), Virudhachalam (TN) **(5)**	Gulbarga(KA), Kadiri (AP), Vamban (TN), Virudhachalam(TN) **(2)**
Minimum temperature	Karjat (MH), Mandya (KA), Junagadh (GJ) **(3)**	Warangal (TS), Mandya (KA), **(2)**	Mandya (KA),Warangal (TS) **(2)**
Rainfall	Aduthurai (TN), Kampasagar (TS), Virudhachalam (TN) **(3)**	-	-

Locations common to all seasons indicated in purple fonts had similar trend across seasons of *kharif, rabi* and summer

Table 6. Seasonal climate variability: no trend

Variable	*Kharif*	*Rabi*	*Summer*
Maximum temperature	Aduthurai (TN), Anantapur (AP), Dharwad (KA), Gulbarga (KA), Rajendranagar (TS), Jabalpur (MP), Jalgaon (MH), Junagadh (GJ), Ludhiana (PB), Rahuri (MH), S.K. Nagar (GJ), Vamban (TN) Warangal (TS) **(13)**	Aduthurai (TN) Anantapur (AP), Dharwad (KA), Rajendranagar (TS), Jabalpur (MP), Jalgaon (MH), Junagadh (GJ), Ludhiana (PB), Mandya (KA), Rahuri (MH), S.K. Nagar (GJ), Varanasi (UP), Warangal (TS) **(13)**	Aduthurai (TN) Dharwad (KA), Rajendranagar (TS), Jabalpur (MP), Jalgaon (MH), **(5)**
Minimum temperature	Anantapur (AP), Chinsurah (WB), Rajendranagar(TS), Kalyani (WB), Kampasagar (TS), Rahuri (MH) Warangal (TS) **(7)**	Jabalpur (MP), Junagadh (GJ), Kalyani (WB), Karjat (MH), **(4)**	Karjat (MH) Vamban (TN) **(2)**
Rainfall	Anantapur (AP), Bengaluru (KA), Chinsurah (WB), Dharwad (KA), Gulbarga(KA), Rajendranagar(TS), Jabalpur (MP), Jalgaon (MH), Junagadh (GJ), Kadiri (AP), Kalyani (WB), Karjat (MH), Ludhiana (PB), Mandya (KA), Rahuri (MH), Raipur (CG), S.K. Nagar (GJ), Vamban (TN), Varanasi (UP), Warangal (TS), **(20)**	Anantapur (AP), Bengaluru (KA), Chinsurah (WB), Dharwad (KA), Gulbarga(KA), Rajendranagar(TS), Jabalpur (MP), Junagadh (GJ), Kalyani (WB), Kampasagar (TS), Ludhiana (PB), Mandya (KA), Raipur (CG) S.K. Nagar (GJ) Varanasi (UP) Warangal (TS) **(16)**	Aduthurai (TN), Anantapur (AP), Bengaluru (KA), Chinsurah (WB), Dharwad (KA), Gulbarga(KA), Rajendranagar (TS), Jabalpur (MP), Jalgaon (MH), Junagadh (GJ), Kadiri (AP), Kalyani (WB), Kampasagar (TS), Karjat (MH), Ludhiana (PB), Mandya (KA), Rahuri (MH), Raipur (CG), S.K. Nagar (GJ) Vamban (TN), Varanasi (UP), Virudhachalam (TN), Warangal (TS) **(23)**

Locations common to all seasons indicated in purple fonts had similar trend across seasons of *kharif, rabi* and summer

IMPACT OF CLIMATIC VARIABILITY AND CHANGE ON INSECTS AND DISEASES

Understanding the real time pest scenarios of insects and diseases at field level in respect of target crops at study locations primarily assisted in their effective management on need basis. The systematic approach to data collection through scientific plans and use of ICT provided the larger scope of examining the multiseasonal and multilocational data from the weather variability and climate change perspective. Scenarios and status of major insects, diseases, and ourbreaks that had occurred along the study period were analysed and highlighted on CV and CC basis, as applicable. While Rice and Tomato crops had three (*kharif, rabi* and summer) and two (*kharif* and *rabi*) seasons, Pigeonpea and Groundnut had only *kharif* covered. Multispecies associations of insects of rice in respect of three seasons for study locations and half decadal comparisions of insects/diseases for those study locations of all target crops that had seasonal dynamics between 2011 and 2020 are also inferred through correlative and 't test', respectively. Prediction of major insects of rice, pigeonpea and groundnut for future climatic projections under A1B emission scenario or at different levels of representative concentration pathways (RCP) worked out selectively are also furnished under relevant target crops. The results on the impact of climate variability/change in respect of the four target crops *viz.,* Rice, Pigeonpea, Groundnut and Tomato have been organized along the following major topics:

- Highlights of insect and disease scenario *vis a vis* climate variability
- Seasonality of insects and diseases: inter seasonal variations
- Inter seasonal variations of actual weather and climatic deviations
- Magnitude of climate change
- Impact of individual climatic variables on insects and diseases – tabulaur and pictorial formats
- Overall impact of climate change on insects and diseases as assessed through species-climate change association index (SAI) – within location
- Overall impact of climate change on insects and diseases as assessed through species-climate change association index (SAI) – between locations
- Impact of climate change on insects and diseases- a listing

RICE

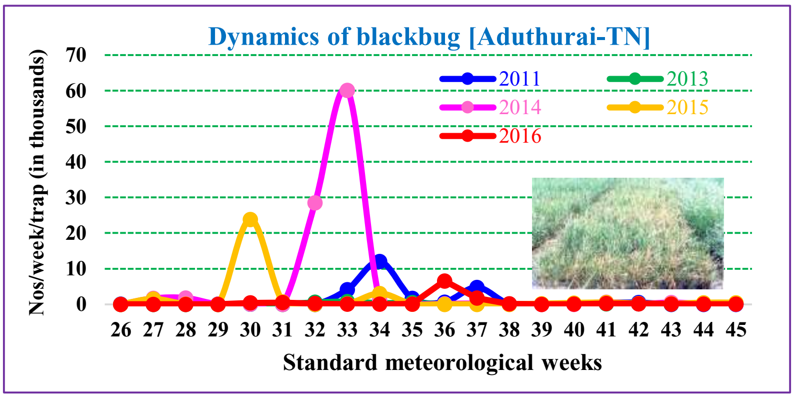
Importance of Indian rice cultivation arises out of its contribution towards food and livelihood security for millions of consumers and producers. Rice is cultivated under dry, wet and semi dry systems covering diverse ecosystems such as irrigated, rainfed, low and upland, hill, shallow lowland, deep water, semi deep water and saline alkaline *etc*., spread across many States and Union Territories together numbering 25. Rice production in the country fluctuates in relation to weather during the crop season. Different categories of pests *viz.,* insects, diseases, weeds, nematodes, rats and crabs cause direct and/or indirect damage at various crop growth stages resulting in reduction of rice yields. Severity of rice pests is influenced both by crop growth and prevailing weather. In the context of climate change, we expect both the crop in terms of phenology and physiology and the pests in their occurrence and abundance likely to change. Seven rice locations (refer map) that represent dominant rice growing climatic zones have been included (Annexure I & II) under NICRA for pest surveillance (Anonymous, 2011). Although rice pest surveillance was carried out in nursery and fields located at the research/experimental station of the identified rice growing region, and at villages in the fields of farmers, the daily recordings of the insects in the light traps of each study centre *vis a vis* weather variables were effectively used to assess the impact of climate change. It is to be mentioned that the field dynamics of rice insects and diseases were largely fractional but for times of outbreak that only insects caught in light traps were accounted for assessing the impact of climate change. However, insects/disease of importance over the study years are highlighted in relation to weather extremes/climatic variability or change. While all the seven locations had season of *kharif*, three locations each had rice cultivation under *rabi* and summer (Annexure III).

Highlights of insect and disease scenario *vis a vis* climate variability

Aduthurai [Tamil Nadu (TN)] [ACZ: East Coast Plains and Hills Region AER: Eastern coastal plain hot subhumid to semi- arid ecoregion]

Rice black bug, *Scoutinophara lurida* Burmeister is an exclusive insect pest of Aduthurai (TN). It had a regular occurrence throughout the year since 2005, however occurred sporadically during summer months between 2010 and 2013 due to the intensive cultivation of rice fallow pulses. The recurrence of the insect during summer, and highest population levels (maximum of 60,080/week/trap in 33 SMW) during *Kharif* in 2014 was noted (Anonymous, 2016). Although direct effects of weather were minimal, the delayed monsoon and canal water release and extended *kharif* season with greater than 50 mm rainfall as against 7.9 mm normal in three rainy days during 27 SMW triggered the brood emergence. Nevertheless, the unusual rainfall on 09.08.14 (13mm) and 11.08.14 (12 mm) favored the emergence of resting stage and the total receipt of 125 mm rainfall [9 mm (14.8.2014), 58 mm (15.8.2014), 48 mm (16.8.2014)] on four continuous rainy days in 33 SMW led to the outbreak of rice blackbug *S. lurida*.

S. lurida catches in light trap



Reduced minimum temperature with increased relative humidity levels brought out by higher rainfall on continuous rainy days during July and August resulted in highest population (maximum of 23,808nos/week/trap in 30 SMW in 2015) of *S. lurida*. Single peak of blackbug in light trap was observed following the (5,115 no/trap) unusual rainfall on 27.08.2016 (55.4 mm) and on 30.08.2016 (16.0 mm) that favored the emergence of resting stage. The time of emergence of *S. lurida* varied between 30 and 34 SMWs due to shift in the occurrence of monsoon and the rainfall pattern at Aduthurai (Tamil Nadu) and the highest peaks in all seasons were always associated with continuous rainy days (Vennila *et al.* 2018b).

***S. lurida*-weather relations**

Weather variables	Correlation coefficient (r)
Min.T (°C)	-0.48***
MRH (%)	0.25**
ERH (%)	0.23*
Rainfall (mm/week)	0.21*
Rainy day (no.)	0.30**

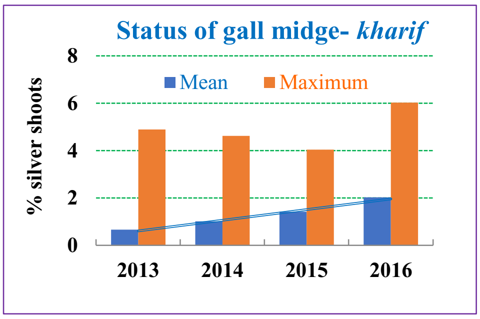
*: $p \leq 0.05$; **: $p \leq 0.01$; ***: $p \leq 0.001$

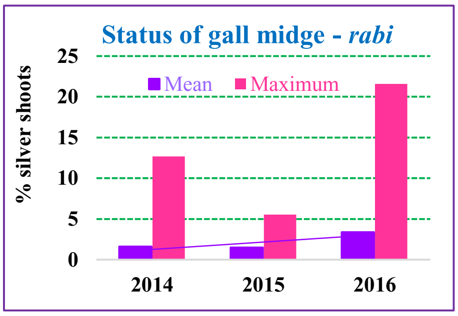
Whorl maggot damage

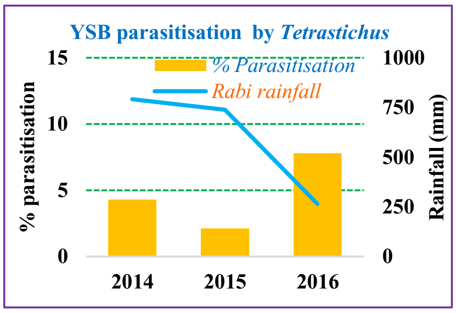
Damage due to whorl maggot (*Hydrellia sasakii* (Ephydridae: Diptera)) between flowering and milky stage, and by coccinellids to pollens in traces during *kharif* 2013 was recorded. Whorl maggot damage was 37% during tillering (August 2016) in Kalancheri of Ammapettai. Dry spell for 2-3 weeks with higher day temperatures in August 2016 coinciding with tillering of rice led to outbreak of yellow leaf mite, *Oligonychus oryzae*. Rice mealybug, *Brevenia rehi* outbreak in direct seeded rice (*cvs.* CR1009 and BPT5204) in Kilvelur block of Nagapattinam district (TN) during October 2013 was noticed following prolonged dry spell of 2 - 3 weeks followed by rains wherein mealybug crawlers were transported through water movement from affected to nearby unaffected fields and the high weed density along bunds (*Echinocloa* spp.) serving as alternate host.

Mealybug affected direct seeded rice field at Kilvelur (TN) (2013)

Stem borer complex during *rabi* was yellow stem borer (YSB) *Scirpophaga incertulas* (81.2 %) > dark headed borer (DHB), *Chilo poychrysus* (12.5 %) > pink stem borer (PSB) > *Sesamia inferens* (6.2%) at 30 days after transplanting





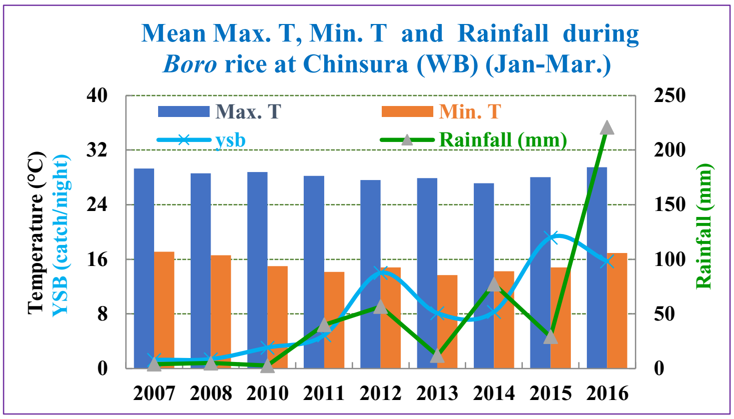


(DAT). YSB (51.4 %)>DHB (31.4 %), striped stem borer (SSB), *Chilo suppressalis* (14.2 %)>PSB (2.8 %) was noted at 50 DAT in 2013. The higher relative humidity (97%) during December 2015 coupled with excessive nitrogen application favored the brown plant hopper *Nilaparvata lugens* multiplication resulting in outbreaks on *rabi* rice at Nachinargudi, Theralanthur and Komal villages of Kuttalam block of Nagapattinam. The silver shoot damage by gall midge (1.7 – 6.1 %) is on the rise over years both in *kharif* and *rabi*. The 84 and 79 % reduction in rainfall in respect of July - August and November-December 2016 over normals (95 & 400 mm) during *kharif* and *rabi* was conducive for gall midge development. Natural parasitisation by *Tetrastichus* sp. on yellow stem borer was higher during 2016 when the rainfall amount was 66% lower over 2014 & 2015 during *rabi*.

'Silver shoots' due to gall midge

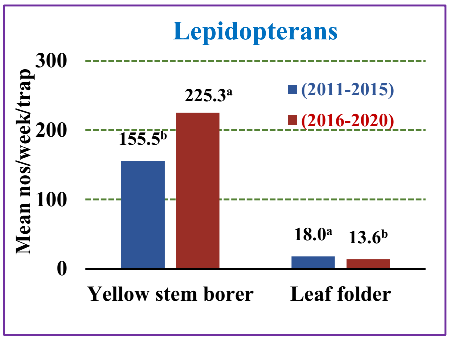
Chinsurah [West Bengal (WB)] [ACZ: Lower Gangetic Plains Region AER: Bengal and Assam plain hot subhumid to humid perhumid ecoregion]

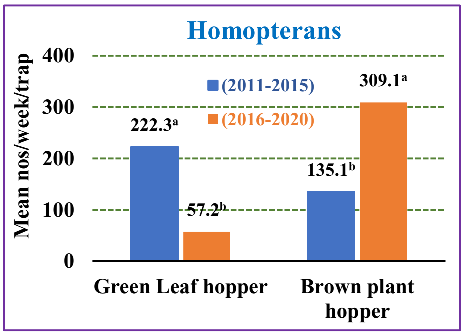
Higher incidence of yellow stem borer was noted from 2011 during *Boro* (summer) season mainly due to the decreasing temperature regimes and increased rainfall over 2007 and 2008. Increasing rainfall during January to March *vis a vis* decreased levels of minimum temperature (by 2°C) resulted in increasing yellow stem borer (YSB) on *boro* rice at Chinsurah (WB) during 2012 and 2013 with white ear damage of 100 and 70%, respectively under no protection. The decreased minimum temperature during the *boro* rice season of the current decade combined with the increased rainfall (>30mm/week) resulted in higher incidence of *S. incertulas* in 2015. Reducing mean temperature (1-2˚C) against normal (23.1˚C) largely brought by declining minimum temperature during January-March leading to higher YSB was confirmed in 2016.

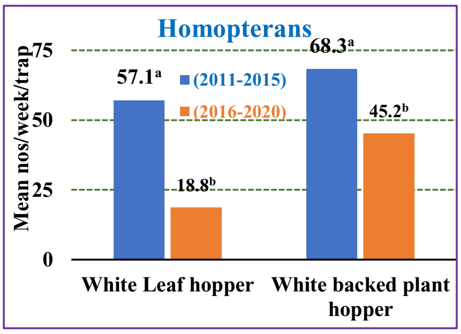


Changing status – a half decadal comparison

Scenario of Lepidopteran and Homopterous insects was significantly different between first and second half of first decade of current century. Significantly increasing and decreasing YSB and LF, respectively was noted during second over first half of the decade. While only BPH had shown increasing trend in the recent years (2016-20), other homopterous *viz.,* GLH, WLH and WPBH had significant decline in abundance (Anonymous, 2020).

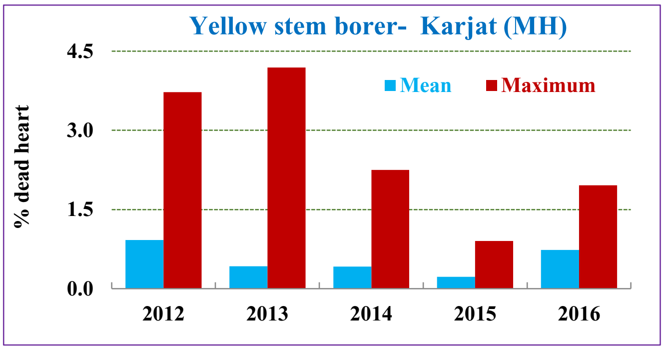


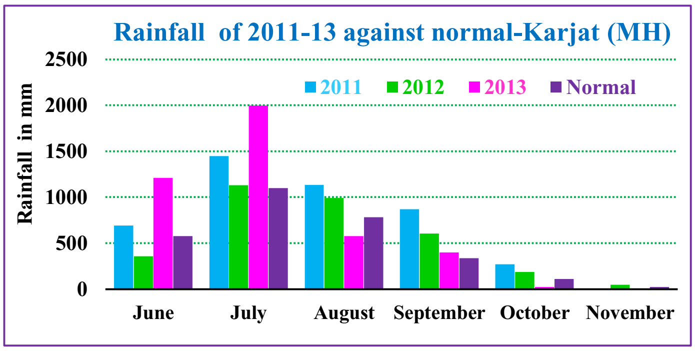




Karjat [Maharashtra (MH)] [ACZ: West Coast Plains and Ghat Region AER: Western ghat & coastal plain hot humid perhumid ecoregion]

Epidemic occurrence of brown plant hopper was noticed in 2011 with increasing temperature and rainfall. While pest status was meager at Konkan during *kharif* 2012, blue beetle and caseworm incidence was 10 and 45 % in some talukas of Ratnagiri and Thane districts, respectively. *Kharif* 2013 had high rainfall of 1210.7 and 1990.7 mm in July and August, respectively. Rainfall was 1.5 to 2 times more than normal although rainfall during August 2013 was less than the normal. Excess rainfall had affected nurseries as well as transplanted rice leading to replanting. This situation was favourable for caseworm occurrence during July and August.

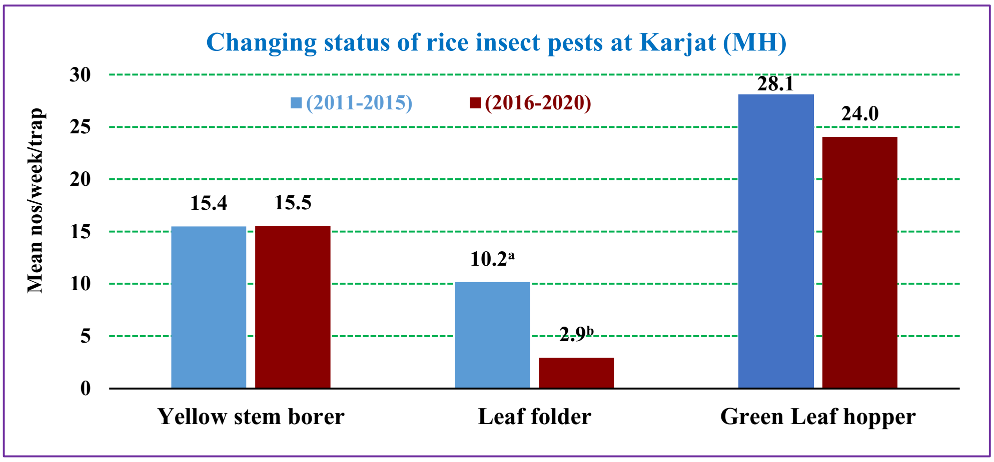




Cloudy weather and intermittent rains in October 2013 caused heavy incidence of rice armyworm at the maturity stage of early varieties of rice crop with low bacterial leaf blight and blast severity. Also late showers in October coinciding with crop maturity resulted in considerable yield loss during 2013. Decreasing incidence of YSB and increasing case worm and leaf folder, later due to the late start of rains and the associated delayed transplanting in *kharif* 2014 was noted. High incidence of rice blue beetle in Alibaug and Murud tehsils of Raigad in 2014 due to dense planting, use of high nitrogenous fertilizers, improper weed management and drainage was noted over the effect of abiotic factors. Unseasonal rains and cloudy weather at *rabi* (2014-15) rice harvest had the incidence of rice army worm throughout Raigad district. Karjat of Raigad district in Konkan region of Maharashtra known to be a hot spot for yellow stem borer (*S. incertulas*) has its abundance and damage declining. The cropping season restricted to only *kharif* of 2011-16 was on account of non-availability of canal irrigation with no change of climate noted for *kharif*.

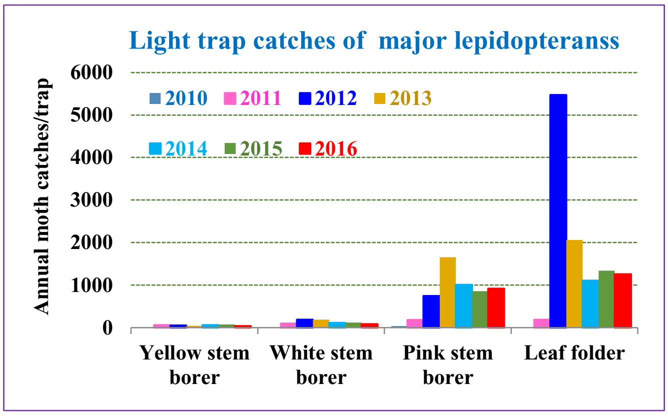
Changing status – a half decadal comparison

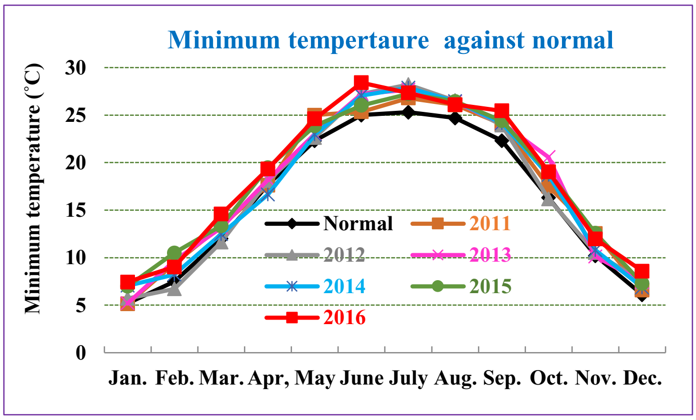
Yellow stem borer and green leafhopper between two half decades of 2011-20 were similar indicating the similar status despite interseasonal differences. Leaf folder of the recent years of 2016-20 had significant reduction indicating a negative shift for the insect and positive from crop production point of view with decreased loss and reduced pest management interventions.



Ludhiana [Punjab State (PB)] [ACZ: Northern Plain and Central Highland including Aravalis, hot semi arid ecoregion]

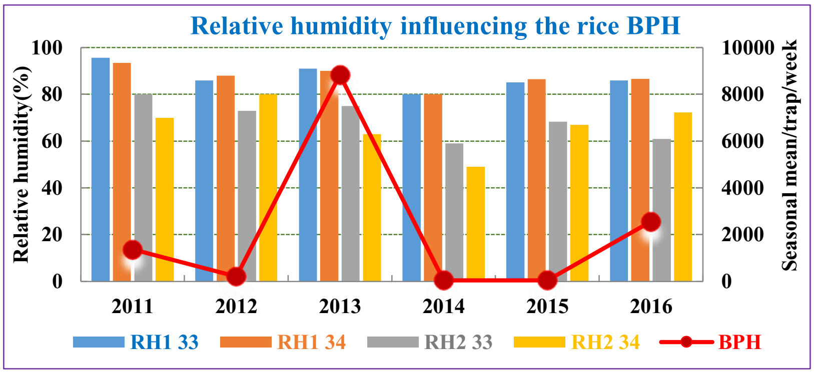
The importance of lepidopterans on rice at Ludhiana (PB) during the current decade is of the order: leaf folder (*Cnaphalocrocis medinalis*) >pink (*Sesamia inferens*)>white (*Scirpophaga innotata*)>yellow (*S. incertulas*) stem borers





under the regimes of increasing minimum temperature well above the normal throughout the year and more during *kharif* (maximum of 4˚C).

Highly reduced brown planthopper, *Nilaparvata lugens* at Ludhiana (PB) observed for the second consecutive *kharif (*2015) indicated the requirement of greater than 90, 70% morning, and evening relative humidity, respectively corresponding to the 33 and 34 SMWs largely governed by the rainfall amounts of the current or previous weeks. Overall, higher morning relative humidity (>85%) during mid-August (33 SMW) associated with fluctuating evening



relative humidity between 60 and 70% in 33 and 34 SMWs contributed to the buildup of brown plant hopper (BPH) with peaks always during October irrespective of the size of population at Ludhiana (PB) during all seasons. Damage due to brown planthopper in farmer fields in Ludhiana, Moga, Barnala, Bathinda, Jalandhar, Kapurthala, Faridkot, Fatehgarh Sahib, Mansa, Patiala and Sangrur districts were common on late duration *cv.* Pusa 44 in 2016.

Mandya [Karnataka (KA)] [ACZ: Southern Plateau and Hills Region AER: Eastern ghat, TN upland and Deccan plateau hot semi- arid ecoregion]

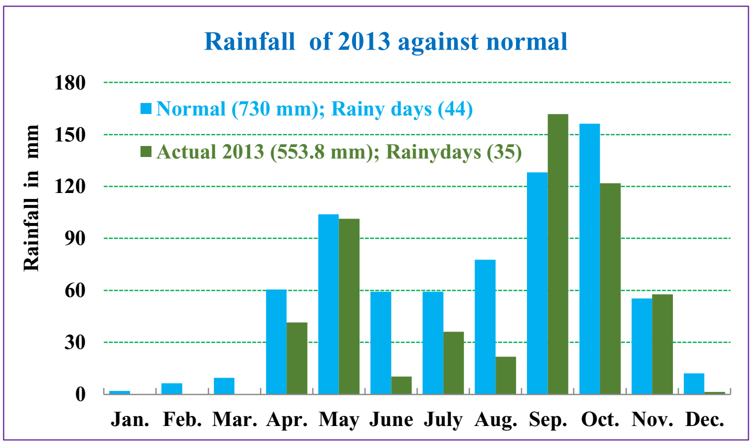
Although Mandya received higher pre monsoon rains that had allowed early land preparation, less rainfall during June and July led to delay in sowing/planting of rice. While the incidence of major pests was below economic threshold levels (ETL) in *kharif* 2013, moderate incidence of BPH was observed in parts of Mysore, Uttarkannada and Koppal districts. Late planting combined with excess rainfall (more number of rainy days) compared to normal during September 2013 resulted in outbreak of case worm in about 3,000 acres of Cauvery command area. Late planting of rice taken up between last week of July to second week of August 2016 due to delayed and uneven distribution of rains led to *N. depunctalis* infestation above economic threshold levels (ETL) during 36-38 SMWs. More than 1,000 acres had severity of neck blast caused by the excess rainfall brought about by Pilene cyclone 2013 *vis a vis* lowered night temperatures during November. Cultivar KCP1 that was flowering at the time of cyclonic rains had 100 % damage due to neck blast. The heavy pre-monsoon (243mm in May) and prolonged rainfall during June (53mm), July (72mm), August (114mm), September (141mm) and October (237mm) coinciding with the peak activity of rice pests led to reduced incidence in *kharif* 2014. Intermittent rains due to depression over Bay of Bengal favoured occurrence of rice blast (*P. oryzae*) to a maximum of 60% at K.R. Nagara and Nanjangud tehsils of Mysore (Karnataka) during the first fortnight of October 2015.

Caseworm infested rice field at Mandya (KA)

Raipur [Chhattisgarh (CG)] [ACZ: Eastern Plateau and Hills Region AER: Eastern plateau (Chhattisgarh) hot semihumid ecoregion]

Increasing cut worms and rat menace due to reduced and erratic rainfall in 2011 was noted. Raipur, a hot spot for gall midge incidence had almost nil population during *kharif* 2012 possibly due to heavy rainfall during August and September. Hispa damage at vegetative stage was noticed after many seasons in 2012. Stem borer was the major pest in 2012 and caused about 25% yield reduction. Intensities of stem borer infestation as dead hearts ranged between 6.5 and 36.2% with white ear up to 23.7% in 2013. BPH had caused significant losses with population range of 23-777 adult counts per 20 hills at panicle stage coinciding with rains and cloudy weather. The extreme event of heavy rains in 2013 at the maturity stage of the crop led to crop lodging. Initial drought for a month followed by high intensity of rainfall during July and August of *Kharif* 2014 resulted in low intensity of insect pests. The gall midge was seen only at a few places of Mungeli and Rajnandgaon districts on late sown crop coupled with moderate intensity of rains during September 2014. Grain discoloration and unfilled grains of rice were observed in almost all parts of Chhattisgarh after cyclonic rains (Hudhud) occurred during 11-13 October 2014. Panicle mite was observed as an emerging problem between July and October 2015 induced by higher maximum (3°C above normal) and minimum (2°C above normal) *vis*

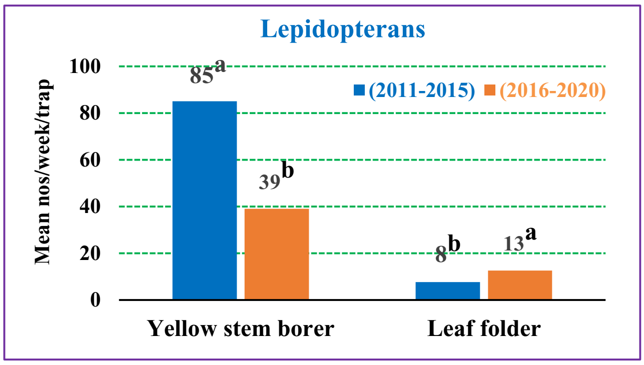
Blast affected rice field at K.R. Nagara (Mysore – KA)

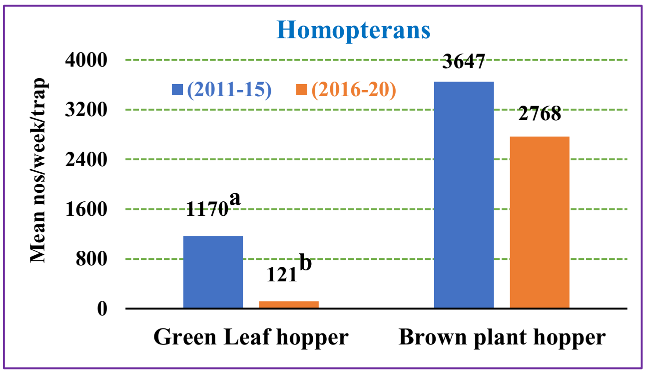


a vis highly reduced rainfall (200 mm less than normal of 860 mm) particularly in medium duration varieties. Cutworm attack on direct seeded rice and gall midge attack (50%) in hybrid rice were noted during first and second fortnights, respectively during August 2016 at Naryanpur. Incidence of rice panicle mite on medium duration cultivars, moderate to high incidence of BPH from Arang block in November on late sown *cv.* Swarna and of false smut damage in late maturing crop under conditions of increasing minimum temperature by 2˚C with well distributed rainfall during *kharif* 2016 was seen.

Changing status of rice insects during the second decade of current century

Analysis of seasonal differences based on light trap catches (mean nos/week/trap) over 10 seasons (2011-2020) of *kharif* rice for two each of lepidopteran and homopteran insects at Raipur (CG) indicated significant variations. Yellow stem borer (YSB) was highest during 2011, 2012 and 2020 over other seven seasons. Leaf folder (LF) was significantly lower in 2017 over all other seasons that were on par. Significantly higher brown plant hopper (BPH) was noted for 2013 and 2020 with the latest season on par with 2015. Within season, variations were so high during 2016-2019, 2011-2012 and 2014 that their mean status was on par. Greenleaf hopper (GLH) followed similar status as that of BPH with the exception of highly reduced population during 2020. Significantly, declining and increasing YSB and LF were observed for first and second half of current decade. Amongst hoppers, GLH had shown significant decline during second over first half of the decade with no differences for BPH (Vennila *et al.* 2015b; Anonymous, 2020).





Kampasagar [Telangana State (TS)] [ACZ: Southern Plateau and Hills Region AER: Deccan plateau and eastern ghat, hot semi- arid ecoregion]

BPH damage ('Hopper Burn') at Kangan Mandal of Nalgonda (TS)

Late plantings with high rainfall during *kharif* 2011 at Nalgonda (TS) had increased gall midge. *Kharif* 2012 had late transplantations and pest status of plant hoppers (WBPH and BPH) during September and October in many mandals of Nalgonda (TS) due to injudicious use of synthetic pyrethroids and combination products (8 –10 sprays) more than the influence of weather factors. Incidence of gall midge during *rabi* very unusual at Telangana was observed after Neelam cyclone at coastal districts. Brown planthopper occurred in severe forms during *kharif* 2011, 2012 and 2013 with no damage in 2014 and 2015 in the Nalgonda district of Telangana (Anonymous, 2013). Well distributed rains (>1100 mm) and early transplanting were conducive for BPH and the higher doses of nitrogenous fertilizers and indiscriminate use of insecticides including application of synthetic pyrethroids during 2011-2013 led to higher damage. Additionally, continuous rainfall during third week of October 2013 (>100mm) with high humidity and cloudy conditions and absence of insecticide sprays led to BPH outbreak. However, late onset and lower rainfall during 2014, delayed plantings and lower winter temperatures resulted in lower BPH damage.

Seasonality of insects - *kharif*

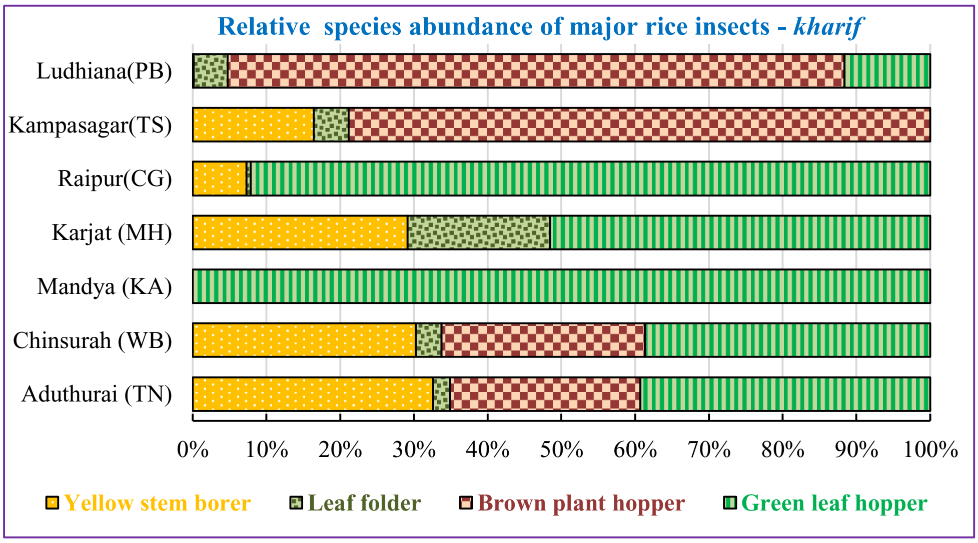
Relative importance of insects over a period of six years (2011-16) worked out varied between locations as well as within locations for different insects (Table 7). Chinsurah (WB) for YSB & WLH, Ludhiana (PB) for LF & BPH and Raipur (CG) for GLH proved to be the specific insect hot spots relative to other study locations.

Table 7. Relative abundance of major rice insects across study locations of seven ACZ -*kharif*

Insect	Aduthurai (TN)	Chinsurah (WB)	Kampasagar (TS)	Karjat (MH)	Ludhiana (PB)	Mandya (KA)	Raipur (CG)	F statistic
Yellow stem borer	76.5^{b}	155.7^{a}	28.2^{c}	13.4^{d}	2.1^{e}	5.2^{de}	74.9^{b}	147.3 ***
Leaf folder	5.4^{d}	18.0^{b}	8.1^{cd}	8.9^{cd}	68.8^{a}	-	5.9^{cd}	31.8 **
Brown plant hopper	61.0^{c}	141.7^{b}	135.6^{b}	-	521.7^{a}	-	-	6.78 **
Green leaf hopper	92.8^{c}	199.1^{b}	178.5^{b}	23.7^{d}		37.0^{d}	927.4^{a}	40.9 **
White backed plant hopper	-	62.5	53.8	-	69.4	-	-	0.2 ^{NS}
White leaf hopper	33.6^{b}	51.1^{a}	-	-	-	-	-	6.94 **

Values are mean no. of insects/trap/week; In a row means followed by the same letter are not significantly different with significance of 'F' denoted by *: $p < 0.05$; p<0.01; ***: $p < 0.001$. ^{NS} : non-significant based on oneway ANOVA; - absence of insects or data not available ; Data sets of 2011-16 acccounted for analysis; analysis based on appropriate transformations; furnished are original means

Overall, the abundance of insect species in rice ecosystem (*kharif*) followed the order YSB >LF for lepidopterans and BPH>GLH for homopterous insects. While YSB was abundant at Chinsurah (WB), least was noticed at Ludhiana (PB) with its insignificant presence at Mandya (KA). The order of importance for YSB was Chinsurah (WB)> Raipur (CG)> Aduthurai (TN)> Kampasagar (TS)> Ludhiana (PB). On the other hand, LF was the highest in abundance at Ludhiana (PB) followed by Chinsurah (WB) with rest of the locations having a lower abundance. Mandya (KA) was also free from the LF. Among homopterans, population of BPH was abundant at Ludhiana (PB), followed by Chinsurah (WB), Kampasagar (TS) and Aduthurai (TN). Raipur (CG), Karjat (MH) and Mandya (KA) did not have occurrence of BPH. Abundance of GLH was maximum at Raipur (CG) followed by Chinsurah (WB), Kampasagar (TS), Aduthurai (TN), Mandya (KA) and Karjat (MH) with its absence at Ludhiana (PB). It was obvious that variations in abundance of each species across locations and of different species in a given location existed. The highest abundance of lepidopterans namely YSB and LF from amongst study locations was noted at the hot sub humid to humid to per humid ecoregion of Chinsurah (WB) of the lower Gangetic plains of ACZ and hot semi-arid ecoregion of Ludhiana (PB) of trans-Gangetic plains, respectively. While the homopteran BPH was the highest at Ludhiana (PB), GLH was at its highest abundance at the hot semi humid ecoregion of Raipur (CG) of the Eastern plateau and hills ACZ. Hot semi-arid and hot humid conditions in respect of West coast plains and ghat and Southern plateau and hills noted at Mandya (KA) and Karjat (MH), respectively have been found to be less favourable for all four-study insects over ACZ having plains. Nevertheless, the generalised trend of abundance was that plains harboured more of YSB, LF, BPH and GLH. Within same ACZ of Southern plateau and hills upland hot semi-arid region (Mandya (KA)) had the least abundance of all four insects over Eastern ghat hot semi-arid ecoregion (Kampasagar (TS)) indicating prevalence of climatically sensitive eco-regions. Soil types, temperature, rainfall, and water availability influencing the type of host in turn acting as modifier for invaded insect species across various agro-climatic zones have been reported. The widely differing agro climatic zones of the present study represent variability for many of the edaphic and atmospheric factors and hence existence of variability in insect abundance are justified. However higher relative importance of a given insect at one over other locations is attributable to the prevalence of congenial macro and micro climatic conditions for the specific insect towards exhibiting higher reproductive fitness as the physiological performance of insects is dependent on environmental thermal conditions that makes them vulnerable to climate change.



Inter seasonal variations of rice insects - *kharif*

The seasonal dynamics of rice insects caught in light traps for study locations arranged under each insect in respect of seasons are furnished in Annexure XVII. Interannual variations (Table 8) for adults of all rice insects in light trap (nos/trap/week) since 2011 indicated significant differences amongst different years in respect of study locations but for yellow and white stem borers at Ludhiana (PB). Aduthurai (TN) had significantly higher YSB in 2011 and 2012 that was declining and on par amongst 2013-2016. Chinsurah (WB) too had the highest abundance of YSB in 2011 on par with 2013 & 2016-2018 followed by reduced and on par status during 2014, 2015 and 2019. Significantly higher YSB at Kampasagar (TS) was in 2016 over the previous five seasons (2011-2015). Abundance of YSB was highest during 2012 and 2017 at Karjat (MH) and in 2013 and 2016 at Mandya (KA). Significantly, higher LF abundance was during 2011 at Aduthrai (TN) and Chinsurah (WB); 2012 at Kampasagar (TS) and Ludhiana (PB) and 2013 and 2014 at Karjat (MH). The lowest and highest LF at Raipur (CG) was in 2017 and 2012 & 2019, respectively with all other seasons having on par abundance with either of the groups (Kumar *et al.,* 2016; Vennila *et al.,* 2020a).

The order of importance of BPH was Raipur (CG)> Ludhiana (PB)> Chinsurah (WB)> Kampasagar (TS) > Aduthurai (TN). Season of 2013 had the highest BPH abundance at Raipur (CG) and Ludhiana (PB), with the former location having continued higher abundance till 2015. Beyond 2015, BPH at Raipur (CG) was higher in 2017 with 2016 & 2018-19 having lesser and on par population. Chinsurah (WB) had the highest population of BPH during the successive years of 2017 and 2018. Lower level of occurrence of BPH was seen during 2014 and 2015 at Chinsurah (WB) although 2016 had significantly higher population over 2011-13. Raipur (CG)> Kampasagar (TS)> Chinsurah (WB)> Aduthurai (TN)> Mandya (KA)> Karjat (MH) was the order of GLH abundance during *kharif*. Significantly higher GLH was at Chinsurah (WB), Karjat (MH), Raipur (CG) and Aduthurai (TN) cum Mandya (KA) in respect of 2011, 2012, 2013 and 2014 over other years. White backed BPH was at its high in 2011 at Chinsurah (WB) with lower abundance between 2012 and 2015. Abundance differed across years at Kampasagar (TS) with 2013 and 2014>2012>2015. Ludhiana (PB) had on par WBPH during 2012, 2013 and 2016 higher over other seasons that had similar but lower abundance. White leafhopper was at significantly higher in 2011 over 2012 followed by further reduced population in the succeeding seven years between 2013 and 2019 at Chinsurah (WB). At Aduthurai (TN), WLH was higher in 2011 and least during 2012 & 2014.

Kampasagar (TS) had gall midge occurrence that was reducing beyond 2013. White stem borer had its presence at Mandya (KA) from 2014 with mean abundance higher over 2015 and 2016. Pink stem borer and caseworm were of importance only at Ludhaiana (PB) and Raipur (CG), respectively with their higher population during 2013 at both the locations. Blackbug specific to Aduthurai (TN) had fluctuating abundance with population levels of 2014>2011>2015>2016. Predatory insects caught in light traps were recorded only at Kampasagar (TS). Green mirid bug was higher during seasons of 2014-2016 and lowest 2012 & 2013. Coccinellids feeding on pollens of rice were regular at Kampasagar (TS) with their high population in light traps during 2015 over all other seasons (2012-2014).

While the homopteran BPH was the highest at Ludhiana (PB), GLH was at its highest abundance at the hot semi humid ecoregion of Raipur (CG) of the Eastern plateau and hills ACZ. Hot semi-arid and hot humid conditions in respect of West coast plains and ghat and Southern plateau and hills noted at Mandya (KA) and Karjat (MH), respectively were found less favourable for insects *viz.,* YSB, LF, BPH and GLH over ACZ having plains. The generalised trend of abundance was that the plains harboured more of YSB, LF, BPH and GLH. Within same ACZ of of Southern plateau and hills, the upland hot semi-arid eco region [Mandya (KA)] had the least abundance of all four insects over Eastern ghat hot semi-arid ecoregion [Kampasagar (TS)] indicating prevalence of climatically sensitive eco-regions determining the occurrence and abundance of rice insects.

Table 8. Inter seasonal variations of insects - *kharif*

Insect	Location	Mean	2011	2012	2013	2014	2015	2016	2017	2018	2019	F statistic
Yellow stem borer	Aduthurai	75.9	123.2^{b}	159.7^{a}	30.5^{c}	55.2^{c}	45.7^{c}	41.4^{c}	-	-	-	12.31***
	Chinsurah	150.7	273.8^{a}	94.2^{c}	154.9^{abc}	132.0^{bc}	122.7^{bc}	156.7^{ab}	136.5^{abc}	158.7^{ab}	127.0^{bc}	2.36*
	Kampasagar	27.3	23.1^{c}	21.1^{c}	4.5^{d}	6.2^{d}	45.9^{b}	63.1^{a}	-	-	-	44.11***
	Karjat	16.2	13.0^{bc}	39.6^{a}	15.7^{b}	5.4^{bcd}	3.9^{bcd}	2.9^{cd}	48.8^{a}	0.4^{d}	-	11.63***
	Ludhiana	2.1	2.4	1.9	1.8	2.3	2.7	1.4	-	-	-	0.23^{NS}
	Mandya	5.2	5.5^{ab}	1.3^{c}	8.8^{a}	4.9^{b}	2.3^{bc}	8.5^{a}	-	-	-	6.88***
	Raipur	59.4	147.5^{a}	100.7^{a}	57.1^{ab}	59.2^{ab}	59.7^{b}	23.5^{b}	36.8^{b}	25.5^{b}	24.7^{b}	3.22**
Leaf folder	Aduthurai	5.4	22.1^{a}	4.6^{bc}	4.04^{b}	0.0^{c}	1.3^{c}	0.0^{c}	-	-	-	16.59***
	Chinsurah	15.2	33.3^{a}	14.8^{bc}	19.0^{b}	9.8^{bc}	13.0^{bc}	18.1^{bc}	12.4^{bc}	8.9^{c}	7.3^{c}	3.75***
	Kampasagar	8.1		20.2^{a}	4.6^{b}	4.9^{b}	4.1^{b}	6.9^{b}	-	-	-	3.42*
	Karjat	7.5	6.1^{bc}	4.8^{bc}	20.8^{a}	14.3^{b}	4.7^{bc}	2.8^{cd}	6.1^{bc}	0.4^{d}	-	8.25***
	Ludhiana	70.6	7.4^{c}	194.3^{a}	79.3^{ab}	42.5^{bc}	51.6^{bc}	48.2^{ab}	-	-	-	3.79**
	Raipur	5.7	3.6^{ab}	9.3^{a}	4.5^{ab}	5.0^{ab}	3.4^{ab}	9.3^{a}	1.2^{b}	4.0^{ab}	10.5^{a}	1.65**
Brown plant hopper	Aduthurai	60.1	86.7^{b}	55.5^{b}	48.7^{b}	0.0^{c}	0.0^{c}	169.9^{a}	-	-	-	17.37***
	Chinsurah	224.5	372.4^{bc}	103.5^{cd}	81.4^{cd}	53.7^{d}	64.5^{d}	174.9^{cd}	641.7^{a}	410.5^{ab}	118.3^{cd}	6.18***
	Kampasagar	135.6		79.9^{bc}	109.0^{ab}	241.0^{a}	38.4^{c}	209.7^{ab}	-	-	-	5.26***
	Ludhiana	1284.1	1050^{ab}	144^{b}	5096^{a}	17^{b}	23^{b}	1375^{ab}	-	-	-	4.64***
	Raipur	2385.7	1379^{bc}	2531^{ab}	6384^{a}	1471^{bc}	4704^{ab}	129.0^{c}	2457^{abc}	827.0^{bc}	1590^{bc}	2.88**
Green Leaf hopper	Aduthurai	91.5	77.7^{b}	63.2^{b}	37.5^{b}	237.8^{a}	62.5^{b}	70.2^{b}	-	-	-	3.00**
	Chinsurah	147.6	579.4^{a}	183.9^{b}	155.5^{b}	119.3^{b}	73.4^{bc}	83.2^{bc}	66.1^{bc}	39.7^{c}	27.6^{c}	9.33***
	Kampasagar	178.5		49.0^{b}	57.6^{b}	355.1^{ab}	183.7^{a}	247.4^{a}	-	-	-	4.04**
	Karjat	17.8	14.1^{bc}	77.6^{a}	23.5^{b}	15.8^{bc}	9.5^{cd}	1.9^{d}	0.2^{d}	0.01^{d}	-	21.88***
	Mandya	37	0.0^{c}	5.0^{c}	42.8^{b}	89.0^{a}	40.4^{b}	44.7^{b}	-	-	-	20.03***
	Raipur	681.7	624.9^{bc}	1484^{ab}	2477.7^{a}	468.4^{cd}	581.9^{bc}	16.6^{e}	290.5^{cde}	65.4^{de}	125.5^{cde}	8.03***
White backed plant hopper	Chinsurah	60.7	186.5^{a}	71.8^{bc}	33.7^{bcd}	26.2^{cd}	23.3^{cd}	33.7^{bcd}	96.2^{ab}	59.7^{bcd}	15.2^{d}	4.76***
	Kampasagar	53.8		55.8^{b}	87.7^{a}	99.9^{a}	25.8^{c}	0.0^{d}	-	-	-	34.84***
	Ludhiana	81.6	21.4^{b}	112.0^{a}	142.3^{a}	37.5^{b}	38.1^{b}	138.1^{a}	-	-	-	3.60**
White leaf hopper	Aduthurai	33.3	66.5^{a}	9.9^{c}	26.8^{b}	14.7^{c}	45.0^{b}	37.09^{ab}	-	-	-	7.79***
	Chinsurah	39.4	159.6^{a}	70.9^{b}	27.4^{c}	17.0^{cd}	10.7^{d}	21.1^{cd}	21.6^{cd}	16.4^{cd}	10.1^{d}	17.59***
Gall midge	Kampasagar	3.6	-	8.8^{a}	1.3^{b}	4.1^{ab}	3.8^{ab}	0.1^{c}	-	-	-	6.13***
White stem borer	Ludhiana	5.2	3.5	9	7.2	4.2	4.6	2.7	-	-	-	1.22^{NS}
	Mandya	6.7	0.01^{c}	0.01^{c}	0.01^{c}	24.0^{a}	10.8^{b}	5.3^{b}	-	-	-	18.26***
Pink stem borer	Ludhiana	25	9.6^{c}	23.8^{bc}	50.6^{a}	31.7^{ab}	17.2^{c}	17.0^{c}	-	-	-	4.17**
Caseworm	Raipur	39.1	32.8^{c}	61.3^{b}	113.9^{a}	28.1^{c}	16.9^{c}	23.1^{c}	15.7^{c}	25.6^{c}	35.0^{bc}	7.01***
Black bug	Aduthurai	1195	1093^{ab}	-	129.0^{b}	4150^{a}	1351^{ab}	447.0^{ab}	-	-	-	2.45*
Green mirid bug	Kampasagar	215	-	18.7^{b}	31.7^{b}	758.0^{a}	142.9^{ab}	123.9^{ab}	-	-	-	2.23*
Coccinellid		3.1	-	2.4^{b}	3.6^{ab}	3.7^{ab}	5.6^{a}	0.1^{c}	-	-	-	12.43***

@: mean no. of insects/trap/week; In a row means followed by the same letter are not significantly different with significance of 'F' denoted by *: $p < 0.05$; p<0.01; ***: $p < 0.001$. ^{NS}: non-significant based on oneway ANOVA; - indicate data not available or absence of insects; Data sets analysed following appropriate transformations; furnished are original means

Seasonality of insects - *rabi*

Out of the three locations that had *rabi* rice cultivation, four of the common insects across locations were compared for their relative abundance (Table 9). Although seasonal mean of LF was double at Aduthrai (TN) over other two locations *viz.,* Kampasagar (TS) and Karjat (MH), the differences were not significant. While YSB and BPH were significantly higher at Aduthurai (TN) followed Kampasagar (TS), the lowest of YSB and absence of BPH was at Karjat (MH). Green leafhopper was of equal abundance at Aduthurai (TN) and Kampasagar (TS) with lowest at Karjat (MH). Rice cultivation using canal irrigation with many overlapping plant dates with cultivars of different durtaions at Aduthurai

(TN), the climatic variability brought in by North East monsoon during *rabi* at Kampasagar (TS) and almost nil rainfall at Karjat (MH) could be the main reasons for the differing relative abundance and hence the importance of insects.

Table 9. Relative abundance of major insects across study locations of three ACZ - *rabi*

Insect $^{@}$	Aduthurai (TN)	Kampasagar (TS)	Karjat (MH)	'F' statistic
Yellow stem borer (YSB)	508.8^{a}	35.6^{b}	4.90^{c}	42.6***
Leaf folder (LF)	15.2	7.1	7.7	0.34^{NS}
Brown plant hopper (BPH)	837.2^{a}	185.5^{b}	-	1.9*
Green leaf hopper (GLH)	578.3^{a}	280.0^{a}	38.6^{b}	1.5*

@: mean no. of insects/trap/week; In a row means followed by the same letter are not significantly different with significance of 'F' denoted by *: $p < 0.05$, ***: $p < 0.001$. ^{NS} : non-significant based on oneway ANOVA; - absence of insects or data not available ; Data sets of 2011-16 analysed following appropriate transformations; furnished are original means

Interseasonal variations of rice insects - *rabi*

Interseasonal variations of insects of importance at *rabi* study locations were highly significant indicating the dynamic nature of population abundance during each crop season (Table 10). The order for YSB, LF, BPH and GLH during *rabi* was Aduthurai (TN)> Kampasagar (TS) > Karjat (MH). Aduthurai (TN) had the highest abundance of YSB during seasons of 2011-12 to 2014-15 with reduction from 2015-16. The converse was noted at Kampasagar (TS) wherein the YSB was higher since 2014-15 over the previous seasons. Karjat (MH) had significantly higher YSB during 2012-13 and 2016-17 over other seasons. Highest abundance of LF in respect of Aduthurai (TN), Kampasagar (TS) and Karjat (MH) was during 2011-12, 2013-14 and 2012-2015, respectively.

Table 10. Inter seasonal variability of insects - *rabi*

Insect	Locations	Mean $^{@}$	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	'F' value
Yellow stem borer	Aduthurai	511.5	1894.0 ^{a}	215.1 ^{a}	314.5 ^{b}	397.0 ^{ab}	66.5 ^{b}	182.3 ^{b}	-	4.1**
	Kampasagar	34.3	18.6 ^{b}	12.0 ^{b}	3.2 ^{c}	80.1 ^{a}	57.6 ^{a}	-	-	48.33***
	Karjat	6.7	3.5 ^{bc}	20.5 ^{a}	0.5 ^{d}	0.0 ^{d}	1.3 ^{cd}	19.8 ^{a}	1.4 ^{cd}	13.34**
Leaf folder	Aduthurai	14.6	37.6 ^{a}	9.7 ^{c}	3.1 ^{c}	0.0 ^{d}	37.3 ^{b}	0.0 ^{d}	-	17.03**
	Kampasagar	7.3	-	4.9 ^{b}	10.0 ^{a}	7.0 ^{b}	6.5 ^{b}	-	-	3.14*
	Karjat	6.7	0.7 ^{b}	11.9 ^{a}	12.3 ^{a}	9.0 ^{a}	3.9 ^{b}	6.7 ^{b}	2.7 ^{b}	8.22***
Brown plant hopper	Aduthurai	851.3	264.1 ^{b}	148.0 ^{b}	259.8 ^{b}	4135.5 ^{a}	126.5 ^{b}	174.5 ^{b}	-	2.16*
	Kampasagar	218.2	284.7 ^{b}	339.2 ^{a}	71.3 ^{c}	306.6 ^{b}	89.3 ^{c}	-	-	2.89*
Green Leaf hopper	Aduthurai	596.1	338.7 ^{b}	158.4 ^{c}	409.9 ^{ab}	2407.8 ^{a}	115.8 ^{c}	146.3 ^{c}	-	5.53***
	Kampasagar	299.5	275.4^{cd}	467.4 ^{ab}	50.1 ^{d}	486.0 ^{a}	218.5 ^{bc}	-	-	9.72***
	Karjat	28.4	23.2 ^{a}	34.4 ^{ab}	20.0 ^{b}	1.3 ^{c}	118.7 ^{ab}	0.6 ^{c}	0.9 ^{c}	13.07**
WBPH	Kampasagar	33.1	-	63.3 ^{a}	75.4 ^{a}	16.0 ^{b}	3.3 ^{c}	-	-	64.85**
White leaf hopper	Aduthurai	81.8	142.0 ^{b}	-	14.0 ^{d}	226.5 ^{a}	52.6 ^{c}	55.8 ^{bc}	-	18.04**
Black bug		205.7	375.7 ^{a}	-	125.6 ^{b}	93.2 ^{b}	169.7 ^{b}	470.5 ^{a}	-	12.89**
Gall midge	Kampasagar	12.1	-	8.3 ^{ab}	1.7 ^{b}	13.4 ^{ab}	19.9 ^{a}	-	-	3.07*
Green mirid bug		453.2	-	72.9 ^{c}	107.6 ^{bc}	1336.1 ^{a}	229.3 ^{ab}	-	-	6.75***
Coccinellid		5.3	-	10.8 ^{a}	6.0 ^{ab}	6.4 ^{b}	1.7 ^{c}	-	-	22.48**

@: mean no. of insects/trap/week; In a row means followed by the same letter are not significantly different with significance of 'F' denoted by *: $p < 0.05$; $p<0.01$; ***: $p < 0.001$. ^{NS} : non-significant based on oneway ANOVA (analysis made after approprite transformations); - indicate data not available or absence of insects; Data sets of 2011-16 analysed following appropriate transformations; furnished are original means

2014-15 and 2012-13 were the *rabi* seasons with the highest BPH in respect of Aduthurai (TN) and Kampasagar (TS) with the later location having GLH abundance higher during 2012-13 and 2014-15. Karjat (MH) had higher LF for three consecutives seasons between 2012 and 2014 followed by significantly lower LF for three seasons (2015-2017). Aduthurai (TN) had the highest GLH similar to BPH in 2014-15, however on par with the previous season of 2013-14.

Karjat (MH) had three seasons of higher on par abundance of GLH (2011-12, 2012-13 and 2015-16) over 2014-15 and 2016-17. Two seasons (2013-14 and 2014-15) of higher abundance of WBPH was noted at Kampasagar (TS), the single study location of importance for the insect during *rabi*. The occurrence of WLH was only at Aduthurai (TN) and the order of abundance was: 2014-15>2011-12>2016-17>2013-14. Blackbug, the exclusive insect of importance at Aduthurai (TN) had the highest population during 2011-12 and 2016-17 over 2013 to 2015. Gall midge was the lowest in 2013-14 over other three seasons of its occurrence at Kampasagar (TS). Green mirid bugs were higher at Kampasagar (TS) during seasons of higher BPH and WBPH abundance *viz.,* 2014-15 with coccinellids higher during 2012-13 and 2013-14 over other seasons.

Seasonality of insects – summer

Out of the three study locations that had summer rice cultivation, four of the common insects across locations were compared for their relative abundance. All four insects had significantly differing populations amongst the locations (Table 11). The order of importance of YSB, GLH, BPH and LF based on their abundance was Chinsurah (WB)> Aduthurai (TN), although statistical difference did not exist for GLH between the two locations. Mandya (KA) had only GLH and YSB presence, but the lowest over other two locations. The summer rice cultivation, equivalent to the *Boro* at Chinsurah (WB), where the crop is grown with residual moisture and irrigation facilities continue to harbour insects as a carry over from *kharif*.

Table 11. Mean abundance of major insects across study locations of three ACZ - summer

Insect @	Aduthurai (TN)	Chinsurah (WB)	Mandya (KA)	F statistic
Yellow stem borer (YSB)	71.8^{b}	178.9^{a}	22.4^{c}	135.9 ***
Leaf folder (LF)	8.8^{b}	15.6^{a}	-	46.7 **
Brown plant hopper (BPH)	102.4^{b}	125.4^{a}	-	10.5 *
Green leaf hopper (GLH)	160.5^{a}	161.9^{a}	32.2^{b}	25.8 **

@: mean no. of insects/trap/week; In a row means followed by the same letter are not significantly different with significance of 'F' denoted by *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$ based on oneway ANOVA; - absence of insects or data not available ; Data sets of 2011-16 analysed following appropriate transformations; furnished are original means

Interseasonal variations of rice insects – summer

Between season variations for insect abundance during summer rice was significant at all locations for all insects (Table 12) the exception being YSB at Mandya (KA). Both Aduthurai (TN) and Chinsurah (WB) had significantly higher YSB during 2011 and declining trend over other seasons. Leaf folder at Aduthurai (TN) was the highest during 2016 on par with 2011 and other seasons between 2012 and 2015 having lower populations. Chinsurah (WB) too had higher population of LF in 2011 and 2016, however at par with 2017 that had equal abundance occurred in 2012-2014. Later years *viz.,* 2018 and 2019 had the lowest abundance. BPH variability at Aduthurai (TN) was higher that seasons of the highest (2014) and lowest (2011) means were on par. Chinsurah (WB) had significantly higher BPH during 2017 and 2018 with 2011, 2016 and 2019 on par with 2018. Four seasons (2012-2015) in continuation had the lowest BPH.

Status of GLH at Aduthurai (TN) indicated higher abundance in 2014 significantly different from other seasons that were on par. Chinsurah (WB) had the higher, moderate and low GLH in respect of 2011, 2012-17 and 2018-19. GLH at Mandya (KA) was in traces during 2011 and higher in 2015. WBPH was of importance at Chinsurah (WB) alone with 2011 and 2017 season exhibiting higher population in relation to other seven seasons. White leaf hopper at Aduthurai (TN) was significantly higher in 2014 on par with 2011 and 2015 and the lowest in 2012 & 2013. Chinsurah (WB) had the highest WLH in 2011 with all other seasons on par. White stem borer at Mandya (KA) was also seen but lower than YSB and higher in 2015 over other seasons. Black bug, only seen at Aduthurai (TN) had increased abundance in 2013 onwards.

Table 12. Inter seasonal variability of insects - summer

Insect	Location	Mean	2011	2012	2013	2014	2015	2016	2017	2018	2019	'F' statistic
Yellow stem borer (YSB)	Aduthurai	598.9	1985.0 ^{a}	189.2 ^{b}	405.8 ^{b}	442.0 ^{b}	139.4 ^{b}	307.1 ^{b}	-	-	-	3.61**
	Chinsurah	177.6	337.5 ^{a}	104.6 ^{d}	130.8 ^{cd}	184.5 ^{b}	130.6 ^{bc}	171.1 ^{b}	170.9 ^{b}	202.6 ^{bc}	165.7 ^{bc}	5.7***
	Mandya	22.4	14.3	25.2	9.7	12.2	59.1	14.2	-	-	-	0.99 ^{NS}
Leaf folder (LF)	Aduthurai	14.9	22.3 ^{ab}	7.4 ^{bc}	0.0 ^{c}	1.0 ^{c}	19.6 ^{bc}	57.0 ^{a}	-	-	-	5.58***
	Chinsurah	13.2	26.7 ^{a}	11.5 ^{bc}	15.0 ^{bc}	8.6 ^{bc}	11.1 ^{c}	16.6 ^{ab}	14.7 ^{ab}	7.8 ^{c}	6.7 ^{c}	4.77***
Brown plant hopper (BPH)	Aduthurai	903	67.5 ^{b}	55.8 ^{b}	256.7 ^{ab}	4436.6 ^{a}	154.2 ^{a}	104.9 ^{a}	-	-	-	4.98***
	Chinsurah	192.1	322.0 ^{b}	76.1 ^{d}	54.1 ^{cd}	48.0 ^{cd}	61.0 ^{c}	180.3 ^{b}	574.9 ^{a}	303.6 ^{ab}	109.2 ^{b}	12.78***
Green Leaf hopper (GLH)	Aduthurai	544.1	157.0 ^{b}	100.8 ^{b}	379.1 ^{b}	2181.9 ^{a}	156.3 ^{b}	98.5 ^{b}	-	-	-	6.63***
	Chinsurah	111	443.0 ^{a}	144.3 ^{b}	100.3 ^{b}	83.8 ^{b}	62.4 ^{b}	63.0 ^{b}	50.2 ^{bc}	28.2 ^{c}	24.0 ^{c}	9.33***
	Mandya	32.3	0.0 ^{d}	25.7 ^{c}	15.3 ^{bc}	13.5 ^{b}	133.5 ^{a}	5.8 ^{c}	-	-	-	41.6***
WBPH	Chinsurah	48.6	145.3 ^{a}	50.7 ^{cd}	21.0 ^{cd}	22.4 ^{cd}	20.5 ^{cd}	33.7 ^{abc}	84.4 ^{ab}	45.4 ^{bcd}	13.7 ^{d}	4.29***
White leaf hopper (WLH)	Aduthurai	544.1	92.1 ^{ab}	13.3 ^{c}	35.1 ^{c}	505.0 ^{a}	195.1 ^{ab}	228.5 ^{b}	-	-	-	17.31***
	Chinsurah	33.6	134.3 ^{a}	49.9 ^{cd}	11.1 ^{de}	11.7 ^{de}	7.4 ^{e}	25.7 ^{bc}	33.5 ^{b}	17.6 ^{bcd}	10.9 ^{de}	15.27***
White stem borer	Mandya	2.1	0.01 ^{c}	0.02 ^{c}	0.4 ^{bc}	0.3 ^{bc}	9.9 ^{a}	1.8 ^{b}	-	-	-	14.8***
Black bug (BB)	Aduthurai	101.4	-	10.7 ^{cd}	292.3 ^{a}	133.0 ^{bc}	119.9 ^{ab}	15.5 ^{cd}	-	-	-	18.63***

Values are mean no. of insects/trap/week; In a row, means followed by the same letter are not significantly different with significance of 'F' denoted by *: $p < 0.05$; $p<0.01$; ***: $p < 0.001$; ^{NS} : non-significant based on oneway ANOVA; - indicate data not available or absence of insects; Data sets of 2011-16 analysed following appropriate transformations; furnished are original means

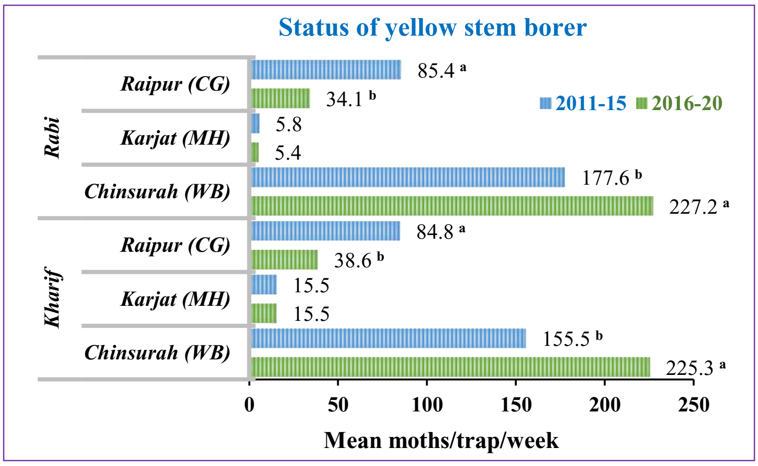
Status of major rice insects across rice agroecologies– decadal analysis for *kharif* & *rabi*

Lepidopterans

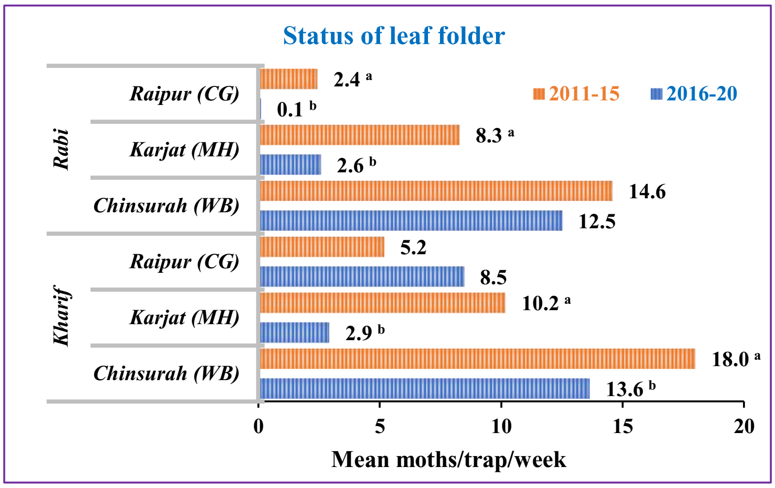
Status of important rice insects belonging to Lepidoptera on annual and for crop season (*kharif* and *rabi*) basis is presented as bar graphs with their significance tested between two halves of the decadal period 2011-2020 in Annexure XVIII for Chinsurah (WB), Karjat (MH) and Raipur (CG). YSB at Chinsurah (WB) had significant increase in the second half (2016-20) of 2011-2020 decade during both *kharif* & *rabi*, and was reflected in annual light trap catches. Leaf folder on the other hand showed significant decline during *kharif* in 2016-20 with no difference for *rabi* however brought out in annual period similar to *kharif*. At Karjat (MH), no differences were found for annual and crop seasons (*kharif* and *rabi*) for YSB between two half decadal periods although second half (2016-20) had significantly reduced leaf folder in both the seasons and for annual period. Declining abundance of YSB and caseworm during annual, *kharif* and *rabi* and of LF during *rabi* in recent years (2016-20) over 2011-15 was significant at Raipur (CG).

Yellow stem borer and leaf folder across locations and seasons-a comparison

Half decadal analysis on the status of YSB and LF was done based on light trap catches (mean nos/week/trap) over 10 seasons (2011-2020) of *kharif* and *rabi*. Three agro climatic zones *viz.,* lower gangetic plains [Chinsurah-West Bengal (WB)], West coast plains and ghat [Karjat-Maharashtra (MH)] and Eastern plateau and hills [Raipur-Chhattisgarh (CG)] were represented. While the sub humid eco region of Chinsurah (WB) had significantly higher YSB during the second half of the decade, the opposite was observed at semi humid Raipur (CG) both during *kharif* and *rabi*. Low level occurrence of YSB and absence of differences between two halves of the decade of both *kharif* and *rabi* were noted at the hot humid eco region of Karjat (MH). The sub humid eco region had higher YSB over hot semi humid and hot humid regions irrespective of *kharif* or *rabi* season.



Leaf folder (LF) had significantly reduced occurrence during the second half of the decade at Chinsurah (WB) during *kharif* with no differences for *rabi*. Second half of the decade had significantly reducing LF at Karjat (MH) for both *kharif* and *rabi*. On the other hand, Raipur (CG) had shown significant differences for *rabi* alone with reduced population during 2016-20. Sub humid and hot humid ecoregions during *kharif* and hot humid and hot semi humid regions during *rabi* had shown reducing populations during the second half indicating differential behavior of LF between seasons of *kharif* and *rabi*. One of the major findings is the opposite nature of population abundance between YSB and LF during *kharif* at Chinsurah (WB), the subhumid ecoregion. The sub humid>hot humid >hot semi humid eco regions facilitated LF abundance both in *kharif* and *rabi*. It is also to be metioned that caseworm at Raipur (CG) (Annexure VIb) also had significantly reduced population during 2016-20 over 2011-15 signifying the recent period reduction of the insect under the observed climatic variability/change.

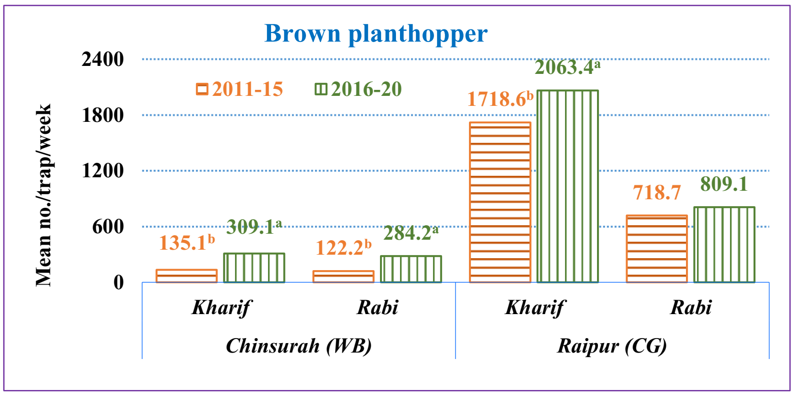


Homopterans

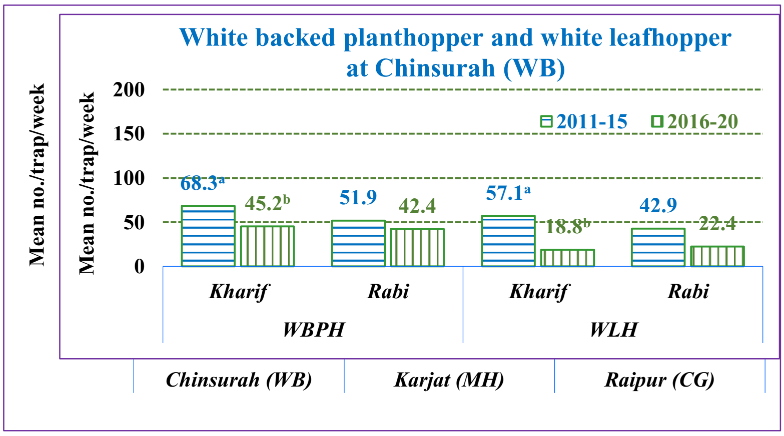
Status of rice insects belonging to Homoptera on annual and for crop seasons (*kharif* and *rabi*) is presented as bar graphs (Annexure XVIII) with their significance tested between two halves of the decadal period 2011-20 for Chinsurah (WB), Karjat (MH) and Raipur (CG). Despite higher abundance of BPH at Raipur (CG) over Chinsurah (WB), differences were insignificant between two five-year periods of 2011-20 (Anonymous, 2020).

Plant and leafhoppers across locations and seasons– a comparison

Half-decadal analyses were made for rice sap feeding insects monitored for their abundance using light traps over 10 years (2011-2020) of *kharif* as well as *rabi* seasons. Brown plant hopper, GLH, WBPH and WLH **(**mean nos/week/trap) at Chinsurah (WB), Karjat (MH) and Raipur (CG) belonging to agro climatic zones of lower gangetic plains, West coast plains and ghat and Eastern plateau and hills, respectively were examined for their changing status between two halves of the 2011-20 decade.



Chinsurah (WB) had significantly increased BPH during the recent years (2016-20) both in *kharif* and *rabi*. At Raipur (CG), the higher BPH abundance during 2016-20 was significant in *kharif* with no change between two halves of 2011-20 decade during *rabi*. GLH abundance did not differ for *kharif* at Karjat (MH) although decline was significant during 2016-20 over 2011-15 in *rabi*. Raipur (CG) and Chinsurah (WB) had highly reduced GLH in recent years (2016-20 over 2011-15 both in *kharif* and *rabi*. *Kharif* population of GLH was higher over *rabi* at Raipur (CG) and over other two locations. All locations had shown significant reduction



of GLH in recent years (2016-20). While no change of population level for WBPH was noted at Chinsurah (WB) for anyone season between two groups of periods (2011-15 and 2016-20) decline during the latter half (2016-20) of 2011-20 was significant for *kharif*. Overall, increased BPH and decline of other hoppers was the case at Chinsurah (WB).

Mutltispecies associations among rice insects

All significant associations among common species of insects belonging to different metamorphosis/feeding groups on rice during *kharif* (Table 13) were positive across all seven locations (Anonymous, 2018). Negative significant associations of yellow and white stem borer (r=-0.16*; P<0.05) at Mandya (KA) and of YSB with BPH (r=-0.13*; p<0.05) and WBPH (r= -0.47*; p<0.05) and GLH (r=-0.13*; P<0.05) with WBPH at Kampasagar (TS) were noted in *kharif*. While the association of YSB with WSB and PSB was significant at Ludhiana (PB) having only *kharif*, WSB and PSB did not show significant temporal occurrence. During *rabi* (Table 14), most of significant associations were positive from among the three locations but for negative relations of WBPH with YSB (r=.0.43*) and GLH (-0.18*) similar to *kharif*. Although abundance of GMB was higher whenever BPH and WBPH were high, the significantly negative coefficients of GMB with WBPH during *kharif* as well as *rabi* at Kampasagar (TS) indicated insignificant predatory role on WBPH however positive and significant on BPH during *rabi*. Summer rice growing locations [Aduthurai (TN), Chinsurah (WB) and Mandya (KA)] showed positive and significant associations among insect species (Table 15). Results conveyed the temporal co-existence among rice insects that was largely space neutral even with significant differential climatic variability across locations among seasons indicating the adaptation of insects in their respective environment to the changing climate. Association of GMB with WBPH in *kharif* and *rabi* was negative and significant indicating the predatory insignificance of former on later at Kampasagar (TS). Kampasagar (TS) was the only location wherein the association between YSB and LF was non-significant during *kharif* as well as *rabi*. Multispecies associations seen in conjunction with the magnitude of climate change worked out for all the study locations and seasons revealed that co-existence among rice insects is largely space neutral even with significant climatic variability across locations.

Table 13. Multispecies associations among insects - *kharif*

Ludhiana (PB)							
Insect	YSB	WSB	PSB	LF	BPH	WBPH	Mean
YSB	1.00	0.38	0.31	0.28	0.22	0.29	2.1
WSB		1.00	-0.03	0.02	0.07	0.28	5.2
PSB			1.00	0.64	0.57	0.43	25.0
LF				1.00	0.58	0.45	70.6
BPH					1.00	0.53	1284.1
WBPH						1.00	81.6

Aduthurai (TN)							
Insect	YSB	LF	GLH	BPH	WLH	BB	Mean
YSB	1.00	0.21	0.21	0.04	0.27	0.26	75.9
LF		1.00	0.03	0.25	0.32	0.12	5.4
GLH			1.00	0.31	0.43	0.07	91.5
BPH				1.00	0.40	-0.01	60.1
WLH					1.00	-0.01	60.7
BB						1.00	1195

Chinsurah (WB)							
Insect	YSB	LF	GLH	BPH	WBPH	WLH	Mean
YSB	1.00	0.55	0.60	0.61	0.56	0.32	150.7
LF		1.00	0.57	0.49	0.58	0.53	15.2
GLH			1.00	0.66	0.69	0.50	147.6
BPH				1.00	0.67	0.39	224.5
WBPH					1.00	0.56	60.7
WLH						1.00	39.4

Kampasagar (TS)									
Insect	**YSB**	**GM**	**GLH**	**BPH**	**WBPH**	**LF**	**GMB**	**CC**	**Mean**
YSB	1.00	0.00	0.29	-0.14	-0.48	0.10	0.30	-0.15	27.3
GM		1.00	0.01	0.04	0.12	0.33	-0.03	0.24	3.6
GLH			1.00	0.19	-0.14	0.10	0.56	-0.07	178.5
BPH				1.00	0.42	0.23	0.12	0.08	135.6
WBPH					1.00	0.08	-0.20	0.37	53.8
LF						1.00	0.07	0.19	8.1
GMB							1.00	0.00	21.5
CC								1.00	3.1

Karjat (MH)				
Insect	**YSB**	**LF**	**GLH**	**Mean**
YSB	1.00	0.46	0.54	16.2
LF		1.00	0.39	7.5
GLH			1.00	17.8

Mandya (KA)				
Insect	**YSB**	**GLH**	**WSB**	**Mean**
YSB	1.00	0.16	-0.16	5.2
GLH		1.00	0.37	37.0
WSB			1.00	6.7

Raipur (CG)							
Insect	**YSB**	**GM**	**LF**	**GLH**	**PH**	**CW**	**Mean**
YSB	1.00	0.00	0.35	0.58	0.48	0.37	59.4
LF			1.00	0.42	0.49	0.33	5.7
GLH				1.00	0.64	0.48	681.7
BPH					1.00	0.32	2385.7
CW						1.00	39.1

Table 14. Multispecies associations among insects - *rabi*

Aduthurai (TN)							
Insect	**YSB**	**LF**	**GLH**	**BPH**	**WLH**	**BB**	**Mean**
YSB	1.00	-0.04	0.35	0.43	0.37	-0.23	511.6
LF		1.00	0.00	0.09	0.33	0.08	14.6
GLH			1.00	0.66	0.32	-0.26	596.1
BPH					0.45	-0.37	851.4
WLH					1.00	-0.23	81.8
BB						1.00	205.8

Karjat (MH)				
Insect	**YSB**	**LF**	**GLH**	**Mean**
YSB	1.00	-0.07	0.18	6.7
LF		1.00	-0.07	6.7
GLH			1.00	28.4

Kampasagar (TS)									
Insect	**YSB**	**GM**	**GLH**	**BPH**	**WBPH**	**LF**	**GMB**	**CC**	**Mean**
YSB	1.00	0.33	0.40	0.01	-0.43	0.09	0.49	-0.21	34.3
GM		1.00	0.24	0.14	-0.14	0.33	0.22	0.03	12.1
GLH			1.00	0.31	-0.18	0.03	0.53	0.07	299.5
BPH				1.00	0.26	0.11	0.19	0.23	218.2
WBPH					1.00	0.19	-0.36	0.32	33.1
LF						1.00	0.01	-0.01	7.3
GMB							1.00	-0.08	453.2
CC								1.00	5.3

Note: In all tables, the coefficient values in the cells with background colours indicate their significance at P<0.05 following Kendall's correlative analysis

Table 15. Multispecies associations among insects – summer

Aduthurai (TN)							
Insect	**YSB**	**LF**	**GLH**	**BPH**	**WLH**	**BB**	**Mean**
YSB	1.00	0.06	0.43	0.39	0.28	-0.23	598.9
LF		1.00	0.07	0.09	0.05	-0.35	14.9
GLH			1.00	0.77	0.21	-0.40	544.1
BPH				1.00	0.24	-0.35	903.0
WLH					1.00	-0.03	544.1
BB						1.00	101.4

Chinsurah (WB)							
Insect	**YSB**	**LF**	**GLH**	**BPH**	**WBPH**	**WLH**	**Mean**
YSB	1.00	0.62	0.60	0.59	0.62	0.59	177.6
LF		1.00	0.69	0.74	0.71	0.74	13.2
GLH			1.00	0.87	0.72	0.84	111.0
BPH				1.00	0.87	0.91	192.1
WBPH					1.00	0.78	48.6
WLH						1.00	33.6

Mandya (KA)				
Insect	**YSB**	**GLH**	**WSB**	**Mean**
YSB	1.00	0.13	0.18	22.4
GLH		1.00	0.31	32.3
WSB			1.00	2.1

Note: In all tables, the coefficient values in the cells with background colours indicate their significance at P<0.05 following Kendall's correlative analysis

Weather and climatic deviations – *kharif*

Seasonal means over 2011-2016 of *kharif* rice (Table 16) for actual weather data series (A-MaxT, A-MinT & A-RF) did not differ for Aduthurai (TN), Chinsurah (WB), Karjat (MH) and Ludhiana (PB). Rainfall did not differ for all seven study locations. Inter seasonal variability based on actual weather was significant for A-MaxT and A-MinT only at Mandya (KA) being highest for 2016 and 2012, respectively. Interseasonal differences for A-MaxT was also noted at Kampasagar (TS) and Raipur (CG). A-MaxT of Kampasagar (TS) had shown distinct difference between 2013 (33.1°C) and 2014 (36.4°C). Raipur (CG) had A-MaxT significantly higher in 2015 (31.9° C) over 2012 and 2013 (30.1°C). Mandya (KA) showed difference across seasons for both MaxT and MinT. Highest A-MaxT of 32.2°C in 2016 followed by 31.6°C in 2012 and 30.3°C in 2011 were significantly different. Seasons 2013, 2014 and 2015 had at par means (29.2-29.7°C) significantly lower over other three seasons. For climatic deviations, D-MaxT differences for crop season of *kharif* of rice were significantly different at Kampasagar (TS), Karjat (MH), Ludhiana (PB), Mandya (KA) and Raipur (CG) with Aduthurai (TN) and Chinsurah (WB) being exceptions. Chinsurah (WB) did not show significance for all three variables over 2011-2016 indicating absence of climatic variability during *kharif* of 2011-16 period. Climatic deviations *viz.,* D-MaxT and D-MinT were positive at Kampasagar (TS), Karjat (MH) and Mandya (KA) indicating significantly rising temperature in recent periods and their between season variabilities. 2014 and 2015 had been the seasons of the highest D-MaxT both at Kampasagar (TS) and Karjat (MH). Kampasagar (TS) had highest D-MaxT as well as D-MinT in 2014 and 2015. Karjat (MH) had D-MinT higher during 2012&2013. Aduthurai (TN) had declining D-MinT with the lowest in 2014-2016 and 2012 (less by 0.28-0.45 °C) and maximum reduction of 0.97°C in 2011. Although Mandya (KA) had a seasonal rise of D-MaxT by an enormous 5.6°C in 2016 > 4.96°C in 2012 and >3.72°C in 2011, increase had been the lowest between 2013 and 2016 (0.1-0.41°C). 2012 had a rise of D-MinT by 3.37°C followed by 2.1°C in 2011.

Raipur (CG) is typical in having a D-MaxT increase by 1.42°C simultaneous with D-MinT by 1.63°C in 2015, and on par amongst 2011-2014 and 2016. A decline of D-MaxT by 0.45-0.48°C during 2012 and 2013 seasons was also noted at Raipur (CG). Kampasagar (TS) had increased rainfall of >200mm/week during 2011&2012 over later seasons of 2013-2016. Only other location having an inter seasonal variability for rainfall was Aduthurai (TN) where in 2013 and 2016 had increased (+15.7mm/week) and reduced (-12.1mm/week) D-RF, respectively.

Table 16. Inter seasonal variability for actual weather and climatic deviations - *kharif*

Location/Weather	2011	2012	2013	2014	2015	2016	'F' statistic
Aduthurai (TN)							
A-Max T (ºC)	34.2	34.8	33.7	34.2	34.5	34.7	1.16^{NS}
A-Min T (ºC)	24.5	24.8	24.7	25.2	25.1	25.0	1.68 ^{NS}
A-RF (mm/week)	30.8	29.9	36.1	30.4	19.1	8.2	1.76^{NS}
D-MaxT (ºC)	-0.40	0.25	-0.80	-0.31	-0.01	0.18	2.09 ^{NS}
D-MinT (ºC)	-0.97^{c}	-0.66^{abc}	-0.71^{bc}	-0.28^{a}	-0.40^{ab}	-0.45^{ab}	2.73*
D-RF (mm/week))	10.4^{ab}	9.6^{ab}	15.7^{a}	10.0^{ab}	-1.2^{ab}	-12.1^{b}	1.11*
Chinsurah (WB)							
A-Max T (ºC)	30.5	31.3	31.1	31.5	31.9	30.9	0.98^{NS}
A-Min T (ºC)	22.6	23.4	23.4	23.2	23.9	22.8	0.24^{NS}
A-RF (mm/week)	69.9	42.8	53.8	41.5	60.2	46.1	0.68^{NS}
D-MaxT (ºC)	-1.14	-0.29	-0.48	-0.06	0.29	-0.73	1.38^{NS}
D-MinT (ºC)	-1.43	-0.58	-0.54	-0.76	-0.08	-1.14	0.97^{NS}
D-RF (mm/week)	26.5	-0.64	10.45	-1.85	16.8	2.73	0.90^{NS}
Kampasagar (TS)							
A-Max T (ºC)	33.7^{bc}	33.7^{bc}	33.1^{c}	36.4^{a}	35.2^{ab}	33.6^{bc}	4.51***
A-Min T (ºC)	25.1	25.3	25.2	26.2	26.4	25.3	1.32^{NS}
A-RF (mm/week)	230.9	250.9	53.7	26.1	43.4	53.1	1.24^{NS}
D-MaxT (ºC)	0.75^{c}	0.77^{c}	0.20^{c}	3.44^{a}	2.31^{b}	0.71^{c}	11.16***
D-MinT (ºC)	1.21^{b}	1.44^{b}	1.32^{b}	2.27^{a}	2.52^{a}	1.41^{b}	4.71***
D-RF (mm/week)	206.0^{a}	226.0^{a}	28.8^{b}	1.17^{b}	18.5^{b}	28.2^{b}	6.25***
Karjat (MH)							
A-Max T (ºC)	30.7	31.2	31.2	32.7	32.5	30.9	1.94^{NS}
A-Min T (ºC)	23.8	24.1	23.9	23.5	23.1	23.6	1.02^{NS}
A-RF (mm/week)	191.8	142.0	183.1	147.6	110.3	146.6	0.54^{NS}
D-MaxT (ºC)	1.05^{b}	1.47^{b}	1.55^{b}	3.05^{a}	2.80^{a}	1.25^{b}	6.10***
D-MinT (ºC)	1.44^{ab}	1.80^{a}	1.55^{ab}	1.21^{bc}	0.73^{c}	1.28^{abc}	2.96*
D-RF (mm/week)	81.1	31.3	72.3	36.8	-0.47	35.8	0.91^{NS}
Ludhiana (PB)							
A-Max T (ºC)	32.5	34.0	32.9	33.9	33.3	33.7	0.64^{NS}
A-Min T (ºC)	22.5	22.6	23.1	22.9	23.0	23.52	0.10^{NS}
A-RF (mm/week)	44.9	18.2	27.0	16.6	16.0	19.4	0.64^{NS}
D-MaxT (ºC)	-0.86^{c}	0.62^{a}	-0.47^{bc}	0.55^{a}	-0.04^{abc}	0.30^{ab}	2.96*
D-MinT (ºC)	1.42	1.55	1.97	1.85	1.90	2.42	1.88^{NS}
D-RF (mm/week)	28.5	1.9	10.6	0.33	-0.31	3.12	1.48^{NS}
Mandya (KA)							
A-Max T (ºC)	30.3^{c}	31.6^{b}	29.2^{d}	29.5^{d}	29.7^{d}	32.2^{a}	31.7***
A-Min T (ºC)	19.5^{b}	20.8^{a}	17.5^{c}	17.8^{c}	17.8^{c}	17.6^{c}	10.3***
A-RF	19.3	10.01	15.2	22.1	14.4	13.4	1.26^{NS}
D-MaxT (ºC)	3.72^{c}	4.96 ^{b}	2.57 ^{d}	2.88 ^{d}	3.09 ^{d}	5.60^{a}	33.9***
D-MinT (ºC)	2.08^{b}	3.37^{a}	0.10^{c}	0.41^{c}	0.36^{c}	0.20^{c}	16.1***
D-RF (mm/week)	2.8	-6.45	-1.33	5.53	-2.12	-3.09	0.83^{NS}
Raipur (CG)							
A-Max T (ºC)	30.9^{bc}	30.1^{c}	30.1^{c}	31.1^{ab}	31.9^{a}	30.7^{bc}	4.79***
A-Min T (ºC)	21.9	21.9	22.2	22.2	22.9	22.0	0.19^{NS}
A-RF	54.8	54.9	60.2	46.8	29.6	48.9	0.53^{NS}
D-MaxT (ºC)	0.38^{b}	-0.45^{c}	-0.48^{c}	0.58^{b}	1.42^{a}	0.17^{bc}	5.79***
D-MinT (ºC)	0.64^{b}	0.68^{b}	0.95^{b}	0.92^{b}	1.63^{a}	0.76^{b}	2.29*
D-RF (mm/week)	15.1^{b}	15.2	20.5	7.0	-10.0	9.2	1.14^{NS}

A: actual weather; D- climatic deviations; In a row means followed by the same letter are not significantly different with significance of 'F' denoted by *: $p < 0.05$; $p<0.01$; ***: $p < 0.001$. ^{NS}: non-significant based on oneway ANOVA

Weather and climatic deviations – *rabi*

All *rabi* rice study locations [Aduthurai (TN), Kampasagar (TS) and Karjat (MH)] had significant differences for D-MinT. While Karjat (MH) had declining D-MinT in all years with maximum decline in 2011-12 (2.18°C), Aduthurai (TN) had reduced D-MinT between 2011-12 & 2014-15 with significant increase by 0.11°C in 2015-16.

Table 17. Inter seasonal variability for actual weather and climatic deviations - *rabi*

Location/ Weather	2011-12	2012-13	2013-14	2014-15	2015-16	F value
Aduthurai (TN)						
A-Max T (°C)	30.9	31.5	31.0	31.0	31.5	0.32^{NS}
A-Min T (°C)	21.8	22.8	22.2	22.6	23.3	1.86^{NS}
A-RF (mm/week)	34.1	29.8	42.6	36.4	38.9	0.67^{NS}
D-MaxT (°C)	-0.44	0.2	-0.28	-0.34	0.19	1.27^{NS}
D-MinT (°C)	-1.46^{c}	-0.44^{ab}	-1.02^{bc}	-0.65^{b}	0.11^{a}	8.19***
D-RF (mm/week)	0.3	-3.97	8.81	2.69	5.13	0.15^{NS}
Kampasagar (TS)						
A-Max T (°C)	32.5^{ab}	31.6^{b}	33.2^{ab}	33.9^{a}	34.1^{a}	2.42*
A-Min T (°C)	18.8^{c}	19.7^{bc}	20.3^{ab}	20.5^{ab}	21.6^{a}	5.13***
A-RF (mm/week)	8.58	3.38	2.79	2.5	3.56	0.05^{NS}
D-MaxT (°C)	0.67^{c}	-0.21^{d}	1.38^{bc}	2.11^{ab}	2.25^{a}	11.08***
D-MinT (°C)	0.08^{c}	1.06^{b}	1.65^{b}	1.86^{b}	2.94^{a}	9.53***
D-RF (mm/week)	6.3	1.1	0.51	0.22	1.28	0.94^{NS}
Karjat (MH)						
A-Max T (°C)	34.8	35.1	35.0	34.9	35.6	0.37^{NS}
A-Min T (°C)	15.0	16.3	16.6	15.4	15.4	1.15^{NS}
A-RF (mm/week)	0.00	2.19	0.56	1.57	0.91	0.45^{NS}
D-MaxT (°C)	3.64	3.98	3.82	3.74	4.46	1.11^{NS}
D-MinT (°C)	-2.18^{c}	-0.87^{ab}	-0.61^{a}	-1.85^{bc}	-1.81^{bc}	2.70*
D-RF (mm/week)	-1.2	1.00	-0.63	0.37	-0.28	0.54^{NS}

A: actual weather; D- climatic deviations; In a row means followed by the same letter are not significantly different with significance of 'F' denoted by *: $p < 0.05$; $p<0.01$; ***: $p < 0.001$. ^{NS}: non-significant based on oneway ANOVA

Kampasagar (TS) not only had an increase of D-MinT by 2.94°C in 2015-16 significantly higher over previous four seasons but D-MaxT increase was the highest (2.25°C) in 2015-16. It is also only at Kampasagar (TS), the A-MaxT and A-MinT differences had been significant with increasing trends since 2013. Inter *rabi* seasonal variations for all weather variables *viz.*, A-MaxT (°C), A-MinT (°C) and A-RF (mm/week) were all non significant at Aduthurai (TN) and Karjat (MH) (Table 17).

Weather and climatic deviations - summer

Mandya (KA) alone had seasonal differences shown for A-MaxT and A-MinT during summer. While 2016-17 had the highest A-MaxT (34.1°C), the A-MinT was at the lowest (15.8°C) duirng the same year implying wider day variations of temeperature on regular basis or the extremities of weather leading to such differences. A-MinT was higher in 2011& 2012 over other seasons. For the climatic deviations, all three locations had differences during summer rice season significant for D-MaxT and D-MinT. Summer of 2015-17 had a significant rise of D-MaxT (1.28°C) over 2012-13 to 2015 and 2017 at Aduthurai (TN). Mandya (KA) had increased D-MaxT being highest in 2017 (3.99°C). D-MinT deviations across seasons at Aduthurai (TN) and Chinsurah (WB) were largely negative over normal, being higher at Chinsurah (WB) (less by 1.47-2.69°C) over Aduthurai (TN) (less by 0.36-1.96°C). No changes for rainfall were noted at all study locations of summer both for actual weather and the climatic deviations (Table 18).

Table 18. Inter seasonal variability for actual weather and climatic deviations - summer

Location/ Weather	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	F value
Aduthurai (TN)							
A-Max T (°C)	32.5	32.3	32.2	31.8	33.3	32.6	0.72^{NS}
A-Min T (°C)	21.0	22.1	21.1	21.4	22.6	21.8	1.96^{NS}
A-RF (mm/week)	4.76	3.47	5.09	10.7	3.72	15.6	1.59^{NS}
D-MaxT (°C)	0.43^{b}	0.25^{b}	0.09^{b}	-0.24^{b}	1.28^{a}	0.48	6.20***
D-MinT (°C)	-1.96^{c}	-0.87^{ab}	-1.92^{c}	-1.57^{bc}	-0.36^{a}	-1.22	6.51***
D-RF (mm/week)	-7.39	-8.68	-7.06	-1.42	-8.42	3.54	0.72^{NS}
Chinsurah (WB)							
A-Max T (°C)	28.8	28.9	29.0	28.9	30.6	29.7	1.02^{NS}
A-Min T (°C)	16.5	16.1	16.7	16.5	18.8	17.4	1.16^{NS}
A-RF (mm/week)	5.7	7.4	12.6	7.4	8.8	6.50	0.21^{NS}
D-MaxT (°C)	-1.29^{b}	-1.17^{b}	-1.07^{b}	-1.14^{b}	0.59^{a}	-0.40	6.21***
D-MinT (°C)	-2.28^{b}	-2.69^{b}	-2.17^{b}	-2.37^{b}	0.02^{a}	-1.47	7.24***
D-RF (mm/week)	-2.87	-1.2	4.04	-1.22	0.21	-2.14	0.45^{NS}
Mandya (KA)							
A-Max T (°C)	31.5^{c}	31.3^{c}	32.8^{b}	32.2^{bc}	31.9^{bc}	34.1^{a}	6.06***
A-Min T (°C)	20.1^{a}	20.9^{a}	18.6^{b}	16.9^{cd}	17.4^{bc}	15.8^{d}	17.2***
A-RF (mm/week)	11.6	3.7	6.1	14.4	7.5	4.7	1.41^{NS}
D-MaxT (°C)	1.38^{d}	1.21^{d}	2.70^{b}	2.12^{bc}	1.75^{cd}	3.99^{a}	16.93***
D-MinT (°C)	2.65^{a}	3.43^{a}	1.15^{b}	-0.61^{c}	-0.09^{c}	-1.72^{d}	27.73***
D-RF (mm/week)	3.38	-4.46	-2.12	6.18	-0.67	-3.51	1.47^{NS}

In a row means followed by the same letter are not significantly different with significance of 'F' denoted by *: $p < 0.05$; $p<0.01$; ***: $p < 0.001$. ^{NS}: non-significant based on oneway ANOVA; Note the summer seasons spreads over two calendar years at Aduthurai (TN) and Chinsurah (WB)

Magnitude of climate change among seven rice growing agroclimatic zones

Variability of maximum temperature (MaxT), minimum temperature (MinT) and rainfall (RF) of 2011-16 from 'normals' measured using 't-test' considering the duration of seasons in study locations indicated significance varying with rice growing locations for a given season, and across seasons for a given location (Table 19).

Table 19. Magnitude of climate change among seasons of rice growing study locations

Location	*Kharif*			*Rabi*			*Summer*		
	MaxT (°C)	MinT (°C)	RF (mm/week)	MaxT (°C)	MinT (°C)	RF (mm/week)	MaxT (°C)	MinT (°C)	RF (mm/week)
Aduthurai (TN)	-0.18 (34.3)	-0.58** (24.8)	5.43 (25.7)	-0.13 (31.2)	-0.69** (22.6)	2.59 (36.4)	0.36 (32.4)	-1.34** (21.6)	-6.59** (5.55)
Chinsurah (WB)	-0.4 (31.2)	-0.76 (23.3)	8.99 (52.4)	-	-	-	-0.82 (29.2)	-1.89** (16.9)	-0.21 (8.41)
Kampasagar (TS)	1.37** (34.3)	1.69** (25.6)	84.8** (109.7)	1.24** (33.1)	1.52** (20.2)	1.88 (4.2)	-	-	-
Karjat (MH)	1.86** (31.6)	1.33** (23.7)	42.8** (153.6)	3.93** (35.1)	-1.46** (15.8)	-0.15 (1.0)	-	-	-
Ludhiana (PB)	0.01 (33.4)	1.85** (23.0)	7.38 (23.7)	-	-	-	-	-	-
Mandya (KA)	3.8** (30.4)	1.09** (18.5)	-0.78 (15.7)	-	-	-	2.19** (32.3)	0.79** (18.3)	-0.20 (8.04)
Raipur (CG)	0.27 (30.8)	0.93* (22.2)	9.51 (49.3)	-	-	-	-	-	-

Values with no brackets represent mean climatic deviations described as climate change for MaxT & MinT in °C and RF in mm/week corresponding to crop seasons; - indicates absence of analysis due to absence of rice growing season; significance denoted by *: $p < 0.05$; $p<0.01$; ***: $p < 0.001$. ^{NS}: non-significant based on 't' test; values in parentheses are the means of actual weather corresponding to crop seasons; RF data analysed after arcsin transformation

Each location had shown significant change at least for one of the three climatic variables during anyone season. While Chinsurah (WB) did not show any significant change for anyone variable during *kharif* although reduced mean temperature (-1.9°C) was significant during summer. Kampasagar (TS) and Karjat (MH) had significantly increasing MaxT and MinT during *kharif* as well as in *rabi* with increased RF specific to *kharif*. Mandya (KA) had increased MaxT and MinT of 3.8 and 1.1, and 2.19 and 0.79°C during *kharif* and summer, respectively. Lowest and highest minimum temperature increase of 0.93 and 1.85°C in respect of Raipur (CG) and Ludhiana (PB) was evident in *kharif*. Aduthurai (TN) had reducing minimum temperature of -0.58, -0.69 and -1.34°C in respect of *kharif, rabi* and summer.

Impact of individual climatic variables on rice insects

Kharif: Relative importance of insects varied across locations based on the seasonal (*kharif*) means caught in light trap. Association of variability of weather variables differed across locations indicating heterogeneous and differential effects of climate change on insects (Table 20). The significant impact of changing climate (increase or decrease) with RF was non-significant across insects for all study locations but for GLH at Raipur (CG) and LF at Aduthurai (TN) where the associations were negative and positive, respectively. Leaf folder at Aduthurai (TN) had the lowest population over other study locations. While YSB population had negative association with declining MinT at Aduthurai (TN) and Chinsurah (WB), increasing MaxT and MinT at Raipur (CG) had positive relations. Significantly increasing MaxT having positive influence and negative but significant effect of MinT on white stem borer at Mandya (KA) was noted. YSB decline was significant with the observed MinT. Declining leaf folder with decreasing MaxT and MinT at Aduthurai (TN) and Chinsurah (WB) was obvious. While leaf folder relations were positively significant with increasing temperature at Raipur (CG), it was negative at Ludhiana (PB). MinT-leaf folder relations were negative at Kampasagar (TS). Declining MinT had significant effect on decreasing GLH at Aduthurai (TN) and Chinsurah (WB). Significantly, increasing rainfall at Kampasagar (TS) had reducing effect on GLH although not significant. While significantly increasing MinT (1.09ºC) had negative association with GLH that was significant at Mandya (KA), the increase of MinT by 0.93ºC had shown positive effect (non-significant) at Raipur (CG). Associations of WBPH and WLH with MaxT and MinT were negative with significance only at Chinsurah (WB). MinT-BB relation at Aduthurai (TN) was singificantly negative for WLH. BPH-MinT relations were significantly negative at Chinsurah (WB) and Kampasagar (TS). The only significant negative relation of MaxT with BPH was at Kamapasagar (TS).

Impact of climatic variability [maximum and minimum temperature (MaxT &MinT in °C) and rainfall (RF in mm/week)] on rice insect abundance during period of 2011-16 for *kharif* of locations *viz.,* Ludhiana (PB), Chinsurah (WB), Raipur (CG), Mandya (KA), Kampasagar (TS) and Aduthurai (TN) indicated significance of at least anyone of the climatic variables significant for each insect at anyone of the locations. Despite significant climatic variability/change, no effect on any insects was seen at Karjat (MH). Response to deviations in MinT was greater over MaxT from across locations. Out of the seven study locations for *kharif* and across the climatic deviations, the negative association outnumbered positive relations implying overall reduced abundance and hence pest status on rice with the ushered changing climate variability and change. Considering the larger impact of temperature on rice insects during the monsoonal *kharif* season over rainfall, it looks feasible to use phenology models using temperature-based development of insects for prediction. However, it is likely that we end up predicting and projecting a higher population since the evolving adaptations and hence change in base temperature in respect of insects are highly anticipated. Considering the larger variations observed for most of the insects between seasons and that the climate variability and change relations indicated a reduced abundance, plant protection on rice can easily be handled over the past periods is a welcome inference. Field data on rice insects based on the surveillance plan and protocols of sampling followed indicated largely fractional values (lesser abundance and hence the damage levels) over the study period suppoting the reduced levels of incidence and damage by rice insects. However, efforts would be made to treat the data and infer effect of other interaction factors (cultivars, system of rice cultivations, improved method of fertilizer application and other agronomic practices) along with the impact of climate variability and change.

Table 20. Impact of individual climatic variables on insects-*kharif*

Location	Insect	Mean@	D- MaxT (°C)	D-MinT (°C)	D-RF (mm/week)
Aduthurai (TN)	Yellow stem borer	75.9	-0.06^{NS}	-0.23***	0.09^{NS}
	Leaf folder	5.4	-0.23***	-0.15*	0.2**
	Green leaf hopper	91.5	-0.1^{NS}	-0.12*	0.09^{NS}
	Brown plant hopper	60.1	-0.07^{NS}	-0.09^{NS}	-0.02^{NS}
	White leaf hopper	33.3	-0.1^{NS}	-0.17**	0.07^{NS}
	Black bug	1195.0	-0.03^{NS}	-0.08^{NS}	0.01^{NS}
Chinsurah (WB)	Yellow stem borer	155.7	-0.08^{NS}	-0.26***	-0.04^{NS}
	Leaf folder	18.0	-0.17**	-0.31***	-0.05^{NS}
	Green leaf hopper	199.1	-0.13*	-0.27***	-0.04^{NS}
	Brown plant hopper	141.7	-0.06^{NS}	-0.27***	-0.04^{NS}
	White backed plant hopper	62.5	-0.13*	-0.26***	-0.04^{NS}
	White leaf hopper	51.1	-0.2***	-0.18**	-0.02^{NS}
Mandya (KA)	Yellow stem borer	5.2	-0.03^{NS}	-0.17**	0.02^{NS}
	Green leaf hopper	37.0	-0.08^{NS}	-0.29***	0.01^{NS}
	White stem borer	6.7	0.04^{NS}	-0.16**	-0.07^{NS}
Karjat (MH)	Yellow stem borer	13.4	-0.07^{NS}	0.07^{NS}	0.08^{NS}
	Leaf folder	8.9	0.05^{NS}	-0.06^{NS}	0.05^{NS}
	Green leaf hopper	23.7	0.07^{NS}	0.04^{NS}	0.01^{NS}
Raipur (CG)	Yellow stem borer	74.6	0.22***	0.14*	-0.11^{NS}
	Gall midge	0.0	0.1^{NS}	-0.11^{NS}	0.02^{NS}
	Leaf folder	5.9	0.18**	-0.08^{NS}	-0.05^{NS}
	Green leaf hopper	942.3	0.16**	0.11^{NS}	-0.08^{NS}
	Brown plant hopper	2766	0.18**	0.03^{NS}	-0.06^{NS}
	Caseworm	46.0	0.02^{NS}	0.01^{NS}	-0.04^{NS}
Kampasagar (TS)	Yellow stem borer	27.3	0.01^{NS}	0.04^{NS}	-0.03^{NS}
	Gall midge	3.6	0.12^{NS}	0.02^{NS}	-0.02^{NS}
	Green leaf hopper	178.5	0.1^{NS}	0.02^{NS}	-0.16*
	Brown plant hopper	135.6	-0.13*	-0.26***	-0.02^{NS}
	White backed plant hopper	53.8	-0.04^{NS}	-0.09^{NS}	-0.04^{NS}
	Leaf folder	8.1	-0.05^{NS}	-0.15*	-0.04^{NS}
	Green mirid bug	215.0	0.11^{NS}	0.09^{NS}	-0.1^{NS}
	Coccinellid	3.1	0.1^{NS}	-0.08^{NS}	-0.04^{NS}
Ludhiana (PB)	Yellow stem borer	2.1	-0.04^{NS}	0.05^{NS}	0^{NS}
	White stem borer	5.2	-0.03^{NS}	0.06^{NS}	-0.1^{NS}
	Pink stem borer	25.0	-0.08^{NS}	-0.07^{NS}	0.07^{NS}
	Leaf folder	70.6	-0.11*	0.02^{NS}	0.03^{NS}
	Brown plant hopper	1284.0	-0.1^{NS}	-0.03^{NS}	0.08^{NS}
	White backed plant hopper	81.6	-0.04^{NS}	-0.03^{NS}	0.01^{NS}

@: mean no. of insects/ week/trap; Values with superscripts are '*tau*' co-efficients based on Kendall's correlations between population dynamics of insects and climatic deviations over 2011-16; *, ** & *** refer to significance at p<,0.05, p<0.01 & p<0.001, respectively; NS Not significant

Pictorial representation indicating the magnitude of climate change for the period 2011-16 and their significant relations to major insects of each study location of *kharif* specified using upward or downward arrows clearly demonstrate the climatic impacts on species abundance to be largely negative (73%) implying lesser abundance of the study insects under changing climate (Table 21).

Table 21. Impact of individual climatic variables on insects - *kharif*: a pictorial summary

Weather variable /Insect/ Location	Ludhiana (PB)	Chinsurah (WB)	Raipur (CG)	Karjat (MH)	Mandya (KA)	Aduthurai (TN)	Kampasagar (TS)
Maximum temperature (°C)	**0.02**	**-0.4**	**0.27**	**1.86*****	**3.80*****	**-0.18**	**1.37*****
Yellow stem borer			↑				
Leaf folder	↓	↓	↑			↓	
Green leaf hopper		↓	↑				
Brown plant hopper			↑				↓
White backed plant hopper		↓					
White leaf hopper		↓					
Minimum temperature (°C)	**1.85****	**-0.76**	**0.93***	**1.34*****	**1.09*****	**-0.58*****	**1.69*****
Yellow stem borer		↓	↑		↓	↓	
Leaf folder		↓				↓	↓
Green leaf hopper		↓	↑		↓	↓	
Brown plant hopper		↓					↓
White backed plant hopper		↓					
White stem borer					↓		
White leaf hopper		↓				↓	
Rainfall (mm/week)	**7.39**	**9.0**	**9.51**	**42.8****	**-0.78**	**5.43**	**84.8*****
Leaf folder						↑	
Green leaf hopper							↓

Cells in white colour indicate absence of the insect in respect of the location; Only significant relations between population dynamics of insects and the climate change in respect of MaxT, MinT and RF are shown with up or downward arrows. coloured cell with no arrow indicates non significance of insect-climate change relation

Increasing YSB, LF, BPH and GLH with a non significant but increasing MaxT (0.27°C) and of YSB and GLH with a significantly increasing MinT (0.93 °C) at Raipur and of LF at Aduthurai (TN) with increasing RF (5.43 mm/week) imply a need for due attention from pest management perspective.

Rabi: The relative abundance of insect pests of rice varied across locations and seasons over 2011-16 for *rabi*. For all insects, Aduthurai (TN) had the highest population of insects. Predatory GMB and CC were found only at Kampasagar (TS). The significant associations of insects with climatic deviations were largely negative but for positive associations of MaxT with YSB at Kampasagar (TS), MinT with YSB at Karjat (MH) and of RF on LF at Karjat (MH). The unchanging MaxT at Aduthurai (TN) had a significant negative impact on LF & GLH resulted in an increase of YSB. Decreasing effect of increasing MinT at Kampasagar (TS) was observed for WBPH and LF. Rainfall effects on insects were significantly negative on GLH and BPH at Aduthurai (TN) and WBPH & LF at Kampasagar (TS). Impact of climate change on predators was noted to be significant only in *rabi* (Table 22).

Table 22. Impact of individual climatic variables on insects - *rabi*

Location	Insect	Mean@	D- MaxT (°C)	D-MinT (°C)	D-RF (mm/week)
Aduthurai (TN)	Yellow stem borer	577.43	-0.07 NS	-0.22***	0.02 NS
	Leaf folder	17.56	-0.17*	0.02 NS	0.07 NS
	Green leaf hopper	686.10	-0.13*	-0.17**	-0.03 NS
	Brown plant hopper	986.78	-0.11 NS	-0.14*	0.01 NS
	White leaf hopper	87.02	-0.06 NS	-0.17*	0.06 NS
	Black bug	152.85	-0.07 NS	0.04 NS	0.13 NS
Karjat (MH)	Yellow stem borer	5.16	0.01 NS	0.14*	0.09 NS
	Leaf folder	7.56	0.07 NS	0.05 NS	0.14*
	Green leaf hopper	39.51	-0.02 NS	0.11 NS	-0.21**
Kampasagar (TS)	Yellow stem borer	38.24	0.16*	0.07 NS	0 NS
	Gall midge	12.07	-0.11 NS	-0.05 NS	-0.1 NS
	Green leaf hopper	305.49	0.02 NS	0.04 NS	0.09 NS
	Brown plant hopper	201.60	-0.06 NS	-0.05 NS	-0.15*
	White backed plant hopper	31.94	-0.29***	-0.21**	-0.1 NS
	Leaf folder	7.27	-0.29***	-0.25**	-0.08 NS
	Green mirid bug	454.35	0.18*	0.09 NS	0.01 NS
	Coccinellid	5.24	-0.18*	-0.01 NS	0.01 NS

@: mean no. of insects/ week/trap; values with superscripts are '*tau*' co-efficients based on Kendall's correlations between population dynamics of insects and climatic deviations over 2011-16; *, ** & *** refer to significance at p<,0.05, p<0.01 & p<0.001, respectively; NS Not significant

Significant effects of rainfall were negative on BPH at Kampasagar (TS) and on GLH at Karjat (MH). Among all significant impacts, decreasing and increasing effects were noted in 83 and 16 % of cases during *rabi* (Table 23).

Table 23. Impact of individual climatic variables on insects - *rabi*: a pictorial summary

Weather variable /Insect/Location	Aduthurai (TN)	Karjat (MH)	Kampasagar (TS)
Maximum temperature (°C)	**-0.13**	**1.24****	**3.93*****
Coccinellid			↓
Gall midge			
Green mirid bug			↑
Leaf folder			↓
White backed plant hopper			↓
Yellow stem borer			↑
Minimum temperature (°C)	**-0.69****	**1.52*****	**-1.47*****
Brown plant hopper	↓		
Green leaf hopper	↓		
Leaf folder			↓
White backed plant hopper			↓
Yellow stem borer	↓		
Rainfall (mm/week)	**2.59**	**1.88**	**-0.15**
Brown plant hopper			↓
Green leaf hopper		↓	

Cells in white colour indicate absence of the insect in respect of the location; Only significant relations between population dynamics of insects and the climate change in respect of MaxT, MinT and RF are shown with up or downward arrows. coloured cell with no arrow indicates non significance of insect-climate change relation

Summer: During summer, significant increase (2.19°C) of MaxT at Mandya (KA) had reducing effect on YSB and MinT increase (0.8°C) had negative impact on GLH and WSB. Aduthurai (TN) had declining GLH and BPH with significant decrease of rainfall. At Chinsurah (WB), the opposite impacts of MinT (positive) and RF (negative) on BPH and WBPH determined the pest status (Table 24).

Table 24. Impact of individual climatic variables on insects - summer

Location	Insect	Mean$^{@}$	D- MaxT (°C)	D-MinT (°C)	D-RF (mm/week)
Aduthurai (TN)	Yellow stem borer	639.6	-0.27***	-0.02^{NS}	-0.06^{NS}
	Leaf folder	9.70	-0.11^{NS}	0.1^{NS}	-0.1^{NS}
	Green leaf hopper	581.24	-0.22**	0.14*	-0.23***
	Brown plant hopper	964.07	-0.17*	0.15*	-0.2**
	White leaf hopper	164.83	0.02^{NS}	0.05^{NS}	-0.03^{NS}
	Black bug	108.69	0.18*	0.03^{NS}	0.1^{NS}
Chinsurah (WB)	Yellow stem borer	177.59	0.1^{NS}	0.15**	-0.18**
	Leaf folder	14.59	0.04^{NS}	-0.03^{NS}	-0.13*
	Green leaf hopper	166.75	0.08^{NS}	0.1^{NS}	-0.16**
	Brown plant hopper	112.24	0.13*	0.17**	-0.13*
	White backed plant hopper	51.98	0.1^{NS}	0.17**	-0.13*
	White leaf hopper	42.89	0^{NS}	0.06^{NS}	-0.09^{NS}
Mandya (KA)	Yellow stem borer	22.45	-0.11*	0^{NS}	-0.15**
	Green leaf hopper	32.30	-0.08^{NS}	-0.15*	-0.01^{NS}
	White stem borer	2.06	0.06^{NS}	-0.2**	0^{NS}

$^{@:}$ mean no. of insects/ week/trap; values with superscripts are '*tau*' co-efficients based on Kendall's correlations between population dynamics of insects and climatic deviations over 2011-16; *, ** & *** refer to significance at $p<0.05$; $p<0.01$ & $p<0.001$, respectively; ^{NS} Not significant

While BB had positive response to unchanging MaxT at Aduthurai (TN), BPH, GLH and YSB had a reduction. Increasing BPH and declining YSB with MinT and RF in respect Chinsurah (WB) and Mandya (KA) were significant.

Table 25. Impact of individual climatic variables on insects - summer: a pictorial summary

Weather/variable/Insect/Location	Aduthurai (TN)	Chinsurah (WB)	Mandya (KA)
Maximum temperature (°C)	**0.36**	**-0.82**	**2.19*** **
Black bug	↑		
Brown plant hopper	↓	↑	
Green leaf hopper	↓		
Yellow stem borer	↓		↓
Minimum temperature (°C)	-1.34***	-1.89***	0.8***
Brown plant hopper		↑	
Green leaf hopper			↑
White stem borer			↓
White backed plant hopper		↑	
Yellow stem borer		↑	
Rainfall (mm/week)	-6.59**	-0.21	-0.2
Brown plant hopper	↓	↓	
Green leaf hopper	↓	↓	
Leaf folder		↓	
White backed plant hopper		↓	
Yellow stem borer		↓	↓

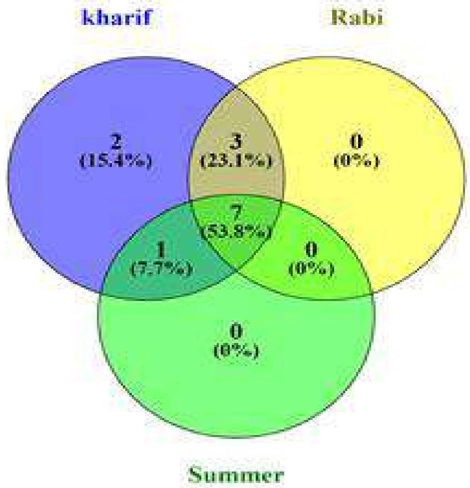
Cells in white colour indicate the insignificance or absence of the insect in respect of the location; Only significant relations between population dynamics of insects and the climate change in respect of MaxT, MinT and RF are shown with up or downeard arrows. coloured cell with no arrow indicates non significance of insect-climate change relation

All significant effects due to rainfall were negative during summer but for GLH increase at Mandya (KA). Among all significant relations during summer, 68 and 31% of cases had decreasing and increasing impacts, respectively of climatic change ((Table 25).

Impact of climate change measured using species - climate change association index

The distribution of rice insects amongst seven study locations based on the prevalence of crop seasons is given in the venn diagram. While seven insects were common amongst three seasons, three were common between *kharif* and *rabi* and one between *kharif* and summer. The exclusive insects of *kharif* were two and none for *rabi* and summer with absence of commonality between *rabi* and summer.

Distribution of rice insects amongst seasons of seven study locations



Coccinellid, Gall midge & Green mirid Bug

Case worm, Pink stem borer

Black bug, Brown plant hopper, Green leaf hopper, Leaf folder, White backed plant hopper, White leaf hopper Yellow stem borer

White stem borer

Note: one or a few insects are sporadic

The cumulative impact of climate change measured through species-climate change association index (SAI) for the insects of within location and of each insect among locations are furnished in Tables 26 and 27. The SAIs furnished are all for all study insects of each location irrespective of the significance of magnitude of climate change and/or the significance of association between population dynamics and climatic variables. However, the index involving the association of at least one climatic variable significant with population dynamics was accounted as a definitive impact of climate variability/change *vis a vis* response by insects. The SAIs differed across insects, locations and seasons.

Kharif: Aduthurai (TN) had all SAIs positive with higher adaptation by lepidopterans (LF &YSB) than hoppers (GLH & WLH). But for the WLH at Chinsurah (WB), other insects (GLH, WBPH, YSB, and BPH &LF) had negative SAIs indicating declining abundance with the observed changing climate. Positive value for WLH indicated increasing abundance at Chinsurah (WB) in *kharif*. While borers (WSB and YSB) had increasing abundance, GLH had reduction at Mandya (KA). Although positive SAIs indicated increasing abundance (YSB, LF&GLH) at Karjat (MH), the non significance of their association with all three changing climatic variables despite significant climate change in *kharif* possibly denotes an evolving or developing adaptation to CC. Raipur had gall midge alone as a positive adapter to climate change with significant reduction noted for BPH>LF>GLH>YSB. Kampasagar (TS) had wider range of negative SAI values. Highest negative SAI (-13.4) for GLH at Kampasagar (TS) was due to the significant and increased rainfall (84.8 mm/week) during *kharif* and its negative association with GLH indicating its lesser adaptation to increasing rainfall. Although BPH, PSB, LF, YSB and WBPH other than WSB had positive SAIs, the significance was noted for LF at Ludhiana (PB) (Table 26).

Rabi: Aduthurai (TN) had six insects with positive SAIs, although BB alone had no significant association with changing climate significant. Increased adaptation of LF at Karjat (MH) over YSB and GLH was observed. At Kamapasagar (TS), unlike *kharif*, *rabi* had positive SAIs significant for GMB and YSB, and insignificant for GLH (Table 26).

Table 26. Species-climate change association index for rice insects - within location

Location	Order of adaptation/vulnerability (insects)	SAIs (ordered)
kharif		
Aduthurai (TN)	LF*>YSB*>GLH*>WLH*>BB>BPH	**1.21*>0.63*>0.58*>0.50*>0.11**>-0.04
Chinsurah (WB)	WLH*>GLH*>WBPH*>YSB*>BPH*>LF*	**0.04***>-0.10*>-0.11*>-0.13*>-0.13*>-0.15*
Mandya (KA)	WSB*>YSB*>GLH*	**0.03***>-0.31*>-0.63*
Karjat (MH)	YSB>LF>GLH	**3.39>2.15>0.61**
Raipur (CG)	GM>CW>BPH*>LF*>GLH*>YSB*	**0.11**>-0.37>-0.49*>-0.50*>-0.62*>-0.86*
Kampasagar (TS)	GM>BPH*>YSB>CC>WBPH>LF*>GMB>GLH*	-1.50>-2.31*>-2.46>-3.39>-3.60>-3.71*>-8.18>-13.4*
Ludhiana (PB)	BPH>PSB>LF*>YSB>WBPH>WSB	**0.53>0.39>0.26*>0.09>0.02>**-0.63
rabi		
Aduthurai (TN)	BB>WLH*>YSB*>LF*>BPH*>GLH*	**0.32>0.28*>0.21*>0.19*>0.11*>0.06***
Karjat (MH)	LF*>YSB*>GLH*	**0.18***>-0.18*>-0.21*
Kampasagar (TS)	GMB*>YSB*>GLH>GM>BPH*>CC*>LF*>WBPH*	**0.57*>0.30*>0.25**>-0.40>-0.43*>-0.69*>-0.76*>-0.82*
summer		
Aduthurai (TN)	GLH*>BPH*>LF>YSB>WLH>BB*	**1.25*>1.06*>0.49>0.33>0.14>**-0.63*
Chinsurah (WB)	LF*>WLH>GLH*>YSB*>WBPH*>BPH*	**0.05***>-0.09>-0.22*>-0.33*>-0.38*>-0.40*
Mandya (KA)	WSB*>YSB*>GLH*	-0.03*>-0.21*>-0.29*

Leaf folder (LF); Yellow stem borer (YSB); Green leaf hopper (GLH); White leaf hopper (WLH); Black bug (BB); White backed plant hopper (WBPH); Brown plant hopper (BPH); White stem borer (WSB); Pink stem borer (PSB); Gall midge (GM); Coccinellid (CC); Green mirid bug (GMB); Caseworm (CW); positive values of SAIs are in bold and indicate adaptation of insects to the observed climate change in respect of locations; negative values specify species vulnerability; symbol * associated with SAI values of insects indicate the definitive influence of atleast one or all-climatic variables (MaxT, MinT, RF) having significant association with population dynamics irrespective of the significance of magnitude of climate change for the variables

Summer: Major lepidopterous and homopterous insects of rice at Aduthurai (TN) had positive SAIs with relatively higher adaptation shown by GLH and BPH and vulnerability by BB. Increased adaptation of LF and significant decline of GLH>YSB>WBPH>BPH was the scenario in response to climate variability/change at Chinsurah (WB). Mandya (KA) had the borers (WSB & YSB) and GLH showing negative SAIs indicating significant reduction of their abundance (Table 26).

It is interesting to note the higher and positive SAIs of insects (YSB, LF & GLH) at Karjat (MH) during *kharif* that had an unchanging climate and of only LF during *rabi* that had significantly increasing MaxT and MinT. Response of YSB and GLH during *rabi* to increasing temperatures at Karjat (MH) was negative with reduced abundance. At Kampasagar (TS), the negative SAI for all insects with all three climatic variables, increasing significantly during *kharif* and positive SAIs for GMB, GLH and YSB with significantly wider variability for temperatures during *rabi* indicated the differential responses to the magnitude of climate change of the insects between seasons in the same location. On the otherhand, WSB at Mandya (KA) had a positive SAI during *kharif* but negative in summer although for YSB and GLH, the negative responses were similar between seasons. SAIs compared across locations for each insect implied differential impact of CC on insects. Positive and negative SAIs indicate adaptation and vulnerability of insect species with climate variability/change (Table 27).

Kharif: Pink stem borer at Ludhiana (PB), and BB in Aduthurai (TN) were location specific with positive SAIs. Green mirid bug and CC at Kampasagar (TS), and caseworm at Raipur (CG), though specific to agroecologies, had negative SAIs. White leafhopper at Aduthurai (TN) showed greater adaptation than the populations of Chinsurah (WB). While GM had positive SAI and hence adaptive response at Raipur (CG), in Kampasagar (TS) it was vulnerable. White stem borer at Mandya (KA) and Ludhiana (PB) had adaptability and vulnerability exhibited to changing climate, respectively. Ludhiana (PB) with a single crop season alone had positive SAIs for BPH and WBPH over other study locations. Karjat (MH) followed by Aduthurai (TN) and Ludhiana (PB) had positive SAIs for both YSB and LF with other locations having negative SAIs. For GLH both Karjat (MH) and Aduthurai (TN) had positive SAIs.

Table 27. Species-climate change association index for rice insects - between locations

Insect	Order of adaptation/vulnerability (locations)	SAIs (ordered)
kharif		
Yellow stem borer	MH>TN*>PB>WB*>KA*>CG*>TS	**3.39>0.63*>0.09**>-0.13*>-0.31*>-0.86*>-2.46
Leaf folder	MH>TN*>PB*>WB*>CG*>TS*	**2.15>1.21*>0.26***>-0.15*>-0.50*>-3.71*
Brown plant hopper	PB>TN>WB*>CG*>TS*	**0.53**>-0.04>-0.13*>-0.49*>-2.31*
Green leaf hopper	MH>TN*>WB*>CG*>KA*>TS*	**0.61>0.58***>-0.10*>-0.62*>-0.63*>-13.14*
White backed plant hopper	PB>WB*>TS	**0.02**>-0.11*>-3.60
White leaf hopper	TN*>WB*	**0.50*>0.04***
Gall midge	CG>TS	**0.11**>-1.50
White stem borer	KA*>PB	**0.03***>-0.63
Pink stem borer	PB	**0.39**
Case worm	CG	-0.37
Blackbug	TN	**0.11**
Green mirid bug	TS	-8.18
Coccinellid	TS	-3.39
rabi		
Yellow stem borer	TS*>TN*>MH*	**0.30*>0.21***>-0.18*
Leaf folder	TN*>MH*>TS*	**0.19*>0.18***>-0.76*
Brown plant hopper	TN*>TS*	**0.11***>-0.43*
Green leaf hopper	TS*>TN>MH*	**0.25*>0.06**>-0.21*
White backed plant hopper	TS*	-0.82*
White leaf hopper	TN*	**0.28***
Blackbug	TN	**0.32**
Gall midge	TS	-0.40
Green mirid bug	TS*	**0.57***
Coccinellid	TS*	-0.69*
summer		
Yellow stem borer	TN*>KA*>WB*	**0.33***>-0.21*>-0.33*
Leaf folder	TN>WB*	**0.49>0.05***
Brown plant hopper	TN*>WB*	**1.06***>-0.40*
Green leaf hopper	TN*>WB*>KA*	**1.25***>-0.22*>-0.29*
White backed plant hopper	WB*	-0.38*
White leaf hopper	TN>WB	**0.14**>-0.09
White stem borer	KA*	-0.03*
Blackbug	TN*	-0.63*

Aduthurai (TN); Chinsurah (WB); Karjat (MH); Kampasagar (TS); Ludhiana (PB); Mandya (KA); Raipur (CG). Positive values of SAIs are in bold and indicate adaptation of insects to the observed climate change in respect of insects; negative values specify species vulnerability; symbol * associated with SAI values of insects and locations indicate the definitive influence of atleast one or all-climatic variables (MaxT, MinT, RF) having significant association with population dynamics irrespective of the significance of magnitude of climate change for the variables

Rabi: WLH and BB exclusive at Aduthurai (TN) had positive SAIs. At Kampasagar (TS), only GMB had positive SAI and were negative for WBPH, GM and CC. Although BPH was of significance at TN with positive SAI and negative at Telangana, GLH had positive SAI at both locations. While YSB had higher adaptation at Kampasagar (TS) over Aduthurai (TN), it was vulnerable at Karjat (MH). Aduthurai (TN) and Karjat (MH) had positive SAI for LF and negative at Kampasagar (TS).

Summer: Positive SAIs were noted only at Aduthurai (TN) for YSB, LF, BPH, GLH and WLH besides for LF at Chinsurah (WB). The only insect species with negative SAI showing vulnerability in summer was BB at Aduthurai (TN). Mandya (KA) had three lepidopterous insects (YSB, LF and WSB) showing decreased association with climatic variability/change.

Overall, differences in the order of insects across different locations had arisen due to the spatial differences in magnitude of climate change and of the insect abundance cum multispecies associations not to discount cropping systems and production practices. It can be expected that the species with positive values of SAI would continue to pose problems in the coming years too. It is to be noted that Aduthurai (TN) having year round cultivation of rice and Ludhiana (PB) having definitive rice monoculture over larger areas for one season had many insects having positive SAI values indicating higher adaptations. Unchanging climate during *kharif* at Karjat (MH) with positive SAIs and changing temperatures during *rabi* still impacting LF in a similar way provide clues to the continued evolutionary adaptations with or without changing climate by the insects. It is to be kept in mind that insects based on SAIs for a given season or across seasons did not typically segregate insects based on their feeding habits (sucking or chewing) or metamorphosis (hemi or holometabolous) in terms of adaptation or vulnerability but largely associated with the ecoregion specific factors including climate change.

Listing and grouping of all study insects of rice in respect of different study locations based on SAI values as adaptive and vulnerable are furnished in Annexure XIX. The following table provides only the listing of insects wherein atleast one or all climatic variables (MaxT, MinT, RF) had shown significant association with their population dynamics irrespective of the significance of magnitude of climate change for the variables (Table 28).

Table 28. Impact of climate change on rice insects - a listing

Location	*kharif*		*rabi*		*summer*	
	Adaptive	Vulnerable	Adaptive	Vulnerable	Adaptive	Vulnerable
Aduthurai (TN)	1. Leaf folder 2. Yellow stem borer 3. Green leaf hopper 4. White leaf hopper	-	1. White leaf hopper 2. Yellow stem borer 3. Leaf folder 4. Brown plant hopper 5. Green leaf hopper	-	1. Green leaf hopper 2. Brown plant hopper 3. Yellow stem borer	Black bug
Chinsurah (WB)	White leaf hopper	1. Green leaf hopper 2. White backed plant hopper 3. Yellow stem borer 4. Brown plant hopper 5. Leaf folder			Leaf folder	1. Green leaf hopper 2. Yellow stem borer 3. White backed plant hopper 4. Brown plant hopper
Karjat (MH)	-	-	Leaf folder	1. Yellow stem borer 2. Green leaf hopper	-	-

Location	kharif		rabi		summer	
	Adaptive	Vulnerable	Adaptive	Vulnerable	Adaptive	Vulnerable
Kampasagar (TS)	-	1. Brown plant hopper 2. Leaf folder 3. Green leaf hopper	1. Green mirid bug 2. Yellow stem borer	1. Brown plant hopper 2. Coccinellids 3. Leaf folder 4. White backed plant hopper	-	-
Ludhiana (PB)	Leaf folder					
Mandya (KA)	White stem borer	1. Yellow stem borer 2. Green leaf hopper	-	-	-	1. White stem borer 2. Yellow stem borer 3. Green leaf hopper
Raipur (CG)	-	1. Brown planthopper 2. Leaf folder 3. Green leafhopper 4. Yellow stem borer	-	-	-	-

Insects have been listed along the order of importance for the cumulative impact of climate change based on significance of species – climate change associations; all species listed had relations between population dynamics and climatic deviations significant (kendall's 'tau') at least for one or two or all three (MaxT; MinT; RF) irrespective of the significance of magnitude of crop season climate change quantified

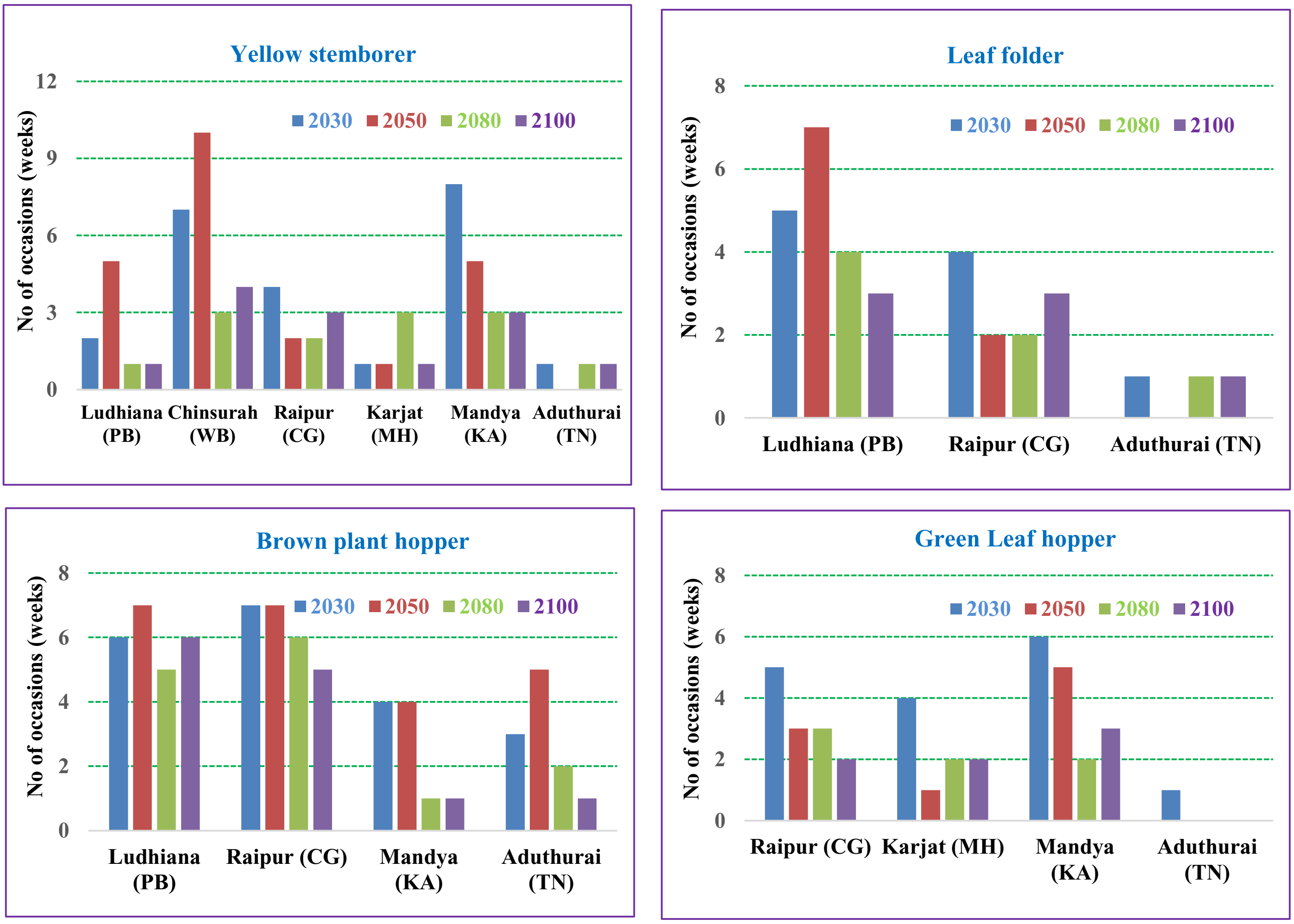
Future of rice insects for projected climate change scenarios

Past, current and future status of rice insects across locations under A1B emission scenario

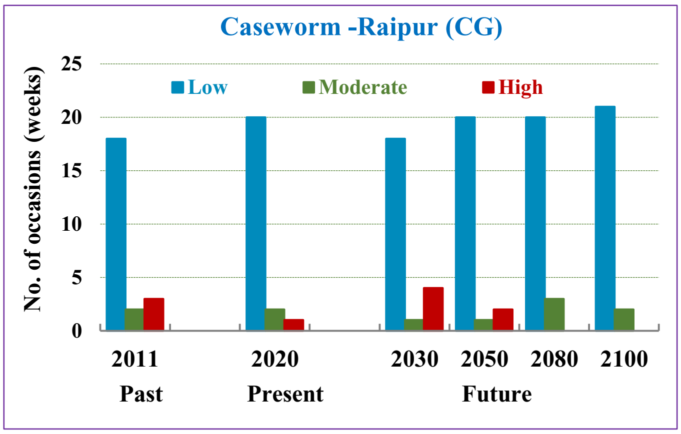
Projections of maximum and minimum temperature besides rainfall derived for future years at a resolution of 50X50 km grid for emission scenario of A1B of PRECIS were obtained for study locations from Central Research Institute for Dryland Agriculture, Hyderabad based on simulated climate projections for India (Krishnakumar, 2011). Projected data relavant to four future periods *viz.,* 2030, 2050, 2080 and 2100 calculated on standard meteorological week (SMW) basis were used to predict future scenarios of YSB severity on SMW basis for a total of 23 SMWs of *kharif* season (22-44 SMWs). Number of weeks with predicted severity of insects into categories of high, moderate and low in respect of four future periods in respect of study locations *viz.*, Ludhiana (PB), Karjat (MH), Hyderabad (TS), Mandya (KA), Chinsurah (WB), Raipur (CG) and Aduthurai (TN). Future projections used the weather and rule based predictions developed in respect of locations and insects (Anonymous, 2016).

Increasing moderate severity of YSB at Ludhiana (PB) and Chinsurah (WB) in 2050 and absence of high severity levels among five locations except Chinsurah (WB) in 2100. Moderate and high severity levels increasing between 2030 and 2050 followed by its decline in 2080-2100 at Mandya (KA) and the lowest severity almost throught all periods at Aduthurai were the projected YSB scenario. While extreme weather events especially high and unseasonal rains and associated fluctauting weather conditions have negative impact on YSB severity during any given season, future projections of YSB imply lesser significance of the insect. Absence of high severity BPH, WBPH and GLH at Chinsurah (WB) and LF and GLH at Aduthurai (TN) was predicted. Increasing moderate severity of LF at Aduthurai (TN) and GLH at Karjat (MH) for 2030 was projected. Increasing GM, GLH and caseworm at Raipur was predicted for 2030.

Prediction of major rice insects under of A1B climate change scenario



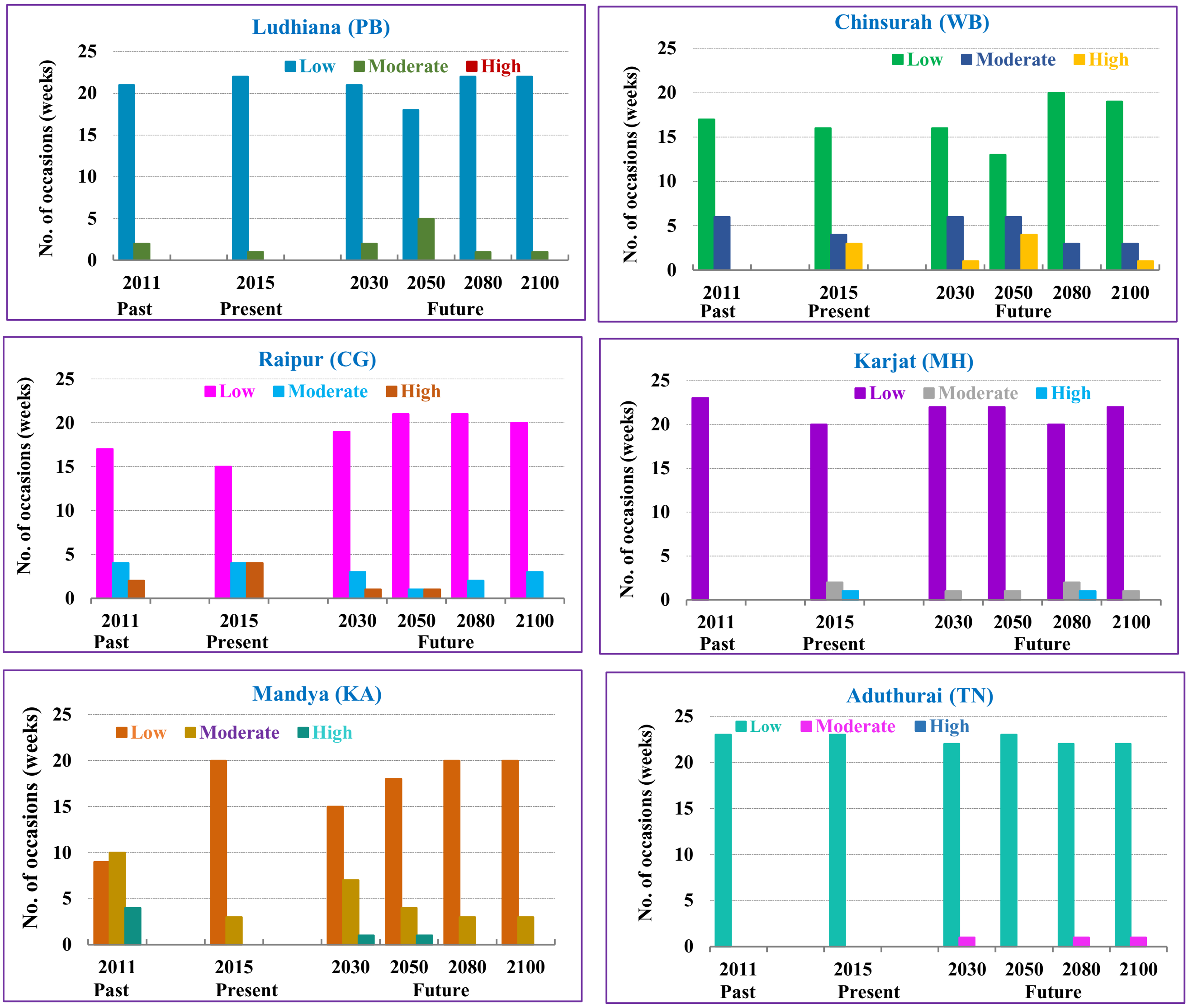
Caseworm at Raipur (CG) would be of significance till 2050 and would have lower severity during 2080 and 2100. No high severity predictions occurred for 20180 and 2100. Oderate severity of caseworm was higher between 2030 and 2050 over 2080 and 2100. In other cases, the trends of the rice insects in the study locations continues to be similar to present status or decreasing. Such weather-based projections are of use for seasonal forecasts of rice pests. The future projections also imply the time and strategies available with protection specialists for management of pests without any weather induced outbreaks expected.



Past, current and future status of YSB severity under A1B emission scenario

Comparison of the predicted severity levels for the past (2011), present (2016) and four different future seasons *viz.,* 2030, 2050, 2080 and 2100 using the temperature and rainfall projections of emission scenario of A1B for six locations was made (Vennila *et al*., 2019a). Predictions indicated increasing moderate severity of YSB at Ludhiana (PB) and Chinsurah (WB) in 2050, and absence of high severity levels among five locations except Chinsurah (WB) in 2100. Moderate and high severity levels of YSB increasing between 2030 and 2050 followed by its decline in 2080 - 2100 at Mandya (KA) and lowest severity almost through all periods at Aduthurai (TN) were projected. Future projections of YSB imply lesser significance of YSB in context of changing climate with rare outbreaks expected. Under these circumstances, it is only prudent to monitor YSB as in present times and use management interventions based on economic threshold levels.

Future projections of YSB severity



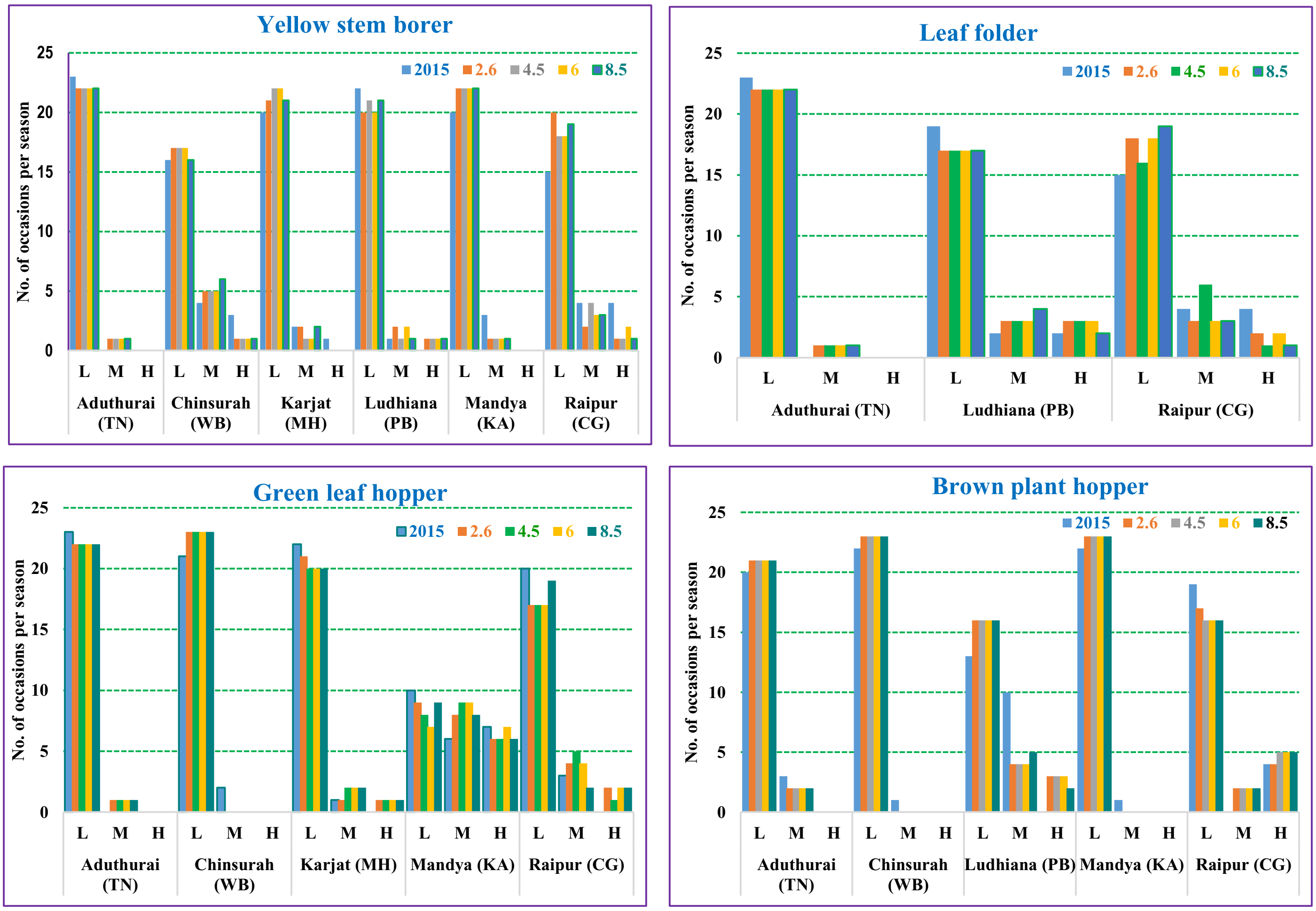
Extreme weather events especially high and unseasonal rains and highly fluctauting weather conditions during any given season can have negative impact on YSB severity. However, changes in multitude of factors such as cropping system, varietal scenario and production practices at macro level, and inter specific competitions and adaptive adjustments by insects in general and YSB in particular on ecological and evolutionary scales would decide ultimately its abundance and hence the severity. Climatic projections for future are available these days based on representative concentarion pathways (RCPs) and their use to ascertain future staus of YSB would be the next logical step.

Prediction of rice insects for climatic projections under representative concentration pathways (RCP)

Scenario of two insects each under lepidopterans (YSB and LF) (Vennila *et al.,* 2019b) and homopterans (BPH and GLH) (Vennila *et al.,* 2021) predicted for climatic projections of 2020 under four different levels of RCP (2.6, 4.5, 6 and 8.5) revealed increasing 'moderate' severity and decreasing 'High' of YSB at Chinsurah (WB) with the levels of RCP over 2015. At Karjat (MH), 'moderate' severity was decreasing under 4.5 and 6.0 over 2.6 and 8.5 levels. Reducing YSB severity under 2.6> 8.5> 4.5 and 6 over present status was noted at Raipur (CG). Occasional 'moderate' severity at Aduthurai (TN), increasing 'moderate' and 'high' at Ludhiana (PB) and reducing severity at Raipur CG) in general with increasing 'moderate' and declining 'high' severities at 4.5.

Decreasing severity of BPH during 2020 was projected at all locations except at Raipur (CG), wherein ''high' severity had increased at RCP levels of 4.5, 6.0 and 8.5 over 2015 and 2.6. Reducing severity was noted at Ludhiana (PB) with shift of 'moderate' to 'high' severity at all levels. For GLH, reducing severity at Chinsurah (WB), slight increase at Karjat (MH) and Raipur(CG) > Aduthurai (TN) with increase of 'moderate' over 'high' severities, with similarities of 2.6 & 8.5 and 4.5 & 6.0 (M); 2.6,4.5 & 8.5 (H). Thus, spatial differences were obvious for a given species of insect in addition to differential variations for the levels of RCP amongst locations. No clear cut support emerged for general increase of sucking insects of rice under climate change although there is indicative increase of GLH (a vector) at locations such as Mandya (KA) and Raipur (CG).

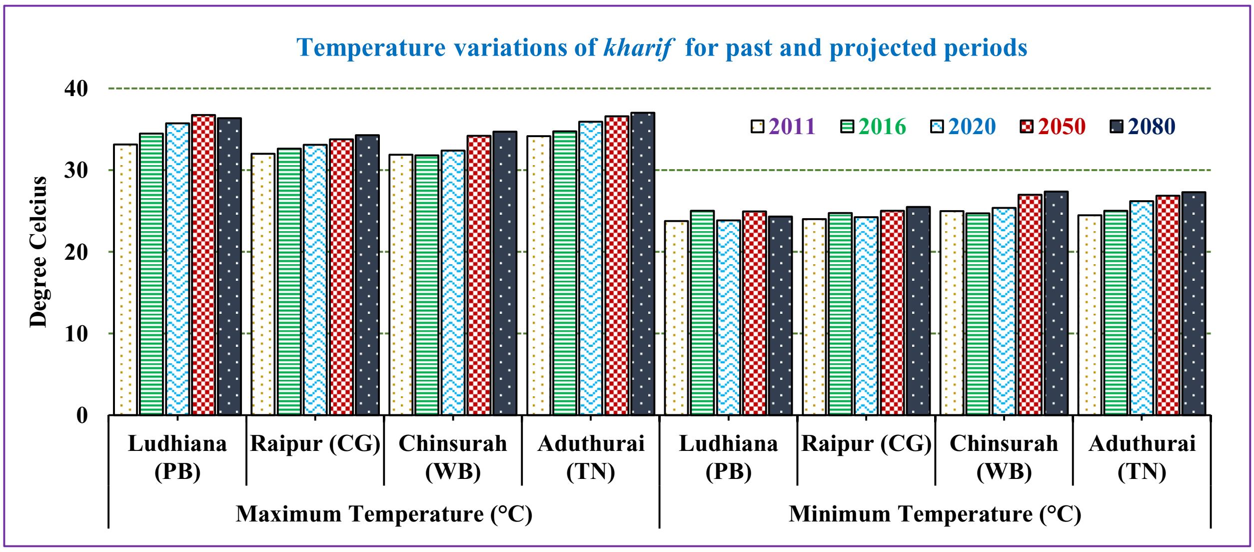
Predicted severity of rice insects under RCP climate change scenarios

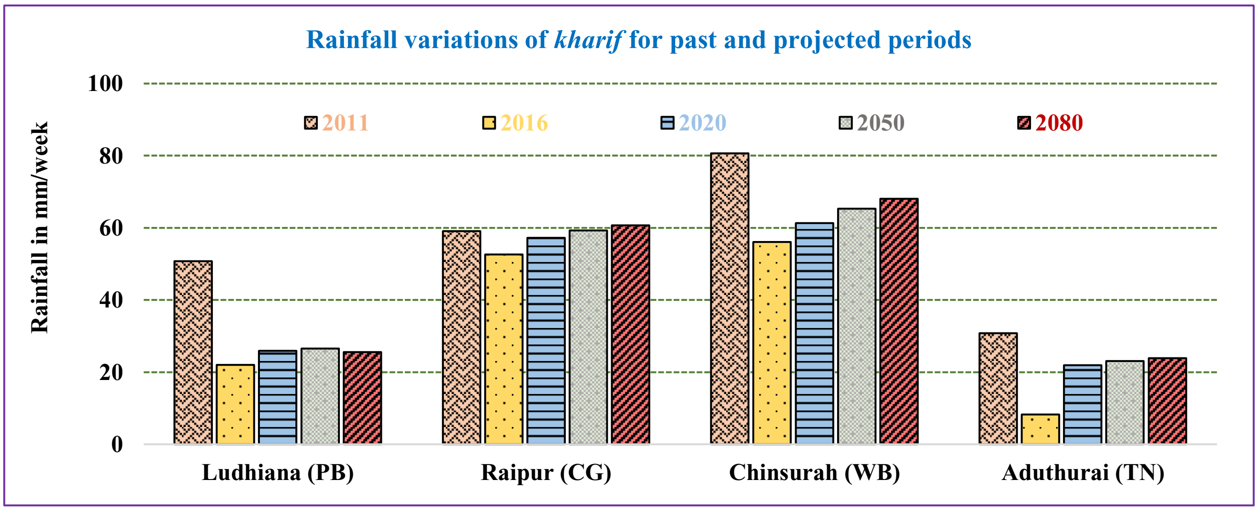


Prediction of brown plant hopper under RCP 4.5 climate change projections

Categorisations of BPH adults caught in light traps (nos/week/trap) into low, moderate and high and formulation of criteria accounting weather variables [maximum/ minimum/ mean temperature (˚C), morning/evening/mean relative humidity (%), rainfall (mm) and sunshine hours (h/day) and wind speed (km/h)] during *kharif* of 2011-16 were made. Four locations *viz.,* Ludhiana (Punjab), Chinsurah (West Bengal), Raipur (Chhattisgarh) and Aduthurai (Tamil Nadu) were considered for weather based BPH prediction. Validation of BPH predictions for *kharif* 2017 indicated 96, 87, 73 and 61% accuracies in respect of Aduthurai (TN), Raipur (CG), Ludhiana (PB) and Chinsurah (WB). Future weather based predictions of BPH based on climatic projections of representative concentration pathway (RCP) 4.5 for 2020, 2050 and 2080 indicated absence of high population at Chinsurah (WB) during all periods of 2020-2080. Current study opted for RCP 4.5 level as it was near to situations of Indian scenario in terms of radio active and green house emission variables wherein a range of technologies and strategies for reducing greenhouse gas emissions to be implemented in the future years. The climatic projections for the four study locations at RCP 4.5 level for 2020, 2050 and 2080 indicated increasing maximum and minimum temperatures by about 1.7 to 0.8^{o}C (hence mean also) across locations along future periods and against the observed past (2011 & 2016), although the trend of rainfall projections varied depending on location and over the past periods (refer Figure).

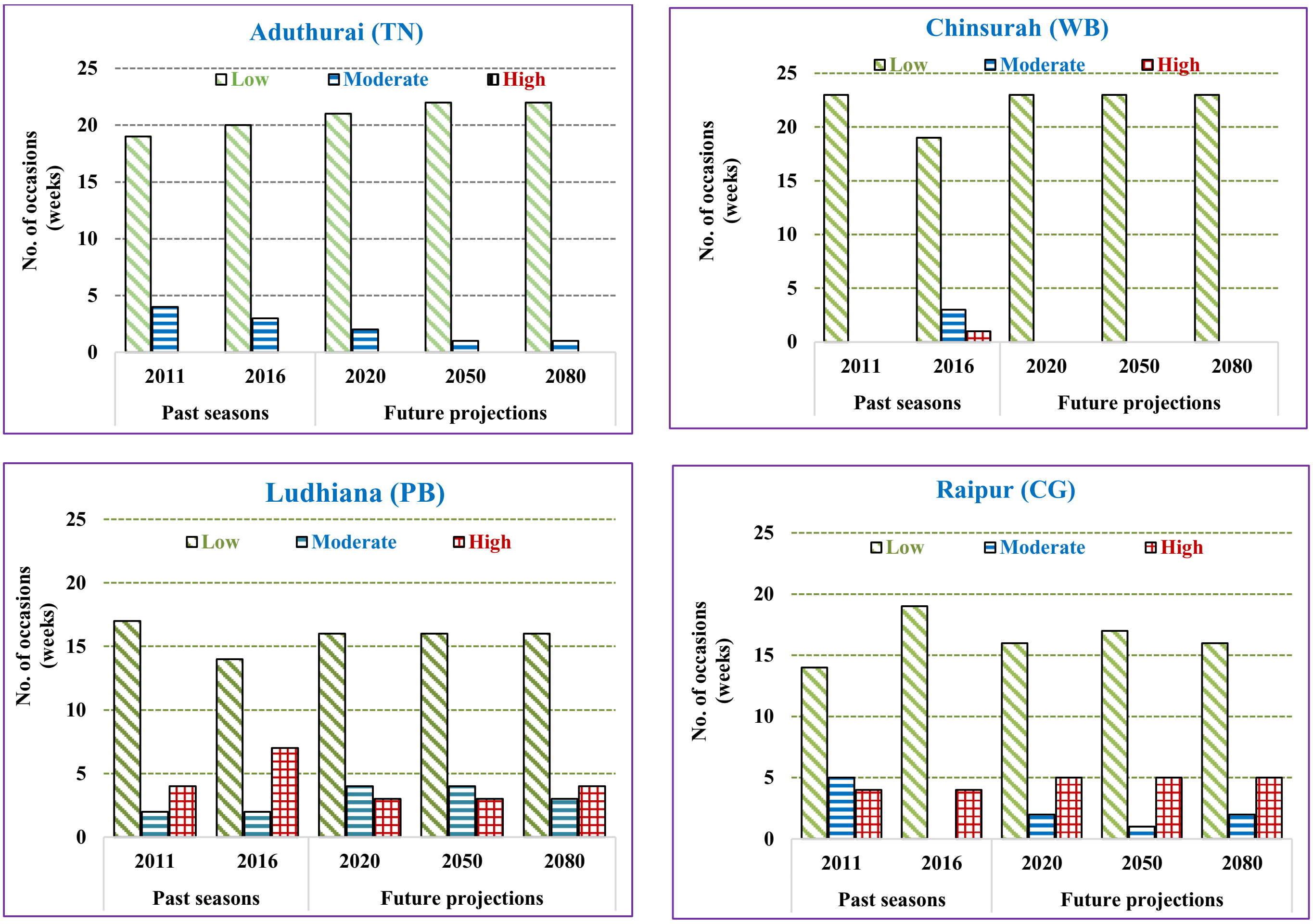
It is interesting to note that the observed mean rainfall (mm/week) between 2011 and 2016 was glaringly different almost in all locations with Aduthurai (TN) showing highly reduced rains during 2016. All locations had increasing trend of maximum and minimum temperature along future periods up to 2080 with the exception of Ludhiana (PB) wherein minimum temperature projections had shown a decline by 1.2, 0.1 and 0.7°C in respect of 2020, 2050 and 2080. For all the locations, RF projections for 2020, 2050 and 2080 were higher over 2016 but lower over 2011 indicating the observed RF variability within the same decade.





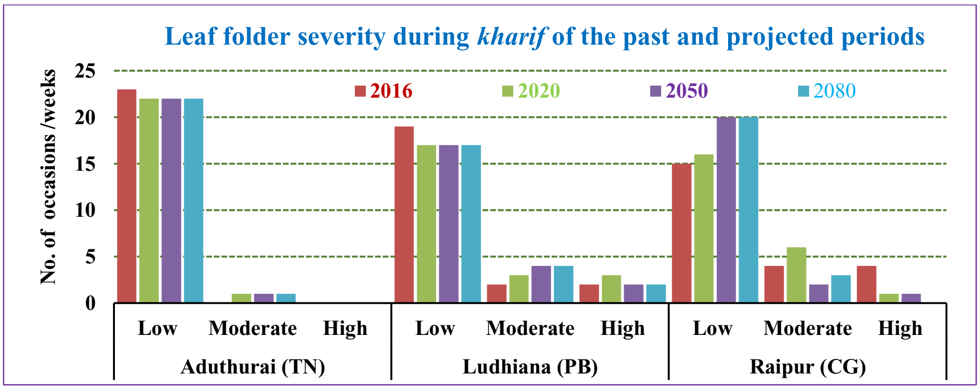
Future predictions of BPH for future scenarios of climate change indicated increasing 'moderate' and declining 'high' abundance during all future years over the past periods (2011&2016) at Ludhiana (PB). While the observed severity at Raipur (CG) showed similar 'high' between 2011 and 2016, the later period had more occasions of 'low' abundance over 2011. Future predictions showed similar levels of 'high' abundance of BPH with slight reduction in 'moderate' during 2050 over 2020 and 2080. Chinsurah (WB) had exclusively 'low' abundance of BPH amongst 2011 (past) and future (2020, 2050 &2080) periods with 2016 and 2017 (validation year) showing all three (low, moderate and high) categories of BPH abundance. However, at Aduthurai (TN), decline and increase in respect of 'moderate' and 'low' abundance was noted beyond 2011, implying the decreased levels of BPH during current and future years of current century. Therefore, future abundance based on RCP 4.5 climatic projections had predicted decreasing BPH levels during the forthcoming *kharif* seasons of current century at Chinsurah (WB) and Aduthurai (TN). Ludhiana (PB) and Raipur (CG) are the locations that would have periods of moderate to high abundance of BPH in the coming years thus emphasising the need for continued monitoring for BPH dynamics during *kharif* that vary along a given crop season amongst locations. The observed spatial variability of climate change influence on BPH implied a need for zonation mapping of rice insects including BPH for India.

Predicted severity of BPH under RCP climate change scenarios



Prediction of leaf folder under RCP 4.5 climate change projections

Future predictions of leaf folder using climate projections of representative concentration pathways (RCP) in conjunction with weather based criteria and rules of prediction indicated increase in moderate severity of leaf folder at Raipur (CG)> Ludhiana (PB) > Aduthurai.



Moderate severity of leaf folder was on more occasions during 2050 and 2080 over 2020 and present periods at Ludhiana (PB). Ludhiana (PB) also had more of high severity in 2020 with similarities of 2050 and 2080 to present period (2016). Although moderate severity was the highest in 2020 followed by 2080 and 2050 at Raipur (CG), high severity was absent during 2080 and lower than present status in 2020 and 2050 (Vennila *et al.,* 2019b). Absence of high severity at all periods was the scenario of leaf folder at Aduthurai (TN). Future projections imply lesser significance of leaf folder at Aduthurai (TN), its careful monitoring until 2020 at Raipur (CG) and relatively increasing and continued importance at Ludhiana (PB) in the context of changing climate.

PIGEONPEA

Pigeonpea (*Cajanus cajan*) is one of the most important legume crops of the tropics and subtropics of Asia and Africa. Pigeonpea, also known by names such as redgram, *arhar* and *tur* in India, offers nutritional security due to its richness in protein (21%) along with mineral supplements *viz.,* iron and iodine. India is the world's largest producer and consumer of pulses including pigeonpea. About 80% of the global pigeonpea area (7.0 mha) is in India contributing to 93% of the global production. Maharashtra, Uttar Pradesh, Madhya Pradesh, Karnataka, Gujarat, Andhra Pradesh, Tamil Nadu and Bihar are the major growing states of our country. Chhattisgarh, Rajasthan, Odisha, Punjab and Haryana also grow the crop but in lesser area. India with its area of 5.58 mha produces 4.29 mt with its productivity ranking eighth in the world as of 2018. The productivity levels range from 360 to 1145 kg/ha owing to the cultivation of the crop on a wide range of soils in different cropping systems across varies agro climatic regions. Crop's ability to resist drought and to add large quantities of biomass to the soil in addition to nitrogen fixation makes it a good choice for rainfed as well irrigated production systems. *Kharif* is the growing season of pigeonpea in India. Moisture stress and sudden drop in temperature coupled with frost and foggy weather during the pod development stage and terminal drought cause yield reduction leading to instability in production. In the context of climate change, it has been revealed that legumes in general and pigeonpea, in particular have the potential to maximize the benefit of elevated CO_2 arising out of climate change effects by matching stimulated photosynthesis with increased nitrogen fixation. Such a positive result illustrates the importance of pigeonpea as a crop of sustained supporter of food and nutritional security under the climate change scenario.

Limitation to the increasing productivity of pigeonpea is also due to biotic stresses prevalent across the pulses growing regions. Among biotic stresses, diseases *viz.,* wilt, sterility mosaic and foliar diseases and insect pests feeding on pods lead to significant yield losses. Climate change is expected to trigger changes in diversity and abundance of arthropods, geographical and temporal distribution of insect pests, insect biotypes, herbivore plant interactions, activity and abundance of natural enemies, and efficacy of crop protection technologies. We expect both the crop in terms of phenology and physiology and the pests in their occurrence and abundance likely to change. Study of impact of climate change on pigeonpea crop-pest interactions requires carefully collected data on long term basis. While already available historical data could form an approach for partial study of climate change impacts, formulation and implementation of a robust research strategy combining the present scenario of cropping patterns, cultivars, and production and protection practices across heterogeneous locations over time would yield improved and holistic understanding. Considering the importance of the pigeonpea grown across Indian cropping systems as a pulse crop and its associated role in food and nutritional security, "National Initiative/Innovations on Climate Resilient Agriculture (NICRA)" provided thrust to improve the productivity level of the crop through assessment of the changing pest dynamics in relation to climate.

Structural plan of pest surveillance carried out in pigeonpea fields at the research/experimental station of the identified centre, and at villages in the farmers' fields. The procedures to be followed towards selection of fields for surveillance at the experimental/research stations, and at villages besides the standard methods to be adopted for recording the observation of pests using the data recording formats formed the primary step. A manual with description of the identification details of the insect pests and diseases for pest surveillance and data sheet formats for surveillance is available at: *https://ncipm.icar.gov.in/nicra2015/datasheetsmanuals.aspx*. Two pigeonpea fields each at the experimental station and in ten selected villages of the region were used for pest surveillance. Fixed fields are those fields grown with pigeonpea (preferably sole crop), that once selected would be continuously monitored year round on weekly basis for pests and diseases. Seven locations selected from seven different States belonging to five agro climatic zones and six agro ecoregions (Annexure Ia&Ib) were part of the NICRA programme since 2011 till 2016. While one [Vamban (TN)] of the seven locations continued till 2018, Warangal (TS) implemented NICRA till 2020. All the locations had *kharif* as the season of pigeonpea cultivation however with varied crop durations (Annexure II). The following paragraphs furnish the scenario of major insects and diseases associated with changing weather identified at various times of the programme before presenting the comprehensive variations across study years and their association with magnitude of climate change in respect of locations.

Highlights of insect pest and disease scenario *vis a vis* weather

Anantapur [Andhra Pradesh (AP)] [ACZ: Southern Plateau and Hills Region AER: Deccan plateau and central highland hot arid ecoregion]

Foliar diseases *viz., Alternaria* and *Cercospora* were lower through 2011 – 2014 at the hot arid location Reddipalli (AP) that had increased maximum as well as minimum temperatures (1.5-3°C) over the normals during pre and post monsoon periods of *kharif*. Rainfall in terms of amount and distribution deficit between July 2013 and January 2014 affected pigeonpea crop growth with flowering delayed to second fortnight of October and the pod borer and pod fly damage was dominant between November and December. The higher rainfall seasons (655 and 640 mm in respect of 2011 and 2013) had higher legume pod borer (*Maruca vitrata*) damage over season with low rainfall (466 mm during 2012). Rainfall effect on crop phenology in turn influencing the damage due to *M. vitrata* was inferred. Rise in minimum temperatures over normal by 1-3˚C, dry spell during October and continuous wet spells in November due to four cyclones during 2015 caused delayed flowering with the leaf folder (*Grapholita critica*) damage during November.

Gulbarga/Kalaburgi [Karnataka (KA)] [ACZ: Southern Plateau and Hills Region AER: Deccan plateau aravallis hot semi- arid ecoregion]

Absence of rainfall during summer before onset of monsoon resulted in lower levels of insect pests and diseases in 2011. Leaf hoppers (jassids), *Empoasca kerri* causing severe yellowing, bronzing and stunted growth of the plants was noticed since 2011 (Rachappa *et al.,* 2016) with its spread over larger areas up to 2015. The seasonal dynamics of *E. kerri* indicated its onset during August with multimodal peaks between last week of September and mid-November with the highest peak during October. During 2014, peak was between 40 and 44 SMW (11-14 nos/3 top fully opened leaflets) wherein increased minimum temperature by 2-5°C over normal throughout the pre and post monsoon periods (mid March to September) followed by torrential rains (195 mm in 35 SMW) coupled with dry spells and intermittent rains (>10mm) was noted.

Jassid damage
Insets: nymphs (left); adults (right)

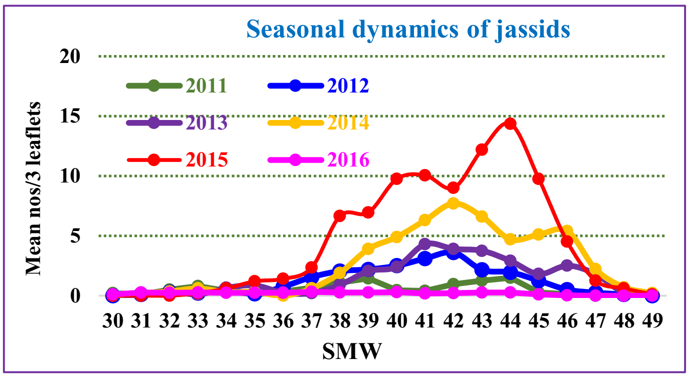
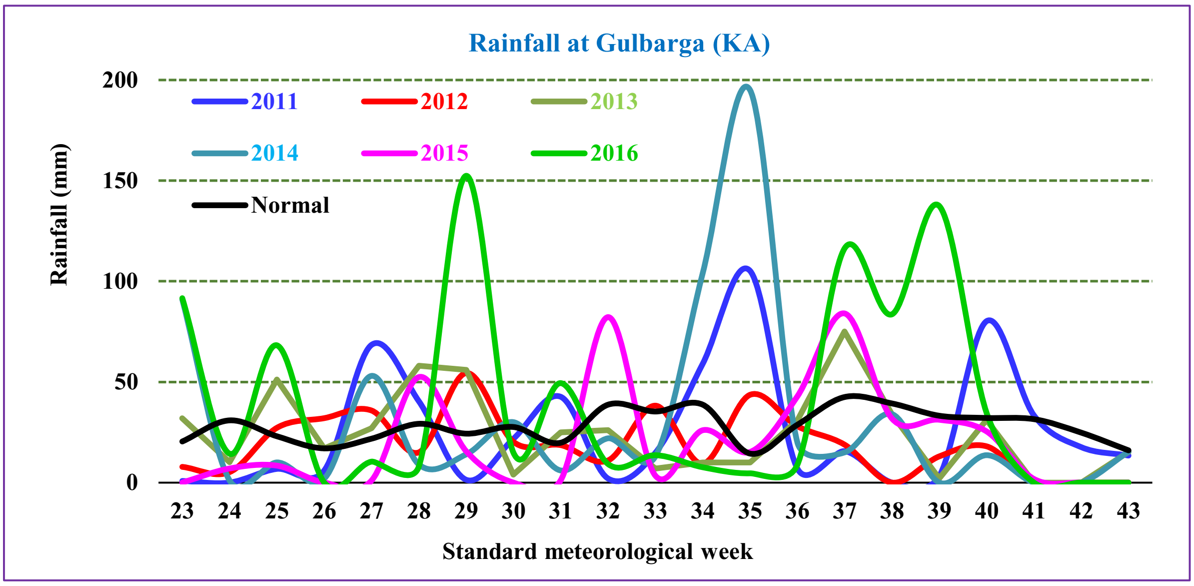


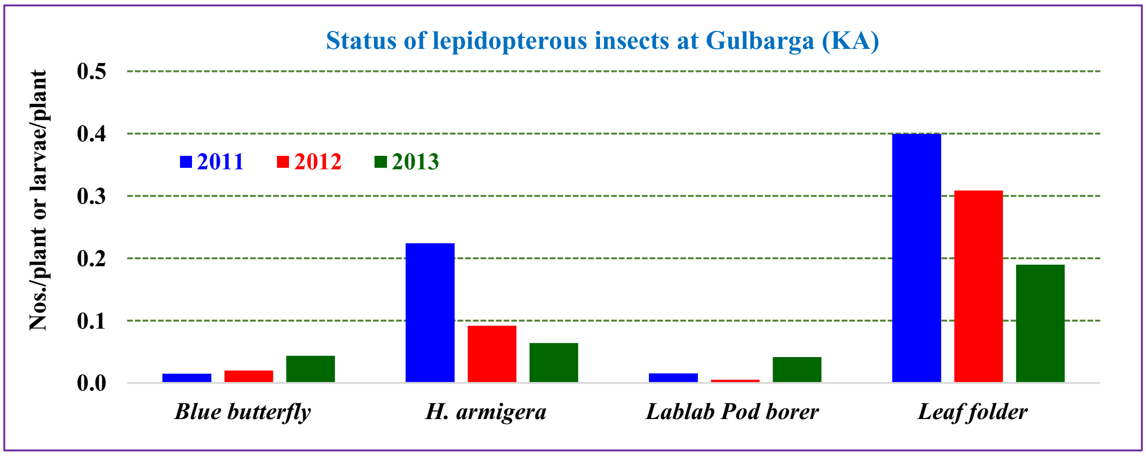
Table 29. Status of jassids at Gulbarga/Kalaburgi (Karnataka)

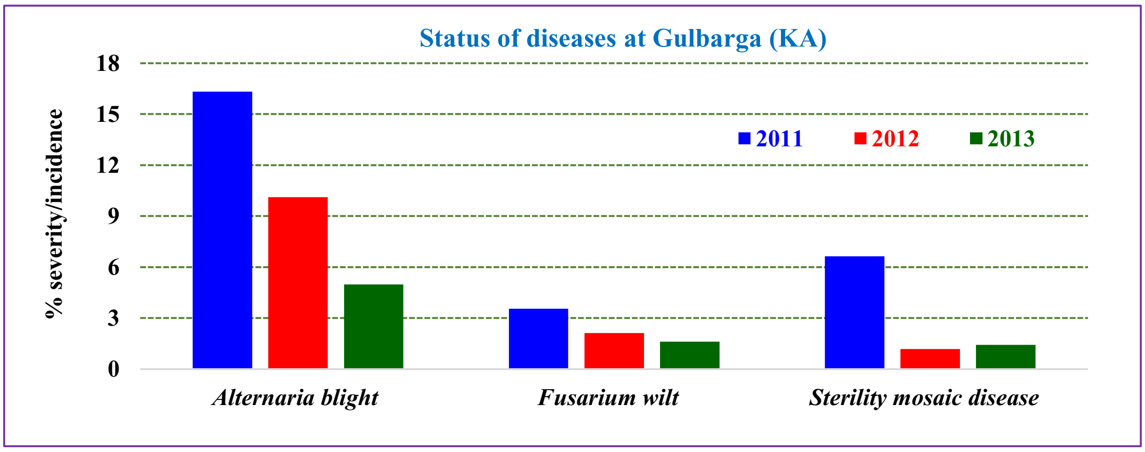
2011	2012	2013	2014	2015	2016	CD
0.65^{c} (1.07)	1.46^{bc} (1.40)	1.67^{bc} (1.47)	2.95^{b} (1.86)	5.41^{a} (2.43)	0.22^{d} (0.85)	(0.48)

Figures in parentheses are (x+0.5) square root transformed values; In the row, means followed by the same letter are not significant at P<0.05 based on DMRT

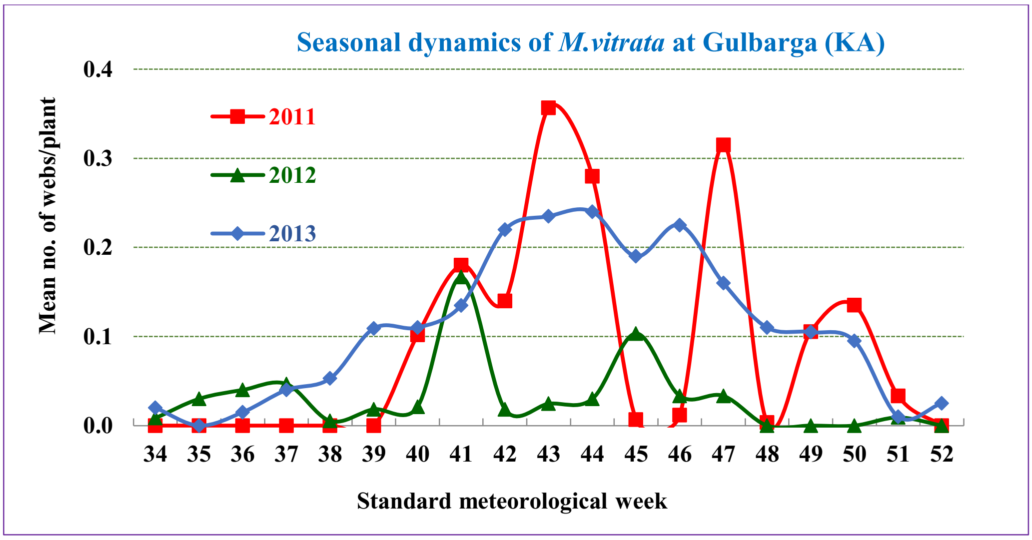


More than double the abundance of *E. kerri* on pigeonpea was observed during 2015 over 2014 with its onset during August and the highest peak during October. Very low population of *E. kerri* was noticed in 2016 compared to earlier years (Table 29) as the initial buildup of population was affected by low maximum temperature (1.4 -3.4˚C) below normal (31.5˚C) between June and July brought about by the higher rainfall over 22 rainy days as against nine rainy days during 2015. The population of the *E. kerri* at a given time was governed significantly by the minimum temperature and morning relative humidity of the previous week. [*E. kerri* (nos./3 leaflets) = 0.241 $MinT_{-1}$ - 0.050MRH_{-1} (R^2: 0.91; n=18)]. Decreasing incidence of pod borer *Helicoverpa armigera* and almost all diseases (*Alternaria*, *Fusarium* and sterility mosaic disease (SMD)) during 2013 over previous two seasons was seen. Blue butterfly and lablab pod borer incidence was higher in 2013 over previous two seasons at least by twice (refer Figures).



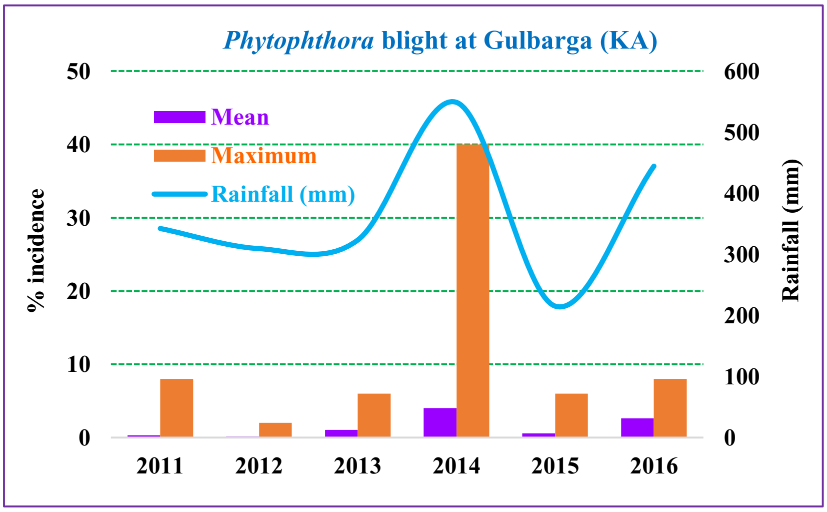


The seasonal damage due to *M. vitrata* was lower during 2012 over 2011 and 2013. The damage had commenced almost six and five weeks earlier during 2012 and 2013 over 2011, respectively. Although level of damage between 40 & 44 SMW, and 47 & 52 SMW were higher in the 2011 season, the early higher damage between 38 and 40 SMW followed by continued higher damage between 45 and 46 SMW during 2013 resulted in higher seasonal damage (refer Figure). The higher rainfall years (655 and 640 mm in respect of 2011 and 2013) had higher *M. vitrata* damage over low rainfall year (466 mm during 2012).



More than the direct effect of rainfall, it is the rainfall influence on crop phenology in turn affecting the damage due to *M. vitrata* was inferred. Vennila *et al.*, (2017) included reporting of calendar (SMW) based observations of *G. critica* damage on crop age basis for testing differences in damage levels amongst sowing periods besides description of relations of damage with crop age and weather variables. Seasonal damage levels of *G. critica* for sowing periods at Raichur (Karnataka) were non-significant but significant ($P<0.05$) across SMWs and crop age with reduced damage during early and late crop stages irrespective of sowing periods. Seven and four weeks of higher damage and the best fit of polynomial relations of second order in respect of crop age over calendar based periods signified crop stage dependent damage due to *G. critica*. Study had revealed that less than 30°C of maximum temperature and greater than 23° C of minimum temperature to be favourable for *G. critica* damage. Crop age and calendar based observations had their importance for an area wide and field basis management of *G. critica,* respectively. Insect pests *viz., H. armigera, M. vitrata,* leaf folder (*G. critica*), podbugs (*Nezera virudula, Riptortus pedastris* & *Clavigralla gibbossa*) had been lower in 2016 over 2015 at Karnataka.

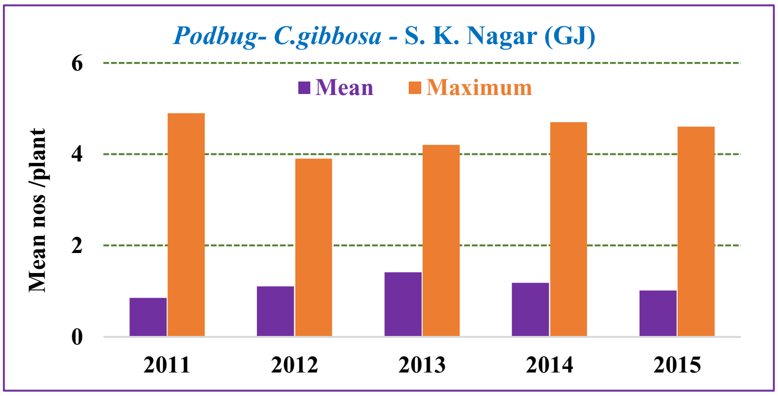
Severity of *Phytophthora* blight (*Phytophthora drechsleri* f. sp. *cajani*) in mid-July sown fields of pigeonpea (40-80%) was observed following continuous and high intensity (50% higher over normal) rains during 36 and 37 SMW of September 2015 at Chincoli, Sedam and Chitappur taluks. *Phytophthora* blight was on the rise in response to increased rainfall during (44 SMW) over normal coinciding with the late crop growth stage. Although summer rains followed by higher monsoonal rains in June 2016 (179 mm) led to early sowing of pigeonpea, higher July rains (226 mm) resulted in water stagnation and occurrence of *Phytophthora* blight and root rot. *Phytophthora* blight incidence was 40% in



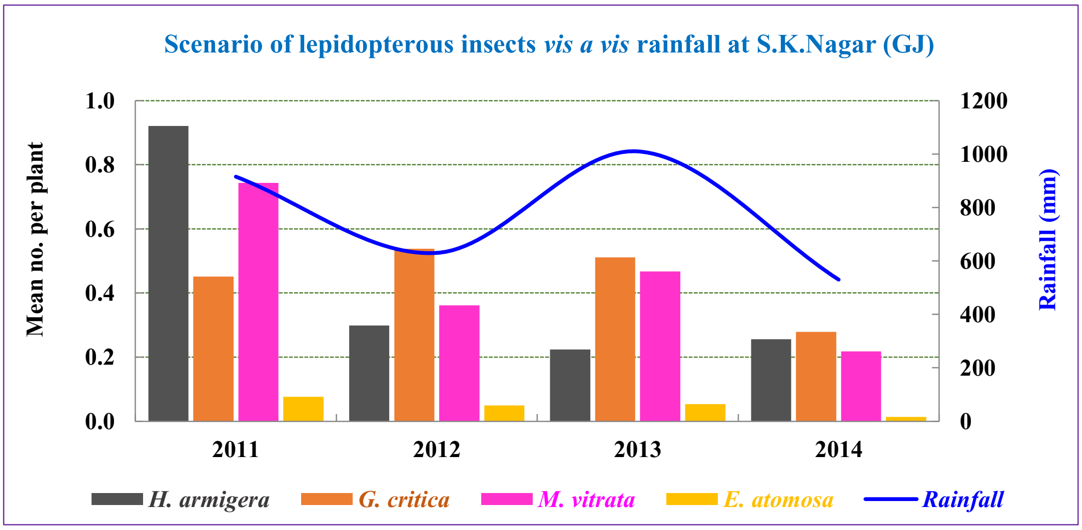
2014 when June-August rains were higher (549 mm) followed by 8% in 2011 and 2016 when rainfall amounts had been 342 and 444 mm, respectively.

Sardarkrushinagar [S.K. Nagar (GJ)] [ACZ: Gujarat Plains and Hills Region AER: Western plain, kachhh and part of Kathiawar peninsular, hot arid ecoregion]

Abundant population of *Clavigralla* associated with decreasing temperature and increasing evening relative humidity in 2012 besides first time occurrence of *Phytophthora* blight and *Alternaria* were observed on pigeonpea. The pod bug, *Clavigralla gibbosa* was abundant during all the seasons, in particular. The increased population of podbugs was significantly associated with decreasing maximum ($r= -0.69$; $p< 0.001$) and minimum ($r=-0.94$; $p<0.0001$) temperature and increasing evening relative humidity ($r=0.75$; $p<0.001$) (Jakar *et al.,* 2017).



Lepidopterous insect pests *viz., H. armigera*, *G.critica*, *A. atkinsoni* and *Exelastis atomosa* were at their lowest during 2014 when the rainfall amount during the season (June - December) had been lower. Seasonal dynamics in respect of three lepidopterous insects *viz.*, *G. critca, H. armigera* and *M. vitrata* for study seasons (2011-16) are depicted in Figures below. The seasonal means for individual insects showed highly significant differences across seasons. The order of larval counts (no./plant) in respect of *H. armigera*, *G. critica* and *M. vitrata* were: 2011>2015>2012> 2013>2014>2016, 2012 > 2011 & 2013 > 2014 > 2015 & 2016 and 2011 > 2012, 2013 & 2015 > 2014 > 2016**.** Although order of variations in seasonal means was different among lepidopterans studied, all three species had significantly reduced population during 2016 over other seasons.



Seasonal variability of actual weather for all three variables (A-MaxT, A-MinT & A-RF) across 2011-16 at Banaskantha region of Gujarat was non significant. On the other hand, climatic variability measured based on their deviations of actuals from 'normals' (D-MaxT, D-MinT & D-RF) indicated significant differences across seasons for D-MinT and D-RF. Minimum temperature (D-MinT) variability was negative as well as positive. While significantly reduced D-MinT by 2.7° C was recorded in 2011, increase by 0.77° C was noted in 2013. D-RF increase approximately by 30 mm/week above normal was also noted in 2013 (Table 30).

Table 30. Inter-seasonal variability of lepidopterous insects, weather and climate

Variables	2011	2012	2013	2014	2015	2016	F value
Seasonal means of lepidopterous insects (Mean no. of larvae/plant)							
G. critica	0.52[b]	0.78[a]	0.47[b]	0.31[c]	0.23[d]	0.25[d]	192.18***
H. armigera	1.10[a]	0.37[c]	0.37[c]	0.36[c]	0.45[b]	0.27[d]	140.96***
M. vitrata	1.58[a]	0.68[b]	0.78[b]	0.48[c]	0.70[b]	0.39[c]	37.50***
Weather fluctuations							
A-MaxT (°C)	33.2	33.1	31.9	33.1	33.3	33.2	0.38 [NS]
A-MinT (°C)	14.8	16.7	18.2	17.7	17.5	17.2	0.76 [NS]
A-RF (mm/week)	0.49	0.34	32.4	0.49	1.21	6.46	1.24 [NS]
Climatic variability							
D-MaxT (°C)	-0.33	-0.52	-1.58	-0.41	-0.3	-0.38	0.71[NS]
D-MinT (°C)	-2.69[c]	-0.81[b]	0.77[a]	0.19[ab]	0.01[ab]	-0.30[ab]	6.49 ***
D-RF (mm/week)	-2.56[b]	-2.71[b]	29.39[a]	-2.56[b]	-1.84[ab]	3.41[ab]	1.29 *

Means in row with same letter are not significantly different; significance of 'F' at * p<0.05; ***p<0.001 based on one way ANOVA; [NS]: Not Significant

The quantified measure of climatic variability for recent periods (2011-16 seasons combined) over the past assessed using 't' test revealed -0.57°C, -0.48°C and 3.85 mm/week of Max.T, MinT and RF against actuals of 33.5°C, 17.5°C and 33.1mm/week, respectively. Significance was noted only for RF implying clear-cut increase of rainfall during pigeonpea growing season in recent periods at Banaskantha with non significant changes of temperature (Vennila *et al.,* 2019c).

Climatic variability associations worked out considering all season (2011-16) data sets of population dynamics of *H. armigera*, *G. critica* and *M. vitrata* considered on SMW basis with respective climatic deviations revealed non-significant impact on all three climatic variables on *G. critica* and *M. vitrata*. The feeding nature of both *G. critica* and *M. vitrata* could be one of the major reasons for the insects not significantly responding to the observed or current climatic variations. For the polyphagous *H.armigera* with higher within plant movement for feeding, increasing D-MaxT as well as D-RF had shown significantly positive effect with D-MinT associated negatively (Table 31).

Table 31. Kendall's 'τ' coefficients between lepidopterans and climatic variability

Insect	Climatic variables		
	D-Max T (°C)	D-MinT (°C)	D-Rainfall (mm/week)
G. critica	-0.02	-0.14	-0.02
H. armigera	0.18*	-0.29***	0.19*
M. vitrata	0.12	-0.15	0.02

Significance of 'τ' coefficient is denoted by *: p<0.05 and ***: p<0.001

Significant and positive impact of RF and negative influence of MinT on *H. armigera* incidence was also reported by Jakhar *et al.* (2016). Current findings suggested an increase of *H. armigera* on pigeon pea with decreasing MinT with increasing MaxT and RF at Banaskantha of Gujarat in recent periods (2011-16). Species associations between pod bugs and *H.armigera* were significantly positive (r=0.73; P<0.001) with the later governed by minimum temperature (r=-0.89; p<0.0001) and sunshine hours (r=0.59; P<0.05) indicating the non competence for common resource of food and simultaneous co existence through the crop season. Red hairy caterpillar at the experimental station and *Cercospora* leaf spot in some farmer fields were also observed that were not reported before.

Field incidence of sterility mosaic disease (SMD) indicated the commencement of infestation during second week of August with peak severity during third week of October to November. Mean seasonal incidence of SMD was significantly lower in 2015 and 2016 over 2011-14 (Table 32) (Paul *et al*., 2018).

Table 32. Inter seasonal variations of SMD incidence at S.K. Nagar (Gujarat)

SMD incidence (%)	2011	2012	2013	2014	2015	2016
Mean	4.95[a]	4.97[a]	4.92[a]	5.01[a]	0.69[b]	0.33 [b]
Maximum	30.2[a]	12.1[b]	8.02[b]	6.66[b]	2.56[b]	2.00 [b]
In a row, the values followed by the same letter are not differ significantly by DMRT at p<0.05 in ANOVA performed on arcsin transformed values						

Correlative analysis indicated significant and negative influence of minimum temperature (r = -0.34*; $p<0.05$) and evening humidity (r = -0.48*; $p<0.05$) of current to two lagged weeks on mean and maximum SMD. Increasing minimum temperature and evening relative humidity levels are expected to reduce SMD in the hot arid ecoregion.

Fusarium wilt incidence across seasons compared through graphical representation indicated its commencement from mid September (38 SMW) during 2014-16, a week later in 2012 and 2013 and a fortnight later (39 SMW) in 2011. While 2013 had significantly the highest incidence, the lowest was noted in 2016 (Table 33). More number of rains (1032 mm) and rainy days (40) and higher incidence of *Fusarium* wilt during 2013 was noticed over 2011 (950 mm in 34 rainy days) and 2012 (630 mm in 22 rainy days).

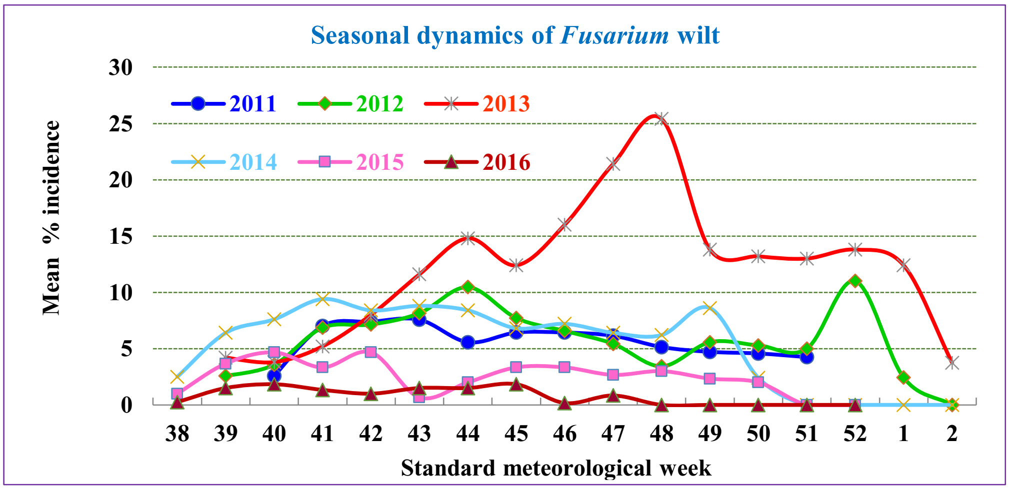


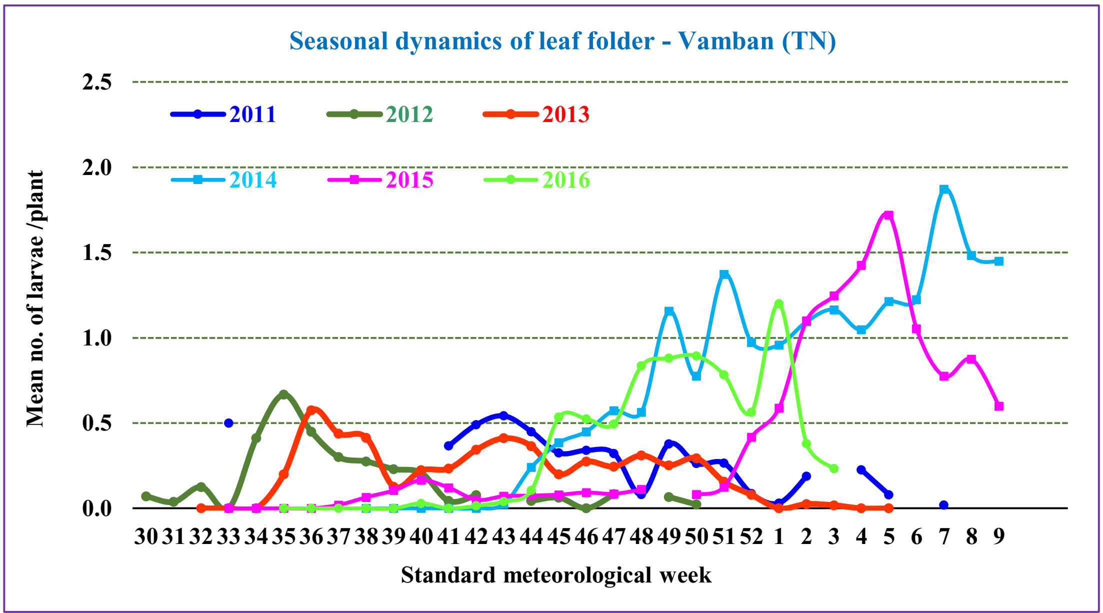
Table 33. Interseasonal variations of *Fusarium* wilt at S.K. Nagar (Gujarat)

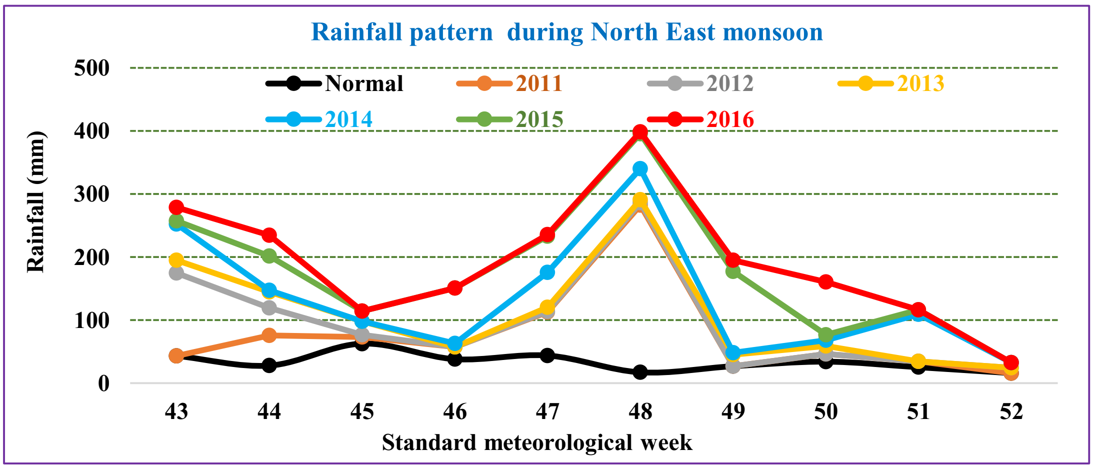
Season	2011	2012	2013	2014	2015	2016
Wilt (%)	8.56 [b]	7.34[c]	11.3[a]	7.25[bc]	3.64[d]	2.41[e]
In a row, the values followed by the same letter are not differ significantly by DMRT at p<0.05 in ANOVA performed on arcsin transformed values						

Seasonal RF in 2013 was the highest (454 mm) over other five seasons (4.8 - 90.4 mm) and the increased seasonal RF of 29.4 mm/week was significant over normal (3.05 mm/week). Minimum tempertature increase was by 0.77 ^{o}C over normal of 17.4 ^{o}C in 2013. On the contrary, *Fusarium* was at its lowest in 2016 that had RF of only 6.5 mm/week with minimum temperature of 17.2^{o}C, the later on par with seasons of 2011-12 and 2014-15 indicating the increased RF and the increased *Fusarium* incidence.

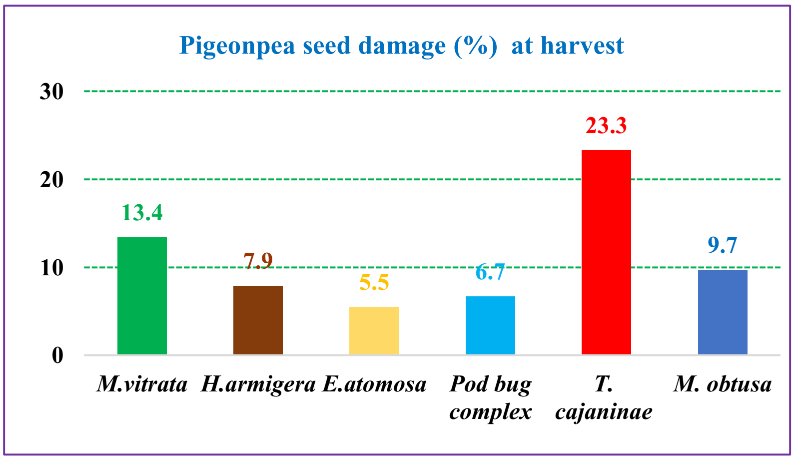
Vamban [Tamil Nadu (TN)] [ACZ: East Coast Plains and Hills Region AER: Eastern ghat, TN upland and Deccan plateau hot semi- arid ecoregion]

Higher leaf folder incidence (2.3 nos/plant) on five month old crop (January 2016) associated with decreasing maximum (r = -0.47*; p<0.05) and minimum temperature (r = -0.63*; p<0.05) besides rainfall (-0.42; p<0.05) was observed.





Maximum of *Maruca* webs on flowers (22 nos/plant) followed by plume moth (18 larvae/plant), blue butterfly (12.5 larvae/plant), and *H. armigera* larvae (11/plant) were observed during 2013. Among the pod bugs, *Clavigralla gibbosa* was dominant (maximum of 25/plant) followed by *Riptortus pedestris* (three/plant) and *Nezara viridula* (2.5/ plant). Among pod borers, podfly (*M. obtusa)* and *H. armigera* damage to pods was 40 and 8%, respectively. Pod wasp, *Tanaostigmodes cajaninae* La Salle (Hymenoptera: Tanaostigmatidae) was an emerging pest of pigeonpea in Tamil Nadu since 2015. The order of importance of pests for pod damage at Vamban during 2015-16 was pod fly (*M. obtusa*: 20%) > pod bugs (*Nezara virudula, C. gibbossa* & *Riptortus pedestris*: 12%) >



spotted pod borer (*Maruca vitrata*; 17.3%)> pod borer (*H. armi*gera; 10%). The order of importance based on % seed damage at harvest was pod wasp (23.3) > *Maruca* (13.4) > podfly (9.7) > *H. armigera* (8.0) > podbugs (6.7) > plume moth (5.5). Highly reduced rainfall during September and November 2016 (62 mm) over previous five seasons and normal (436 mm) reduced the crop duration that the insect pests were of lesser significance. Incidence of pod fly was the highest 68% in 2016-17 in relation to significantly increasing and decreasing maximum and minimum temperature by 2.3°C and 0.3°C over respective normals of 33.7 °C and 24.1°C (Vennila *et al*., 2020b).

Warangal [Telangana State (TS)] [ACZ: Southern Plateau and Hills Region AER: Deccan plateau and eastern ghat, hot semi- arid ecoregion]

Frequent dry spells facilitated leafhoppers *E. kerri* but reduced *Fusarium* wilt in 2011. Rainfall during flowering in 2011 led to induction of second flush *vis a vis* increase in pod fly damage. Leaf folder (*G. critica*) unlike in 2011 extended even up to November 2012 when the crop phenology was delayed. Increasing pod fly damage was noticed owing to the extension of the crop period either due to rainfall at flowering or due to irrigation resulting in second flush. Insect pest load was low, in general and *H. armigera* and *M. vitrata*, in particular during 2013.

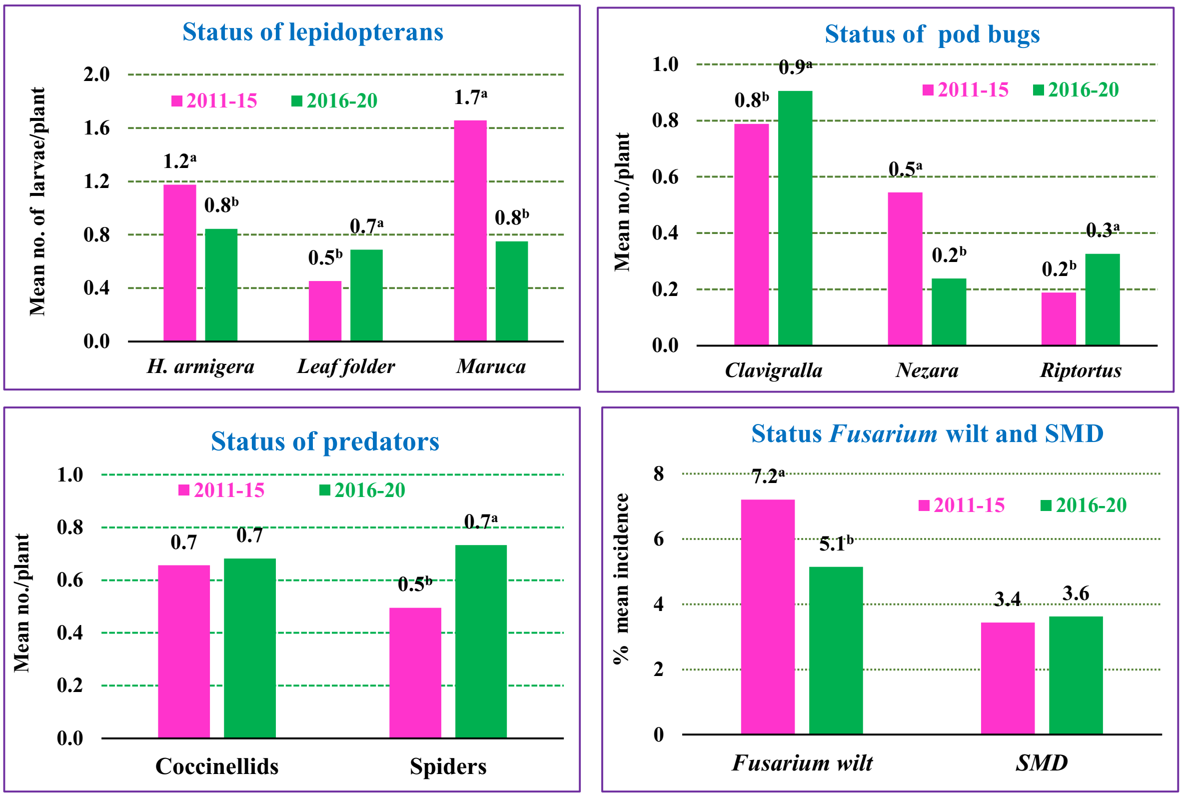
Characterization of *H.armigera* spatial distribution in pigeonpea crop using geostatistical methods based on NICRA database was developed from twenty-eight pigeonpea fields considering four seasons (2017-2020) and nine sampling weeks per season. Variogram and voronoi diagram and mapping of *H. armigera* larval distribution patterns along temporal occurrence of larval *H. armigera* were made. Significant difference for *H. armigera* larval infestation was noticed between sampling weeks, and higher larval infestation was observed between last week of November and first week of December. The availability of pigeonpea reproductive structures from first week November resulted in buildup of larval infestation. Variogram revealed moderate to strong larval aggregation (spatial dependence) of *H. armigera* in all nine sampling weeks. Based on variogram, the average aggregation distance of *H. armigera* larvae was estimated to be 2426.48 m. The intra-population variability of *H. armigera* larvae was associated with a geographical space and temporal patterns. A sampling distance of ~2427meters was worked out between pigeonpea fields for *H. armigera* larval monitoring (Seetalam *et al.,* 2021).

Sporadic incidence of mealybugs and severe wilt incidence at certain locations favored by excess moisture due to 235.2 mm of rainfall during October 2013 in nine rainy days as against normal of 59.2 mm was noted. The frequent dry spells *vis a vis* increasing trend of pod bugs was observed at pod development stage. Although *H. armigera* on pigeonpea decreased drastically over the last decade after the introduction of transgenic cotton, its incidence was higher during 2014-15 reaching even up to 20 larvae per plant. Increase in the damage levels of pod fly, *Melanagromyza obtusa* during October and November was noted. Deficit or no rainfall but for June and July, and high unseasonal rains of September of 2016 resulted in reduced *M. vitrata* at vegetative stage and increased podfly and *H. armigera* in harvested pods with pod bugs causing near to 8% seed damage. Frequent dry spells also led to pod bugs at reproductive crop stage. The occurrence of leaf folder (*Grapholita critica*) extended even up to December (2011- 2015) with the extension of crop period due to irrigation or rainfall during flowering (Vennila *et al*., 2018). Sporadic incidence of of cowbugs (*Otinotus oneratus*) and coffee borer (*Zezura* sp.) was conspicuous during 2015-16. During *kharif* 2015, *Fusarium* wilt incidence was low because of drought. Pigeonpea in early vegetative stage was infested with tingid bug (*Urentius sp*) with incidence of leaf webber (*G. critica*) noticed from August first week onwards with overall status of other insect pests and diseases minimal.

Status of major insects of pigeonpea – a decadal scenario

Significant decline in abundance of *H. armigera* and *Maruca* during 2016-20 and increasing leaf folder over previous five years (2011-15) was noted. Amongst podbugs, *Clavigralla* and *Riptortus* had significantly increasing abundance during periods between 2016 and 2020. *Nezara* population showed significant reduction in 2016-20 over 2011-15. While coccinellids maintained similar mean density levels during both half decadal periods, significantly increased spiders were noted for 2016-20. Among major diseases, significantly declining wilt incidence for 2016-20 was seen. Sterility mosaic disease (SMD) was endemic over the decade (2011-20).

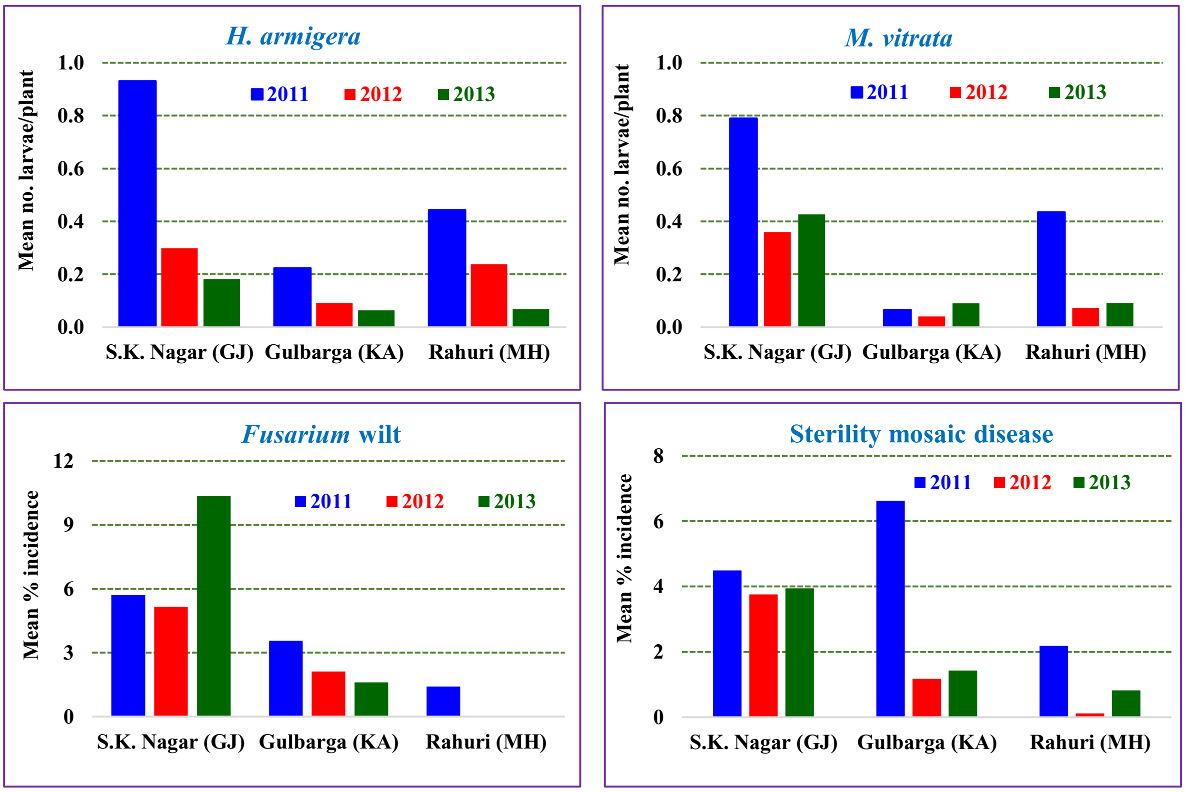
Status of insects and diseases at Warangal (TS)



Scenario of major insects and diseases across locations

While *M. vitrata* damage was higher at S.K. Nagar (GJ) (15-35%) and Vamban (TN) (55%), the scenario of other insect pests *viz.,* blue butterfly, *H. armigera*, lab lab pod borer and plume moth in 2012 were at low levels at almost all locations. All species of pod bugs *viz., Clavigralla, Nezera* and *Riptortus* were prevalent at all locations but relatively higher at S.K. Nagar (GJ) in 2012.

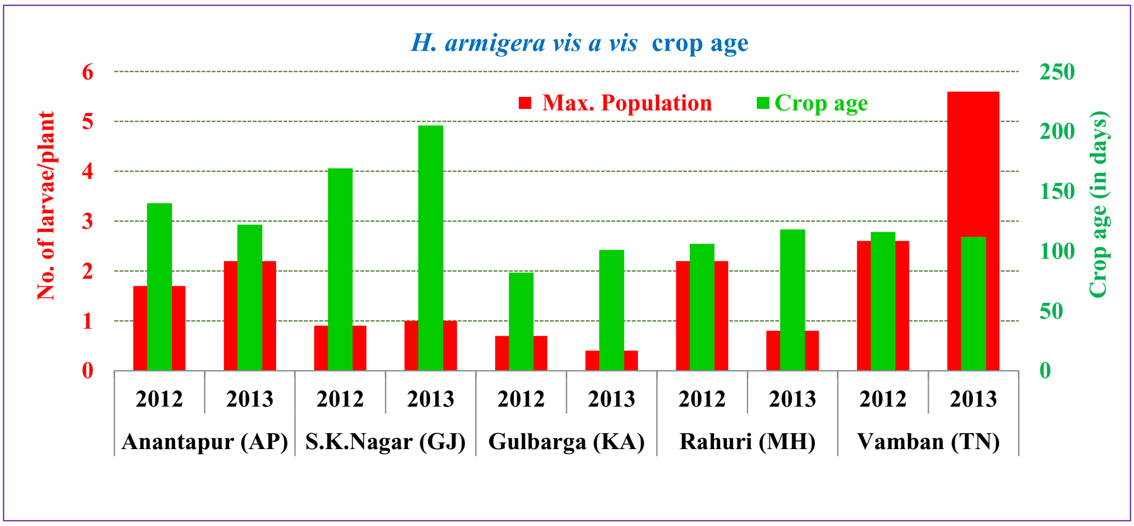
Status of insects and diseases on pigeonpea across locations

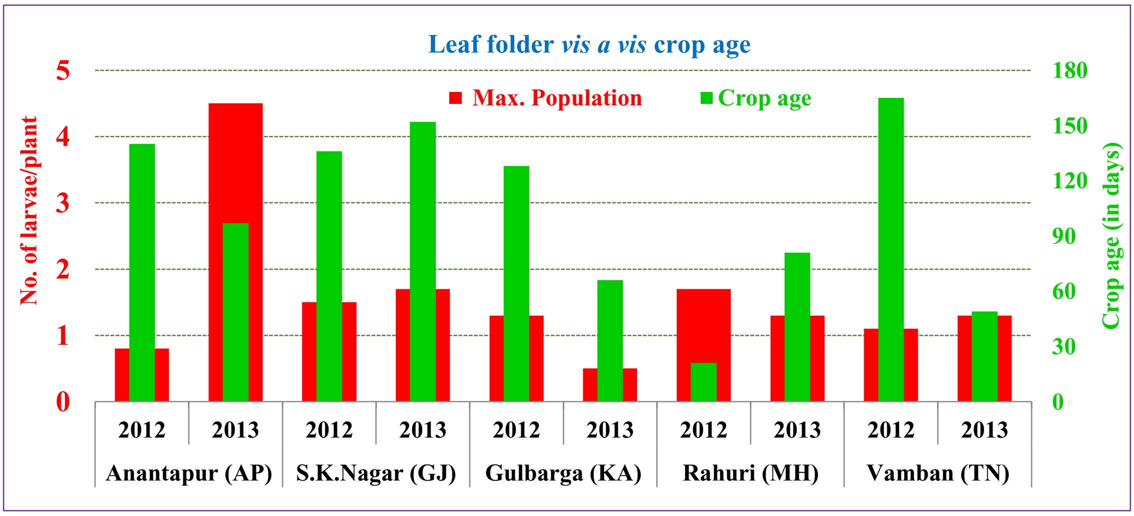


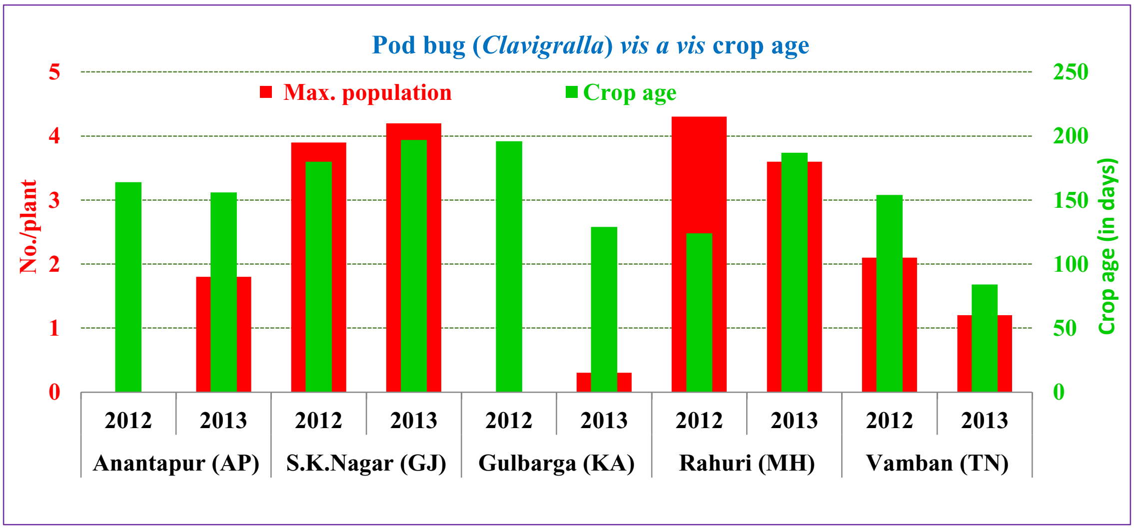
The order of incidence of *Alternaria* blight was Gulbarga (KA) (10%) > Badnapur (MH) (7%) > Kanpur (UP) (1.2%) > S.K. Nagar (GJ) (0.5%). *Fusarium* wilt was also considerable during 2012 with its order of incidence at S.K. Nagar (GJ) (8%) > Ananthpur (AP) and Badnapur (MH) (3%) > Kanpur (UP) (2.1%) > Gulbarga (KA) (2.0%) > Pudukkottai (TN) (0.3%). Maximum of six % sterility mosaic virus at S.K. Nagar (GJ) although it was present at all locations below 1%. Status of *H. armigera* and *M. vitrata* across locations indicated declining trend of the former pest at all study locations over seasons with overall occurrence of both the pests higher at S.K. Nagar (GJ) > Rahuri (MH) and Gulbarga (KA). Rahuri (MH) had meagre severity of sterility mosaic disease over S.K. Nagar (GJ) and Gulbarga (KA).

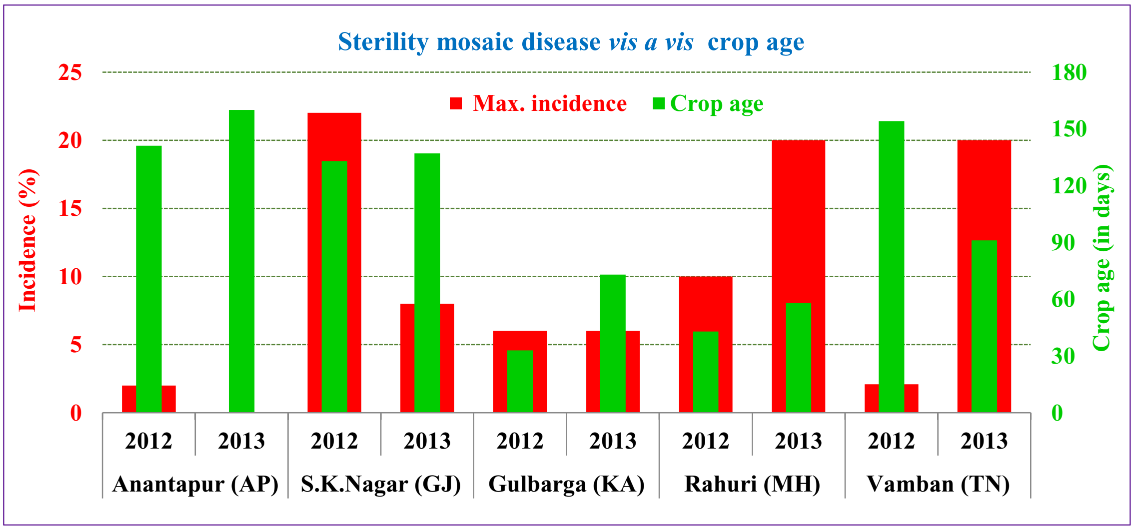
In view of the seasonal means of insects and diseases, represented largely by the peak populations and severity, respectively, a case study to understand the effect of crop phenology on dynamics of pests was made accounting maximum population or severity and crop age in respect of a few years for a particular location, and over locations on the hypothesis that the crop age of peak population would be same across locations if the insect/disease is exclusively dependent or associated with crop growth. Pod borer *H. armigera*, leaf folder and pod bug (*Clavigralla*) among insects and sterility mosaic among diseases were taken up for validation. In all cases, both population/incidence of insects/disease across locations did not show a definitive trend of relation of the pests and crop age implying the dominant role of other ecological interactive forces (biotic and abiotic) in determining the population dynamics. Therefore, quantitative analysis of climate change using climate deviations to the field level population dynamics holds value. In addition, glimpses of effect of weather extremities at a given space and time could also be inferred relatively easily.

Mean status of maximum abundance/severity of insects and diseases across locations









Inter seasonal variations - insects

The population/seasonal dynamics arranged for study locations under each insect of pigeonpea are furnished in Annexure XX. Interannual differences were non significant only at locations where the insects were of minor importance [LLPB at Rahuri (MH) & Warangal (TS); BB at Anantapur (AP) & Jabalpur (MP); mealybug at Warangal (TS & Gulbarga (KA); podbugs – *Nezera* & *Riptortus* at Anantapur (AP)]. Leaf folder abundance differed significantly across seasons at different locations. Jabalpur (MP) & Rahuri (MH) in 2011, Gulbarga (KA), Anantapur (AP), Warangal (AP) and Vamban (TN) in respect of 2012, 2014, 2017 and 2018, seasons had significantly higher LF. Leaf folder abundance was relatively higher at locations of Southern plateau and hills (Anantapur (AP), Gulbarga (KA) and Warangal (TS) and East coast plains and hills (Vamban (TN)) ACZ. Similarly, the occurrence of *H. armigera* was relatively higher in Southern states and locations [Warangal (TS) & Vamban (TN)]. Mean population of *H. armigera* (no. of larvae/plant) differed significantly across seasons at all seven locations. Anantapur (AP) had significantly higher population during 2014 and 2015 with the lowest in 2016. S.K. Nagar (GJ) and Rahuri (MH) had the highest population in 2011. Gulbarga (KA) had the order of significant variations as 2014>2012 & 2015>2013 & 2016. Jabalpur (MP) had the highest seasonal mean of [0.95 larvae/plant- near to economic threshold level (ETL)] significantly different from 2016 that had the lowest (0.25 larvae/plant) with other seasons overlapping amongst themselves. Vamban (TN) had significantly higher *H. armigera* in 2018, 2012 and 2013, however on par with 2016 and 2017. Population levels of *H. armigera* were higher in the order of 2015, 2012, 2014 and 2011. Population in 2012 and 2015 was significantly higher over 2013 and 2017 at Warangal (TS) although other seasons had similarity with any one of the seasons (Table 34).

Table 34. Inter seasonal variations of insects

Insect	Location	2011	2012	2013	2014	2015	2016	2017	2018	2019	*F* value
Leaf folder (LF) [No. of larvae/plant]	Anantapur (AP)	-	0.22^{c}	0.52^{b}	1.36^{a}	0.55^{b}	0.34^{c}	-	-	-	75.5***
	Gulbarga (KA)	-	0.51^{a}	0.26^{d}	0.46^{b}	0.30^{c}	0.27^{cd}	-	-	-	113.5***
	Jabalpur (MP)	1.38^{a}	0.39^{b}	-	0.10^{b}	1.00^{a}	0.24^{b}	-	-	-	85.1***
	Rahuri (MH)	0.68^{a}	0.33^{b}	0.25^{c}	-	-	-	-	-	-	62.3***
	S.K. Nagar (GJ)	0.52^{b}	0.78^{a}	0.47^{b}	0.31^{c}	0.23^{d}	0.25^{d}	-	-	-	192.2***
	Vamban (TN)	0.39^{e}	0.31^{ef}	0.53^{d}	0.80^{c}	0.19^{f}	0.63^{cd}	1.92^{b}	2.04^{a}		115.1***
	Warangal (TS)	0.72^{b}	0.57^{c}	0.43^{d}	0.30^{e}	0.35^{de}	0.28^{e}	1.44^{a}	0.62^{bc}	0.61^{bc}	60.1***
Pod borer- *Helicoverpa* (PB) [No. of larvae/plant]	Anantapur (AP)	-	0.40^{b}	0.41^{b}	0.95^{a}	0.81^{a}	0.24^{c}	-	-	-	30.9***
	Gulbarga (KA)	-	0.27^{b}	0.17^{c}	0.54^{a}	0.29^{b}	0.20^{c}	-	-	-	77.7***
	Jabalpur (MP)	0.95^{a}	0.83^{ab}	0.48^{c}	0.67^{bc}	0.77^{ab}	0.25^{d}	-	-	-	51.1***
	Rahuri (MH)	0.58^{a}	0.48^{b}	0.20^{c}	-	-	-	-	-	-	73.8***
	S.K. Nagar (GJ)	1.10^{a}	0.37^{c}	0.37^{c}	0.36^{c}	0.45^{b}	0.27^{d}	-	-	-	140.9***
	Vamban (TN)	0.18^{bc}	1.10^{ab}	1.44^{a}	0.16^{bc}	0.10^{c}	0.72^{abc}	0.73^{abc}	1.67^{a}	-	10.6***
	Warangal (TS)	1.11^{abc}	1.39^{ab}	0.30^{e}	1.20^{abc}	1.44^{a}	0.91^{cd}	0.59^{d}	0.89^{bc}	0.91^{bc}	7.7***
Lablab pod borer (LLPB) [No. of larvae/plant]	Gulbarga (KA)	-	0.15^{bc}	0.17^{b}	0.21^{a}	0.14^{c}	0.14^{bc}	-	-	-	15.5***
	Jabalpur (MP)	-	-	2.87^{a}	0.58^{b}	0.10^{b}	0.20^{b}	-	-	-	19.4***
	Rahuri (MH)	0.18	0.15	-	-	-	-	-	-	-	0.2^{NS}
	S.K. Nagar (GJ)	0.40^{a}	0.15^{b}	0.40^{a}	-	0.10^{b}	0.10^{b}	-	-	-	11.9***
	Warangal (TS)	-	-	-	-	-	0.10^{a}	0.20^{a}	0.14^{a}		1.3^{NS}
Blue butterfly (BB) [No. of larvae/plant]	Anantapur (AP)	-	-	0.30	-	0.30	0.18	-	-	-	4.9^{NS}
	Gulbarga (KA)	-	0.15^{b}	0.16^{b}	0.32^{a}	0.18^{b}	0.17^{b}	-	-	-	34.2***
	Jabalpur (MP)	-	-	-	0.1	0.4	-	-	-	-	1.9^{NS}
	Rahuri (MH)	0.30^{a}	0.17^{b}	0.16^{b}	-	-	-	-	-	-	25.7***
	S.K. Nagar (GJ)	0.74^{a}	0.43^{b}	0.71^{a}	0.34^{b}	0.44^{b}	0.12^{c}	-	-	-	27.8***
	Vamban (TN)	0.24^{cd}	0.51^{bc}	0.68^{b}	0.22^{cd}	0.13^{d}	0.21^{cd}	0.52^{bc}	1.11^{a}		26.6***
	Warangal (TS)	0.18^{bc}	0.18^{bc}	0.12^{c}	0.31^{abc}	0.41^{a}	0.13^{c}	0.33^{ab}	0.13^{c}	0.13^{c}	5.4***
Plume moth (PM) [No. of larvae/plant]	Gulbarga (KA)	-	0.11^{c}	0.15^{b}	0.36^{a}	0.16^{b}	0.14^{bc}	-	-	-	61.8***
	Jabalpur (MP)	0.54^{b}	1.02^{a}	1.03^{a}	0.55^{b}	0.46^{b}	0.12^{c}	-	-	-	15.7***
	Rahuri (MH)	0.22^{b}	0.32^{a}	0.30^{a}	-	-	-	-	-	-	9.7***
	SK Nagar (GJ)	0.88^{a}	0.24^{bc}	0.26^{b}	0.18^{d}	0.19^{cd}	0.11^{e}	-	-	-	87.8***
	Vamban (TN)	0.15^{b}	0.55^{b}	2.09^{a}	0.40^{b}	0.21^{b}	0.64^{b}	0.63^{b}	1.76^{a}		26.6***
	Warangal (TS)	0.50^{a}	0.24b^{c}	0.16^{c}	0.31^{b}	0.37^{b}	0.13^{c}	0.29^{b}	0.28^{b}	0.16^{c}	8.7***
Legume pod borer (LPB) [No. of larvae/plant]	Anantapur (AP)	-	0.25^{b}	1.01^{a}	-	0.34^{b}	0.41^{ab}	-	-	-	19.6***
	Gulbarga (KA)	-	0.19^{c}	0.18^{c}	0.63^{a}	0.26^{b}	0.24^{b}	-	-	-	126.2***
	Rahuri (MH)	0.71^{a}	0.31^{b}	0.33^{b}	-	-	-	-	-	-	16.9***
	S.K. Nagar (GJ)	1.58^{a}	0.68^{b}	0.78^{b}	0.48^{c}	0.70^{b}	0.39^{c}	-	-	-	37.5***
	Vamban (TN)	0.24^{c}	0.97^{b}	2.71^{a}	0.31^{c}	0.50^{bc}	0.86^{b}	2.61^{a}	3.52^{a}	-	35.8***
	Warangal (TS)	1.89^{a}	1.88^{a}	2.54^{a}	0.52^{bc}	0.85^{b}	0.50^{bc}	0.45^{bc}	0.31^{c}	0.89^{b}	15.6***
Blister beetle (BBtl) [Nos./plant]	Anantapur (AP)	-	0.16^{c}	0.87^{a}	0.39^{b}	0.36^{b}	0.45^{b}	-	-	-	12.1***
	Rahuri (MH)	-	0.36^{a}	0.21^{b}	-	-	-	-	-	-	51.1***
	S.K. Nagar (GJ)	-	0.60^{a}	0.40^{ab}	-	0.20^{b}	0.22^{b}	-	-	-	6.1***
	Vamban (TN)	-	0.26^{c}	0.71^{b}	0.59^{b}	0.62^{b}	0.91^{b}	0.86^{b}	1.21^{a}	-	13.1***
	Warangal (TS)	-	0.12^{c}	0.23^{abc}	0.17^{bc}	0.19^{bc}	0.10^{c}	0.40^{a}	0.34^{ab}	0.17^{bc}	2.9**
Cow bugs (CB) [Nos./plant]	Anantapur (AP)	-	0.67^{b}	2.65^{a}	2.59^{a}	0.71^{b}	0.75^{b}	-	-	-	84.9***
	Gulbarga (KA)	-	0.53^{b}	0.26^{e}	0.88^{a}	0.37^{c}	0.31^{d}	-	-	-	135.7***

Insect	Location	2011	2012	2013	2014	2015	2016	2017	2018	2019	*F* value
Cow bugs (CB) [Nos./plant]	Rahuri (MH)	-	0.40^{a}	0.30^{b}	-	-	-	-	-	-	9.9***
	S.K. Nagar (GJ)	-	-	1.28^{a}	1.39^{a}	0.74^{b}	0.31^{c}	-	-	-	118.0***
	Vamban (TN)	-	1.00^{b}	0.58^{c}	0.28^{d}	0.25^{d}	2.28^{a}	1.18^{b}	0.18^{d}	-	25.9***
	Warangal (TS)	-	0.67^{e}	0.28^{e}	1.97^{cd}	5.14^{a}	2.54^{cd}	3.34^{b}	2.63^{bc}	1.57^{d}	23.7***
Mealy bug (MB) [Severity]	Gulbarga (KA)	-	-	0.06^{c}	0.18^{a}	0.13^{b}	0.07^{c}	-	-	-	78.2***
	Warangal (TS)	-	0.10^{b}	0.07^{b}	0.16^{ab}	0.16^{ab}	0.15^{ab}	0.22^{a}	0.15^{ab}	0.16^{ab}	1.5^{NS}
Scales [Severity]	Gulbarga (KA)	-	-	0.04	0.14	0.17	0.07	-	-	-	18.2^{NS}
Pod bug - *Clavigralla* [Nos./plant]	Anantapur (AP)	-	-	0.50^{b}	1.81^{a}	0.27^{b}	0.23^{b}	-	-	-	84.5***
	Gulbarga (KA)	-	-	0.12^{c}	0.24^{a}	0.15^{b}	0.13^{bc}	-	-	-	33.1***
	Jabalpur (MP)	0.66^{bc}	0.50^{cd}	1.07^{a}	0.39^{de}	0.83^{ab}	0.28^{e}	-	-	-	46.9***
	Rahuri (MH)	0.28^{c}	0.59^{b}	1.13^{a}	-	-	-	-	-	-	61.2***
	S.K. Nagar (GJ)	0.91^{cd}	1.05^{c}	1.21^{b}	1.96^{a}	1.77^{a}	0.81^{d}	-	-	-	51.8***
	Vamban (TN)	0.21^{d}	0.80^{b}	0.47^{bcd}	0.63^{bc}	0.26^{cd}	0.80^{b}	0.32^{cd}	1.61^{a}		16.5***
	Warangal (TS)	1.19^{a}	0.73^{b}	0.66^{b}	0.64^{b}	0.58^{b}	0.49^{b}	1.15^{a}	0.37^{b}	1.14^{a}	11.5***
Pod bug (*Nezara*) [Nos./plant]	Anantapur (AP)	-	0.20	-	0.30	0.15	0.25	-	-	-	0.2^{NS}
	Gulbarga (KA)	-	-	0.16^{c}	0.33^{a}	0.20^{b}	0.18^{bc}	-	-	-	56.5***
	Jabalpur (MP)	0.30^{b}	0.52^{a}	0.41^{ab}	0.10^{c}	0.36^{ab}	0.28^{b}	-	-	-	9.4***
	Rahuri (MH)	0.28^{b}	0.25^{b}	0.48^{a}	-	-	-	-	-	-	43.7***
	S.K. Nagar (GJ)	1.69^{a}	0.47^{b}	0.28^{c}	0.19^{d}	0.17^{d}	0.18^{d}	-	-	-	229.9***
	Vamban (TN)	0.26^{bc}	0.32^{abc}	0.42^{ab}	0.49^{ab}	0.11^{c}	0.18^{c}	0.59^{a}	0.46^{ab}	-	3.7**
	Warangal (TS)	1.21^{a}	$0.25b^{c}$	0.17^{c}	0.21^{c}	0.53^{b}	0.16^{c}	$0.36b^{c}$	0.13^{c}	0.20^{c}	36.5***
Pod bug (*Riptortus*) [Nos./plant]	Anantapur (AP)	-	-	-	0.35	0.20	0.21	-	-	-	3.5^{NS}
	Gulbarga (KA)	-	-	0.15^{b}	0.28^{a}	0.17^{b}	0.16^{b}	-	-	-	45.5***
	Jabalpur (MP)	0.21^{b}	0.19^{b}	-	-	0.33^{a}	0.12^{b}	-	-	-	34.1***
	Rahuri (MH)	0.28^{c}	0.39^{b}	0.59^{a}	-	-	-	-	-	-	34.7***
	S.K. Nagar (GJ)	-	0.37^{a}	0.34^{a}	0.13^{b}	0.17^{b}	0.13^{b}	-	-	-	15.0***
	Vamban (TN)	0.26^{d}	0.66^{bc}	2.73^{a}	0.39^{cd}	-	0.13^{e}	0.40^{cd}	0.87^{b}	-	32.1**
	Warangal (TS)	0.24^{abc}	0.11^{d}	0.27^{ab}	0.19^{abcd}	0.15^{bcd}	0.12^{cd}	0.30^{a}	0.31^{a}	0.20^{abcd}	7.2***
Jassids (JS) [Nos. /3 leaflets/plant]	Gulbarga (KA)	0.65^{c}	1.46^{bc}	1.67^{bc}	2.95^{b}	5.41^{a}	0.22^{d}	-	-	-	19.7**
	Warangal (TS)	-	-	-	-	-	0.49^{b}	-	0.91^{a}	0.59^{b}	22.5***
Coccinellids (CC) [Nos./plant]	Anantapur (AP)	-	-	1.07^{a}	0.51^{b}	0.40^{b}	-	-	-	-	28.8***
	Gulbarga (KA)	-	0.42^{b}	0.31^{c}	0.83^{a}	0.38^{b}	0.27^{c}	-	-	-	143.6***
	Jabalpur (MP)	0.33^{d}	0.92^{b}	1.66^{a}	0.64^{c}	0.63^{c}	0.25^{d}	-	-	-	38.7***
	Rahuri (MH)	0.33^{c}	0.53^{a}	0.42^{b}	-	-	-	-	-	-	15.8***
	S.K. Nagar (GJ)	-	0.94^{a}	0.66^{b}	0.48^{c}	0.44^{c}	0.28^{d}	-	-	-	39.7***
	Vamban (TN)	0.31^{abc}	0.31^{abc}	0.24^{bc}	0.45^{a}	0.20^{c}	0.31^{abc}	0.36^{ab}	0.34^{abc}		4.4***
	Warangal (TS)	1.60^{a}	0.58^{c}	0.42^{cd}	0.44^{cd}	0.47^{cd}	0.36^{d}	1.05^{b}	0.32^{d}	0.46^{cd}	58.1***
Spiders (SP) [Nos./plant]	Anantapur (AP)	-	-	0.66^{a}	0.66^{a}	0.54^{b}	0.38^{c}	-	-	-	45.6***
	Gulbarga (KA)	-	0.29^{d}	0.34^{c}	0.83^{a}	0.42^{b}	0.28^{d}	-	-	-	182.3***
	Jabalpur (MP)	0.45^{c}	0.57^{b}	-	-	0.78^{a}	0.34^{c}	-	-	-	82.0***
	Rahuri (MH)	0.35^{b}	0.46^{a}	0.45^{a}	-	-	-	-	-	-	5.9***
	S.K. Nagar (GJ)	1.35^{a}	1.22^{a}	1.22^{a}	0.86^{b}	0.72^{c}	0.64^{d}	-	-	-	110.1***
	Vamban (TN)	0.57^{de}	0.46^{e}	0.66^{d}	0.23^{f}	0.32^{f}	0.95^{b}	1.13^{a}	0.83^{c}		46.8***
	Warangal (TS)	0.74^{b}	0.51^{c}	0.46^{cd}	0.40^{cd}	0.44^{cd}	0.49^{c}	1.4^{a}	0.34^{d}	0.49^{c}	137.8***

* In a row means followed by the superscript of same at $p<0.05$ based on DMRT; - indicate the absence of data on accout of absence of the insect or observations not made; analysis performed on [x+0.5] square root transformed values; given values in the table are the original means

The locations of Central India [Jabalpur (MP)/Rahuri (MH)/S.K. Nagar (GJ)] had the highest *H. armigera* in 2011 that declined in the following seasons up to 2016. Lablab pod borer was of lesser importance at all places, but for Jabalpur (MP) during 2013. Warangal (TS) reported the occurrence of LLPB since 2016. Plume moth and blister beetle had their occurrence at low levels with seasonal variability across locations. Legume pod borer (*M. vitrata*) was of higher significance at Warangal (TS), Vamban (TN), and S.K. Nagar (GJ) with highest damage noticed in 2011-2013, 2017-2018 and 2011, respectively. Anantapur (AP) had higher LPB abundance in 2013. Cow bug occurrence was significantly higher at Anantapur (AP) in 2013 and 2014. Relatively higher levels of CB were noted at Warangal (TS) from 2015 and in 2016 at Vamban (TN).

Significance of mealy bug at Gulbarga (KA) was noticed although severity of MB was at low levels. Amongst pod bugs, only *Clavigralla* sp. was of significance at Anantapur (AP), whereas all three species (*Riptortus, Clavigralla* & *Nezera*) were regularly observed at other locations with interannual variations. Significantly higher *Clavigralla* was noted during 2011, 2017 and 2019 at Warangal (TS) and during two consecutive seasons of 2014 and 2015 at S.K. Nagar. While Anantapur (AP) and Rahuri (MH) had higher abundance of *Clavigralla* in 2013 along with Jabalpur (MP), Vamban (TN) had the highest in 2018. Importance of *Nezera* across locations was: SK Kagar (GJ) & Warangal (TS), Jabalpur (MP), Rahuri (MH), Gulbarga (KA) and Vamban (TN) during 2011, 2012, 2013, 2014 and 2017, respectively. Gulbarga (KA) was the only locating that reported jassids on pigeonpea since 2011 with its progressive increase till 2015. Warangal (TS) had jassids occurring on the crop from 2016 with a maximum seasonal mean in 2018. Both predators CC and SP had significant interannual fluctuations at all locations. Warangal (TS) and Vamban (TN) had reported regular and considerable population of CC and SP between 2011-2019 & 2011-2018, respectively. While CC and SP were at their highest population in 2017 at Warangal (TS), the CC and SP was significantly higher in respect of 2011 and 2017.

Inter seasonal variations - diseases

The diseasewise progression arranged for study locations are furnished in Annexure XX. Inter seasonal variability for seven diseases of pigeonpea analysed using one-way ANOVA showed significant differences for all locations but for Anantapur (AP), Rahuri (MH) and Warangal (TS) in realtion to SMD (Table 35).

Table 35. Inter seasonal variations of diseases

Disease	Location	2011	2012	2013	2014	2015	2016	2017	2018	2019	F value
Fusarium wilt (FW)	Anantapur (AP)	-	5.86^{b}	7.79^{a}	8.11^{a}	8.71^{a}	2.65^{c}	-	-	-	32.8***
	Gulbarga (KA)	-	4.06^{c}	3.17^{d}	8.89^{a}	4.29^{bc}	4.47^{b}	-	-	-	175.5***
	Jabalpur (MP)	2.40^{b}	7.00^{a}	-	-	6.99^{a}	-	-	-	-	4.3***
	S.K. Nagar (GJ)	8.56^{b}	7.34^{c}	11.3^{a}	7.25^{bc}	3.64^{d}	2.41^{e}	-	-	-	166.6***
	Vamban (TN)	2.00^{b}	2.00^{b}	13.0^{a}	-	4.30^{b}	-	-	3.96^{b}	-	6.8*
	Warangal (TS)	9.30^{bc}	4.67^{d}	13.7^{a}	5.68^{d}	4.53^{d}	7.62^{cd}	10.6^{b}	4.92^{d}	5.43^{d}	9.9***
Phytophthora blight	Anantapur (AP)	-	3.00^{b}	7.33^{a}	6.29^{a}	6.63^{a}	3.09^{b}	-	-	-	22.1***
Sterility mosaic (SMD)	Anantapur (AP)	-	2.00	-	-	4.67	3.38	-	-	-	0.9^{NS}
	Gulbarga (KA)	-	3.46^{b}	2.55^{c}	9.48^{a}	3.51^{b}	3.81^{b}	-	-	-	289.8***
	Rahuri (MH)	4.78	3.64	5.37	-	-	-	-	-	-	1.2^{NS}
	S.K. Nagar (GJ)	72.8^{a}	5.68^{b}	5.41^{b}	6.07^{b}	2.93^{c}	2.33^{c}	-	-	-	355.4***
	Vamban (TN)	3.75^{c}	4.16^{c}	10.8^{a}	2.97^{c}	-	3.0^{c}	8.70^{b}	-	-	41.4***
	Warangal (TS)	3.84	2.20	-	4.00	2.50	2.00	2.00	5.00	2.91	4.6^{NS}
MSC	Warangal (TS)	18.2^{ab}	-	-	6.00^{b}	-	-	34.00^{a}	4.08^{b}		23.6***
Alternaria blight		-	15.06^{a}	8.43^{c}	9.66^{b}	7.19^{d}	7.90^{cd}	-	-	-	97.0***
Powdery mildew	Gulbarga (KA)	-	-	-	6.26^{a}	1.79^{b}	1.39^{b}	-	-	-	256.2***
CLS		-	10.66^{a}	6.87^{b}	4.97^{c}	5.49^{c}	5.22^{c}	-	-	-	180.6***

* Means followed by the superscript of same at $p<0.05$ based on DMRT; - indicate the absence of data on accout of absence of the disease or observations not made; analysis performed on arc sin transformed values; given values in the table are the original means

Fusarium wilt (FW) incidence was on par during 2013-2015 at Anantapur (AP). Highest *Fusarium* wilt at Gulbarga (KA) was during 2014. Jabalpur (MP) had the highest of FW during 2012 and 2015. S.K. Nagar (GJ), Vamban (TN) and Warangal (TS) had significantly higher FW in 2013 (>10 %). Locations such as Gulbarga (KA), Jabalpur (MP) and Vamban (TN) did not exhibit FW during some seasons of study years. *Phytophthora* blight was noticed only at Anantapur (AP) with three consecutive seasons (2013-2015) having the highest incidence. S.K. Nagar (GJ) during 2011 and Vamban (TN) during 2013 and Gulbarga (KA) during 2014 had significantly higher SMD over other seasons. At Warangal (TS), SMD incidence ranged between 2 and 5 % and did not differ among seasons between 2011 and 2019, although 2013 did not have SMD. *Macrophomina* stem canker was only prevalent at Warangal (TS) and was the highest in 2017. *Alternaria* blight was observed only at Gulbarga (KA) with highest severity in 2012. Powdery mildew was seen from 2014 and prevailed during next two seasons with overall severity of 1.39 to 6.26%. *Cercospora* leaf spot was again specific at Gulbarga (KA) with 2012 having significantly higher severity (10.7 %) followed by 2013 (6.9 %).

Magnitude of climate change

Anantapur (AP), Gulbarga (KA) and Rahuri (MH) had shown significance for change of MaxT, MinT and RF with significant increase and decrease of MinT and RF, respectively. Despite increasing MinT (1.62°C) at Gulbarga (KA), MaxT had a significant reduction by 0.48°C. Significant increase (2.27°C) at Vamban and reduction (-1.66°C) at Warangal (TS) was noted for MaxT. S.K. Nagar (GJ), Jabalpur (MP) and Warangal (TS) had significantly increased RF and that of Anantapur (AP), Gulbarga (KA), Rahuri (MH) and Vamban (TN) had reduced RF that was significant. Changing temperature, (MaxT & MinT) were not significant at S.K. Nagar (GJ) and Jabalpur (MP) and that of MinT alone at Vamban (TN) and Warangal (TS) (Table 36).

Table 36. Magnitude of climate change among seven pigeonpea growing locations

Location	Actual means of 2011-16			Change from 'normals'		
	A-MaxT	A-MinT	A-RF	D-MaxT	D-MinT	D-RF
Anantapur (AP)	32.5	21.6	14.2	2.3***	1.0***	-0.4***
Gulbarga (KA)	30.2	21.5	17.6	-0.5***	1.6***	-2.2***
Jabalpur (MP)	30.0	18.4	46.1	0.4	-0.5	0.9***
Rahuri (MH)	31.0	21.8	25.3	0.9***	0.7***	-1.7***
S.K.Nagar (GJ)	33.0	17	6.9	-0.58	-0.48	3.9***
Vamban (TN)	34.1	23.3	25.4	2.3***	-0.17	-4.7***
Warangal (TS)	29.2	19.9	20.2	-1.7***	-0.28	6.5***

A is actual weather and D is the climatic deviations over 2011-16; units of climatic variables are : MaxT (˚C), MinT (˚C) & RF (mm/week); $^{\$}$Significance of change described as climatic variability/change is based on the 't' test : ***: $p < 0.001$

Weather and climatic deviations

Weather fluctuations were obvious for A-MaxT and A-MinT at Gulbarga (KA) and Vamban (TN) and only for A-MaxT at Warangal (TS). Gulbarga (KA) had higher A-MaxT (31.4°C) in 2015 significantly different from 2011-2014 and 2016. While Vamban (TN) had a higher A-MaxT in 2013 on par with 2011, three seasons (2012 and 2014 -2016) had on par values. 2016 at Warangal (TS) had significantly higher A-MaxT over other seasons that differentiated into three groups *viz.,* 2011 & 2014, 2012-2014 and 2012-2013 & 2015. The actual rainfall (A-RF) variations across seasons at all locations were non significant. Based on climatic deviations at least one variable had shown inter seasonal differences at all locations. Locations *viz.,* Gulbarga (KA), Jabalpur (MP), Vamban (TN) and Warangal (TS) had significance for D-MaxT and D-MinT while Rahuri (MH) had only D-MaxT significantly differing among seasons. Anantapur (AP), and S.K. Nagar (GJ) had significance only for D-MinT and Jabalpur (MP) alone had rainfall variations with an increase amongst 2013, 2011 and 2016 on par, with 2011 and 2016 on par with 2012, 2014 and 2015. Locations having inter seasonal variations with both positive and negative changes for D-MaxT were Gulbarga (KA), Jabalpur (MP), Rahuri (MH) and Warangal (TS) with significance over seasons indicated. Vamban (TN) had distinctly increasing D-MaxT with a rise of 0.83°C in 2015 to 3.81°C in 2013. D-MinTs were positive at all seasons in Anantapur (AP) (Table 37).

Table 37. Inter seasonal variability for actual weather and climatic deviations

Location	Variable	2011	2012	2013	2014	2015	2016	*F* value
Anantapur (AP)	A-MaxT	32.3	32.3	31.8	32.5	33.0	32.7	1.3[NS]
	A-MinT	21.3	21.0	21.0	21.1	22.8	21.8	1.6[NS]
	A-RF	11.6	13.9	12.0	9.3	22.3	15.8	1.2[NS]
	D-MaxT	2.1	2.2	1.6	2.4	2.8	2.6	1.9[NS]
	D-MinT	0.8[bc]	0.5[c]	0.5[c]	0.7[bc]	2.3[a]	1.3[b]	6.7***
	A-MaxT	-2.9	-0.7	-2.6	-5.3	7.8	1.3	0.9[NS]
Gulbarga (KA)	A-MaxT	30.4[b]	30.4[b]	29.4[c]	29.8[bc]	31.4[a]	29.6[c]	7.0.***
	A-MinT	18.1[c]	22.1[ab]	20.7[b]	23.1[a]	23.5[a]	21.7[ab]	9.2***
	A-RF	17.3	11.7	14.3	20.9	15.1	26.3	0.1[NS]
	D-MaxT	-0.2[b]	-0.3[bc]	-1.3[d]	-0.8[bcd]	0.7[a]	-1.1[cd]	5.6***
	D-MinT	-1.8[c]	2.2[bc]	0.8[c]	3.2[ab]	3.6[a]	1.9[d]	17.2***
	D-RF	-2.4	-8.0	-5.5	1.2	-4.6	6.6	0.8[NS]
Jabalpur (MP)	A-MaxT	29.9	30.0	28.8	30.4	30.8	29.7	1.7[NS]
	A-MinT	17.5	18.7	18.5	18.8	19	17.9	0.2[NS]
	A-RF	57.1	24.1	80.7	30.1	36.6	47.9	0.5[NS]
	D-MaxT	0.4[b]	0.5[ab]	-0.8[c]	0.8[ab]	1.3[a]	0.2[b]	4.8***
	D-MinT	-1.4[c]	-0.2[a]	-0.4[ab]	-0.1[a]	0.1[a]	-1.1[bc]	4.1**
	D-RF	11.9[ab]	-20.9[b]	35.6[a]	-15.1[b]	-8.6[b]	2.7[ab]	2.6*
Rahuri (MH)	A-MaxT	30.9[b]	30.8[b]	30.2[b]	30.5[b]	32.1[a]	30.2[b]	5.4***
	A-MinT	17.9	18.0	18.0	18.1	19.1	17.3	0.4[NS]
	A-RF	13.3	12.5	15.1	25.6	8.4	25.1	0.2[NS]
	D-MaxT	0.6[b]	0.5[b]	-0.1[b]	0.2[b]	1.8[a]	-0.1[b]	5.7***
	D-MinT	-0.4	-0.2	-0.2	-0.2	0.9	-0.9	2.2[NS]
	D-RF	-3.2	-4.1	-1.5	9.0	-8.2	8.5	1.1[NS]
S.K. Nagar (GJ)	A-MaxT	33.2	33.0	31.9	33.1	33.2	33.1	0.4[NS]
	A-MinT	14.7	16.6	18.2	17.6	17.4	17.1	0.8[NS]
	A-RF	0.5	0.3	32.4	0.5	1.2	6.5	1.9[NS]
	D-MaxT	-0.3	-0.5	-1.6	-0.4	-0.3	-0.4	0.7[NS]
	D-MinT	-2.7[c]	-0.8[b]	0.8[a]	0.2[ab]	0.0[ab]	-0.3[ab]	6.5***
	D-RF	-2.6[b]	-2.7[b]	29.4[a]	-2.6[b]	-1.8[ab]	3.4[ab]	1.3[NS]
Vamban (TN)	A-Max T	35.0[ab]	33.5[c]	35.6[a]	33.8[bc]	32.7[c]	34.1[bc]	4.3**
	A-MinT	23.4[bc]	21.1[d]	24.2[ab]	23.2[c]	23.3[bc]	24.6[a]	11.1***
	A-RF	30.1	26.2	15.0	21.8	39.4	19.8	1.0[NS]
	D-MaxT	3.2[ab]	1.6[cd]	3.8[a]	1.9[cd]	0.8[d]	2.3[bc]	6.71***
	D-MinT	-0.1[bc]	-2.3[d]	0.7[ab]	-0.3[c]	-0.2[c]	1.2[a]	16.2***
	D-RF	0.0	-3.9	-15.0	-8.2	9.4	-10.2	0.8[NS]
Warangal (TS)	A-Max T	29.7[b]	28.6[cd]	28.3[cd]	29.2[bc]	28.2[d]	31.2[a]	11.3***
	A-Min T	21.6	19.9	19.6	19.2	20.3	18.8	1.2[NS]
	A-RF	7.2	22.8	24.4	10.7	19.1	36.9	1.0[NS]
	D-MaxT	-1.2[b]	-2.2[cd]	-2.6[d]	-1.7[bc]	-2.7[d]	0.4[a]	16.5***
	D-MinT	1.4[a]	-0.3[bc]	-0.5[bcd]	-0.9[cd]	0.1[b]	-1.4[d]	6.7***
	D-RF	-6.6	9.1	10.6	-3.1	5.9	23.1	1.4[NS]

A is actual weather and D is the climatic deviations over 2011-16; units of climatic variables are : MaxT (˚C), MinT (˚C) & RF (mm/week); In a row, means followed by the same letter are not significantly different with significance of 'F' denoted by *: p < 0.05; p<0.01; ***: p < 0.001. [NS]: non-significant based on one way ANOVA

Gulbarga (KA), S.K. Nagar (GJ), Vamban (TN) and Warangal (TS) had both positive as well as negative values of D-MinT differing significantly across seasons. Jabalpur (MP) had reduced D-MinT except in 2015. D-MinT differences at Rahuri (MH) were not significant over pigeonpea seasons. Rainfall variations based on deviations (D-RF) indicated significance only at Jabalpur (MP) wherein the highest D-RF of 35.6 mm/week was noted in 2012 on par with other seasons (2011 & 2016) having increased (+) RF.

Impact of individual climatic variables on insects and diseases

The declining MaxT (-0.48°C) and rainfall (-2.17 mm/week) at Gulbarga (KA) affected the dynamics of leaf folder significantly and negatively. On the other hand, unchanging MaxT at Jabalpur (MP) had an increasing impact on LF although significant D-RF increase was evident. Unchanging MinT having positive and negative impacts at Vamban (TN) and S.K. Nagar (GJ), respectively on leaf folder was noted. Despite increasing temperature (MaxT and MinT) and decreasing rainfall significant at Anantapur (AP), such changes did not impact population dynamics of LF, pod borer (*H. armigera*) (PB) and legume pod borer (*Maruca*) (LPB). The increasing temperature (MaxT& MinT) and decreasing rains significant at Rahuri (MH) also had shown no association with LF, PB, LPB. The declining but not significant MaxT and MinT at S.K. Nagar (GJ) had positive and negative effects, respectively on PB with the increasing rainfall having positive association. Between southern locations of Vamban (TN) and Warangal (TS), only the significantly declining MaxT in the later location had significant negative effect on PB (*H. armigera*) (Table 38).

Table 38. Impact of individual climatic variables on insects and diseases

Insect/Disease	Location	D-MaxT (^{0}C)	D-MinT (^{0}C)	D-RF (mm/week)
Leaf folder (LF)	Anantapur (AP)	-0.04^{NS}	0.03^{NS}	0.02^{NS}
	Gulbarga (KA)	-0.06*	0.06^{NS}	-0.17**
	Jabalpur (MP)	0.26*	-0.06^{NS}	0.02^{NS}
	Rahuri (MH)	0.00^{NS}	0.10^{NS}	0.01^{NS}
	S.K. Nagar (GJ)	-0.02^{NS}	-0.14$^{\$}$	-0.02^{NS}
	Vamban (TN)	0.05^{NS}	0.15*	-0.05^{NS}
	Warangal (TS)	-0.14*	0.05^{NS}	-0.04^{NS}
Pod borer (PB)	Anantapur (AP)	-0.02^{NS}	0.06^{NS}	0.02^{NS}
	Gulbarga (KA)	0.16*	0.04^{NS}	-0.17
	Jabalpur (MP)	-0.25^{NS}	0.24^{NS}	0.3$^{\$}$
	Rahuri (MH)	0.08^{NS}	-0.16^{NS}	0.05^{NS}
	S.K. Nagar (GJ)	0.18*	-0.29***	0.19*
	Vamban (TN)	0.15^{NS}	0.19$^{\$}$	-0.09^{NS}
	Warangal (TS)	-0.15*	-0.03^{NS}	0.00^{NS}
Legume pod borer (LPB)	Anantapur (AP)	-0.18^{NS}	-0.18^{NS}	-0.08^{NS}
	Gulbarga (KA)	0.14$^{\$}$	0.16*	-0.13^{NS}
	Jabalpur (MP)	-0.43^{NS}	-0.09^{NS}	0.36^{NS}
	Rahuri (MH)	0.00^{NS}	0.12^{NS}	-0.06^{NS}
	S.K. Nagar (GJ)	0.12^{NS}	-0.15^{NS}	0.02^{NS}
	Vamban (TN)	0.11^{NS}	0.07^{NS}	-0.07^{NS}
	Warangal (TS)	-0.38***	-0.01^{NS}	-0.09^{NS}
Pod sucking bug *Clavigralla* (PSB)	Anantapur (AP)	-0.49***	-0.12^{NS}	0.26$^{\$}$
	Gulbarga (KA)	0.03^{NS}	0.29**	-0.1^{NS}
	Jabalpur (MP)	-0.01^{NS}	0.55***	0.2^{NS}
	Rahuri (MH)	-0.06^{NS}	0.03^{NS}	0.27*
	S.K. Nagar (GJ)	0.26**	-0.12^{NS}	0.13^{NS}

Insect/Disease	Location	D-MaxT (^{0}C)	D-MinT (^{0}C)	D-RF (mm/week)
Pod sucking bug *Clavigralla*	Vamban (TN)	0.00 ^{NS}	-0.03 ^{NS}	-0.05 ^{NS}
	Warangal (TS)	-0.01^{NS}	-0.01 ^{NS}	0.08 ^{NS}
Jassids (JS)	Anantapur (AP)	0.28^{NS}	-0.22^{NS}	-0.32$^{\$}$
	Gulbarga (KA)	-0.27 ^{NS}	-0.02 ^{NS}	0.37*
	S.K. Nagar (GJ)	-0.1^{NS}	0.21^{NS}	-0.42*
	Warangal (TS)	0.73*	0.2 ^{NS}	-0.47 ^{NS}
Spiders (SP)	Anantapur (AP)	-0.09 ^{NS}	-0.19*	0.00 ^{NS}
	Gulbarga (KA)	0.07 ^{NS}	0.33***	-0.04 ^{NS}
	Jabalpur (MP)	-0.08 ^{NS}	-0.33**	0.19$^{\$}$
	Rahuri (MH)	-0.41***	-0.03 ^{NS}	0.08 ^{NS}
	S.K. Nagar (GJ)	0.00^{NS}	-0.17*	0.22**
	Vamban (TN)	0.16*	0.32***	-0.04 ^{NS}
	Warangal (TS)	0.02^{NS}	0.08^{NS}	0.01^{NS}
Fusarium Wilt (FW)	Anantapur (AP)	0.07^{NS}	-0.01^{NS}	0.0 ^{NS}
	Gulbarga (KA)	0.12*	-0.01 ^{NS}	-0.07 ^{NS}
	Jabalpur (MP)	-0.20$^{\$}$	-0.16 ^{NS}	0.02 ^{NS}
	Rahuri (MH)	-0.36 ^{NS}	0.00^{NS}	0.14 ^{NS}
	S.K. Nagar (GJ)	-0.04^{NS}	-0.15*	0.09 ^{NS}
	Vamban (TN)	0.21 ^{NS}	0.21 ^{NS}	0.02 ^{NS}
	Warangal (TS)	-0.12$^{\$}$	0.03^{NS}	0.00^{NS}
Phytophthora blight (PBlt)	Anantapur (AP)	-0.19$^{\$}$	0.04 ^{NS}	0.12 ^{NS}
	Gulbarga (KA)	-0.14$^{\$}$	-0.08 ^{NS}	0.04 ^{NS}
	Jabalpur (MP)	-0.04 ^{NS}	0.07 ^{NS}	0.04 ^{NS}
	S.K. Nagar (GJ)	-0.31 ^{NS}	-0.36 ^{NS}	-0.13 ^{NS}
Sterility mosaic (SM)	Anantapur (AP)	-0.1 ^{NS}	0.00 ^{NS}	0.11 ^{NS}
	Gulbarga (KA)	0.12$^{\$}$	-0.09 ^{NS}	-0.09 ^{NS}
	Rahuri (MH)	0.04 ^{NS}	-0.11^{NS}	-0.14^{NS}
	S.K. Nagar (GJ)	0.06 ^{NS}	-0.26**	-0.09 ^{NS}
	Vamban (TN)	0.45***	0.25*	-0.14 ^{NS}
	Warangal (TS)	-0.45***	0.2^{NS}	0.04^{NS}
Phyllody (PH)	Gulbarga (KA)	-0.3 ^{NS}	0.08 ^{NS}	0.48*
Macrophomina stem canker (MSC)	Anantapur (AP)	-0.17 ^{NS}	-0.59***	-0.07 ^{NS}
	Gulbarga (KA)	-0.19 ^{NS}	0.4 ^{NS}	0.4 ^{NS}
	Warangal (TS)	-0.45***	0.23$^{\$}$	0.08^{NS}
Alternaria blight (AB)	Gulbarga (KA)	0.08 ^{NS}	-0.23***	-0.05 ^{NS}
	Vamban (TN)	0.01 ^{NS}	-0.61**	-0.13 ^{NS}
Powdery mildew (PM)	Anantapur (AP)	-0.01 ^{NS}	0.19 ^{NS}	0.08 ^{NS}
	Gulbarga (KA)	-0.13 ^{NS}	0.07 ^{NS}	-0.04 ^{NS}
	Vamban (TN)	0.46**	0.07 ^{NS}	0.09 ^{NS}
	Warangal (TS)	-0.5***	0.38**	-0.01^{NS}
Cercospora leaf spot (CLS)	Anantapur (AP)	0.06 ^{NS}	0.28 ^{NS}	-0.22 ^{NS}
	Gulbarga (KA)	0.10 ^{NS}	-0.07 ^{NS}	-0.03 ^{NS}
	Vamban (TN)	-0.18 ^{NS}	-0.41$^{\$}$	0.38$^{\$}$

Values with superscripts are '*tau*' co-efficients based on Kendall's correlations between insects and climatic deviations over 2011-16; *, ** & *** refer to significance at p<,0.05, p<0.01 & p<0.001, respectively; ^{NS}: Not significant

For legume pod borer, significant impact was positive and negative in respect of MinT (1.62 °C) and MaxT (-1.66 °C) at Gulbarga (KA) and Warangal (TS), respectively although a highly significant increase of D-MinT additionally indicated a positive association in the former location [Gulbarga (KA)].

Not all locations showed any significant relationship with significantly increasing or decreasing rainfall possibly due to the internal feeding nature of the insect and flower webs. Climatic variables did not show any siginificant association with the occurrrenc of *Clavigralla* at Vamban (TN) and Warangal (TS). The increasing rainfall at Rahuri (MH) had positive association with *Clavigralla*. No change and increasing MinT at Jabalpur (MP) and Gulbarga (KA) had an increasing effect that were significant on *Clavigralla*. Association of *Clavigralla* with MaxT at S.K. Nagar was significantly positive. The significantly declining and increased rainfall at Anantapur (AP) and S.K. Nagar (GJ) had reducing effect on jassids although the declining rains had a positive and significant association at Gulbarga (KA).

The increasing MaxT at Rahuri (MH) and unchanging MinT at S.K. Nagar (GJ) had a significant negative impact on spiders. Increased MinT at Anantapur (AP) and unchanging MinT at Jabalpur (MP) and S.K. Nagar (GJ) had significant associations that showed negative impact on spiders. Gulbarga (KA) with an increasing MinT (1.6 °C) and Vamban (TN) with unchanging MinT (-0.17 °C) had a positive impact on population of spiders conveying the variability within similar ACZ. Warangal (TS) was the only location where declining MaxT had an increasing effect on jassids. Spider population on pigeonpea did not show any impact by changing climatic variables at Warangal (TS) indicating the robust adapatability of spiders as a group of predators at that ACZ. Positive effect of significantly increasing rainfall (3.85 mm/week) at S.K. Nagar and Jabalpur (MP) on spiders was obvious (refer Table 36).

Locations *viz.,* Anantapur (AP), Rahuri (MH) and Vamban (TN) had an unchanging status of *Fusarium* wilt irrespective of changing climatic variables of temperaure and rainfall. Increased *Fusarium* with declined MaxT (-0.48°C) was noted at Gulbarga (KA). Jabalpur (MP) and S.K. Nagar (GJ) had reduced *Fusarium* with an unchanging MaxT (0.39^{0}C) and MinT (-0.48°C), respectively (Puran *et al*., 2017). Negative effect of significantly increasing and reducing MaxT on *Phytophthora* blight was noted in respect of Anantapur (AP) and Gulbarga (KA). Anantapur (AP) and Rahuri (MH) did not show any impact of climate change on sterility mosaic diseaee (SM). Decrease and increase of MaxT in respect of Gulbarga (KA) and Vamban (TN) resulted in increased SM. Significantly decreasing MaxT at Warangal (TS) had a reducing effect on SM.

Unchanging MinT at S.K. Nagar and Vamban (TN) had negative and positive impacts on SMD. Increasing rainfall (6.45 mm/week) had a positive impact at Warangal (TS) for the Phyllody on pigeonpea. Declining MaxT at Warangal (TS) and increasing MinT at Anantapur (AP) had a negative impact on *Macrophomina* stem canker. Significantly reduced *Alternaria* blight was noted at Vamban (TN) and Gulbarga (KA) in response to significantly increased (1.62 °C) and unchanging MinT (-0.17°C), respectively. Powdery mildew at Anantapur (AP) (Sharma *et al*., 2011) and Gulbarga (KA) had no associations significant with changing climate. However, increasing PM with increased MaxT at Vamban (TN) and reduced MaxT (-1.66 °C) at Warangal (TS) indicating negative impact on PM were noted. PM at Warangal (TS) however had a positive association with unchanging MinT indicating the possible sensitivity of the pathogen to MinT over MaxT. Amongst the locations of Anantapur (AP), Gulbarga (KA) and Vamban (TN) that had *Cercospora* leaf spot, only Vamban (TN) had significance (negative) of the declining rainfall by 4.66 mm/week. Amongst all diseases (eight) of pigeonpea, only phyllody and *Cercopsora* leaf spot at Gulbarga (KA) and Vamban (TN) respectively responded positively with significantly reducing RF (Table 39).

Table 39. Impact of individual climatic variables on insect pests and diseases - a pictorial summary

Weather variable/ Insect/Location	S.K.Nagar (GJ)	Anantapur (AP)	Gulbarga (KA)	Jabalpur (MP)	Rahuri (MH)	Vamban (TN)	Warangal (TS)
Maximum temperature (°C)	**-0.58**	**2.28*** **	**-0.48*** **	**0.39**	**0.48** **	**2.27*** **	**-1.66*** **
Leaf folder, *G. critica*			↓	↑			↓
Pod borer *H. armigera*	↑		↑				↓
M. vitrata			↑				↓
Pod bug - *Clavigralla*	↑	↓					
Jassids							↑
Spiders					↓	↑	
Fusarium wilt			↑	↓			↓
Phytophthora blight		↓	↓				
Sterility mosaic			↑			↑	↓
Macrophomina							↓
Powdery mildew						↑	↓
Minimum temperature (°C)	**-0.48**	**1.01*** **	**1.62*** **	**-0.54**	**-0.18**	**-0.17**	**-0.28**
Leaf folder, *G. critica*	↓					↑	
Pod borer *H. armigera*	↓					↑	
M. vitrata			↑				
Pod bug - *Clavigralla*			↑	↑			
Spiders	↓	↓	↑	↓		↑	
Fusarium wilt	↓						
Sterility mosaic	↓					↑	
Macrophomina		↓					↑
Alternaria blight			↓			↓	
Powdery mildew							↑
Cercospora leaf spot						↓	
Rainfall (mm/week)	**3.85*** **	**-0.38*** **	**-2.17*** **	**0.94*** **	**0.10*** **	**-4.66*** **	**6.45*** **
Leaf folder, *G. critica*			↓				
Pod borer *H. armigera*	↑			↑			
Pod bug - *Clavigralla*		↑			↑		
Jassids	↓	↓	↑				
Spiders	↑			↑			
Phyllody			↑				
Cercospora leaf spot						↑	

Empty cells with no (white) colour indicates the absence or very low presence of insects or diseases in the location. Only significant relations between population dynamics of insects/diseases with the change in respect of MaxT, MinT and RF are shown with up or downward arrows. Coloured cell with no arrow indicates non significance of insect/disease to respective climate variable

Impact of climate change measured using species - climate change association index

The species - climate change association indices (SAI) for a given insect/disease differed across locations indicating the differential and location specific impact of climate change. Rahuri (MH) accounted for SAI calculations had datasets limited to three seasons. The Tables (40 &41) show both insects and diseases ordered together based on SAI values whether significant or not. The SAIs of positive nature indicated the increase (adaptiveness) and the negative ones implied a reduction (vulnerability) of insect population/ diseases severity/incidence as the case may be. Listing and grouping of all study insects and diseases in respect of different study locations based on SAI values as adaptive and vulnerable are furnished in Annexure XXI. None of the seven study locations had similar qualitative and quantitative sequence of climatic adaptations shown by insects and diseases put together. Locations had differing number of insects/diseases significantly influenced by the changing climate.

The total of insects and diseases had differered for their occurrence across locations with Gulbarga (KA) (14) > Anantapur (AP) (12) > Vamban (TN) & Warangal (TS) (10) > S.K. Nagar (GJ) (9)> Rahuri (MH) & Jabalpur (MP) (7). The order of impact of climate change leading to positive response was Vamban (TN) (9)> Warangal (TS) (8) > Gulbarga (KA) (7)> S.K. Nagar (GJ) (6)> Anantapur (AP) & Jabalpur (MP) (5) > Rahuri (MH) (2). Anantapur (AP) & Gulbarga (KA) (7) > Rahuri (MH) (5) > S.K. Nagar (GJ) (3)> Jabalpur (MP) &Warangal (TS) (2)> Vamban (TN) (1) was the order negative effects of climate change. Vamban (TN), Warangal (TS), Jabalpur (MP) and S.K. Nagar (GJ) had more insects cum diseases having increasing over the decreasing adaptations to climate change. Gulbarga (KA) had equal number of pests (insects & diseases) responding positively as well as negatively. Rahuri (MH) (5) and Anantapur (AP) (7) had higher number that had decreasing effects shown to climate change. The cumulative impact of climate change worked out as SAI brought out adaptation of insects and diseases accounted together to be: Vamban (TN) (90%) >Warangal (TS) (80%)> Jabalpur (MP) (71.4%)> S.K. Nagar (GJ) (66.7 %) > Gulbarga (KA) (50%) > Anantapur (AP) (41.7%) > and Rahuri (MH) (28.6%). In other terms, vulnerability to climate change of insects and diseases accounted together was of the reverse order. The vulnerability was found to be more at hot arid ecoregion than hot semi arid eco regions of the different ACZ (Table 40). The values of SAI across locations ranged between -4.3 to +1.63.

Table 40. Species-climate change association index for insects and diseases - within location

Location	Order of adaptation/vulnerability (insects & diseases)	SAIs (ordered)
Anantapur (AP)	JS>CLS>FW>PM>PB>LF>SMD>SP*>PBlt>LPB>MSC*>PSB*	**0.54>0.50>0.15>0.14>0.01**>-0.06>-0.27>-0.40>-0.44*>-0.56>-0.96*>-1.34*
Gulbarga (KA)	PSB*>SP*>LF*>LPB*>PB*>PM>FW*>SMD>CLS>MSC>PBlt>AB*>JS*>PH*	**0.67*>0.59*>0.49*>0.47*>0.36*>0.26>0.08***>-0.01>-0.10>-0.13>-0.15>-0.30*>-0.71*>-0.77*
Rahuri (MH)	PB>SMD>PSB*>LF>LPB>FW>SP*	**0.07>0.03>**-0.01*>-0.02>-0.03>-0.16>-0.18*
Jabalpur (MP)	SP*>LPB >LF*>PB>FW>PBlt>PSB*	**0.33*>0.22>0.15*>0.05>0.03**>-0.02>-0.11*
S.K. Nagar (GJ)	SP*>PB*>FW*>PSB*>LPB>LF>PBlt>SMD*>JS*	**0.93*>0.77*>0.44*>0.41*>0.08>0.002**>-0.15>-0.26*>-1.66*
Vamban (TN)	SMD*>AB*>PB>PM*>LPB>SP*>FW>LF*>PSB>CLS*	**1.63*>0.73*>0.73>0.61*>0.56>0.50*>0.35>0.32*>0.24**>-2.11*
Warangal (TS)	MSC*>SMD*>PM*>PSB*>PB*>FW*>LPB*>SP>LF*>JS*	**1.20*>0.95*>0.66*>0.54*>0.26*>0.19*>0.05*>0.01**>-0.04*>-4.30*

Alternaria blight (AB); *Cercospora* Leaf spot (CLS); *Fusarium* Wilt (FW); Pod borer (PB); Jassid (JS); Leaf folder (LF); *Macrophomina* stem canker (MSC); Legume pod borer (LPB); Phyllody (PH); *Phytophthora* blight (PBlt); Pod Sucking bug (PSB); Powdery mildew (PM); Spiders (SP); Sterility mosaic disease (SMD); Positive values in bold indicate adaptation of insects to the observed climate change in respect of locations. negative values specify species vulnerability; Symbol * associated with SAI values of insects/diseases indicate the definitive influence of atleast one or all-climatic variables (MaxT, MinT, RF) having significant association with population dynamics irrespective of the significance of magnitude of climate change for the variables

The highest vulnerability in respect of Anantapur (AP), Gulbarga (KA), Rahuri (MH), Jabalpur (MP), S.K. Nagar (GJ), Vamban (TN) and Warangal (TS) was for PSB, PH, SP, CLS, JS, CLS and JS. Highest species adaptation was JS, PSB, PB, SP, SP, SMD and MSC in respect of Anantapur (AP), Gulbarga (KA), Rahuri (MH), Jabalpur (MP), S.K. Nagar (GJ), Vamban (TN) and Warangal (TS) indicating the differences of vulnerability/adaptability of a given species differing across locations. For instance, the PSB adapting at Gulbarga (KA), S.K. Nagar (GJ) and Warnagal (TS) had shown vulnerability at Anantapur (AP), Rahuri (MH) and Jabalpur (MP).

Out of six insects, the pod borer (*H. armigera*) had shown increased adaptation at all seven pigeonpea study locations by having positive SAIs irrespective of their significance (Table 41; also refer Annexure XXI). All study insects (5) at Vamban (TN) had significant positive associations with changing climate. Jassids at Gulbarga (KA), S.K. Nagar (GJ), and Warangal (TS) had reduced impact due to observed climate change in those locations. Pod sucking bug (*Clavigralla*) adaptation was significant and positive at Gulbarga (KA), S.K. Nagar (GJ), Vamban (TN) and Warangal (TS) but negative only at Anantapur (AP). Pod sucking bugs were less at Rahuri (MH) and Jabalpur (MP) but had negative SAIs. All locations but for Anantapur (AP) had positive SAIs for spiders.

The ranking of study locations based on number of diseases occurring in pigeonpea was: Gulbarga (KA) > Anantapur (AP) > Vamban (TN) > Warangal (TS) > Rahuri (MH) and S.K. Nagar (GJ) and Jabalpur (MP) with number of prevalent diseases varying between three and eight. Of the eight diseases, a swing of SAIs more towards negative impact of climate change was noted irrespective of locations. It has to be mentioned that occurrences of diseases were highly restrictive across locations. The only disease across all locations was *Fusarium* wilt and the diseases such as *Alternaria* blight and phyllody were present only at Gulbarga (KA). *Fusarium* wilt, an omnipresent disease persisted and had positive SAIs at all locations but for Rahuri (MH). *Cercospora* leaf spot was absent at Warangal (TS) and S.K. Nagar (GJ) and increased and decreased severity was noted with climate change at Anantapur (AP) and in other four locations [Gulbarga (KA), Rahuri (MH), Jabalpur (MP) and Vamban (TN)], respectively (Table 41).

Table 41. Species-climate change association index for insects and diseases - between locations

Insect/Disease	Order of adaptation/vulnerability (locations)	SAIs (ordered)
Leaf folder	KA*>TN*>MP*>GJ>MH>TS*>AP	**0.49*>0.32*>0.15*>0.002**>-0.02>-0.04*>-0.06
Pod borer- *H. armigera*	GJ*>TN>KA*>TS*>MH>MP>AP	**0.77*>0.73>0.36*>0.26*>0.07>0.05>0.01**
Legume pod borer-*Maruca*	TN>KA*>MP>GJ>TS*>MH>AP	**0.56>0.47*>0.22>0.08>0.05***>-0.03>-0.56
Pod sucking bug - *Clavigralla*	KA*>TS*>GJ*>TN>MH*>MP*>AP*	**0.67*>0.54*>0.41*>0.24**>-0.01*>-0.11*>-1.34*
Jassids	AP>KA*>GJ*>TS*	**0.54**>-0.71*>-1.66*>-4.30*
Spiders	GJ*>KA*>TN*>MP*>TS>MH*>AP*	**0.93*>0.59*>0.50*>0.33*>0.01**>-0.18*>-0.40*
Fusarium wilt	GJ*>TN>TS*>AP>KA*>MP>MH	**0.44*>0.35>0.19*>0.15>0.08*>0.03**>-0.16
Phytophthora blight	MP>GJ>KA>AP	-0.02>-0.15>-0.15>-0.44
Sterility mosaic disease	TN*>TS*>MH>KA>GJ*>AP	**1.63*>0.95*>0.03**>-0.01>-0.26*>-0.27
Macrophomina stem canker	TS*>KA>AP*	**1.20***>-0.13>-0.96*
Alternaria blight	TN*>KA*	**0.73***>-0.30*
Powdery mildew	TS*>TN*>KA>AP	**0.66*>0.61*>0.26>0.14**
Cercospora leaf spot	AP>KA>TN*	**0.50**>-0.10>-2.11*
Phyllody	KA*	-0.77*

AP= Anantapur (AP); GJ= S.K. Nagar(GJ); KA= Gulbarga (KA); MH= Rahuri (MH); MP= Jabalpur (MP); TN= Vamban (TN); TS= Warangal (TS); positive values of indices in bold indicate adaptation of insects to the observed climate change in respect of locations; negative values specify species vulnerability; symbol*associated with SAI values of insect/disease and location indicate the definitive influence of atleast one or all-climatic variables (MaxT, MinT, RF) having significant association with population dynamics irrespective of the significance of magnitude of climate change for the variables

Powdery mildew was positively associated with climatic deviations in the southern pigeonpea growing locations of Anantapur (AP), Gulbarga (KA), Vamban (TN) and Warangal (TS). Increasing importance of sterility mosaic disease at Rahuri (MH), Vamban (TN) and Warangal (TS) and its declining status at Gulbarga (KA) and S.K. Nagar (GJ) was observed with changing climate. *Phytophthora* blight was absent at Rahuri (MH), Vamban (TN) and Warangal (TS).

Phytophthora blight occurred sporadically at Anantapur (AP), Gulbarga (KA), Jabalpur (MP) and S.K. Nagar (GJ) and its decreased severity *vis a vis* climate change was noted at all these locations. *Macrophomina* stem canker at Warangal (TS) had the highest SAI implying its emerging status, however reducing at Anantapur (AP) and Gulbarga (KA). Change in MaxT > MinT > RF significantly affected (positive or negative) the population of insects or severity of diseases (also refer pictorial summary). Table 42 lists only insects and diseases whose population dynamics/progression had significant association with atleast one or two or all climatic variables. Out of 38 cases of significant associations between seasonal dynamics and climatic deviations across pigeonpea study locations, 63% had positive SAIs implying higher adaptation (increased abundance/severity) to climatic variability/change on a spatial scale across agro climatic zones pigeonpea production system.

Table 42. Impact of climate change on insects and diseases - a summary

Location	Adaptive	Vulnerable
Anantapur (AP)	Nil	1. Spiders 2. *Macrophomina* stem canker 3. Pod sucking bug
Gulbarga (KA)	1. Pod sucking bug 2. Spiders 3. Leaf folder 4. Legume pod borer 5. Pod borer 6. *Fusarium* wilt	1. *Alternaria* blight 2. Jassid 3. Phyllody
Rahuri (MH)	Nil	1. Pod sucking bug 2. Spiders
Jabalpur (MP)	1. Spiders 2. Leaf folder	Pod sucking bug
S.K. Nagar (GJ)	1. Spiders 2. Pod borer 3. *Fusarium* wilt 4. Pod sucking bug	1. Sterility mosaic disease 2. Jassid
Vamban (TN)	1. Sterility mosaic disease 2. *Alternaria* blight 3. Powdery mildew 4. Spiders 5. Leaf folder	*Cercospora* leaf spot
Warangal (TS)	1. *Macrophomina* stem canker 2. Sterility mosaic disease 3. Powdery mildew 4. Pod sucking bug 5. Pod borer 6. *Fusarium* wilt 7. Legume pod borer	1. Leaf folder 2. Jassids

Insects and diseases have been listed along the order of importance for the cumulative impact of climate change based on significance of species – climate change associations; all species listed had relations between population dynamics and climatic deviations significant (kendall's 'tau') at least for one or two or all three (MaxT; MinT; RF) irrespective of the significance of magnitude of crop season climate change quantified

Status of *Helicoverpa armigera* on pigeonpea across locations

Mean population of larval *H. armigera* differed significantly amongst seasons in each of the six study locations. While Anantapur (AP) had the highest incidence during 2014 and 2015, S.K. Nagar (GJ) had in 2011. Mean population of *H. armigera* was generally low (< 0.6 larvae/plant) at Gulbarga (KA) and Rahuri (MH) although significant inter seasonal differences existed. Jabalpur (MP), Vamban (TN) and Warangal (TS) had two successive seasons having on par higher mean incidence (≥1 larva/plant). Seasonal mean incidence was higher than the ETL of more than one larva per plant on two (2012 & 2013) and four (2011,2012, 2014 & 2015) seasons at Vamban (TN) and Warangal (TS), respectively (Table 43).

Table 43. Seasonal variability of *H. armigera* for study locations

Location	2011	2012	2013	2014	2015	2016	2017	F value
Anantapur (AP)	-	0.40^{b}	0.41^{b}	0.95^{a}	0.81^{a}	0.24^{c}	-	30.9***
S.K. Nagar (GJ)	1.10^{a}	0.37^{c}	0.37^{c}	0.36^{c}	0.45^{b}	0.27^{d}	-	140.9***
Gulbarga (KA)	-	0.27^{b}	0.17^{c}	0.54^{a}	0.29^{b}	0.20^{c}	-	77.6***
Rahuri (MH)	0.58^{a}	0.48^{b}	0.20^{c}	-	-	-	-	73.7***
Jabalpur (MP)	1.00^{a}	0.83^{ab}	0.48^{c}	0.67^{bc}	0.77^{ab}	0.25^{d}	-	51.1***
Vamban (TN)	0.18^{b}	1.10^{a}	1.44^{a}	0.16^{b}	0.10^{b}	0.72^{ab}	0.73^{ab}	9.8***
Warangal (TS)	1.11^{ab}	1.39^{a}	0.30^{d}	1.20^{ab}	1.44^{a}	0.91^{bc}	0.59^{c}	8.8***

Means followed by the same letter in a row are not significantly different based on Tukey's test following one way ANOVA; - indicates absence of data

Impact of climatic change on *H. armigera*

Significantly increasing MaxT at Anantapur (AP), Rahuri (MH) and Vamban (TN) did not impact *H. armigera*. While the declining MaxT at S.K. Nagar (GJ) and Gulbarga (KA) had significant positive impact, it was negative at Warangal (TS). Significant impact of MinT was observed only at S.K. Nagar (GJ) that was negative. Significantly increasing RF had a significant positive association at S.K. Nagar (GJ) and Jabalpur (MP). The magnitude of variability of both temperature and rainfall variables were significant on *H. armigera* at S.K. Nagar (GJ) (Table 44). The climatic variability impacts are not space neutral, hence requiring location specific approaches for predictions and management.

Table 44. *H. armigera* and climate change amongst study locations

Location	Correlation coefficients of *H.armigera* with climatic deviations		
	D-MaxT (°C)	D-MinT (°C)	D-RF (mm/week)
Anantapur (AP)	-0.02^{NS}	0.06^{NS}	0.02^{NS}
S.K. Nagar (GJ)	0.18*	-0.29***	0.19*
Gulbarga (KA)	0.16*	0.04 ^{NS}	-0.17
Rahuri (MH)	0.08 ^{NS}	-0.16 ^{NS}	0.05 ^{NS}
Jabalpur (MP)	-0.25 ^{NS}	0.24 ^{NS}	0.30*
Vamban (TN)	0.15 ^{NS}	0.19^{NS}	-0.09 ^{NS}
Warangal (TS)	-0.15*	-0.03 ^{NS}	0 ^{NS}

Values specify the 'τ' correlation coefficients between climatic deviations and insect dynamics (2011-16); significance of 'τ' is denoted by *: $p < 0.05$; ***: 0.001; ^{NS}: non-significant

Projection of future scenarios of *H. armigera*

Considering that climatic variabilities had shown significant associations only for *H. armigera*, (refer Table 31) for only its status for future periods was projected at at S.K. Nagar considering the common periods of occurrence of all three lepidopteran insects. Srinivasa Rao *et al*. (2016) had suggested that the incidence of *H. armigera* could be higher due to projected increase in temperature across locations based on predictions using growing degree day approach for future climatic periods using combined emission scenarios (A2, A1B &B1) for eight locations of India which did not have any region of Gujarat. In present study, climatic variables of MaxT, MinT and RF projected for representative concentration pathway (RCP) at radiative forcing level of 4.5 W/m^{2} with stabilization after 2100 was considered. Although there are many alternative pathways to achieve a radiative forcing level of 4.5 W m^{2}, the application of the RCP4.5 provided a common platform for climate models to explore the climate system response to stabilizing the anthropogenic components of radiative forcing (Thompson *et al*., 2011) and hence RCP 4.5 was selected. Projected values for MaxT, MinT and RF had range of 31.9-32.4°C, 15.9-18.3°C and 33.8 -39.2 mm/week for pigeonpea cropping season periods between 2020 and 2080 at S.K. Nagar. Projected values for RCP 4.5 for all three variables had shown values falling near to or within the range of recent periods. The associations of current period seasonality of *H. armigera* with deviations of projected values (DP) from 'normals' *viz.,* DP-MaxT, DP-MinT and DP-RF revealed significant but negative associations of all climatic variables for all periods (2020, 2050 & 2080) but for non-significance of DP-MaxT in 2050 (Table 45).

Table 45. Kendall's 'τ' coefficients between *H. armigera* and climatic projections - RCP 4.5

Climatic variables	Future periods#		
	2020	2050	2080
DP-Max T. (°C)	-0.41* (31.9)	0.20 NS (32.0)	-0.41*(32.4)
DP-Min T. (°C)	-0.81*** (15.9)	-0.86*** (18.3)	-0.81 ** (17.3)
DP-Rainfall (mm/week)	-0.46 *(33.8)	-0.70***(39.2)	-0.46 *(38.5)

#values outside brackets are Kendall 'τ' correlations between *H. armigera* larval populations and deviations of climatic projections; NS :Not significant; values within brackets are projected means of Max T, MinT in °C and RF in mm/week in respect of future periods

Such associations project only reducing populations of *H. armigera* during coming decades of current century. With the observed absence of weather fluctuations, significant climatic variability across pigeonpea growing seasons for MinT and RF and non-significant temperature changes quantified for Banaskantha, it is obvious that the current level of reduced *H. armigera* would continue. From pest management perspective, it is a good sign that the cropping system of the Banaskantha region would have lesser damage due to *H. armigera* and frequency of chemical applications would be less. It would be also interesting to study the impact of climatic variability on the population dynamics of *H. armigera* on dominant alternate host crops such as cotton and maize for the same region.

Kendall's correlation coefficients between the 2016 (latest common season for all locations) levels of *H. armigera* with MaxT, MinT and RF projections for 2050 and 2080 under representative concentration pathways (RCP at forcing level of 4.5 W/m^2 with stabilization after 2100) (Annexures XXII – XXIV) indicated significance for all three variables at S.K. Nagar (GJ) both in 2050 and 2080.

Table 46. *H. armigera* scenario under climatic projections - RCP 4.5

Location	2050			2080		
	MaxT (°C)	MinT (°C)	RF (mm/week)	MaxT (°C)	MinT (°C)	RF (mm/week)
Anantapur (AP)	-0.18NS (30.6)	-0.13NS (21.3)	0.00NS (18.2)	-0.18NS (31.0)	-0.13NS (21.8)	0.00NS (19.6)
S.K. Nagar (GJ)	-0.39* (32.9)	-0.80*** (16.9)	-0.49* (35.1)	-0.38* (32.4)	-0.80*** (17.3)	-0.49* (38.5)
Gulbarga (KA)	-0.06NS (31.4)	-0.33NS (21.8)	-0.13NS (51.3)	-0.01NS (31.8)	-0.34NS (22.2)	-0.13NS (54.1)
Rahuri (MH)	0.13 NS (32.5)	0.15 NS (19.0)	0.15 NS (14.1)	0.12NS (33.0)	0.14NS (19.4)	0.15NS (14.7)
Jabalpur (MP)	-0.25NS (30.6)	-0.38 NS (15.7)	-0.45NS (1.9)	-0.21NS (31.1)	-0.38NS (16.3)	-0.45NS (2.1)
Vamban (TN)	-0.47* (31.8)	-0.66** (24.2)	-0.08NS (72.4)	-0.50* (32.2)	-0.67** (24.6)	-0.10NS (74.4)
Warangal (TS)	-0.14 NS (31.7)	-0.51** (21.6)	-0.38* (21.3)	-0.13NS (32.1)	-0.51** (22.2)	-0.38* (22.4)

values without brackets specify the 'τ' correlation coefficients between climatic deviations and larval *H. armigera* dynamics (2011-16) & within brackets are the seasonal means for the respective projections of climatic variables; significance of 'τ' is denoted by *: $p < 0.05$; ***: 0.001; NS: non-significant

The different coefficient values of *H. armigera* and future climatic projections (Table 31 & 43) for S.K. Nagar had arisen due to the varied common periods of seasonal dynamic and projected climatic datasets considered (common amongst lepidopteran at S.K. Nagar *per se* & of the locations in the former and the later case, respectively). Significance of MaxT and MinT at Vamban (TN) and of MinT and RF at Warangal (TS) was noted that were similar in 2050 and 2080. All the significant associations were all negative irrespective of locations indicating the reduced occurrence of *H. armigera* in the future. No change in *H. armigera* status or the the status of 2016 was projected for Anantapur (AP), Gulbarga (KA), Rahuri (MH) and Jabalpur (MP) during future years (Table 43) (Anonymous, 2019b; 2020).

The tool of SAI measuring the adaptiveness or vulnerability of insects and diseases to climate change could be visualized at two level. The first based on just the signs of the SAIs and secondly based on the relation of species dynamics with the deviations of climatic variables being significant. Adaptiveness of the polyphagous pod borer was obvious irrespective of the study ecoregions *viz.,* hot arid (two locations), hot semi arid (four locations) and hot semi humid (one location) (refer Annexure I &II). Pod sucking bug (*Clavigralla*) had increased adaptation to climate change at hot semi arid locations but for Rahuri (MH) where it was absent. Such exception of Rahuri (MH) among hot semi arid ecoregions could have arisen also due to the lesser number of study seasons despite indicativeness of vulnerability to changing climate. While leaf folder at hot semi arid locations *viz.*, Gulbarga (KA) and Vamban (TN) had shown positive response similar ecological places *viz.*, Rahuri (MH) and Warangal (TS) in addition to arid ecoregion [Anantapur (AP)] had negative or declining impact due to observed changes in climatic variables. *Fusarium* wilt also had higher adaptation at all ecoregions but for one of the hot semi arid location [Rahuri (MH)]. Powdery mildew wherever was important had increased response to change in climate of the ecoregion be it hot arid or hot semi arid. Such differences for impact of climatic variability/change with similar agroecologies point to the fact that the approach of agroecological based planning of resource allocations to consider differential management relevance of biotic stressors. Between insects and diseases of importance at different locations, insects had shown relatively higher adaptability at Jabalpur (MP) > S.K. Nagar (GJ) > Vamban (TN) > Gulbarga (KA). While the adaptability was equal between insects and diseases at Warangal (TS) and Rahuri (MH), Anantapur (AP) had more diseases over insects showing increase in relation to climate change. A definitive and common impact of adaptiveness to climate change could only be arrived at for pod borer on pigeonpea for all locations across different agroecological regions of different agro climatic zones. Considering the differing importance of insects and magnitude of climate change and the later's asoociation with population dynamics of insects and diseases across locations, it has become obvious that the problems due to pests need to be tackled at local levels always.

GROUNDNUT

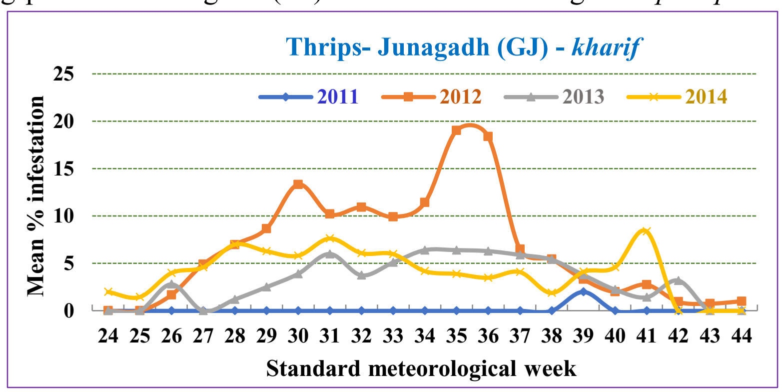
Groundnut (*Arachis hypogea*) in India is a major oilseed crop used both domestically as cooking oil and confectionery and as an important export commodity. Globally, groundnut is grown in more than 100 countries in an area of 27.6 mha with a production of 43.9 mt (FAO, 2017). India is the second largest producer (6.69 mt) of groundnut next only to China from an area of 4.81 mha. Among the major groundnut growing states, Gujarat is the leading producer of 2.2 mt from an area of 1.59 mha contributing 32.7% of the countries production (Anonymous, 2019c). Productivity in India is less (16.6 q/ha) compared to China (37.0 q/ha), USA (45.6 q/ha) and Argentina (30.8 q/ha). Biotic and abiotic stresses combined with erratic rains, poor crop management practices, and weak seed supply chain are the major constraints reducing productivity of groundnut. Quite a few studies on the impact of changing temperature and elevated CO_2 levels independently as well as in their combinations have been made under controlled conditions for insects such as *Aphis craccivora* (sap feeder) and *Spodoptera litura* (foliage feeder) on groundnut. Elevated CO_2 affected the quality of groundnut foliage resulting in higher consumption, lower digestive efficiency, slower growth, and longer time to pupation (one day more than ambient) (Srinivasa Rao *et al.,* 2012). Temperature projections using CNRM-CM3, ECHams5 and CSIRO-Mk3.5 models and their impact on *S. litura* studied indicated a decrease of 18–22% generation time (Srinivasa Rao *et al.,* 2015a). Significant and cumulative effect of elevated CO_2 on *S. litura* was reported over four successive generations. (Srinivasa Rao *et al.,* 2015b). Increase in number of generations of *S. litura* even with altered crop duration was predicted (Srinivasa Rao *et al.,* 2020). Interactive effects of elevated CO_2 and temperature levels affecting toxicity of insecticides were reported (Srinivasa Rao *et al*., 2021).

Rust and late leaf spot are the major foliar diseases causing significant yield loss and deteriorating quality of the produce throughout India (Shashidhar *et al*., 2020).The co-occurrence of rust (*Puccinia arachidis*) and late leaf spot (*Cercosporidium personatum*) causes chlorotic lesions leading to defoliation, which lowers crop yield and fodder quality. Late leaf spot and rust infect during seed setting stage and result in 15 to 59 % and 10 to 52% yield loss respectively (Kumar and Thirumalaisamy, 2016). Higher levels of humidity promote the severity of both rust and late leaf spot. Around 80% of groundnut cultivation in India is during the rainy season, during which these fungal diseases spread more rapidly. Crop health, productivity and quality are likely to be impaired in coming years owing to fluctuating climatic conditions such as uncertain rain and high temperature, especially in semi-arid regions of the world including India (Varshney *et al*., 2018). Reduction in groundnut phenological duration, growth and development during 2070 to 2100 in Rajkot, Bhavanagar, Kesod and Bhuj districts of Gujarat is projected due to air and soil temperatures above optimum causing significant yield loss in peanut (Yadav *et al.,* 2013). Groundnut as an edible oil grown across Indian cropping systems has a dominant role in Indian economy and NICRA chose the crop with the mission of assessing the impact of climate change on the varied insects and diseases. Five locations (Annexure Ia & Ib) selected from five states belonging to five different agroclimatic zones and four agro ecoregions were part of the pest-weather surveillance since 2011. Junagadh (GJ) and Jalgaon (Maharashtra) of the five locations continued till 2020. All the locations had *kharif* as the season of groundnut cultivation with their effective growing periods as given in Annexure II. Pest surveillance plan had the coverage of both experimental station fields of the identified locations and at villages in the farmers' fields. The procedures to be followed towards selection of fields for surveillance at the experimental/research station, and at villages besides the standard methods to be adopted for recording the observation of pests using the data recording formats formed the primary step.

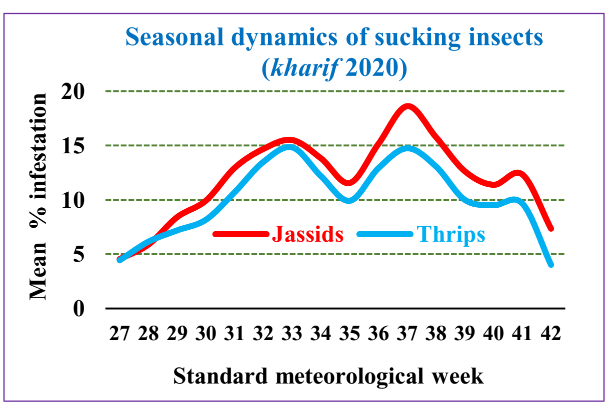
A manual with description of the identification details of the insect pests and diseases for pest surveillance and data sheet formats with guidelines for surveillance is available at: *https://ncipm.icar.gov.in/nicra2015/datasheetsmanuals.aspx*. Two groundnut fields each at the experimental station and in ten selected villages of the region were used for pest surveillance. Fixed fields are those fields grown with groundnut and once selected were continuously monitored throughout the season on weekly basis for insects and diseases. The following paragraphs furnish the scenario of major insects and diseases associated with changing weather identified during various study seasons. Interseasonal variations across study seasons (years), magnitude of climate change in respect of locations and its impact on insect and disease dynamics deduced are presented.

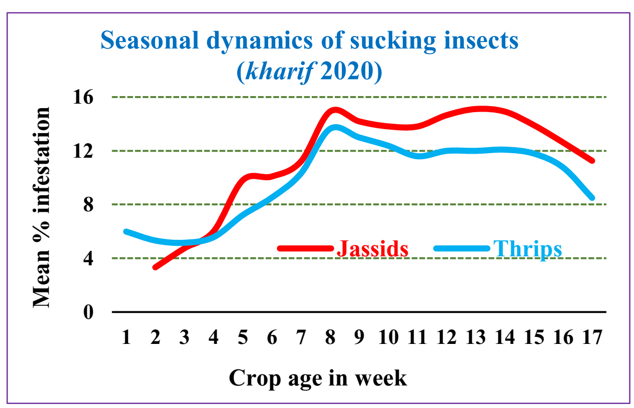
Scenario of insect pests and diseases *vis a vis* changing weather

Junagadh [Gujarat (GJ)] [ACZ: Gujarat Plains and Hills Region AER: Central highland Gujarat plains & Kathiawar peninsula hot semi- arid ecoregion]

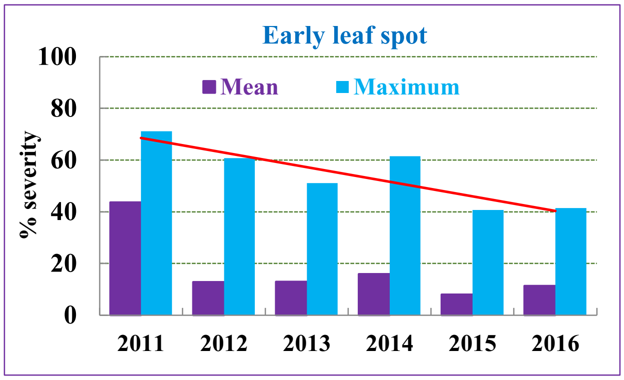


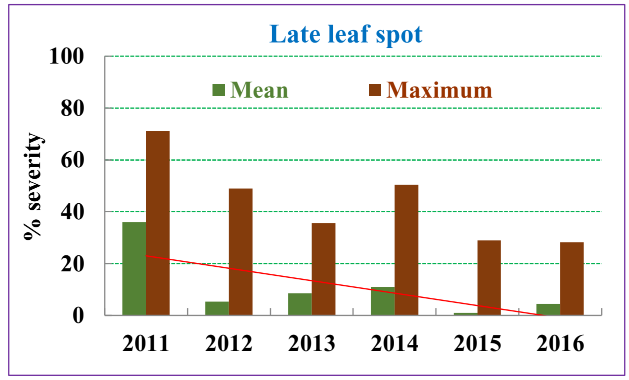
Change in rainfall coupled with cropping pattern at Junagadh (GJ) was attributed to highest *Spodoptera* pheromone trap catches during summer 2013 over *kharif* 2012. High soil moisture during germination followed by dry spell from 2nd week of June to 1st week of August coupled with uneven distribution of rainfall resulted in 25 to 30% incidence of collar rot (*Aspergillus niger*) at Saurashtra (GJ) in 2012. Jassids, thrips and leaf miner severity was higher during 2012 over 2011 related to rainfall amounts of 423 mm and 963 mm, respectively implying lower rains facilitating higher sap feeders and leaf miner. The rare occurrence of thrips damage at maturity period of groundnut was due to the prevalence of high temperature in day time and absence of rains in 2014. *Kharif* 2020 witnessed



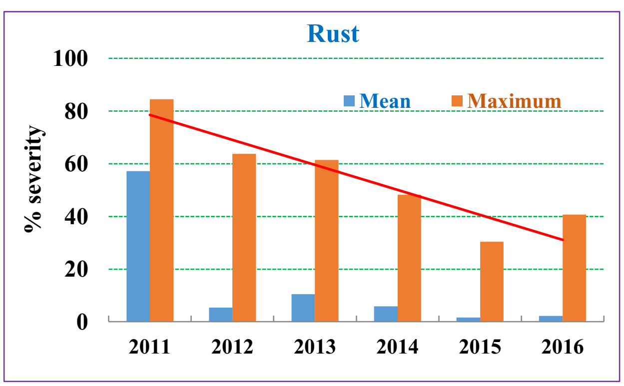


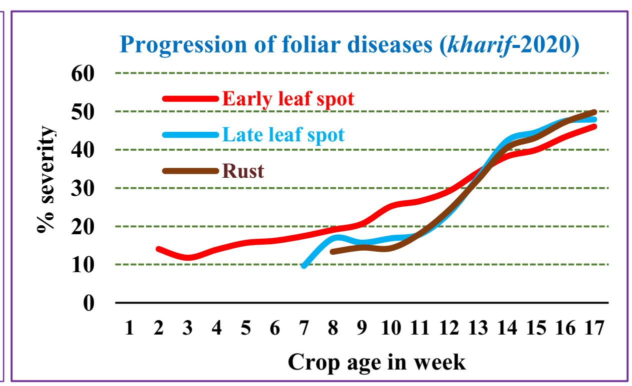
simultaneous infestation due to jassids (*Empoasca kerri*) and thrips (*Scirtothrips dorsalis*) throughout the crop period at Junagadh (GJ). While the period between 32 and 39 SMWs had greater than 10 % infestation of both sap feeders, jassids had higher abundance above ETL (10% infestation) two weeks before thrips. Early (*Cercospora arachidicola*) and late (*Cercosporidium personatum*) leaf spots besides rust (*Puccinia arachidis*) was favoured by heavy rainfall (963 mm in 45 days during the entire crop period) and high humidity (76% in morning and 43% in evening) in 2011. Lower disease severity of foliar diseases due to low rainfall of 425 mm in 25 rainy days during 2012 compared to 963mm in 45 rainy days during 2011 and 1558mm in 64 rainy days during 2010 was noted. Late leaf spot and rust severity was above 15 and 10%, respectively in 2012.





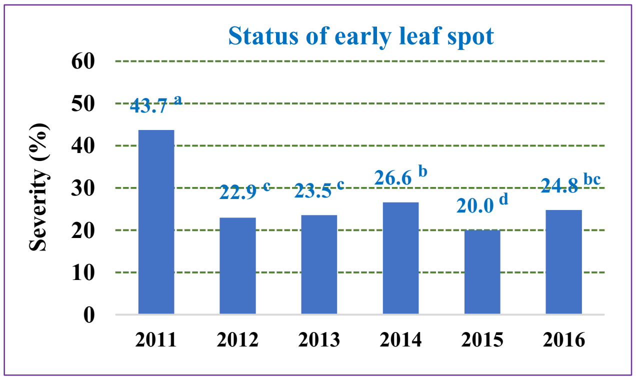
The rust disease severity was low (< 30%) during 2014 compared to previous season (above 50%) but higher than 2012 modulated by the amount of rainfall between 30 and 34 SMW (86 mm in 2012 <172 mm in 2014 < 433 mm in 2013). Highly reduced mean relative humidity (RH) levels (not greater than 78%) during August and September *kharif* 2015 resulted in reduced occurrence of groundnut foliar diseases *viz.,* rust (*P. arachidis*), early (*C. arachidicola*) and late (*P.personata*) leaf spots over the previous four seasons (2011-2014) that had 78-88% RH. Higher severity of rust at harvest in 2016 was noticed with rains >600mm in August-September. In general, reduced mean RH levels (not>79%) during September reduced the occurrence of foliar diseases. Moreover, the rainfall amounts and their distribution during August and September modulated the severity of foliar diseases. Foliar diseases *viz.,* rust, early and late leaf spots were at their high beyond 11 weeks of crop age during 2020. Although their initiations were of the order early leaf spot followed by late leaf spot and rust, their seasonal mean severity indicated the reverse order.

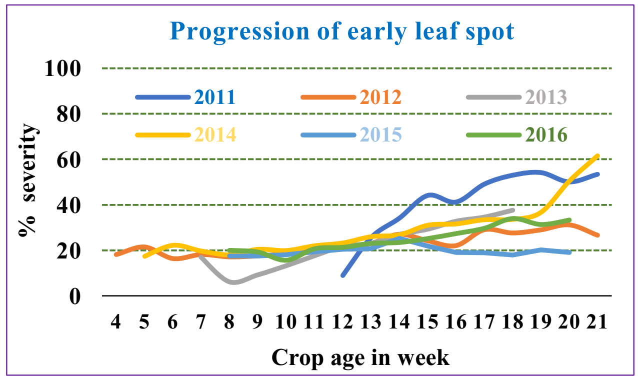




Impact of climatic variability/change on early leaf spot

Early leaf spot severity over six *kharif* seasons (2011-2016) analysed had mean severity differing significantly across seasons being the highest and lowest during 2011 and 2015, respectively. Early onset was recorded four weeks after sowing (WAS) in 2012 and the latest by 12 WAS in 2011. Disease severity increased with increasing crop age despite variations in rates of disease progression. Terminal leaf spot severity was >50% in 2011 and 2014 while other seasons had < 40%. Seasons of 2011 and 2013 had shown two peaks and such a bimodal disease curve had arisen out of emergence of new healthy leaves. Disease progression was below 30% till 13 WAS in all seasons (2011-16) with variations thereafter till crop harvest. Increased severity of ELS with crop age was evident across all seasons (refer Figure). Increased susceptibility





of plants to disease with increasing crop age has been well established. The second peak of the severity progression in the bi modal curve was higher than the first and could again be attributable to the increased susceptibility associated with older leaves.

Magnitude of climate change for the *kharif* (22-45 SMWs) periods aggregated for 2011-16 quantified and tested for their significance over long term 'normals' in respect of temperature (MaxT and MinT) at Junagadh (GJ) indicated significantly increased maximum temperature (0.63°C) and rainfall (12.4 mm/week). Magnitude of climate change in respect of minimum (-0.45°C) temperature was non-significant (Table 47). The quantified measures of climate change for the periods of 2011-16 for Banaskantha region situated in the same hot semi-arid region of Gujarat also indicated significantly increasing rainfall (33.1 mm/week) pertaining to pigeonpea crop season (38-51 SMWs) with non-significant changes in temperature confirming the climate change in terms of rainfall amounts at Gujarat. Kendall correlations worked out between ELS and climatic deviations for the past periods of 2011-16 had shown positive significance of the increasing rainfall with ELS and insignificant relations with temperature (MaxT and MinT) variables.

Table 47. Impact of climate change deviations with early leaf spot over 2011-16 at Junagadh (GJ)

Climatic variables	Actual mean (11-16)	Magnitude of climate change#	Kendall 'τ' coefficients of ELS with climatic deviations
MaxT (°C)	33.5	0.63*	0.01^{NS}
MinT (°C)	24.1	-0.45 ^{NS}	0.03 ^{NS}
Rainfall (mm/week)	41.7	12.4***	0.16*

#: mean deviations (actual minus normal) of variables compared based on Student's 't' test and significance of 't' and Kendall's 'τ' denoted by *:p<0.05 ;***: p<0.001; ^{NS}: not significant

It is highly obvious that the increasing rainfall amounts of the past periods directly determined the disease severity of ELS on groundnut at Junagadh (GJ). In field conditions, rainfall is the main source of humidity that makes leaves wet and in turn facilitates higher disease severity.

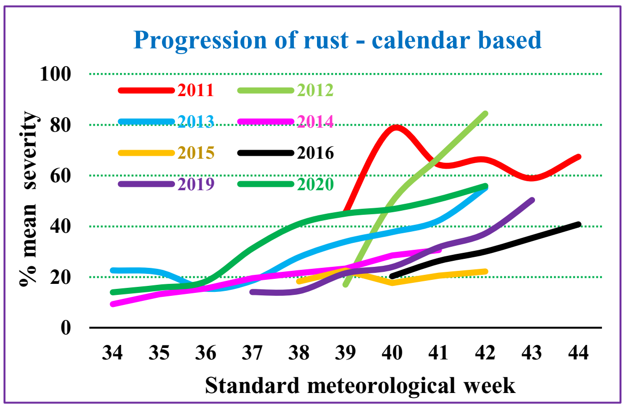
Impact of cultivars, planting dates and climatic variability/change on rust

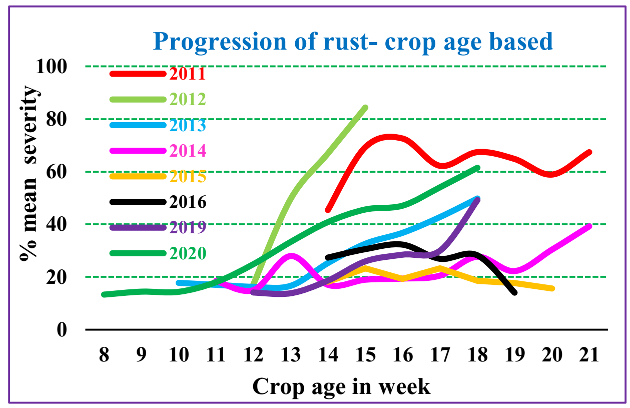
Severity of groundnut rust disease caused by pathogen *Puccinia arachidis* was studied over eight *kharif* seasons between 2010 and 2020 at Junagadh located in hot semi-arid eco region under agro climatic zone of Gujarat plains and hills. Rust severity was measured on five cultivars (GG 20, GJG 22, TG 37A, TLG 45

& Western 66) grown during three sowing periods (May II fortnight, first and second fortnights of June). Climatic variability for the *kharif* period of groundnut cultivation was quantified for three climatic variables *viz.,* temperature (maximum & minimum) and rainfall to relate to rust severity.

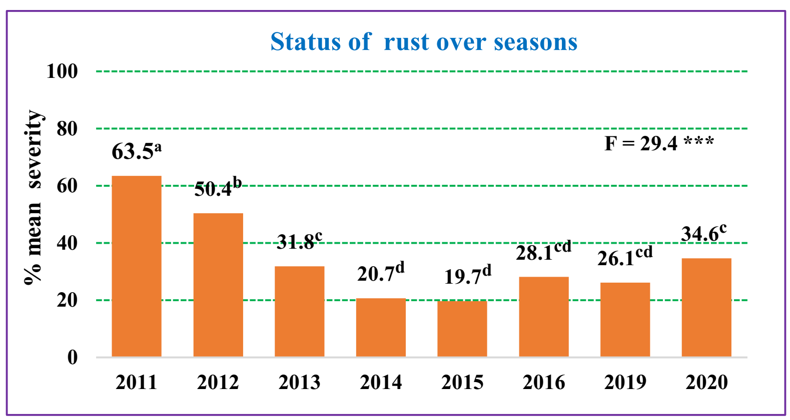
Seasonality of rust severity

Rust symptoms appeared at 34 SMW during 2013, 2014 and 2020 and during later weeks of 37, 38 39 and 40 SMW in respect of 2019, 2015, 2011-2012 and 2020. While maximum severity of 84.4% at 42 SMW in 2012 followed by 78.5% at 39 SMW in 2011 were noted, 2015 had a severity around 20% at all times. The rust progressions in respect of seasons aggregated over cultivars and sowing time on calendar and crop age basis indicated varying duration and severity of the disease. The differing rates of disease progression was evident across seasons based on the slope of lines. Seasons 2011 and 2016 had rust occurrence till 44 SMW irrespective of the dynamics along cultivars and sowing periods. Inter seasonal analysis of rust severity





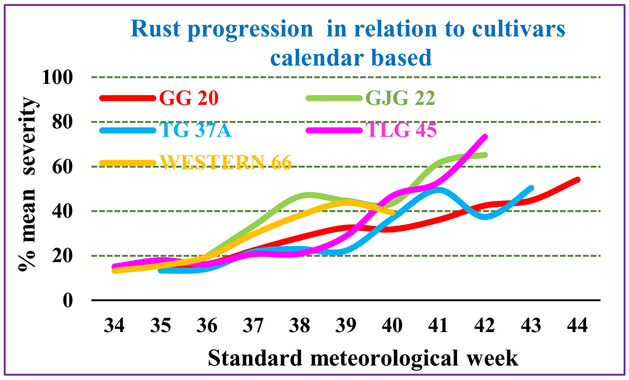
indicated significantly higher mean in 2011 followed by 2012 over all other later study seasons (refer Figure).

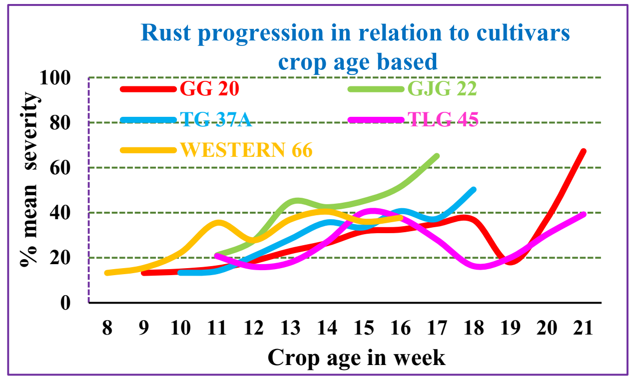


The rust commencement varied across seasons with a range of 8 to 14 weeks after sowing (WAS) with early commencement coinciding with 2020 and the late appearance during 2011, 2015 and 2016. While 2012 had a steep progression between 17 and 84 % in respect of 12 and 15 WAS, late season high severity (45-67%) was noted between 13 and 21 WAS in 2011, the seasons that had the highest severity over all other seasons. In addition to the high rust severity seasons of 2011 and 2012, 2020 alone had more than 50% at any age or stage of crop growth (refer Figure). Rust severity between 2013 &2020 was on par and significantly higher over 2014 &2015. However, the seasons of 2016 and 2019 had rust severity not only statistically on par between themselves but also on par with other four seasons (2013-2015 &2020) other than 2011 and 2012 (refer Figure).

Rust severity in relation to cultivars

Rust appearance was early and simultaneous on GG 20, TLG 45 and Western 6 during 34 SMW. The disease initiated during 35 and 36 SMWs in respect of TG 37A and GJG 22. The terminal severity also differed among cultivars being early for Western 66 (40 SMW) followed by GJG 22 and LG 45 (42 SMW), TG 37A (43 SMW) and GG 20 (44 SMW) (Figures below). It was highly obvious that the dynamics of rust progression was earliest in respect of Western 66 followed by GG20. The window of commencement of rust over the seasons for cultivars irrespective of periods of planting ranged from eight to eleven WAS. Although the terminal severity was the highest for GG 20, the late commencement and steep progression relevant to GJG 22 had led to the significantly higher rust status on the later cultivar (refer Figure). Mean rust severity

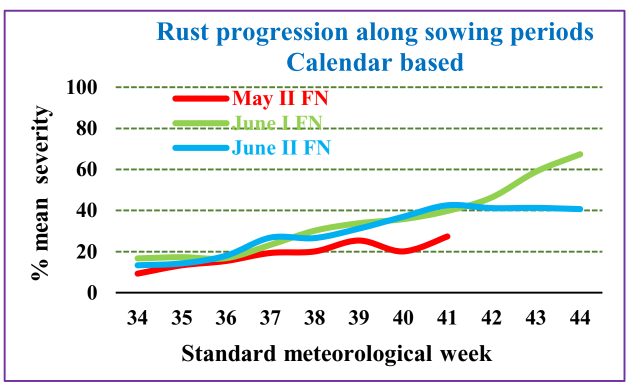


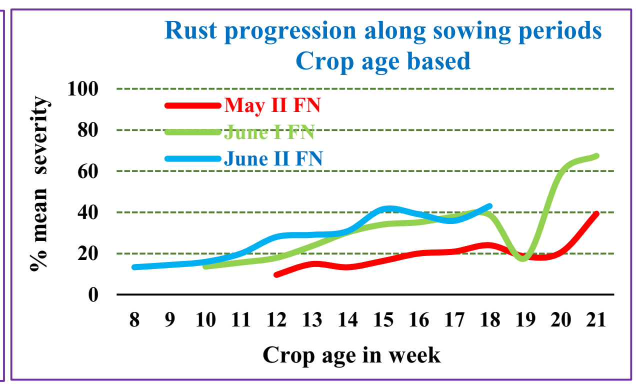


was significantly higher for GJG 22 (40.6%) over all other five cultivars *viz.,* GG20, TG37A, TLG 45 and Western 66 which were on par (refer Figure). Differential susceptibility of cultivars to rust at any given time could be the reason over and above the seasonal and /or sowing period effects as all cultivars belonged to the medium maturity group with duration of 110-115 days.

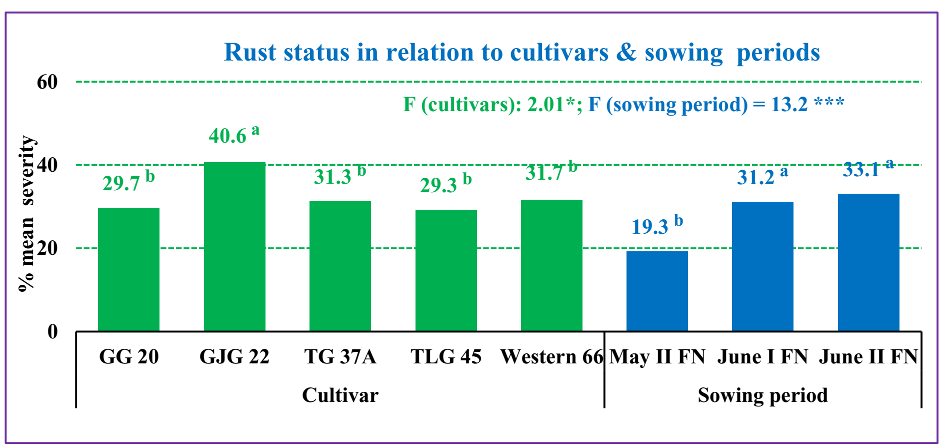
Rust severity in relation to sowing periods

May IIFN sowing had shown lesser and shorter period of disease progression (34-41 SMW) of rust severity although commencement of disease was similar at 34 SMW (refer Figure). With each fortnight delay in





sowing period of groundnut the commencement of occurrence was delayed by a fortnight indicating start of the disease at the crop age of eight weeks from the planting time (refer Figures). However, mean severity was significantly lesser with the early planting (May IIFN) (19.3%) over June plantings that were on par.



Magnitude of climatic variability at Junagadh and its relation to rust severity

The magnitude of climate variability worked out for Junagadh (GJ) for the *kharif* seasons of study periods indicated a significant rise of maximum temperature (MaxT) by 0.7°C and of rainfall (RF) by 16.9 mm/week with no change for minimum temperature (MinT) (Table 48; Column 3). It is to be mentioned that the magnitude of climatic variability worked out for 2011-16 seasons using same normals (long term average of 1980-2010) used in the present study indicated a similar pattern of change till 2020 with variability in respect of Max T, MinT and RF as 0.63°C ($p<0.05$),-0.45 (NS) and 12.4mm/week ($p<0.001$), respectively (Anonymous, 2019).

Table 48. Magnitude of climate variability and its impact on rust severity at Junagadh (GJ)

Climatic variables	Actual mean (2011-20)	Magnitude of climate variability$^{\#\$}$	Kendall's 'tau' coefficients $^{\$}$
MaxT (°C)	33.6	0.70**	-0.03 ^{NS}
MinT (°C)	24.4	-0.17 ^{NS}	0.28***
RF (mm/week)	46.2	16.9 **	-0.10**

$^{\#}$: quantified based student 't' test between actual values of climatic variables and their corresponding normals on SMW basis over study seasons $^{\$}$: significance denoted by **:$p<0.01$; ***:$p<0.001$; NS: not significant

Impact of climatic variability and change on rust severity

The associational analysis of rust dynamics aggregated over all study seasons *vis a vis* the climatic deviations of MaxT, MinT and RF indicated significant and positive association with an unchanging MinT and a significant decline due to significantly increased RF, in general, irrespective of the effects of cultivars and sowing periods (Table 49; Column 4). The response of cultivars and sowing periods to the observed climatic variability varied and none of it reflected the pattern of general effect over seasons. While impact of climatic variability was absent on rust severity in relation to cultivars (GJG 22 and TLG 45), the unchanging MinT had a significantly decreasing effect on rust severity of GG 20, TG 37A and Western 66. However, an increasing MaxT had shown positive and negative impacts that were significant for rust occurrence on CG 20 and TG 37A, respectively indicating the differential responses of cultivars to climate variability.

Table 49. Impact of climate variability on rust severity in relation to cultivars and sowing periods at Junagadh (GJ)

Particulars	Kendall's '*tau*' coefficients $^{\$}$		
	MaxT (°C)	MinT (°C)	RF (mm/week)
Cultivars			
GG 20	0.10*	-0.35***	-0.04 ^{NS}
GJG 22	-0.11 ^{NS}	-0.09 ^{NS}	0.18 ^{NS}
TG 37A	-0.24*	-0.25*	0.43***
TLG 45	-0.12 ^{NS}	-0.13 ^{NS}	0.16 ^{NS}
Western 66	-0.09 ^{NS}	-0.39*	0.29*
Sowing periods			
May II FN	0.09 ^{NS}	0.16 ^{NS}	-0.10 ^{NS}
June I FN	0.06 ^{NS}	-0.44***	-0.006 ^{NS}
June II FN	-0.19**	-0.08 ^{NS}	0.32***

$^{\$}$: significance of association between rust severity and climatic variables worked out using Kendall's '*tau*' coefficients denoted by *:$p<0.05$; **:$p<0.01$; ***:$p<0.001$; ^{NS}: not significant

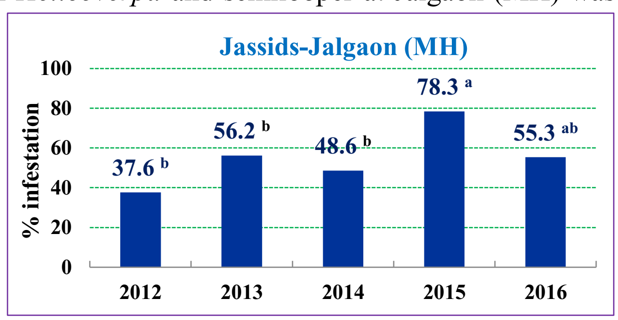
A significant and positive association of the rust severity with increased RF was noted on *cv.* TG 37A and Western 66. With regard to sowing periods, early planting (May IIFN) did not show climatic variability impacting rust severity. For June IFN sowing, the impact of MinT was significantly negative and was non-significant for the June IIFN sowing. Significantly decreasing and increasing rust severity in respect of MaxT and RF were noticed for the sowing period of June IIFN. The varied patterns were noted for the impact of climatic variability on rust severity over seasons, cultivars and sowing periods clearly pointed to the complex interactions of the cultivar-disease-production practices influenced by the observed climatic variability/change. Nevertheless, the suitability of GJG 22 and TLG 45 and sowing during second fortnight of May emerged as the climate resilient cultivars and sowing time, respectively.

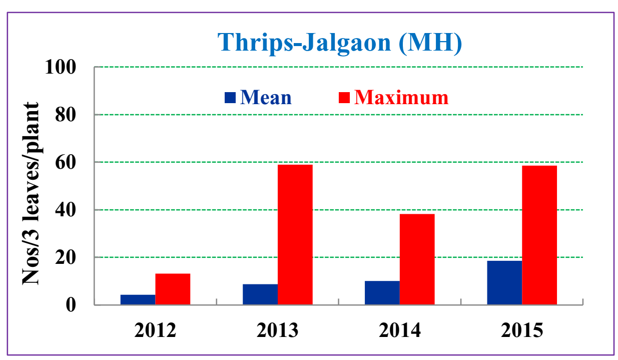
Status of major insects, predators and diseases – half-decadal comparisons

Significantly increasing sap feeders (thrips and jassids), lepidopterous insects (leaf miner and *Spodoptera*) and spiders formed the insect and predator status at Junagadh (GJ). Unchanging but low levels of aphids during 2011-2020, highly reduced aphidophagous and predatory coccinellids during 2016-20 imply a density independent reduction of the later. Among rots, dry root rot alone had increased incidence during 2016-20, the second half of 2011-20 decade. Among foliar diseases, no change instatus for early leaf spot and rust was noted, although late leaf spot had shown increased severity during second half (2016-20) of 2021-20 decade (Annexure XXV).

Jalgaon [Maharashtra (MH)] [ACZ: Western Plateau and Hills Region AER: Deccan plateau aravallis hot semi- arid ecoregion]

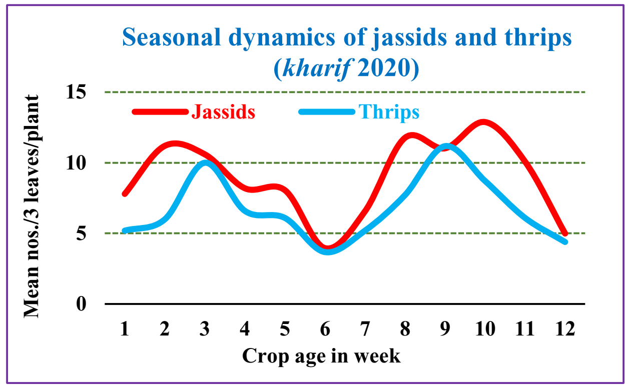
Absence of rains in 2011 leading to non-emergence of *Helicoverpa* and semilooper at Jalgaon (MH) was noted. Higher thrips infestation during *kharif* of 2012 (>70%) and 2013 (>90%), and *rabi* of 2012 (>80%) was seen. In general, the trend of sucking pest severity and peanut bud necrosis virus disease (PBND) transmitted by thrips was at hot semi-arid >arid zones. Higher thrips (*S. dorsalis*) and jassids (*E. kerri*) induced by maximum and minimum temperature above normal throughout the *kharif* combined with low (422 mm in 2015 against normal of 600 mm) and erratic rainfall with frequent dry spells was seen. Increased maximum temperature coupled with reduced rains in 2016 (50-55%) over normal (109 mm) interspersed with at least one dry spell in August contributed to higher jassid infestations. Early and late season dry spells and comparatively high rainfall events amidst crop season during 2014 (refer Annexure IVc) had the increasing population levels of jassids *Empoasca kerri*, thrips *Scirtothrips dorsalis* and leaf miner *Aproaerema modicella*. At Jalgaon (MH), simultaneous occurrence of jassids and thrips with early peak at three weeks and late peaks between eight and ten weeks of crop age (above ETL of 10%) was noted in 2020 with infestations on plant throughout the crop season. Amongst diseases, the order of importance was early leaf spot >rust>dry root rot>collar rot>stem rot and late leaf spot with their dynamics during 2014 associated with the early season higher and late season lower temperatures above and below normal, respectively.





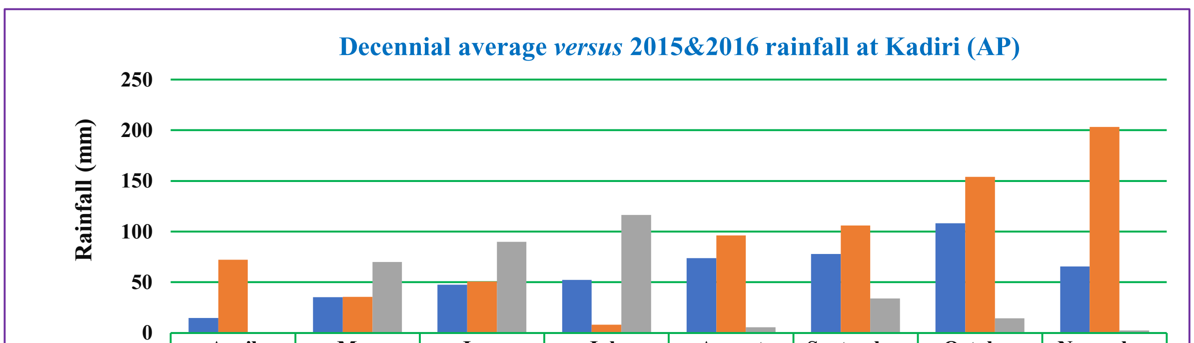
Status of major insects, predators and diseases – half-decadal comparison

Among sap feeders, only jassids had increased infestation during 2016-20. Despite higher infestation level of *Spodoptera* over leaf miner, the later insect had significantly increased infestation during 2016-20 over 2011-15. Temperature based phenology model for predicting establishment and survival of *S. litura* on groundnut during climate change scenario indicated significant increase in activity index and establishment risk index with higher growth in future (2050) climatic conditions compared to the past (2000) indicating the strong suitability for establishment and survival of *S. litura* in India. (Srinivasa Rao and Prasad, 2020). Significant decline of fungal rots (collar rot, dry root rot and stem rot) during 2016-20 over previous five years (2011-15) was noticed. Both coccinellids and spiders had similar mean abundance levels over the decadal period of 2011-20 (Annexure XXVI).



Kadiri [Andhra Pradesh (AP)][ACZ: Southern Plateau and Hills Region AER: Deccan plateau and central highland hot arid ecoregion]

Low rainfall with more and long dry spells during 2011 in September (Sep 3 -13; 22-31), October (13 -23) and November (5-25) resulted in outbreak of leaf miner. The low amount of rainfall in 2014 witnessed the dominance of thrips infestation (28-52%) followed by jassids (20-48 %). Highly reduced rainfall (8.2 mm against decennial average 52.5mm) in July 2015 with frequent dry spells resulted in heavy damage due to thrips (13-47%) and jassids (8-32%). Lower maximum temperature but for August *vis a vis* reduced minimum temperature and rainfall throughout *kharif* than normal during 2011-2016 was the climatic



	April	May	June	July	August	September	October	November
Decennial	14.8	35.3	47.5	52.5	73.9	77.9	108.3	65.7
2015	72.4	35.6	50.8	8.2	96.3	106.2	154	203.4
2016	0	69.9	90.1	116.5	5.7	34.1	14.6	2.4

variability wherein higher infestations of thrips (29-40%) and jassids (21-46%) on groundnut were common. While the frequent dry spells with reduced rains during early season reduced the infestations of thrips and jassids 2011-15, well-distributed rains (542 mm in May-July) favoured significantly higher infestations in 2016.

Impact of climatic variability on jassid infestation

Inter-seasonal variability of jassid infestations was significant and followed the order of 2013 (46.8%)>2014(38.1%)>2011(34.7%) &2016(33.4%)>2012(30.3%)>2015(20.8%). Seasonal variations for weather fluctuations was significant only for maximum temperature (MaxT). Long-term climatic variability had shown significance for both maximum and minimum temperature. Significantly higher maximum temperature (33.3°C) recorded in 2011 was 2.9°C above normal. Lowest maximum temperature was in 2013 and 2012 (29.7 & 30.4°C) that had least increase of 0.02 and 0.69°C, respectively over normal. Minimum temperature (MinT) variability was lowest in 2011 (0.11°C) and on par amongst 2012-16 that had a range of 0.84 to 1.47°C. Impact of weather fluctuations on jassid infestations indicated differences amongst seasons implying maximum temperature fluctuations in particular in combination with other system factors affecting the season-to-season variations in jassid infestations (Table 50).

Table 50. Inter-seasonal variability of jassid infestations, weather and climate at Kadiri (AP)

Variables	2011	2012	2013	2014	2015	2016	F value
Jassid infestation (%)	34.7^{c}	30.3^{d}	46.8^{a}	38.1^{b}	20.8^{e}	33.4^{c}	146.0
Weather fluctuations							
A-MaxT (°C)	33.3^{a}	30.4^{bc}	29.7^{c}	31.5^{b}	30.9^{b}	31.0^{b}	8.5***
A-MinT (°C)	21.3	22.0	22.05	22.6	22.6	22.1	1.4 ^{NS}
A-RF (mm/week)	14.6	24.8	19.6	8.5	22.5	9.1	1.5 ^{NS}
Climatic deviations							
D-MaxT (°C)	2.9^{a}	-0.02^{cd}	-0.69^{d}	1.10^{b}	0.58^{bc}	0.63^{bc}	11.4 ***
D-MinT (°C)	0.11^{b}	0.84^{a}	0.85^{a}	1.37^{a}	1.47^{a}	0.87^{a}	3.9 **
D-RF (mm/week)	-3.80	6.51	1.23	-9.92	4.12	-9.32	1.3 ^{NS}
Kendall's correlation coefficients (r) between jassid infestations and climatic variability							
JDI & MaxT (°C)	-0.10**	0.27***	0.01	-0.28***	-0.12***	0.06	-
JDI & MinT (°C)	-0.09**	0.39***	-0.08	-0.05	-0.29***	0.37***	-
For A &B, means in row followed by the same letter are not significantly different based on DMRT following one way ANOVA; For C, values and significance pertain to correlation between jassid infestations and climatic variability are ** significance of F at p<0.01.; *** significant at p<0.001							

Actual values and quantified variability (deviations from normal) of MaxT (in °C) and MinT (in °C) for 2011-16 period of groundnut cropping season at Kadiri (AP) was 31.1 and 21.1 and 0.76 and 0.92, respectively with deviations being highly significant (Table 51; column:3). Significantly increasing trends of maximum and minimum temperature had negative associations with jassid infestations although Kendall 'tau' was significant for MaxT and non-significant with MinT. This again reiterates that increasing maximum temperature with no significant change in minimum temperature in recent years had a reducing effect on jassid infestations (Table 51).

Table 51. Magnitude of climatic variability and its relation to jassid infestations at Kadiri (AP)

Climatic variables	Actual means of weather (2011-16)	Quantified climatic variability$^{\$}$	Correlation coefficients (tau) $^{@}$
MaxT (°C)	31.1	0.76***	-0.09***
MinT (°C)	22.1	0.92***	-0.01^{NS}
$^{\$}$ climatic variability of 2011-16 calculated over normals of 40 years based on 't' test between actual and deviations of respective weather variables from normals over 2011-16; $^{@}$ values pertain to Kendall correlations between jassid infestations and climatic variability over 2011-16; *** significant at p<0.001			

From pest management perspective, the significant variations across seasons due to short-term weather fluctuations would make jassid infestation forecasts unreliable.

Impact of climatic variability dynamics of thrips, its infestation and disease transmission

Dynamics of abundance, infestation and disease transmission by thrips studied on groundnut over six *kharif* seasons of 2011-16 indicated significantly higher abundance of thrips in 2016 over 2011-15 with infestations on par among 2013, 2014 and 2016 and higher over other seasons. PBND incidence (%) was significantly higher during 2011 and 2014 over 2012, 2013, 2015 and 2016. During 2015 and 2016, significantly lowest PBND incidence was observed (Table 52) possibly due to meagre availability of virus inoculum. Importance of thrips causing direct feeding damage to plants over disease transmission at Kadiri (AP) was inferred through present study.

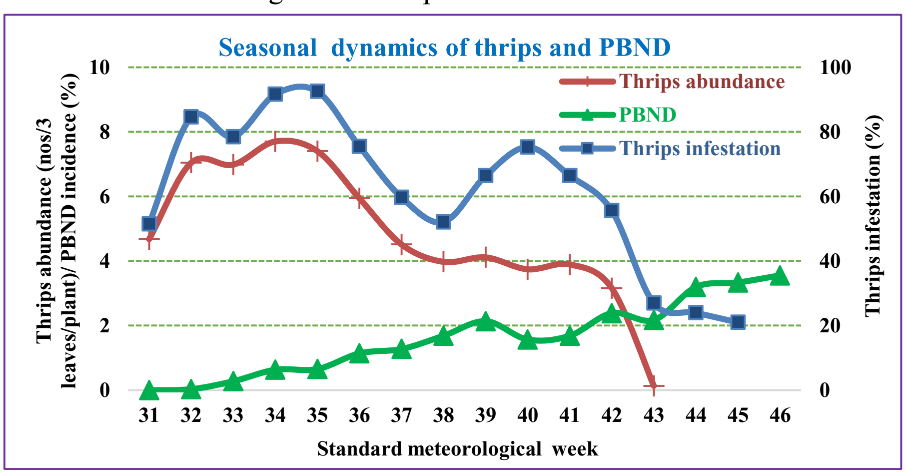
Table 52. Status of thrips abundance, infestation and PBND at Kadiri (AP)

Particulars	Season					
	2011	2012	2013	2014	2015	2016
Thrips (nos/3 leaves/plant)	1.30[b] (1.32)	1.11 [b] (1.25)	1.15[b] (1.26)	1.52[b] (1.39)	1.67[b] (1.39)	3.38[a] (1.96)
Thrips infestation (%)	33.39[b] (0.61)	30.32[b] (0.57)	47.13 [a] (0.75)	49.21[a] (0.77)	29.29[b] (0.56)	42.78[a] (0.71)
PBND incidence (%)	3.43[a] (0.17)	0.53[b] (0.05)	0.63[b] (0.06)	3.47[a] (0.16)	0.02[c] (0.00)	0.03[c] (0.00)

In a row, values followed by the same letters are not significantly different at 5% level of significance based on DMRT; Figures in parentheses are square root transformed values

Tabassum (2014) reported maximum PBND incidence of 8.5% in Anantapur district. Seasonal dynamics pooled over the study seasons (2011- 2016) indicated similar trends of fluctuations of thrips population (nos/3 leaves/plant) and infestation (%) with their peaks during second fortnight of August (34 & 35 SMWs) coinciding with peak vegetative growth phase of groundnut. Occurrence of higher thrips population was during vegetative over flowering stage of groundnut.

High fluctuation in populations of thrips and their infestations over the PBND noted was obvious due to the greater impact of biotic and abiotic factors including weather expected on these two attributes. However, progressively increasing trend of PBND (%) incidence was noted because of the fact that once virus establishes in plants, symptoms are continuous. Nevertheless, fluctuations in PBND within a given season had arisen due to random spot selections for sampling during each week of observation and that PBND plants wither away making unavailable for sampling during subsequent periods. Higher levels of thrips infestations on plants over PBND revealed the significance of direct damage by thrips on groundnut through feeding over their role as vector of PBND.



Relationship between thrips abundance, infestaion and PBND: Simple linear relations quantifying effect of thrips abundance on infestation and of thrips abundance as well as infestation on PBND considering current, one and two lagged values of response variables in each case indicated positive and highly significant associations ($p<0.001$) of thrips population up to three weeks with infestation as well as PBND. Such temporal associations implied direct strong relations of thrips abundance with infestations and PBND, which are manifestations of direct feeding damage and virus transmission, respectively. On the other hand, significance of only the current week infestation with PBND incidence indicated development of PBND within one week of feeding damage (Table 53).

Table 53. Inter-relationships amongst thrips abundance, infestations and PBND at Kadiri (AP)

Particulars	Equation	R^2	Probability of 'F'
Thrips infestation (%)	0.547+ 0.037 *** Thrips abundance	0.25	<.0001
PBND (%)	0.039 + 0.027 *** Thrips abundance	0.20	0.0008
PBND (%)	-0.020+ 0.003 *** Thrips infestation	0.10	0.0033
*** significant at p<0.001 and relations pertain to concurrent observations			

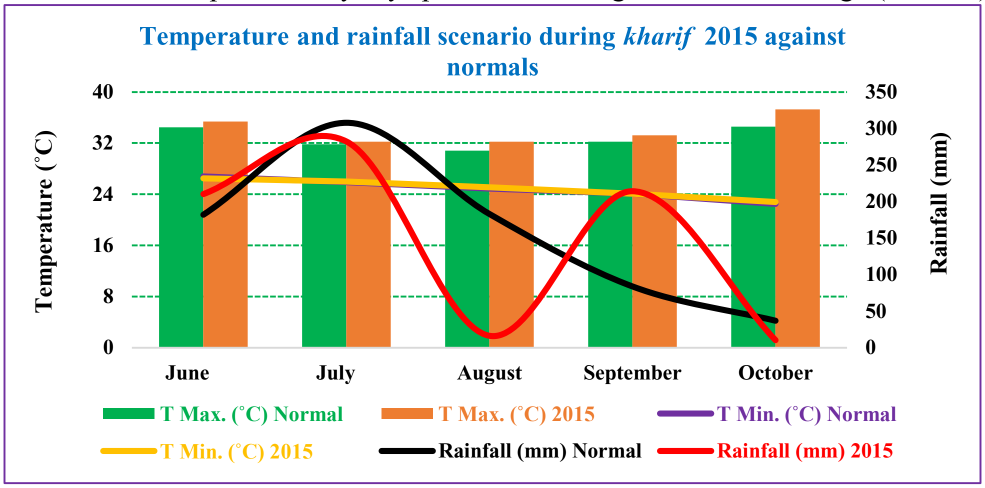
Infestation and PBND are dependent on thrips abundance always. Sowmya Lakshmi (2015) reported that bud necrosis was significantly and positively correlated with thrips population (r=0.67). Present study showed lower R^2 values of 0.10-0.25 for significant relations between any two variables of thrips abundance, infestation and PBND indicating 75-90% variability governed by factors other than weather in groundnut ecosystems. Since thrips are cryptic insects with their distribution within and between plants and fields as well as across seasons and locations highly variable, it is only expected that microclimatic variables to play major role over atmospheric weather, with latter only being used in present study. In groundnut, where crop canopy is close to soil, influence of microclimate on different stages of thrips as well as on development of symptoms of feeding damage and virus infection could override the macro level weather effects.

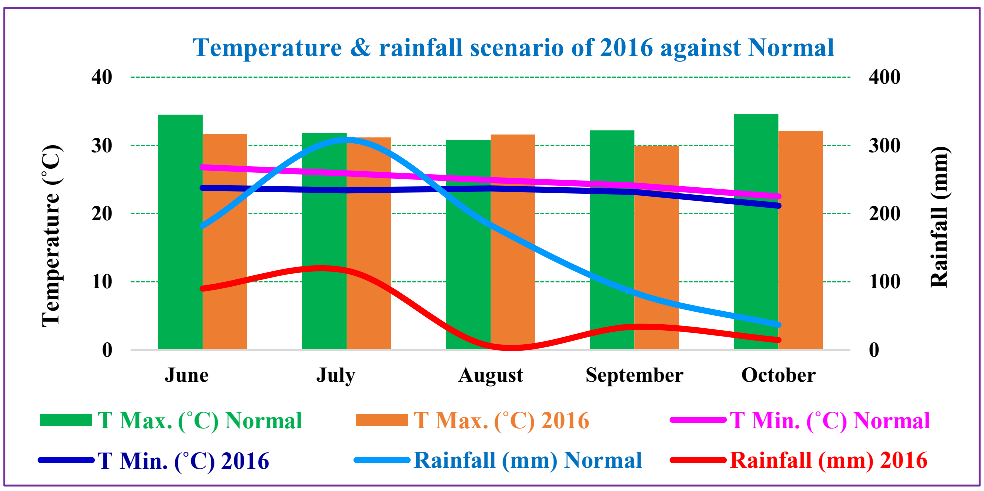
Relation of thrips abundance, infestation and PBND with weather: Weather affects the population build up and expression of symptoms of direct feeding and disease transmission by thrips. Considering period of occurrence of thrips (29- 47 SMW) during *kharif* groundnut season at Kadiri, the calculated climatic variability over 2011 to 2016 signified an increase of 0.75 °C and 0.91°C in MaxT and MinT, respectively besides an estimated decline in mean RF of 1.8 mm per week. Relations of deviations of weather variables with thrips revealed positive effect of increasing minimum temperature on incidence of PBND and negative effect of decreasing rainfall on thrips infestation (Table 54).

Table 54. Effect of climatic variability on thrips abundance, infestation and PBND at Kadiri (AP)

Climatic variable	Actual means of weather (2011-16)	Quantified climatic variability	Kendall's correlation coefficients (r)		
			Thrips abundance (Nos./3leaves/plant)	Thrips infestation (%)	PBND (%)
Max T(°C)	31.2	0.80***	0.001	0.04	0.04
MinT(°C)	22.1	0.92***	-0.12	0.06	0.21**
Rainfall (mm/week)	16.5	-1.9***	-0.02	-0.24**	-0.01
*** significant at p<0.001 based on 't' test; ** significance of 'r' values at p<0.01					

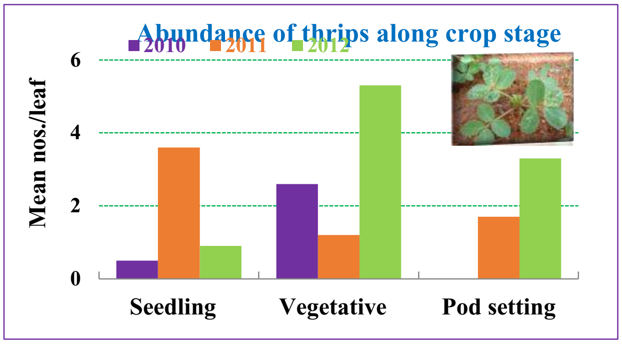
Highly reduced rainfall (8.2 mm against decennial average 52.5mm) in July with frequent dry spells of 2015 that resulted in heavy damage due to thrips (13-47%) and jassids (8-32%). Increased minimum temperature (0.8-3°C) over normal throughout the *kharif* 2015 with cloudy weather and regular rains between August and November subsequent to July dry spells aided in higher *S. litura* damage (18-52%). Occurrence of the leaf miner (*Aproaerama modicella*) was negligible during 2015. Maximum severity of dry root rot (22%) were recorded in 2014 at harvest stage where frequent dry spells with lesser intermittent rains occurred up to end of the season. Severity of foliar diseases *viz.,* rust, early and late leaf spot was higher up to 7-9 scale due to the moderate temperature (< 27 °C mean temperature) and high humidity (>90% MRH) that prevailed from mid-October and November at Kadiri (AP) in 2015 and yield loss due to pests was estimated as 36%. Abnormal rains (203 mm against the normal of 65mm) received during November led to the pre harvest germination of groundnut pods resulting in complete crop failure in about 14,000 hectares in Ananthapuram district in 2015. Highly reduced seasonal rainfall (173 mm) against 396 mm of decennial rainfall in 2016 with six dry spells reduced the groundnut yields with reduced occurrence of insect pests and foliar diseases due to low humidity.

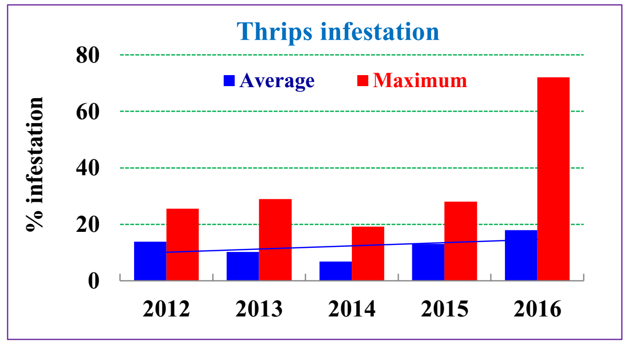


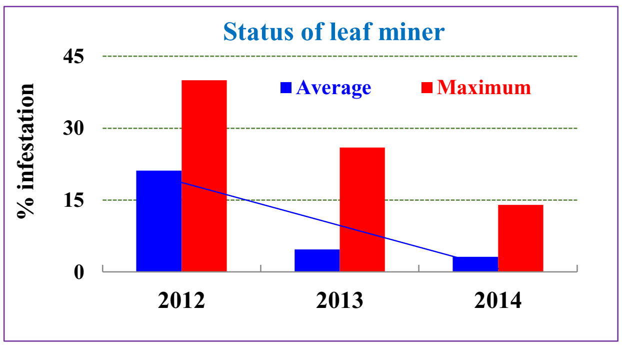


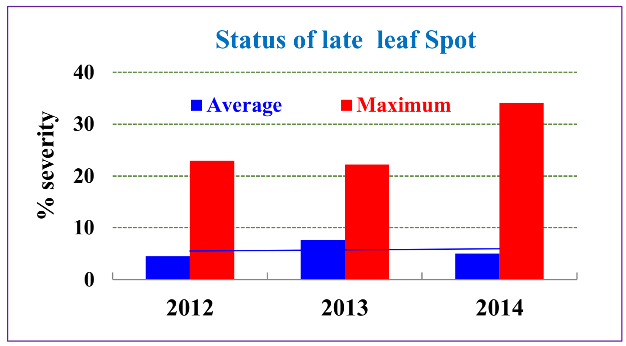
Dharwad [Karnataka (KA)] [ACZ: West Coast Plains and Ghat Region AER: Deccan plateau aravallis hot semi- arid ecoregion]

Thrips severity increased during the vegetative and pod setting stages in 2012 when mean temperature was higher by more than 4 and 5°C during 41 and 42 SMW, respectively. Very low status of insect pests and diseases in general was observed following the highly reduced rainfall of 92, 56 and 55% in respect of July, August and September 2015 over normal and the drought like situation coinciding with the vegetative crop growth. Increasing trend of thrips over seasons starting 2011 was noted with significantly declining MaxT (-1.66 °C) as well as MinT (-2.04 °C) in 2016. Decreasing trend of leaf miner between 2012 and 2014 were seen associated with the increasing rainfall over the seasons (406 mm in 2012 <493 mm in 2013 <635mm in 2014). Higher temperature during pre-monsoon period coupled with delayed rains and late sowing of groundnut followed by continuous rains till October during *Kharif* 2014 saw moderate to high damage due to *Spodoptera litura* (40-50% leaf defoliation) and with leaf miner, *A. modicella* at its low. Increasing late leaf spot (*P. personata*) between 2012 and 2014 were seen associated with the increasing rainfall over the seasons (406 mm in 2012 <493 mm in 2013 <635mm in 2014). Increased peak severity of





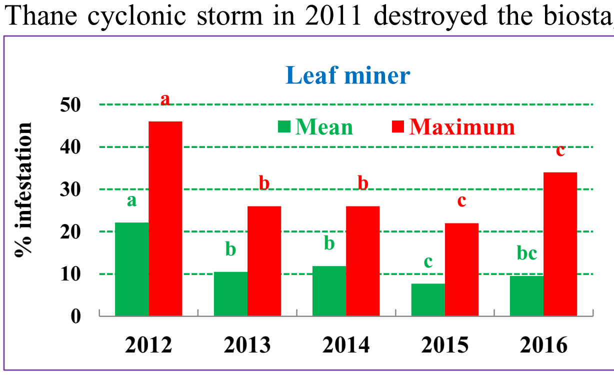


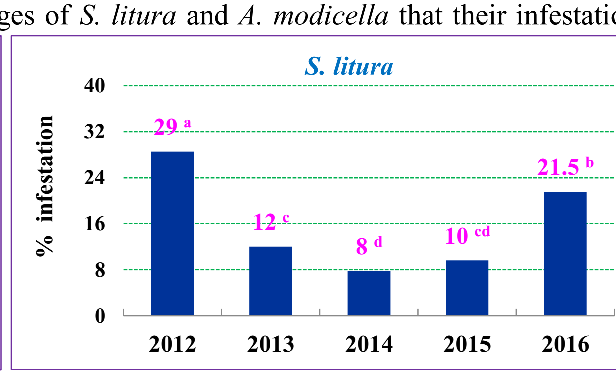


late leaf spot with increasing rainfall at Dharwad (KA) was very clear.

Virudhachalam [Tamil Nadu (TN)] [ACZ: East Coast Plains and Hills Region AER: Eastern coastal plain hot subhumid to semi- arid ecoregion]

Thane cyclonic storm in 2011 destroyed the biostages of *S. litura* and *A. modicella* that their infestations

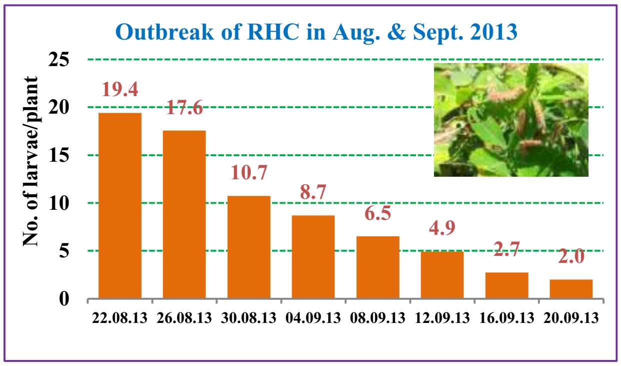


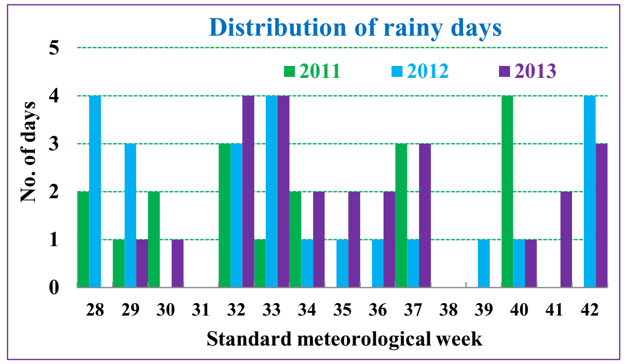


were minimal. Infestation of leaf miner and *S. litura* differed across seasons and was the highest in 2012. Least infestation levels of sap feeders and leaf miner occurred mainly due to the higher regimens of both maximum and minimum temperature from 2013 onwards.

Outbreak of red hairy caterpillar, *Amsacta* spp. for the second successive season (2012 & 2013) at Chinnavadavadi village of Virudhachalam (TN) was noticed from 35 SMW mainly attributable to the receipt of continuous rains during all weeks of August and first fortnight of September (esp. 35 & 36 SMW) besides monocropping of groundnut. The non-outbreak season of 2011 and before did not have rains during 35 and

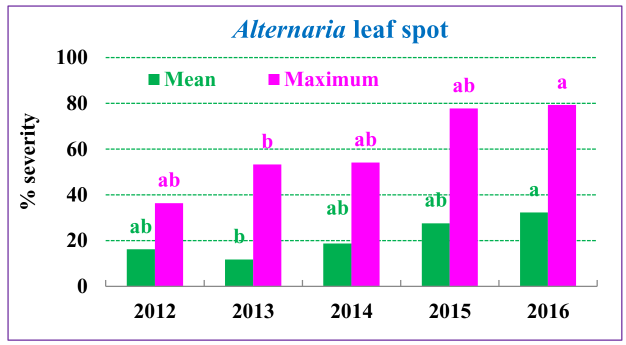
36 SMWs is a notable observation although previous three weeks (32-34 SMW) had rains during all seasons.





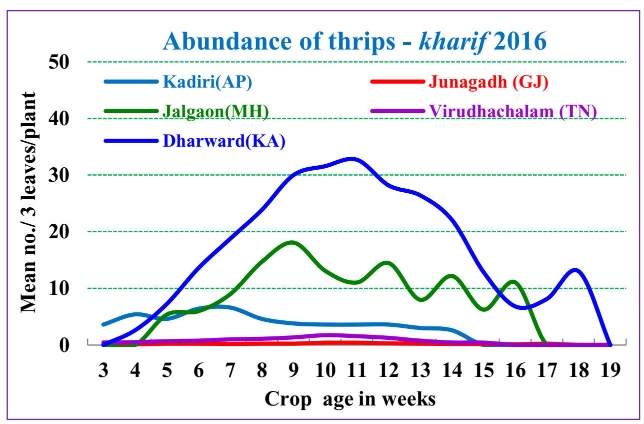
28 SMW too did not have any rains indicating 2013 typically had dry spells followed by rains that could have been conducive for outbreak of red hairy caterpillar.

Severity of *Alternaria* leaf disease had been on the increasing trend with the rainfall amounts of June and July 2016 higher by 2-3 times over normal (122 mm) coinciding with the initial development of the disease in the hot sub humid to semi-arid ecoregion of Virudhachalam (TN). The mean as well as maxiumum severity had exactly similar patterns of differences across study seasons implying the peaks largely determine the seasonal means not accounting the multimodal fluctuations based on random selection of spots in a given field during each time of surveillance that is common for field dynamics of diseases.



Scenario of thrips across groundnut growing locations

The order of importance of thrips across locations: Dharwad (KA)>Jalgaon (MH)>Kadiri (AP)> Virudhachalam (TN)>Junagadh (GJ). Dharwad (KA) and Ja lgaon (MH) are the hot spots where in terms of climatic variability that have the trends of increasing maximum temperature and decreasing/fluctuating minimum temperature. Increasing maximum temperature of the recent periods (2011-16) had a reducing effect on jassid infestation at Kadiri (AP). Jalgaon (MH) and Junagadh (GJ) also had increasing thrips abundance in tune with significantly increasing maximum temperature. At Junagadh (GJ), significantly increasing maximum temperature (0.64*) and rainfall (29.3 mm/week) led to increased thrips infestation.



Inter seasonal variations of insects

The seasonal dynamics of insects in terms of abundance and/or their damage levels in respect of locations for study periods are depicted in graphs along calendar (SMW) and crop age basis (Annexure XXVII). Aphids with significant interseasonal differences were important only at Junagadh (GJ), Jalgaon (MH) and Kadiri (AP). Kadiri (AP) had the highest abundance during 2011 and 2012 over other locations. Jalgaon (MH) and Junagadh (GJ) had significantly higher aphid infestation during 2020.

Table 55. Inter seasonal variations of insects

Insect	Location	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	F-value
Aphids (% infestation)	Junagadh (GJ)	-	5.4^{b}	2.1^{d}	2.1^{bcd}	2.1^{cd}	1.6^{d}	-	4.0^{bc}	4.0^{bc}	11.1^{a}	14.2***
	Jalgaon (MH)	-	5.5^{c}	5.3^{c}	5.3^{c}	5.4^{c}	4.1^{c}	-	-	29.9^{b}	52.1^{a}	244.3**
	Kadiri (AP)	15.2^{a}	15.5 ^{a}	-	-	3.9^{b}	-	-	-	-	-	27.6***
Thrips (% infestation)	Junagadh (GJ)	4.0^{d}	9.7^{cd}	5.8^{cd}	5.9^{cd}	7.9^{bcd}	4.9^{d}	-	17.6^{a}	13.4^{ab}	10.5^{abc}	63.0***
	Jalgaon (MH)	-	83.0^{c}	92.3^{b}	97.5^{a}	99.1^{a}	91.3^{b}	99.7^{a}	87.3^{b}	88.8^{b}	99.3^{a}	19.4***
	Dharwad (KA)	-	33.5^{b}	29.1^{c}	26.9^{d}	34.6^{b}	39.1^{a}	-	-	-	-	48.1*
	Kadiri (AP)	37.6 ^{c}	29.9 ^{d}	47.0 ^{a}	49.1 ^{a}	28.9^{d}	43.9^{b}	-	-	-	-	144.8***
	Virudhachalam	-	29.4 ^{a}	7.06 ^{e}	10.84^{c}	8.85^{d}	13.1 ^{b}	-	-	-	-	157.8**
Thrips (Nos./ 3 leaves /plant)	Junagadh (GJ)	0.4^{bc}	0.8^{ab}	0.34^{c}	0.4^{bc}	0.4^{bc}	0.3^{c}	-	1.3^{a}	1.2^{a}	0.6^{bc}	88.9***
	Jalgaon (MH)	-	5.1^{e}	8.6^{d}	10.0^{c}	18.8^{a}	10.2^{c}	12.3^{b}	13.6^{b}	12.0^{b}	6.9^{d}	35.8***
	Dharwad (KA)	-	12.1^{ab}	9.1^{c}	6.9^{c}	12.5^{b}	19.3 ^{a}	-	-	-	-	12.2***
	Kadiri (AP)	1.5 ^{b}	1.1^{c}	1.1^{c}	1.6^{b}	1.6^{b}	3.6 ^{a}	-	-	-	-	131.9***
	Virudhachalam	-	1.4 ^{a}	0.5^{e}	0.8 ^{c}	0.7^{d}	0.9^{b}	-	-	-	-	39.2***
Jassids (% infestation)	Junagadh (GJ)	4.5^{f}	11.2^{c}	7.8^{de}	6.1^{ef}	7.7^{d}	5.8^{ef}	-	16.0^{a}	12.6^{b}	12.4^{b}	55.7***
	Jalgaon (MH)	-	40.2^{e}	57.5^{d}	48.1^{e}	76.8^{c}	67.5^{c}	99.6^{a}	86.2^{b}	88.6^{b}	99.8^{a}	66.3***
	Dharwad (KA)	-	18.9^{a}	12.4^{ab}	2.0^{c}	9.2^{bc}	8.5^{bc}	-	-	-	-	25.2***
	Kadiri (AP)	35.2 ^{cd}	30.3 ^{d}	46.8 ^{a}	38.1 ^{b}	20.8 ^{e}	33.4 ^{c}	-	-	-	-	149.2**
	Virudhachalam	-	34.5^{a}	7.6^{b}	9.1^{b}	-	2.0 ^{b}	-	-	-	-	232.9***
Jassids (Nos/plant)	Junagadh (GJ)	0.4^{c}	0.9^{a}	0.5^{c}	0.4^{cd}	0.4^{cd}	0.3^{d}	-	1.23^{a}	1.0^{a}	0.7^{b}	69.9***
	Jalgaon (MH)	-	3.5^{e}	2.7^{e}	5.9^{d}	11.9^{bc}	9.4^{c}	11.8^{ab}	12.7^{a}	12.0^{a}	9.1^{c}	86.1***
	Dharwad (KA)	-	1.1^{a}	0.8^{a}	0.0^{b}	0.6^{a}	0.7^{a}	-	-	-	-	27.3***
	Kadiri (AP)	1.3 ^{b}	0.7^{d}	1.2^{b}	1.0^{c}	0.6^{e}	3.0^{a}	-	-	-	-	236.7**
	Virudhachalam	-	0.3	0.6	0.6	-	0.4	-	-	-	-	45.0NS
Leaf miner (% infestation)	Junagadh (GJ)	0.01^{c}	0.5^{b}	0.1^{bc}	0.2^{bc}	0.01^{c}	0.0^{c}	-	8.1^{a}	-	6.4^{a}	120.7**
	Jalgaon (MH)	-	28.5^{de}	28.8^{e}	70.1^{b}	48.9^{cd}	57.8^{bc}	98.6^{a}	42.2^{d}	96.1^{a}	63.5^{b}	69.2***
	Dharwad (KA)	-	19.8^{a}	10.0 ^{c}	8.4 ^{b}	8.4 ^{b}	7.6^{b}	-	-	-	-	54.0***
	Kadiri (AP)	20.0^{a}	1.9 ^{b}	1.0^{b}	1.8^{b}	-	0.5^{b}	-	-	-	-	192.2**
	Virudhachalam	-	22.2^{a}	11.0^{b}	11.9^{b}	7.7^{c}	11.3^{b}	-	-	-	-	158.8**
Leaf miner (Nos./ plant)	Junagadh (GJ)	0.6^{a}	6.8^{a}	2.0^{a}	1.5^{a}	3.3^{a}	2.0^{a}	-	0.5^{a}	-	0.2^{a}	8.7***
	Jalgaon (MH)	-	0.1^{d}	0.4^{bc}	0.4^{bc}	0.4^{bc}	0.3^{c}	0.4^{bc}	0.3^{c}	2.7^{a}	0.6^{b}	122.6***
	Dharwad (KA)	-	1.2^{b}	0.5^{d}	0.5^{d}	0.6^{bc}	0.6^{b}	-	-	-	-	56.6***
	Kadiri (AP)	1.1 ^{c}	45.7 ^{a}	30.0 ^{b}	26.6 ^{b}	43.3 ^{a}	5.3 ^{c}	-	-	-	-	379.3**
	Virudhachalam	-	0.3^{e}	0.9^{a}	0.9^{b}	0.6^{d}	0.8^{c}	-	-	-	-	121.9**
Spodoptera (% infestation)	Junagadh (GJ)	6.0^{c}	0.03^{d}	0.01^{d}	0.01^{d}	0.01^{d}	0.01^{d}	-	14.9^{a}	10.2^{b}	12.2^{ab}	709.5***
	Jalgaon (MH)	-	90.7^{b}	82.8^{bc}	65.0^{e}	78.9^{cd}	74.8^{d}	98.7^{a}	43.7^{f}	96.2^{a}	99.4^{a}	62.3***
	Kadiri (AP)	15.2 ^{a}	0.0 ^{b}	0.04 ^{b}	0.02 ^{b}	0.06 ^{b}	-	-	-	-	-	286.3**
	Virudhachalam	-	29.1^{a}	13.5^{c}	9.2 ^{e}	11.6 ^{d}	23.1 ^{b}	-	-	-	-	184.03**
Spodoptera (No./3 leaves /plant)	Junagadh (GJ)	0.5^{b}	0.05^{bc}	0.03^{bcd}	0.02^{cd}	0.02^{d}	0.03^{cd}	-	0.10^{a}	0.05^{bc}	0.05^{bc}	25.8***
	Jalgaon (MH)	-	0.1^{c}	0.08^{cde}	0.01^{cd}	0.06^{de}	0.25^{b}	0.05^{de}	0.04^{e}	0.3^{a}	0.3^{ab}	50.9***
	Kadiri (AP)	0.01^{c}	0.05^{b}	0.01^{c}	0.11^{a}	0.01^{c}	-	-	-	-	-	73.3***
	Virudhachalam	-	0.04^{d}	0.11^{a}	0.07 ^{b}	0.06^{c}	0.07^{b}	-	-	-	-	65.9***
RHC (No./plant)	Junagadh (GJ)	-	0.07^{b}	-	0.4^{a}	0.02^{b}	-	-	0.08^{b}	0.02^{bc}	0.02^{b}	7.4***
	Jalgaon (MH)	-	0.1^{a}	0.1^{a}	0.1^{a}	0.1^{a}	0.1^{a}	-	-	-	-	0.2^{NS}
	Kadiri (AP)	0.1 ^{a}	0.1 ^{a}	0.1 ^{a}	0.1 ^{a}	0.03 ^{a}	0.1 ^{a}	-	-	-	-	2.6*
H. armigera (Nos.larvae /plant)	Junagadh (GJ)	0.1^{b}	0.1^{bc}	0.02^{d}	0.02^{d}	0.02^{d}	0.03^{cd}	-	0.1^{a}	0.04^{bcd}	0.04^{bcd}	52.0***
	Jalgaon (MH)	-	0.1^{ab}	0.1^{b}	0.1^{b}	0.1^{ab}	0.2^{a}	-	-	-	-	4.5**
	Dharwad (KA)	-	0.1^{a}	0.1^{ab}	0.02 ^{c}	0.1^{b}	0.1^{b}	-	-	-	-	25.1***
	Kadiri (AP)	0.1^{d}	0.1^{d}	0.1^{d}	0.1^{dc}	0.1^{b}	0.3^{a}	-	-	-	-	402.9**
	Virudhachalam	-	0.2^{a}	0.04^{a}	0.02^{a}	0.2^{a}	0.1^{a}	-	-	-	-	5.8***
Semilooper (Nos.larvae /plant)	Junagadh (GJ)	-	0.04^{a}	0.02^{a}	-	0.02^{a}	-	-	0.03^{a}	-	0.02^{a}	0.5^{NS}
	Jalgaon (MH)	-	0.1^{ab}	0.1^{a}	0.1^{a}	0.1^{b}	0.04^{b}	-	-	-	-	6.5***
	Dharwad (KA)	-	0.14^{a}	0.1^{ab}	0.02^{c}	0.1^{bc}	-	-	-	-	-	33.0***
	Kadiri (AP)	-	0.1 ^{a}	-	0.04^{a}	-	-	-	-	-	-	2.5^{NS}
	Virudhachalam	-	-	0.03	0.02	-	-	-	-	-	-	1.7 ^{NS}
Coccinellid beetles (No./plant)	Junagadh (GJ)	-	1.5^{a}	-	0.2^{b}	0.3^{b}	-	-	0.6^{b}	-	0.3^{b}	25.1***
	Jalgaon (MH)	-	1.4^{a}	1.3^{a}	1.9^{a}	2.7^{a}	1.8^{a}	-	-	-	-	2.1^{NS}
	Dharwad (KA)	-	1.2^{a}	0.9^{b}	0.9^{b}	1.2 ^{a}	1.3^{a}	-	-	-	-	27.0***
	Kadiri (AP)	0.8^{c}	3.3^{a}	1.3^{b}	0.8^{c}	0.4^{d}	0.4^{d}	-	-	-	-	144.8***
	Virudhachalam	-	0.7^{a}	0.3^{b}	0.4^{b}	0.5^{ab}	0.6^{ab}	-	-	-	-	6.1***
Spiders (No./plant)	Junagadh (GJ)	0.4^{bc}	0.3^{bc}	0.2^{c}	0.2^{c}	0.2^{c}	0.2^{c}	-	0.8^{a}	0.4^{bc}	0.5^{b}	64.5***
	Jalgaon (MH)	-	2.0^{a}	1.3^{b}	-	1.3^{b}	1.5^{b}	-	-	-	-	3.0*
	Dharwad (KA)	-	1.2^{b}	1.2^{c}	1.1^{bc}	1.4 ^{a}	1.5^{a}	-	-	-	-	23.4***
	Kadiri (AP)	0.7^{a}	0.2 ^{c}	0.4^{abc}	0.5^{abc}	0.5^{abc}	0.3^{bc}	-	-	-	-	29.6***
	Virudhachalam	-	0.4^{c}	0.3^{d}	0.4^{c}	0.5^{b}	0.7^{a}	-	-	-	-	67.6***

In a row, means followed by the same letter are not significantly different with significance of 'F' denoted by *: $p < 0.05$; $p<0.01$; ***: $p < 0.001$. ^{NS}: non-significant based on oneway ANOVA; - indicate data not available or absence of insects; analysis done following (X+1) square root transformed values

Prediction of *A. craccivora* for eleven groundnut cultivating locations that are inclusive of current study locations revealed reduced generation time and hence more number of generations (Srinivasa Rao *et.al.,* 2017) . Thrips in terms of abundance and infestation had been higher at Jalgaon (MH) during all study seasons. Dharwad (KA) had significantly higher thrips in 2016. At Kadiri (AP) the higher population of thrips was noted in 2013 and 2014 (Vennila *et al*., 2018d). Virudachalam (TN) had significantly lesser thrips between 2013 and 2016. Jalgaon (MH) was the hot spot with increasing trends of jassids during last six years (2015-2020). Kadiri (AP) was second in rank for jassid infestation on groundnut (Vennila *et al.,* 2019d). But for 2012, jassids were not a pest of significance at Virudhachalam (TN). Kadiri (AP) had higher levels of jassids over Dharwad (KA) despite situated in same agroclimatic zone. Leaf miner abundance and infestation were the highest during 2019 at Jalgaon (MH). Jalgaon (MH)>Kadiri (AP)>Virudhachalam (TN)>Dharwad (KA)> Junagadh (GJ) was the order of leaf miner importance across locations. Despite very low levels of *Spodoptera*, the damage levels were highly obvious at Jalgaon (MH) and Virudhachalam (TN). Based on moth catches (Girish *et al.,* 2016; 2017; Vennila *et al.,* 2017), other lepidopternan insects *viz.,* red hairy caterpillar and *Helicoverpa* were occasional in occurrence but always at very low levels but for the outbreak of red hairy caterpillar at Virudhachalam (TN) during 2012 and 2013. Jalgaon (MH) had higher population of coccinellids (no. /plant) during all seasons over other locations concomitant with the higher levels of sucking insects (aphids, jassids and thrips) (Table 55). While Dharwad (KA) had significantly higher coccinellids in 2012, 2015 and 2016, Kadiri (AP) had the highest coccinellid during 2012 and 2013 to 2016 over 2011. Significantly, higher spiders at Jalgaon (MH) in 2012 and during 2015 and 2016 at Dharwad (KA) over other seasons were seen. Although interseasonal variations could be noticed across all locations, the general mean poluation of spiders were lower at Junagadh (GJ), Kadiri (AP) and Virudhachalam (TN).

Inter seasonal variations of diseases

The disease progressive curves along calendar (SMW) and crop age basis in respect of locations for study periods are graphically presented in Annexure XXVI. Overall, the inter seasonal variations were significant for all diseases and at all locations but for stem rot at Junagadh (GJ). Collar and stem rots were endemic at Junagadh (GJ) with seasonal differences observed only for former, being highest during 2012 and 2018. At Kadiri (AP), collar rot was significantly high during 2013 followed by 2014 and 2012. Virudhachalam (TN) had sporadic occurrence of stem rot as against regular collar rot incidence that was significantly higher during 2016 on par with 2012. Significantly higher dry root rot at Jalgaon (MH) during early years (2011-2015) and *vice versa* at Junagadh (GJ) was noted. Kadiri (AP) had the highest dry root rot incidence during 2015 over previous four seasons (2011-2014). Inter seasonal differences for all foliar disieases were significant across at all locations. Junagadh (GJ)>Kadiri (AP)>Jalgaon (MH) for early and late leaf spot was noted. While the severity of early and late leaf spots were similar at Jalgaon (MH), higher severity of early over late leaf spot was observed at Junagadh (GJ). Late and *Alternaria* leaf spots were of higher significance at Virudhachalam (TN). On the otherhand, early leaf spot significance was relatively higher at Kadiri (AP) from among the three southern states. *Alternaria* leaf spot at Kadiri (AP) was recorded only during 2011 and 2013 and did not appear in other study seasons since 2014. Declining rust severity both at Junagadh (GJ) and Jalgaon (MH) and *vice versa* at Virudhachalam (TN) and Dharwad (KA) was the scenario. While rust was endemic at Jalgaon (MH), its occurrence was nil at Virudhachalam (TN) after 2016. While PBND and PSND were regular at Kadiri (AP) upto 2014, only PBND was important at Jalgaon (MH) with declining status over increasing years (Table 56).

Table 56. Inter seasonal variations of diseases

Disease	Locations	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	F-value
Collar rot (% Incidence)	Junagadh (GJ)	-	8.1^{a}	2.4^{d}	2.7^{cd}	3.2^{cd}	2.9^{cd}	-	8.4^{a}	5.4^{b}	3.7^{c}	32.7***
	Kadiri (AP)	5.6^{c}	6.5^{bc}	10.6^{a}	8.1^{b}	5.3^{c}	6.0^{bc}	-	-	-	-	13.4***
	Virudhachalam	-	3.9^{d}	4.7^{cd}	5.1^{c}	8.1^{b}	10.4^{a}	-	-	-	-	54.5***
Stem rot (% Incidence)	Junagadh (GJ)	4.1	9.7	3.2	3.0	3.3	2.9	-	11.5	3.7	2.0	0.7^{NS}
	Jalgaon (MH)	-	20.1^{a}	7.2^{c}	6.3^{c}	5.3^{cd}	3.6^{d}	-	3.3^{d}	-	11.5^{b}	33.9***
	Kadiri (AP)	4.2^{c}	8.1^{b}	12.7^{a}	-	9.4^{b}	-	-	-	-	-	33.5***
	Virudhachalam	-	10.0^{a}	3.8^{b}	-	-	11.5^{a}	-	-	-	-	68.9***
Dry root rot (% Incidence)	Junagadh (GJ)	2.0^{c}	4.1^{bc}	2.0^{c}	-	-	-	-	9.6^{a}	8.0^{ab}	-	11.0***
	Jalgaon (MH)	-	10.7^{ab}	8.6^{ab}	10.3^{ab}	8.4^{ab}	2.4^{c}	2.0^{c}	2.8^{c}	5.1^{bc}	12.1^{a}	18.3***
	Kadiri (AP)	4.1^{c}	11.0^{b}	12.9^{b}	8.0^{bc}	21.0^{a}	-	-	-	-	-	94.7***
Early leaf spot (% Severity)	Junagadh (GJ)	43.6^{a}	22.9^{cd}	23.5^{cd}	26.7^{b}	20.0^{d}	24.9^{bc}	-	12.0^{e}	20.2^{d}	25.8^{bc}	30.6***
	Jalgaon (MH)	-	23.1^{b}	24.7^{b}	21.0^{bc}	14.7^{d}	16.6^{cd}	14.4^{d}	16.3^{cd}	4.4^{e}	31.9^{a}	32.6***
	Dharwad (KA)	-	12.4^{c}	16.3^{b}	19.0^{a}	-	19.5^{a}	-	-	-	-	35.9***
	Kadiri (AP)	25.0^{b}	34.2^{a}	27.2^{ab}	-	28.9^{ab}	-	-	-	-	-	3.0*
	Virudhachalam	-	-	8.9^{b}	-	-	29.4^{a}	-	-	-	-	31.9***
Late leaf spot (% Severity)	Junagadh (GJ)	34.5^{a}	20.2^{c}	19.7^{c}	25.0^{b}	20.2^{c}	15.6^{d}	-	15.9^{d}	33.6^{a}	31.7^{a}	39.0***
	Jalgaon (MH)	-	26.7^{c}	33.1^{b}	9.9^{g}	11.9^{fg}	15.1^{ef}	14.3^{ef}	17.1^{de}	22.0^{cd}	43.9^{a}	44.6***
	Dharwad (KA)	-	18.5^{b}	17.7^{b}	17.9^{b}	-	23.6^{a}	-	-	-	-	51.1***
	Kadiri (AP)	29.8^{b}	52.5^{a}	35.6^{b}	29.5^{b}	27.3^{b}	-	-	-	-	-	26.1***
	Virudhachalam	-	39.0^{c}	36.9^{c}	35.4^{c}	48.7^{b}	55.8^{a}	-	-	-	-	28.3***
Alternaria leaf spot (% Severity)	Junagadh (GJ)	4.4^{d}	13.4^{bc}	-	-	13.6^{bc}	-	-	9.9^{c}	21.6^{a}	19.1^{ab}	13.5***
	Jalgaon (MH)	-	18.5^{a}	11.5^{ab}	13.0^{ab}	12.6^{ab}	8.9^{bc}	13.7^{ab}	14.0^{ab}	4.4^{c}	-	7.2***
	Kadiri (AP)	24.0^{a}	-	15.4^{b}	-	-	-	-	-	-	-	14.7***
	Virudhachalam	-	22.7^{d}	29.5^{c}	22.9^{d}	43.7^{b}	49.5^{a}	-	-	-	-	167.5**
Rust (% Severity)	Junagadh (GJ)	49.4^{a}	35.1^{b}	31.5^{bc}	20.8^{de}	19.4^{e}	26.1^{cd}	-	-	25.4^{de}	33.8^{b}	18.1***
	Jalgaon (MH)	-	25.3^{a}	23.6^{a}	14.8^{ab}	16.0^{ab}	11.9^{b}	13.4^{b}	14.9^{ab}	15.6^{ab}	4.4^{c}	14.2***
	Dharwad (KA)	-	18.7^{a}	-	4.4^{b}	-	21.4^{a}	-	-	-	-	44.9***
	Kadiri (AP)	25.1^{b}	45.8^{a}	19.6^{b}	-	25.2^{b}	-	-	-	-	-	44.8***
	Virudhachalam	-	21.3^{c}	18.9^{c}	38.2^{b}	-	56.4^{a}	-	-	-	-	63.5***
PBND (% Incidence)	Jalgaon (MH)	-	15.7^{a}	5.7^{bc}	4.9^{bc}	5.8^{b}	4.0^{c}	2.2^{d}	4.0^{c}	4.4^{c}	-	40.7***
	Kadiri (AP)	4.19^{a}	2.41^{b}	2.74^{b}	4.76^{a}	-	-	-	-	-	-	31.51**
PSND	Kadiri (AP)	9.0^{b}	3.3^{e}	7.2^{c}	10.1^{a}	6.9^{c}	4.5^{d}	-	-	-	-	93.2***

In a row means followed by the same letter are not significantly different with significance of 'F' denoted by *: $p < 0.05$,; $p<0.01$; ***: $p < 0.001$. ^{NS}: non-significant based on one way ANOVA; - indicate data not available or absence of disease(s); analysis performed after appropriate transformations; given values are the original means

Magnitude of climate change among five groundnut growing ACZ

Groundnut growing study locations had shown significant change for MaxT but for decline by 1.34 ˚C at Dharwad (KA) and increase by 0.63 to 1.92˚C at other locations. Anantapur (AP) alone had significantly increasing MinT by 0.91˚C with Dharwad (KA) and Virudhachalam (TN) had reduced MinT. Non signicance for change of MinT at Junagadh (GJ) got reflected in MeanT also. While Anantapur (AP) and Dharwad (KA) had decreasing rainfall, increase was noted at Junagadh (GJ) and Virudhachalam (TN). Jalgaon (MH) alone did not show significant change for rainfall. Decrease in rainfall during groundnut season was significant at Anantapur (AP) and Dharwad (KA). Junagadh (GJ) and Virudhachalam (TN) had significantly increasing rainfall (Table 57).

Table 57. Magnitude of climate change among study locations

Location	A-MaxT	D-MaxT	A-MinT	D-MinT	A-MeanT	D-MeanT	A-RF	D-RF
Junagadh (GJ)	33.5	0.63*	24.1	-0.45 NS	28.8	0.09 NS	41.7	12.4***
Jalgaon (MH)	32.7	1.45***	21.2	-0.08 NS	26.9	0.68***	31.8	7.3 NS
Dharwad (KA)	28.3	-1.34***	19.5	-1.87***	23.8	-1.6***	22.5	-5.15***
Kadiri (AP)	31.2	0.75***	22.1	0.91***	26.6	0.83***	16.5	-1.8***
Virudhachalm(TN)	36.2	1.92***	24.9	-0.36*	30.5	0.77***	37.0	11.3***

A is actual weather and D is the climatic deviations over 2011-16; units of climatic variables are : MaxT (˚C), MinT (˚C) & RF (mm/week); $Significance of CV is based on the 't' test : *: p < 0.05, **:p<0.01, ***: p < 0.001, NS Non significant ***: p<0.001; Values in bole are the significant change of the respective climatic variable

Inter seasonal variability for actual weather and climatic deviations

Jalgaon (MH) and Virudhachalam (TN) had significance for A-MaxT and A-MinT with all other locations on par for rainfall across seasons. A-MaxT alone had seasonal differences at Junagadh (GJ), Kadiri (AP) and Dharwad (KA). Seasons 2013 and 2015 were significantly different for A-MaxT at Jalgaon (MH), with A-MinT on par for 2015 and 2016, with 2016 on par with 2011-2014. Highest A-MaxT (34.6˚C) at Junagadh (GJ) was on par with 2011-2012 & 2014 and other seasons *viz.,* 2013 & 2016 on par with 2011. 2011>2012, 2014-2016>2013 was noted for A-MaxT at Kadiri (AP). Dharwad (KA) had the highest A-MaxT (29.7 ˚C) in 2015 over other seasons (2011-2014 and 2016) that were on par. Increased A-MinT (25.6 ˚C) slightly higher during 2013-2016 over 2011 and 2012 was noted at Virudhachalam (TN) (Table 58).

All *kharif* groundnut growing study locations had both D-MaxT and D-MinT differing amongst seasons but for Dharwad (KA) where D-MinT differences were non significant. D-MaxT increase by 3.14˚C in 2015 and of 4.2˚C in 2012 were recorded for Jalgaon (MH) and Virudhachalam (TN), respectively. D-MinT increased by 0.84-1.47˚C between 2012 and 2016 significantly higher over 2011 at Kadiri (AP). D-MaxT also increased at Kadiri (AP) with the lowest increase of D-MinT (0.11˚C) in 2011. D-MinT had negative as well as positive changes amongst seasons at Jalgaon (MH), Junagadh (GJ) and Virudhachalam (TN). Dharwad (KA) alone had no significant change for D-MinT amongst seasons with reductions over normal ranging between 1.24 and 2.1˚C. No significant change for rainfall existed at all locations of *kharif* groundnut.

Table 58. Inter seasonal variability based on actual weather and climatic deviations

Location/Weather	2011	2012	2013	2014	2015	2016	F values$
Junagadh (GJ)							
A-Max T	33.2^{abc}	34.3^{ab}	32.3^{c}	33.9^{ab}	34.6^{a}	32.8^{bc}	2.52*
A-Min T	24.7	24.3	24.4	23.1	24.5	23.6	1.67^{NS}
A-RF	40.1	17.6	63.4	51.4	30.5	46.8	1.36^{NS}
D-MaxT	0.37^{bc}	1.44^{a}	-0.60^{d}	0.99^{ab}	1.70^{a}	-0.07^{cd}	7.05***
D-MinT	0.16^{a}	-0.24^{a}	-0.09^{a}	-1.49^{b}	-0.08^{a}	-0.99^{b}	8.11***
D-RF	10.8	-11.6	34.1	22.1	1.32	17.6	1.30^{NS}
Jalgaon (MH)							
A-Max T	32.8^{bc}	32.8^{bc}	31.3^{d}	33.1^{ab}	34.4^{a}	31.7^{cd}	5.11***
A-Min T	20.2^{b}	21.1^{b}	19.9^{b}	20.9^{b}	23.2^{a}	21.6^{ab}	2.62*
A-RF	30.2	18.4	45.6	42.7	17.4	36.2	0.74^{NS}
D-MaxT	1.56^{b}	1.56^{b}	0.06^{c}	1.89^{b}	3.14^{a}	0.51^{c}	9.72***
D-MinT	-1.0^{cd}	-0.18^{bc}	-1.34^{d}	-0.30^{bc}	1.98^{a}	0.33^{b}	10.49***
D-RF	5.84	-5.96	21.19	18.31	-6.99	11.83	1.45^{NS}
Dharwad (KA)							
A-Max T	28.2^{b}	28.2^{b}	27.4^{b}	28.0^{b}	29.7^{a}	27.9^{b}	3.95***
A-Min T	19.2	19.2	19.2	19.3	20	19.2	0.60^{NS}
A-RF	27.2	19.4	23.5	31.8	15.1	18.8	0.80^{NS}
D-MaxT	-1.34^{b}	-1.44^{b}	-2.20^{c}	-1.58^{bc}	0.10^{a}	-1.66^{bc}	8.44***
D-MinT	-2.03^{b}	-2.04^{b}	-2.10^{b}	-1.96^{ab}	-1.24^{a}	-2.04^{b}	1.57^{NS}
D-RF	-0.21	-7.96	-3.93	4.41	-12.27	-9.05	1.00^{NS}
Kadiri (AP)							
A-Max T	33.3^{a}	30.4^{bc}	29.7^{c}	31.5^{b}	30.9^{b}	31.0^{b}	8.52***
A-Min T	21.3	22	22	22.5	22.6	22	1.41^{NS}
A-RF	14.5	24.8	19.6	8.4	22.5	9.06	1.43^{NS}
D-MaxT	2.93^{a}	-0.02^{cd}	-0.69^{d}	1.10^{b}	0.58^{bc}	0.63^{bc}	11.4***
D-MinT	0.11^{b}	0.84^{a}	0.85^{a}	1.37^{a}	1.47^{a}	0.87^{a}	3.87**
D-RF	-3.8	6.51	1.23	-9.92	4.12	-9.32	1.26^{NS}
Virudhachalam (TN)							
A-Max T	37.6^{a}	38.4^{a}	34.8^{b}	34.9^{b}	35.5^{b}	35.6^{b}	10.2***
A-Min T	23.8^{b}	23.8^{b}	25.0^{a}	25.5^{a}	25.6^{a}	25.6^{a}	11.3***
A-RF	61.3^{a}	45.9^{ab}	44.8^{ab}	29.2^{ab}	25.0^{b}	15.3^{b}	0.49^{NS}
D-MaxT	3.42^{a}	4.20^{a}	0.60^{b}	0.63^{b}	1.28^{b}	1.40^{b}	18.7***
D-MinT	-1.45^{c}	-1.48^{c}	-0.25^{b}	0.29^{ab}	0.35^{a}	0.37^{a}	19.2***
D-RF	35.7	20.3	19.2	3.63	-0.55	-10.32	1.96^{NS}

A is actual weather and D is the climatic deviations over 2011-16; units of climatic variables are: MaxT (˚C), MinT (˚C) & RF (mm/week); In a row, means followed by the same letter are not significantly different with significance of 'F' denoted by *: $p < 0.05$; $p<0.01$; ***: $p < 0.001$. ^{NS}: non-significant based on one way ANOVA

Influence of individual climatic variables on insects and diseases

Effect of increasing MaxT and unchanging MinT was significantly poisitive for jassid abundance at Jalgaon (MH), although unchanging rain had a significant and negative impact. The impact of changing climatic variables was different on jassid population and crop response measured as infestation. The significantly increasing MaxT at Kadiri (AP) and Virudhachalam (TN) had reducing and increasing effects, respectively on jassid infestation. The reducing MinT at Virudhachalam (TN) affected jaasid infestation negatively. Between the significantly declining MaxT and MinT at Dharwad (KA), MaxT alone had shown negative impact on jassid abundance. Significantly increasing MaxT did not have any significant association with jassids although the non-significant but declining MinT had significant and positive association with jassid infestation and abundance at Junagadh (GJ) (Table 59).

Table 59. Impact of individual climate variables on insects and diseases

Insect/Disease	Location	Mean	D-MaxT	D-MinT	D-RF
Jassids (No/Plant)	Junagadh (GJ)	0.42	0.06 ^{NS}	0.21**	-0.04 ^{NS}
	Jalgaon (MH)	6.22	0.18*	0.27**	-0.14$^{\$}$
	Dharwad (KA)	0.76	-0.23*	-0.09^{NS}	-0.07 ^{NS}
	Kadiri (AP)	1.20	0.06 ^{NS}	0.03 ^{NS}	-0.07 ^{NS}
	Virudhachalam (TN)	0.85	-0.15^{NS}	0.13^{NS}	0.01^{NS}
Jassids (% Infestation)	Junagadh (GJ)	6.93	0.05^{NS}	0.25***	-0.007 ^{NS}
	Jalgaon (MH)	56.27	0.14$^{\$}$	0.10^{NS}	-0.11^{NS}
	Dharwad (KA)	11.57	-0.16 ^{NS}	-0.14 ^{NS}	-0.28**
	Kadiri (AP)	33.43	-0.14$^{\$}$	0.01 ^{NS}	-0.06 ^{NS}
	Virudhachalam (TN)	18.26	0.52***	-0.24*	-0.06 ^{NS}
Aphids (% infestation)	Junagadh (GJ)	2.51	0.08 ^{NS}	0.15 ^{NS}	-0.09 ^{NS}
	Jalgaon (MH)	5.17	0.02^{NS}	0.14 ^{NS}	-0.02 ^{NS}
	Virudhachalam (TN)	8.88	-0.01^{NS}	-0.07 ^{NS}	0.06 ^{NS}
Thrips (Nos./3 leaves/plant)	Junagadh (GJ)	0.39	0.09 ^{NS}	0.08 ^{NS}	-0.08^{NS}
	Jalgaon (MH)	10.42	0.23**	0.27**	-0.10^{NS}
	Dharwad (KA)	11.01	0.03^{NS}	0.16*	-0.12 ^{NS}
	Kadiri (AP)	1.91	0.22**	0.15*	-0.07^{NS}
	Virudhachalam (TN)	0.73	0.01^{NS}	-0.10 ^{NS}	0.06^{NS}
Thrips (% infestation)	Junagadh (GJ)	6.37	0.21**	0.14*	-0.15*
	Jalgaon (MH)	90.28	0.05^{NS}	0.02^{NS}	0.02 ^{NS}
	Dharwad (KA)	29.96	-0.04 ^{NS}	0.08^{NS}	-0.17*
	Kadiri (AP)	38.50	-0.08^{NS}	0.06^{NS}	-0.14^{NS}
	Virudhachalam (TN)	12.15	0.16*	-0.14$^{\$}$	0.03 ^{NS}
Leaf miner (Nos./plant)	Junagadh (GJ)	3.86	-0.10 ^{NS}	0.22$^{\$}$	0.02^{NS}
	Jalgaon (MH)	0.31	-0.04 ^{NS}	0.06 ^{NS}	0.13^{NS}
	Dharwad (KA)	0.66	-0.21*	-0.09 ^{NS}	-0.01^{NS}
	Kadiri (AP)	0.93	0.26**	-0.08^{NS}	-0.14^{NS}
	Virudhachalam (TN)	0.65	-0.36***	0.16*	-0.03^{NS}
Leaf miner (% infestation)	Junagadh (GJ)	0.24	0.04 ^{NS}	-0.01 ^{NS}	0.05^{NS}
	Jalgaon (MH)	43.65	0.02 ^{NS}	0.12 ^{NS}	-0.03 ^{NS}
	Dharwad (KA)	10.59	-0.14^{NS}	-0.10^{NS}	-0.07^{NS}
	Kadiri (AP)	25.58	-0.11^{NS}	-0.19*	0.03^{NS}
	Virudhachalam (TN)	12.26	0.29***	-0.27*	0.02 ^{NS}
Spodoptera (No.larvae /plant)	Junagadh (GJ)	0.03	0.02 ^{NS}	0.11 ^{NS}	-0.08 ^{NS}
	Jalgaon (MH)	0.11	0.04^{NS}	0.08 ^{NS}	-0.12 ^{NS}
	Dharwad (KA)	0.02	0.03 ^{NS}	0.10 ^{NS}	-0.09^{NS}
	Virudhachalam (TN)	0.06	-0.26***	0.06^{NS}	0.07^{NS}

Table 59 (contd.). Impact of individual climate variables on insects and diseases

Insect/Disease	Location	Mean	D-MaxT	D-MinT	D-RF
Spodoptera (% Infestation)	Junagadh (GJ)	0.16	-0.09^{NS}	-0.04^{NS}	-0.04^{NS}
	Jalgaon (MH)	74.79	0.03^{NS}	-0.07^{NS}	-0.05^{NS}
	Dharwad (KA)	26.22	0.06^{NS}	0.18*	-0.07^{NS}
	Virudhachalam (TN)	17.14	0.34***	-0.16*	-0.06^{NS}
Collar rot (% incidence)	Junagadh (GJ)	5.73	0.30*	0.31**	-0.03^{NS}
	Jalgaon (MH)	6.70	-0.27*	-0.45***	-0.10^{NS}
	Kadiri (AP)	6.40	-0.13^{NS}	0.07^{NS}	0.06^{NS}
	Virudhachalam (TN)	5.54	-0.29*	0.25*	-0.05^{NS}
Dry root rot (% incidence)	Jalgaon (MH)	8.06	-0.06^{NS}	-0.12^{NS}	0.23$^{\$}$
	Kadiri (AP)	6.90	-0.57***	0.05^{NS}	0.25*
	Virudhachalam (TN)	5.95	-0.24$^{\$}$	0.29*	-0.07^{NS}
Stem rot (% incidence)	Junagadh (GJ)	4.08	-0.01^{NS}	0.15*	0.04^{NS}
	Jalgaon (MH)	8.63	0.05^{NS}	-0.37**	-0.06^{NS}
	Kadiri (AP)	6.69	-0.41**	0.03^{NS}	0.14^{NS}
	Virudhachalam (TN)	6.17	-0.20^{NS}	0.29^{NS}	-0.15^{NS}
Early leaf spot (% severity)	Junagadh (GJ)	25.43	0.006^{NS}	0.03^{NS}	0.16*
	Jalgaon (MH)	18.52	-0.02^{NS}	-0.15^{NS}	0.02^{NS}
	Dharwad (KA)	17.84	0.15^{NS}	0.28*	-0.11^{NS}
	Kadiri (AP)	27.48	-0.34*	-0.02^{NS}	0.30$^{\$}$
Late leaf spot (% severity)	Junagadh (GJ)	21.82	0.10^{NS}	-0.04^{NS}	-0.02^{NS}
	Jalgaon (MH)	22.14	0.01^{NS}	-0.22$^{\$}$	-0.08^{NS}
	Dharwad (KA)	19.51	-0.01^{NS}	0.17^{NS}	-0.27*
	Kadiri (AP)	34.35	-0.10^{NS}	-0.11^{NS}	0.09^{NS}
Alternaria leaf spot (% severity)	Junagadh (GJ)	12.27	-0.02^{NS}	-0.20^{NS}	0.02^{NS}
	Jalgaon (MH)	13.80	0.06^{NS}	0.01^{NS}	0.03^{NS}
	Dharwad (KA)	16.31	0.19^{NS}	-0.39^{NS}	-0.29^{NS}
	Virudhachalam (TN)	33.38	-0.06^{NS}	0.23**	-0.15$^{\$}$
Rust (% severity)	Junagadh (GJ)	30.53	0.03^{NS}	0.05^{NS}	-0.06^{NS}
	Jalgaon (MH)	19.36	-0.01^{NS}	-0.24*	0.08^{NS}
	Dharwad (KA)	18.89	-0.18^{NS}	-0.01^{NS}	-0.33^{NS}
	Kadiri (AP)	28.97	-0.11^{NS}	-0.24^{NS}	0.02^{NS}
	Virudhachalam (TN)	33.16	-0.41*	0.14^{NS}	0.01^{NS}
PBND (% incidence)	Jalgaon (MH)	6.95	0.09^{NS}	-0.16^{NS}	-0.29*
	Kadiri (AP)	3.39	0.15*	0.01^{NS}	-0.05^{NS}
PSND	Kadiri (AP)	6.77	0.15*	0.01^{NS}	-0.05^{NS}

Values with superscripts are '*tau*' co-efficients based on Kendall's correlations between insects and climatic deviations over 2011-16; *, ** & *** refer to significance at p<0.05, p<0.01 & p<0.001, respectively; ^{NS}: not significant; significant positive value refer to adaptation of insect/disease to the respective climatic variable; negative value with significance specify species vulnerability

Aphids did not respond to the changing climatic variations at Junagadh (GJ), Jalgaon (MH) and Virudhachalam (TN) where they were present. All the significant relations of thrips be it abundance or infestation with climatic variations were positive. All variables at Junagadh (GJ) had a positive effect on thrips infestation despite non-significant change of MinT. Significantly increasing MaxT had an increasing effect on thrips abundance at Jalgaon (MH) and Kadiri (AP) and on infestation at Junagadh (GJ) and Virudhachalam (TN). Significantly, declining MinT and RF had increasing and decreasing impact on thrips abundance and infestation, respectively at Dharwad (KA). Relation of increasing MaxT with thrips infestaion was positive and significant at Junagadh (GJ) and Virudhachalam (TN) although decreasing MinT at Virudhachalam (TN) had a decreasing effect. Declining rainfall had reducing effect on thrips infestation at Dharwad (KA) and Kadiri (AP). At Virudhachalam (TN), increasing or higher MaxT and reduced MinT had negative and positive effects on both leaf miner abundance and infestation, respectively. It is common that the responses of population of sap feeders and leaf miner and symptoms on crop had shown differential assocaitions which also varied across locations. Infesation due to *Spodoptera* was impacted in an opposite way as that of leaf miner at Virudhachalam (TN). Pest scenario based on pheromone trap catch of adults of tobacco caterpillar, *S. litura* with temperature under controlled conditions indicated that temperature could play a significant role in population dynamics of *S. litura* and it is likely that the pest incidence would be higher during future climate change scenario (Srinivasa Rao *et al*., 2015c). Current analysis based on field level population dynamics however had shown at least similar status over periods of 2011-16 and rather reducing significance at Virudhachalam (TN). This point to the adaptations of *S. litura* are based on interactive atmospheric and edaphic factors affecting life stages of the insect stages at field level.

Table 60 presents the summary of the climatic variables that had significant associations with dynamics of insects and diseases excluding the non-significant association based on values of '*tau*' coefficients in the Table 59. While MaxT and MinT had an increasing and decreasing impact on collar rot at Junagadh (GJ) and Jalgaon (MH), respectively it was significantly negative with MaxT and positive with MinT at Virudhachalam (TN). While significantly increasing MaxT decreased dry root rot at Kadiri (AP) and Virudhachalam (TN), the declining MinT had positive effect at Virudhachalam (TN). Increasing MaxT and its significantly negative association at Kadiri (AP) for stem rot and early leaf spot with only later disease having increased severity with significanly declining MinT at Dharwad (KA). Late leaf spot declined at Jalgaon (MH) in response to unchanging MinT and at Dharwad (KA) with significantly reducing rainfall. While the role of changing MaxT across all four locations was absent for *Alternaria*, significant positive and negative associations were seen with declining MinT and increasing rainfall at Virudhachalam (TN). Declining scenario of rust in response to increasing MaxT at Virudhachalam (TN) and unchanging MinT at Jalgaon (MH) was noted. Only the increased MaxT at Kadiri (AP) had an increasing impact both on PBND and PSND. Decline of PBND at Jalgaon (MH) was significant despite no change in rainfall. In *toto*, the significance of the observed climatic deviations over 2011-16 in respect of MaxT, MinT and RF with inssects/diseases together among five study locations indicated highest increasing response to MinT (17 cases) followed by MaxT (12 cases) and RF (4 cases). For the decreasing insect abundance/damage/disease severity in relation changing climatic variables was of the order MaxT (12 cases)>MinT (eight cases) >RF (six cases). Based on individual climatic varianble influence on overall biotic stressors of groundnut cropping system among five locations, the RF had lesser role over the temperature variables (MaxT & MinT) with the cumulative effect to be seen in respect of each candidate species in specific locations.

Table 60. Impact of individual climatic variables on insect pests and diseases - a pictorial summary

Climatic variable/ Insect/Disease	Junagadh (GJ)	Jalgaon (MH)	Dharwad (KA)	Kadiri (AP)	Virudhachalam (TN)
Maximum temperature (˚C)	**0.63***	**1.45*****	**-1.34*****	**0.75*****	**1.92*****
Jassids (No/Plant))		↑	↓		
Jassids (% infestation)		↑		↓	↑
Thrips (Nos./3 leaves/plant)		↑		↑	
Thrips (% infestation)	↑				↑
Leaf miner (No./plant)			↓	↑	↓
Leaf miner (% infestation)					↑
Spodoptera (Nos.larvae/plant)					↓
Spodoptera (% infestation)					↑
Collar rot	↑	↓			↓
Stem rot				↓	
Dry root rot				↓	↓
Early leaf spot				↓	
Rust					↓
PBND				↑	
PSND				↑	
Minimum temperature (˚C)	**-0.45**	**-0.08**	**-1.87*****	**0.91*****	**-0.36***
Jassids (No./Plant))	↑	↑			
Jassids (% infestation)	↑				↓
Aphids (Severity grade)	↑				
Thrips (Nos./3 leaves/plant)		↑	↑	↑	
Thrips (% infestation)	↑				↓
Leaf miner (No./plant)	↑				↑
Leaf miner (% infestation)				↓	↓
Spodoptera (% infestation)			↑		↓
Collar rot	↑	↓			↑
Stem rot	↑	↓			
Dry root rot					↑
Early leaf spot			↑		
Late leaf spot		↓			
Alternaria leaf spot					↑
Rust		↓			
Rainfall (mm/week)	**12.41*****	**7.36**	**-5.15*****	**-1.86*****	**11.33*****
Jassids (No/Plant))		↓			
Thrips (% infestation)			↓	↓	
Dry root rot		↑		↑	
Early leaf spot				↑	
Late leaf spot			↓		
Alternaria leaf spot	↑				↓
Rust	↓				
PBND		↓			

Empty cells with no (white) colour indicates the absence or very low presence of insects or diseases in the location. Only significant relations between population dynamics of insects/diseases with the change in respect of MaxT, MinT and RF are shown with up or downward arrows. Coloured cell with no arrow indicates non significance of insect/disease and climate change

Impact of climate change measured using species – climate change association index

The cumulative impact of climate change was worked out based on SAIs for a total of three sucking insects, two lepidopterans, three rots, four foliar and two viral diseases from among the five study locations. The ordering of insects and diseases based on SAIs irrespective of the significance of association with climatic deviations for each of the locations are given (Table 61). Diseases namely early leaf spot, dry root rot and *Aletrnaria* leaf spot had the highest SAI in respect of Junagadh (GJ), Jalgaon (MH) and Dharwad (KA). Kadiri (AP) and Virudhachalam (TN) had the highest SAI for thrips abundance and leaf miner infestation, respectively. SAI for thrips abundance was negative at Junagadh (GJ) and Jalgaon (MH) and was positive at Dharwad (KA), Kadiri (AP) and Virudhachalam (TN).

Table 61. SAI based ranking of insects and diseases - within location

Location	Order of adaptation/vulnerability	SAIs (ordered)
Junagadh (GJ)	ELS*>LMI>SR*>APHS*>ALS>LMN>LLS>JDI*>CR*>SPDI>JDN*>RST>TRPN*>SPDN>APHI>TRPI*	**1.98*>0.65>0.42*>0.41*>0.33>0.09**>-0.17>-0.17*>-0.32*>-0.54>-0.55*>-0.75>-0.97*>-1.03>-1.13>-1.79*
Jalgaon (MH)	DRR>>LMN>RST*>ALS>TRPI>ELS>APHI>LMI>APHS>SPDI>SR*>TRPN*>LLS>JDI>JDN*>SPDN>CR*>PBND*	**1.62>0.89>0.59*>0.31>0.22>0.13**>-0.13>-0.20>-0.25>-0.32>-0.34*>-0.42*>-0.56>-0.61>-0.79*>-0.83>-1.09*>-1.99*
Dharwad (KA)	ALS>RST>LLS*>JDN*>TRPI*>LMI*>JDI*>LMN*>TRPN*>SPDN>SPDI*>ELS*	**1.97>1.96>1.09*>0.84*>0.78*>0.74*>0.63*>0.50*>0.28*>0.24**>-0.06*>-0.16*
Kadiri (AP)	TRPN*>LMN*>TRPI>PBND*>PSND*>JDN>JDI>CR>LMI*>RST>LLS>SR*>ELS*>DRR*	**0.43*>0.38*>0.26>0.21*>0.21*>0.20>0.02**>-0.15>-0.31*>-0.34>-0.34>-0.54*>-0.83*>-0.85*
Virudhachalam (TN)	LMI*>TRPN*>TRPI>APHI>JDI*>SPDN*>SPDI*>JDN>APHS>RST*>LMN*>CR*>DRR*>ALS*>SR	**0.88*>0.74*>0.70>0.69>0.41*>0.27*>0.03***>-0.22>-0.40>-0.72*>-1.09*>-1.21*>-1.36*>-1.90*>-2.19

ALS= *Alternaria* leaf spot (% severity); APHI= Aphids (% infestation);APHS= Aphid severity (Grade); CR= Collar rot (% Incidence); DRR= Dry root rot (% incidence); ELS= Early leaf spot (% severity); JDI= Jassids (% infestation); JDN= Jassids (no./plant); LLS= Late leaf spot (% severity); LMI= Leaf miner (% infestation); LMN= Leaf miner (nos./plant); PBND= PBND (% incidence); PSND= PSND (% incidence); RST= Rust (% severity); SPDI= *Spodoptera* (% infestation); SPDN= *Spodoptera* (nos.larvae/plant); SR= Stem rot (% incidence); TRPI= Thrips (% infestation); TRPN= Thrips (Nos./3 leaves/plant); positive values of indices in bold indicate adaptation of insects/diseases to the observed climate change in respect of locations. Negative values specify species vulnerability; Symbol*associated with SAI values of insects/diseases indicate the definitive influence of at least one or all-climatic variables (MaxT, MinT, RF) having significant association with population dynamics irrespective of the significance of magnitude of climate change for the variables

The spectrum of insects and diseases together in terms of frequency across locations was of the order: Jalgaon (MH) (18)>Junagadh (GJ) (16)>Virudhachalam (TN) (15)>Kadiri (AP) (14)> Dharwad (KA) (12). The adaptive response irrespective of the significance represented with SAIs was greater at Dharwad (KA) (83%)>Kadiri (AP) (50%)>Virudhachalam (TN) (47%)>Junagadh (GJ) (38%)>Jalgaon (MH) (33%) implying the higher the species diversity lesser or equal the species possessing adaptiveness with the exception of Dharwad (KA). On the other hand, the range of SAIs in respect of each location offer an understanding on the interactive effects of changing climate on the interspecific adjustments/competition of the species. The range of SAIs in respect of locations along decreasing order indicated Junagadh (GJ)> Jalgaon (MH)>Virudhachalam (TN)>Dharwad (KA)>Kadiri (AP). Among insects, the internal feeder, the leaf miner abundance was classified as adaptive at four of the five locations although its damage was under adative category in three of the five locations.

Table 62. SAI based ranking of insects and diseases - between locations

Insect	Order of adaptation/vulnerability	SAIs (ordered)
Jassids (Nos/plant)	KA*>AP>TN>GJ*>MH*	**0.84*>0.20**>-0.22>-0.55*>-0.79*
Jassids (% infestation)	KA*>TN*>AP>GJ*>MH	**0.63*>0.41*>0.02**>-0.17*>-0.61
Aphids (% infestation)	TN>MH>GJ	**0.69**>-0.13>-1.13
Aphid severity (Grade)	GJ*	**0.41***
Thrips (Nos/3 leaves/plant)	TN>AP*>KA*>MH*>GJ*	**0.74>0.43*>0.28***>-0.42*>-0.97*
Thrips (% infestation)	KA*>TN*>AP>MH>GJ*	**0.78*>0.70*>0.26**>0.22>-1.79*
Leaf miner (Nos/plant)	MH>KA*>AP*>GJ>TN*	**0.89>0.50*>0.38*>0.09**>-1.09*
Leaf miner (% infestation)	TN*>KA*>GJ>MH>AP*	**0.88*>0.74*>0.65**>-0.20>-0.31*
Spodoptera (No. of larvae/plant)	TN*>KA>MH>GJ	**0.27*>0.24**>-0.83>-1.03
Spodoptera (% infestation)	TN*>KA*>MH>GJ	**0.03***>-0.06*>-0.32>-0.54
Collar rot (% incidence)	AP>GJ*>MH*>TN*	-0.15>-0.32*>-1.09*>-1.21*
Stem rot (% incidence)	GJ*>MH*>AP*>TN	**0.42***>-0.34*>-0.54*>-2.19
Dry root rot (% incidence)	MH>AP*>TN*	**1.62**>-0.85*>-1.36*
Early leaf spot (% severity)	GJ*>MH>KA*>AP*	**1.98*>0.13**>-0.16*>-0.83*
Late leaf spot (% severity)	KA*>GJ>AP>MH	**1.09***>-0.17>-0.34>-0.56
Alternaria leaf spot (% severity)	KA>GJ>MH>TN*	**1.97>0.33>0.31**>-1.90*
Rust (% severity)	KA>MH*>AP>TN*>GJ	**1.96>0.59***>-0.34>-0.72*>-0.75
PBND (% incidence)	AP*>MH*	**0.21***>-1.99*
PSND (% incidence)	AP*	**0.21***

Junagadh, Gujarat (GJ); Jalgaon, Maharashtra (MH); Dharwad, Karnataka (KA); Kadiri, Andhra Pradesh (AP); Virudhachalam, Tamil Nadu (TN); Positive values of indices in bold indicate adaptation of insects/diseases to the observed climate change in respect of locations. Negative values specify species vulnerability; Symbol*associated with SAI values of insects/diseases and locations indicate the definitive influence of at least one or all-climatic variables (MaxT, MinT, RF) having significant association with population dynamics irrespective of the significance of magnitude of climate change for the variables

Thrips abundance was categorised in three and its damage at four of the five locations as adaptive. Such variations indicated the impact of climate change operating through crop mediated effects. Diseases also had shown differential responses to climate variability/change on spatial scale across different agroecologies. The fungal rots had shown negative SAIs, otherwise vulnerability to climate change possibly due to extremes of weather especially rainfall. Dry root rot at Rahuri (MH) and stem rot at Junagadh (GJ) showing positive SAIs signify the ecological or evolutionary adaptation of the pathogen under the production system. Among four foliar fungal diseases, only rust was common at all locations with adaptation and vulnerability with significance at Rahuri (MH) and Virudhachalam (TN) although Dharwad (KA) had the highest SAIs for three of the four fungal diseases including rust (Table 61). The ordering of locations based on SAIs for each of the insects and diseases are given in Table 62. Not a single insect had shown a similar response to climate change across locations. Changing climate led to increased jassids at Dharwad (KA) and Kadiri (AP)) with reduction at Junagadh (GJ) and Jalgaon (MH). Significant decrease of aphids at Junagadh (GJ) and Jalgaon (MH) with its increase only at Virudhachalam (TN). Insignificance of aphids at Kadiri (AP) and Dharwad (KA) was notable. While thrips increase was evident at Virudhachalam (TN), Kadiri (AP) and Dharwad

(KA), decline was seen at Junagadh (GJ). Definitive increase of leaf miner at Dharwad (KA) and Junagadh (GJ) was inferred. *Spodoptera* increase at Virudhachalam (TN) and decline at Jalgaon (MH) and Junagadh (GJ) were indicated. Differential impact on abundance (nos/plant) and damage level (% infestation) (crop response) for insects *viz.,* jassids at Virudhachalam (TN), thrips at Jalgaon (MH), leaf miner at Jalgaoan (MH), Virudhachalam (TN) and Kadiri (AP), and *Spodoptera* at Dharwad (KA) could have arisen out of the interactive effcts of climate change with the dominant varietal and crop production scenarios in the locations. Impact of climate change on insects of groundnut conform to the spatial variations in terms of different agroclimatic zones/production systems. Stem rot was declining at all locations of its presence *viz.,* Kadiri (AP), Junagadh (GJ), Jalgaon (MH) and Virudhachalam (TN). Dry root rot was also absent at Junagadh (GJ). *Alternaria* leaf spot was absent at Kadiri (AP). Both viral diseases (PBND & PSND) were of non-significance at Dharwad (KA), Junagadh (GJ) and Virudhachalam (TN) although both had an increasing response at Kadiri (AP). Despite Jalgaon (MH) also being a hot spot for thrips, impact of climate change on PBND was significantly negative possibly related to the declined virulence of virus (refer Table 62).

Table 63. Impact of climate change on insects and diseases - a listing

Location	Adaptive	Vulnerable
Junagadh(GJ)	1. Early leaf spot 2. Stem rot 3. Aphid severity	1. Jassid infestation 2. Collar rot 3. Jassid abundance 4. Thrips abundance 5. Thrips damage
Jalgaon (MH)	1. Rust	1. Stem rot 2. Thrips abundance 3. Jassid abundance 4. Collar rot 5. PBND
Dharwad (KA)	1. Late leaf spot 2. Jassid abundance 3. Thrips damage 4. Leaf miner damage 5. Jassid infestation 6. Leaf miner abundance 7. Thrips abundance	1. *Spodoptera* damage 2. Early leaf spot
Kadiri (AP)	1. Thrips abundance 2. Leaf miner abundance 3. PBND 4. PSND	1. Leaf miner damage 2. Stem rot 3. Early leaf spot 4. Dry root rot
Virudhachalam (TN)	1. Leaf miner damage 2. Thrips abundance 3. Jassid damage 4. *Spodoptera* abundance 5. *Spodoptera* damage	1. Rust 2. Leaf miner abundance 3. Collar rot 4. Dry root rot 5. *Alternaria* leaf spot

Insects and diseases are listed along the order of importance for the cumulative impact of climate change based on species climate change adaptation index (SAI) values

Listing and grouping of all study insects and diseases in respect of different study locations based on SAI values as adaptive and vulnerable are furnished in Annexure XXVIII. The table above (Table 63) lists only insects and diseases whose population dynamics of insect or the disease progression had significant association with atleast one or two or all climatic variables and the SAIs were calculated considering magnitude of change in all three parameters (whether significant or not *per se*). The order of importance of locations based on the increasing number of insects and diseases due to observed climate change was: Dharwad (KA)>Kadiri (AP) & Jalgaon (MH)>Junagadh (GJ)> Virudhachalam (TN). The order of importance of locations based on the number of insects and diseases declining/vulnerable to observed climate change was: Jalgaon (MH)> Junagadh (GJ) &Virudhchalam (TN)> Kadiri (AP) >Dharwad (KA). Finite and intrinsic rates of increase, net reproductive rate, mean generation time and doubling time of *S. litura* on groundnut varied significantly with temperature and CO_2 and had quadratic relationships with temperature. Prediction of pest scenarios based on such process based relations using PRECIS A1B emission scenario climatic data for near and distant future of climate change periods showed an increase of finite and intrinsic rates with varied net reporducitve rate and reduced generation time (Srinivasa Rao *et al.,* 2014). However, it remains to be seen at the field level with the current changing emphasis given on the farming systems and the management ecosystems proposed such as natural and organic farming in addition to the modern approaches including the new molecules of insecticides and fungicides.

From agroecological perspective, differential responses were inferred for insect pests and diseases of groundnut within and between hot semi-arid, hot arid and sub humid-semi arid regions. Changing climate led to increased jassids at Dharwad (KA) and Kadiri (AP)) with reduction at Junagadh (GJ) and Jalgaon (MH). Increased adaptation of thrips and leaf miner and increased thrips transmitted viral diseases were on rise with all other diseases of decreasing importance at the hot arid location, Kadiri (AP) of southern plateau hills. Leaf miner proved to be increasing at hot semi arid and arid regions. Sucking insects jassids, thrips and aphids declined at all study hot semi arid locations with exception being West Coast Plains and Ghat climatic zone. Sub humid and semi arid ecoregions had increased thrips and aphids and decreased jassids. Lepidopteran *Spodoptera* had positive impact of climate change shown at hot semi arid and sub-humid-semi arid ecoregions and negative at the hot semi arid locations Central and Western India. Hot arid ecology of southern plateau and hills ACZ had positive effect of its climate change on jassids and thrips. While hot arid ecoregion was found favourable for jassids, both hot semi arid and hot arid had shown overlapping impacts on thrips and aphids across agro ecoregions. The diseases transmitted by thrips increased only at hot arid ecoregion. While significance of *Alternaria* leafspot was positive at hot-semi arid and negative at sub humid-semi arid locations, it was absent at hot arid ecoregion. However, stem rot had positive effect at only one of the hot semi arid locations with negative impact at other hot semi arid, hot arid and sub humid-semi arid ecologies. Dry root rot at one of the hot semi arid location was positive but negative at hot arid and sub humid-semi arid places. Foliar disease rust had similar increasing effect at hot semi arid places. Early leafspot was on increasing trend at hot semi arid location belonging to agroclimatic zone of Gujarat Plains and hills and western plateu and hills. On the contrary, hot semi arid and hot arid ecoregions in respect of West coast plains & ghat and Southern plateu & hills had shown declining effect.

Late leaf spot showed increasing trend only at hot semi arid location of West Coast plains and Ghat with decline at other hot semi arid location of Gujarat plains and hills and Western Plateu and hills in addition to the hot arid Southern Plateau and hills. Although certain similarity in respect of a few insects/diseases were seen amongst different agroecologies, hot semi arid locations at large had relatively higher positive impact due to climate change. Considering the impacts of climate change across AER and ACZ, it becomes clear that a generalized impact of climate change on a given insect or disease cannot be declared at the national level. With spatial and temporal variabilities found for climate change/variability for insects and diseases, the agro ecological planning or area wide pest management would not be correct and the pests and their management have to be dealt precisely with minimum scale being a field to a well-coordinated community farming across similar soil-climate situations with their management tuned on need basis. In otherwords, grouping of locations with similar natural endowments (edaphic and climatic) followed by community approach to farming can offer effective insect and disease management when they attain pest status.

Projection of future scenario of an insect and a disease

Jassids at Kadiri (AP)

Future scenario of jassid infestation at Kadiri (AP) under changing climate using representative concentration pathway 4.5 scenario was understood through Kendall's '*tau*' correlations between jassid infestation dynamics of current period with the projected climatic variables. Kendall's 'tau' correlation coefficients worked out between current dynamics of jassid infestations and MaxT and MinT projections under 4.5 level of representative concentration pathway (RCP) (radiative forcing level of 4.5 W/m² with stabilization after 2100) of future periods *viz.,* 2020, 2050 and 2080 had shown non-significant associations implying absence of climate change impacts on jassid infestation (Table 64). Decreasing jassid infestations on groundnut with current (for past periods of 2011-16, refer Table 51) and future periods with magnitudes of increasing temperature (MaxT & MinT) at Kadiri (AP) is expected to reduce the load of insecticides on the crop. It remains to be seen, the adaptability of jassids under future climate change scenarios and response to uncertain weather aberrations that may arise. Systematic field based real time pest surveillance put in place for decision making on pest management options in conjunction with crop condition would prove to be highly effective under all scenarios of climate and pest dynamics.

Table 64. Future status of jassid infestations on groundnut at Kadiri (AP) - RCP 4.5

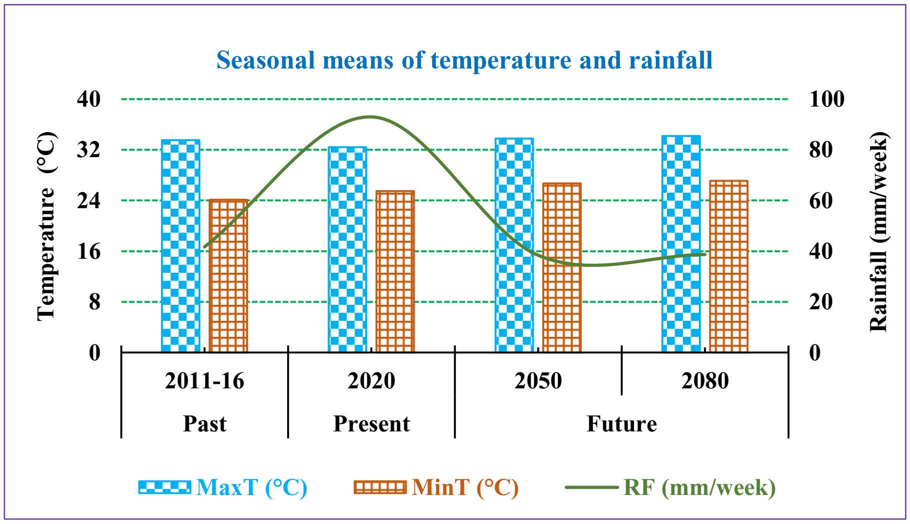
Climatic variables	Future periods		
	2020	2050	2080
MaxT (°C)	0.14 ^{NS} (32.4)	-0.16 ^{NS} (32.6)	0.01 ^{NS} (36.9)
MinT (°C)	-0.05 ^{NS} (23.6)	-0.50 ^{NS} (26.2)	-0.07 ^{NS} (26.9)

#: values outside brackets are Kendall correlations between jassid infestations and climatic projections; ^{NS} non-significant; values within brackets are projected means of Max T and MinT in °C

Early leaf spot at Junagadh (GJ)

Although many models and their versions projecting climate change scenarios are available, present study used radioactive stabilization scenario of RCP 4.5 as it fitted to the Indian scenario (Ramaraj and Geethalakshmi, 2014) accommodating technologies and strategies that would be implemented in the future years for reducing greenhouse gas emissions. The seasonal means of observed and projected temperature and rainfall along the *kharif* groundnut season for the past, present and future periods of 2050 and 2080 are furnished in Figure. It is interesting to note that the observed seasonal maximum (32.4°C) and minimum (25.5°C) temperatures of 2020 was glaringly lower (1.1°C) and higher (1.4°C), respectively over the past (2011-2016) periods. The climatic projections for Junagadh (GJ) made at representative concentration pathway (RCP) 4.5 level (refer Figure) for future periods of current century *viz.,* 2050 and 2080 indicated increasing maximum and minimum temperatures by about 1.8 to 1.6 °C, respectively across locations against the current period of 2020 (Figure) confirming increasing temperatures and hence changing climate. Decrease in minimum temperature below 18°C together with rise in morning and afternoon relative humidity by 92 and 85 %, respectively contributing significantly to ELS disease severity at Junagadh (GJ) was reported

(Samui *et al.*, 2005). However, in the current study, despite an increased seasonal rainfall during 2020 that could have assisted higher relative humidity, the significance of higher minimum temperature with ELS severity indicated a changed disease scenario under changing climatic variables at Junagadh (GJ).



Kendall correlations worked out between ELS and climatic deviations for the past periods of 2011-16 had shown positive significance of the increasing rainfall with ELS and insignificant relations with temperature (MaxT and MinT) variables. It is highly obvious that the increasing rainfall amounts of the past periods directly determined the disease severity of ELS on groundnut at Junagadh (GJ). In field conditions, rainfall is the main source of humidity that makes leaves wet and in turn facilitates higher disease severity. However, during the present period of 2020, the observed rainfall (93 mm/week) (Table 65) was more than double of the past (refer Table 47) and future periods of 2050 and 2080. It is interesting to note that the observed seasonal maximum (32.4°C) and minimum (25.5°C) temperatures of 2020 was glaringly lower (1.1°C) and higher (1.4°C), respectively over the past (2011-2016) periods.

Table 65. Impact of current and future climate on early leaf spot severity

Climatic variables	Current period	Future periods	
	2020	2050	2080
MaxT (°C)	0.05 NS (32.4)	-0.15 NS (33.8)	-0.18 NS (34.2)
MinT (°C)	0.45** (25.5)	-0.22 NS (26.7)	-0.19 NS (27.1)
Rainfall (mm/week)	-0.07 NS (93.0)	0.35* (38.4)	0.34* (38.7)

values outside brackets are Kendall 'τ' coefficients between disease severity and deviations of climatic variables and significance of 'τ' indicated by *: $p<0.05$; **: $p<0.01$; NS: not significant; values inside the brackets are the observed (for 2020) and projected means for future periods (2050 and 2080) in respect of climatic variables

The mean ELS severity during 2020 was 27.3% and its significant association was noted with the MinT unlike past and future periods where rainfall had a positive significance. The higher minimum temperature *vis a vis* higher rainfall in 2020 could be attributable to the unseasonal/aberrant nature of weather arising out of western disturbances. The moderate severity of ELS and its significance and non-significance with MinT and RF, respectively during the very high rainfall season of 2020 over the past and future periods indicated the interacting factors of importance influencing status of ELS on groundnut. While positive associations of rainfall and relative humidity in the growth and development of early blight was reported more than a decade earlier (Chaerani and Voorrips, 2006).

Present study confirmed the changing climate during the *kharif* of groundnut in terms of temperature and rainfall and the increasing importance of rainfall on ELS during the past and future periods at the Central highland Gujarat plains and Kathiawar peninsula hot semi-arid ecoregion of the agro climatic zone of Gujarat plains and Hills. Under field conditions, ELS could also be influenced by additional factors such as cultivars and planting dates of the production system. With the climate as an environmental variable signifying ELS increase for future, the evolving varietal scenario and changing agronomic practices of groundnut and the adaptation of the pathogen of ELS to those changing situations would determine the disease management strategy to be adopted. An attempt to develop, validate and use weather based models for ELS utilizing the additional weather factors such as relative humidity and rainy days apart from temperature and rainfall could be a way forward to achieve its successful prediction for integration with groundnut pest management during future years of the current decade.

TOMATO

Tomato (*Lycopersicon esculentum*) is considered as a 'protective food' due to its special nutrition endowed with vitamin A, vitamin C, potassium, phosphorus, magnesium, calcium and antioxidant lycopene that reduce the risk of cancer (USDA, 2009 and Miller *et al*., 2002). Fruits are used as salad, processed for soup, juice, ketchup, puree, paste and powder. Tomato is field grown almost throughout the country mostly by small and marginal farmers and its price suffers heavy fluctuations time to time. Tomato can be taken up in off-season and in open fields as well as under protected cultivation thus continuous supply to the consumers and income to the producers are ensured. Area under tomato has increased substantially over years from an area of 0.478 mha in 2002-03 to 0.813 mha during 2020 with current production volume of 21 million metric tons. Each of Andhra Pradesh, Madhya Pradesh and Karnataka states contribute greater than 10% of national area with production exceeding two lakh metric tonnes per state. Gujarat, Odisha, West Bengal, Maharashtra, Telangana and Chhattisgarh are the other states contributing significantly for the area and production of tomato. Better varieties and hybrids, drip irrigation system and modern production technologies have facilitated a productivity of 25.8 t/ha as of 2020. At national level, more than 25 open-pollinated varieties and 10 hybrids have been released, in addition to several varieties and hybrids released at the State level.

Cultivation of new varieties/hybrids of tomato *vis a vis* the observed global warming led to altered insect and disease profiles across India. While dry climatic conditions limited some of the insect pests in a few agro eco regions, higher moisture and rainfall favored most of the foliar diseases and soil borne pathogens. High rainfall, humidity coupled with moderate temperatures triggered late blight in Belgaum, Karnataka during 2012. Amount of rainfall and number of rainy days also affected the appearance and severity of buckeye rot, powdery mildew and *Septoria* leaf spot. At elevated temperature, late blight becoming intense in the autumn crop in the Northern plains was predicted. Besides, under climate change, growth and rates of insect and disease development alter directly or in response to host plants. Investigation on the dynamics of insects and diseases in tomato due to climate change was implemented with systematic surveillance plans and uniform sampling methodologies adopted across seven states belonging to six different agro climatic zones and six agro eco regions of the country (Annexure I & II) (refer map).

All locations were part of the ICT based pest-weather surveillance since 2011 with the mission of assessing the impact of climate change on the varied insects and diseases. Two seasons of tomato cultivation were accounted under this study. Only six locations other than Kalyani (WB) were accounted for *kharif*. Kalyani (WB) had only *rabi* season covered along with other six study locations. Rajendranagar (TS) for both *kharif* and *rabi*, and Kalyani (WB) for *rabi* continued till 2020. The growing season of tomato crop varied among the locations for *kharif* as well as *rabi* and are furnished in Annexure III.

Pest surveillance plan had the coverage of both experimental station and farmer fields at the study locations. The insects and diseases covered for surveillance under each of the two (*kharif* and *rabi*) seasons and their scientific names with the scale of measurement and reporting units are furnished in

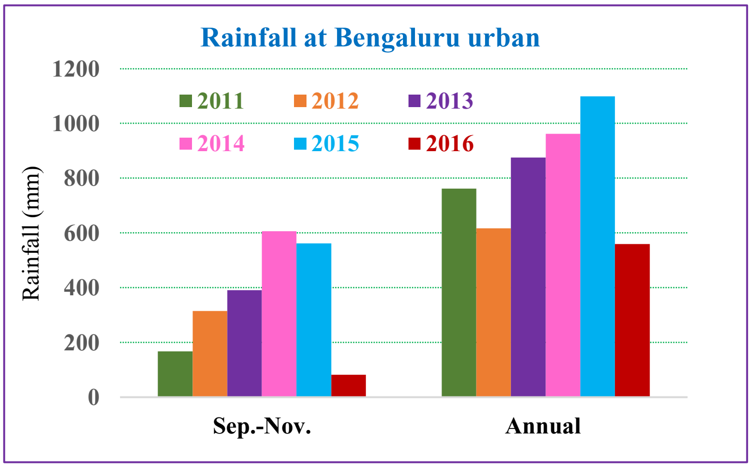
Annexures XIV-XVI. The procedures to be followed towards selection of fields for surveillance at the experimental/research station, and at villages besides the standard methods to be adopted for recording the observations of pests using the data recording formats formed the primary step. A manual with description of the identification details of the insects and diseases for tomato pest surveillance and data sheet formats along with guidelines for surveillance is available at: *https://ncipm.icar.gov.in/nicra2015/datasheetsmanuals.aspx*. The data sheets also form a part of the manual. Two tomato fields (one under protection and other under unprotected condition) at the experimental station, and one field per village in ten selected villages of each were used for pest surveillance during the cultivation cycle of *kharif* and *rabi* tomato (Annexure III) corresponding to each study location (Annexure I &II). All fields once selected were continuously monitored for insects and diseases throughout the season on weekly basis. The following paragraphs furnish the scenario of major insects and diseases associated with changing weather identified during various individual study season(s). Inter seasonal variations across study years for *kharif* and *rabi*, magnitude of climate change (2011-16) in respect of locations and the impact of quantified climate change on insect and disease dynamics worked out are furnished.

Scenario of insect pests and diseases *vis a vis* changing weather

Bengaluru [Karnataka (KA)] [ACZ: Southern Plateau and Hills Region AER: Eastern ghat, TN upland and Deccan plateau hot semi- arid ecoregion]

Higher temperature in 2011 *vis a vis* most severe late blight>early blight>*Septoria* leaf spot with no wilt was noted. Sap feeders *viz.,* mites (*Tetranychus urticae*) and whiteflies (*Bemisia tabaci*) were significantly higher in summer compared to *kharif,* and the incidence of *H. armigera* was ($F_{(2, 40)}$: 5.06; $P \leq 0.05$) greater in *kharif* compared to summer. The first summer showers and subsequent pheromone trap catches observed in SMW 17 (20 mm rainfall) for *H. armigera* and *S. litura* during 2012 and after SMW 11 (five mm rainfall) for *S. litura* and after SMW 15 (33.2 mm rainfall) for *H. armigera* during 2013 indicated existence of higher threshold moisture required for *H. armigera* over *S. litura* for emergence. Virus diseases *viz.,* tomato leaf curl Bengaluru virus (begomo), cucumo mosaic virus (mosaic and leaf distortion), and groundnut bud necrosis virus (tospo virus) were confirmed during 2013-14. Incidence of tomato leaf curl virus was whitefly population dependent and higher during summer over *kharif* ($F_{(2, 40)}$: 4.94; $P \leq 0.05$). Year round occurrence of South American Pinworm *Tuta absoluta* was seen in 2015-16 with higher summer >*rabi*>*kharif* populations having got reported in 2014 at Bengaluru, Karnataka. Under conditions of the lowest annual rainfall of 559 mm in 2016 over past 12 years with relatively higher temperatures (refer Annexure X), *T. absoluta* had its peak incidence (52/trap/day) during 9 SMW.

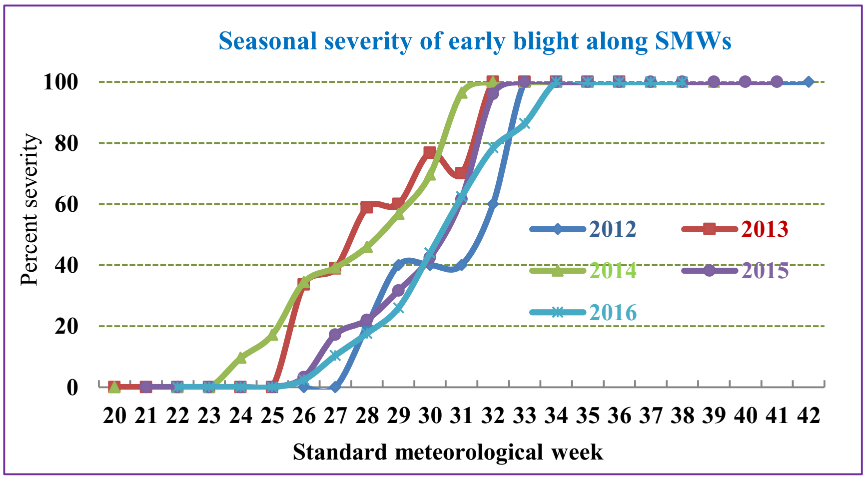
Powdery mildew was severe (>50%) during *kharif* 2014 and milder (10%) during *rabi*. Intense rainfall increased diseases and high temperatures increased the incidence of insect vectors and viral diseases. Irregular pre (May-183.7 mm) and post (low rainfall in June (89 mm) and July (62 mm) after a normal monsoon coupled with above average rainfall during August (140 mm), September (251 mm), October (145 mm) and November (173 mm) impacted *kharif* tomato in 2014. The unseasonal heavy rainfall of 187 mm during November and December of 2012 compared to only 13.6 mm during the corresponding period of 2011 led to cent percent early blight in 2012-13 *rabi* tomato. Rainfall of near to 100 mm in 39 SMW of 2014 triggered late blight culminating in cent percent severity

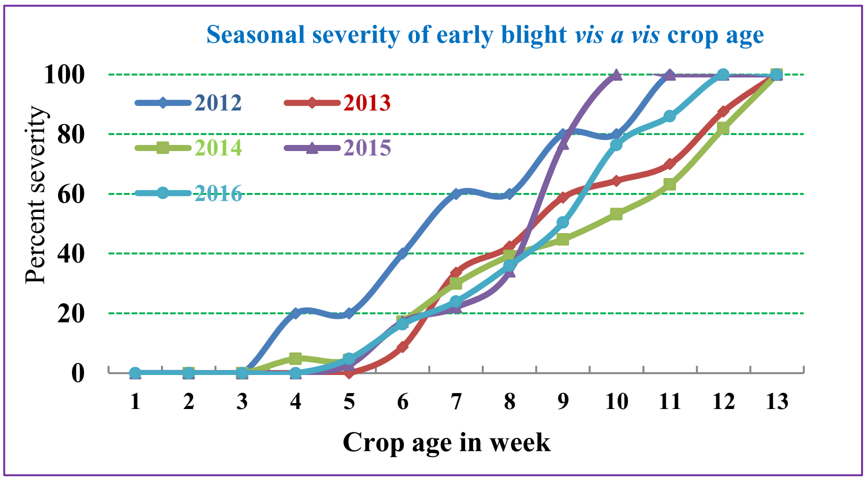


by the end of the season although crop transplanted during second fortnight of May escaped. Continuous rainfall in September - November aggravated late blight (*Phytophthora infestans*) but the yield losses were minimal due to the crop at final harvest stage in 2015. Heavy rains also delayed the transplanting of *rabi* tomato and subsequently delayed the transplanting of summer tomato in 2016.

Early blight in eastern dry zone of Karnataka

Kharif: Early blight initiated during 24 and 28 SMWs during 2014 and 2012, respectively while 2013, 2015 and 2016, early blight initiated during 26 SMW and reached almost cent percent during 31-34 SMWs. Maximum severity (>20%) was recorded during 26 to 29 SMWs during all seasons. As the dates of transplanting across fields were different, severity levels of early blight based on weeks of transplanting (WAT equivalent to crop age) were worked out. While early blight appeared three WAT during 2012 and 2013, it appeared at five WAT during 2015 and 2016. Greater than 20% severity beyond fourth and seventh weeks in respect of 2012 and rest of seasons was recorded. Attainment of cent percent severity was during 10 WAT in 2015 followed by 11 WAT in 2012 and at 12 WAT during 2016. Severity of 100% was attained 13 WAT during 2013 and 2014. Increased severity of early blight with crop age was evident across all seasons. Field occurrence of early blight over seasons (2012-16) at Bengaluru (KA) coincided with mean temperature range of 20.4-26.9°C and mean RH of 50.3-72.9% falling within the reported congenial values. The observed differences in time of start and levels of severity across seasons on SMW and crop age basis indicate role of crop phenology influencing the progression of early blight. Degree of susceptibility of tomato plants with increasing crop age was well established.





Correlation analysis of mean and maximum early blight severity with weather variables indicated significant and positive influence of morning and evening RH prevalent during one and two weeks before besides that of current week. Morning RH had higher influence on early blight. Despite the general negative impact of maximum and minimum temperatures on mean as well as maximum early blight severity, significance of current week's minimum temperature and of maximum temperature lagged by two weeks had significant negative effect on the maximum severity of early blight (Table 66).

Table 66. Correlation coefficients between early blight and weather factors at Bengaluru urban (KA)

Weather variable#	Mean severity			Maximum severity		
	Current week	One week prior	Two weeks prior	Current week	One week prior	Two weeks prior
MaxT (˚C)	-0.117	-0.188	-0.409	-0.225	-0.326	-0.522*
MinT (˚C))	-0.447*	-0.302	-0.165	-0.521*	-0.380	-0.260
MRH (%)	0.675**	0.715**	0.675**	0.647**	0.674**	0.628**
ERH (%)	0.414*	0.525*	0.442*	0.484*	0.574**	0.491*
RF (mm/week)	0.248	0.137	0.221	0.212	0.139	0.250
Sun shine (h/day)	-0.172	-0.343	-0.291	-0.202	-0.358	-0.335
Wind (km/h)	-0.344	-0.330	-0.263	-0.356	-0.334	-0.265

#: early blight severity was related to weather of corresponding to different (current, a week and two weeks prior) periods; **: significant at p< 0.01; *: significant at P< 0.05

The multiple linear equations (1) and (2) to predict mean and maximum disease severity of early blight on tomato developed using 2012-15 data set for Eastern dry region are:

$$(1)\ \mathrm{PDI}_{\mathrm{mean}} = -8.701 + 0.175\ MRH_1 - 0.125\,MaxT_2 - 0.043\,Wind_2 \qquad R^2 = 0.79$$

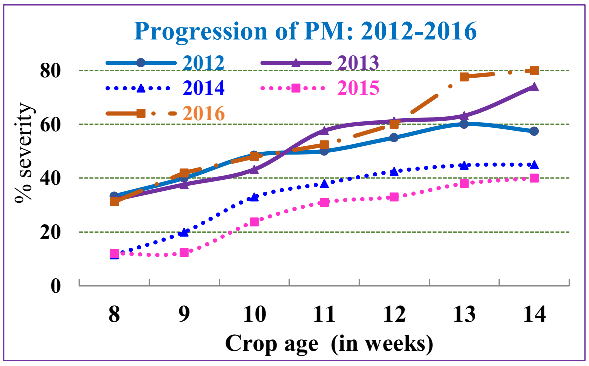
$$(2)\mathrm{PDI}_{\mathrm{max}} = -9.541 + 0.215\,MRH_1 - 0.191\,MaxT_2 - 0.054\,Wind_2 \qquad R^2 = 0.78$$

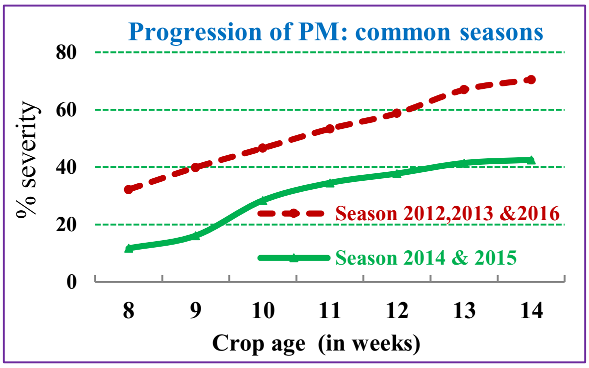
where, $MaxT_2$ and MRH_1 are the maximum temperature and morning RH, respectively of two and one lag week and, $wind_2$ denote the wind velocity prior to two weeks. The adequacy of the fitted prediction model measured by the coefficient of the determination R^2 indicated 79 and 78% of variations in respect of mean and maximum severity of early blight in fields explained by the weather variables accounted in the equations. Validation of the developed models using 2016 early blight disease progression indicated higher deviations of predicted from observed values during the early stages of crop growth up to 31 and 29 SMWs in respect of mean and maximum severity indicating the weather extremes especially distribution of rainfall directly offering the higher relative humidity conducive for disease development.

***Rabi* & summer:** On *rabi* tomato (39-52 SMW), only early blight was observed with cent per cent severity with no bacterial and viral diseases. During summer (12-27 SMW), early blight was the most serious, with its initiation in 17 SMW reaching 100% severity by 26 SMW when the range of maximum and minimum temperature was 28.4-38.1°C and 19.1-24.0°C and morning and evening relative humidity was 66.5-84.2 and 32.7-48.2%, respectively.

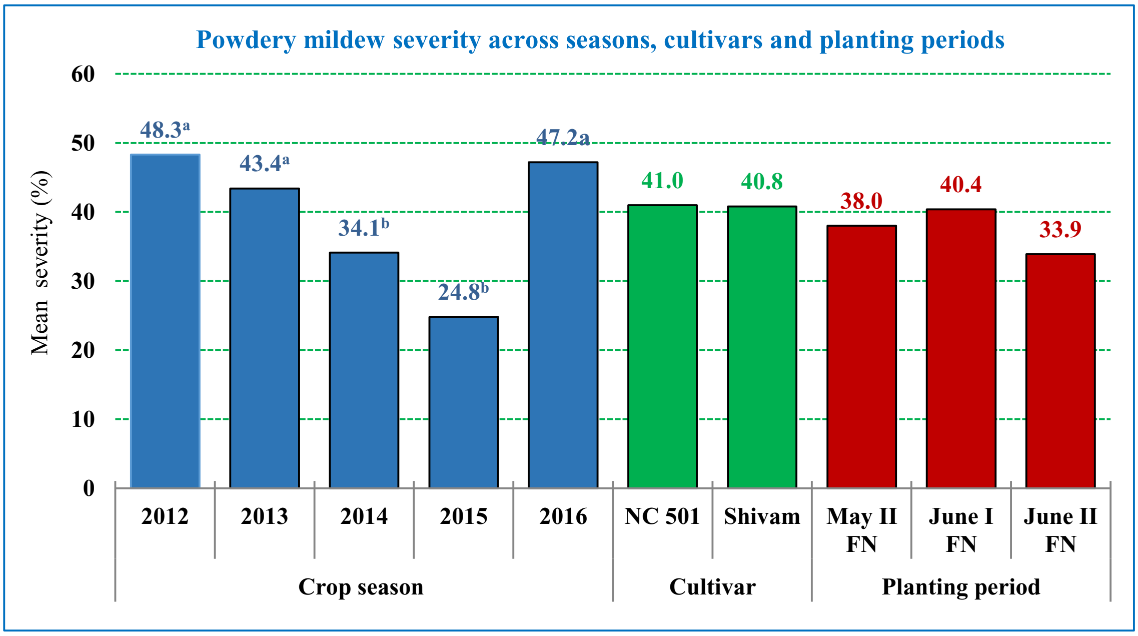
Factors influencing powdery mildew severity

Powdery mildew onset varied over seasons *viz.,* fifth, seventh, eight and fourth weeks after planting during 2012, 2013, 2014 and 2015 cum 2016, respectively. Powdery mildew (PM) disease severity in respect of seasons (2012-16) along crop age revealed more or less similar trends of disease progression





but for levels of severity. Two statistically similar groups (1) 2014 & 2015 and (2) 2012, 2013 & 2016 at the crop age of 10 weeks after planting (WAP) indicated increased powdery mildew severity at flowering and fruiting with change of sink-source relationships. Maximum severity at the end of crop season (14 WAP) in respect of two groups of seasons namely 2014 & 2015 and 2012, 2013 & 2016 was 45% and 80%, respectively (refer Figures). Seasonal mean severity amongst 2012 (48.3%), 2013 (43.4%) and 2016 (47.2%) was on par and significantly higher over 2014 (34.1%) and 2015 (24.8%) and non-significant over cultivars and planting periods (refer the bar graph). With no differences for the powdery mildew severity between cultivars and the planting periods, it is possible that the weather of the seasons could have played a role.



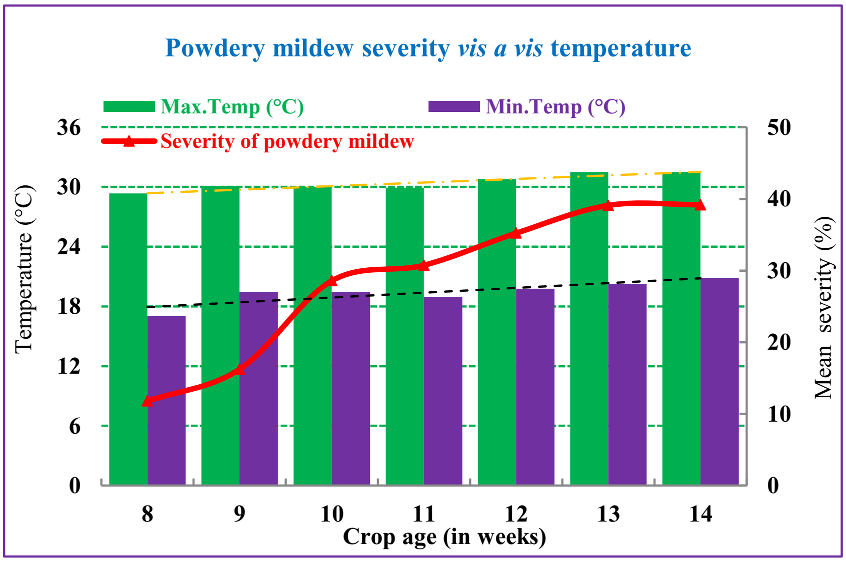
An attempt to look into the variations in seasonal means of temperature revealed significant differences (Table 67). While the order of increase for maximum temperature was 2015 & 2012>2016, 2014&2013, it was 2016, 2015&2014>2013&2012, 2015&2016>2014, 2012>2013 for minimum and mean temperature, respectively.

Table 67. Mean seasonal temperature for study seasons of *kharif* tomato at Bengaluru (KA)

Weather variable	2012	2013	2014	2015	2016	F value & its significance #
MaxT (˚C)	30.1[a]	28.4[b]	28.8[b]	30.4[a]	28.9[a]	5.04**
MinT (˚C)	19.1[b]	19.3[b]	20.6[a]	20.6[a]	20.8 [a]	9.38**
MeanT (˚C)	24.6[b]	23.9[c]	24.7[b]	25.5[a]	24.9[ab]	6.20**

#: significance of 'F' denoted by *: p<0.05 ; **: p<0.01; In a row means followed by the same letter are not significantly different based on DMRT

Such a trend did not completely explain the two groups of seasons observed for disease severity again point out to the factors in addition to temperature involved in determining severity at any one period along the crop growing season. Association of high levels of powdery mildew severity with high vegetative vigour and cultural practices that favour vegetative vigour predispose host to an increased development of disease**.** Report of high nitrogen supply increasing severity of tomato powdery mildew *Oidium lycopersicum* in addition to a very dense, poorly ventilated and poorly illuminated canopy offering favourable micro-climate to powdery mildew development. Considering the high severity seasons (2012, 2013 and 2016) of powdery mildew of the current study, it is inferred that the ranges of maximum, minimum and mean temperature congenial for disease progressions under field conditions were 28.4 to 30.1°C, 19.1-20.8 °C and 23.9-24.9 °C, respectively at the eastern dry zone of Karnataka. Since the weather variables of different periods ranging from a week to fortnight could affect the severity levels and that step down regression approach identifies only the significant variables of influence dependence of powdery mildew severity (%) in relation to weather variables (maximum and minimum temperature, morning and evening humidity, sunshine hour, wind velocity, total rainfall and rainy days) corresponding to current, one and two lag weeks were considered for multiple linear regression model (MLR). Since the trends of disease severity during all seasons were the same, aggregate data sets of 2012-2016 were used to identify the nature and degree of weather factor influence. Such a MLR brought out an equation of the form: powdery mildew severity (%) =0.431 + 0.025 $MaxT_0$ - 0.024 $MinT_0$ (R^2: 0.036*; $p<0.05$) where T_0 represents the weather factor of the current week. The positive effect of maximum temperature and an equally negative impact of minimum temperature imply the importance of increased temperature in positive progression of the disease (as indicated by positive intercept). With only 3% variation of powdery mildew severity explained by temperature the way forward would be to understand the effect of agronomic practices on crop canopy and phenology of tomato production to effectively manage the disease. Investigation on the interaction of atmospheric variable of temperature with other system variables of tomato production would enhance further understanding of additional factors determining powdery mildew severity.



Rajendranagar [Telangana (TS)] [ACZ: Southern Plateau and Hills Region; AER: Deccan plateau and eastern ghat, hot semi- arid ecoregion]

Absence of thrips (*Thrips tabaci*) due to uniform distribution of rainfall in *kharif* and higher population favored by dry spells throughout *rabi* were recorded. Increasing population of mirids (*Nesidiocoris tenuis*) and damage by white grubs in red soils of rainfed grown tomato were reported during 2012 at Shamshabad. Leaf miner *T. absoluta* infestation of 14-97% was reported for the first time during March 2015 along with naturally occurring predators such as spiders *(Argiope* sp*),* and mirid bugs (*N. tenuis*). Continuous rainfall during *kharif* 2013-14 at Moinabad led to low levels of aphids and whiteflies throughout the crop growth period. Leaf miner incidence during first few weeks of crop growth and fruit borer *Helicoverpa armigera* between flowering and fruiting stage were noted. *T. absoluta* had become an established insect with maximum trap catch of 24 adults/trap in 34 SMW during *kharif* 2016 and 40 adults/trap in *rabi* 2016-17. *H. armigera* and mite infestations were higher during *rabi* than *kharif.* Increasing viral diseases were noted since 2011. During field surveys, symptoms like big bud and phyllody were observed on tomato in Moinabad and Shamshabad Mandals in Ranga Reddy district of Telangana from 2014-2016 causing 100 per cent yield loss in affected plants. Incidence of big bud phytoplasma causing elongated calyx uniting to form green bud like structure with the flowers becoming sterile was confirmed for the first time during *rabi* 2014 and the severity was16-20% and 43% at Moinabad and Shamshabad mandals, respectively. Molecular characterization of big bud, a phytoplasma disease that occurs to an extent of 10-16% was done through nested and semi nested PCR assays primed by primer pairs P1/P7 and R16F2n/R16R2 for *16S rRNA*. DNA fragments of 1.2 kb (R16F2n/R16R2) and 480 bp (secAF2/R3) were amplified from symptomatic tomato samples.

Big bud phytoplasma **Green buds** **Sterile flowers**

A representative amplicon of *Cucurbita pepo* phytoplasma strain was purified and sequenced directly. Study confirmed association of 16Sr II-D subgroup of phytoplasma associated with tomato big bud disease in Telangana State of India.

Simultaneous occurrence of bacterial spot, bacterial blight and early blight of tomato with incidence levels up to 40, 20 and 40% during alternate wet and dry period of 30-35 SMWs across mandals of Rangareddy (TS) was observed. The incidence was upto 42 % during *kharif* 2015 when increased temperature of 0.5 to 2°C over normal of the preceding five years was noted coinciding with the active crop growth stage. Continuous rainfall between 29 and 44 SMWs of 2013 resulted in increasing bacterial spot (*Xanthomonas vesicatoria*) incidence from 34 - 47 SMW reaching 60- 85% at crop maturity during *kharif.* Its incidence was high (up to 80%) during March and April 2014 in *rabi* tomato. Very heavy rains (390 mm) during September 2016, the highest over half a decade not only affected the plant stand but resulted in higher buck eye rot on fruits due to *Phytophthora nicotianae* var. *parasitica*.

Early blight infestation across *kharif* seasons, cultivars and planting dates

Early blight initiated as early as 29 SMW (July third week) in 2012 and the latest by 36 SMW (September first week) in 2011 and 2013 in terms of calendar year (SMW based). However, onset in terms of crop age indicated crop of one week after planting (WAP) during 2011 and seven WAP in 2015 and 2016 had shown initial symptoms thus indicating early or delayed onset of disease. Periods of peaks of severity in terms SMW and crop age across seasons ranged from 36 to 46 SMW (September first to November second weeks) and 9-14 WAP, respectively (Paul *et al.,* 2019; Vennila *et al.,* 2020c). Mean seasonal severity across years indicated similar trends on calendar (SMW) as well as crop age (CA) basis. Highest mean severity was observed in 2012 followed by 2015 (Table 68).

Four seasons *viz.,* 2011, 2013, 2014 and 2016 had on par severity lower over 2012 and 2015. Direct proportionality of peak and mean severity levels noted for individual years imply that peaks always govern the differences in seasonality across seasons. Differing periods of onset and peaks of early blight severity besides disease progressions across seasons provided clues that varied factors of higher importance are involved in disease manifestation over crop age. Effects of cultivars and planting periods on early blight (EB) severity studied over six *kharif* seasons (2011-16). Progress of disease in respect of cultivars pooled over seasons along crop age are depicted in Figure with respective trends described as polynomial equations (Table 69) of second order.

Table 68. Severity of early blight *A. solani* across seasons at Rajendranagar (TS)

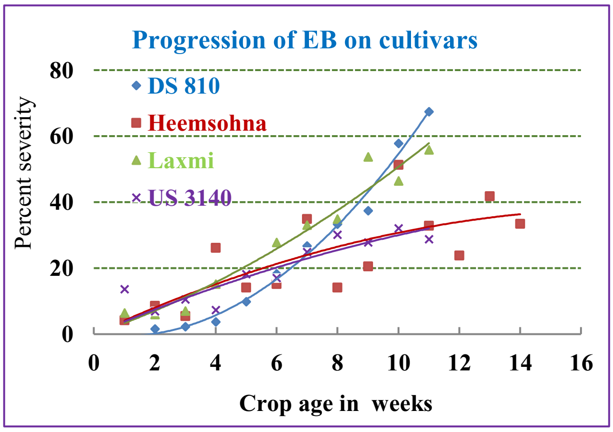
Particulars	2011	2012	2013	2014	2015	2016
Period of onset* SMW (CA in weeks)	36 (1)	29 (4)	36 (3)	33 (5)	34 (7)	32 (7)
Period of peak severity* SMW (CA in weeks)	42 (9)	46 (14)	46 (12)	38 (13)	37(12)	36 (13)
Peak disease severity*	24.6	97.6	44.5	40.8	58.2	26.4
Seasonal mean severity (%) (on SMW basis)[$]	16.3[c]	47.8[a]	20.8[c]	13.6[c]	37.2[b]	19.1[c]
Seasonal mean severity (%) (on CA basis)[$]	19.5 [c]	64.1[a]	20.9 [c]	16.0 [c]	43.5 [b]	19.7[c]

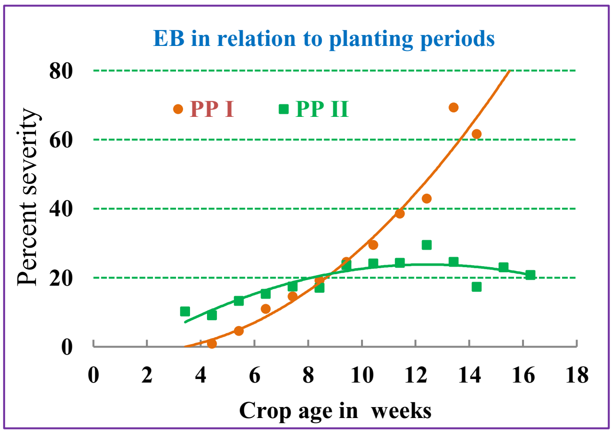
*: based on initial incidence across 10 fields; [$]: means with similar alphabet in row are not significantly different based on DMRT following one way ANOVA at $p<0.05$; values in parentheses correspond to crop age expressed in weeks after planting

Table 69. Cultivar effects on early blight severity at Rajendranagar (TS)

Cultivar	Equation on disease progression	Mean severity (%)*
Heemsohna	$= -0.12x^2 + 4.27x$ ($R^2 = 0.56$)	24.2[a]
US 3140	$= -0.09x^2 + 3.92x$ ($R^2 = 0.78$)	20.8[b]
DS 810	$= 0.67x^2 - 1.24x$ ($R^2 = 0.98$)	25.2[a]
Lakshmi	$= 0.19x^2 + 3.18x$ ($R^2 = 0.95$)	21.8[b]

*: means with similar alphabet as superscript in a row are not significantly different based on DMRT following one-way ANOVA performed on aggregate data of 2011-16





Cultivar effects of early blight was noted in terms onset and rate of progression on four commonly grown tomato hybrids. Early onset at least by a week in Heemsohna, Lakshmi and US3140 with similar rate of progression up to four WAP was noted. Disease severity increased with crop age. Rate of progression was similar for Heemsohna and US 3140 till crop maturity unlike Lakshmi which had higher rates beyond four WAP. On the other hand, DS 810 had slow progression till seven WAP with steep increase thereafter.

Early blight progression in relation to planting dates

Progression of early blight described along crop season using second order polynomial curves in respect of two planting periods PP I (June & July- early plantings) and PP II (August &September-late plantings) are shown in Table 70 and refer figure. Initial rate of progression of early blight was higher for late over early plantings up to eight weeks of crop age possibly due to the availability of inoculum from the early plantings. However, steeper rate of progression observed with early over late plantings beyond mid-season indicated relative susceptibility of early-plantings to early blight.

Table 70. Effects of date of sowing on early blight severity at Rajendranagar (TS)

Date of sowing	Equation on disease progression	Mean severity (%)*
June & July (PP I)	$= 0.42x^2 - 1.35x$ ($R^2 = 0.95$)	27.9[a]
August & September (PP II)	$= -0.13x^2 + 3.39x$ ($R^2 = 0.74$)	19.1[b]

*: means in a column with similar alphabet as superscript are not significantly different based on 't' test with equal variances (n_1=172 and n_2=198)

Significantly higher mean disease severity in early (27.9%) over late (19.1%) plantings described by equations also confirm the above finding by way of the opposite signs associated with intercept and coefficient. The drop in disease progress in late plantings could also be due to many cultivars carrying different levels of resistance to early blight besides number of cultivars in the mixture influencing the disease progress. In the present study, the groupings for PP I accounted five cultivars, and that of PP II had eight cultivars and the later PP had significantly lower severity as well as slower rate of progression.

Differentiating weather fluctuations and climatic variability/change impacts on EB

Weather and climatic variability across seasons: Range of A-MaxT, A-MinT and A-RF across crop seasons was 30.1 to 32.1°C, 22-23°C and 21-44.8 mm/week, respectively. Climatic variables D-MaxT, D-MinT and D-RF had values of -0.32 to 1.7°C, 0.4 to 1.5°C and -2.5 to 18.1 mm/week, respectively. While one-way ANOVA on weather (A) variability indicated significance for A-MaxT alone, D-MaxT and D-MinT showed significance across seasons. Seasons 2014 and 2015 had significantly higher A-MaxT over 2012, 2013 and 2016 with 2011 on par with all other seasons. Climatic variable D-MaxT had three groups with significantly higher values 2014 and 2015 similar to A-MaxT for D-MinT, 2014 had the highest mean deviation that was on par with 2015 and 2012 followed by non-significant differences among 2011, 2012, 2015 and 2016 seasons. Means of weekly rainfall (both A-RF & D-RF) were not significantly different across seasons under weather as well as climatic situations (Table 71).

Table 71. Weather fluctuations and climatic variability at Rajendranagar (TS)

Particulars	2011	2012	2013	2014	2015	2016	'F' value
Weather variability							
A-Max T (°C)	31.2[ab]	30.7[b]	30.8[b]	32.0[a]	32.1[a]	30.1[b]	3.8**
A-Min T (°C)	22.2	22.4	22.0	23.0	22.5	22.0	1.1 NS
A-RF (mm/week)	26.7	32.5	27.9	24.1	21.0	44.8	0.8 NS
Climatic variability							
D-MaxT (°C)	0.8 [b]	0.3[bc]	0.4 [bc]	1.6[a]	1.7[a]	-0.3[c]	4.9***
D-MinT (°C)	0.6[b]	0.8[ab]	0.4[b]	1.5[a]	1.0[ab]	0.4[b]	2.6*
D-RF (mm/week)	0.04	5.8	1.2	-2.5	-5.6	18.1	0.8NS

[#] Significance of 'F': * $p<0.05$; **: $p<0.01$; ***: $p< 0.005$; NS-Not Significant; In a row means followed by the same letter are not significantly different based on DMRT

Association of early blight severity with weather and climatic variables

For individual seasons - Associative analysis using Kendall's correlations of early blight severity with actual weather and climatic deviations for individual and pooled seasons was made to understand the responses of pathogen manifestation in fields in relation to short and long term weather and climate variations, respectively. Early blight severity showed significant positive association with A-MaxT during 2011 and negative during 2013 and 2016. With A-MinT, the only significant association was negative in 2013. A-RF had shown negative and positive significance in respect of 2012 and 2016. Despite non-significant differences of A-MinT and A-RF across seasons, the significant association of these weather variables with disease severity in one or more seasons might have arisen due to the variations in distribution pattern. In climatology, it is often found that the mean for weather variables over a period for different seasons are constant but their distribution varies. Such variations in respect of A-MinT in 2013 and A-RF during 2012 and 2016 possibly had an influence on disease progression of early blight. Kendall correlations between disease severity and the deviations of actual weather from long term normal representing effect of climate variability had similar significance as that of actual weather but for non-significance with D-MaxT. Significance of D-MinT association with disease was similar to that of A-MinT although weather and climatic variabilities for MinT was significant and non-significant, respectively across seasons (Table 72).

Table 72. Association of actual weather and climatic deviations *vis a vis* early blight severity at Rajendranagar (TS)

Variable	2011	2012	2013	2014	2015	2016
Early blight associations with weather variability						
A-MaxT (°C)	0.57**	0.20	-0.48*	-0.14	-0.33	-0.60*
A-MinT (°C)	0.007	-0.26	-0.56**	-0.35	-0.33	-0.20
A-RF (mm/week)	0.06	-0.34*	0.27	-0.40	0.33	0.69*
Early blight associations with climatic variability						
D-MaxT (°C)	0.085	0.100	-0.21**	-0.116	0.012	-0.51**
D-MinT (°C)	-0.025	-0.001	-0.18*	-0.206	0.011	-0.18
D-RF (mm/week)	0.066	-0.22*	-0.001	-0.005	-0.104	0.62**

All figures are the Kendall's correlative values; # Significance of 'τ': * $p<0.05$; **: $p<0.01$

On the other hand, the associations of A-RF and D-RF were significant in negative and positive during 2012 and 2016, respectively despite non-significant differences of RF across seasons for weather and climatic terms. While similarity of associations between weather and climatic variables indicate the ongoing adaptability of early blight organism to changing climate. The capability of *A. solani* to grow over a temperature of 4 - 36°C makes it highly adaptable. The shift of highly significant positive association of A-MaxT to non-significance in 2011 followed by all the significant associations being negative in later seasons (2013 and 2016) speculates an expected decline of disease with increasing MaxT. It is highly difficult to attribute such a significance at this stage based on analysis along individual seasons although the differential contribution by other biotic or interactive factors during each season could be a plausible explanation.

For all seasons - Magnitude of climatic variability over seasons (2011-16) quantified using normals of MaxT, MinT and RF indicated their significant increase to the tune of 0.7 (°C), 0.8 (°C) and 3.6 mm/week, respectively during *kharif* tomato with their distributions also displaying significance as observed through significance of equality of variances. Such a significance for mean and variances only emphasize the observed seasonal variability for associations in respect of individual seasons as in Table 73. Kendall correlations worked out between early blight disease severity, weather and climatic variability values considered over seasons (2011-16) indicated negative significance of A-MinT and of D-MaxT. D-RF had positive influence on early blight severity. It was obvious that the quantified increases of MaxT and MinT had negative impact and that of increasing RF had positive effect on early blight on tomato.

Table 73. Impact of climate change on early blight severity at Rajendranagar (TS)

Variables	Actual Mean	Magnitude of climate change#	Equality of variances	Kendall 'τ' EB severity with	
				Actual (A) weather	Deviations (D) from normal
MaxT (°C)	31.8	0.7*	**	-0.04	-0.08*
MinT (°C)	22.5	0.8**	**	-0.18*	-0.03
Rainfall (mm/week)	28.3	3.6***	***	0.03	0.10**

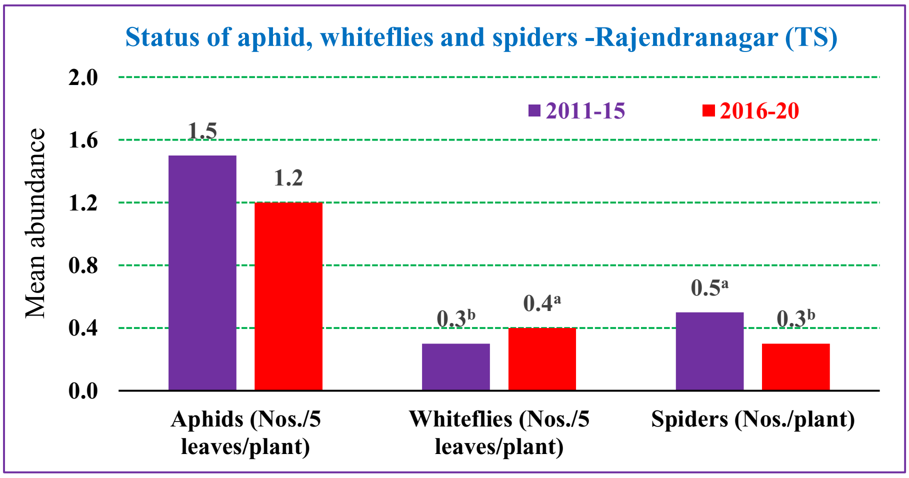
#: Mean deviation (actual minus normal) of variables compared based on Student's t test with significance of 't': *p<0.05 ; **: p<0.01;***: p<0.001

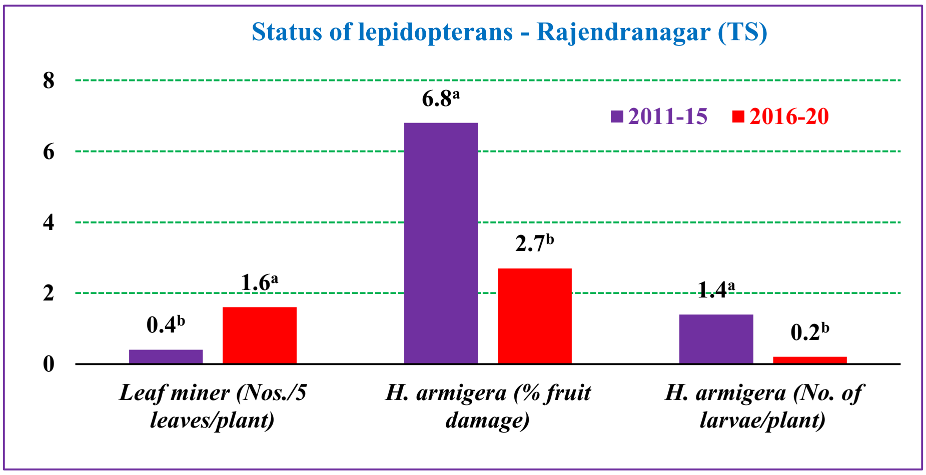
It would not be an understatement to conclude that the interplay of increasing temperature and rainfall variables determine the disease severity of early blight at Telangana State on tomato. Positive significant effect of rainfall and relative humidity in the growth and development of early blight is well known (Chaerani, and Voorrips, 2006). Early blight is most damaging in regions with heavy rainfall, high humidity and high temperatures (24 - 29°C). Mean temperature during the different seasons (2011-16) of the present investigation ranged between 26.4 and 27.5°C within limits of congenial conditions.

In essence, significance of weather fluctuations for maximum temperature and climatic variations for maximum and minimum temperature across seasons was noted. Similarities in significance of associations of early blight severity with weather and climatic variability along individual seasons indicated possible adaptations of early blight to climate change. With the increasing MinT fluctuations and MaxT variability having negative impact and increasing rainfall with positive effect on early blight severity, it remains to be seen the role of interplay of increasing temperature and rainfall on disease severity in the coming seasons so as to strategize production practices and early blight management on tomato. Multiple and frequent change in cultivars possessing varied resistance to early blight season to season, growing conditions, weather factors markedly influenced the early blight progress.

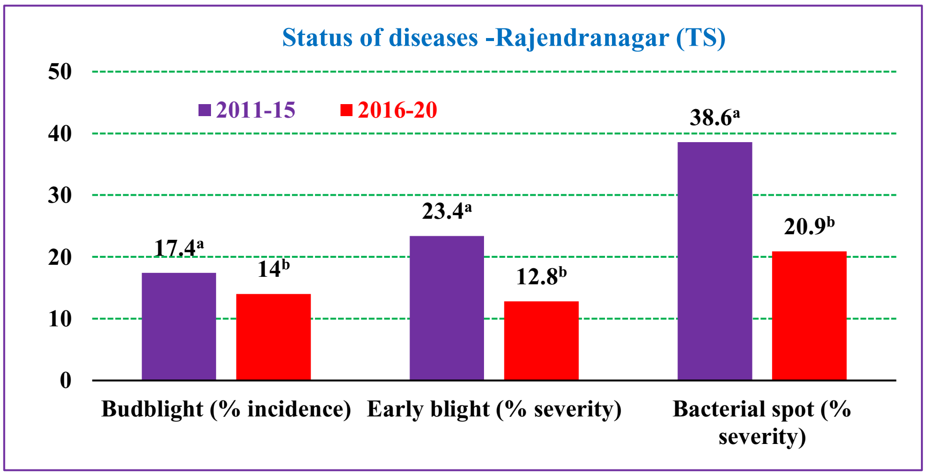
Status of major insects and diseases – a half decadal comparison

Aphids maintained similar status between two halves of 2011-20 decade indicating the unchanging abundance on a seasonal basis. While whiteflies had significant increase, the spiders, a significant decrease during the second half (2016-20). Among lepidopteran insects, *H. armigera* fruit damage and abundance had been higher significantly during 2011-15 over 2016 - 20 implying the reduced *H. armigera* and its damage to tomato in the recent past over the past. Leaf miner increase on tomato was on an average four times significantly higher in the latter half (2016 -20).





Diseases *viz*., bud blight, early blight and bacterial spot compared for their differential status over the two periods of the decade had shown declined incidence/severity during 2016-20 at Telanagana region.



Rahuri [Maharashtra (MH)] [ACZ: Western Plateau and Hills Region; AER: Deccan plateau aravallis hot semi- arid ecoregion]

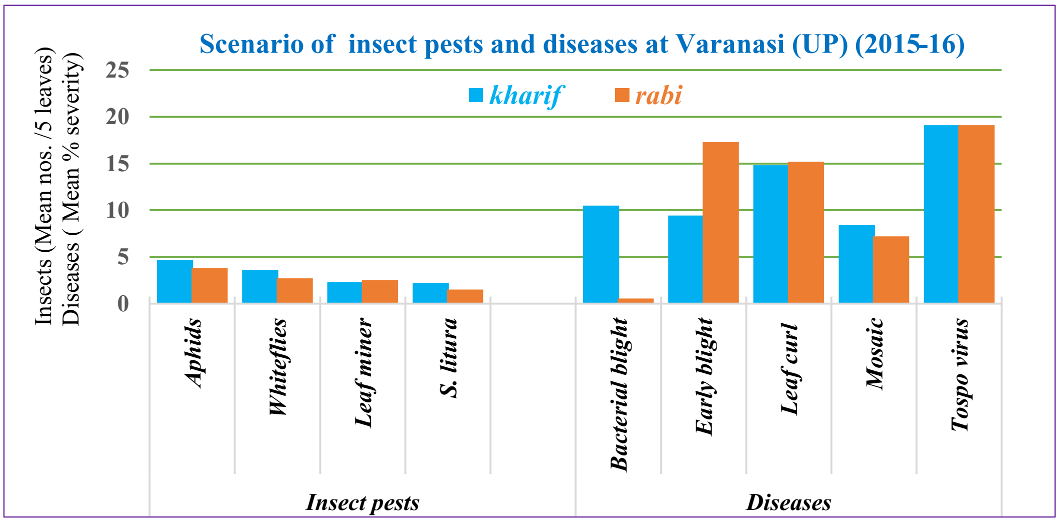
Increased leaf miner and whiteflies from 2012 to 2013 in *kharif* and their decrease from 2012 to 2013 in *rabi* was noted. *Kharif* temperature variability higher than normal, and the occurrence of unseasonal rains at different periods varying with seasons of 2011-14 modulated the severity of powdery mildew (absent in 2013 to 27% in 2012).

Varanasi [Uttar Pradesh (UP)] [ACZ: Middle Gangetic Plains Region; AER: Northern Plain and central Highland including Aravalis, hot semi-arid ecoregion]

In *kharif* nursery of 2011, bacterial spot caused by *X. vesicatoria* was severe (100%). During *rabi*, early blight (*Alterneria solani*) was more rampant (30-75%) after a brief unprecedented rains during second fortnight of February 2013. Mosaic incidence varied from 20-25 % in both *kharif* and *rabi* of 2012-13. An unusual higher infestation (47.1 %) of root parasitic weed (*Orobanche* sp.) was observed in farmer fields at Bedawali, Basaratpur, Iswarpatti and Madhopur in 2012. While bacterial spot was higher in *kharif* 2015 over *rabi* and the converse was noted with early blight.

***Orobanche* infestation**

Incidence of viral diseases were almost similar during *kharif* and *rabi* of 2015-16.



South American pinworm *Tuta absoluta* (Lepidoptera: Gelechiidae) was recorded for the first time at Varanasi and Mirzapur districts starting January 2017. The highest mean trap catch was recorded at Iswarpatti and Chaudaripur (~17 nos/trap) and lowest at Parsupur (~ 4 nos/trap) during January - March 2017 (refer Figure) with leaf and fruit damage levels lower at all locations. Overall mean damage was greater at Varanasi over Mirzapur (Table 74).

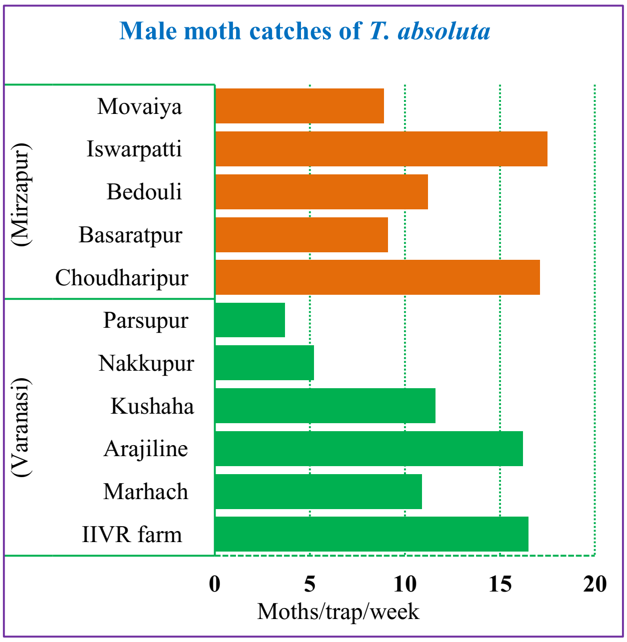
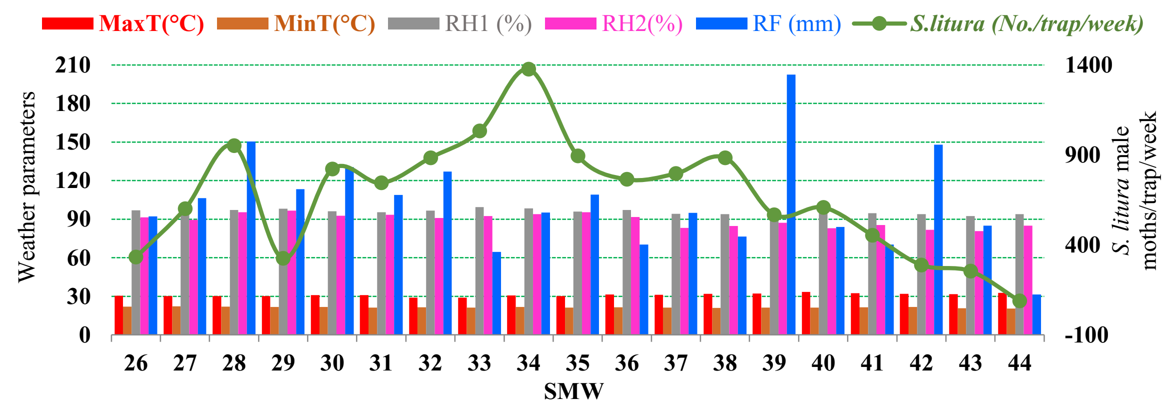


Table 74. Leaf and fruit damage due to *T. absoluta*

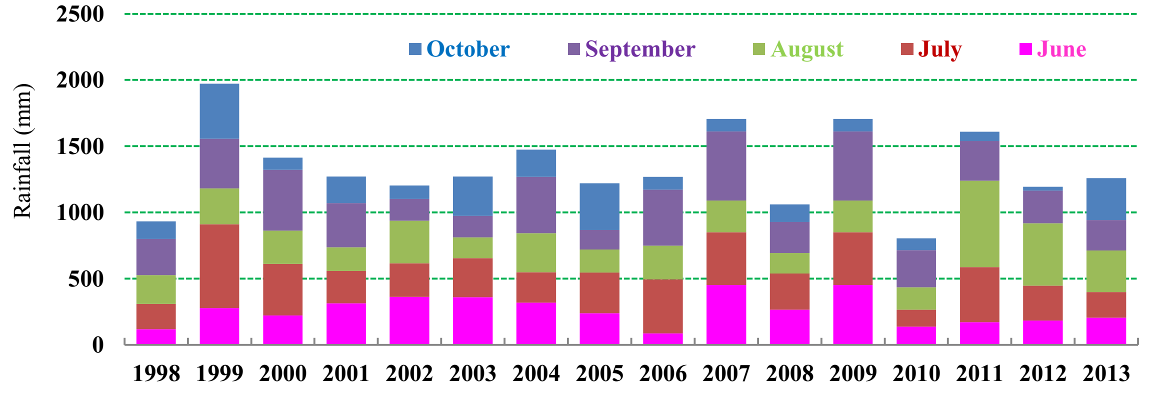
Name of village	Seasonal mean	
	Mines/plant	% fruit damage
(Varanasi)		
IIVR farm	0.33	0.82
Marhach	0.08	1.11
Arajiline	0.03	0.37
Kushaha	2.77	0.71
Nakkupur	0.29	1.39
Parsupur	0.17	0.30
(Mirzapur)		
Choudharipur	0.16	0.20
Basaratpur	0.74	0.05
Bedouli	0.19	0.83
Iswarpatti	0.99	0.39
Movaiya	0.19	0.34

Kalyani [West Bengal (WB)] [ACZ: Lower Gangetic Plains Region; AER: Bengal and Assam plain hot subhumid (moist) to humid (per humid) ecoregion]

Higher August rainfall delayed transplanting of tomato in 2011 with *S.litura* and *Liriomyza trifolii* assuming pest status. During autumn-winter of 2012-13, infections of leaf curl virus (30.8%) and target leaf spot (23.9%) were higher over 2011-12. *S. litura* and *L. trifolii* populations were lower during 2012-13 possibly due to the lower minimum temperature by 3.5ºC and no rainfall during January over the prevailing 13.2 ºC and 57 mm in 2011-12. The peak *S. litura* adult catches in pheromone traps noticed during May of 2013 was a shift from April observed in 1987 and 2012. Population of *S. litura* in 2014 and 2015 was the highest among the all the years (2011-15) with highest peak in April-May, a shift in peak period from March-April (1987 and 1988). However, there has been a decline in abundance of *S. litura* during November, the period of second peak coinciding with *rabi* tomato. The abundance of *S. litura* has increased during 2011-15 with two peaks, the first during summer (May-June), and the second during *rabi* (November). Higher minimum temperature during May and November from 2011 onwards were associated with higher *S.litura* in summer and *rabi*.



S. litura abundance vis a vis weather conditions



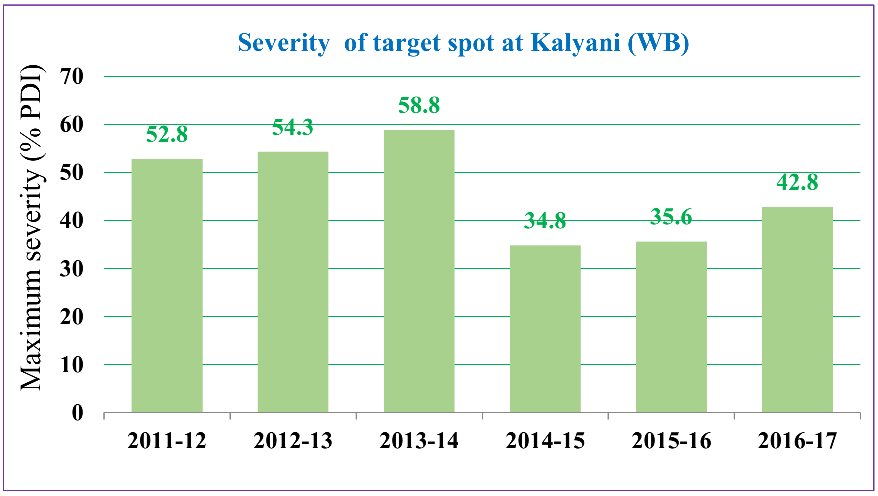
Changing rainfall distribution at Kalyani (WB)

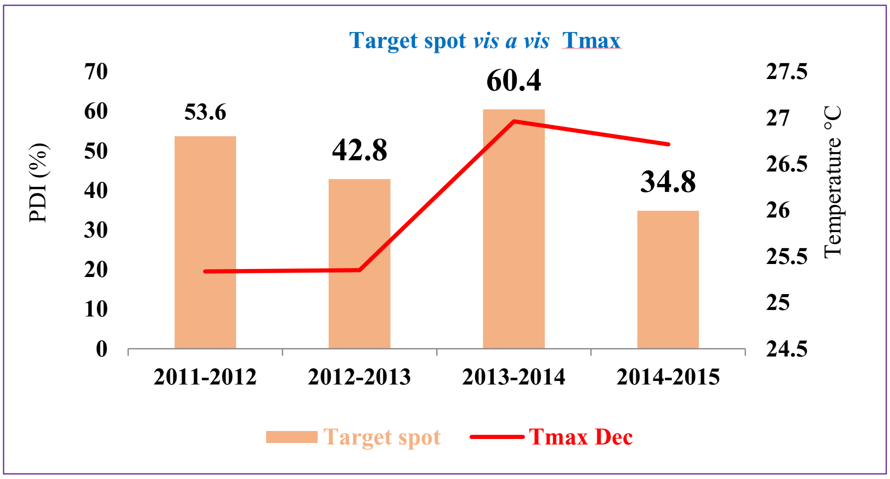
Late blight appeared in February since 2011 after its complete absence in previous two seasons (2009 and 2010). Target spot (*Corynespora cassiicola*) and the leaf curl virus are the economic pests. Incidence of *Corynespora* started in *rabi* 2011 with its onset between 44 and 50 SMWs. Leaf curl incidence and early blight during *rabi* of 2012-13 and 2013-14 were lower compared to 2011-12. All three seasons of *rabi* had different onset and the peak periods for diseases (2013-14>2012-13 >2011-12) and for the insects (Table 75). Planting dates shifted to October due to very heavy rainfall in August in a way changing the crop seasonality. *Rabi* tomato of 2015-16 had leaf curl and *C. cassiicola* leaf spot that initiated at 43 and 44 SMWs with the highest incidence and severity of 34 and 35.2% at 3 and 4 SMWs, respectively.

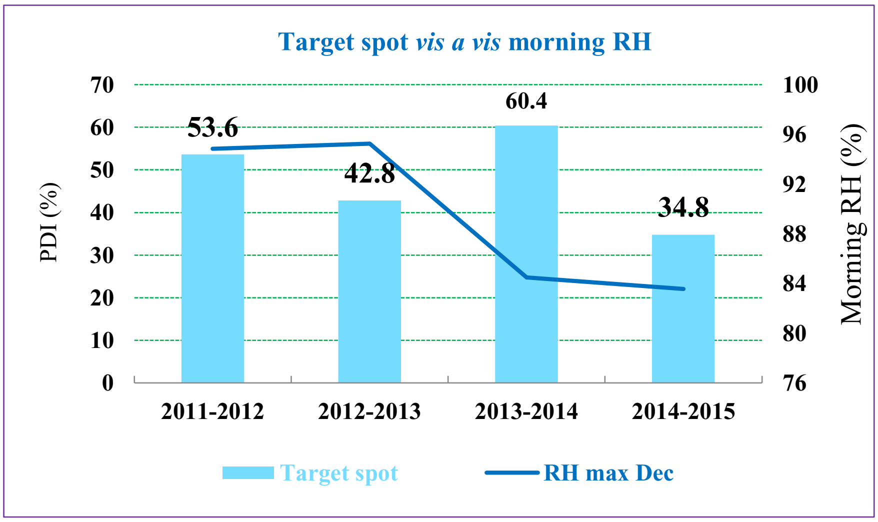
Table 75. Initiation and peak periods of insect pests on *rabi* tomato at Kalyani (WB)

Insect pests	2011-12		2012-13		2013-14	
	Initiation	Peak	Initiation	Peak	Initiation	Peak
Aphids	40	46	42-43	50	47-48	50
Whiteflies	37	46	40-41	45	45-46	47
Mites	40	44	43-44	49	47-48	51
Thrips	37-38	46	43-44	50	47-48	49
Leaf miner	40-41	46	47-48	5	51-52	8
S. litura	38-39	46	41-42	47	46-47	47
H. armigera	42-43	48	49-50	3	2	5
All values in the table correspond to the standard meteorological weeks (SMW)						

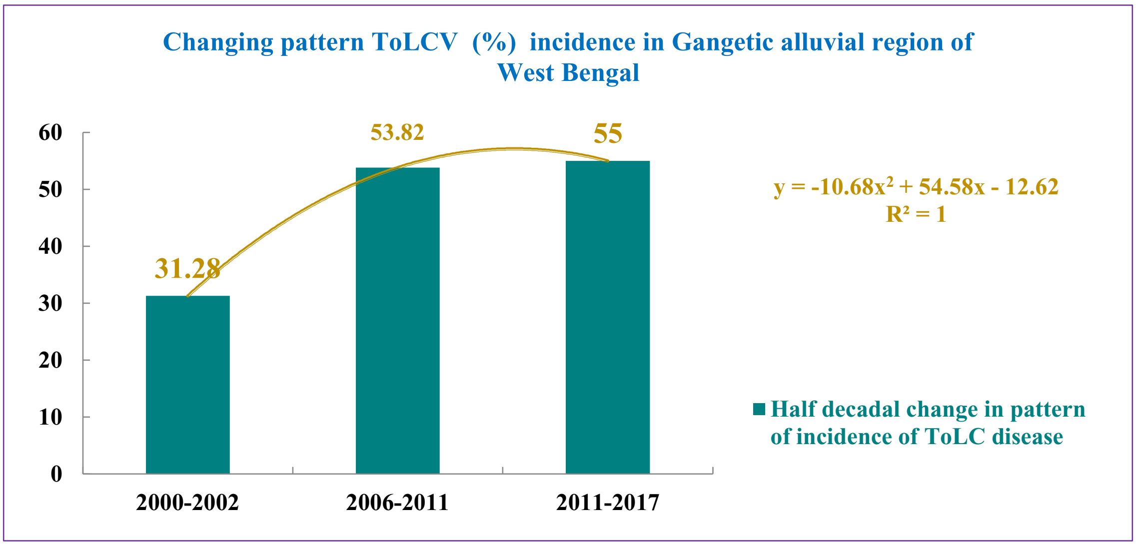
Investigation of foliar disease scenario of tomato made in the Gangetic alluvial plains of West Bengal using past and projected data indicated an increasing dynamics of incidence of tomato leaf curl and target leaf spot of tomato. Target leaf spot has emerged as a major disease during *rabi* tomato cultivation. Target leaf spot disease indicated highest record of the percent disease severity in 2013-14 as compared to other *rabi* seasons. Target spot disease initiated early at 42 SMW during the consecutive years 2011-12 and 2012-3 and appeared late during at 46 and 45 SMW in 2013-14 and 2014-15, respectively. Of the six years of observations, the first three years since its report in 2011 had higher overall mean severity in the region that was reduced in the following three seasons. The MRH decline was evident in the year of maximum severity of target leaf spot. Maximum temperature of December and January, irrespective of the year of observations, negatively influenced target leaf spot disease. Both early and late blight severity pattern showed a decreasing trend over the periods between 2011-12 and 2016-17. However, late blight disease occurred only sporadically. The morning relative humidity of January and December was positively correlated to the disease severity pattern of the early blight disease. Late blight usually found on summer tomato was noted during *rabi* 2015-16 with its initiation at 2 SMW when the mean minimum temperature was the highest (17.3°C) compared to previous four years (14.7 to 17 °C). Humidity greater than 85% brought about by rainfall during 3 SMW intensified late blight severity.







Further, total rainfall and average maximum temperature in January of all the observed years were identified as the important determinants of the temporal difference between disease initiation and attaining peak incidence of ToLCV. The pattern of an increase in total rainfall in January along with a decrease in average Tmax for the month of December extended the temporal difference between disease initiation and attaining peak disease incidence of ToLC disease and was solely due to the effect of



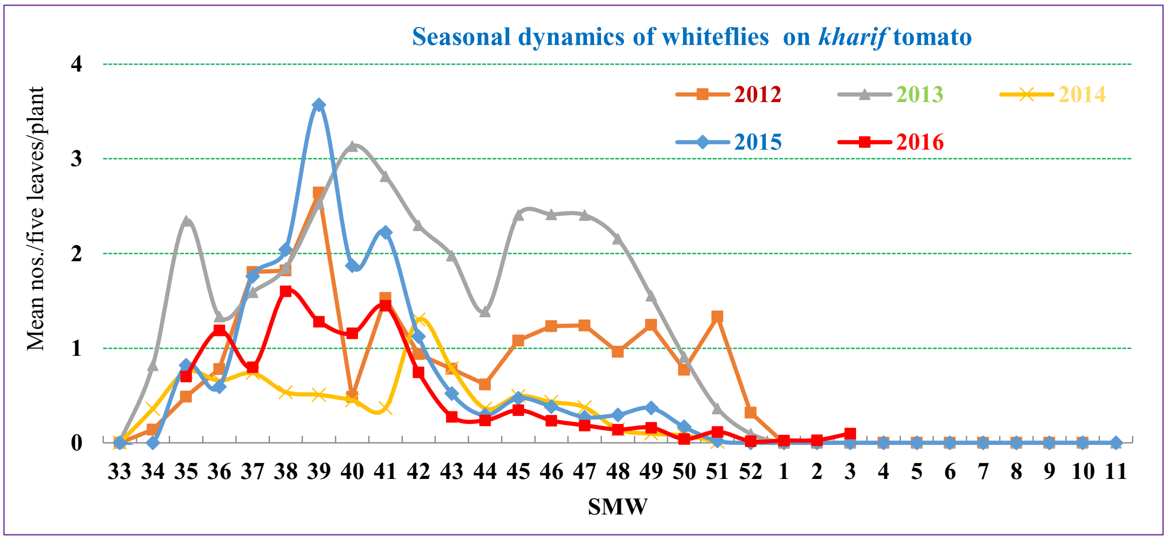
temperature on the vector activities (Adam Kamei *et al.,* 2020). Overall comparisons led to the changing pattern of ToLCV in the regions as given in the figure.

Tomato fruit damage due to *H. armigera* was greater during *rabi* over *kharif*, highest during 2011-12 over other years as compared to that of 1987-88. Simultaneous comparisons of locations between seasons (*kharif* and *rabi*) for each pest reflected the general trends of its status, similarities or otherwise over space and time.

Ludhiana [Punjab (PB)] [ACZ: Trans-Gangetic Plains Region; AER: Northern Plain and central Highland including Aravalis, hot semi-arid ecoregion]

Mealybugs and thrips among insects and bacterial spot, leaf curl, mosaic and *tospo* virus among diseases emerging at Ludhiana (PB) were documented in 2011 under situations of delayed transplanting. Survival of leaf miner during frosty winter and delayed winter resulting early termination of *kharif* crop by a month also happened in 2011. Higher incidence of *S. litura* was observed between September and October 2012 as against August and September 2011. High leaf miner infestation occurred in December 2012 unlike during October and November 2011. Fruit cracking occurred whenever the difference between day and night temperatures was wider (frost days) during December and January 2012. Aphids and whiteflies were low during *kharif* 2013 with the leaf miner population increasing from second week of November to mid-December with peak in December. Leaf miner population declined to traces with lowering of temperature and frost during December last week (frost days on 25-30 December, 2013 and 4-7 January, 2014). *H. armigera* damage to fruits was to a maximum of 15% between second fortnight of February and March 2014. Damping off incidence was higher in August (12.5 - 60%) due to heavy rains and high temperature necessitating gap filling in the main fields during first week of September 2013. Damping off (70-80%**)** occurred in nursery sown during mid-October leading to resowing of nursery for the *rabi* crop. Severity of early blight was always low, possibly due to the lower inoculum governed by the features of cropping system and varietal scenario *vis a vis* crop phenology. Tomato leaf curl virus incidence in *rabi* 2014 was 8 % at the end of August and increased to 22 and 44% during early September to November end respectively. Tomato leaf curl virus New Delhi strain from Ludhiana and Patiala, and Palampur strain in Patiala were recorded in 2015 with their incidence ranging 20-30% and 30-80%, respectively. *Rabi* tomato had 40-50% severity of late blight during third week of March

2015 (12 SMW) at Patiala. Whitefly incidence in 2015 was low (0.72-0.92 adults/leaf) from August to first week of September. Population increased (0.88-7.32 adults/leaf) from second week of September



and reduced to moderate levels (0.28-2.88 adults/leaf) during mid-October and to traces in mid-December due to lowering temperature. The progression of tomato leaf curl virus (ToLCV) was 8, 16, 38, 42, 50, 62, 66, 68 and 70% in respect of third week of September, end of September, first week of October, second week of October, first to fourth week of November and December with same level of incidence till third week of March 2016. Higher initial ToLCV incidence could be due to the hot and humid conditions combined with lesser rainfall during August and September 2015 that were conducive to the vector. Status of tomato diseases as inferred through random surveys at different places other than NICRA study locations in relation to observed weather variability are furnished in Annexure XXIX.

Inter seasonal variations of insects and diseases of *kharif* tomato

The seasonal dynamics of the insects and progression of diseases that were important in respect of tomato study locations (six) during *kharif* (refer Annexure Ia & Ib; Annexure II and Annexure Va & Vb) are presented graphically and arranged insect and diseasewise (Annexure XXX).

Insects: Aphids, whiteflies and leaf miner among insects and spiders as predators were found at all study locations. While significance of thrips was noticed at Rajendranagar (TS) and Rahuri (MH), mites were important at Bengaluru (KA) followed by Rahuri (MH) and Raipur (CG). Despite the inter seasonal variations over years for aphids, which had occurred at all locations, their pest status was hardly noticed. Rahuri (MH)>Rajendranagar (TS) was the order of importance for thrips and their inter-seasonal variations were significant as against the very low populations (0.2-0.9 no./five leaves /plant) not significant across years at Varanasi (UP). For whiteflies, 2013 was the year of significance at Rahuri (MH) with higher population (2.7 nos/5 leaves/plant). Ludhaina (PB) had significantly higher whiteflies in 2013>2012>2015>2014 & 2016. Bengaluru (KA) had higher mites in 2012 over the ensuing seasons of 2013-2016. Varanasi (UP) had the highest of whiteflies in 2011 and the lowest between 2012 and 2014. Leaf miner infestation was significantly higher during 2012 at Raipur (CG) and 2012 and 2013 at Ludhiana (PB). Amongst six locations of different climatic zones, Rahuri (MH) had the highest *H. armigera* population as well as its damage to fruits. Raipur (CG) showed the least fruit damage due to *H. armigera*. *S.litura* occurrence on *kharif* tomato was lower and found only at Varanasi (UP) and Ludhiana (PB). The fruit damage due to *H. armigera* at Rajendranagar (TS) was the highest in 2020 (Anonymous, 2020) with preceding nine seasons. Increasing trend of *H. armigera* damage was noted at Rahuri (MH) from 2012 with highest (26.3 %) in 2015. Coccinellids were obvious only at Rahuri (MH). Inter-annual variations for spiders were significant at all locations but for Rajendranagar (TS). Varanasi

(UP) in general had relatively higher mean population levels of spiders over other locations that had significant variations amongst years (Table 76).

Table 76. Inter seasonal variations of insects of *kharif*

Insect	Location	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	F value
Aphids (nos./5 leaves/plant)	Bengaluru (KA)	-	0.5^{b}	1.0^{a}	0.4^{b}	0.2^{c}	0.4^{b}	-	-	-	-	17.3***
	Rajendranagar (TS)	0.5^{def}	4.4^{a}	0.5^{ef}	0.3^{f}	1.2^{cde}	1.2^{cd}	2.3^{b}	0.4^{ef}	0.8^{cdef}	1.1^{c}	19.8***
	Rahuri (MH)	-	1.4^{d}	2.5^{a}	1.8^{c}	2.1^{b}	-	-	-	-	-	19.7***
	Raipur (CG)	-	4.09^{a}	0.44^{b}	0.66^{b}	0.54^{b}	0.67^{b}	-	-	-	-	85.6***
	Varanasi (UP)	1.2^{a}	0.5^{bc}	0.7^{c}	0.2^{bc}	0.1^{b}		-	-	-	-	12.1***
	Ludhiana (PB)		3.59^{a}	-	0.28^{b}	0.43^{b}	4.62^{a}	-	-	-	-	19.21***
Thrips (nos./5 leaves/plant)	Rajendranagar (TS)	0.6^{bc}	0.1^{c}	1.2^{a}	-	1.0^{ab}	0.2^{c}	0.4^{bc}	0.4^{bc}	0.2^{c}	0.3^{c}	8.6***
	Rahuri (MH)	-	1.4^{c}	2.3^{a}	1.9^{b}	2.1^{b}	-	-	-	-	-	18.7***
	Varanasi (UP)	0.4^{a}	0.2^{a}	0.5^{a}	0.9^{a}	0.4^{a}	-	-	-	-	-	0.9^{NS}
Whiteflies (nos./5 leaves/plant)	Bengaluru (KA)	-	0.4^{a}	0.2^{b}	0.2^{b}	0.2^{b}	0.4^{a}	-	-	-	-	6.2***
	Rajendranagar (TS)	0.4	0.3	0.2	0.1	0.1	0.2	0.4	0.3	-	0.9	0.5^{NS}
	Rahuri (MH)	-	1.9^{c}	2.7^{a}	1.8^{cb}	1.8^{b}	-	-	-	-	-	9.7***
	Raipur (CG)	-	0.75^{a}	0.31^{b}	0.56^{a}	0.5^{ab}	0.64^{a}	-	-	-	-	8.7***
	Varanasi (UP)	0.8^{a}	0.4^{cd}	0.41^{cd}	0.6^{b}	0.8^{b}		-	-	-	-	8.81***
	Ludhiana (PB)	-	1.25^{b}	1.75^{a}	0.6^{d}	1.02^{c}	0.53^{d}	-	-	-	-	62.9***
Mites (nos./5 leaves/plant)	Bengaluru (KA)	-	30.0^{a}	18.1^{b}	13.3^{b}	2.7^{c}	14.1^{b}	-	-	-	-	14.1***
	Rahuri (MH)	-	1.3^{a}	0.7^{b}	-	0.6^{b}	-	-	-	-	-	146.8***
	Raipur (CG)	-	0.05^{b}	0.18^{a}	0.15^{ab}	0.07^{ab}	0.1^{ab}	-	-	-	-	3.03*
Leaf miner (nos./5 leaves/plant)	Bengaluru (KA)	-	1.0^{ab}	1.1^{a}	0.8^{b}	0.4^{c}	0.5^{c}	-	-	-	-	12.2***
	Rajendranagar (TS)	0.1^{c}	0.6^{c}	0.3^{c}	0.6^{c}	0.1^{c}	0.1^{c}	0.2^{c}	0.4^{c}	3.6^{a}	1.5^{b}	43.9***
	Rahuri (MH)	-	1.5^{c}	2.3^{a}	1.3^{b}	1.3^{b}	-	-	-	-	-	18.4***
	Raipur (CG)	-	2.45^{a}	0.22^{c}	0.75^{b}	0.28^{c}	0.64^{b}	-	-	-	-	27.7***
	Varanasi (UP)	0.9^{a}	0.8^{ab}	0.2^{c}	0.2^{bc}	0.8^{bc}		-	-	-	-	11.9***
	Ludhiana (PB)	-	2.12^{b}	2.18^{a}	0.37^{d}	0.74^{c}	0.41^{d}	-	-	-	-	172.3***
H. armigera (larvae/plant)	Rajendranagar (TS)	0.2^{ab}	0.1^{b}	0.1^{b}	0.1^{b}	0.1^{b}	0.1^{b}	0.1^{b}	0.3^{ab}	0.4^{a}	0.1^{b}	3.7***
	Rahuri (MH)	-	1.7^{b}	6.4^{a}	8.3^{a}	6.8^{a}	-	-	-	-	-	23.2***
H. armigera (% fruit damage)	Rajendranagar (TS)	2.6^{c}	2.0^{c}	2.0^{c}	3.4^{bc}	3.5^{bc}	5.0^{b}	2.2^{c}	3.2^{bc}	5.0^{b}	25.1^{a}	110.0***
	Rahuri (MH)		6.6^{c}	19.8^{b}	19.8^{b}	26.3^{a}	-	-	-	-	-	31.8***
	Raipur (CG)		1.29	0.43	1.04	1.96	1.82	-	-	-	-	0.99^{NS}
	Varanasi (UP)	9.4^{a}	10.7^{a}	5.8^{b}	11.6^{a}	5.2^{b}		-	-	-	-	6.1***
	Ludhiana (PB)		2.29^{d}	5.76^{bc}	3.95^{dc}	7.04^{a}	7.33^{ab}	-	-	-	-	8.3***
S. litura (nos./plant)	Varanasi (UP)	0.6^{c}	0.7^{c}	0.3^{c}	0.5^{a}	0.7^{ab}	-	-	-	-	-	8.1***
	Ludhiana (PB)		0.3^{ab}	0.12^{c}	0.16^{bc}	0.23^{bc}	0.44^{a}	-	-	-	-	20.4***
Coccinellids	Rahuri (MH)		1.4^{a}	0.2^{c}	0.1^{b}	0.6^{b}	-	-	-	-	-	15.9***
Spiders (nos./plant)	Bengaluru (KA)		0.22^{a}	0.20^{a}	0.12^{b}	0.14^{a}	0.1^{a}	-	-	-	-	14.3***
	Rajendranagar (TS)	0.1	1.1	0.7	0.3	0.2	0.5	0.5	0.4	0.1	0.2	0.8^{NS}
	Rahuri (MH)		0.2^{c}	0.1^{b}	0.5^{b}	0.2^{a}	-	-	-	-	-	22.1***
	Raipur (CG)		0.07^{b}	0.07^{b}	0.09^{b}	0.11^{b}	0.17^{a}	-	-	-	-	21.9***
	Varanasi (UP)	0.8^{bc}	0.5^{c}	0.6^{bc}	0.2^{bc}	0.1^{ab}	-	-	-	-	-	5.2***
	Ludhiana (PB)		-	0.2^{c}	0.1^{c}	0.3^{b}	0.3^{a}	-	-	-	-	95.4***

In a row, means followed by the same letter are not significantly different with significance of 'F' denoted by *: $p < 0.05$; $p<0.01$; ***: $p < 0.001$. NS : non-significant based on one way ANOVA; - indicate data not available or absence of insects; analysis done following (X+1) square root transformed values; given are the original means

Diseases: Consistently higher early blight severity was found at Bengaluru (KA) over all other locations (Narayana Bhat *et al.,* 2017; 2018). Rajendranagar (TS) had the highest early blight severity in 2015 (41.8 %) over preceding and succeeding four seasons. While Raipur (CG) had the highest severity in 2014 (10.9%) amongst seasons which itself was of low intensity, it was during 2015, the highest severity of 34 % at Varanasi (UP) was noted. Although significant difference for late blight severity was noted across years, the highest was (30.3 %) at Varanasi (UP) in 2012 and Ludhiana (PB) had only 5.3%. Importance of powdery mildew was only at Bengaluru (KA) being higher (43.4 - 47.8%) during 2012, 2013 and 2016 over 2014 and 2015 (26.1-33.7%). *Septoria* leaf spot was exclusive at Raipur (CG) and higher in 2012 and 2016. Bengaluru (KA) reported bacterial spot in 2014 (18.2 %) with significant increase during 2015 and 2016 (36.9 to 47.8%). Significantly higher bacterial spot was observed in 2015 at Varanasi (UP) over the preceding four seasons. Raipur (CG) had the highest of 8.6% bacterial spot severity in 2016>2014>2015. Although bacterial canker of 12.1% was noted at Rahuri (MH) during 2012, Raipur (CG) had the highest of only 5.1% in 2016 on par with 2014 and 2015. Leaf curl was the least at Raipur (CG) with a maximum of 11 % in 2016. The order of importance of leaf curl was Bengaluru (KA)> Rahuri (MH)> Varanasi (UP) and Ludhiana (PB)> Raipur (CG). A maximum of 65.5% incidence at Bengaluru (KA) was in 2012 and Ludhiana (PB) had its highest incidence of leaf curl in 2015 (37.8 %). Seasons of 2011 and 2012 had on par higher incidence (29-34 %) compared to 2013-16 (9-16%) at Varanasi (UP). Regular occurrence of mosaic was at Raipur (CG) and an increased incidence was noted in 2016 over 2012-2015. Varanasi (UP) on the other hand had significantly higher mosaic (16-21%) incidence between 2011 and 2014 over 2015 (9.3%). Bud blight incidence was on par between 2011 and 2017 (10.7 to 21.1%) with drastic reduction in 2018 (2%) at Rajendranagar (TS). Bud blight incidence was the lowest at Raipur (CG) in 2013 (3.3%) over other seasons (2012 and 2014-2016) having 5-7%. Rahuri (MH) had reported bud blight of ~19% during 2013 and 2014. Rahuri (MH) had the highest *Fusarium* wilt incidence of 23.6% in 2015 over preceding three seasons. *Sclerotium* wilt was found at Varanasi (UP) with non-significant differences among three seasons (2011, 2012 and 2015) with a range of 7-8% (Table 77). *Ralstonia* wilt was recorded only at Raipur (CG) and Varanasi (UP) with the later location having significant differences amongst seasons (2011, 2012 & 2014). Sunscald incidence was around 2-3% between 2014 and 2016 reported only at Raipur (CG) (Mobin *et al*., 2015).

Table 77. Inter seasonal variations of diseases of *kharif*

Disease	Location	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	'F'
Early blight (% severity)	Bengaluru (KA)	-	57.0	55.1	54.9	61.2	57.6	-	-	-	-	1.0^{NS}
	Rajendranagar (TS)	15.4^{c}	47.2^{a}	21.1^{bc}	14.6^{cd}	41.8^{a}	19.7^{bc}	26.2^{b}	17.0^{c}	-	7.1^{d}	24.3***
	Raipur (CG)	-	9.76^{a}	2.2^{b}	10.9^{a}	3.34^{b}	9.44^{a}	-	-	-	-	24.8***
	Varanasi (UP)	4.5^{d}	9.3^{c}	7.7^{c}	14.3^{b}	34.0^{a}	-	-	-	-	-	43.6***
Late blight (s)	Raipur (CG)	-	1.68^{a}	0.6^{c}	1.02^{b}	0.8^{cb}	1.59^{a}	-	-	-	-	37.4***
Late blight (% incidence)	Varanasi (UP)	6.4^{a}	4.7^{b}	1.0^{c}	-	-	-	-	-	-	-	19.6***
	Ludhiana (PB)	-	2.12^{b}	1.56^{b}	-	4.8^{a}	2.2^{b}	-	-	-	-	28.9***
Powdery mildew (s)	Bengaluru (KA)	-	47.8^{a}	43.4^{a}	33.7^{b}	26.1^{b}	43.4^{a}	-	-	-	-	7.5***
Septoria leaf spot (s)	Raipur (CG)	-	6.8^{a}	1.14^{b}	4.4^{ab}	3.93^{ab}	7.4^{a}	-	-	-	-	14.4***
Bacterial spot (% severity)	Bengaluru (KA)	-	-	-	18.2^{b}	36.9^{a}	47.8^{a}	-	-	-	-	6.3**
	Rahuri (MH)	-	14.7	18.9	14.4	-	-	-	-	-	-	1.6 ^{NS}
	Raipur (CG)	-	0.7^{d}	1.3^{dc}	6.6^{ab}	3.3^{bc}	8.6^{a}	-	-	-	-	24.7***
	Varanasi (UP)	5.4^{b}	4.4^{b}	5.1^{b}	3.9^{b}	30.8^{a}	-	-	-	-	-	40.4***
Bacterial canker (s)	Rahuri (MH)	-	12.1^{a}	-	0.9^{b}	-	-	-	-	-	-	19.7***
	Raipur (CG)	-	-	0.43^{b}	2.8^{ab}	1.2^{ab}	5.1^{a}	-	-	-	-	17.2***

Table 77 (contd.). Inter seasonal variations of diseases of *kharif*

Disease	Location	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	'F'
Tomato leaf curl (% incidence)	Bengaluru (KA)	-	65.5^{a}	34.7^{ab}	-	30.1^{ab}	2.0^{b}	-	-	-	-	18.4***
	Rahuri (MH)	-	21.4^{b}	20.9^{b}	17.8^{c}	29.2^{a}	-	-	-	-	-	22.4***
	Raipur (CG)	-	5.67^{b}	5.41^{b}	10.1^{a}	6.6^{b}	11.0^{a}	-	-	-	-	21.5***
	Varanasi (UP)	34.2^{a}	29.2^{a}	16.0^{b}	16.6^{b}	16.3^{b}	-	-	-	-	-	10.4***
	Ludhiana (PB)	-	13.8^{d}	17.1^{c}	19.8^{c}	37.8^{a}	25.9^{b}	-	-	-	-	61.3***
Tomato mosaic (% incidence)	Rahuri (MH)	-	21.1^{a}	-	6.0^{b}	31.3^{a}	-	-	-	-	-	3.3*
	Raipur (CG)	-	5.7^{c}	4.0^{c}	9.9^{b}	8.6^{b}	13.7^{a}	-	-	-	-	43.9***
	Varanasi (UP)	19.7^{a}	16.0^{a}	15.7^{a}	20.6^{a}	9.3^{b}	-	-	-	-	-	7.4***
	Ludhiana (PB)	-	-	17.8^{a}	17.9^{a}	-	-	-	-	-	-	0.9^{NS}
Bud blight (% incidence)	Rajendranagar (TS)	12.8^{a}	16.9^{a}	-	16.8^{a}	21.1^{a}	10.7^{a}	13.6^{a}	2.0^{b}	-	-	5.0***
	Rahuri (MH)	-	-	19.5^{a}	19.4^{a}	-	-	-	-	-	-	0.2 ^{NS}
	Raipur (CG)	-	5.0^{a}	3.3^{b}	6.3^{a}	5.6^{a}	6.9^{a}	-	-	-	-	8.3***
Fusarium wilt (% incidence)	Rahuri (MH)	-	17.8^{cb}	19.6^{b}	16.8^{c}	23.6^{a}	-	-	-	-	-	11.7***
	Varanasi (UP)	8.8^{ab}	7.8^{ab}	10.4^{ab}	6.5^{b}	12.6^{a}	-	-	-	-	-	2.1*
Ralstonia wilt (% incidence)	Raipur (CG)	-	2.7	-	2.9	3.4	2.9	-	-	-	-	1.11 ^{NS}
	Varanasi (UP)	8.2^{a}	8.7^{a}	-	4.7^{b}	-	-	-	-	-	-	7.4***
Sclerotium wilt	Varanasi (UP)	8.5	8.0	-	-	7.0	-	-	-	-	-	5.9 ^{NS}
Sun scald	Raipur (CG)	-	-	1.0^{a}	2.41^{b}	2.1^{b}	2.7^{b}	-	-	-	-	4.8**

In a row, means followed by the same letter are not significantly different with significance of 'F' denoted by *: $p < 0.05$; $p<0.01$; ***: $p < 0.001$. ^{NS}: non-significant based on oneway ANOVA; - indicate data not available or absence of diseases; analysis done following appropriate (arc sin in per cent data sets) transformations; given here are the original means; (s): severity

Inter seasonal variations of insects and diseases of *rabi*

Graphical representations of the seasonal dynamics of insects and diseases of *rabi* tomato for six locations (refer Annexure Ia&Ib; Annexure II and Annexure Va &Vb) are furnished in Annexure XXXI**.**

Insects: Although abundance of aphids at Rajendranagar (TS), Kalyani (WB) and Rahuri (MH) was higher over Bengaluru (KA) and Raipur (CG), interseasonal variations were significant at all locations. At Rajendranagar (TS), aphid abundance was higher 4.3-6.6 nos/5 leaves /plant in respect of 2016-17 and 2017-18 over all other seasons. Rahuri (MH) had on par aphids among 2011-12, 2013-14 and 2014-15 significantly higher over 2012-13. Kalyani (WB) had highest aphid abundance during 2012-13 followed by 2013-14 significantly different from all other seasons. Both Rajendranagar (TS) and Kalyani (WB) had significantly reduced population of aphids during the three consecutive seasons between 2018-19 and 2020-21. Importance of thrips was of the order Kalyani (WB)>Rahuri (MH) and Rajendranagar (TS). Likewise of aphids, thrips abundance was significantly greater in 2012-13 at Kalyani (WB). Both Rahuri (MH) and Varanasi (UP) had the highest thrips during 2011-12 followed by 2014-15. Whiteflies at Kalyani (WB) had similar inter seasonal variations as that of thrips and aphids being higher in 2012-13 followed by 2013-14. Rahuri (MH) had significantly higher whiteflies (2.8-3.0 nos/five leaves/plant) in 2011-12, 2013-14 and 2014-15 over 2012-13 (1.8 nos/five leaves/plant). Rajendranagar (TS)>Varanasi (UP)>Raipur (CG)>Bengaluru (KA) was the order of significance for whitefly occurrence over seasons. Bengaluru (KA) was the hotspot for mites during first three seasons between 2011-12 and 2013-14 with later two seasons having significantly reduced populations. Rajendranagar (TS) had on par abundance of mites during 2011-12, 2013-2016 with the latest seasons between 2018 and 2021 with reduced populations (Table 78).

Table 78. Inter seasonal variations of insects of *rabi*

Insect	Location	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	F-value
Aphids (Nos./5 leaves/plant)	Bengaluru	0.2^{c}	0.6^{a}	0.7^{a}	0.7^{a}	0.4^{b}	0.5^{ab}	-	-	-	-	7.5***
	Rajendranagar	1.6^{c}	3.34^{b}	3.18^{b}	1.5^{c}	1.6^{c}	4.2^{ab}	6.6^{a}	0.9^{cd}	0.5^{de}	0.4^{e}	27.4**
	Rahuri	3.0^{a}	1.8^{b}	2.9^{a}	2.9^{a}	-	-	-	-	-	-	20.5**
	Raipur	0.9^{b}	1.1^{a}	0.8^{b}	0.8^{b}	0.6^{c}	0.6^{c}	-	-	-	-	11.3**
	Varanasi	1.1^{b}	0.6^{d}	0.5^{e}	0.7^{cd}	0.8^{c}	1.5^{a}	-	-	-	-	53.3**
	Kalyani	1.6^{f}	14.04^{a}	10.3^{b}	6.0^{c}	4.2^{d}	3.3^{e}	3.1^{e}	4.4^{d}	4.3^{d}	4.2^{d}	186**
Thrips (Nos./5 leaves/plant)	Rajendranagar	0.7^{cb}	1.6^{a}	1.5^{a}	0.9^{cb}	0.4^{d}	0.7^{c}	0.9^{bc}	1.0^{b}	0.3^{de}	0.16^{e}	17.8**
	Rahuri	3.0^{a}	1.8^{c}	2.6^{b}	2.9^{ab}	-	-	-	-	-	-	20.6**
	Varanasi	0.4^{a}	0.3^{b}	0.2^{c}	0.4^{a}	0.3^{b}	0.4^{b}	-	-	-	-	15.0**
	Kalyani	1.2^{g}	13.7^{a}	11.1^{b}	8.6^{c}	3.9^{d}	4.2^{d}	2.0^{f}	3.1^{e}	2.2^{f}	1.7^{fg}	232**
Whiteflies (Nos./5 leaves/plant)	Bengaluru	0.2^{b}	1.1^{a}	0.1^{b}	0.1^{b}	0.2^{b}	0.3^{b}					7.1***
	Rajendranagar	0.4^{c}	0.8^{b}	0.4^{c}	0.5^{c}	0.8^{b}	0.4^{c}	0.5^{c}	1.4^{a}	0.3^{d}	0.7^{b}	21.4**
	Rahuri	3.0^{a}	1.8^{b}	2.8^{a}	2.9^{a}	-	-	-	-	-	-	21.4**
	Raipur	0.1^{d}	0.3^{c}	0.3^{c}	0.4^{b}	0.5^{b}	0.7^{a}	-	-	-	-	69.8**
	Varanasi	0.8^{a}	0.4^{d}	0.4^{d}	0.6^{b}	0.5^{c}	0.3^{e}	-	-	-	-	48.8**
	Kalyani	1.5^{f}	14.9^{a}	9.3^{b}	4.6^{c}	-	3.7^{d}	2.5^{e}	3.7^{d}	4.0^{cd}	4.3^{cd}	161***
Mites (Nos./5 leaves/plant)	Bengaluru	51.5^{a}	42.1^{a}	40.5^{a}	6.4^{b}	10.9^{b}	12.9^{b}	-	-	-	-	29.2**
	Rajendranagar	16^{ab}	4.1^{cd}	6.9^{abc}	9.8^{abc}	5.3^{bcd}	17.3^{a}	-	0.14^{d}	0.13^{d}	0.13^{d}	5.8***
	Rahuri	3.0^{a}	1.8^{b}	1.6^{b}	1.1^{c}	-	-	-	-	-	-	133***
	Kalyani	0.9^{g}	16.2^{a}	10.0^{b}	4.8^{c}	0.3^{h}	2.0^{de}	-	2.3^{d}	1.6^{ef}	1.2^{fg}	383***
Leaf miner (Nos./5 leaves/plant)	Kalyani	1.2^{f}	-	1.3^{fg}	1.9^{bc}	1.4^{ef}	2.1^{b}	1.0^{g}	2.9^{a}	1.7^{cd}	1.5^{de}	37.8**
	Bengaluru	1.3^{a}	1.0^{b}	1.2^{ab}	0.6^{c}	0.4^{c}	0.5^{c}	-	-	-	-	29.6**
	Rajendranagar	0.4^{b}	0.7^{a}	0.3^{cb}	0.2^{cb}	0.2^{c}	0.4^{b}	0.2^{bc}	0.3^{bc}	0.7^{a}	0.4^{b}	10.1**
	Rahuri	3.0^{a}	1.7^{c}	2.6^{b}	2.9^{ab}	-	-	-	-	-	-	23.3**
	Raipur	0.9^{b}	1.6^{a}	1.0^{b}	0.8^{b}	0.7^{c}	0.67^{c}	-	-	-	-	27.2**
	Varanasi	1.2^{a}	0.5^{d}	0.3^{e}	0.6^{cd}	0.7^{b}	0.7^{c}	-	-	-	-	78.3**
H. armigera (no. of larvae/plant)	Bengaluru	0.4	11.4	0.2	0.2	0.2	0.4	-	-	-	-	0.90 NS
	Rajendranagar	0.2^{bc}	0.1^{bc}	0.23^{a}	0.2^{bc}	0.2^{bc}	0.2^{bc}	0.13^{c}	-	-	-	4.98**
	Rahuri	1.7^{c}	2.4^{c}	8.5^{a}	6.9^{b}	-	-	-	-	-	-	88.9**
	Raipur	0.9^{bc}	0.1^{b}	-	0.2^{a}	0.1^{b}	0.1^{c}	-	-	-	-	24.0**
	Varanasi	0.3^{b}	0.3^{b}	0.2^{b}	0.4^{a}	0.2^{b}	0.2^{b}	-	-	-	-	9.0***
	Kalyani	0.9^{a}	0.55^{b}	0.3^{c}	0.3^{c}	0.28^{c}	0.15^{e}	0.08^{f}	0.21^{d}	0.1^{ef}	0.1^{ef}	182**
H. armigera (% fruit damage)	Bengaluru	5.2^{a}	1.1^{c}	2.8^{b}	3.0^{b}	3.1^{ba}	4.4^{a}	-	-	-	-	5.7***
	Rajendranagar	2.1^{bc}	2.9^{b}	1.5^{cd}	2.1^{bcd}	6.6^{a}	2.7^{b}	1.2^{d}	1.5^{cd}	2.5^{bc}	-	39.1**
	Rahuri	10.2^{b}	7.8^{b}	26.2^{a}	21.0^{a}	-	-	-	-	-	-	17.1**
	Raipur	4.6^{a}	1.8^{bc}	0.7^{d}	3.1^{b}	1.5^{bc}	1.3^{cd}	-	-	-	-	15.4**
	Varanasi	11.1^{a}	11.9^{b}	2.9^{d}	5.2^{c}	5.7^{c}	2.8^{d}	-	-	-	-	38.6**
	Kalyani	22.6^{a}	4.8^{cb}	4.1^{c}	4.1^{c}	5.1^{b}	1.8^{d}	1.2^{e}	0.9	0.52^{f}	0.6^{f}	343.8*
Spodoptera litura (Nos./plant)	Rajendranagar	0.05^{b}	0.29^{a}	0.24^{a}	0.3^{a}	0.23^{a}	0.28^{a}	-	-	-	-	2.0*
	Raipur	0.1^{a}	0.7^{b}	0.9^{b}	0.5^{c}	0.8^{bc}	4.3^{a}	-	-	-	-	8.7***
	Varanasi	-	0.2^{c}	0.3^{b}	0.4^{a}	0.4^{a}	0.3^{b}	-	-	-	-	41.7**
	Kalyani	2.1^{b}	1.3^{c}	0.5^{ef}	0.5^{e}	5.8^{a}	0.4^{f}	0.2^{g}	0.2^{g}	0.2^{g}	1.0^{d}	348.0*

In a row, means followed by the same letter are not significantly different with significance of 'F' denoted by *: $p < 0.05$; $p<0.01$; ***: $p < 0.001$. NS : non-significant based on one way ANOVA; - indicate data not available or absence of insects; analysis done following (X+1) square root transformed values; given here are the original means; refer other tables for the name of states in respect of locations; predators continued in next page

Table 78 (contd.). Inter seasonal variations of insects of *rabi*

Insect	Location	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	F-value
Coccinellids (no./plant)	Rahuri	1.6^{a}	0.9^{b}	0.8^{b}	0.7^{b}	-	-	-	-	-	-	43.4**
	Kalyani	0.2^{cb}	0.4^{a}	0.4^{a}	0.2^{cb}	0.2^{bcd}	0.4^{a}	0.2^{cd}	0.3^{b}	0.1^{d}	0.1^{d}	21.8**
Spiders (Nos./plant)	Bengaluru	0.2^{b}	0.1^{b}	0.2^{a}	0.1^{b}	0.2^{b}	0.1^{b}	-	-	-	-	4.1***
	Rajendranagar	0.1^{g}	0.9^{a}	0.8^{b}	0.4^{de}	0.3^{ef}	0.4^{de}	0.6^{c}	0.4^{dc}	0.1^{g}	0.2^{fg}	45.5**
	Rahuri	0.5^{a}	0.5^{b}	0.5^{a}	-	-	-	-	-	-	-	3.8*
	Raipur	0.7^{d}	0.8^{cd}	0.8^{bc}	0.9^{bc}	0.1^{a}	0.1^{ab}	-	-	-	-	8.1***
	Varanasi	0.4^{c}	0.5^{b}	0.4^{c}	0.6^{b}	0.7^{a}	0.3^{d}	-	-	-	-	59.8**
	Kalyani	0.5^{b}	0.5^{b}	0.6^{a}	0.3^{c}	0.5^{b}	0.5^{b}	0.2^{d}	0.2^{d}	0.2^{d}	0.2^{d}	110**

In a row, means followed by the same letter are not significantly different with significance of 'F' denoted by *: $p < 0.05$; $p<0.01$; ***: $p < 0.001$. ^{NS} : non-significant based on one way ANOVA; - indicate data not available or absence of insects; analysis done following (X+1) square root transformed values; given here are the original means; refer other tables for the name of states in respect of locations

Mites at Kalyani (MH) had followed similar high population levels during 2012-13 > 2013-14> 2014-15 with decreased populations between 2018 and 2021. Leaf miner was of greater importance at Rahuri MH)>Kalyani (WB)>Raipur (CG)>Bengaluru (KA)>Varanasi (UP)>Rajendranagar (TS). Kalyani (WB) had significantly higher leaf miner during 2018-19>2016-17. While seasons 2011-14 had significantly higher leaf miner, 2014-16 (three seasons) had significantly reduced population at Bengaluru (KA). Regular occurrence of leaf miner at Rajendranagar (TS) in moderate levels was noted despite significant inter seasonal variations. Rahuri (MH) had significantly lesser leaf miner in 2012-13 over 2011-12, 2013-14 and 2014-15. The seasons between 2011 and 2015 (four seasons) had significantly higher leaf miner over 2015 and 2018 (two seasons) at Raipur (CG). Although Varanasi (UP) had significantly higher leaf miner during 2011-12, subsequent five seasons had lower levels.

Larval incidence of *H. armigera* across seasons was non-significant at Bengaluru (KA). For fruit damage due to *H. armigera*, Rahuri (MH)>Kalyani (WB)>Bengaluru (KN)>Rajendranagar (TS)>Raipur (CG) was the order of importance. While Kalyani (WB), Raipur (CG), Varanasi (UP) and Bengaluru (KA) had significantly higher *H. armigera* on fruits during 2011-12, Rahuri (MH) and Rajendranagar (TS) recorded the highest fruit damage during 2013-15 (two seasons) and 2015-16, respectively. Kalyani (WB) had significantly higher *S. litura* in 2016-17 before and after which reduced populations were noted over 2011-2021. Varanasi (UP) and Raipur (CG) had relatively less *Spodoptera* despite inter seasonal variations. Coccinellids were significantly abundant during 2011-12 over three subsequent seasons of 2012-15 at Rahuri (MH). Kalyani (WB) showed regular occurrence of coccinellids with the highest and on par abundance among 2012-13, 2013-14 and 2016-17. Spiders were consistent predators across all locations with significantly higher population in Bengaluru (KA), Rajendranagar (TS), Rahuri (MH), Raipur (CG), Varanasi (UP), Kalyani (WB) in respect of 2013-14, 2012-13, 2011-12, 2015-16, 2015-16, and 2013-14 with all other seasons having reduced population.

Diseases: Early blight severity among locations was of the order Benglauru (KA) & Rajendranagar (TS) > Varanasi (UP)>Rahuri (MH)>Kalyani (WB)>Raipur (CG) with the latter two locations having seasonal mean < 10 %. All six locations showed inter seasonal significant differences. Bengaluru (KA) had the highest and on par severity during 2012-13 and 2015-16. Three seasons *viz.,* 2013-14, 2014-15 and 2016-17 were on par with range of severity between 51.8 and 56.1 % with the lowest severity (28.9 %) in 2011-12 at Bengaluru (KA). While highest severity of early blight was in 2012-13 at Rajendranagar (TS), on par severities were noted during years of 2013-14 to 2018-19 (six seasons). Significantly lower severity (2.3%) was noted during 2020-21 at Rajendranagar (TS). The range of severity at Varanasi (UP) and Rahuri (MH) was 6.1-40.2 % and 9.7-18.6 %, respectively. Kalyani (WB) had the lowest severity of 2.6 % in 2018-19 with the highest (12.6%) seen in 2011-12. On the other hand, the highest of 13.5% in 2012-13 and on par severity (5 - 7.5 %) during 2011-12 and 2013-14 to 2016-17 was recorded at Raipur

(CG). Early blight incidence on fruits was higher during 2013-14 and 2019-2021 at Rajendranagar (TS). The highest incidence of early blight at Varanasi (UP) was 36.5 % in 2012-13. Raipur (CG) had the highest of 4.6 % incidence of early blight in 2011-12 which got reduced by half in the following five seasons (2012-13 to 2016-17) (Table 79).

Table 79. Inter seasonal variations of diseases of *rabi*

Disease	Location	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	F-value
Early blight (% severity)	Bengaluru	28.9^{c}	62.7^{a}	56.1^{b}	53.9^{b}	65.5^{a}	51.8^{b}	-	-	-	-	16.3***
	Rajendranagar	11.4^{d}	44.5^{a}	35.5^{abc}	32.4^{abc}	40.3^{ab}	28.1^{bc}	35.8^{abc}	29.6^{bc}	23.7^{c}	2.3^{e}	37.3***
	Rahuri	9.7^{b}	13.2^{b}	16.7^{a}	18.6^{a}	-	-	-	-	-	-	11.9***
	Raipur	6.7^{b}	13.5^{a}	7.5^{b}	5.3^{b}	7.2^{b}	5.0^{b}	-	-	-	-	11.1***
	Varanasi	10.6^{d}	21.6^{b}	6.1^{e}	12.9^{cd}	40.2^{a}	17.6^{c}	-	-	-	-	95.3***
	Kalyani	12.6^{a}	8.6^{abc}	11.9^{ab}	8.7^{bc}	9.1^{abc}	10.7^{abc}	3.3^{d}	2.6^{d}	9.0^{abc}	8.2^{c}	8.6***
Early blight (% fruits)	Rajendranagar	-	6.2^{cd}	17.4^{ab}	7.7^{bcd}	4.0^{d}	5.0^{cd}	-	-	17.0^{abc}	25.9^{a}	16.0***
	Rahuri	-	-	46.0^{a}	29.0^{b}			-	-	-	-	18.8***
	Raipur	4.6^{a}	2.0^{b}	2.2^{b}	2.0^{b}	2.0^{b}	1.6^{b}	-	-	-	-	16.5***
	Varanasi	6.5^{d}	36.5^{a}	7.2^{dc}	20.3^{b}	10.3^{c}	4.7^{d}	-	-	-	-	41.8***
Late blight (%)	Raipur	1.7^{c}	3.1^{a}	2.0^{bc}	2.5^{ba}	1.6^{c}	1.4^{c}	-	-	-	-	11.3***
	Varanasi	17.3^{b}	3.1^{c}	23.6^{a}	12.8^{b}	2.9^{c}	2.8^{c}	-	-	-	-	22.1***
Late blight (% fruits)	Bengaluru	18.7^{b}	23.0^{ab}	32.9^{a}	24.4^{b}	6.9^{c}	44.3^{a}	-	-	-	-	23.2***
	Raipur	0.3^{c}	1.4^{ab}	0.8^{c}	0.7^{c}	1.2^{b}	1.4^{a}	-	-	-	-	32.8***
	Varanasi	6.1^{c}	16.0^{b}	33.8^{a}	21.1^{b}	3.1^{dc}	1.4^{d}	-	-	-	-	27.4***
Powdery mildew-%	Rahuri	9.3	12.3	-	-	-	-	-	-	-	-	1.4^{NS}
	Raipur	2.3^{a}	2.4^{a}	1.3^{b}	0.6^{c}	-	-	-	-	-	-	4.6*
Septoria leaf spot	Raipur	2.5^{c}	1.4^{c}	4.8^{b}	6.8^{a}	7.3^{a}	4.2^{b}	-	-	-	-	11.1***
	Varanasi	8.0^{b}	10.0^{a}	-	-	-	4.9^{c}	-	-	-	-	4.9*
Bacterial spot (% severity)	Rajendranagar	-	64.4^{a}	26.5^{b}	30.2^{b}	38.1^{b}	19.9^{b}	-	22.2^{b}	23.4^{b}	1.8^{c}	35.7***
	Rahuri	11.3^{b}	11.0^{b}	21.2^{a}	-	-	-	-	-	-	-	20.5***
	Varanasi	5.9^{c}	8.6^{cb}	1.5^{d}	2.4^{d}	15.9^{a}	14.0^{b}	-	-	-	-	27.7***
Bac. spot	Rajendranagar	-	14.6^{ab}	11.6^{ab}	-	4.9^{b}	10.1^{ab}	-	6.5^{b}	12.4^{ab}	22.7^{a}	4.4***
Tomato leaf curl (%)	Rajendranagar	15.0	15.5	6.0	4.0	9.2	-	-	-	-	10.2	1.3^{NS}
	Rahuri	19.6^{b}	22.9^{a}	19.4^{b}	23.0^{a}	-	-	-	-	-	-	3.5***
	Raipur	23.8^{a}	7.0^{c}	7.8^{c}	7.0^{c}	10.0^{b}	10.7^{b}	-	-	-	-	74.3***
	Varanasi	36.4^{a}	30.5^{c}	7.0^{e}	13.7^{d}	14.4^{d}	34.3^{b}	-	-	-	-	199.1**
	Kalyani	36.7^{b}	41.6^{a}	34.7^{b}	36.6^{b}	22.6^{c}	22.6^{c}	17.2^{d}	12.8^{d}	17.0^{d}	19.4^{dc}	47.8***
Tomato mosaic (%)	Rajendranagar	-	13.8^{b}	16.5^{b}	6.0^{b}	3.1^{b}	34.0^{a}	-	-	-	5.4^{b}	6.6***
	Rahuri	20.7	18.1	-	-	-	-	-	-	-	-	1.3^{NS}
	Varanasi	15.5^{a}	15.9^{a}	7.7^{c}	13.0^{b}	7.8^{c}	5.5^{d}					69.6***
Cucumo %	Rahuri	18.9^{b}	22.9^{a}	-	-	-	-	-	-	-	-	6.5***
Bud blight (%)	Rajendranagar	8.2^{c}	6.1^{d}	15.4^{a}	9.6^{c}	12.2^{b}	9.7^{c}	-	-	-	-	12.9***
	Raipur	14.2^{a}	4.7^{b}	4.2^{b}	4.8^{b}	5.0^{b}	5.9^{b}	-	-	-	-	20.8***
Ralstonia wilt (%)	Varanasi	5.8^{b}	8.3^{a}	-	-	-	-					11.1***
	Kalyani	8.6^{c}	10.2^{c}	8.8^{c}	2.7^{d}	9.4^{c}	5.9^{dc}	22.2^{ba}	-	26.7^{a}	16.9^{b}	25.6***
Sclerotium wilt (%)	Varanasi	5.9^{b}	8.0^{a}	-	-	5.6^{b}	-	-	-	-	-	6.2**
	Kalyani	6.3^{b}	3.2^{c}	4.1^{c}	9.5^{a}	-	-	-	6.7^{b}	6.4^{b}	-	20.9***

In a row, means followed by the same letter are not significantly different with significance of 'F' denoted by *: p < 0.05; p<0.01; ***: p < 0.001. NS : non-significant based on one way ANOVA; - indicate data not available or absence of diseases; analysis done following appropriate (arc sin in per cent data sets) transformations; given here are the original means; refer other tables for the name of states in respect of locations; reporting units can be verified from annexure

Late blight severity indicated Varanasi (UP) to be the hot spot over Raipur (CG) and other locations. The lowest of late bight severity (3.1%) was the higher severity at Raipur (CG) during 2012-13. Late blight incidence on fruits was the highest at Bengaluru (KA) followed by Varanasi (UP) with meagre values at Raipur (CG). Powdery mildew importance although was higher at Rahuri (MH) over Raipur (CG), inter seasonal variations were significant at the later location only. *Septoria* leaf spot at Raipur (CG) and Varanasi(UP) was 1.4 -7.3% and 8-10%, respectively. The order of importance of bacterial leaf spot severity was Rajendranagar (TS)>Rahuri (MH)>Varanasi (UP) with inter seasonal variations significant. Rajendranagar (TS) had the highest incidence (22.7%) of bacterial spot in 2020-21, which was on par with all other seasons but for 2015-16 & 2018-19. Leaf curl was higher at Kalyani (WB), Varanasi (UP) and Rahuri (MH) over Rajendranagar (TS) and Raipur (CG). Highest leaf curl incidence at Kalyani (WB) was in 2012-13 with preceding one season and succeeding two seasons having on par values. Seasons between 2014-15 and 2020-21 had significantly lower incidence of tomato leaf curl. 2011-12 had the highest leaf curl at Varanasi (UP) with subsequent seasons having lower but differential levels. Highest of 23.8 and 23% were noted at Raipur (CG) and Rahuri (MH), respectively. At Rajendranagar (TS), leaf curl incidence between 4 and 15.5 % however not significant across seasons. Incidence of tomato mosaic greater at Rahuri (MH)>Varanasi (UP) and Rajendranagar (TS) with no inter seasonal differences between the seasons of occurrences (21-12 & 2012-13). Varanasi (UP) had significantly higher mosaic incidence (16 %) in 2011-12 and 2012-13 with following four seasons recording significantly lower incidence. Rajendranagar (TS) had the highest incidence of 34 % in 2015-16 with previous four seasons and 2020-21 on par and lower over 2016-17. Cucumo virus recorded only at Rahuri (MH) during two seasons of 2011-12 and 2012-13 with later significantly higher over the former. Bud blight was of significance only at Rajendranagar (TS) and Raipur (CG) with inter seasonal differences. The highest incidences were noted during 2013-14 and 2011-12 in respect of Rajendranagar (TS) and Raipur (MH). *Ralstonia* and *Sclerotium* wilts were reported from Varanasi (UP) and Kalyani (WB). The *Ralstonia* wilt incidence at Varanasi (UP) was 5.8 to 8.3 % during 2011-12 and 2012-13, respectively. Kalyani (WB) had the highest *Ralstonia* in 2019-20>2017-18 and 2020-21 than seasons between 2011-12 and 2016-17. Wilt due to *Sclerotium* was the highest during 2012-13 and 2014-15 at Varanasi (UP) and Kalyani (WB), respectively. Some seasons did not manifest wilt incidence due to both *Ralstonia* and *Sclerotium* from among the study seasons at both Varanasi (UP) and Kalyani (WB).

Magnitude of climate change - *kharif* & *rabi*

Ludhiana (PB) during *kharif* and Bengaluru (KA) and Kalyani (WB) during *rabi* did not show any climatic change in respect of all three variables (MaxT, MinT & RF). Climate change for *kharif* across tomato growing locations indicated significantly increasing MaxT at Bengaluru (KA), Rajendranagar (TS), Rahuri (MH) and Raipur (CG). MinT increase was significant only at Bengaluru (KA).

Table 80. Magnitude of climate change during *kharif* and *rabi* across study locations

Location	*kharif*			*rabi*		
	MaxT	MinT	RF	MaxT	MinT	RF
Bengaluru (KA)	0.36* (29.2)	0.92*** (20.0)	-0.35*** (29.9)	0.54 (28.8)	1.57 (17.9)	-0.67 (13.5)
Rajendranagar (TS)	0.88*** (30.6)	0.19 (19.5)	1.99*** (21.0)	1.03*** (30.6)	-0.19 (16.3)	-1.23*** (6.7)
Rahuri (MH)	0.48** (30.8)	-0.18 (18.1)	0.10*** (16.7)	0.06 (33.8)	-0.79 (17.2)	-1.27*** (4.1)
Raipur (CG)	0.39* (30.3)	0.89 (19.9)	6.00*** (33.4)	0.34 (31.7)	0.94 (17.7)	-0.73*** (6.6)
Varanasi (UP)	-0.41 (29.6)	0.8 18.2)	-0.46*** (13.3)	-0.71 (27.8)	0.15 (15.1)	1.99*** (10.3)
Ludhiana (PB)	-0.24 (28.4)	1.69 (15.9)	2.06 (8.4)	-	-	-
Kalyani (WB)	-	-	-	0.23 (29.0)	-0.62 (16.1)	0.10 (6.8)

Values outside and in parentheses represent mean climatic deviations and actual weather, respectively for MaxT & MinT in °C and RF in mm/week corresponding to seasons of tomato at study locations; - indicates absence of season or no data available; Analysis based on 't' test

RF at Rajendranagar (TS), Rahuri (MH) and Raipur (CG) had significant increase as against its decrease at Bengaluru (KA) and Varanasi (UP). Rajendranagar (TS), Rahuri (MH) and Raipur (CG) had significantly decreasing RF during *rabi* with increased RF only at Varanasi (UP). The only significant change for temperature in *rabi* was relating to MaxT at Rajendranagar (TS) that had a significant rise by 1.03˚C (Table 80).

Inter seasonal variations for actual weather and climatic deviations - *kharif* & *rabi*

Kharif: Ludhiana (PB) and Varanasi (UP) did not have changing seasonality of weather for seasons of tomato cultivation across 2011-2016 for A-MaxT, A-MinT and A-RF. Bengaluru (KA) had A-MaxT of >30°C during 2012 and 2015 significantly higher over other seasons that were on par (28.3 - 28.9°C).

Table 81. Inter seasonal variability based on actual weather and climatic deviations for *kharif*

Weather/Location	2011	2012	2013	2014	2015	2016	F-value
Bengaluru (KA)							
A-MaxT (°C)	28.3^{b}	30.1^{a}	28.4^{b}	28.8^{b}	30.4^{a}	28.9^{b}	5.04***
A-MinT (°C)	19.7^{b}	19.2^{b}	19.3^{b}	20.6^{a}	20.6^{a}	20.8^{a}	9.38***
A-RF (mm/week)	25.9	15.5	48.9	32.8	35.1	20.6	1.34^{NS}
D-MaxT (°C)	-0.43^{b}	1.28^{a}	-0.38^{b}	-0.01^{b}	1.63^{a}	0.11^{b}	6.94***
D-MinT (°C)	0.65^{b}	-0.04^{b}	0.17^{b}	1.49^{a}	1.52^{a}	1.73^{a}	7.85***
D-RF (mm/week)	-4.25	-14.6	18.7	2.66	4.92	-9.56	1.29^{NS}
Rajendranagar (TS)							
A-MaxT (°C)	31.1^{ab}	30.7^{b}	30.8^{b}	31.9^{a}	32.1^{a}	30.0^{b}	3.80**
A-MinT (°C)	22.1	22.4	22.0	23.0	22.5	21.9	1.14^{NS}
A-RF (mm/week)	26.6	32.5	27.8	24.1	21.0	44.7	0.66^{NS}
D-MaxT (°C)	0.79^{ab}	0.32^{bc}	0.42^{bc}	1.57^{a}	1.71^{a}	-0.33^{c}	4.90***
D-MinT (°C)	0.63^{b}	0.85^{ab}	0.45^{b}	1.48^{a}	0.96^{ab}	0.43^{b}	2.63*
D-RF (mm/week)	0.04	5.85	1.21	-2.54	-5.61	18.14	0.78^{NS}
Ludhiana (PB)							
A-MaxT (°C)	28.5	28.0	28.0	27.5	28.9	29.4	0.29^{NS}
A-MinT (°C)	15.6	15.1	15.9	15.5	16.3	16.7	0.12^{NS}
A-RF (mm/week)	10.8	16.0	5.2	11.4	5.3	1.17	0.95^{NS}
D-MaxT (°C)	-0.14^{abc}	-0.64^{bc}	-0.61^{bc}	-1.16^{c}	0.30^{ab}	0.79^{a}	2.39*
D-MinT (°C)	1.47^{bc}	0.91^{c}	1.76^{abc}	1.36^{bc}	2.09^{ab}	2.56^{a}	2.45*
D-RF (mm/week)	4.53	9.73	-1.03	5.19	-0.96	-5.13	1.43^{NS}
Rahuri (MH)							
A-MaxT (°C)	30.7^{bc}	31.0^{bc}	30.2^{c}	31.5^{ab}	32.5^{a}	30.2^{c}	5.34***
A-MinT (°C)	21.9	21.7	21.4	21.9	22.1	21.7	0.49^{NS}
A-RF (mm/week)	21.7	18.5	25.0	34.0	12.3	40.1	0.49^{NS}
D-MaxT (°C)	0.60^{bc}	0.93^{bc}	0.10^{c}	1.38^{ab}	2.38^{a}	0.07^{c}	5.53***
D-MinT (°C)	0.89	0.71	0.33	0.86	0.99	0.66	1.10^{NS}
D-RF (mm/week)	-5.3	-8.51	-2.02	7.01	-14.6	13.14	1.00^{NS}
Varanasi (UP)							
A-MaxT (°C)	28.6	29.7	29.3	29.5	31.2	29.1	0.73^{NS}
A-MinT (°C)	18.4	16.5	17.6	17.9	19.4	19.3	0.46^{NS}
A-RF (mm/week)	25.6	16.5	8.59	8.01	7.76	13.3	0.20^{NS}
D-MaxT (°C)	-1.37^{b}	-0.28^{b}	-0.71^{b}	-0.45^{b}	1.23^{a}	-0.88^{b}	4.83***
D-MinT (°C)	1.01^{ab}	-0.91^{c}	0.21^{bc}	0.55^{b}	2.04^{a}	1.90^{a}	6.25***
D-RF (mm/week)	11.89	2.79	-5.2	-5.79	-6.04	-0.43	0.56^{NS}
Raipur (CG)							
A-MaxT (°C)	30.4^{b}	29.9^{b}	29.6^{b}	30.2^{b}	31.4^{a}	30.3^{b}	3.08*
A-MinT (°C)	19.5	19.8	19.8	19.7	21.0	19.6	0.24^{NS}
A-RF (mm/week)	39.5	38.2	44.3	25.9	22.7	29.4	0.22^{NS}
D-MaxT (°C)	0.47^{a}	-0.04^{a}	-0.26^{a}	0.28^{a}	1.53^{b}	0.36^{a}	5.30***
D-MinT (°C)	0.45^{b}	0.79^{b}	0.82^{b}	0.72^{b}	2.00^{a}	0.56^{b}	3.09*
D-RF (mm/week)	12.18	10.85	16.97	-1.44	-4.61	2.08	1.03^{NS}

A is actual weather and D is the climatic deviations over 2011-16; units of climatic variables are : MaxT (˚C), MinT (˚C) & RF (mm/week); In a row, means followed by the same letter are not significantly different with significance of 'F' denoted by *: $p < 0.05$; $p<0.01$; ***: $p < 0.001$. ^{NS}: non-significant based on one way ANOVA

Rajendranagar (TS) had A-MaxT on par over 2015, 2014 and 2011 and over other three seasons (2012, 2013 and 2016). While Raipur (CG) had significantly higher A-MaxT in 2015 (31.4°C) with other seasons that had similar weather (29.6-30.3°C). Rahuri (MH) too had highest A-MaxT (32.5°C) in 2015 followed by 2014 (31.5°C), the later on par with 2011 with this season on par with 2013 and 2016. Only location that had A-MinT variations for *kharif* tomato was Bengaluru (KA) with first (2011-2013) and rest (2014-2016) three seasons being similar in having 19.2-19.7°C and 20.6-20.8°C, respectively (Table 81). In terms of climatic deviations during *kharif*, five out of six locations excluding Rahuri (MH) had shown seasonal variability for both D-MaxT and D-MinT. Rahuri (MH) had shown increased D-MaxT by 1.38 and 2.38°C in 2014 and 2015, respectively that were on par. 2014 had D-MaxT similar to 2011 and 2012 with the later on par with 2013 and 2016 at Rahuri (MH). For D-MaxT, climatic deviations among seasons were both negative and positive at Bengaluru (KA), Rajendranagar (TS), Ludhiana (PB), Varanasi (UP) and Raipur (CG). On the other hand, D-MinT was positive at Rajendranagar (TS), Ludhiana (PB) and Raipur (CG). Raipur (CG) had D-MinT rise of 2°C in 2015 over 0.45-0.82°C in other seasons. D-MinT increase amongst all locations had been the highest in 2015 indicating increased temperature across different agroclimatic zones.

***Rabi*:** Variations amongst tomato *rabi* seasons 2011-12 to 2016-17 for the actual (A) weather of A-MaxT, A-MinT and A-RF did not differ statistically at Rajendranagar (TS), Kalyani (WB) and Varanasi (UP). Differences amongst seasons for A-MaxT and A-MinT with no significant change for A-RF were noted for Bengaluru (KA) and Rahuri (MH). Rahuri (MH) typically had increased A-MaxT and A-MinT between 2012-13 and 2016-17 (five seasons) over 2011-12. On the other hand, fluctuations for A-MaxT was higher for Bengaluru (KA) with significantly increased value (30.2°C) in 2016-17, however on par with 2012-13 and 2015-16 and other seasons *viz.,* 2011-12, 2013-14 and 2014-15 had lower but on par A-MaxT. A-MinT at Bengaluru (KA) was significantly lower for two consecutive seasons of 2011-12 and 2012-13 and higher over three seasons between 2014 -15 and 2016-17 again implying the progressive increase temperature with increasing time although 2015-16 had on par A -MinT with 2013-14. Raipur (CG) did not show significant differences for A-MinT and A-RF. However, the seasonal differences were significant for A-MaxT being the highest (34.7°C) during 2016-17 over other preceding five seasons (Table 82).

The deviations of rainfall D-RF across all *rabi* tomato seasons (2011-12 to 2016-17) were non-significant at all six study locations. Despite no significant differences for A-MaxT at Rajendranagar (TS), D-Max T had shown significant differences wherein four seasons namely 2011-12, 2012-13 and 2015-16 & 2016-17 had significantly higher MaxT increase ranging 1.32-1.62°C as against two seasons (2013-14 and 2014-15). D-MaxT and D-MinT differences were significant following the pattern of A-MaxT largely at Bengaluru (KA). Both D-MaxT and D-MinT variations across seasons were significant at Kalyani (WB) and the first three seasons between 2011and 2014 had shown significantly decreased D-MaxT (-0.39 to -0.19°C) with other seasons showing increased D-MaxT (0.31 to 1.19°C). On the other hand, D-MinT had significant decrease (-1.63 to -0.8°C) between 2012-13 to 2014-15 (three seasons) with increased D-MinT during 2015-16, 2016-17 and 2011-12 (0.15 to 1.07°C) as against declined values of -1.63 to -0.8°C during 2012-13 to 2014-15 at Kalyani (WB). Raipur (CG) had shown significant variations amongst seasons for D-MaxT and D-MinT with significantly increased values during 2016-17 with decreased D-MaxT and increased D-MinT similar for seasons between 2011-12 and 2015-16. Significantly reduced (-1.4°C) and increased (0.95°C) D-MaxT was observed in respect of 2011-12 and 2016-17 at Varanasi (UP). Increases in D-MinT at Varanasi (UP) for 2015-16 was significantly higher and on par with 2016-17 and 2011-12. Significantly lower D-MinT was also noted at Varanasi (UP) for 2012-13 (-0.98°C) on par with 2013-14 indicating the extremes of fluctuations happening during the cultivation cycle of *rabi* tomato. In general, increased D-MaxT and D-MinT were noted during later years of 2016-17 at Bengaluru (KA), Kalyani (WB). Rahuri (MH) and Raipur (CG) and Varanasi (UP) where overall significance across seasons were found.

Table 82. Inter seasonal variability based on actual weather and climatic deviations for *rabi*

Weather/Location	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	'F'
Bengaluru (KA)							
A-MaxT (°C)	29.1^{bc}	30.0^{ab}	28.7^{c}	28.5^{c}	30.1^{ab}	30.2^{a}	4.89***
A-MinT (°C)	17.7^{c}	17.1^{c}	18.7^{b}	19.9^{a}	19.2^{ab}	20.1^{a}	13.42***
A-RF (mm/week)	12.9	11.5	25.3	19.2	21.4	10.7	1.30^{NS}
D-MaxT (°C)	-0.11^{b}	0.81^{a}	-0.52^{b}	-0.69^{b}	0.86^{a}	0.98^{a}	10.78***
D-MinT (°C)	-0.10^{c}	-0.67^{c}	0.90^{b}	2.16^{a}	1.47^{b}	2.37^{a}	25.07***
D-RF (mm/week)	-4.63	-5.98	7.77	1.74	3.88	-6.79	1.45^{NS}
Rajendranagar (TS)							
A-MaxT (°C)	30.7	30.9	29.7	30.2	30.8	31.6	2.10^{NS}
A-MinT (°C)	16.7	16.3	15.9	16.4	16.3	15.7	0.11^{NS}
A-RF (mm/week)	5.99	5.51	14.24	5.64	4.52	0	0.77^{NS}
D-MaxT (°C)	1.53^{a}	1.36^{a}	0.22^{b}	0.67^{ab}	1.32^{a}	1.62^{a}	2.96*
D-MinT (°C)	-0.49	-0.16	-0.5	-0.02	-0.13	0.44	0.32^{NS}
D-RF (mm/week)	-5.89	-2.45	6.28	-2.32	-3.44	-1.41	0.82^{NS}
Kalyani (WB)							
A-MaxT (°C)	29.4	28.4	28.5	29.1	29.9	28.3	0.61^{NS}
A-MinT (°C)	18.7	15.9	15.1	15.1	17.1	15.0	1.36^{NS}
A-RF (mm/week)	8.83	7.05	11.43	5.02	3.19	5.27	0.67^{NS}
D-MaxT (°C)	-0.30^{c}	-0.39^{c}	-0.19^{bc}	0.31^{abc}	1.19^{a}	1.03^{ab}	2.85*
D-MinT (°C)	0.15^{ab}	-0.80^{bc}	-1.56^{c}	-1.63^{c}	0.37^{ab}	1.07^{a}	5.36***
D-RF (mm/week)	-0.67	0.35	4.72	-1.69	-3.52	2.59	0.93^{NS}
Rahuri (MH)							
A-MaxT (°C)	30.4^{b}	34.0^{a}	33.7^{a}	33.2^{a}	33.3^{a}	35.5^{a}	2.26*
A-MinT (°C)	11.8^{b}	16.2^{a}	17.1^{a}	17.2^{a}	17.4^{a}	19.2^{a}	2.44*
A-RF (mm/week)	0.00	2.21	4.16	1.65	5.40	8.87	1.40^{NS}
D-MaxT (°C)	0.53^{aba}	0.30^{ab}	-0.01^{ab}	-0.52^{b}	-0.38^{b}	1.01^{a}	2.88*
D-MinT (°C)	-1.59^{b}	-1.78^{b}	-0.84^{ab}	-0.76^{ab}	-0.50^{ab}	0.29^{a}	3.22**
D-RF (mm/week)	-2.42	-3.2	-1.25	-3.75	-0.01	2.8	1.17^{NS}
Raipur (CG)							
A-MaxT (°C)	30.7^{b}	31.5^{b}	31.3^{b}	31.3^{b}	31.6^{b}	34.7^{a}	2.36*
A-MinT (°C)	17.0	17.3	17.5	17.5	17.9	18.8	0.30^{NS}
A-RF (mm/week)	6.43	7.22	8	7.08	7.18	0.68	0.43^{NS}
D-MaxT (°C)	0.95^{ab}	-0.03^{c}	-0.24^{c}	-0.24^{c}	0.10^{bc}	1.64^{a}	4.44***
D-MinT (°C)	0.19^{b}	0.58^{b}	0.82^{b}	0.87^{b}	1.22^{ab}	2.27^{a}	2.41*
D-RF (mm/week)	-2.68	0.09	0.87	-0.05	0.05	-4.7	0.47^{NS}
Varanasi (UP)							
A-MaxT (°C)	28.4	28.0	27.5	27.0	28.3	27.0	0.37^{NS}
A-MinT (°C)	17.9	13.7	14.3	15.0	16.4	12.9	1.69^{NS}
A-RF (mm/week)	24.6	11.3	7.6	9.3	7.4	3.2	0.76^{NS}
D-MaxT (°C)	-1.41^{c}	-0.27^{abc}	-0.83^{bc}	-1.27^{bc}	0.05^{ab}	0.95^{a}	3.23**
D-MinT (°C)	1.02^{ab}	-0.98^{d}	-0.42^{cd}	0.37^{bc}	1.75^{a}	1.47^{ab}	8.16***
D-RF (mm/week)	13.38	3.37	-0.34	1.3	-0.55	-0.08	0.48^{NS}

A is actual weather and D is the climatic deviations over 2011-16; units of climatic variables are : MaxT (˚C), MinT (˚C) & RF (mm/week); In a row, means followed by the same letter are not significantly different with significance of 'F' denoted by *: p < 0.05; p<0.01; ***: p < 0.001. NS: non-significant based on one way ANOVA

Impact of climatic variables on insects and diseases of *kharif*

Significantly increased and unchanging MaxT at Bengaluru (KA) and Varanasi (UP) had negative and positive impacts, respectively on aphid abundance. MinT increase by 0.73°C at Rahuri (MH) had a significantly negative impact on aphids. Despite climatic variability/change, its influence on aphids was not significant at Rajendranagar (TS) and Ludhiana (PB). Increased RF by 6 mm/week at Raipur (CG) had significant positive association with aphids. The significant association of aphid abundance with unchanging climate at Varanasi (UP) only indicated other factors modulating aphid abundance possibly the effect of cropping systems. For thrips, an increased MinT (by 0.73°C over normal) significantly reduced the population at Rahuri (MH) (Table 83). While MaxT changes across locations did not show clear impact on whiteflies, the unchanging MinT at Rajendranagar (TS) and Varanasi (UP) had negative and positive significance, respectively although RF impact was positively significant at both the locations. The only impact of climatic change in terms of increasing MaxT and reduced RF on mites was negative at Bengaluru (KA). Although leaf miner reductions were obvious at most locations, significance was noted at Bengaluru (KA) and Rahuri (MH) in relation to MaxT and MinT deviations. Climatic variations did not have any relevance to *H. armigera* population and its damage, S*podoptera litura*, mealy bug and predators (coccinellids & spiders) wherever found on *kharif* tomato (Table 83).

While bacterial canker incidence on fruits was significant and positive in its association with changing MaxT at Raipur (CG), its severity on plants was non-significant with any climatic variable. At Rahuri (MH), association of bacterial canker on plants was significantly associated with changing MinT negatively. Bacterial spot at Raipur (MH) did not show any significance with any of the climatic variables. However, MaxT had a significantly positive association with bacterial spot at Varanasi (UP) and negative associations with respect to both MaxT and MinT at Rahuri (MH). Wilts (*Fusarium*, *Ralstonia* & *Sclerotium* sp.) that were of importance mainly at Varanasi (UP) maintained their *status quo* without any influence from the climatic variability and/or change. *Ralstonia* wilt at Raipur (CG) was related to MaxT positively and with RF negatively. The importance of early blight amongst study locations was of the order Bengaluru (KA)>Rajendranaga (TS)>Rahuri (MH) and Varanasi (UP)>Raipur (CG). While rainfall had a significant and negative influence at Bengaluru (KA), Varanasi (UP) had significant positive association with MaxT for the early blight severity. Late blight severity with positive association with MaxT at Raipur (CG) and of rainfall at Ludhiana (PB) was noted. Although Varanasi (UP) had the changing climate impact on early blight over 2011-16, it was absent for late blight. Only Bengaluru (KA) and Rahuri (MH) had powdery mildew and its associations were significant and negative with RF and MaxT, respectively. *Septoria* leaf spot was endemic at Raipur (CG) and Varanasi (UP) and maintained similar status over years. Tomato leaf curl incidence was greater at Bengaluru (KA)>Varanasi (UP) & Rahuri (MH)>Raipur (CG), and none of these locations had shown any significant impact due to changing climate. Mosaic was greater at Rahuri (MH) and in traces at Varanasi (UP) and the later location had significant and negative relation with MaxT, MinT and RF. *Cucumo* virus had mean status of around 19% over 2011-16 with changing MaxT significantly reducing the disease. While many of the disease progressions with climatic deviations were non-significant, a few locations had negative significance for a few diseases, in general. Only to summarise the significance amongst diseases, bacterial canker at Raipur (CG) had non-significant association with D-MinT although positive and significant with D-MaxT for its occurrence on fruits. Reduction of bacterial spot at Rahuri (MH) relating to increased D-MinT was noted. Increased early blight and bacterial spot in relation to unchanging D-MaxT at Varanasi (UP) was recorded. Reduced tomato mosaic incidence with MaxT, MinT and RF deviations were also noted at Varanasi (UP) (Table 84).

Table 83. Impact of individual climatic variables on insects of *kharif*

Insect	Location	Mean	D-MaxT	D-MinT	D-RF
Aphids (Nos./5 leaves/plant)	Bengaluru (KA)	0.45	-0.26**	-0.09 NS	-0.13 NS
	Rajendranagar (TS)	1.47	-0.05NS	-0.03 NS	0.03NS
	Rahuri (MH)	1.98	-0.08 NS	-0.18*	0.05 NS
	Raipur (CG)	0.74	-0.001NS	-0.002 NS	0.19**
	Varanasi (UP)	0.69	0.23**	0.22*	0.27**
	Ludhiana (PB)	1.63	-0.07 NS	0.21 NS	0.13 NS
Thrips (Nos./5 leaves/plant)	Rahuri (MH)	1.89	-0.10 NS	-0.18*	0.04 NS
	Varanasi (UP)	0.38	0.05NS	-0.16NS	-0.08NS
Whiteflies (Nos./5 leaves/plant)	Bengaluru (KA)	0.28	0.15$	0.08 NS	0.002 NS
	Rajendranagar (TS)	0.29	0.01 NS	-0.13$	0.16*
	Rahuri (MH)	1.91	-0.09 NS	-0.19*	0.003 NS
	Raipur (CG)	0.46	0.03 NS	-0.06 NS	-0.03 NS
	Varanasi (UP)	0.55	0.06NS	0.17*	0.14*
	Ludhiana (PB)	0.98	0.03 NS	0.01 NS	-0.01 NS
Mites (Nos./5 leaves/plant)	Bengaluru (KA)	14.88	-0.27**	0.05NS	-0.19*
	Rajendranagar (TS)	33.59	0.07 NS	-0.07 NS	0.21 NS
	Rahuri (MH)	0.96	0.01 NS	0.15 NS	0.01 NS
	Raipur (CG)	0.11	-0.05 NS	-0.10 NS	0.03 NS
Leaf miner (Nos./5 leaves/plant)	Bengaluru (KA)	0.80	-0.15*	-0.15*	-0.06 NS
	Rahuri (MH)	1.83	-0.16$	-0.17*	0.04 NS
	Raipur (CG)	0.72	-0.03 NS	-0.06 NS	0.11$
	Varanasi (UP)	0.52	-0.07NS	0.11NS	0.07NS
	Ludhiana (PB)	1.03	-0.06 NS	-0.10$	-0.01 NS
H. armigera (No. of larvae/plant)	Rahuri (MH)	5.99	-0.20 NS	-0.14 NS	-0.16 NS
	Raipur (CG)	0.08	0.04 NS	0.01 NS	-0.03 NS
	Rajendranagar (TS)	0.10	-0.01 NS	-0.06 NS	-0.01 NS
H. armigera (% fruit damage)	Rahuri (MH)	17.91	-0.11 NS	-0.14 NS	-0.12 NS
	Raipur (CG)	2.00	0.12$	0.004 NS	-0.06 NS
	Varanasi (UP)	8.49	0.01NS	-0.05NS	0NS
	Ludhiana (PB)	6.67	0.11 NS	0.04 NS	-0.02 NS
S.litura (Nos./plant)	Varanasi (UP)	0.36	0.01NS	0.06NS	0.03NS
Mealy bug (Severity)	Varanasi (UP)	0.42	0.11NS	0.07NS	0.13NS
Coccinellids (Nos./plant)	Rahuri (MH)	0.74	-0.06 NS	-0.09 NS	-0.01 NS
Spiders (Nos./plant)	Bengaluru (KA)	0.16	0.01 NS	-0.001 NS	-0.11 NS
	Rajendranagar (TS)	0.52	-0.08 NS	-0.03 NS	0.05 NS
	Rahuri (MH)	0.41	0.05 NS	0.01 NS	0.07 NS
	Raipur (CG)	0.12	0.04 NS	-0.03 NS	0.01 NS
	Varanasi (UP)	0.59	0.04NS	0.12NS	0.08NS

Values with superscripts are '*tau*' co-efficients based on Kendall's correlations between insects and climatic deviations over 2011-16; *, ** & *** refer to significance at p<,0.05, p<0.01 & p<0.001, respectively; NS: not significant; significant positive value refer to adaptation of insect/disease to the respective climatic variable; Negative value with significance specify species vulnerability

Table 84. Impact of individual climatic variables on diseases of *kharif*

Disease	Location	Mean	D-MaxT	D-MinT	D-RF
Bacterial canker (% severity)	Rahuri (MH)	9.69	-0.36 NS	-0.64*	-0.11 NS
	Raipur (CG)	3.42	0.08 NS	-0.08 NS	-0.03 NS
Bacterial canker (% Incidence) on fruits	Rajendranagar (TS)	35.79	-0.33*	-0.07 NS	-0.12 NS
	Raipur (CG)	0.67	0.16*	0.08 NS	-0.14$
Bacterial spot (% incidence)	Raipur (CG)	0.44	0.09 NS	-0.09 NS	-0.06 NS
Bacterial spot (% Severity)	Bengaluru (KA)	33.62	-0.02 NS	-0.11 NS	-0.13 NS
	Rahuri (MH)	15.46	-0.31*	-0.26*	0.10 NS
	Raipur (CG)	6.20	0.07 NS	0.04 NS	0.05 NS
	Varanasi (UP)	9.40	0.18*	-0.04NS	0.06NS
Bud blight (% Incidence)	Rajendranagar (TS)	16.64	-0.28**	0.09 NS	0.03 NS
	Raipur (CG)	5.71	-0.01 NS	-0.09 NS	-0.02 NS
Fusarium wilt (% Incidence)	Varanasi (UP)	9.26	0.11NS	-0.08NS	0.02NS
Ralstonia wilt (% Incidence)	Raipur (CG)	3.32	0.14$	-0.01 NS	-0.22**
	Varanasi (UP)	9.38	-0.07NS	-0.11NS	-0.06NS
Sclerotium wilt (%)	Varanasi (UP)	8.23	-0.08NS	-0.19NS	-0.15NS
Early blight (% Incidence)	Ludhiana (PB)		0.04NS	-0.06 NS	-0.18$
Early blight (% Severity)	Bengaluru (KA)	58.3	0.05 NS	0.07 NS	-0.13$
	Rajendranagar (TS)	24.1	-0.09 NS	-0.11 NS	0.10 NS
	Rahuri (MH)	15.3	-0.13 NS	-0.13 NS	0.05 NS
	Raipur (CG)	8.7	0.04 NS	-0.01 NS	0.08 NS
	Varanasi (UP)	15.6	0.16*	0.05NS	0.11NS
Late blight (% Incidence)	Ludhiana (PB)	2.05	0.02 NS	0.11 NS	0.10NS
Late blight (% Severity)	Raipur (CG)	1.21	0.11$	-0.04 NS	0.003 NS
	Varanasi (UP)	18.77	0.03NS	-0.3NS	-0.23NS
	Ludhiana (PB)	8.34	0.01 NS	0.03 NS	0.22$
Powdery mildew (% Severity)	Bengaluru (KA)	35.68	-0.07 NS	0.05 NS	-0.23**
	Rahuri (MH)	12.83	-0.64**	-0.24 NS	0.18 NS
Septoria leaf spot (% Severity)	Raipur (CG)	5.36	0.10 NS	0.01 NS	0.04 NS
	Varanasi (UP)	9.61	-0.02NS	-0.17NS	-0.15NS
Tomato leaf curl (% incidence)	Bengaluru (KA)	41.45	-0.07 NS	-0.08 NS	-0.06NS
	Rahuri (MH)	21.21	-0.11 NS	-0.13 NS	0.01 NS
	Raipur (CG)	7.87	0.04 NS	-0.02 NS	0.04 NS
	Varanasi (UP)	21.94	-0.05NS	-0.11NS	-0.09NS
Tomato mosaic (% incidence)	Rahuri (MH)	22.54	-0.17 NS	-0.20 NS	-0.06NS
	Raipur (CG)	8.66	0.04 NS	0.01 NS	-0.04 NS
	Varanasi (UP)	0.39	-0.14*	-0.14*	-0.19*
Cucumo virus (% incidence)	Rahuri (MH)	18.87	-0.56**	-0.27 NS	0.03 NS
Sun scald (% incidence)	Raipur (CG)	2.29	-0.02 NS	0.11 NS	-0.01 NS

Values with superscripts are '*tau*' co-efficients based on Kendall's correlations between insects and climatic deviations over 2011-16; *, ** & *** refer to significance at p<,0.05, p<0.01 & p<0.001, respectively; NS: not significant; significant positive value refer to adaptation of insect/disease to the respective climatic variable; Negative value with significance specify species vulnerability

While all significant associations of increasing MaxT at Rahuri (MH) was negative, it was all positive at Raipur (CG). MaxT relations were absent on all insects and diseases at Ludhiana (PB). All significant associations of dynamics of insects/diseases with MinT deviations across locations were negative but for increased whiteflies at Varanasi (UP) where MinT change was significant. All significant impacts of reducing RF at Bengaluru (KA) were negative and were noted with mites, early blight and powdery mildew. Impact of significantly reducing RF at Rahuri (MH) was absent on insects or diseases. Significantly, increased RF at Rajendranagar (TS) and Raipur (CG) had positive significance with whiteflies and leaf miner, respectively (Table 85).

Table 85. Impact of climatic variables on insects and diseases of *kharif* - a pictorial summary

Weather variable/Insect	Bengaluru (KA)	Rajendranagar (TS)	Rahuri (MH)	Raipur (CG)	Varanasi (UP)	Ludhiana (PB)
Maximum temperature (°C)	**0.36***	**0.88*****	**0.90*****	**0.38***	**-0.41**	**-0.24**
Aphids	↓					
Whiteflies	↑					
Mites	↓					
Leaf miner	↓		↓			
H. armigera (Larval No.)				↑		
H. armigera (% damage)				↑		
Bacterial canker		↓		↑		
Bacterial spot			↓		↑	
Bud blight		↓				
Ralstonia wilt				↑		
Early blight (% severity)					↑	
Late blight (% severity)				↑		
Powdery mildew			↓			
Tomato mosaic					↓	
Cucumo virus			↓			
Minimum temperature (°C)	**0.92*****	**0.19**	**0.73*****	**0.89**	**0.8**	**1.69**
Aphids			↓		↑	
Thrips			↓			
Whiteflies		↓	↓		↑	
Leaf miner	↓		↓			↓
Bacterial canker			↓			
Bacterial spot			↓			
Tomato mosaic					↓	
Rainfall (mm/week)	**-0.35*****	**1.99*****	**-1.72*****	**6.00*****	**0.19**	**2.05**
Aphids				↑		
Thrips					↓	
Whiteflies		↑				
Mites	↓					
Leaf miner				↑		
Fusarium wilt (% incidence)					↓	
Bacterial canker				↓		
Ralstonia wilt				↓		
Early blight (incidence)						↓
Early blight (severity)	↓					
Late blight (% incidence)						↑
Late blight (% severity)					↑	
Powdery mildew	↓					

Empty cells with no (white) colour indicates the absence or very low presence of insects or diseases in the location. Only significant relations between population dynamics of insects/diseases with the change in respect of MaxT, MinT and RF are shown with up or downward arrows;.coloured cell with no arrow indicates non significance of insect/disease and climate change; For reporting units for insects/diseases relating to table 85 under different climatic variables can be referred from Table 84.

Impact of climatic variables on insects and diseases of *rabi*

Significantly reducing rainfall at Rajendranagar (TS) and unchanging MaxT and MinT at Varanasi (UP) had increased effect on aphids. However, at Kalyani (WB), the unchanging MinT had reducing impact on aphids. Thrips had significantly reduced impact of increased rainfall at Varanasi (UP) and of MinT at Kalyani (WB). All climatic deviations (unchanging temperature and significantly decreasing RF) at Rahuri (MH)) did not impact population levels of aphids, thrips and whiteflies.

The significant positive impact of significantly increasing MaxT and RF at Rajendranagar (TS) and of unchanging MaxT and MinT at Varanasi (UP) on whiteflies was seen. Despite no significant climatic variability observed at Bengaluru (KA), positive impact of MaxT and negative of MinT and RF on mites were noted. In contrast, reduced RF had increased significance on mites at Rajendranagar (TS) and at Kalyani (WB) with MinT association significantly negative and of RF positive in the later location. The unchanging MinT at all study locations had no significance with leaf miner population except in Bengaluru (KA) where the effect was positive. The negative significance of MaxT and RF on leaf miner was also obvious at Bengaluru (KA). While Raipur (CG) had MaxT - leaf miner associations negatively significant, it was positive at Varanasi (UP). Significantly reducing and unchanging RF at Rajendranagar (TS) and Kalyani (WB) respectively had positive impact on leaf miner. While MaxT deviations, although not significant over normal at Bengaluru (KA), Rahuri (MH) and Kalyani (WB), the impact on *H. armigera* abundance was negatively significant. The only positive association of *H. armigera* were with MinT and RF was at Rahuri (MH). For fruit damage due to *H. armigera*, the only location of Rajendranagar (TS) that had significantly increased MaxT by 1.03°C had positive impact that was significant. Significance of MaxT at Rahuri (MH) and MinT at Varanasi (UP) in reducing *H. armigera* fruit damage was noted. Unchanging MinT at Kalyani (WB) and significantly reducing RF at Rajendranagar (TS) had indicated increased population of *S. litura* on *rabi* tomato. Mealy bugs and coccinellids noted at some locations did not show any significant influence possibly due to their reduced population levels. With MaxT differences from respective normals across all study locations not existing, increased spiders at Varanasi (UP) and decrease at Kalyani (WB) were significant showing their predatory role as inferred through their higher population (Table 86).

Increased early blight severity at Bengaluru (KA) and Varanasi (UP) in relation to MaxT and with RF at Rajendranagar (TS) was indicated. Bengaluru (KA) additionally had shown counter effects on early blight due to MinT and RF that were significant. Late blight severity increasing at Bengaluru (KA) with MaxT and reducing at Varanasi (UP) in relation to MinT was obvious. Severity of powdery mildew had increased at Rahuri (MH) in response to MaxT and MinT. *Septoria* leaf spot increase at Bengaluru (KA) and reduction at Varanasi (UP) in response to MaxT and MinT, respectively was the scenario. Bacterial spot had increasing severity at Varanasi (UP) and Rahuri (MH) in response to MaxT and MinT, respectively. All climatic variables (MaxT, MinT and RF) at Rahuri (MH) had significant associations with bacterial canker being positive with MaxT and MinT and negative with RF. For tomato leaf curl, opposing responses of positive significance with MaxT and negative with RF was noted at Varanasi (UP). Negative association of leaf curl incidence with MaxT and MinT and positive with RF occurred at Kalyani (WB). Mosaic incidence was significant at Rajendranagar (TS) and Rahuri (MH) alone in relation to D-MinT. Cucumo virus at Rahuri (MH) increased with MaxT and MinT, although temperature changes were not significant over normals during crop season. Bud blight incidence at Rajendranagar (TS) was increasing with significantly reducing RF. Incidence of wilts (*Ralsotania* and *Sclerotium*) during *rabi* was increasing significantly in response to changing climate (Table 87).

Table 86. Impact of individual climatic variables on insects of *rabi*

Insect	Location	Mean$^{@}$	D-MaxT	DMinT	DRF
Aphids (nos./5 leaves/plant)	Bengaluru (KA)	0.57	0.11^{NS}	-0.05^{NS}	-0.01^{NS}
	Rajendranagar (TS)	2.13	-0.03^{NS}	-0.07^{NS}	0.19**
	Rahuri (MH)	2.91	-0.07^{NS}	0.01^{NS}	0.08^{NS}
	Raipur (CG)	0.77	-0.04^{NS}	-0.07^{NS}	0.05^{NS}
	Varanasi (UP)	0.90	0.16*	0.20**	0.01^{NS}
	Kalyani (WB)	5.74	-0.05^{NS}	-0.26***	0.05^{NS}
Thrips (nos./5 leaves/plant)	Rajendranagar (TS)	1.12	-0.06^{NS}	0.11^{NS}	0.11^{NS}
	Rahuri (MH)	2.87	-0.03^{NS}	0.05^{NS}	0.08^{NS}
	Varanasi (UP)	0.39	0.01^{NS}	-0.11^{NS}	-0.14*
	Kalyani (WB)	6.06	-0.04^{NS}	-0.30***	-0.01^{NS}
Whiteflies (nos./5 leaves/plant)	Bengaluru (KA)	0.37	-0.09^{NS}	0.03^{NS}	0.01^{NS}
	Rajendranagar (TS)	0.47	0.11$^{\$}$	0.11$^{\$}$	0.13*
	Rahuri (MH)	2.83	-0.06^{NS}	0.07^{NS}	0.11^{NS}
	Raipur (CG)	0.38	0.04^{NS}	0.01^{NS}	0.07^{NS}
	Varanasi (UP)	0.58	0.17*	0.25**	-0.14$^{\$}$
	Kalyani (WB)	5.72	-0.002^{NS}	-0.22***	-0.03^{NS}
Mites (nos./5 leaves/plant)	Bengaluru (KA)	31.56	0.11*	-0.04*	-0.06*
	Rajendranagar (TS)	12.24	-0.04^{NS}	-0.12^{NS}	0.23*
	Rahuri (MH)	2.29	0.17*	-0.01^{NS}	-0.08^{NS}
	Kalyani (WB)	5.48	-0.09^{NS}	-0.29***	0.11$^{\$}$
Leaf miner (nos./5 leaves/plant)	Bengaluru (KA)	0.82	-0.09*	0.11*	-0.11*
	Rajendranagar (TS)	0.31	0.02^{NS}	-0.01^{NS}	0.17*
	Rahuri (MH)	2.79	-0.04^{NS}	0.04^{NS}	0.10^{NS}
	Raipur (CG)	0.87	-0.17**	0.01^{NS}	0.02^{NS}
	Varanasi (UP)	0.66	0.22***	0.07^{NS}	-0.10$^{\$}$
	Kalyani (WB)	1.54	0.03^{NS}	-0.10^{NS}	0.16*
H. armigera (no. of larvae/plant)	Bengaluru (KA)	0.21	-0.25**	0.06^{NS}	-0.12^{NS}
	Rajendranagar (TS)	0.13	-0.12^{NS}	0.02^{NS}	0.08^{NS}
	Rahuri (MH)	3.49	-0.23*	0.22*	0.12^{NS}
	Raipur (CG)	0.13	-0.06^{NS}	0.02^{NS}	0.11^{NS}
	Varanasi (UP)	0.28	0.07^{NS}	-0.04^{NS}	-0.02^{NS}
	Kalyani (WB)	0.43	-0.27***	-0.02^{NS}	0.08^{NS}
H. armigera (% fruit damage)	Bengaluru (KA)	3.49	-0.18^{NS}	-0.01^{NS}	-0.03^{NS}
	Rajendranagar (TS)	2.62	0.28***	0.05^{NS}	-0.06^{NS}
	Rahuri (MH)	13.26	-0.30**	0.01^{NS}	0.15^{NS}
	Raipur (CG)	3.08	0.03^{NS}	-0.11^{NS}	-0.06^{NS}
	Varanasi (UP)	6.13	0.10^{NS}	-0.18*	-0.008^{NS}
	Kalyani (WB)	9.32	-0.18*	0.08^{NS}	0.07^{NS}
S. litura (nos./plant)	Bengaluru (KA)	0.25	0.30^{NS}	0.31^{NS}	0.08^{NS}
	Rajendranagar (TS)	0.23	-0.02^{NS}	-0.01^{NS}	0.13$^{\$}$
	Rahuri (MH)	1.53	-0.10^{NS}	-0.01^{NS}	-0.02^{NS}
	Raipur (CG)	0.08	0.04^{NS}	-0.02^{NS}	0.06^{NS}
	Varanasi (UP)	0.32	0.05^{NS}	0.05^{NS}	0.11^{NS}
	Kalyani (WB)	1.54	-0.008^{NS}	0.16*	-0.01^{NS}
Mealybug (severity)	Kalyani (WB)	1.43	0.1^{NS}	-0.03^{NS}	-0.06^{NS}
Coccinellids (nos./plant)	Rahuri (MH)	1.44	0.08^{NS}	-0.06^{NS}	-0.01^{NS}
	Kalyani (WB)	0.28	-0.01^{NS}	-0.09^{NS}	-0.03^{NS}
Spiders (Nos./plant)	Bengaluru (KA)	0.21	0.23**	-0.10^{NS}	0.08^{NS}
	Rajendranagar (TS)	0.45	-0.13^{NS}	0.10$^{\$}$	0.14*
	Rahuri (MH)	0.54	0.02^{NS}	-0.01^{NS}	0.06^{NS}
	Raipur (CG)	0.08	0.003^{NS}	0.05^{NS}	-0.08^{NS}
	Varanasi (UP)	0.51	0.12*	-0.02^{NS}	0.04^{NS}
	Kalyani (WB)	0.44	-0.14*	0.01^{NS}	0.07^{NS}

$^{@}$ indicate seasonal means over 2011-12 & 2016-17 *rabi* tomato; values with superscripts are '*tau*' co-efficients based on Kendall's correlations between insects and climatic deviations over 2011-16; *, ** & *** refer to significance at p<,0.05, p<0.01 & p<0.001, respectively; ^{NS}: not significant; significant positive value refer to adaptation of insect/disease to the respective climatic variable; negative values with significance specify species vulnerability

Table 87. Impact of individual climatic variables on diseases of *rabi*

Insect	Location	Mean@	D-MaxT	D-MinT	D-RF
Early blight (% severity)	Bengaluru (KA)	50.43	0.20**	-0.24***	-0.10*
	Rajendranagar (TS)	27.52	-0.05 NS	0.05 NS	0.24***
	Rahuri (MH)	12.83	-0.06 NS	0.18*	0.14*
	Raipur (CG)	7.34	-0.04 NS	-0.01 NS	0.02 NS
	Varanasi (UP)	17.16	0.13*	0.11$	-0.15*
	Kalyani (WB)	10.51	-0.02 NS	-0.02 NS	-0.01 NS
Late blight (% incidence) on fruits	Raipur (CG)	1.80	-0.25*	-0.27*	-0.03 NS
	Varanasi (UP)	14.44	-0.03 NS	-0.04 NS	0.04 NS
Late blight (% severity)	Bengaluru (KA)	34.41	0.52***	0.01 NS	-0.20 NS
	Varanasi (UP)	14.44	-0.17 NS	-0.28**	0.05 NS
Powdery mildew (% severity)	Rahuri (MH)	9.17	0.24*	0.26*	-0.11 NS
	Raipur (CG)	2.63	0.03NS	-0.16NS	0.03NS
Septoria leaf spot (% severity)	Bengaluru (KA)	28.57	0.34*	-0.005 NS	-0.41*
	Raipur (CG)	4.19	-0.05 NS	0.05 NS	0.07 NS
	Varanasi (UP)	8.95	-0.01 NS	-0.28*	0.04 NS
Bacterial spot (% incidence)	Rajendranagar (TS)	5.97	-0.01NS	-0.02 NS	-0.25*
Bacterial spot (% severity)	Rajendranagar (TS)	20.07	-0.04 NS	-0.03 NS	0.04 NS
	Rahuri (MH)	11.66	0.07 NS	0.26**	-0.03 NS
	Varanasi (UP)	7.44	0.21**	0.03 NS	-0.19*
Bacterial canker (% incidence)	Rajendranagar (TS)	4.61	0.15 NS	0.01 NS	-0.21 NS
Bacterial canker (% severity)	Rahuri (MH)	7.51	0.46***	0.33*	-0.31*
Tomato leaf curl (% incidence)	Bengaluru (KA)	55.72	0.24 NS	-0.23 NS	-0.08 NS
	Rajendranagar (TS)	16.28	-0.23 NS	0.22 NS	0.27$
	Rahuri (MH)	20.63	0.11 NS	0.13 NS	-0.01 NS
	Raipur (CG)	10.17	-0.06 NS	-0.01 NS	0.01 NS
	Varanasi (UP)	21.96	0.12*	0.06 NS	-0.14*
	Kalyani (WB)	30.88	-0.18**	-0.17**	0.21***
Tomato mosaic (% incidence)	Rajendranagar (TS)	10.87	0.07 NS	0.23*	-0.06 NS
	Rahuri (MH)	18.57	0.20$	0.21*	-0.10 NS
	Raipur (CG)	7.98	-0.09 NS	0.07 NS	-0.03 NS
	Varanasi (UP)	11.43	-0.03 NS	-0.17 NS	-0.02 NS
	Kalyani (WB)	5.66	-0.05NS	-0.01NS	0.12NS
Cucumo virus (% incidence)	Rahuri (MH)	19.62	0.23*	0.28*	-0.09 NS
Bud blight (% incidence)	Rajendranagar (TS)	9.57	0.02 NS	0.01 NS	0.14*
	Raipur (CG)	6.06	-0.08 NS	-0.05 NS	0.01 NS
Ralstonia wilt (% incidence)	Varanasi (UP)	7.42	-0.16 NS	0.02 NS	-0.01 NS
	Kalyani (WB)	8.56	-0.04 NS	-0.06 NS	0.03 NS
Sclerotium wilt (% incidence)	Varanasi (UP)	6.71	-0.04 NS	-0.06 NS	-0.07 NS
	Kalyani (WB)	5.47	0.05NS	0.05NS	0.04NS

@ indicate seasonal means over 2011-12 & 2016-17 *rabi* tomato; values with superscripts are '*tau*' co-efficients based on Kendall's correlations between insects and climatic deviations over 2011-16; *, ** & *** refer to significance at p<,0.05, p<0.01 & p<0.001, respectively; NS: not significant; significant positive value refer to adaptation of insect/disease to the respective climatic variable; negative values with significance specify species vulnerability

Table 88 depicts the significance of dynamics of insects and diseases-climate change associations as arrows (upward for positive & downward for negative relations). Bengaluru (KA) had increased mites, spiders, early blight, late blight and *Septoria* leaf spot in relation to MaxT with the leaf miner alone on decline. Changing MaxT relations significant at Rajendranagar (TS) affected whiteflies and *H. armigera* positively. Rahuri (MH) had significant increase of mites and decline of *H. armigera* among insects, although MaxT increase was not significant. Powdery mildew, bacterial canker, tomato mosaic and cucumo virus were on rise under those unchanging MaxT. MaxT impact at Raipur (CG) was negative and significant only for leaf miner and late blight incidence. Varanasi (UP) had the declining MaxT (-0.71°C) although not significant had positive relation with aphids, whiteflies, leaf miner, spiders, early blight severity, bacterial spot (% incidence) and tomato leaf curl. Tomato leaf curl among diseases, *H. armigera* and spiders alone had significant increase with MaxT at Kalyani (WB).

Table 88. Impact of climatic variables on insects and diseases of *rabi* - a pictorial summary

Weather variable/ Insect/ Disease	Bengaluru (KA)	Rajendranagar (TS)	Rahuri (MH)	Raipur (CG)	Varanasi (UP)	Kalyani (WB)
Maximum temperature (°C)	**0.54**	**1.03*** **	**0.06**	**0.34**	**-0.71**	**0.23**
Aphids					↑	
Whiteflies		↑			↑	
Mites	↑		↑			
Leaf miner	↓			↓	↑	
H. armigera (Nos/plant))		↑	↓			↑
H. armigera (% fruit damage)		↑	↓			↑
Spiders	↑				↑	↑
Early blight	↑				↑	
Late blight	↑			↓		
Powdery mildew			↑			
Septoria leaf spot	↑					
Bacterial spot					↑	
Bacterial canker			↑			
Tomato leaf curl					↑	↑
Tomato mosaic			↑			
Cucumo virus			↑			
Minimum temperature (°C)	**1.57**	**-0.19**	**-0.79**	**0.94**	**0.15**	**-0.62**
Aphids					↑	↓
Thrips						↓
Whiteflies		↑			↑	↓
Mites	↓					↓
Leaf miner	↑					
H. armigera (nos/plant))	↓		↑			
H. armigera (% fruit damage)					↓	
Spodoptera litura						↑
Spiders		↑				
Early blight	↓		↑		↑	
Late blight				↓	↓	
Powdery mildew			↑			
Septoria leaf spot					↓	
Bacterial spot			↑			
Bacterial canker			↑			
Tomato leaf curl						↓
Tomato mosaic		↑	↑			
Cucumo virus			↑			

Table 88 (contd.). Impact of climatic variables on insects and diseases of *rabi* - a pictorial summary

Weather variable/ Insect/ Disease	Bengaluru (KA)	Rajendranagar (TS)	Rahuri (MH)	Raipur (CG)	Varanasi (UP)	Kalyani (WB)
Rainfall (mm/week)	**-0.67**	**-1.23*****	**-1.27*****	**-0.73*****	**1.99*****	**0.1**
Aphids		↑				
Thrips					↓	
Whiteflies		↑			↓	
Mites	↓	↑				↑
Leaf miner	↓	↑			↓	↑
Spodoptera litura		↑				
Spiders		↑				
Early blight	↓	↑	↑		↓	
Septoria leaf spot	↓					
Bacterial spot		↓			↓	
Bacterial canker			↓			
Tomato leaf curl		↑			↓	↑
Bud blight		↑				

Empty cells with no (white) colour indicates the absence or very low presence of insects or diseases in the location; only significant relations between population dynamics of insects/diseases with the change in respect of MaxT, MinT and RF are shown with up or downward arrows. coloured cell with no arrow indicates non significance of insect/disease and climate change

MinT change had positive significance with leaf miner and negative with mites, *H. armigera* and early blight at Bengaluru (KA). Slightly reducing MinT at Rajendranagar (TS) had a positive impact on whiteflies, spiders and mosaic disease. All associations of the reducing but non-significant MinT at Rahuri (MH) had positive relation with *H. armigera*, early blight, powdery mildew, bacterial spot (% incidence), bacterial canker, tomato mosaic and cucumo virus. The only significant association of increasing MinT at Raipur (CG) was negative with late blight incidence on fruit. Kalyani (WB) was typical in having the decreasing MinT reducing significantly the population of all sucking insects (aphids, thrips, mites & whiteflies) but increasing *S. litura*. Among diseases, leaf curl reduced significantly in relation to MinT. Varanasi (UP) showed significant but reducing effect on *H. armigera*, late blight and *Septoria* leaf spot and increased aphids, whiteflies and early blight.

Changing rainfall although was not significant at Bengaluru (KA), had reducing effect on mites, leaf miner, early blight and *Septoria* leaf spot. Significantly decreased RF (-1.23 mm/week) had reducing effect on bacterial spot incidence and increasing impact on aphids, whiteflies, mites, leaf miner, *S. litura*, spiders, early blight, leaf curl and bud blight at Rajendranagar (TS). Increasing early blight and decreasing bacterial canker was significant with reducing RF at Rahuri (MH). Despite significant reduction of RF at Raipur (CG), no insect or disease had a significant association. All associations of aphids, thrips and leaf miner among insects and early blight, bacterial spot and leaf curl were significant and negative at Varanasi (UP) where RF increase was significant. Mites, leaf miner, and tomato leaf curl had significant positive associations with RF at Kalyani (WB).

Impact of climate change measured using species – climate change association index (SAI)

The tables 89 & 90 show the ordered insects/diseases along the values of SAI in respect of locations for both *kharif* and *rabi* aiding to understand the relative impact of climate change at a given location. The order of importance of insects and diseases to climatic variability and change in respect of locations and seasons differed indicating varied impacts along ACZ and seasons (Table 89). While mites at Rajendranagar (TS) and Rahuri (MH) had the highest adaptation, aphids had higher SAI at Raipur (CG) and Ludhiana (PB) with the later having lesser SAI over the former location. At Bengaluru (KA), early blight had higher SAI on par with whiteflies. Raipur (CG) and Rajendranagar (TS) had wide range of

SAIs during *kharif*. Very narrow range of SAI were noted at Varanasi (UP) during *kharif* over *rabi*. The leaf miner was of insignificance at Rajendranagar (TS) but vulnerable at Bengaluru (KA), Rahuri (MH) and Ludhiana (PB) with adaptive response at Raipur (CG) and Varanasi (UP). While *S. litura* had shown highest adaptation at Bengaluru (KA) and Varanasi (UP), it had the least SAIs value at Kalyani (WB) in addition to being highly vulnerable over other insects and diseases during *rabi*. The number of insects with high adaptive response to climate change in *rabi* was at Kalyani (WB) than all other locations.

Table 89. Impact of climate change on insects and diseases of *kharif* and *rabi* - within location

Location	Order of adaptation/vulnerability	SAIs (Ordered)
kharif		
Bengaluru (KA)	EBS>WF>PDW*>SP>MIT*>BSS>TLC>APH*>LM*	**0.13>0.13>0.10*>0.04>0.02***>-0.06>-0.08>-0.13*>-0.17*
Rajendranagar (TS)	MIT>WF*>EBS>SP>APH>HAN>BB*>BCI*	**0.47>0.30*>0.10>0.02>0.01**>-0.04>-0.17*>-0.54*
Rahuri (MH)	MIT>HAF>HAN>SP>CC>TM>TLC*>WF*>APH*>TRP*>EBS*>LM*>BCS*>BSS*>CV*>PDW*	**0.10>0.01**>-0.01>-0.07>-0.10>-0.20>-0.21*>-0.22*>-0.29*>-0.29*>-0.30*>-0.34*>-0.60*>-0.64*>-0.75*>-1.06*
Raipur (CG)	APH*>LM>EBS>BSS>SLS>TLC>MIT>SP>SS>LBS>HAN>BB>TM>BCS>WF>HAF>BSI>BCI*>RW*	**1.14*>0.60>0.49>0.36>0.29>0.24>0.07>0.05>0.03>0.02**>-0.16>-0.20>-0.22>-0.22>-0.22>-0.31>-0.41>-0.71*>-1.28*
Varanasi (UP)	FW*> WF*> LM> MB> APH*> SP> SL> EBS*> TRP*> HAF> RW> BSS*> LBS*> TM*> TLC> SW> SLS	**0.09*>0.07*>0.06>0.04>0.04*>0.03**>-0.01>-0.02*>-0.04*>-0.05>-0.07>-0.07*>-0.08*>-0.08*>-0.09>-0.13>-0.16
Ludhiana (PB)	APH>LBS>LBI>HAF>WF>LM>EBI	**0.64>0.50>0.39**>0.00>-0.01>-0.18>-0.48
rabi		
Bengaluru (KA)	SL>SLS*>LBS*>LM*>HAN*>MIT*>WF>APH>SP*>HAF>TLC>EBS*	**0.60>0.45*>0.43*>0.20*>0.04*>0.04***>-0.01>-0.01>-0.09*>-0.09>-0.18>-0.20*
Rajendranagar (TS)	BCI>HAN*>HAF*>BSI*>TM*>WF*>BSS>BB*>SL>LM*>TRP>APH*>MIT*>SP*>EBS*>TLC	**0.41>0.35*>0.35*>0.30*>0.10***>-0.07*>-0.08>-0.15*>-0.18>-0.19*>-0.22>-0.25*>-0.30*>-0.33*>-0.36*>-0.61
Rahuri (MH)	BCS*>MIT*>CC>SL>TM*>PDW*>SP*>TLC*>CV*>APH>TRP>LM>BSS*>WF>HAF*>EBS*>HAN*	**0.15*>0.12*>0.06>0.03**>-0.03*>-0.06*>-0.06*>-0.08*>-0.10*>-0.11>-0.14>-0.16>-0.16*>-0.19>-0.21*>-0.32*>-0.34*
Raipur (CG)	SP>TM>SLS>WF>TLC>EBS>SL>HAF>LM*>BB>HAN>APH>PDW*>LBI*	**0.11>0.06**>-0.02>-0.03>-0.04>-0.04>-0.05>-0.05>-0.06*>-0.08>-0.08>-0.12>-0.16*>-0.32*
Varanasi (UP)	SL>LBS*>RW>LBI>APH*>SLS*>SP*>TM*>HAN>HAF*>SW>TRP*>LM*>TLC*>WF*>EBS*>BSS*	**0.19>0.18*>0.10>0.09>0.08*>0.04***>-0.01*>-0.04*>-0.10>-0.11*>-0.12>-0.30*>-0.34*>-0.35*>-0.36*>-0.37*>-0.52*
Kalyani (WB)	TRP*>MIT*>APH*>WF*>TLC*>LM*>CC>MB>RW>EBS>TM>SW>SP*>HAN*>HAF*>SL*	**0.18*>0.17*>0.15*>0.13*>0.09*>0.08*>0.05>0.04>0.03>0.01>0.01**>-0.02>-0.03*>-0.04*>-0.08*>-0.10*

APH= Aphids (Nos./5 leaves/plant); BCS= Bacterial canker (% severity); BCI= Bacterial canker (% Incidence); BSI= Bacterial spot (% Incidence); BSS= Bacterial spot (% Severity); BB= Bud blight (% Incidence); CC= Coccinellids (Nos./plant); CV= Cucumo virus (% Incidence); EBI= Early blight (% Incidence); EBS= Early blight (% Severity); FW=*Fusarium* wilt (% Incidence); HAF= *H. armigera* (% fruit damage); HAN= *H. armigera* (No. of larvae/plant); LBI= Late blight (% Incidence); LBS= Late blight (% Severity); LM= Leaf miner (Nos./5 leaves/plant); MB= Mealybug (Severity); MIT= Mites (Nos./5 leaves/plant); PDW= Powdery mildew (% Severity); RW= *Ralstonia* wilt (% Incidence); SS: Sun scald SW= *Sclerotium* wilt (% Incidence); SLS= *Septoria* leaf spot (% Severity); SP= Spiders (Nos./plant); SL= *Spodoptera litura* (Nos./plant); TRP= Thrips (Nos./5 leaves/plant); TLC= Tomato leaf curl (% Incidence); TM= Tomato mosaic (% Incidence); WF= Whiteflies (Nos./5 leaves/plant). Positive values of SAI in bold indicate adaptation of insects/diseases to the observed climate change in respect of locations; negative values specify species vulnerability; symbol on SAI * indicates the significance of the relation between population dynamics/disease progression and magnitude of the climate change at least with one or two or all three climatic variables (MaxT, MinT and/or RF) irrespective of the significance or non-significance of magnitude of change in climatic variable(s) *per se*

Ordering of locations in respect of each insect and disease (Table 90) clearly showed the degree of adaptation or vulnerability across ACZ. Highest adaptation of aphids to climate change was at Raipur (CG) and Ludhiana (PB). Leaf miner significance to climate change was higher at Raipur (CG). Rahuri

(MH) had shown the highest vulnerability for bacterial canker, bacterial spot, early blight, aphids, thrips, whiteflies and tomato leaf curl over all other locations wherever insect/disease was present.

Table 90. Impact of climate change on insects and diseases of *kharif* tomato - between locations

Insect/Disease	Order of adaptation/vulnerability	Cumulative indices (ordered)
Aphids (nos./5 leaves/plant)	CG*>PB>UP*>TS>KA*>MH*	**1.14*>0.64>0.04*>0.01**>-0.13*>-0.29*
Thrips (nos./5 leaves/plant)	UP*>MH*	-0.04*>-0.29*
Whiteflies (nos./5 leaves/plant)	TS*>KA> UP*>PB>CG>MH*	**0.30*>0.13*>0.07**>-0.01>-0.22>-0.22*
Mealybug (severity)	UP	**0.04**
Mites (nos./5 leaves/plant)	TS>MH>CG>KA*	**0.47>0.10>0.07>0.02***
Leaf miner (nos./5 leaves/plant)	CG> UP>KA*>PB>MH*	**0.60>0.06**>-0.17*>-0.18>-0.34*
H. armigera (no. larvae/plant)	MH>TS>CG	-0.01>-0.04>-0.16
H. armigera (% fruit damage)	MH>PB> UP>CG	**0.01>0.00**>-0.05>-0.31
Spodoptera litura (nos./plant)	UP	-0.01
Coccinellids (nos./plant)	MH	-0.10
Spiders (nos./plant)	CG>KA>UP>TS>MH	**0.05>0.04>0.03>0.02**>-0.07
Bacterial canker (% incidence)	TS*>CG*	-0.54*>-0.71*
Bacterial canker (% severity)	CG>MH*	-0.22>-0.60*
Bacterial spot (% severity)	CG>KA> UP*>MH*	**0.36**>-0.06>-0.07*>-0.64*
Bacterial spot (% incidence)	CG	-0.41
Bud blight (% incidence)	TS*>CG	-0.17*>-0.2
Fusarium wilt (% incidence)	UP*	**0.09***
Ralstonia wilt (% incidence)	UP>CG*	-0.07>-1.28*
Sclerotium wilt (% incidence)	UP	-0.13
Early blight (% incidence)	PB	-0.48
Early blight (% severity)	CG>KA>TS> UP*>MH*	**0.49>0.13>0.10**>-0.02*>-0.30*
Late blight (% incidence)	PB	**0.39**
Late blight (% severity)	PB>CG >UP*	**0.50>0.02**>-0.08*
Powdery mildew (% severity)	KA*>MH*	**0.10***>-1.06*
Septoria leaf spot (% severity)	CG >UP	**0.29**>-0.16
Tomato leaf curl (% incidence)	CG>KA> UP>MH*	**0.24**>-0.08>-0.09>-0.21*
Tomato mosaic (% incidence)	UP*>MH>CG	-0.08*>-0.20>-0.22
Cucumo virus (% incidence)	MH*	-0.75*
Sun scald (% incidence)	CG	**0.03**

KA= Bengaluru (KA); TS = Rajendranagar (TS); MH= Rahuri (MH); CG= Raipur (CG); PB= Ludhiana (PB): UP=Varanasi (UP); Positive values of indices in bold indicate adaptation of insects to the observed climate change in respect of locations. Negative values specify species vulnerability; Positive values of SAI in bold indicate adaptation of insects/diseases to the observed climate change in respect of locations; negative values specify species vulnerability; symbol on SAI * indicates the significance of the relation between population dynamics/disease progression and magnitude of the climate change at least with one or two or all three climatic variables (MaxT, MinT and/or RF) irrespective of the significance or non-significance of magnitude of change in climatic variable(s) *per se*

For *rabi*, Kalyani (WB) ranked first for all the sap feeders including whiteflies and the leaf curl virus transmitted by it. While Rajenedranagar (TS) had high adaptiveness of *H. armigera,* Bengaluru (KA) had the highest adaptiveness of *Spodoptera* over other locations. Varanasi (UP) was unique with high adaptability of late blight incidence and severity although Bengaluru (KA) had the highest SAI over UP for late blight severity. Bacterial canker and spots were exclusive to Rajendranagar (TS) and had increasing incidence (Table 91).

Table 91. Impact of climate change on insects and diseases of *rabi* - between locations

Insect/Disease	Order of adaptation/vulnerability	Cumulative indices (ordered)
Aphids (Nos./5 leaves/plant)	WB*>UP*>KA>MH>CG>TS*	**0.15*>0.08***>-0.01>-0.11>-0.12>-0.25*
Thrips (Nos./5 leaves/plant)	WB*>MH>TS>UP*	**0.18***>-0.14>-0.22>-0.30*
Whiteflies (Nos./5 leaves/plant)	WB*>KA>CG>TS*>MH>UP*	**0.13***>-0.01>-0.03>-0.07*>-0.19>-0.36*
Mealybug (mean severity)	WB	**0.04**
Mites (nos./5 leaves/plant)	WB*>MH*>KA*>TS*	**0.17*>0.12*>0.04***>-0.30*
Leaf miner (nos./5 leaves/plant)	KA*>WB*>CG*>MH>TS*>UP*	**0.20*>0.08***>-0.06*>-0.16>-0.19*>-0.34*
H. armigera (no. of larvae/plant)	TS*>KA*>WB*>CG>UP>MH*	**0.35*>0.04***>-0.04*>-0.08>-0.10>-0.34*
H. armigera (% fruit damage)	TS*>CG>WB*>KA>UP*>MH*	**0.35***>-0.05>-0.08*>-0.09>-0.11*>-0.21*
Spodoptera litura (Nos./plant)	KA>UP>MH>CG>WB*>TS	**0.60>0.19>0.03**>-0.05>-0.10*>-0.18
Coccinellids (nos./plant)	MH>WB	**0.06>0.05**
Spiders (nos./plant)	CG>UP*>WB*>MH*>KA*>TS*	**0.11**>-0.01*>-0.03*>-0.06*>-0.09*>-0.33*
Early blight (% severity)	WB>CG>KA*>MH*>TS*>UP*	**0.01**>-0.04>-0.20*>-0.32*>-0.36*>-0.37*
Late blight (% incidence)	UP>CG*	**0.09**>-0.32*
Late blight (% severity)	KA*>UP*	**0.43*>0.18***
Powdery mildew (% severity)	MH*>CG*	-0.06*>-0.16*
Septoria leaf spot (% severity)	KA*>UP*>CG	**0.45*>0.04***>-0.02
Bacterial spot (% incidence)	TS*	**0.30***
Bacterial spot (% severity)	TS>MH*>UP*	-0.08>-0.16*>-0.52*
Bacterial canker (% incidence)	TS	**0.41**
Bacterial canker (% severity)	MH*	**0.15***
Tomato leaf curl (% incidence)	WB*>CG>MH*>KA>UP*>TS	**0.09***>-0.04>-0.08*>-0.18>-0.35*>-0.61
Tomato mosaic (% incidence)	TS*>CG>WB>MH*>UP*	**0.10*>0.06>0.01**>-0.03*>-0.04*
Cucumo virus (% incidence)	MH*	-0.10*
Bud blight (% incidence)	CG>TS*	-0.08>-0.15*
Ralstonia wilt (% incidence)	UP>WB	**0.10>0.03**
Sclerotium wilt (% incidence)	WB>UP	-0.02>-0.12

KA= Bengaluru (KA); TS = Rajendranagar (TS); MH= Rahuri (MH); CG= Raipur (CG); UP=Varanasi (UP); WB=Kalyani (WB); positive values of indices in bold indicate adaptation of insects to the observed climate change in respect of locations. Negative values specify species vulnerability; positive values of indices in bold indicate adaptation of insects to the observed climate change in respect of locations; negative values specify species vulnerability; symbol on SAI* and locations indicates the significance of the relation between population dynamics of insects/disease progression and magnitude of the climate change at least with one or two or all three climatic variables (MaxT, MinT and/or RF) irrespective of the significance or non-significance of magnitude of change in respect of climatic variable *per se*

Listing and grouping of all study insects and diseases in respect of different study locations for *kharif* and *rabi* based on SAI values as adaptive and vulnerable are furnished in Annexure XXXII. Table 92 lists only insects and diseases whose population dynamics of insect or the disease progression had significant association with at least one or two or all climatic variables and the SAIs were calculated considering magnitude of change in all three (whether significant or not). Differences existed for insects and diseases for their adaptive or vulnerable response between *kharif* and *rabi* for a given location. Some insects and/or diseases were unique in their presence or absence in a given season and location.

Table 92. Impact of climate change on *kharif* and *rabi* tomato insects and diseases - a listing

Location	*Kharif*		*Rabi*	
	Adaptive	Vulnerable	Adaptive	Vulnerable
Bengaluru (KA)	1. Powdery mildew 2. Mites	1. Aphids 2. Leaf miner	1. *Septoria* leaf spot 2. Late blight – severity 3. Leaf miner 4. *H. armigera* - larval population 5. Mites	1. Spiders 2. Early blight – severity
Rajendra nagar (TS)	Whiteflies	1. Bud blight 2. Bacterial canker – incidence	1. *H. armigera* –fruit damage & larval population 2. Bacterial spot – incidence 3. Tomato mosaic	1. Whiteflies 2. Bud blight 3. Leaf miner 4. Aphids 5. Mites 6. Spiders 7. Early blight severity
Rahuri (MH)		1. Tomato leaf curl 2. Whiteflies 3. Aphids 4. Thrips 5. Early blight – severity 6. Leaf miner 7. Bacterial canker – severity 8. Bacterial spot - severity 9. Cucumo virus 10. Powdery mildew	1. Bacterial canker – severity 2. Mites	1. Tomato mosaic 2. Powdery mildew 3. Tomato leaf curl 4. Cucumo virus 5. Bacterial spot – severity 6. *H. armigera* –fruit damage & larval population 7. Early blight - severity
Raipur (CG)	Aphids	1. Bacterial canker – incidence 2. *Ralstonia* wilt		1. Leaf miner 2. Powdery mildew 3. Late blight – incidence
Varanasi (UP)	1. *Fusarium* wilt 2. Whiteflies 3. Aphids	1. Early blight – severity 2. Thrips 3. Bacterial spot – severity 4. Late blight –severity 5. Tomato mosaic	1. Late blight - severity 2. Aphids 3. *Septoria* leaf spot	1. Spiders 2. Tomato mosaic 3. *H. armigera* –fruit damage 4. Thrips 5. Leaf miner 6. Tomato leaf curl 7. Whiteflies 8. Early blight – severity 9. Bacterial spot – severity
Kalyani (WB)	-	-	1. Thrips 2. Mites 3. Aphids 4. Whiteflies 5. Tomato leaf curl 6. Leaf miner	1. Spiders 2. *H. armigera* –larval population & fruit damage 3. *Spodoptera litura* – larval population

Insects and diseases have been listed along the order of importance under each column in respect of locations to understand the cumulative impact of climate change based on species adaptaion index values. Insects or diseases in bold indicate the significance of the magnitude of climate change for any one or two or all three climatic variables (MaxT, MinT & RF); the unit of pest reporting is standard as in SAI tables and specific mention has been made wherever the reporting units have been double for a single insect/disease in a given location or the units differed between locations for a given insect/disease

The reverse was noted for leaf miner being adaptive in *rabi* but vulnerable during *kharif*. Such seasonal differences for the responses of insects and diseases portray differing interspecific competitions modulated directly in addition to impact of their crop-environment interactions. Leaf curl disease was on decline in response to climate variability and change both in *kharif* and *rabi* at Bengaluru (KA). At Rajendranagar (TS), whiteflies, aphids and spiders that were increasing with changing climate of *kharif* had negative impacts during *rabi*. While *H. armigera* and bacterial canker had shown negative response during *kharif*, it was positive in *rabi*. Impact of changing climate reducing bud blight in *kharif* and *rabi* was noted at Rajendranagar (TS). Occurrence of bud blight reported at Telangana State in this decade and its decline within few seasons could possibly due to the extremes of weather between seasons than the gradual and unidirectional changing climate influencing the vector-virus relations. Only mites had an increased response during *kharif* and *rabi* at Rahuri (MH). Many insects and diseases of tomato at Rahuri (MH) had declining abundance or severity during both seasons. Many insects (whiteflies, leaf miner, mealy bug and aphids) in *kharif* and diseases (late blight, *Ralstonia* wilt and *Septoria* leaf spot) in *rabi* were increasing at Varanasi (UP). *Fusarium* wilt during *kharif* and *S. litura* in *rabi* at Varanasi (UP) showed positive response in addition to aphids during both *kharif* and *rabi*. Ludhiana (PB) growing tomato only in *kharif* had aphids, *H. armigera* and late blight being adaptive although climate change variables (MaxT, MinT & RF) as well as their association with dynamics of insects and diseases were also non-significant. Whiteflies, leaf miner and early blight responded negatively despite non-significant change in seasonal climate. Therefore, it can be said that Ludhiana (PB) is the only location where there was neither changing climate during the tomato cultivation nor any significant impact on insects and diseases during *kharif* over 2011-16. This could have arisen due to the tomato cultivation cycle of *kharif* extending between last week of August and end of February covering larger weather/climatic fluctuations. On the contrary, Kalyani (WB) cultivating tomato largely in *rabi* had increased sucking pests, leaf miner, early blight, leaf curl, *Ralstonia* wilt and tomato mosaic and decreased *Sclerotium* wilt, spiders, *H. armigera* and *S. litura* in response to unchanging climate over the past due to high humid conditions and diversified cropping systems. Irrespective of the seasons, the range of SAIs indicated the degree of impact of climate change largely governed by the location specific inter species competitions and other system components of production (edaphic/cultivars) interactions that could vary with species based on the mechanism of feeding/life history in insects and of infection/progression of diseases.

Although tomato study locations except Raipur (CG) belong to hot semi humid ecologies, the magnitude of climate change and their influence on insects or diseases were highly varied. For a given location, the adaptive response of insects and diseases visualized together was higher at Rajendranagar (TS) (62.5%)>Bengaluru (KA)>Raipur (CG) (55.6%)>Ludhiana (PB) (50%)>Varanasi (UP) (31.3%)>Rahuri (MH) (12.5%) during *kharif.* But in *rabi*, the highest adaptiveness was seen at Kalyani (WB) (73.3%)>Bengaluru (KA) (45.5%)>Varanasi (UP) (33.3%)>Rajendranagar (TS) (26.6%)>Rahuri (MH) (25%)>Raipur (CG) (15.4%). The reverse ordering correspond to the vulnerability status of insects and diseases. Differential seasonal impacts of a given insect and disease at a given location were quite common. The exceptions being mites at Bengaluru (KA) and aphids at Varanasi (UP) for their adaptive response during *kharif* and *rabi* to the observed climate change. Early blight, thrips, bacterial spot severity and tomato mosaic at Varanasi (UP) had reducing significance both in *kharif* and *rabi.* Bud blight at Rajendranagar (TS), tomato leaf curl, early blight, bacterial spot severity, cucumo virus and powdery mildew at Rahuri (MH) were vulnerable during both *kharif* and *rabi* seasons. While thrips alone was the insect of significant vulnerability in *rabi*, a large number of diseases had reduced significance to climate change. No disease was found to be adaptive both in *kharif* and *rabi* at a given location possibly due to absence of continued tomato plantings in the same fields breaking the disease cycle. It is highly common that the mono-cropping of tomato does not exist and that the fields are scattered amongst many other crops in a given production system. Although the intensified disease management practices largely adopted in growing tomatoes do not allow the evolution of pathogens, the weather extremes could act as trigger for higher severity within a given season.

Documented evidences of effect of climate change on insects, diseases and their management options are amply available globally and within India, however based on experiments conducted under controlled conditions or their projections for future climate change scenarios the latter associated with many assumptions. Field level data sets establishing the impact of climate change was missing although every change in insect/disease scenario be it attaining pest status or minor becoming major or emerging pests, and transboundary invasions often annex the factor of 'climate change' with no established proofs. Segregating the field level impact of climate change on insects and diseases although would be a highly impossible research preposition, there is always a need to attempt and validate the observed and acclaimed phenomena of effects of climate change on insects and diseases alongside of cropping seasons including climate change *per se*. Such an attempt could have borne instant results had we possessed a system of centralised data repository for all entomological, pathological and meteorological observations alongwith management interventions on a common platform given the structural and functional framework of research by commodity and theme based institutes of ICAR, state agricutural universities, All India co-ordinated research projects and *krishi vigyan kendras*. Given the circumstances of disjunct and indiscrete past data sets, NICRA provided the much needed fillip by funding a project following brainstorm sessions and group meetings. The uniqueness of the project has been the assessment of impact of climate change on the field dynamics of insects and diseases on crops that represented monocot/dicots encompassing cereal, pulse, oilseed and vegetable (rice, pigeonpea, groundnut and tomato) categories grown at different agro ecologies and climatic zones of India.

Population abundance or damage to plants by insects, the incidence and severity of diseases at a given time and field are depenedent on the ecological interactive forces (both biotic and abiotic) in addition to the evolved and cumulative response of insects and diseases to the environmental resistance over time. Glimpses of effect of weather extremities on insect/disease outbreaks at a given space and time are inferred relatively easily but assessment of impact of climate change needed careful assembly of datasets on seasonal dynamics and examination of changes in conjunction with happening climate varaibility and change under the settings of other resource management strategies adopted including protection practices were unavailable.

Having identified agro ecologies in respect of each target crop and held consultations with experts of multidiscipline within the country, development and implementation of surveillance plan and procedures through formulation of standard data recording formats, guidelines and manuals for pest surveillance were prepared. Proforma for general and specific information collection relevant to each crop along with reporting units have set standard protocols for research community involved in plant protection. Explorative surveys embedded with real time insect and disease surveillance at study regions documented new and emerging pests that directly cannot be attributed to climate variability and change but serve as a recorded event to pursue for their geographical or host crop expansions. Since, the project exploited the ICT tools for real time data assemblage and reporting of insects/diseases/meteorological variables, the database availability and accessibility is guaranteed for future. The utilisation of field datasets for development of weather based forecast models that are in validation stage constituted another half of outputs of the implemented NICRA project.

Records on incidence of new insects *viz.*, *Celosterna scabrator* Fabricius, powder post beetle, *Sinoxylon anale* Lesne and phyllody disease on pigeonpea (Anantapur, AP), painted bug, *Begrada hilaris* (Burn) (Kanpur, UP), and fungal target spot disease of tomato *Corynespora cassiicola,* (Kalyani, WB) were made in 2011. Ghujhia weevil, *Tanymecus indicus* Faust (Curculionidae; Coleoptera) and tingid *Urentius* sp. on pigeonpea were documented at Gulbarga (KA) and Warangal (TS), respectively. *Mylabris pustulata* Lefroy (Chrysomelidae: Coleoptera) and *Anarsia ephippias* (Meyrick) (Gelechiidae: Lepidoptera) were recorded as new insects on groundnut at Virudhachalam (TN) indicating host range expansion. *Xanthomonas vesicatoria* was a new disease noted during April-May at Amritsar (PB) during 2011 and 2012 with maximum infection levels of 100 and 25%, respectively. Invasive *Tuta absoluta* (Meyrick) infesting tomato was reported for the first time in November 2014 at Bengaluru (KA). Spread to other states Telangana, Punjab and Uttar Pradesh during March 2015, September 2016 and January 2017, respectively and its establishment as an additional insect on tomato was documented. Pod wasp, *Tanaostigmodes cajaninae* La Salle (Hymenoptera: Tanaostigmatidae) was seen as an emerging pest of pigeonpea in Vamban (TN) since 2016. Incidence of big bud phytoplasma at Rajendranagar (TS) and Bengaluru (KA) was confirmed during *rabi* 2015-16. While record of insects/diseases at a new location/or a host plant denote a possibility of expansion of geographic distribution and host range, respectively attributing such documentations to the effects of climate variability and change directly would be folly at this stage. Multi locational and multi seasonal studies on their dynamics *vis a vis* climatic deviations of the geographies and crop seasons are areas of further research.

While most studies on climate change in general, captured trends and magnitude on annual and seasonal basis for all India, regions and standard cropping seasons, the project specifically enveloped the location specific cropping seasons for quantification of climate change and associated with the seasonal dynamics of insects and their or disease progressions. The finding that many locations had shown significance at least for one climatic variables (temperature and precipitation) pointed to 'climate change' as an event happening at study locations. It also emerged that the magnitude worked out for the crop seasons of the locations allowed deducing more precise associations of the seasonal climate change with the population dynamics of insects and their damage and incidence and severity of diseases. The changes in climatic variables (esp. temperature) could be utilized in phenology models for identification of the hotspot zones of important insects for present and future.

Considering the inter seasonal variations of both dependent (occurrence of insects and diseases) and independent (actual weather and climatic deviations) parameters by themselves, it could easily be inferred that their associations would also be highly variable over time and space. The nonlinear and multi modal dynamics of insects and within and between field variations of insect and disease distributions made us to select the non-parametric Kendall's correlations for the associative analysis of parameters of insects/disease with deviations of temperature and rainfall. The significance of the coefficients pointed to the impact *per se* of individual climatic variable. The only factor, the magnitude of change for climatic variables worked out using actual values and their deviations from 40 years' average when accounted with the associative coefficients brought out impact of climate variability and change on a given species that was scale neutral allowing comparisons among species within each location and between locations. There were insects/diseases having a cyclical pattern of attaining pest status and such a phenomenon in their dynamics can only be authenticated with database of more seasons. With all other system variables equal, and that climatic variables (temperature and rainfall) are auto related, the assessment of associations of each species with climatic deviations integrated with respective magnitude of change rationalized the expression of impact of climate change into a single index names as species-climate change association index (SAI). Since changes are only permanent and living organisms in all probabilities continue to evolve with as well as without climate change, the SAI calculations for all species are meaningful. The relevant tracks under each study crop highlight the impact of climate change to the readers specifically and explicitly.

The vulnerability to climate change for insects elicited over study locations in terms of significantly reduced population with the observed climate change (in temperature and rainfall considered separately) over six years (2011-16) in respect of *kharif*, *rabi* and summer rice seasons were 73, 83 and 68%, respectively. However, the cumulative impact (temperature and rainfall effects considered together) revealed the significant vulnerability (reduced abundance) for summer (73.8%)>*kharif* (52.4%)>*rabi* (43.1%). In general and over seasons, 43.3 and 56.7% adaptive and vulnerable responses to observed climate change were estimated based on the profile of rice insects over seven study locations. Scrutiny of responses of insects to climate change for a given season or across seasons did not typically segregate insects based on their feeding habits (sucking or chewing) or metamorphosis (endo or exopterygotes) for adaptation or vulnerability but largely associated with the eco region specific factors (such as monocropping/cropping intensity/cultivation cycle) including climate change.

In pigeonpea, a long duration crop, had the insect and disease profile across study locations ranging between seven and fourteen. The range of vulnerable responses of insects and diseases put together based on seven study locations ranged between 10 and 71 % indicating the higher and lower significance, respectively of pest management needs. Although, the vulnerability of pigeonpea insects and diseases was found to be more at hot arid than hot semi-arid eco regions of the different study climatic zones, differences for adaptability or vulnerability to climate change differed across locations belonging to similar eco regions in some species.

The cumulative impact of climate change based on measure of species-climate change association index for a total of three sucking insects, two lepidopterans, three rots, four foliar and two viral diseases from among the five study locations of groundnut indicated differential responses within and between hot semi-arid, hot arid and sub humid-semi arid regions. Adaptive or vulnerable responses to climate change of groundnut insects and diseases visualised at each study location offered an understanding on the interactive effects of changing climate not only on higher species adaptations *vis a vis* higher species diversity but also on a gross interspecific adjustments/competition of species. Insects and diseases at locations of rainfed agriculture had shown higher adaptations despite higher inter seasonal variations. Insect-virus associations on groundnut under changing climate indicated inclusiveness of crop mediated effects. Significant influence of increased rainfall increasing severity of early leaf spot during the past and future periods implied not only the changing climatic conditions that are conducive for higher foliar diseases on groundnut but also the evolving adaptations of pathogens in relation to climate change.

Differences existed for insects and diseases of tomato for their adaptive or vulnerable response between seasons of *kharif* and *rabi* at a given location. Some insects and/or diseases were unique in their occurrence in a given season and location. Differential seasonal impacts of climate change on a given insect and disease on tomato at a given location were common with the exceptions of mites at Bengaluru (KA) and aphids at Varanasi (UP) displaying adaptive response during *kharif* and *rabi* to the observed climate change. Seasonal differences for the responses of insects and diseases also portrayed differing interspecific competitions modulated directly by changing climate in addition to impact of their crop-environment interactions. The only location where there was neither changing climate during the tomato cultivation nor any significant impact on insects and diseases was Ludhiana (PB) during *kharif* based on the fact that crop cultivation cycle extended between August and February covering larger climatic fluctuations. No disease was found to show adaptive response both in *kharif* and *rabi* in any of the seven study locations possibly due to absence of continued tomato plantings in the same fields in addition to fields of tomato scattered amongst many other crops in a given production system not to discount the intensified disease management practices keeping check of the diseases.

Prediction for future projected climatic scenarios for some major insects for select locations of rice, pigeonpea and groundnut brought out requirement of continued monitoring strategies to be put in place at identified locations for specific insects/diseases from pest management perspective. Equally, lesser significance of insects/diseases during future periods was also projected. Unlike the controlled experiments under increased temperature or elevated carbon di oxide impacting physiological processes of plants and insects/diseases such as higher number of generations and reduced generation time leading to unilateral projections of higher incidence for future periods, the quantified field level impacts and the projections for future periods present a variable status. While extreme weather events, especially high and unseasonal rains and associated fluctuating weather conditions could have largely negative impact on insects, they were noted to be triggers for rare and potential disease outbreaks in the context of changing climate.

Overall, differences in impact of climatic variability/change among insects in a given location, and across locations and seasons for a given insect were all obvious through the current research on four crops. The observed spatial variability of climate change influence on insects and diseases implied a need for their zonation mapping at national level. Multi-field and multi-season data of population dynamics of insect using geo statistical tools in select cases proved to be valuable in determining the field selection/sampling plan for wide area surveillance for their management. Definitive grouping of agro ecologies for their impact on insects and diseases also was not easy. The study brought out significant adaptations by insects and diseases at locations and seasons where no definitive climate change was noticed indicating continued and a possible unhindered evolution by the organisms happening. The differing impacts of changing climate on insects and diseases deciphered through the present studies covering crops and agro climatic zones portray the complexity of the ecosystems and their interactions to be way beyond our comprehension. Hence, it is only prudent to operate the applied and augmentative management interventions on real time and need basis keeping the enhancement or recouping or revival of the natural resource factors be it soil, water and air for a sustainable crop production. From applied pest management perspective, systematic farm level surveillance of insects and diseases in conjunction with simple but robust sampling methods put in place for decision making on pest management options would prove to be highly effective under all scenarios of weather/climate and pest dynamics. Considering that the implementation mechanism of agricultural packages in our country is State based, federal departments of both research and development can only support the design and hand holding of scientific methods of surveillance and strategies of crop health management through necessary tools and techniques in co-ordination and collaboration with State stakeholders.

The experiences gained in developing and testing the tool of SAI have been enormous and there is still possibility to handle the data sets in many different ways to arrive at the patterns of species responses. The way forward would be: handling of individual field datasets on calendar basis with the concurrent climatic deviations so as to have larger datasets; considering the seasons with similar status together and other seasons individually or in combinations; simply considering the common periods of occurrence across fields and over seasons; data sets on seasonal dynamics rarified based on crop age and use climatic deviations based on those periods in consonance and so on. Also the crop age and plant resistance dependent association of insects and diseases need to be identified and the analytics for deducing impact of climate change should be tailored for a meaningful inference. Since the onset and peak vary with seasons and that peaks of abundance or severity contribute/determine seasonal means, considering only the maximum of each period among fields with concurrent climatic deviations could yield a response pattern that can be compared. Datasets of seasonal dynamics of insects and diseases can also be segregated along cultivars/periods of planting/management or no management interventions and subjected to steps of SAI using appropriate climatic deviations could make the tool. It is to be highlighted that use of the above mentioned approaches for SAIs for select insects/diseases of study crops aided in bringing out cultivars and planting periods with climate resilience. In all cases, the way forward would be to have the 'dynamic or shifting normals' (the long term data of recent past 40 years with each succeeding year) used in calculation of climatic deviations and their use for relating to seasonal dynamics of insects/diseases and for working out SAIs. Additionally, the systematic database when handled with the objective of assessing within field and between field distributions under the known management practices, the impact of anthropogenic activities on insects and diseases can very well be brought out.

Plant health differs depending on geographies, their climatic features and agronomic practices and so will the management efforts. The diversified Indian agro ecosystems, the episodes of invasive pests, climate change, research cum developmental organizational set up and industries dealing with plant protection have all the paraphernalia needed for an effective preparedness and management of pest events. However, the operationalization is fraught with lack of coordination and collaborations. Need exists for uplifting the standards of plant health diagnostics, preparedness and management. Since changes in management approaches of crop protection are continuous, research gaps are also continuous. Continued documentation of insect and disease dynamics across agri and horticultural crops of different regions under multifactorial situations is a must. Simultaneous focus on the assessment and reporting of changing/emerging status, outbreaks, potential yield losses, effects and efficacy of management interventions on insects and diseases *vis a vis* weather extremes and changing climate need to be prioritized for implementation through a harmonized platform fortified with standardized sampling protocols cum reporting units and deployment of digital repository on each unit of data collected with associated reporting systems and data analytics. Geographical information system platform with embedded data analytics should be exploited to draw more meaningful impacts of climate change on status of insects/diseases on real time basis and to implement climate adaptive IPM strategies. Agro advisories integrated with weather based insect/disease forecasting supplemented with real time ground surveillance of crop health using simple pest severity thresholds established for all crops would aid to upscale the practices of integrated pest management. Levels of integration of crop health management also needs biotic interactions of below ground organisms (nematodes and microbes) and weeds accounted vis *a vis* their responses to climate change. Development of crop cultivars for different abiotic stress tolerance should incorporate simultaneous assessment of their response to insects/diseases and ecosystem services to offer stimulus to climate resilience. National level profiling of crop cultivars and pest management interventions based on their performance against insects and diseases with their costing under current farming and climatic conditions is the need of hour so as to designate them as climate-insect-disease resilient and promote them for adoption at farm level. Such of the possibilities can only be fulfilled effectively by having a holistic web portal enhanced with data processing and analytics based on goals. This requires a policy framework of plant protection research in our country essentially involving digital networking for crop-insect-disease-weather surveillance for all agricultural and horticultural crops such that the same database gets visualized through all possible filters including climate variability and change.

With spatial and temporal variability found for impact of climate change on insects and diseases, the agro ecological planning for crop production or wide area pest management would not be apt unless farming and crop management operations are well-coordinated on community basis firstly accounting soil-climate endowments followed by ecologically compatible good agricultural practices and lastly the management of insects and diseases on need basis. However, it remains to be seen with the current changing emphasis given on management of farming ecosystems including natural/organic/co-operative and conservation agriculture. While suitable alternative management interventions can be substituted based on current and emerging status of insects and diseases with associated research findings, redesigning crop protection using agro ecology based pest management interventions focusing on biodiversity maintenance and improved ecosystem services constitute another level of research cum developmental approach. Potential opportunities for crop protection are greater under the envisaged transformation for Indian agriculture towards secure, nutritive and safe food with or without the projected climate change for future periods of the current century. Integration of tools and technologies of several disciplines with common socio economic and environmental goals along value chains of agricultural production suited to present times and priorities would accommodate readiness to climate change and much needed sustainability.

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ANNEXURES

Annexure I

Details of co-opted institutions (locations) and their geographical profile relating to studies on insect and disease dynamics in relation to climate change

S.No.	Institute/University/Study location	Agro Ecological Region	Agro Climate Zone
Crop: Rice			
1	Punjab Agricultural University, **Ludhiana**, Punjab	R4 (Northern Plain and Central Highland including Aravalis, hot semi-arid ecoregion)	6 (Trans-Gangetic Plains Region)
2	Indian Institute of Rice Research (earlier Directorate of Rice Research, Hyderabad),(**Kampasagar**), Telangana	R7 (Deccan plateau and eastern ghat, hot semi- arid ecoregion)	10 (Southern Plateau and Hills Region)
3	University of Agricultural Sciences, ZARS, **Mandya**, Karnataka	R8 (Eastern ghat, TN upland and Deccan plateau hot semi- arid ecoregion)	10 (Southern Plateau and Hills Region)
4	Indira Gandhi Krishi Vishwavidyalaya, **Raipur,** Chhattisgarh	R11 (Eastern plateau (Chhattisgarh) hot semihumid ecoregion)	7 (Eastern Plateau and Hills Region)
5	Rice Research Station, **Chinsurah,** West Bengal	R15 (Bengal and Assam plain hot subhumid to humid (perhumid ecoregion)	3 (Lower Gangetic Plains Region)
6	Tamil Nadu Rice Research Institute, Tamil Nadu Agricultural University, **Aduthurai,** Tamil Nadu	R18 (Eastern coastal plain hot subhumid to semi- arid ecoregion)	11 (East Coast Plains and Hills Region)
7	Agriculture Research Station, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, **Karjat**, Maharashtra	R19 (Western ghat &coastal plain hot humid perhumid ecoregion)	12 (West Coast Plains and Ghat Region)
Crop: Pigeonpea			
8	Centre of Excellence for Research on Pulses, S. D. Agricultural University, **S.K. Nagar**, Gujarat	R2 (Western plain, kachhh and part of Kathiawar peninsular ,hot arid ecoregion)	13 (Gujarat Plains and Hills Region)
9	Krishi Vigyan Kendra, Reddipalli, **Anantapur**, Andhra Pradesh	R3 (Deccan plateau and central highland hot arid ecoregion)	10 (Southern Plateau and Hills Region)
10	Agricultural Research Station, Aland Road, **Gulbarga**, Karnataka	R6 (Deccan plateau aravallis hot semi- arid ecoregion)	10 (Southern Plateau and Hills Region)
11	Regional Agricultural Research Station, Professor Jayashankar Telangana State Agricultural University, **Warangal**, Telangana	R7 (Deccan plateau and eastern ghat, hot semi- arid ecoregion)	10 (Southern Plateau and Hills Region)
12	National Pulses Research Centre, Tamil Nadu Agricultural University, **Vamban**, Tamil Nadu	R8 (Eastern ghat, TN upland and Deccan plateau hot semi- arid ecoregion)	11 (East Coast Plains and Hills Region)
13	Jawaharlal Nehru Krishi Vishwavidyalaya, **Jabalpur**, Madhya Pradesh	R10 (Central highland (Malwa, Bundelkhand & Eastern Satpura) hot semihumid ecoregion)	8 (Central Plateau and Hills Region)

S.No.	Institute/University/Study location	Agro Ecological Region	Agro Climate Zone
Crop: Groundnut			
14	Agricultural Research Station, Kadiri, **Anantapur,** Andhra Pradesh	R3 (Deccan plateau and central highland hot arid ecoregion)	10 (Southern Plateau and Hills Region)
15	Directorate of Groundnut Research, PO Box 5, **Junagadh**, Gujarat	R5 (Central highland Gujarat plains& Kathiawar peninsula hot semi- arid ecoregion)	13 (Gujarat Plains and Hills Region)
16	University of Agricultural Sciences, **Dharwad**, Karnataka	R6 (Deccan plateau aravallis hot semi- arid ecoregion)	12 (West Coast Plains and Ghat Region)
17	Oil Seed Research Station, Mahatma Phule Krishi Vishwavidyalaya, **Jalgaon**, Maharashtra	R6 (Deccan plateau aravallis hot semi- arid ecoregion)	9 (Western Plateau and Hills Region)
18	Regional Research Station, Tamil Nadu Agricultural University, **Virudhachalam**, Tamil Nadu	R18 (Eastern coastal plain hot subhumid to semi- arid ecoregion)	11 (East Coast Plains and Hills Region)
Crop: Tomato			
19	AICRP on Vegetable Crops, Punjab Agricultural University, **Ludhiana**, Punjab	R4 (Northern Plain and central Highland including Aravalis ,hot semi arid ecoregion)	6 (Trans-Gangetic Plains Region)
20	Indian Institute of Vegetable Research, **Varanasi**, Uttar Pradesh	R4 (Northern Plain and central Highland including Aravalis ,hot semi arid ecoregion)	4 (Middle Gangetic Plains Region)
21	AICRP on Vegetable Crops, Sri Konda Laxman Telangana State Horticultural University, **Rajendranagar**, Hyderabad, Telangana	R7 (Deccan plateau and eastern ghat, hot semi- arid ecoregion)	10 (Southern Plateau and Hills Region)
22	Indian Institute of Horticultural Research, **Bengaluru**, Karnataka	R8 (Eastern ghat, TN upland and Deccan plateau hot semi- arid ecoregion)	10 (Southern Plateau and Hills Region)
23	Indira Gandhi Krishi Vishwavidyalaya, **Raipur**, Chhattisgarh	R11 (Eastern plateau (Chhattisgarh) hot semihumid ecoregion)	7 (Eastern Plateau and Hills Region)
24	Bidhan Chandra Krishi Vishwavidyalaya, **Kalyani**, West Bengal	R15 (Bengal and Assam plain hot subhumid (moist) to humid (perhumid) ecoregion	3 (Lower Gangetic Plains Region)
Locations and periods of insect and disease surveillance: S.No. 4,11, 15 ,17, 21 & 24: 2011-2020 ; S.No. 12 : 2011-19; S.No.1: 2011-18; S.No.6: 2011-17; S.No. 1-24 (all) : 2011-16			

Annexure II

Study locations and their agro climatic zones with geographical coordinates

Locations	Name of Agro Climate Zone (ACZ)	ACZ No.	Latitude	Longitude	Altitude
Chinsurah-WB	Lower Gangetic Plains Region	3	22:56:46	88:22:07	08
Kalyani-WB	Lower Gangetic Plains Region	3	22:59:08	88:22:00	7.8
Varanasi-UP	Middle Gangetic Plains Region	4	01:11:04	85:52:14	74
Ludhiana- PB	Trans-Gangetic Plains Region	6	06:54:00	75:48:00	247
Raipur- CG	Eastern Plateau and Hills Region	7	21:16:00	81:36:00	289
Jabalpur-MP	Central Plateau and Hills Region	8	23:10:00	79:59:00	412
Jalgaon- MH	Western Plateau and Hills Region	9	21:02:34	75:34:21	174
Rahuri- MH	Western Plateau and Hills Region	9	19:22:59	74:39:08	511
Anantapur-AP	Southern Plateau and Hills Region	10	14:43:16	77:40:04	330
Bengaluru-KA	Southern Plateau and Hills Region	10	13:07:58	77:29:27	920
Gulbarga-KA	Southern Plateau and Hills Region	10	17:21:42	76:48:54	490
Kadiri- AP	Southern Plateau and Hills Region	10	14:06:34	78:08:49	524
Kampasagar -TS	Southern Plateau and Hills Region	10	16:51:04	79:28:43	148
Mandya-KA	Southern Plateau and Hills Region	10	12:45:13	76:45:24	695
Rajendranagar-TS	Southern Plateau and Hills Region	10	17:19:23	78:23:25	542.3
Warangal-TS	Southern Plateau and Hills Region	10	18:00:52	79:36:15	271
Aduthurai-TN	East Coast Plains and Hills Region	11	11:00:28	29:28:49	34
Vamban-TN	East Coast Plains and Hills Region	11	10:21:05	78:54:06	122
Virudhachalam-TN	East Coast Plains and Hills Region	11	11:31:48	79:21:29	71
Dharwad- KA	West Coast Plains and Ghat Region	12	15:21:20	74:57:52	639
Karjat-MH	West Coast Plains and Ghat Region	12	18:54:57	73:19:02	63
Junagadh-GJ	Gujarat Plains and Hills Region	13	21:31:00	70:33:00	83
S.K. Nagar-GJ	Gujarat Plains and Hills Region	13	00:19:20	72:18:00	177

Annexure III
Period of crop seasons for study locations

S.No.	Location	Standard meteorological weeks (SMW)		
		Kharif	*Rabi*	*Summer*
Crop: Rice				
1	Ludhiana, Punjab	22-47	-	
2	Kampasagar, Telangana	22-44	45-13	
3	Mandya, Karnataka	27-52		1-25
4	Raipur, Chhattisgarh	27-48	-	
5	Chinsurah, West Bengal	26-48	-	40-17
6	Aduthurai, Tamil Nadu	22-44	35-4	49-17
7	Karjat, Maharashtra	22-44	44-13	-
Crop: Pigeonpea				
1	S.K. Nagar, Gujarat	38-51	-	
2	Anantapur, Andhra Pradesh	26-52		
3	Gulbarga, Karnataka	25-4		
4	Rahuri, Maharashtra	30-52		
5	Warangal, Telangana	35-52		
6	Vamban, Tamil Nadu	35-52		
7	Jabalpur, Madhya Pradesh	26-52		
Crop: Groundnut				
1	Kadiri, Andhra Pradesh	25-47	-	
2	Junagadh, Gujarat	22-45		
3	Dharwad, Karnataka	26-47		
4	Jalgaon, Maharashtra	27-45		
5	Virudhachalam, Tamil Nadu	26-44		
Crop: Tomato				
1	Ludhiana, Punjab	35-8	-	-
2	Varanasi, Uttar Pradesh	36-8	37-11	
3	Rajendranagar, Telangana	26-4	38-9	
4	Bengaluru, Karnataka	22-42	37-12	
5	Raipur, Chhattisgarh	31-8	38-17	
6	Rahuri, Maharashtra	28-42	47-27	
7	Kalyani, West Bengal	-	40-9	

Annexure IV

Proforma for new pest record (Insect/disease/weed/predator/parasitoid)

"Pest Dynamics in relation to Climate Change" [National Innovations in Climate Resilient Agriculture]

S.No.	Particulars	Details
1	Name of Reporter	
2	Common name of specimen	
3	Category: Insect Pest/ Disease/ Predator /Parasitoid/ Weeds	
4	Name of location where recorded	
	Village	
	Taluka	
	District	
	GPS coordinates (if possible)	
5	Date of record	
6	Common name	
	Scientific name with authority (if known)	
	Family	
	Order	
7	Name of host crop	
	Stage of host crop	
	Name of cultivar	
	Name of host insect (for predator & parasitoid)	
8	Stage(s) of insect pest/ predator/parasitoid observed	
9	Observed incidence (write unit of reporting)	
10	Extent of damage	
11	Description on pest stages/nature of damage/symptoms/life history etc., *(Furnish in separate sheet with images)*	
12	Prevalent weather during the period of record	
13	Other/ alternate host records (source: from literature/noted in fields)	
14	Reference on origin (source: from literature)	
15	Place where the specimen identity was confirmed and deposited	
16	Place where the (type) specimen is deposited or available	
17	Any other remarks	
	Photos can be attached as jpeg separately (.jpeg)	

Annexure V

Proforma for pest outbreak (Insect/disease/weed/predator/parasitoid)

"Pest Dynamics in relation to Climate Change" [National Innovations in Climate Resilient Agriculture]

S.No.	Particulars	Details
1	**Name of the crop**	
2	**Name of Insect/disease/weed**	
3	**Name of location**	
	Village	
	Taluka	
	District	
4	**Season** (*Rabi*/ *Kharif*/Summer/Others)	
5	**Details of outbreak**	
	a. Time of start	
	b. Severity level (categorical)	Mild/Moderate/Severe
	c. Area of infestation (acres/ hectares)	
	d. Range of incidence and/or severity (measured in standard unit as applicable to specific pest/ if different specify)	
	Seasonal dynamics (if recorded) (attach separate sheet as table or graph)	
6	**Extent of area infested/infected** (approx.)	
7	**Monetary loss** (approx. Rs/ha)	
8	**Possible/Major causes/reasons for outbreak**	
9	**Extreme weather events noticed** (during the outbreak period)	
10	**Year of earlier outbreak of the same pest in the region**	
11	**Cropping system of the region**	
12	**Description on major change in cropping system and / or cropping pattern and / or cultivar and / or production practices (fertilizer, irrigation, pesticides etc.) in the recent years**	
13	**Any other remarks**	
	Images in close up and field views can be attached separately (.jpeg)	

Annexure VI: Newly documented insects and diseases

New records: Pigeonpea

Stem borer

The *Celosterna scabrator* Fabricius (Cerambycidae; Coleoptera) was first noticed on pigeonpea in Anantapur (AP) during October 2011 when rainfall in respect of August, September, October was deficient, scanty and excess with -27, -86 and 33 per cent deviation from normal and with decrease in temperature from a mean of 28^{o} C to 24^{o} C. Insect feeding on dead wood of mango trees shifted to pigeonpea causing 18% damage by feeding on green stem.

Cerambycid beetle

Plant lodging

Powder post beetle

Shot holes on stem

Sinoxylon beetles

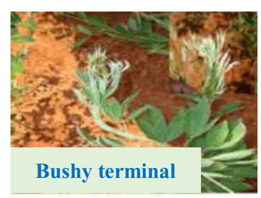
Powder post beetle, *Sinoxylon anale* Lesne (Bostrichidae; Coleoptera), was recorded on pigeonpea at Anantapur, AP during pod maturity stage of 2011 when mean temperature was between 21 and 25^{0}C and the sunshine hours decreased from 9.0 to 7.0 hours/day during December. The maximum infestation was 25%.

Ghujhia weevil, *Tanymecus indicus* Faust (Curculionidae; Coleoptera) was recorded on pigeonpea damaging the germinating seedlings and reducing plant stand in the fields of Gulbarga (KA) in 2012.

Ghujhia weevil

Phyllody

Phyllody (mycoplasma disease) on pigeonpea was observed during November, 2011 on the 15th September (*rabi*) sown crop only at ARS, Reddipalli (AP).



Bushy terminal

Tingid bug

Tingid bug

Warangal (Telangana) [18°00’52” N & 79°36’15”] had recorded the severe incidence of tingid bug (*Urentius* sp.) (Tingidae; Hemiptera) on pigeonpea at early vegetative stage in 2015.

New records: Groundnut

Blister beetle & Bud borer - *Mylabris pustulata* Lefroy (Chrysomelidae: Coleoptera) and *Anarsia ephippias* (Meyrick) (Gelechiidae: Lepidoptera) were recorded during 2012 as new insects on Groundnut at Virudhachalam (TN).

Leaf weevil - *Cyrtozemia dispar* Pascoe (Curculionidae; Coleoptera) was recorded as a new insect pest on the rainfed crop (July- October) with its feeding rate of 2.3 to 6.7 sq.cm/day in India from Junagadh (GJ) in 2015. The defoliation by *C. dispar* on peanut is the first record of its damage as it has not been recorded in any other part of the world so far.

M. pustulata beetle

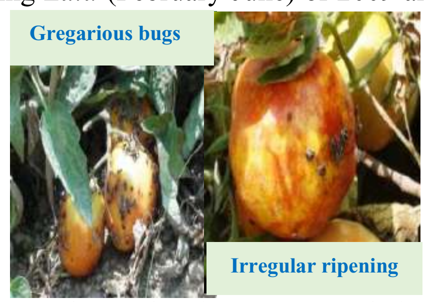
A. ephippias larvae

C. dispar weevil

New records: Tomato

Painted bug

Surveys across tomato fields of Kanpur Nagar of Uttar Pradesh during *Zaid* (February-June) of 2009 and 2010 indicated the gregarious occurrence and feeding by nymphs and adults of painted bug *Begrada hilaris* (Burn) (Pentatomidae; Hemiptera) on tomato plants including fruits from first week of April to third week of May considerably reducing the market value of the commodity.



Gregarious bugs

Irregular ripening

Target leaf spot

Corynespora cassiicola, target leaf spot was a new fungal disease record at Kalyani, West Bengal since 2011 and the morphological characterisation of conidiospores indicated length, breadth and number of pseudo septa as 102.80 µm, 13.63 µm, and 9.2 in number, respectively. Phylogenetic classification of *C. cassiicola* [CcHaTom Accession No. KJ767193] indicated absence of location and/or host specificity and formed a separate group.

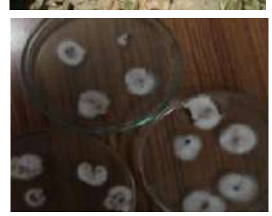
Symptoms & conidiophore of *Corynespora*

Bacterial spot

Xanthomonas vesicatoria was a new disease noted during months of April-May at Amritsar (PB) during 2011 and 2012 seasons with maximum severity levels of 100 and 25%, respectively.

Root rot

Pathogen of root rot of tomato in established crop after transplanting (September 2016) at Ludhiana (PB) was diagnosed as *Fusarium solani* (I.D No. 10,418.16 at ITCC, IARI, New Delhi) during 2016.



Big bud

In Rajendranagar (TS) and Bengaluru (KA) incidence of big bud phytoplasma causing elongated calyx uniting to form green bud like structure with the flowers becoming sterile was confirmed during *rabi*

2013-14. Molecular characterization of big bud during 2016 indicated occurrence of *Cucurbita pepo* phytoplasma strain at Rajendranagar (TS).

Big bud due to Phytoplasma

Plant with big bud symptoms

Green buds with elongated calyx

Sterile flowers

Bud blight

Bud necrosis on tomato

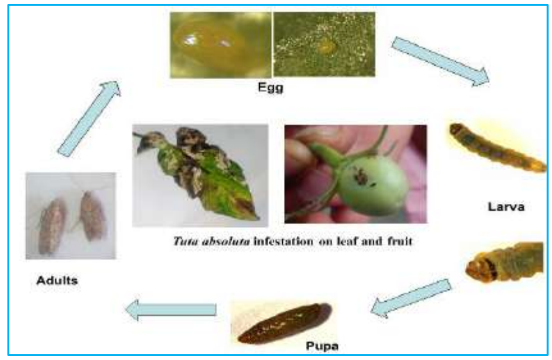
Bud blight caused by groundnut bud necrosis virus (GBNV) incidence was severe at Moinabad and Shamshabad mandals (42%) of Ranga Reddy (TS) during *kharif* 2015-16 with the increased temperature of 0.5 to 2 °C more than the normal over past five years during the active crop growth stage.

Tomato leaf curl

Diagnostics revealed the existence of different strains of tomato leaf curl virus (ToLCV) in West Bengal. Existence of four symptomatic variations of ToLCV *viz.,* (a) severely stunted plant showing small, chlorotic, distorted leaves with curled-up margins; (b) leaf curling, yellowing, puckering and erect growth; (c) severe curling, leaves erect with interveinal chlorosis with entire leaf margin rolled upward; (d) stunted distorted leaves with some interveinal chlorosis were characterized. Molecular diagnostic tools based on 14 begomoviruses of tomato and of four important viruses *viz.,* tomato leaf curl New Delhi virus (ToLCNDV), tomato leaf curl Palampur virus (ToLCPV), tomato leaf curl Joydebpur virus (ToLCJV), tomato leaf curl Gujrat virus (ToLCGV) of India were developed using common primer pair and specific primers, respectively.

South American pinworm

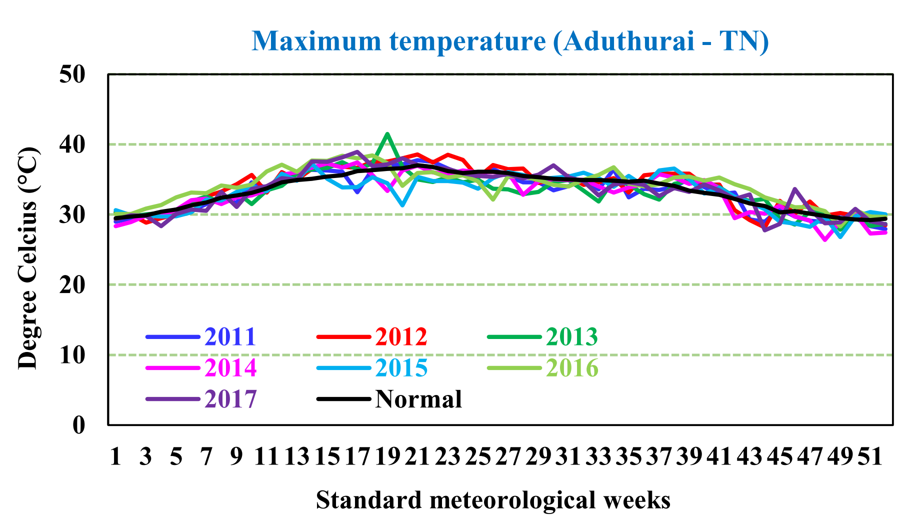
South American pinworm, *Tuta absoluta* (Meyrick) (Gelechiidae; Lepidoptera) was documented as a new invasive pest from India during *rabi* 2014 at Bengaluru (Karnataka) with its severity continuing in summer also. Leaf miner *T. absoluta* in tomato infesting leaves (14-97%) was reported for the first time during March 2015 from Telangana at Rajendranagar. While moths of *T. absoluta* were seen in September-October 2016 at Ludhiana (PB), infestation on foliage and fruits were seen on *rabi* tomato during March-April to an extent of 1%. *T. absoluta* was recorded on tomato for the first time at Varanasi and Mirzapur districts starting January 2017. The highest mean trap catch was recorded at Chaudaripur and Iswarpatti and lowest at Parsupur during the period of January - March 2017 with leaf and fruit damage levels lower at all locations.

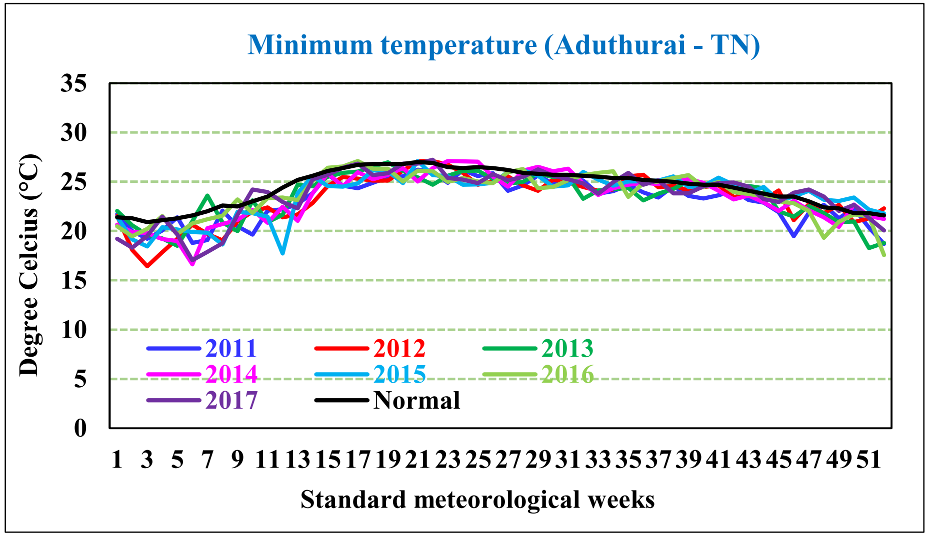


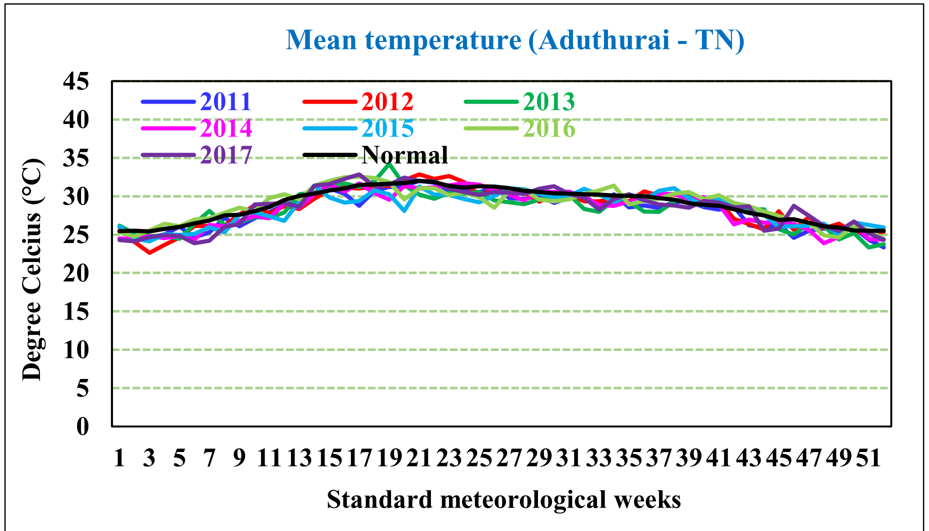
Life cycle and symptoms of *T. absoluta*

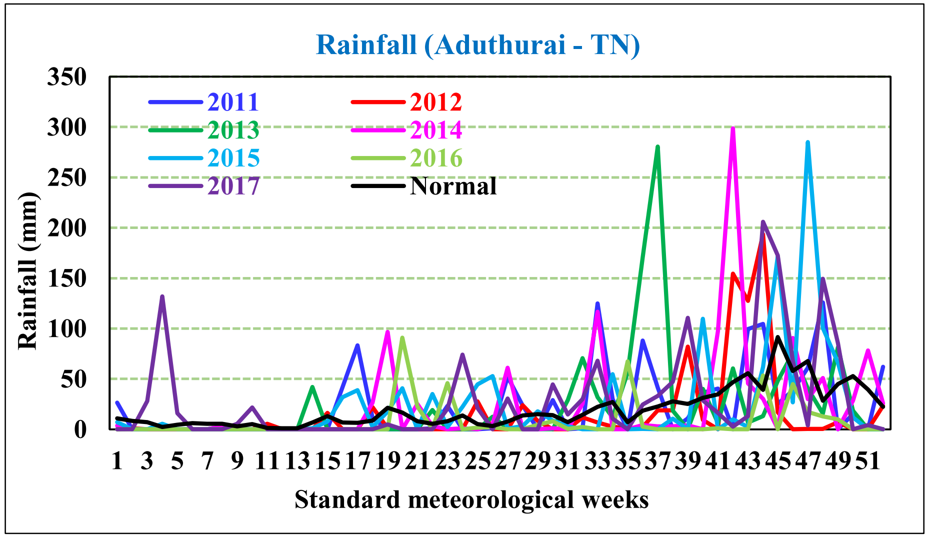
Annexure VII

Actual and 'normal' of temperature (maximum, minimum and mean) and rainfall at study locations of rice



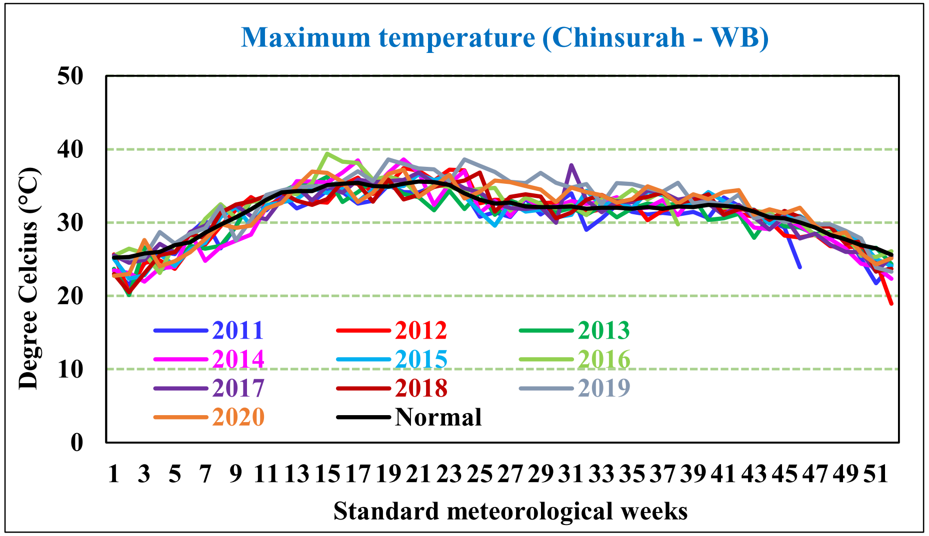


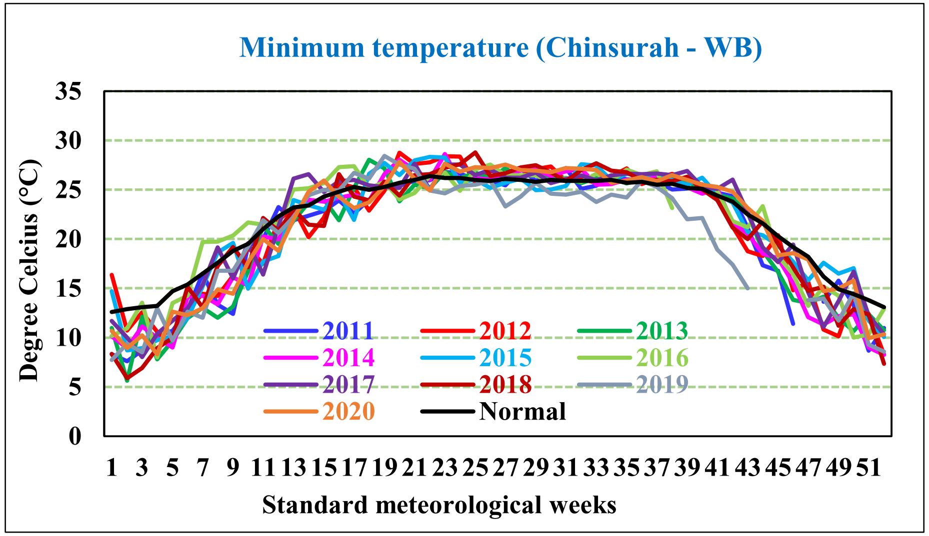


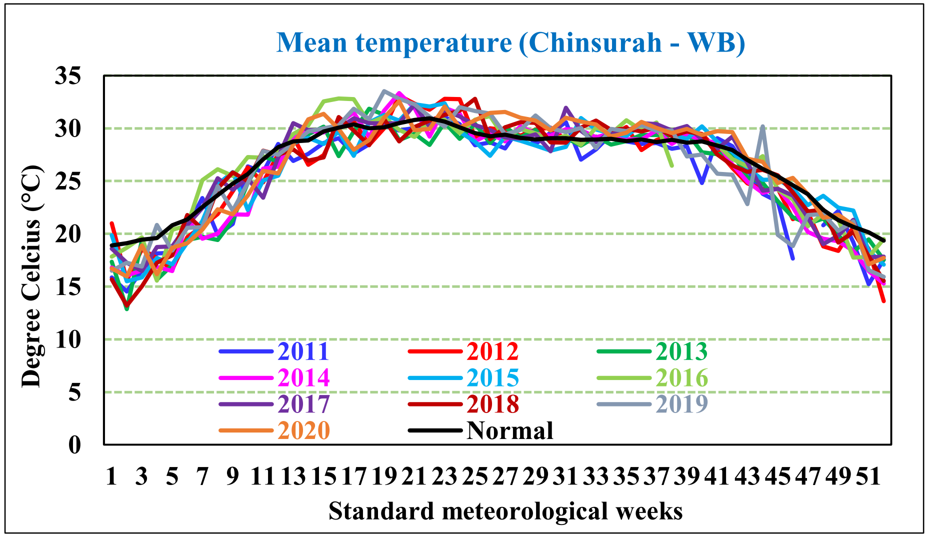


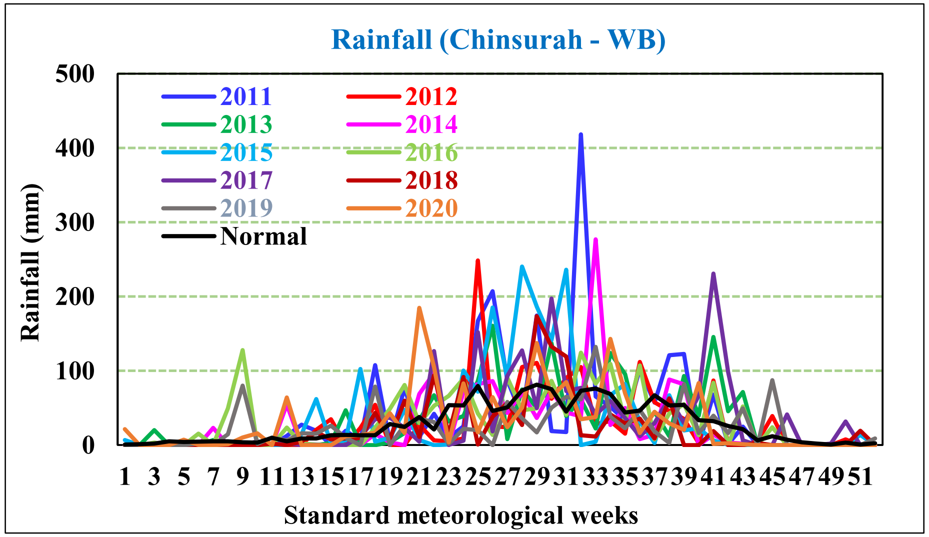
Annexure VII

Actual and ‘normal’ of temperature (maximum, minimum and mean) and rainfall at study locations of rice



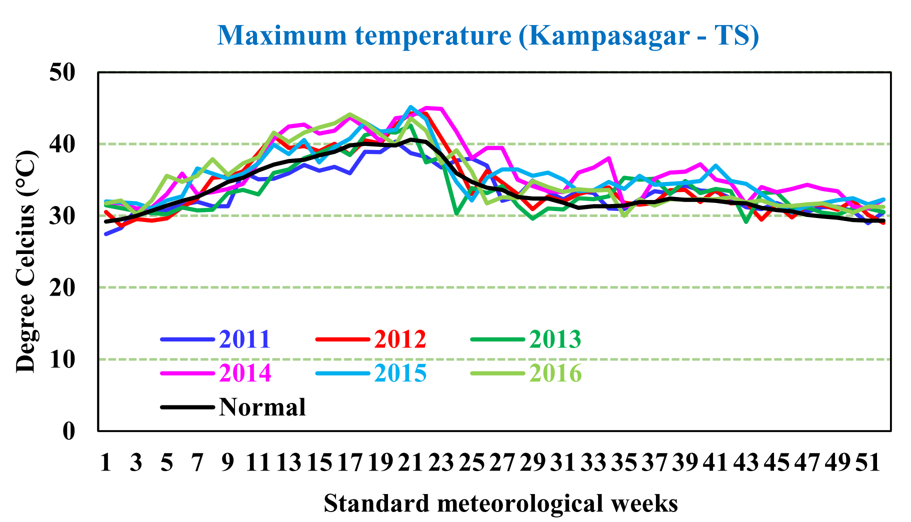


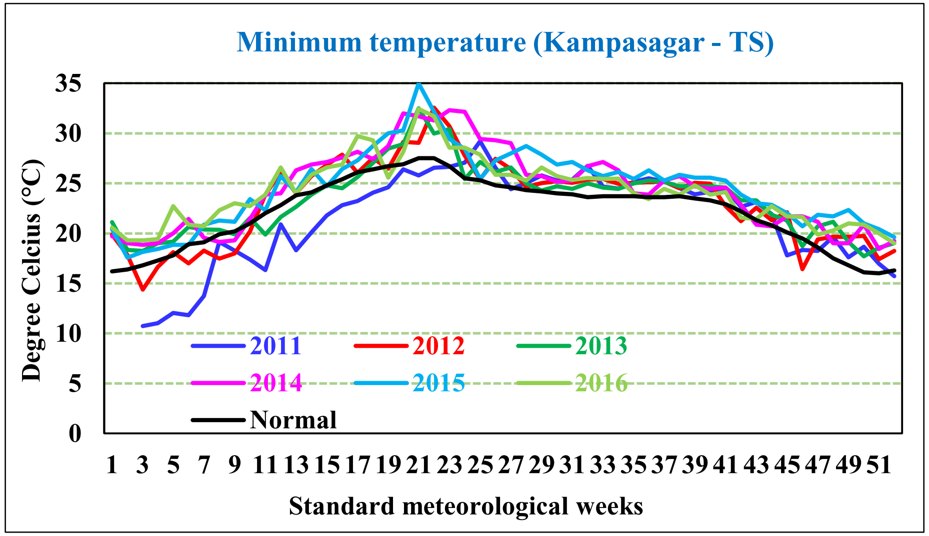


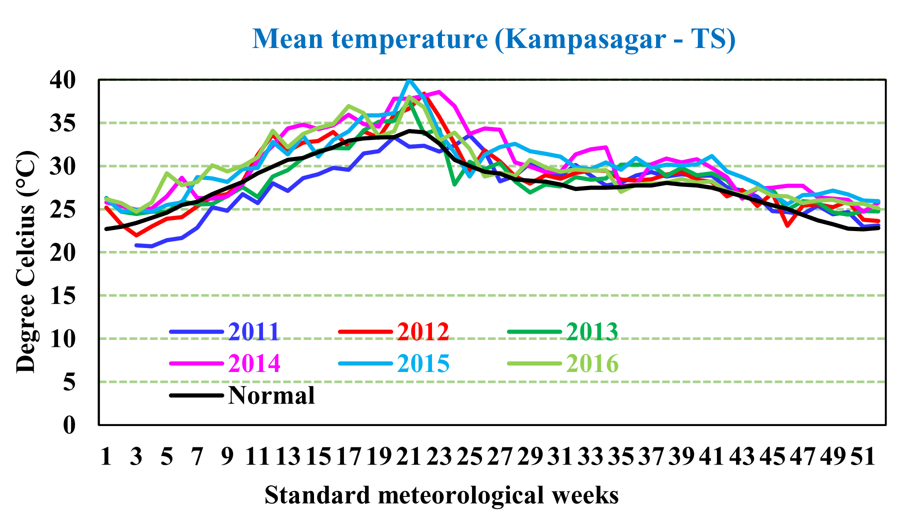


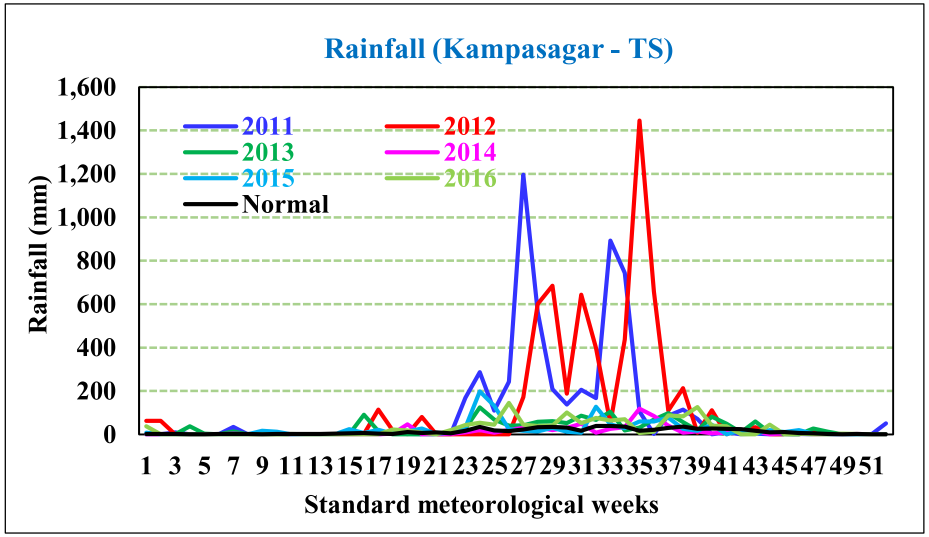
Annexure VII

Actual and 'normal' of temperature (maximum, minimum and mean) and rainfall at study locations of rice



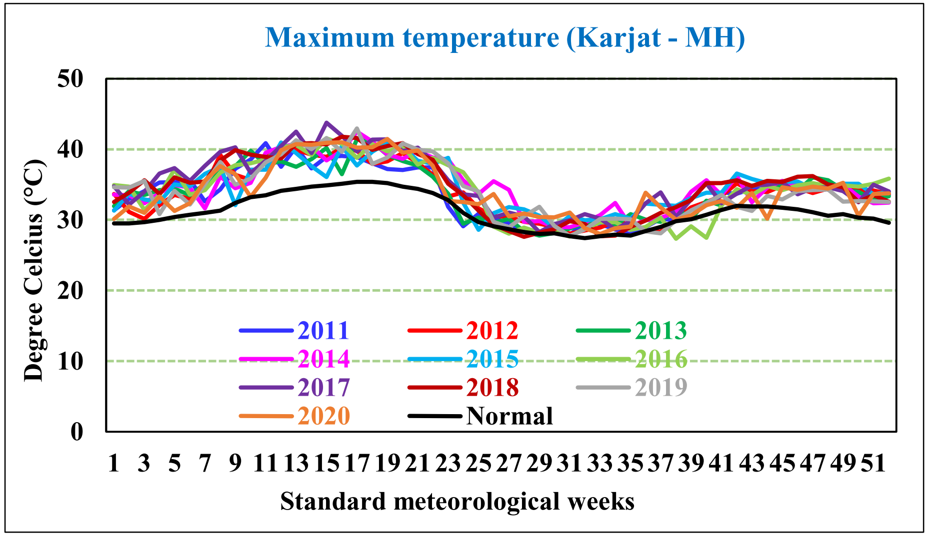


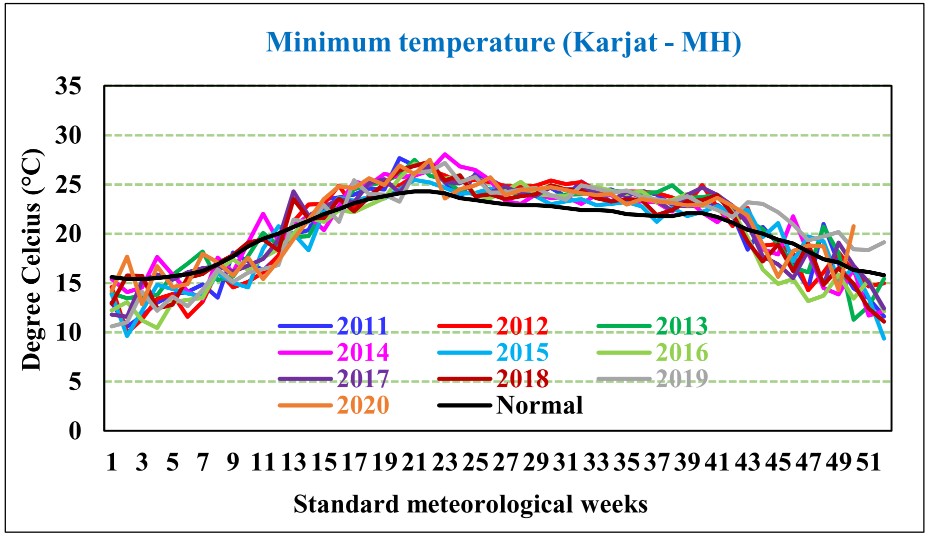


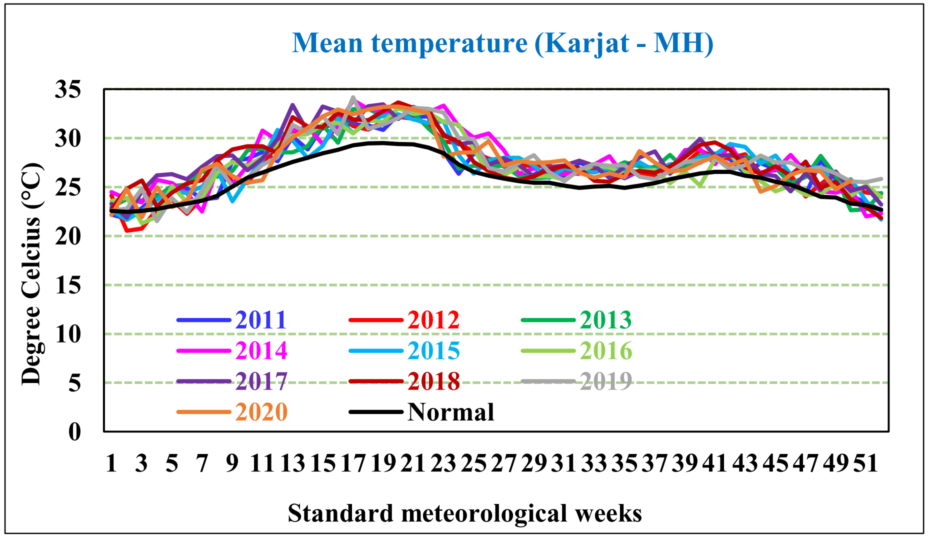


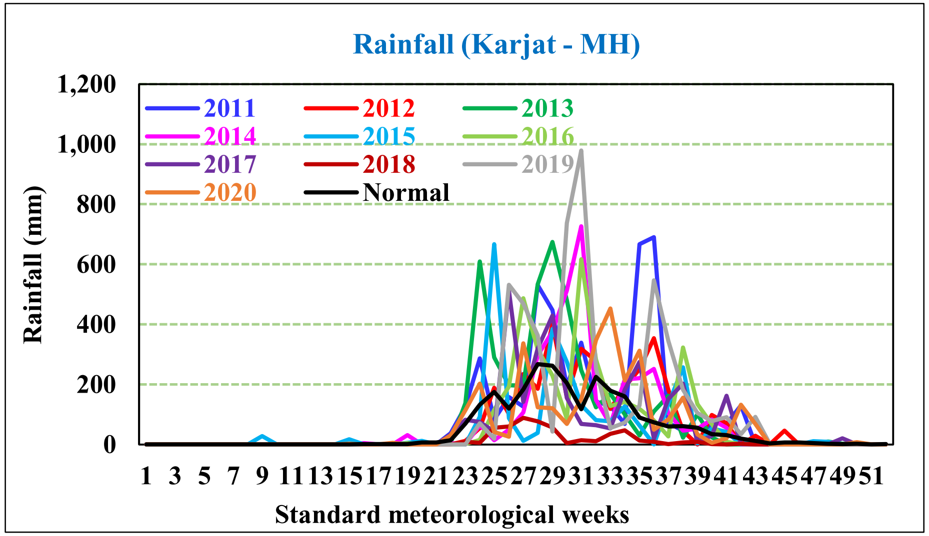
Annexure VII

Actual and 'normal' of temperature (maximum, minimum and mean) and rainfall at study locations of rice



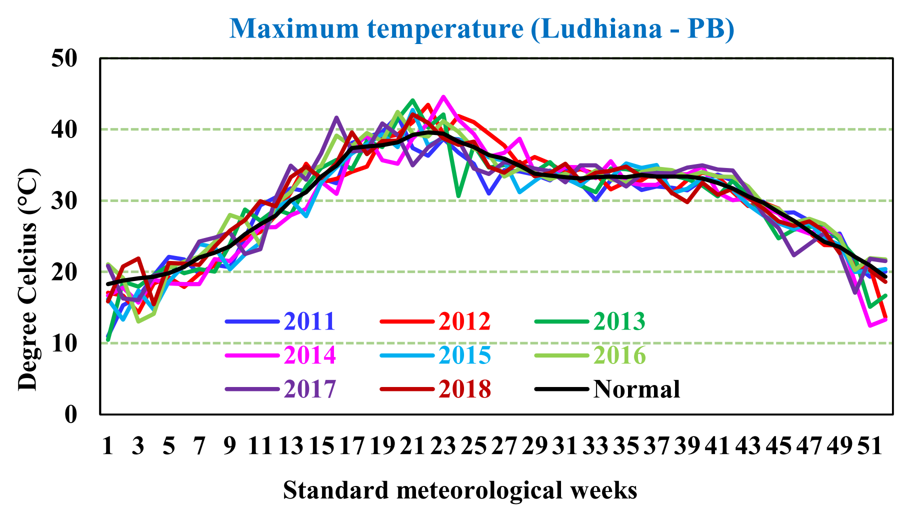


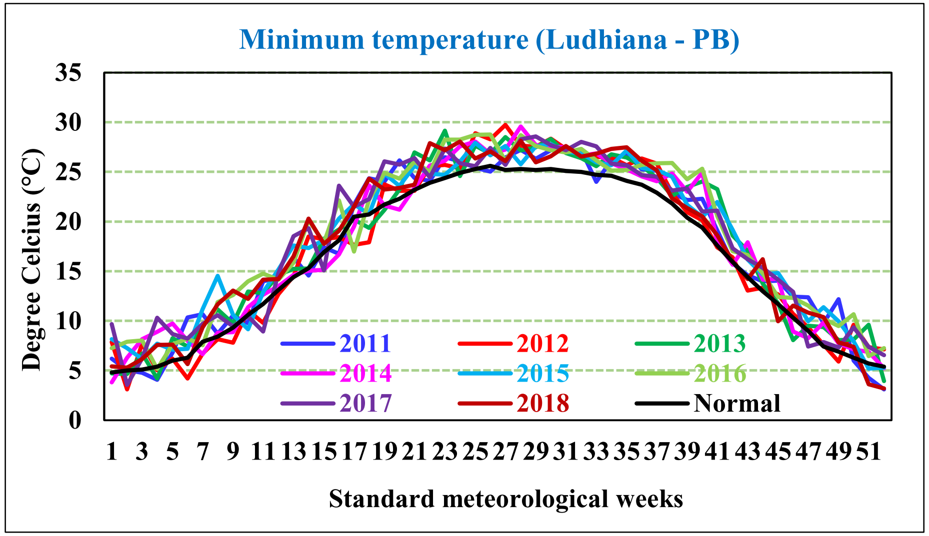


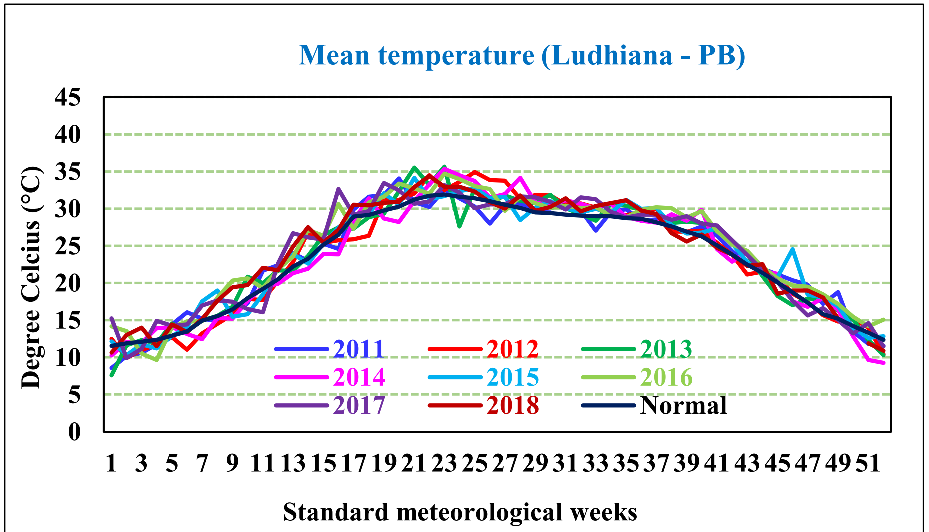


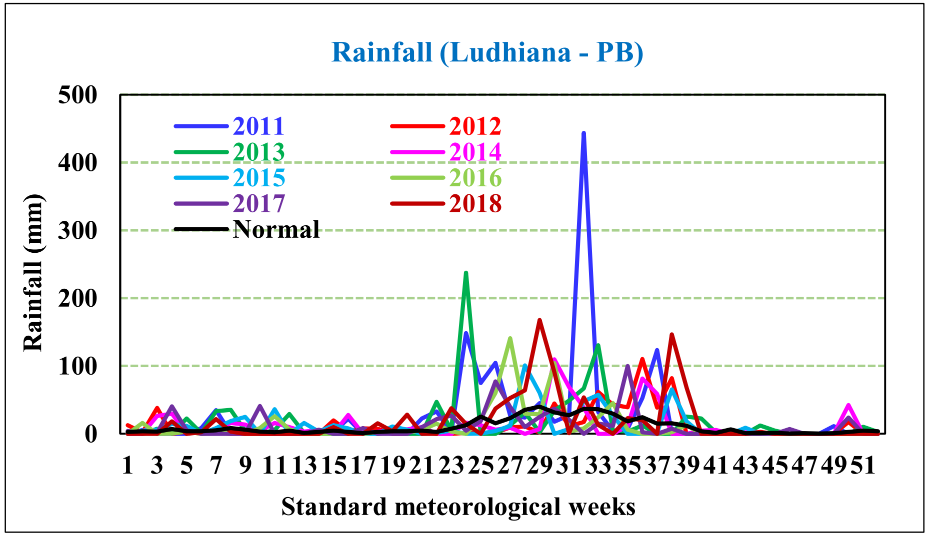
Annexure VII

Actual and 'normal' of temperature (maximum, minimum and mean) and rainfall at study locations of rice



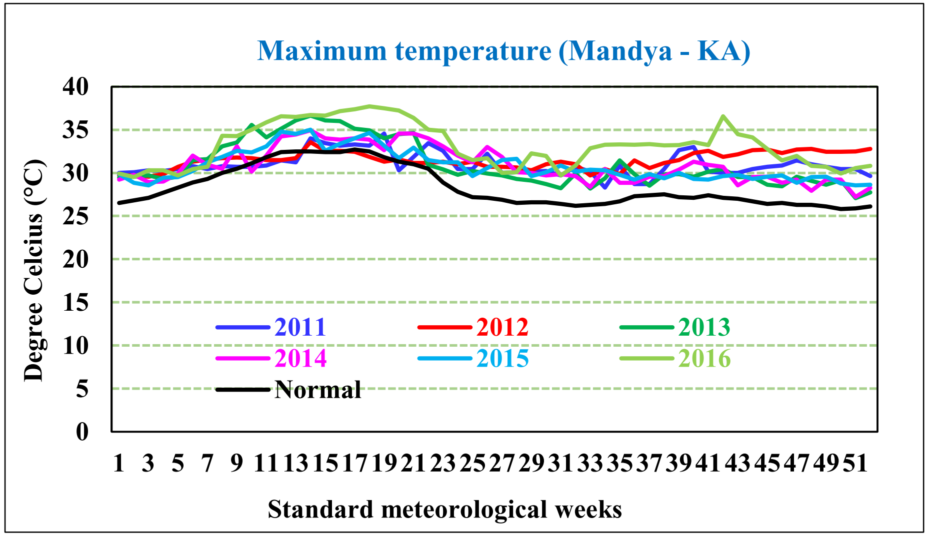


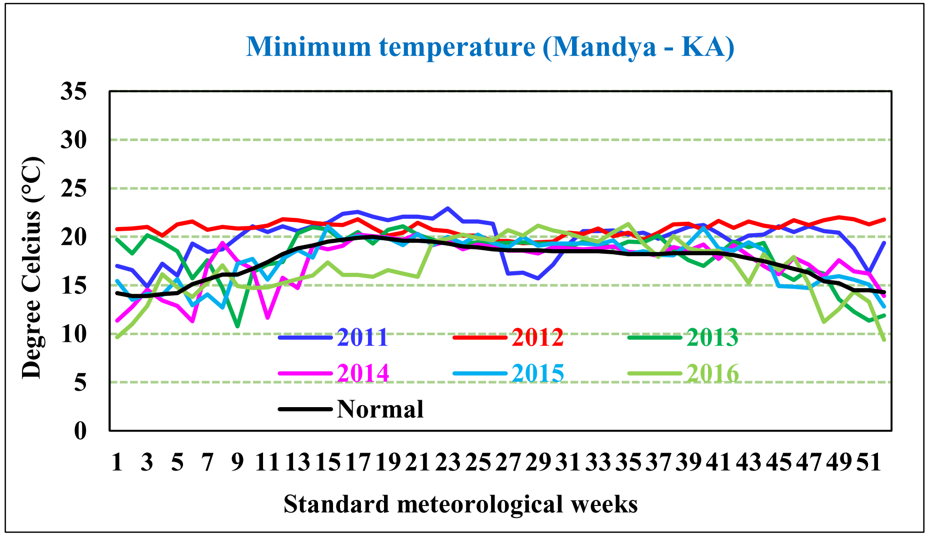


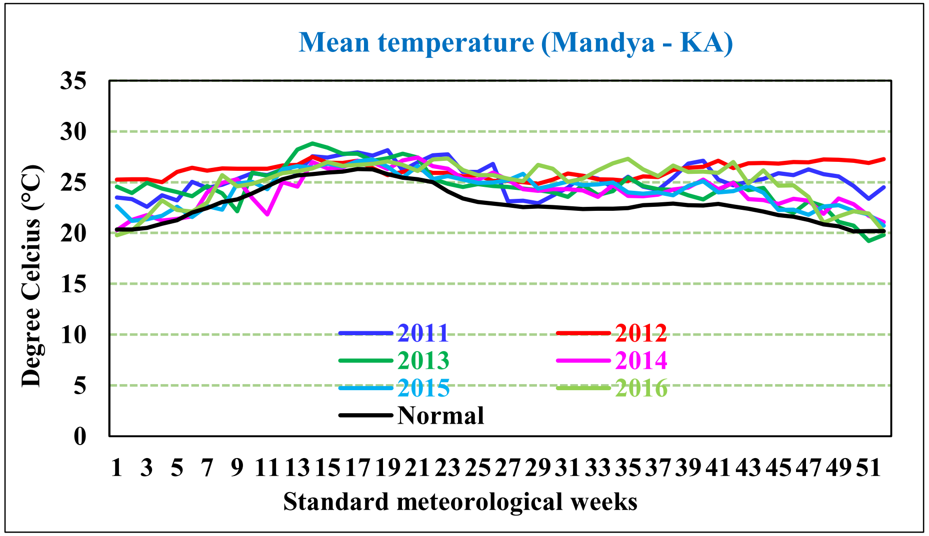


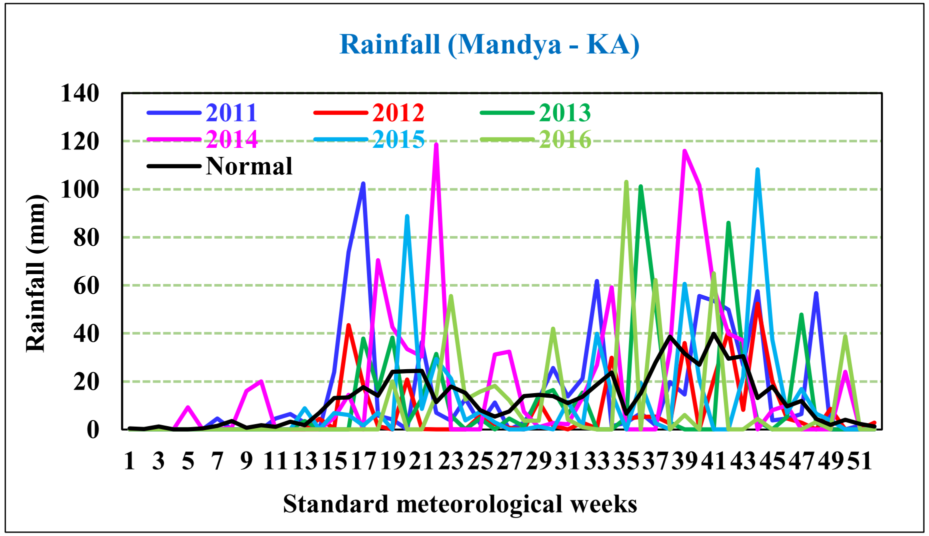
Annexure VII

Actual and 'normal' of temperature (maximum, minimum and mean) and rainfall at study locations of rice



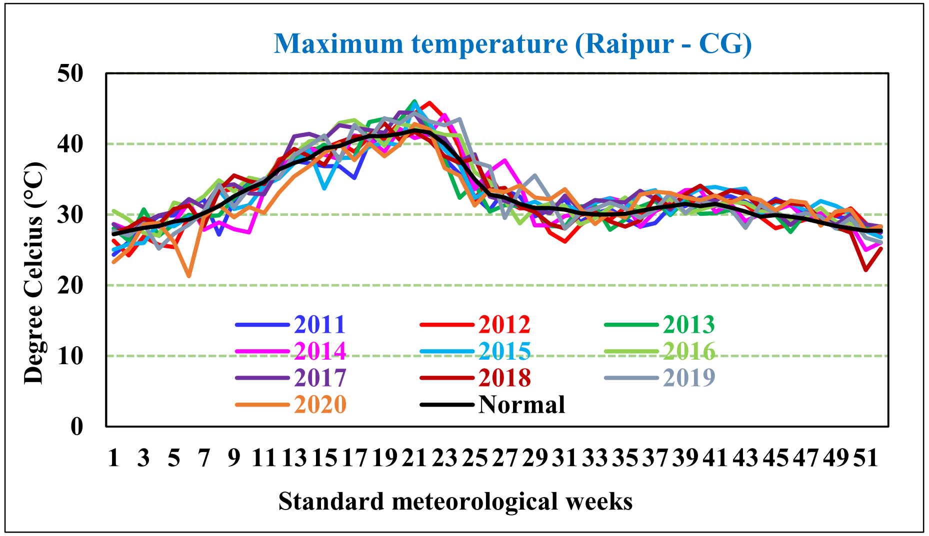


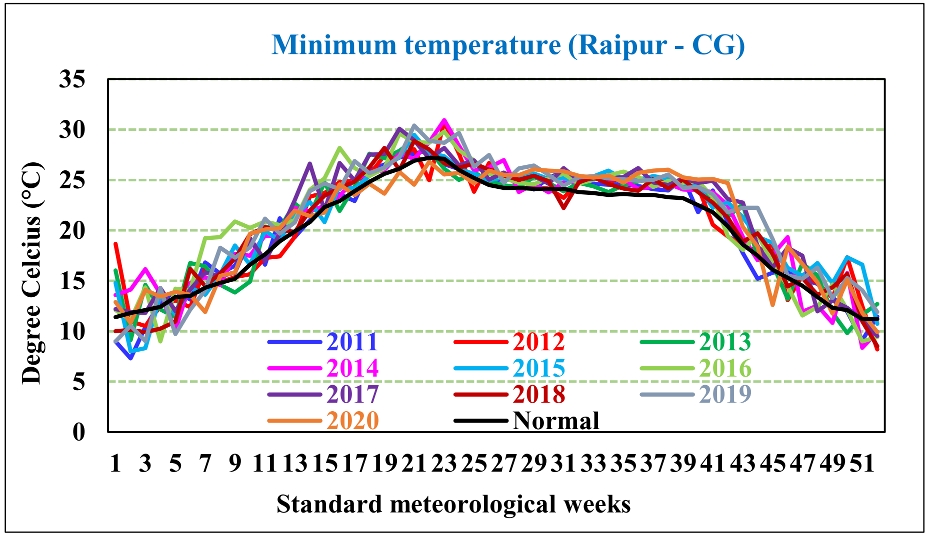


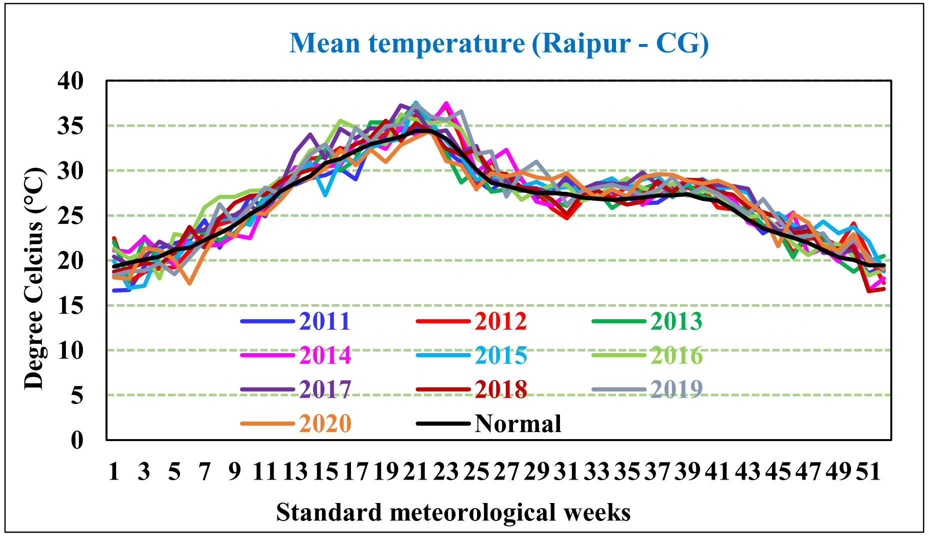


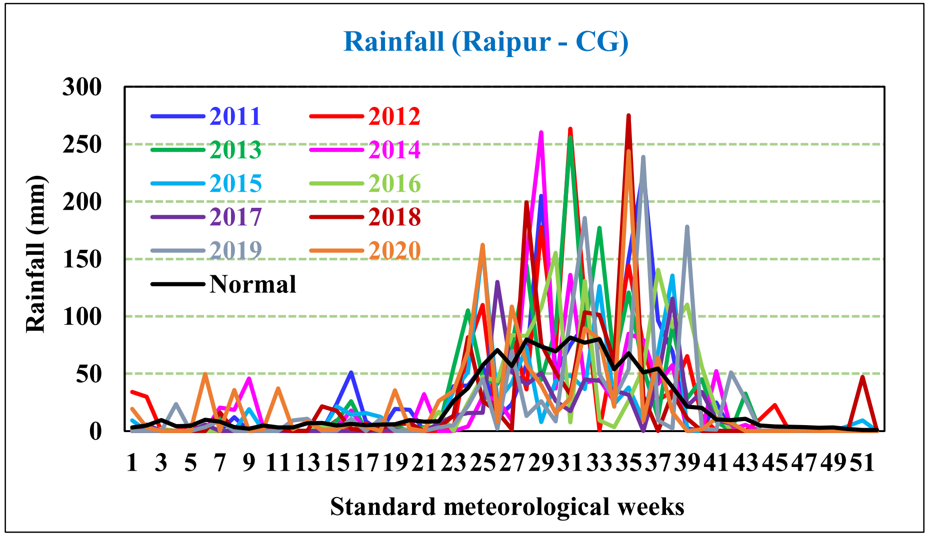
Annexure VII

Actual and 'normal' of temperature (maximum, minimum and mean) and rainfall at study locations of rice



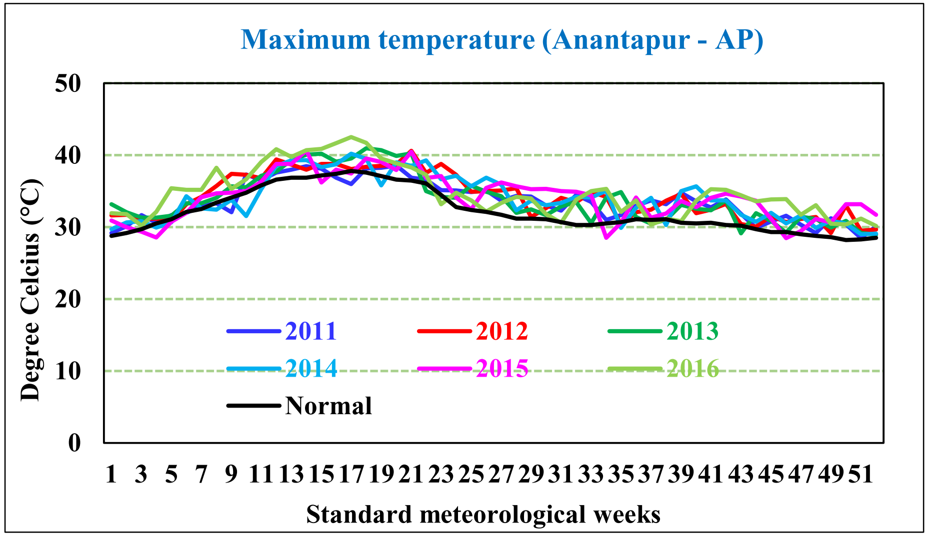


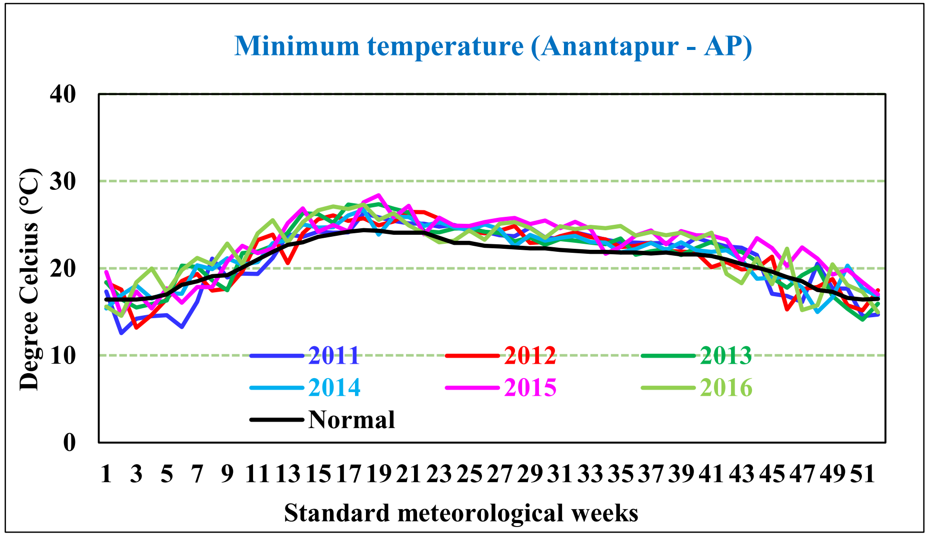


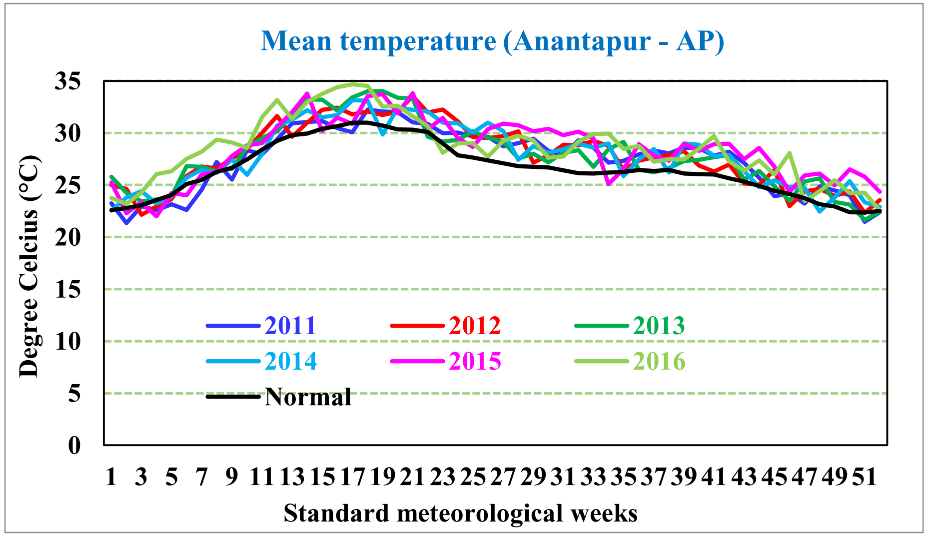


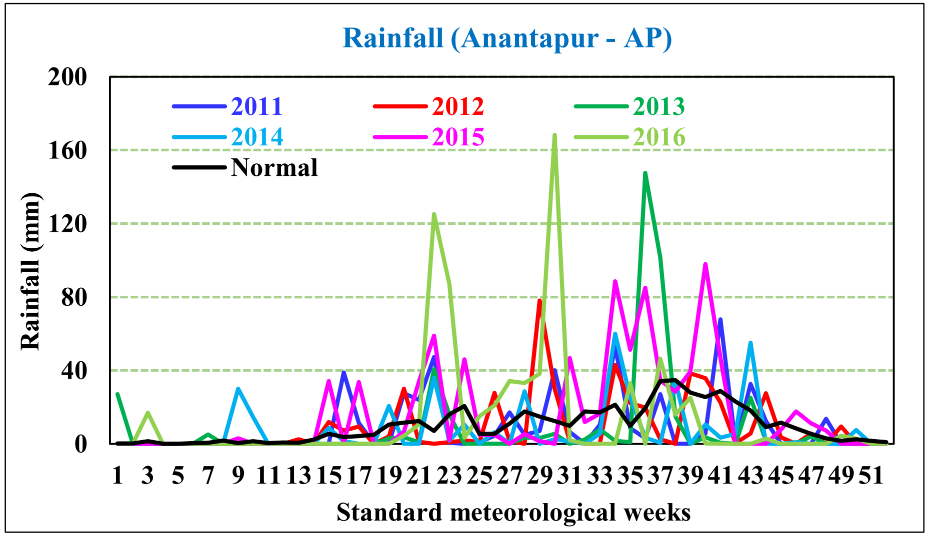
Annexure VIII

Actual and 'normal' of temperature (maximum, minimum and mean) and rainfall at study locations of pigeonpea



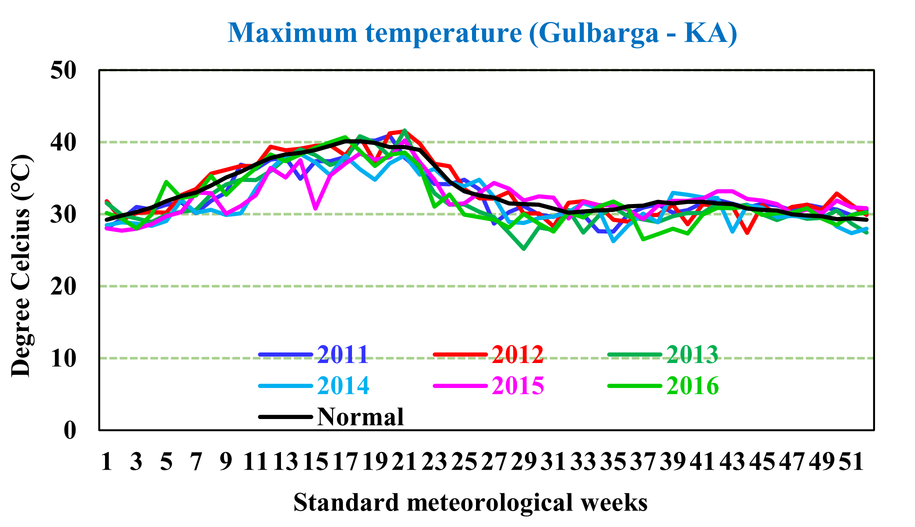


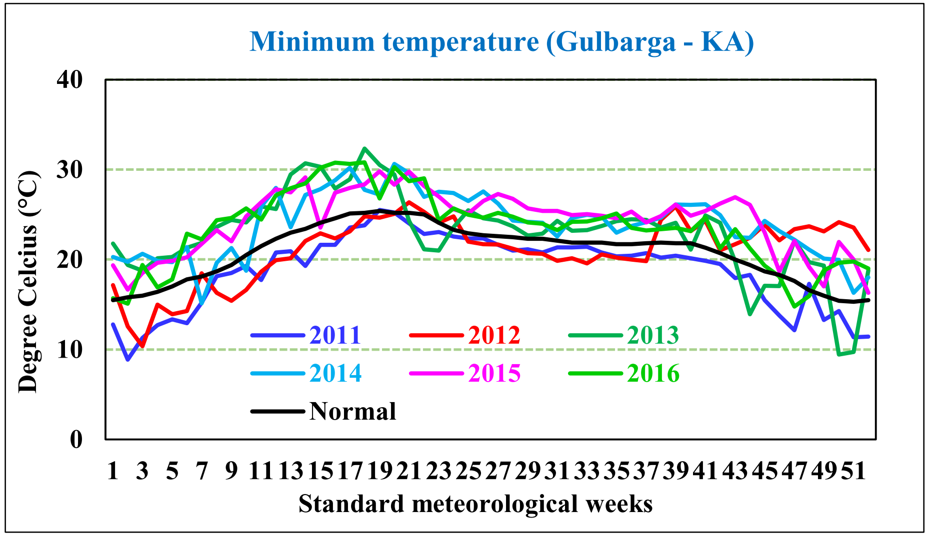


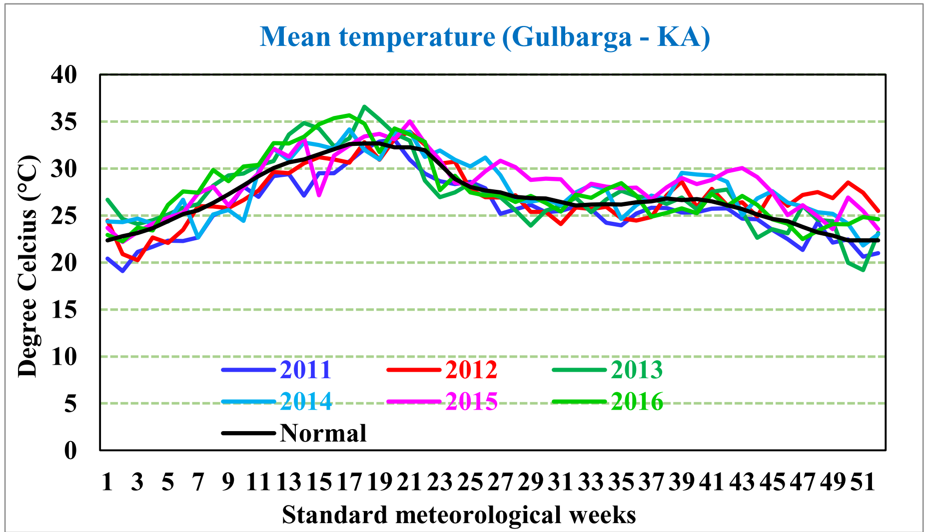


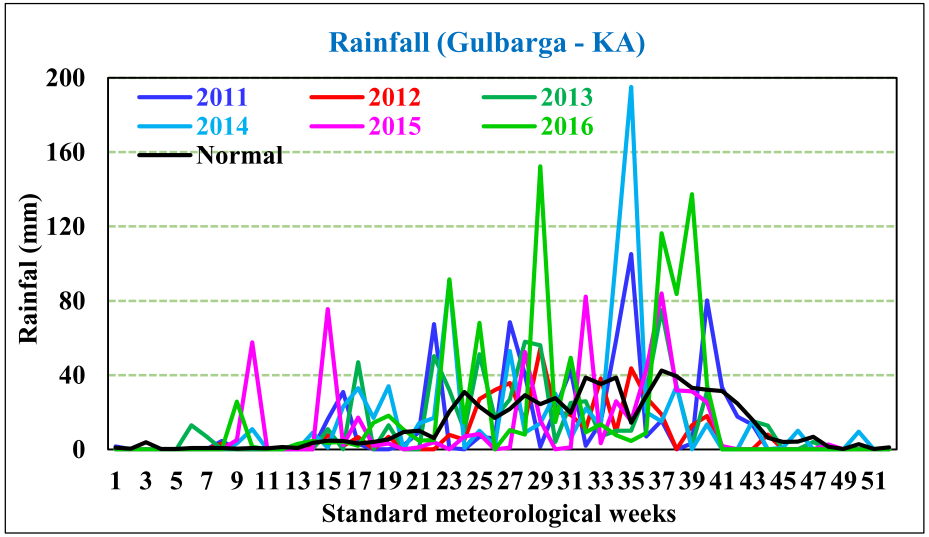
Annexure VIII

Actual and 'normal' of temperature (maximum, minimum and mean) and rainfall at study locations of pigeonpea



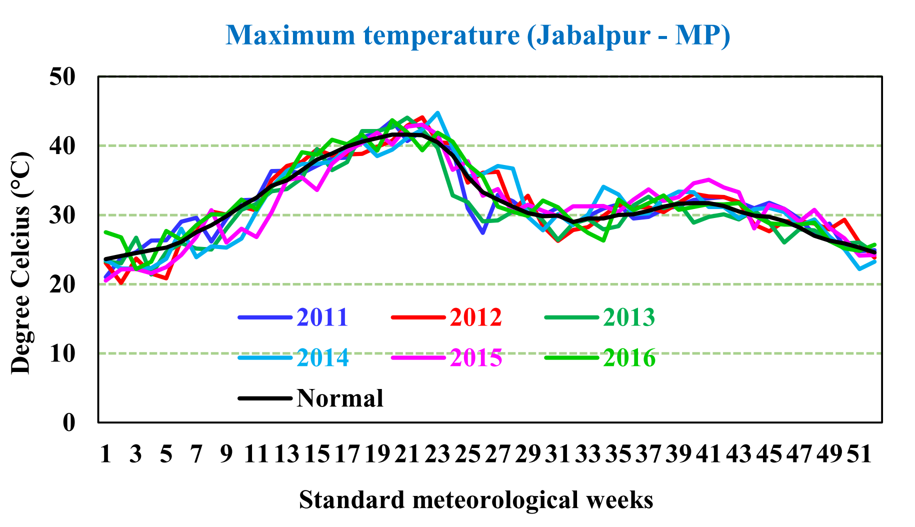


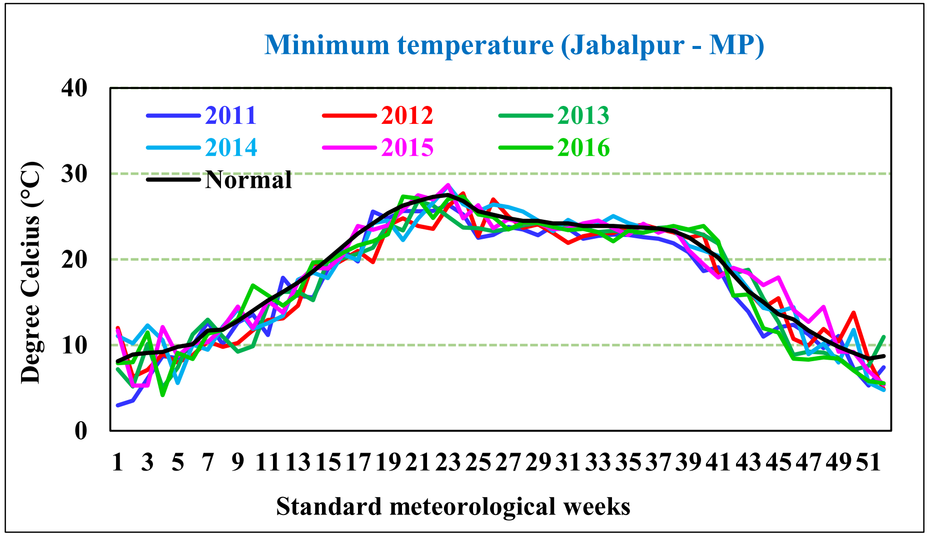


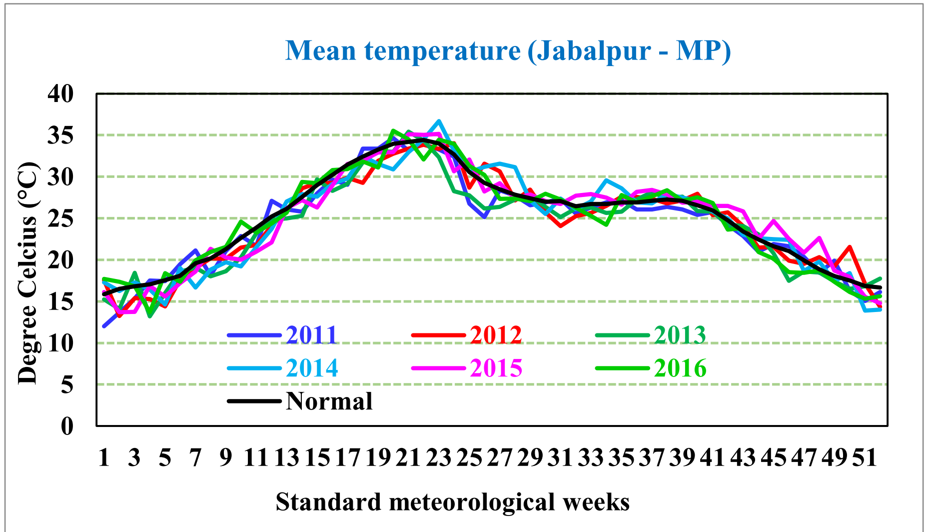


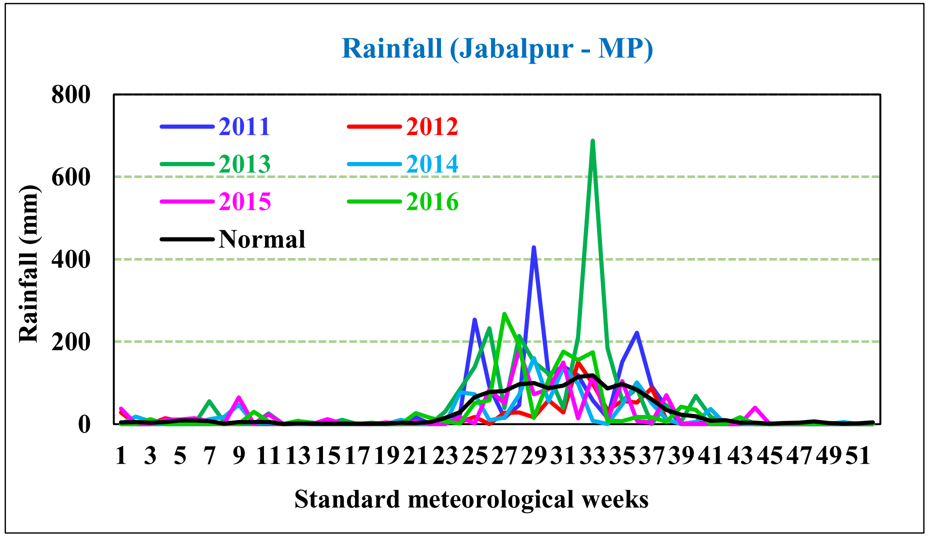
Annexure VIII

Actual and 'normal' of temperature (maximum, minimum and mean) and rainfall at study locations of pigeonpea



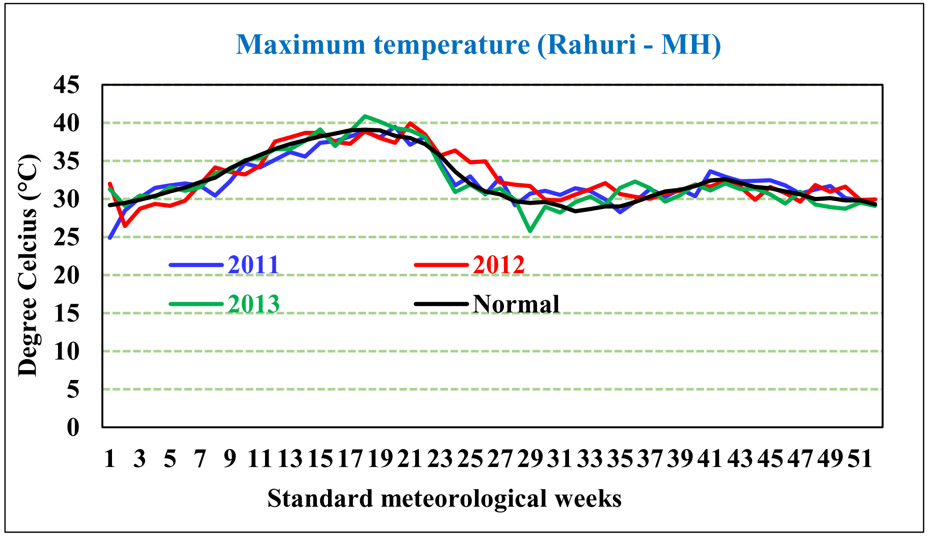


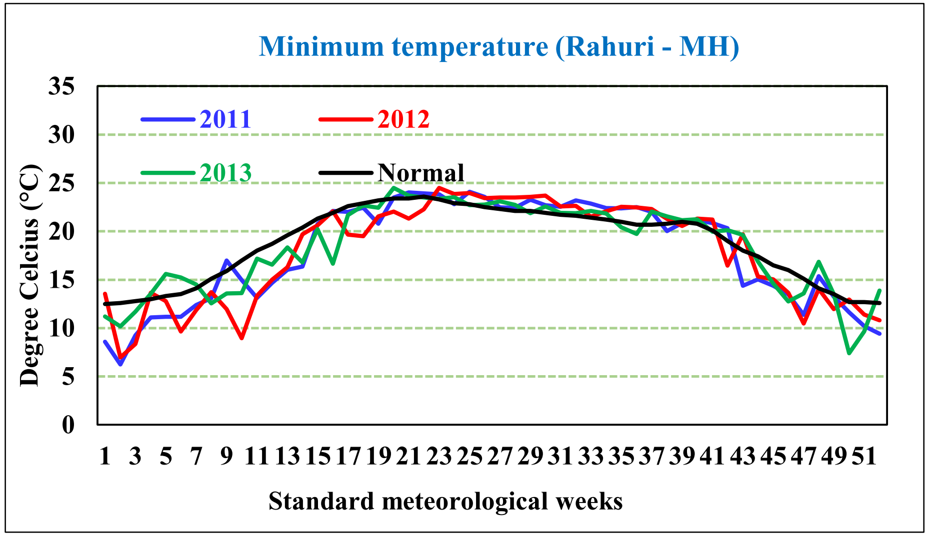


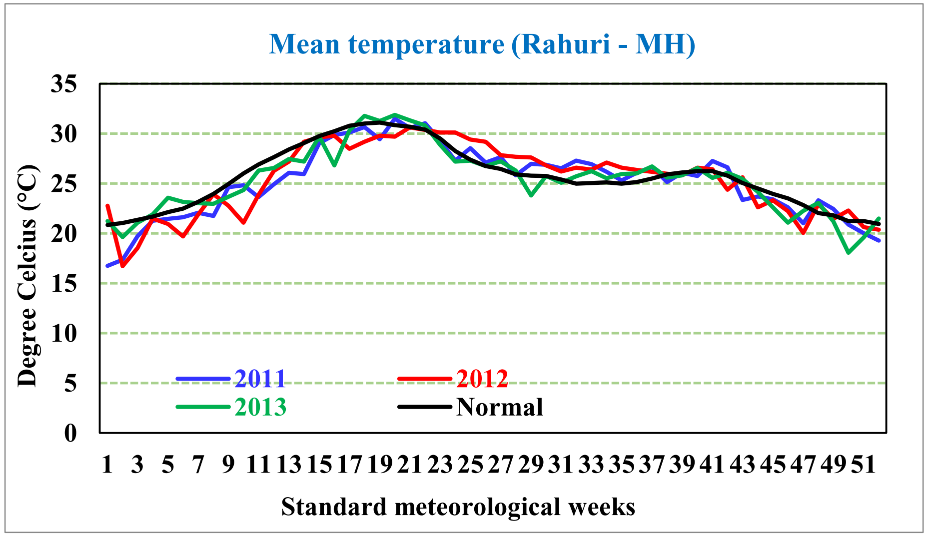


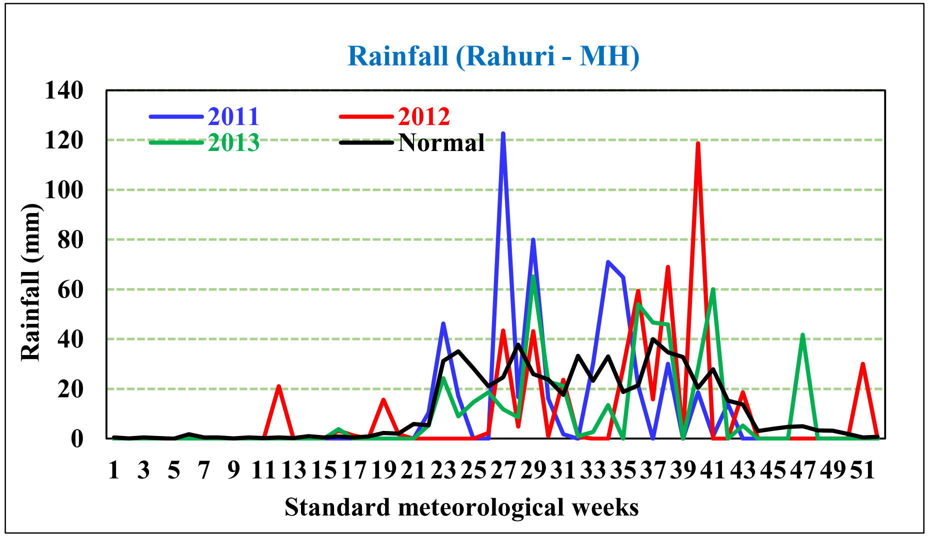
Annexure VIII

Actual and 'normal' of temperature (maximum, minimum and mean) and rainfall at study locations of pigeonpea



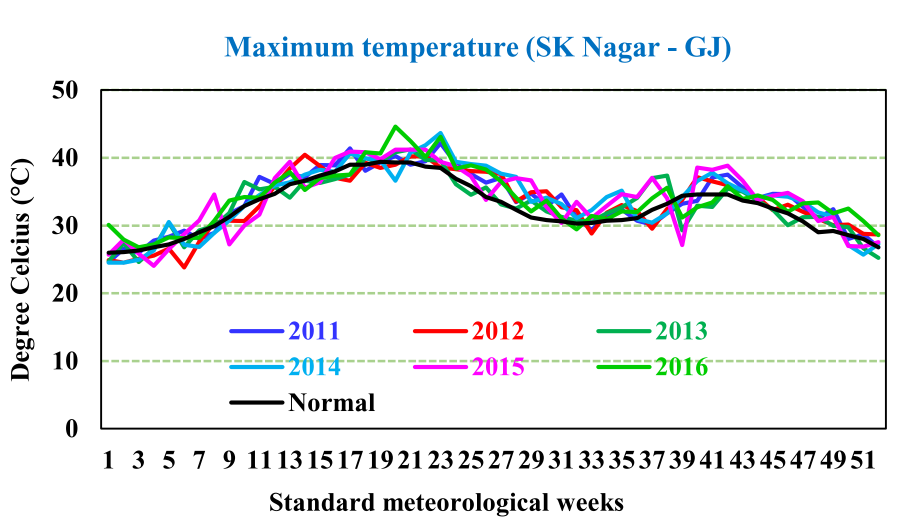


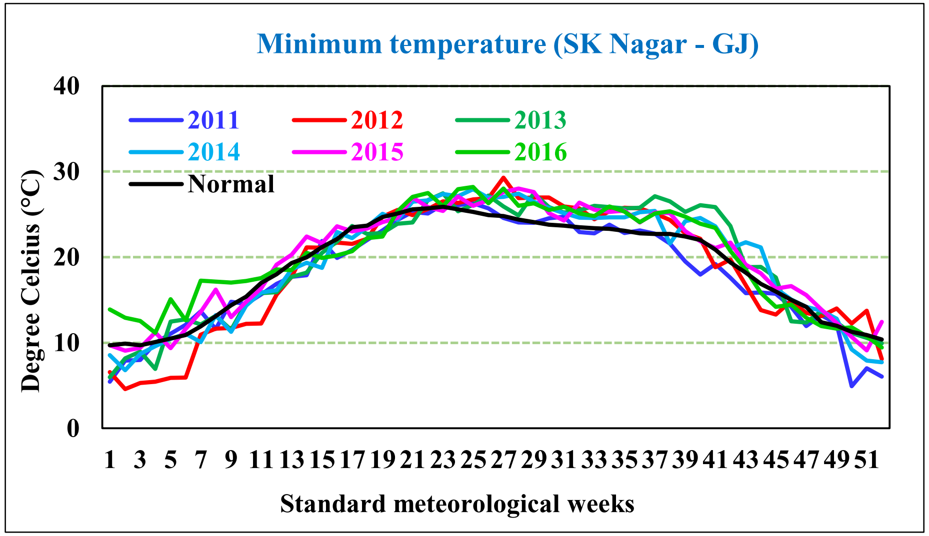


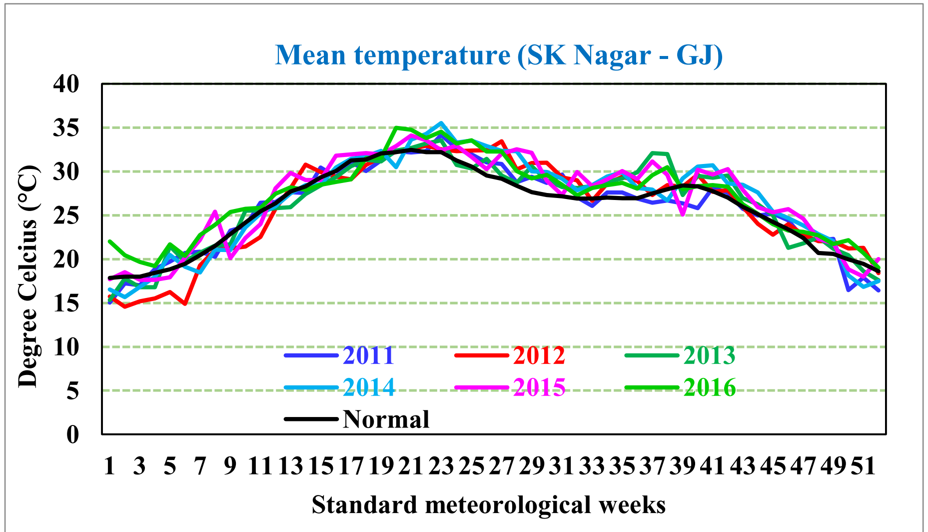


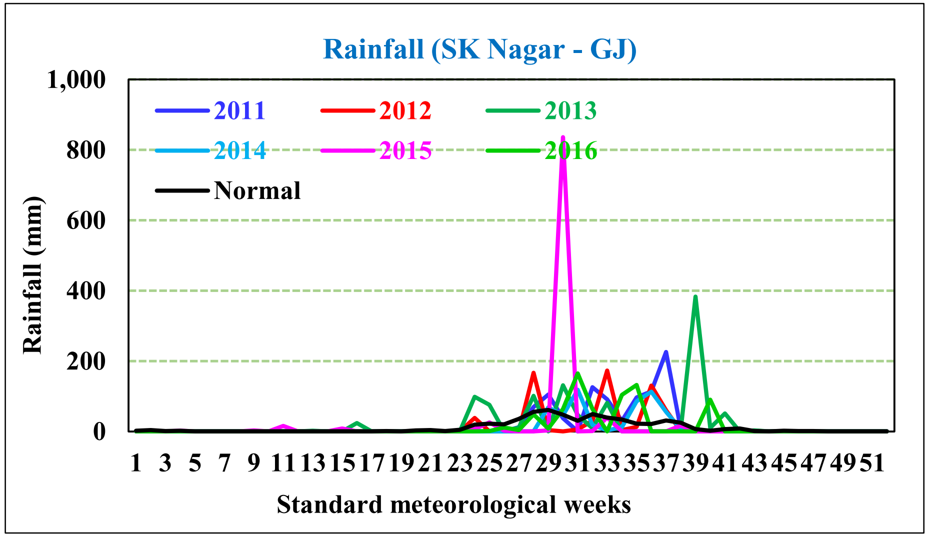
Annexure VIII

Actual and 'normal' of temperature (maximum, minimum and mean) and rainfall at study locations of pigeonpea



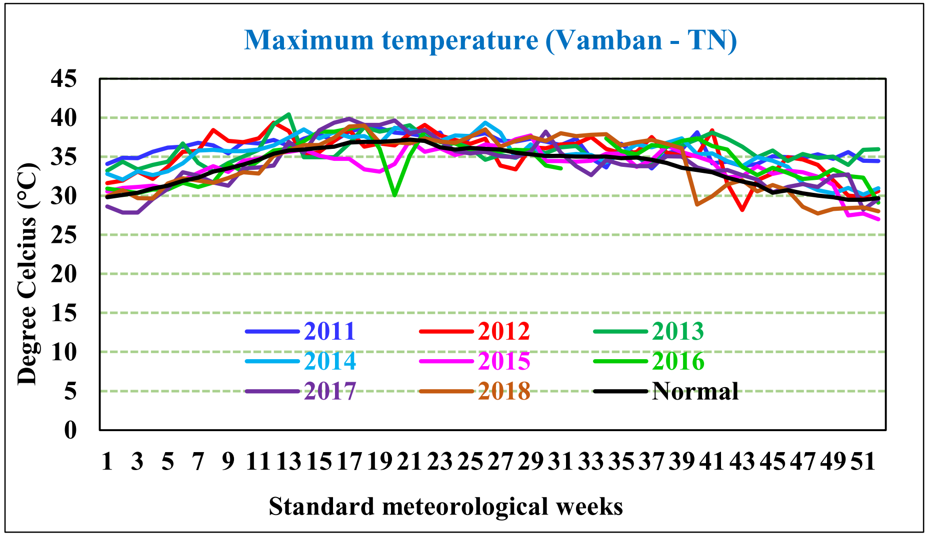


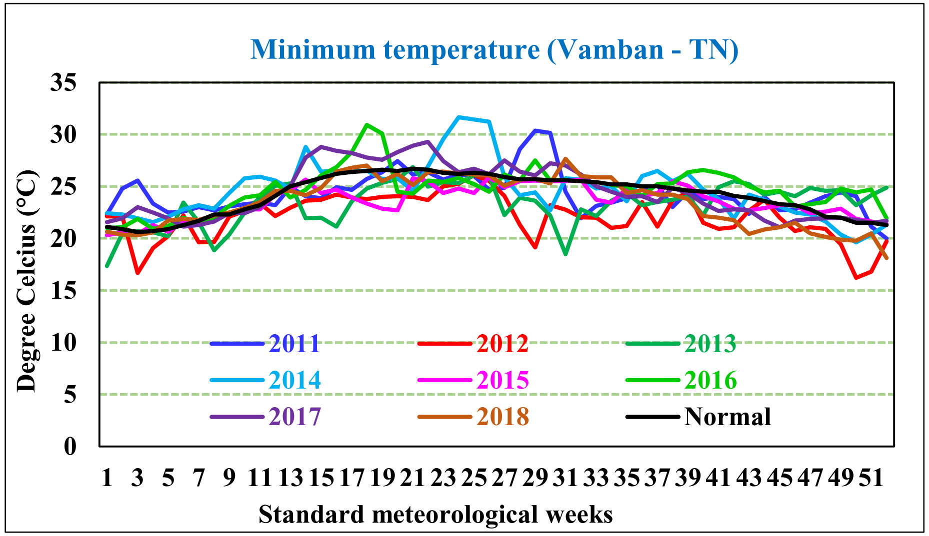


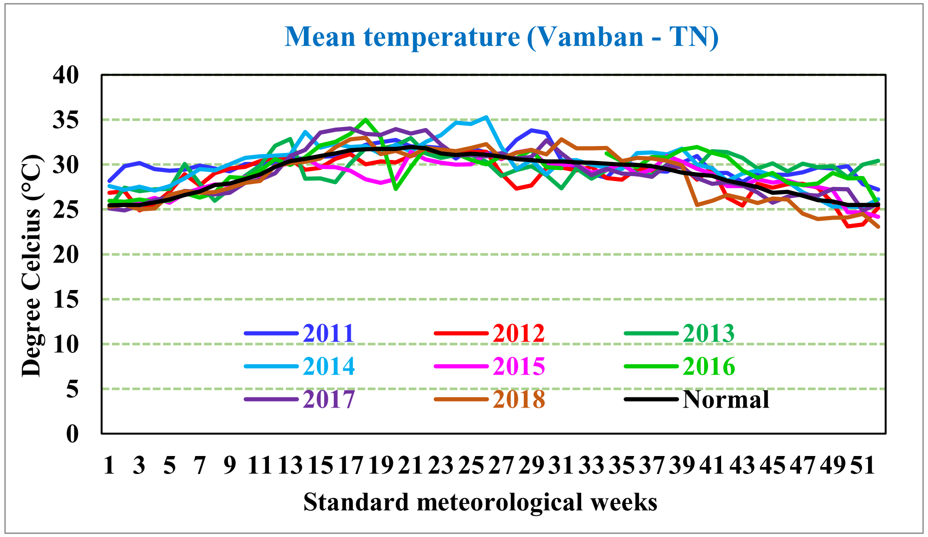


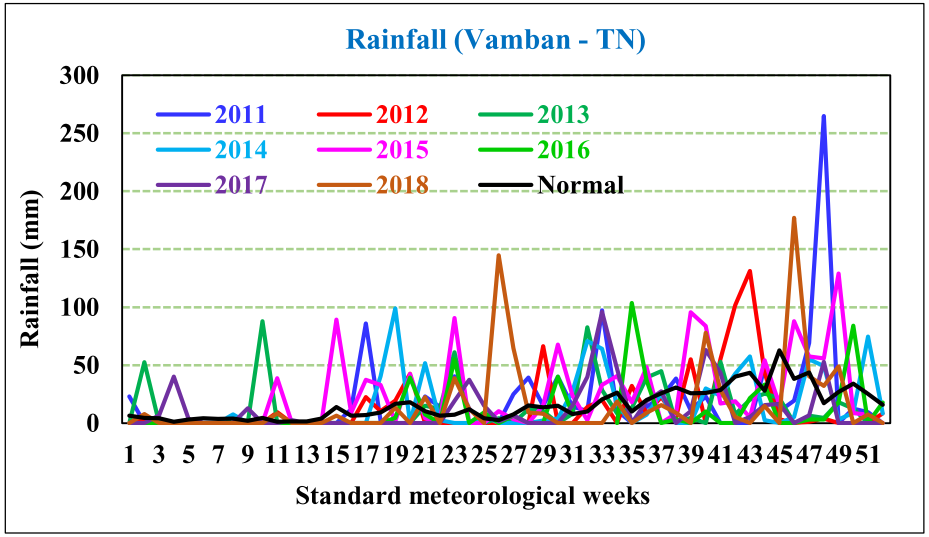
Annexure VIII

Actual and 'normal' of temperature (maximum, minimum and mean) and rainfall at study locations of pigeonpea



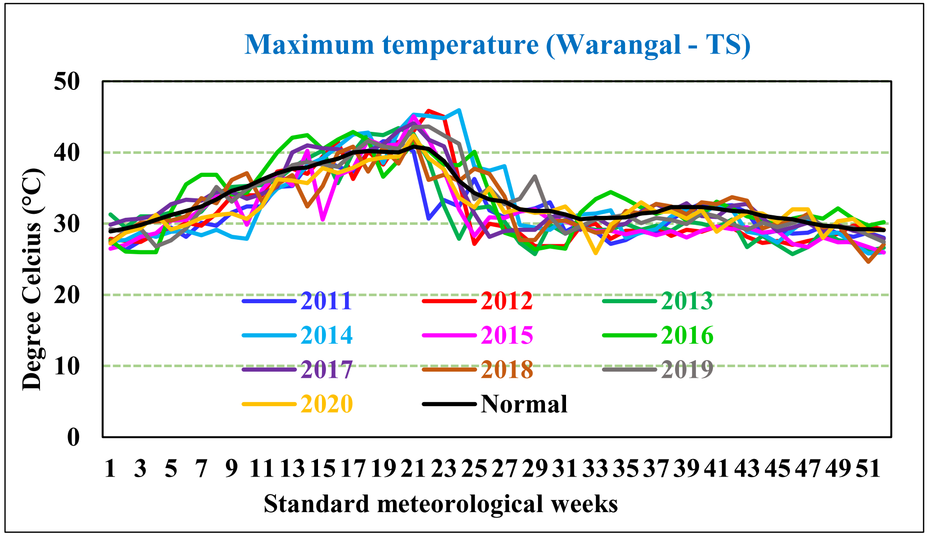


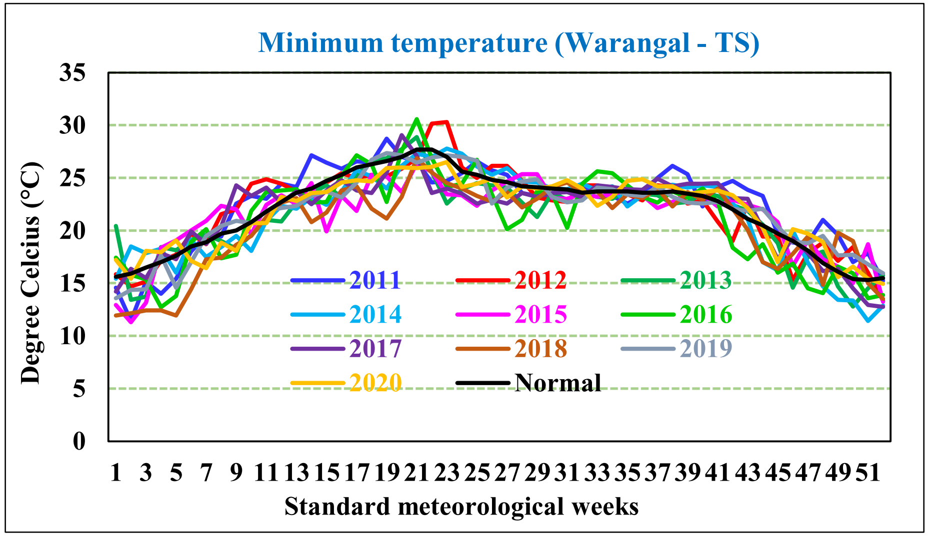


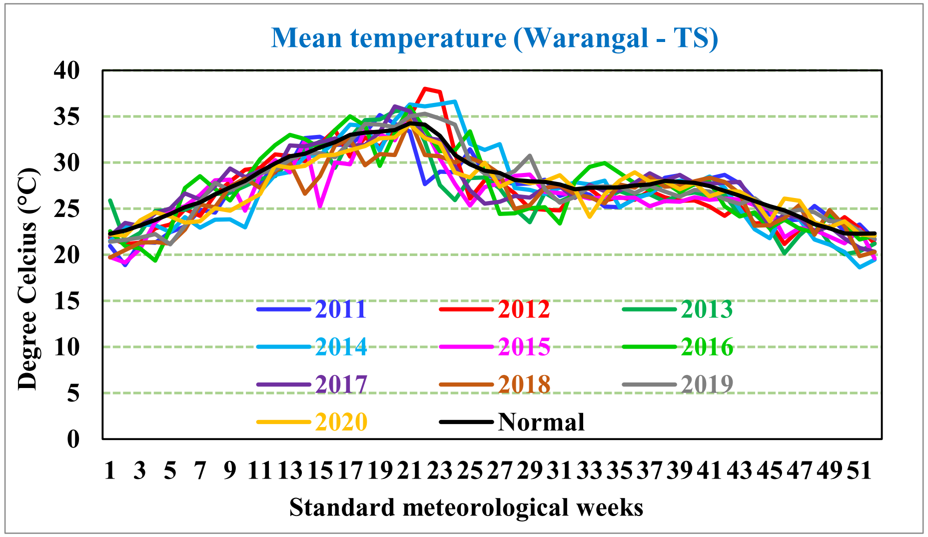


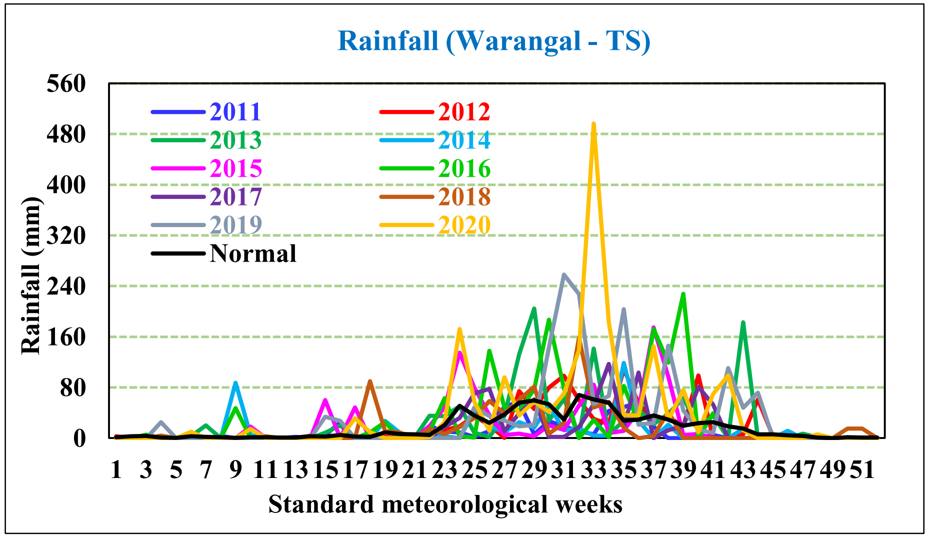
Annexure VIII

Actual and 'normal' of temperature (maximum, minimum and mean) and rainfall at study locations of pigeonpea



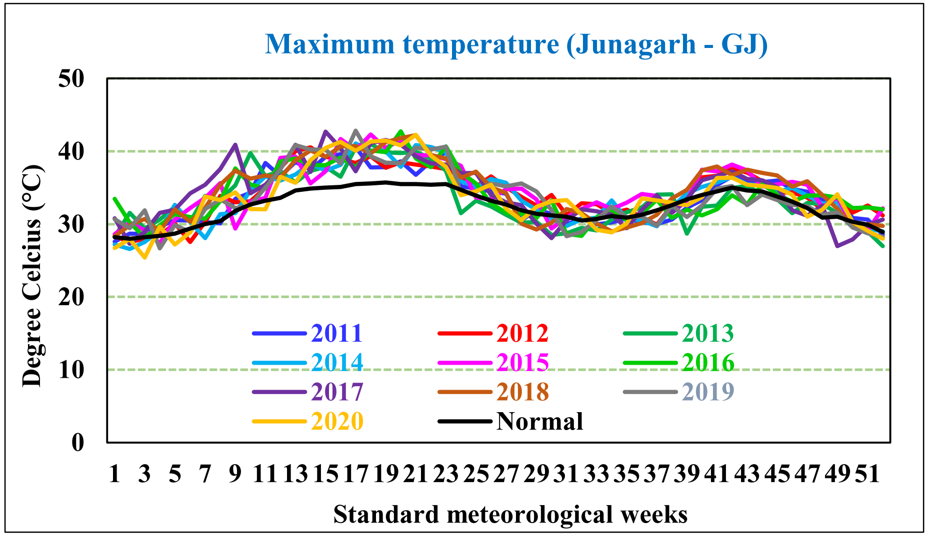


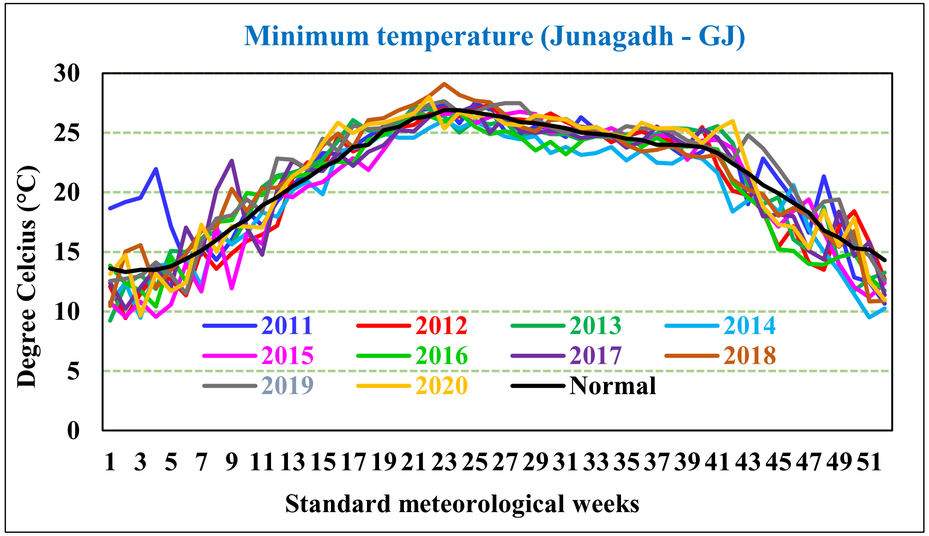


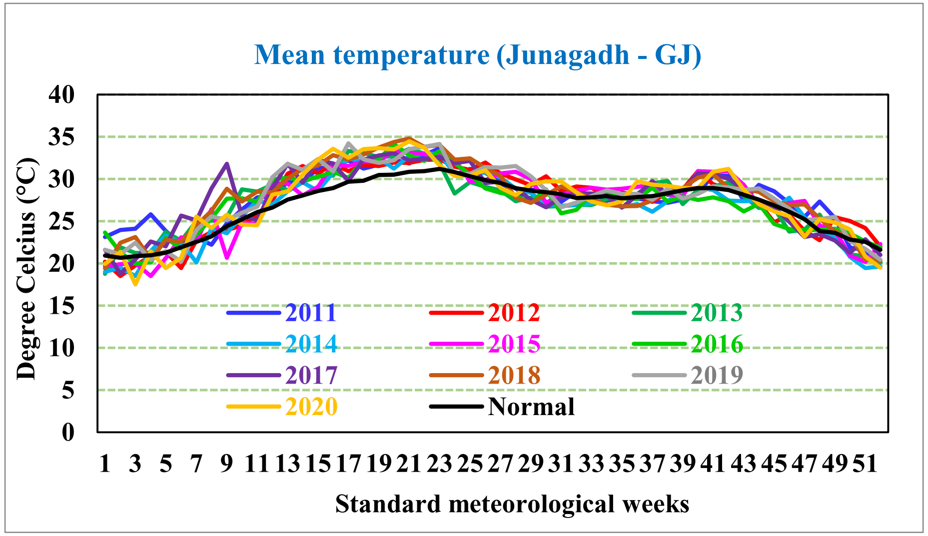


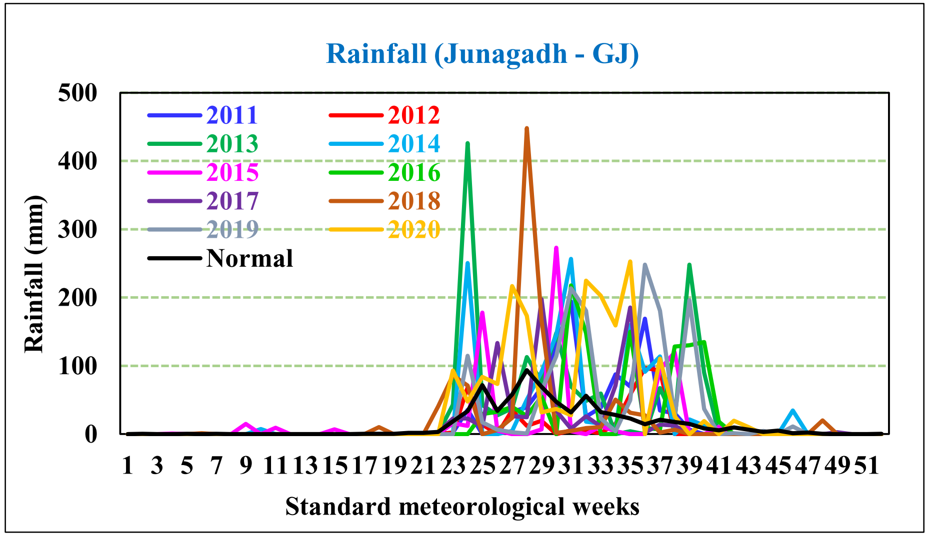
Annexure IX

Actual and ‘normal’ of temperature (maximum, minimum and mean) and rainfall at study locations of groundnut



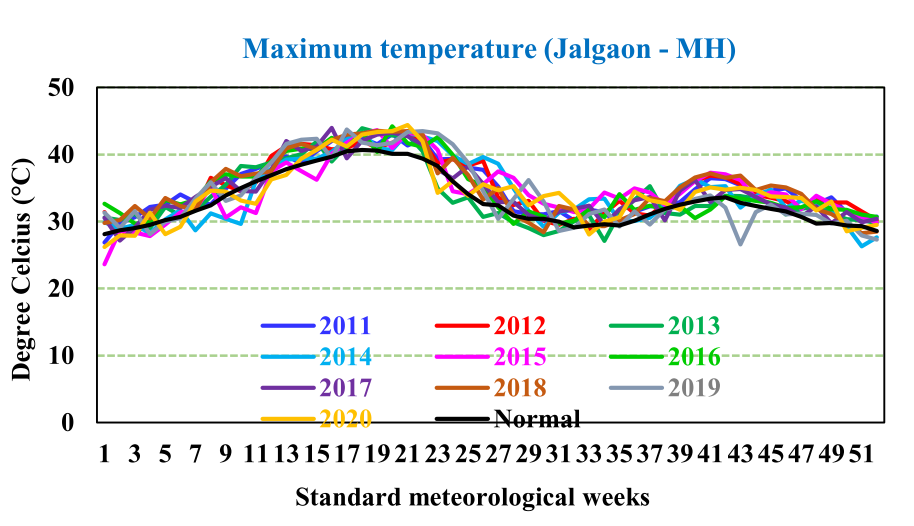


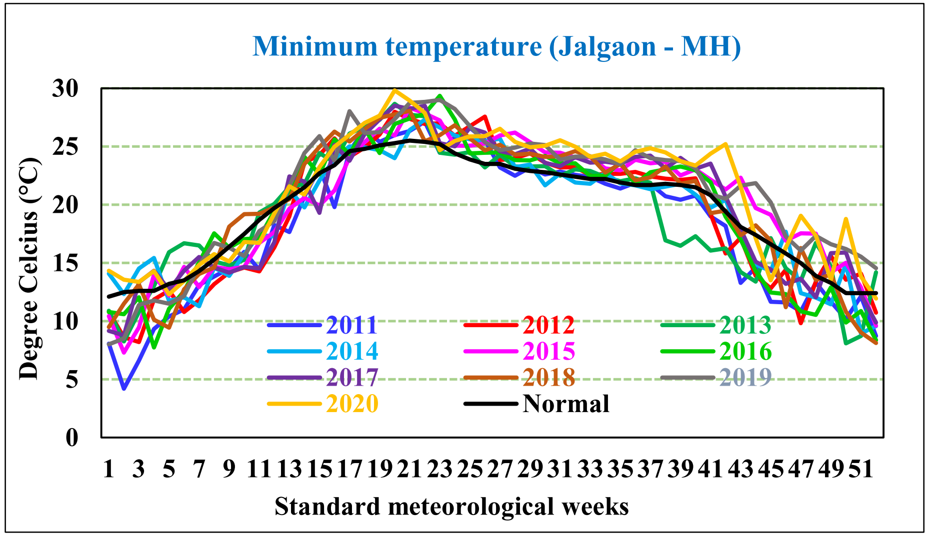


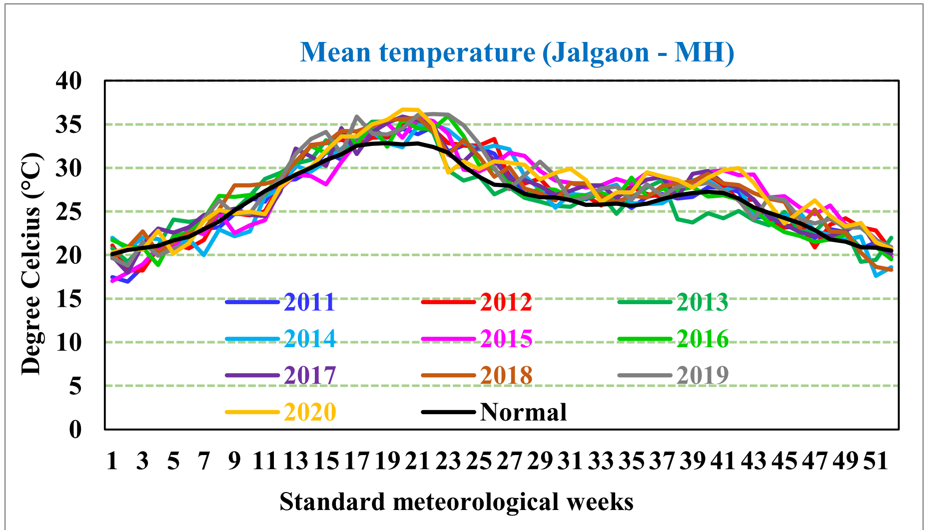


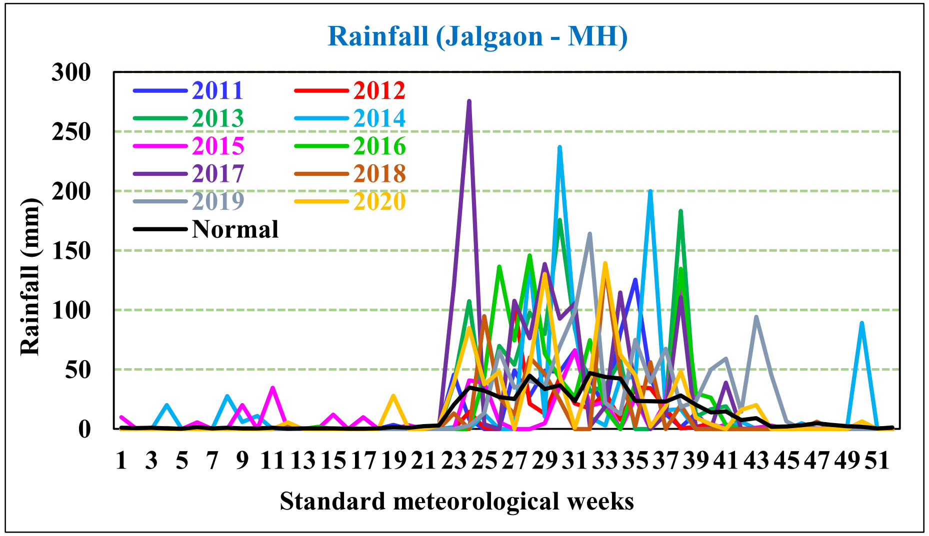
Annexure IX

Actual and 'normal' of temperature (maximum, minimum and mean) and rainfall at study locations of groundnut



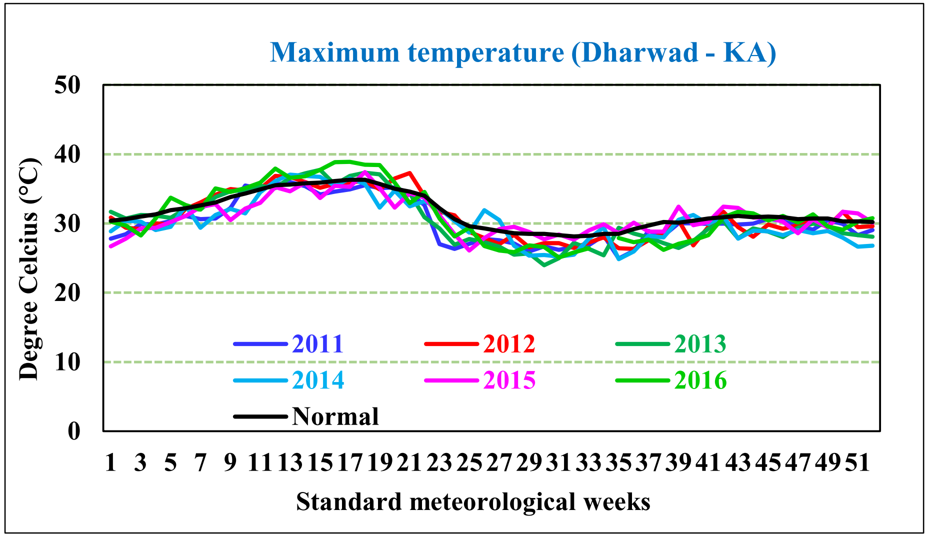


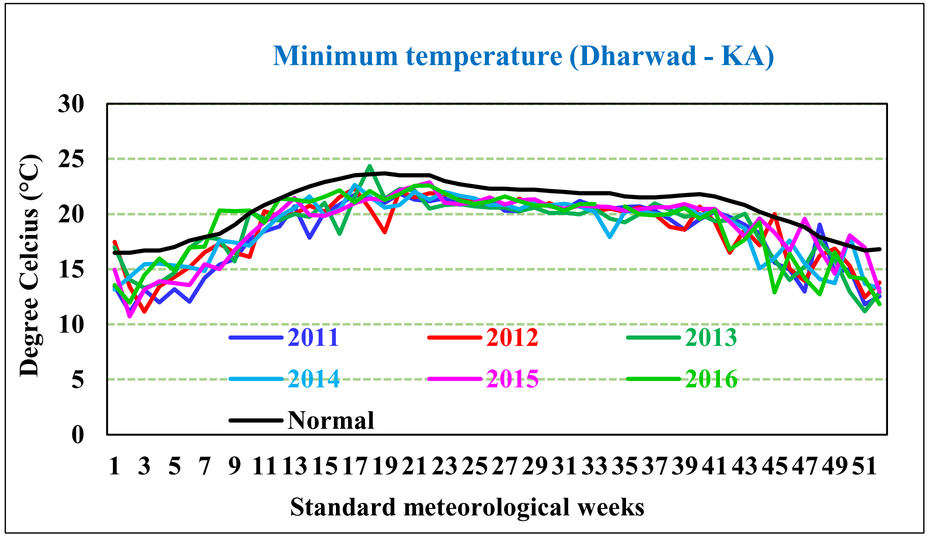


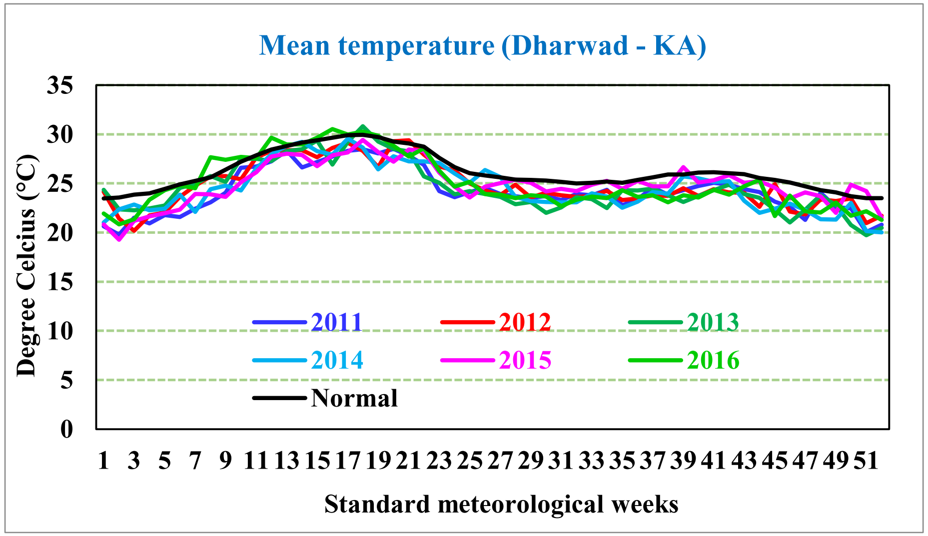


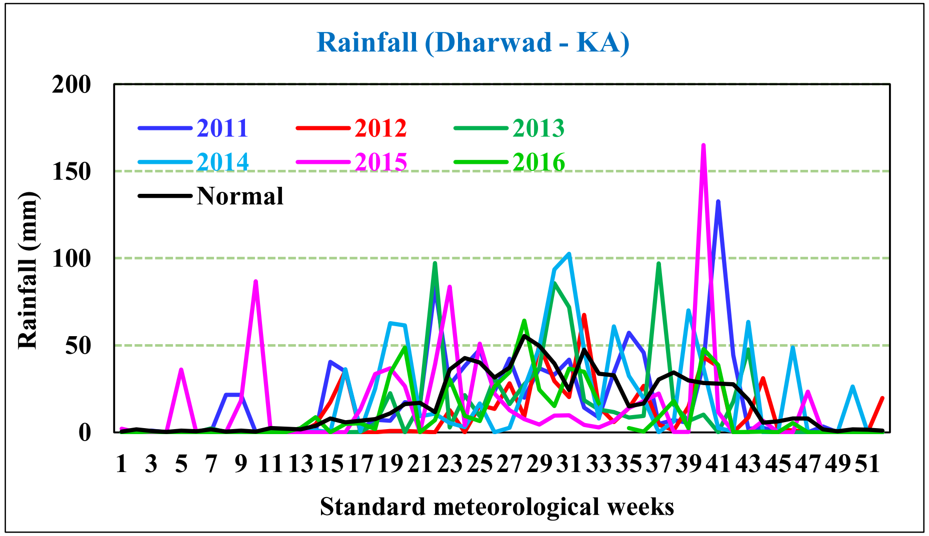
Annexure IX

Actual and ‘normal’ of temperature (maximum, minimum and mean) and rainfall at study locations of groundnut



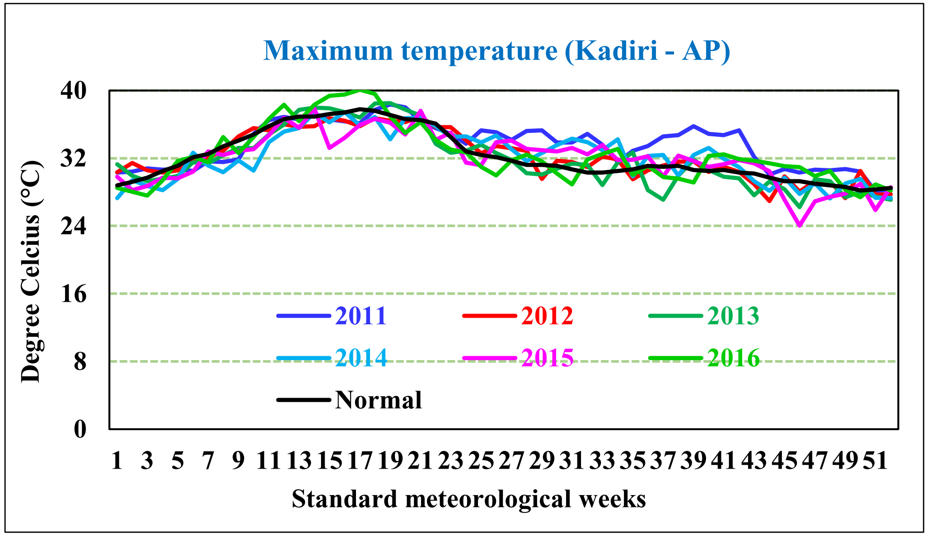


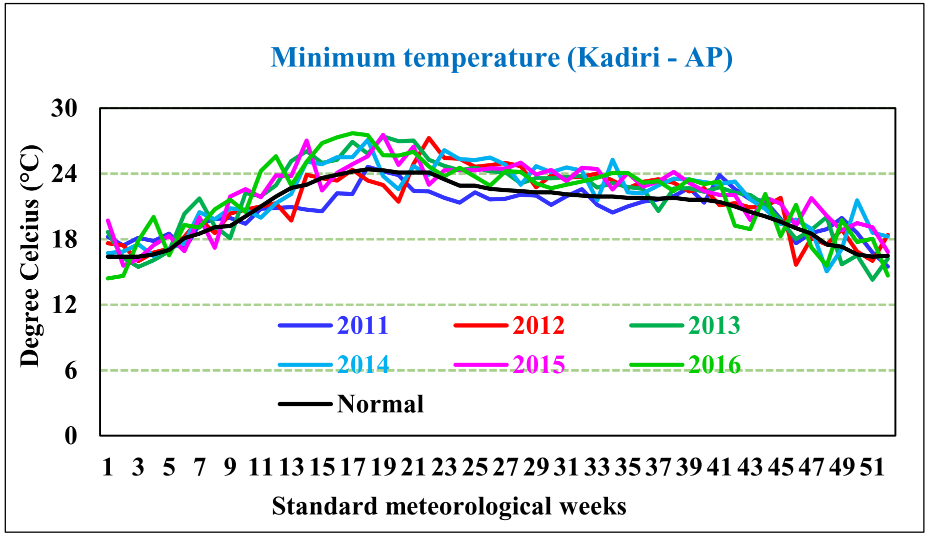


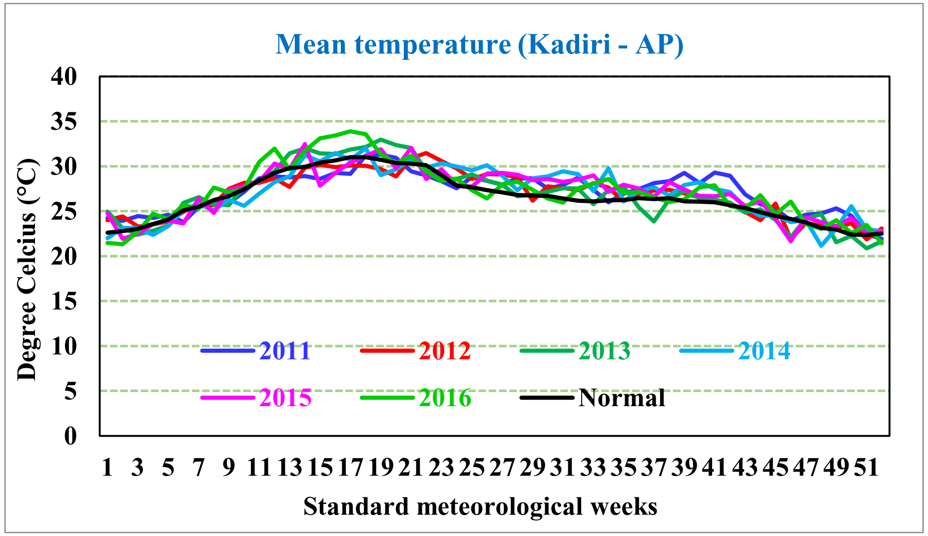


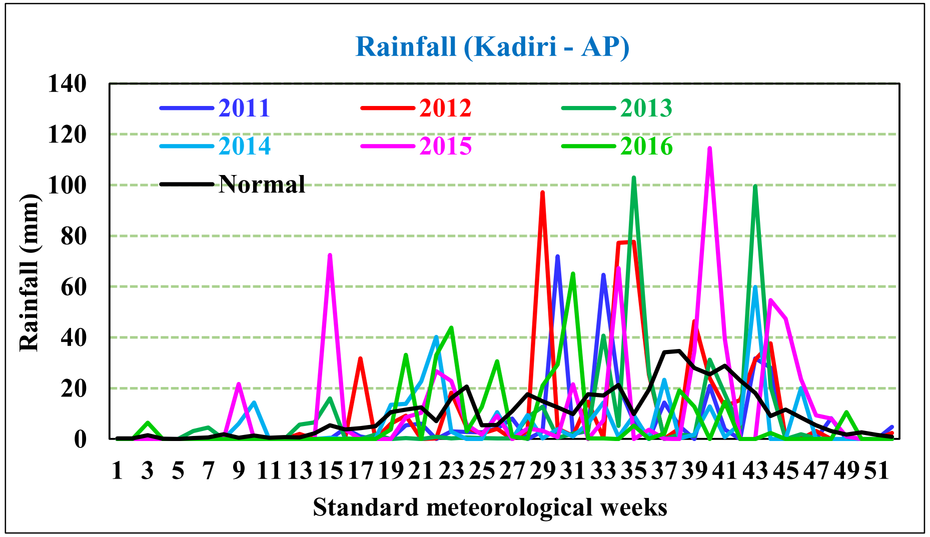
Annexure IX

Actual and 'normal' of temperature (maximum, minimum and mean) and rainfall at study locations of groundnut



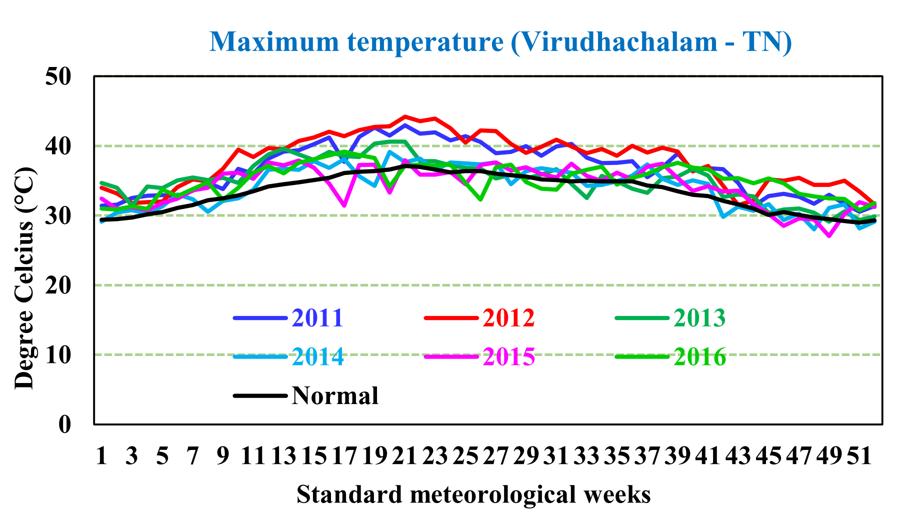


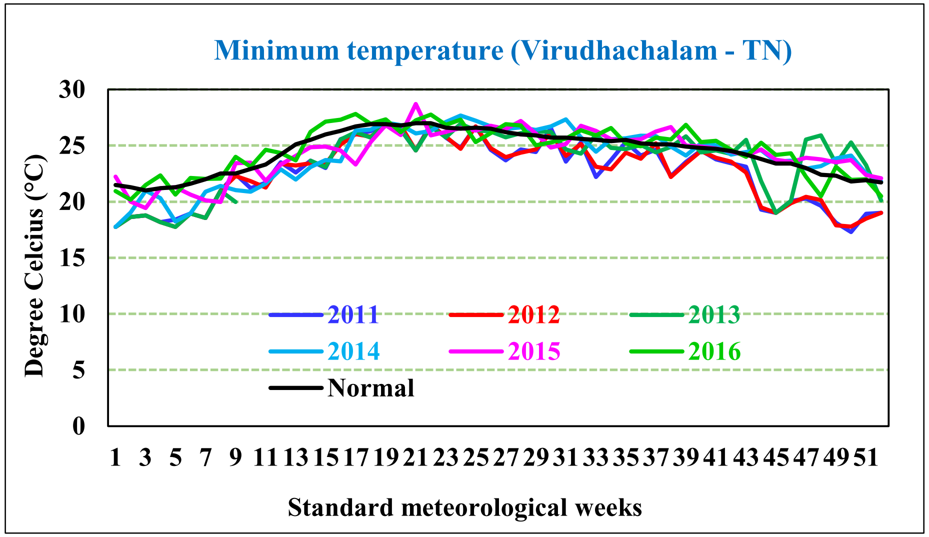


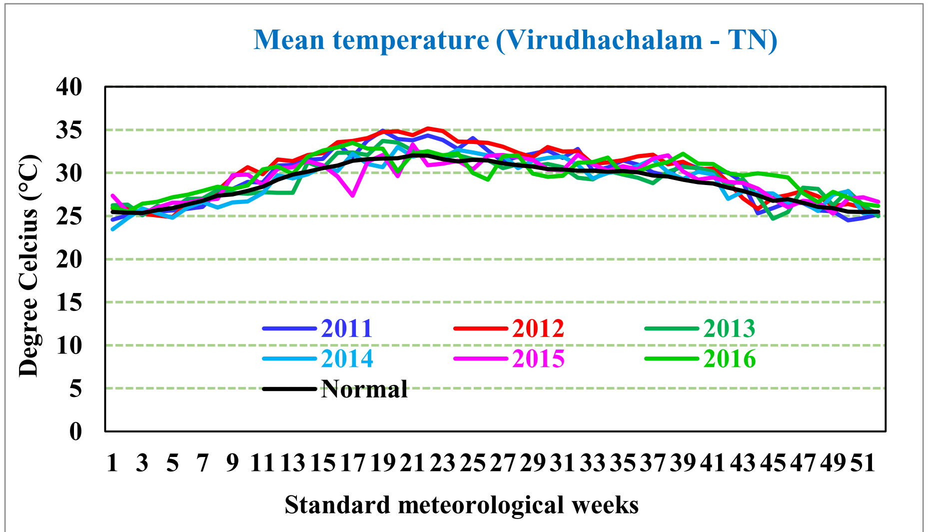


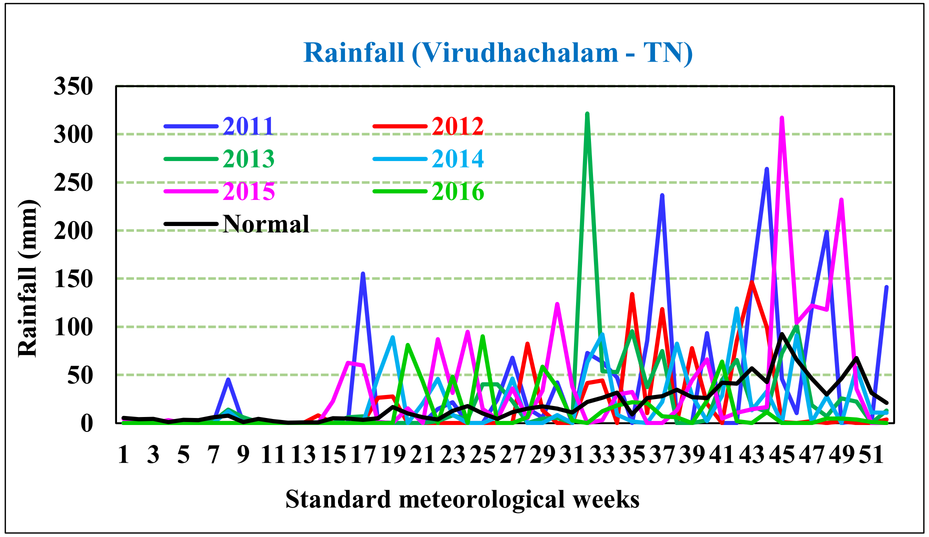
Annexure IX

Actual and 'normal' of temperature (maximum, minimum and mean) and rainfall at study locations of groundnut



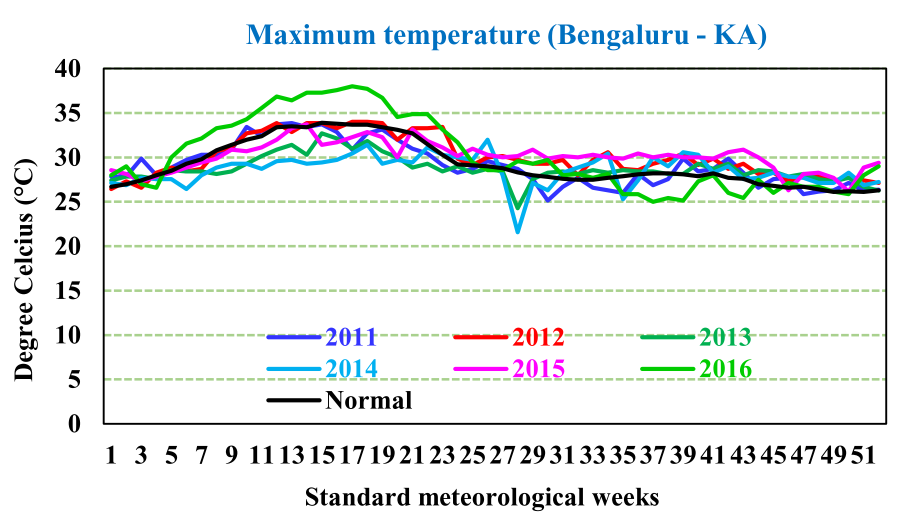


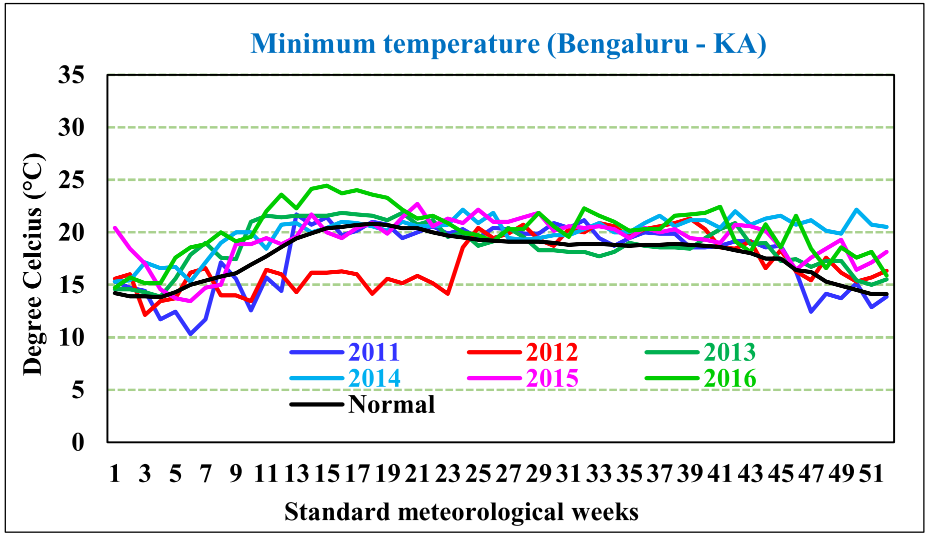


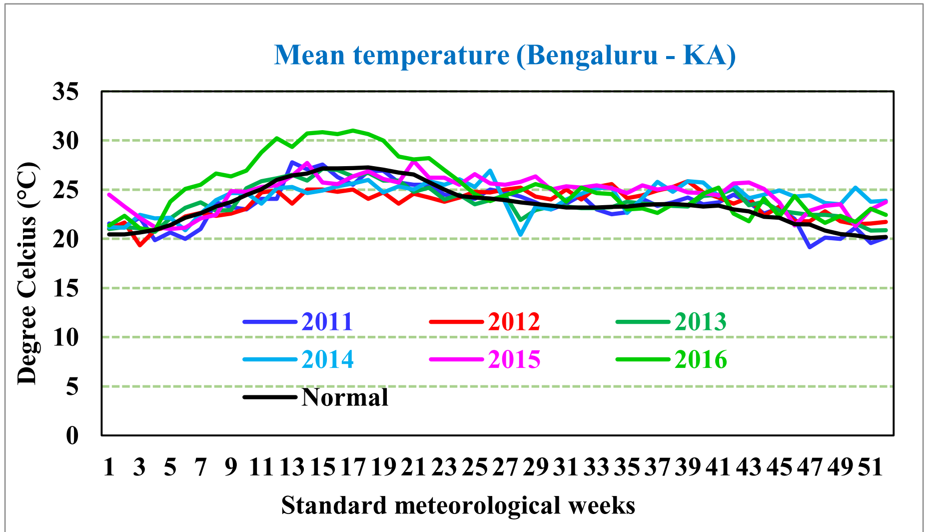


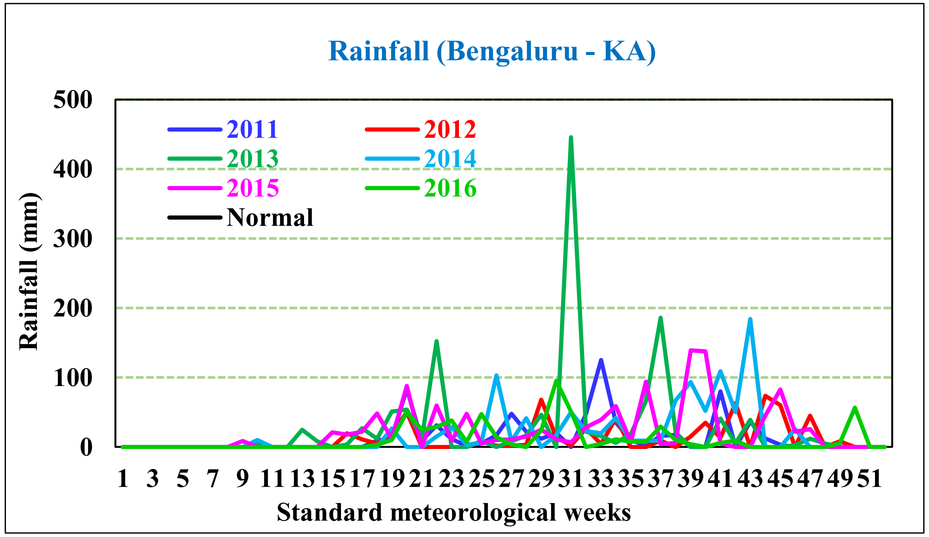
Annexure X

Actual and 'normal' of temperature (maximum, minimum and mean) and rainfall at study locations of tomato



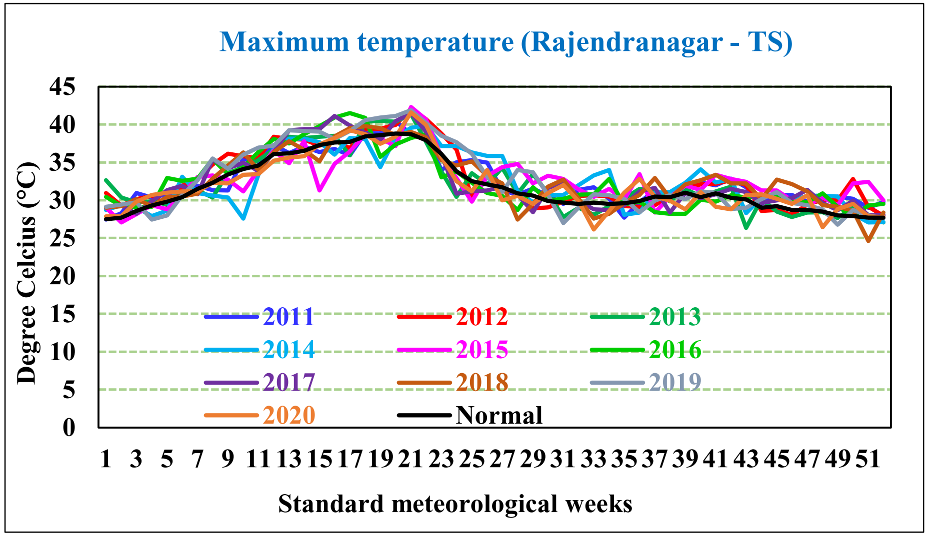


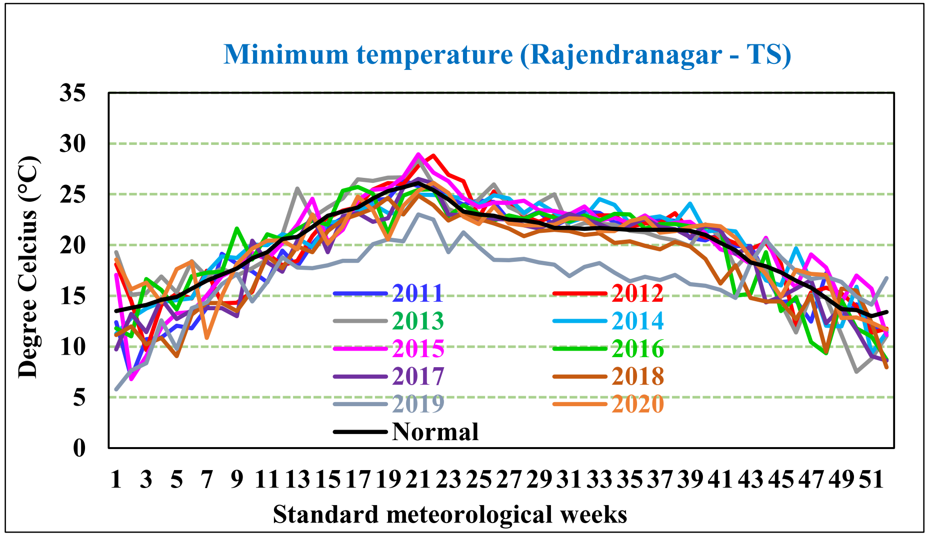


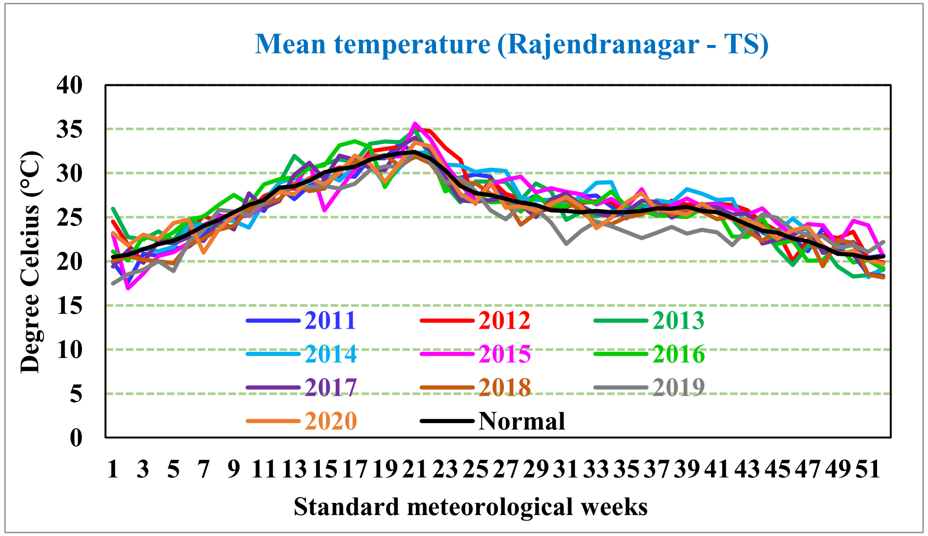


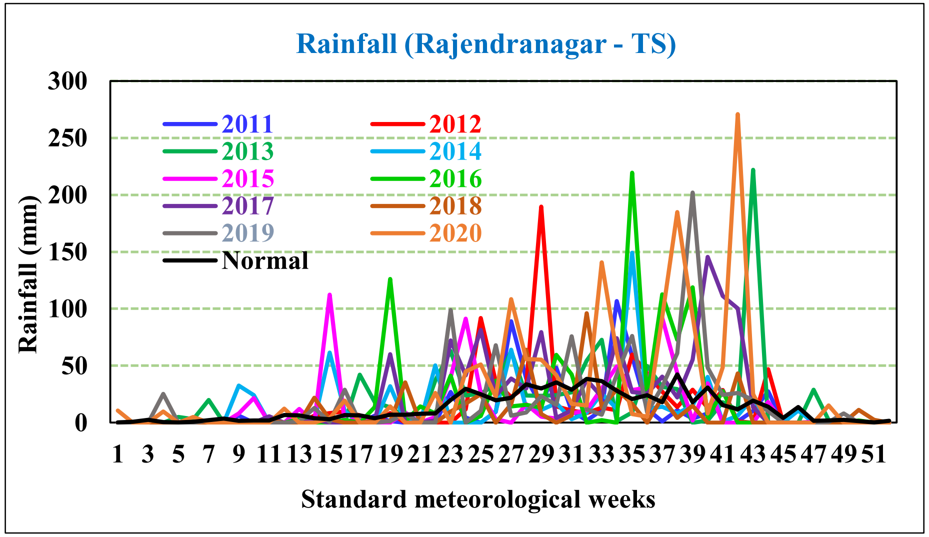
Annexure X

Actual and ‘normal’ of temperature (maximum, minimum and mean) and rainfall at study locations of tomato



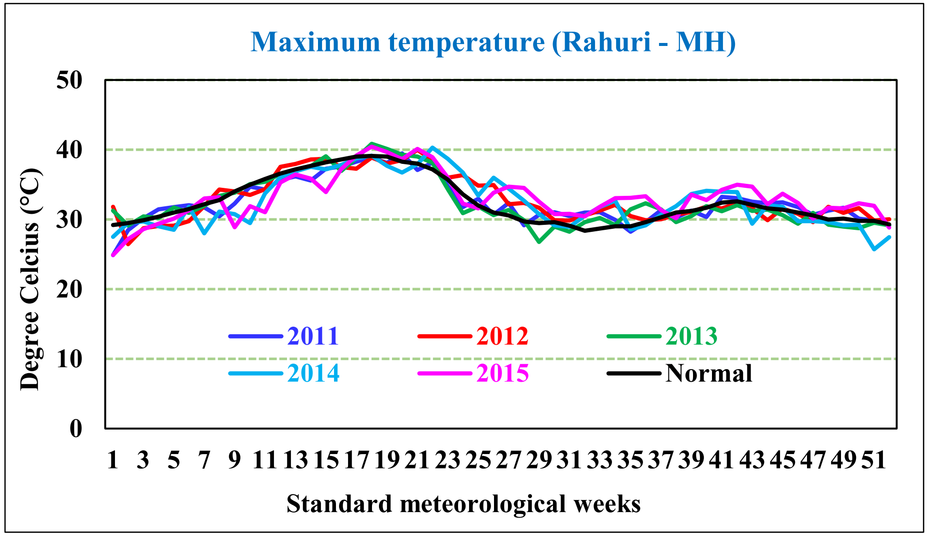


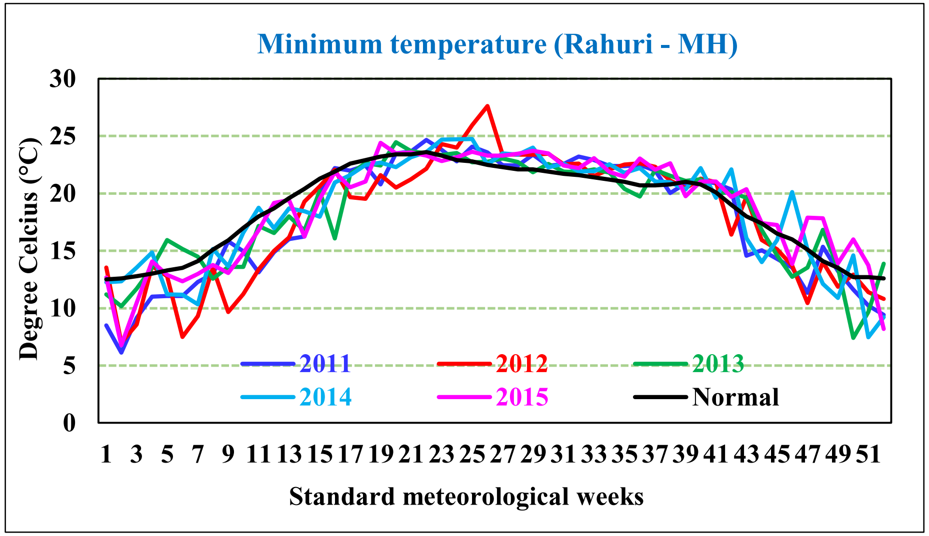


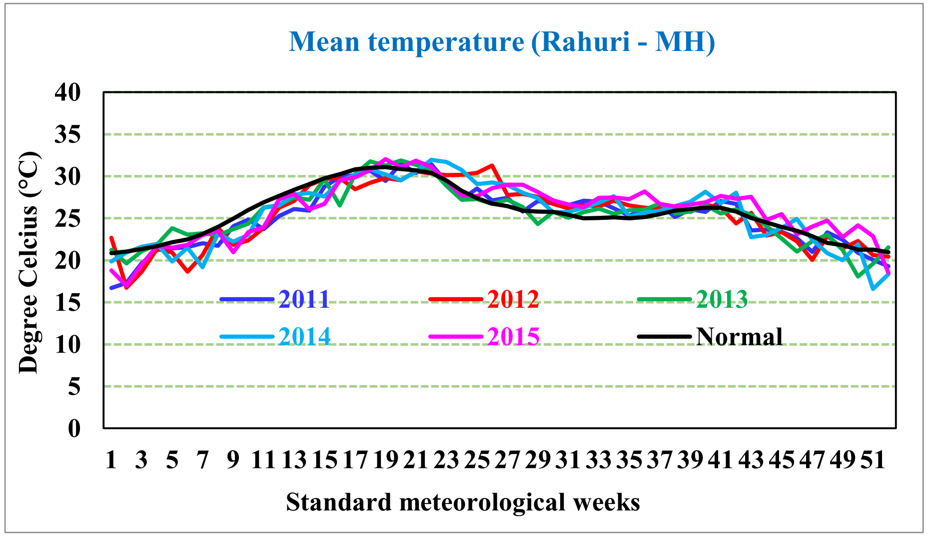


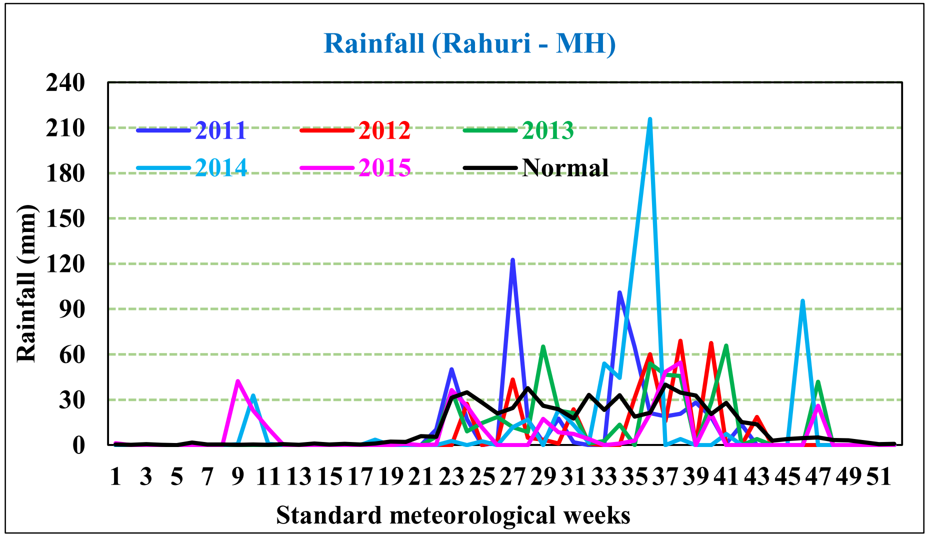
Annexure X

Actual and 'normal' of temperature (maximum, minimum and mean) and rainfall at study locations of tomato



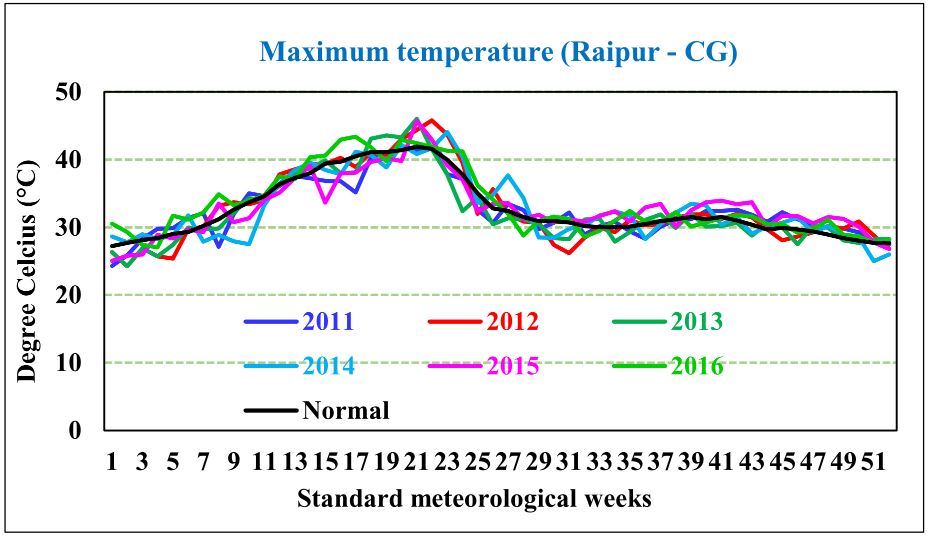


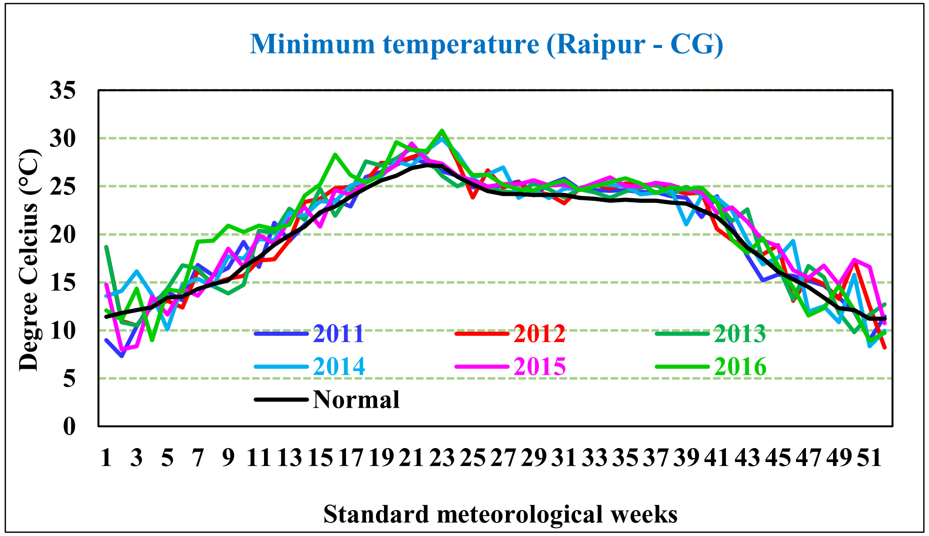


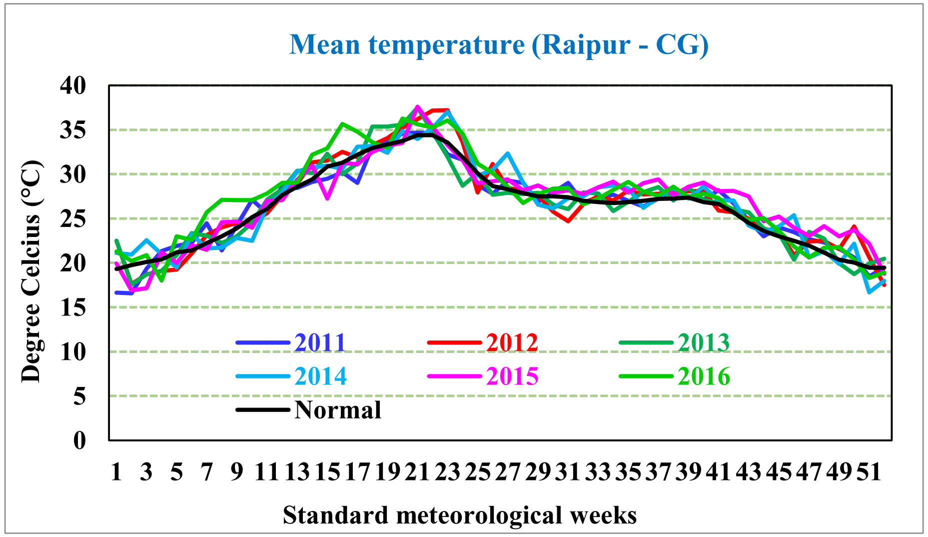


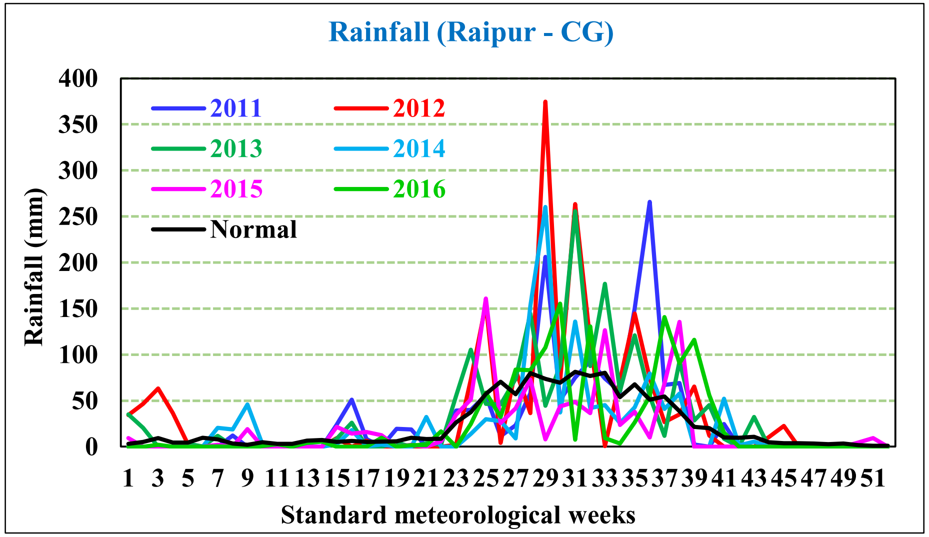
Annexure X

Actual and 'normal' of temperature (maximum, minimum and mean) and rainfall at study locations of tomato



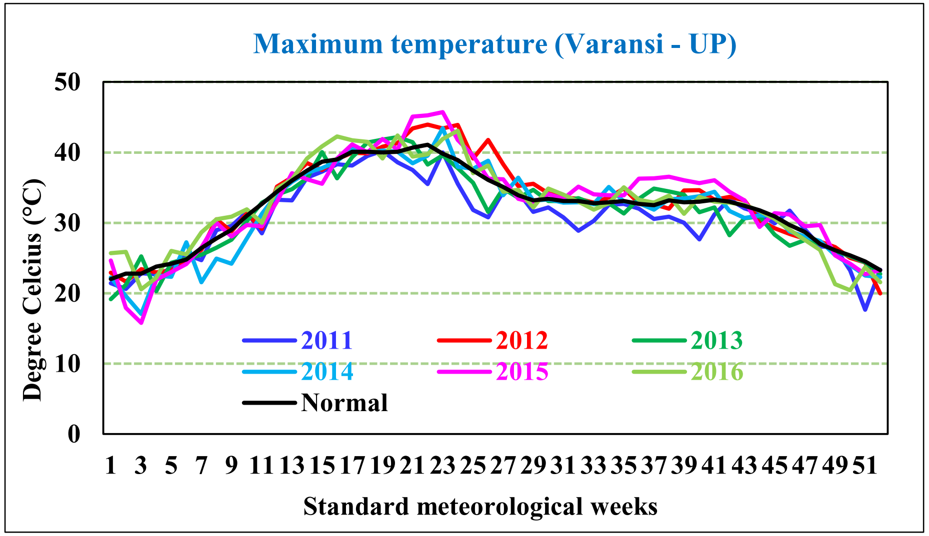


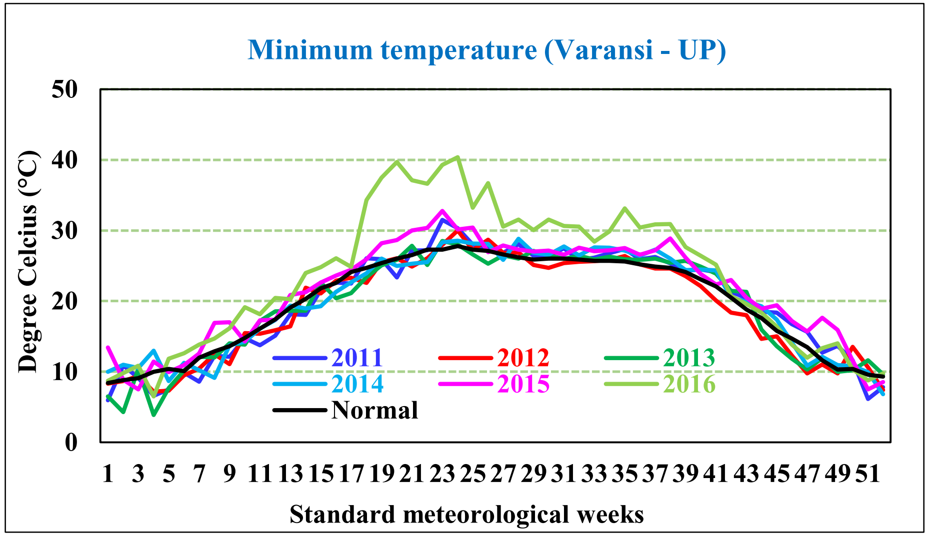


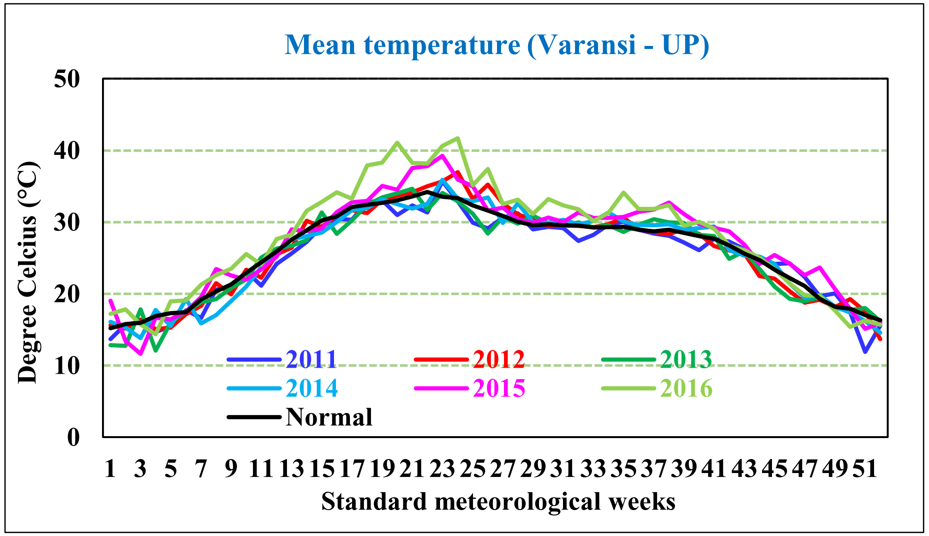


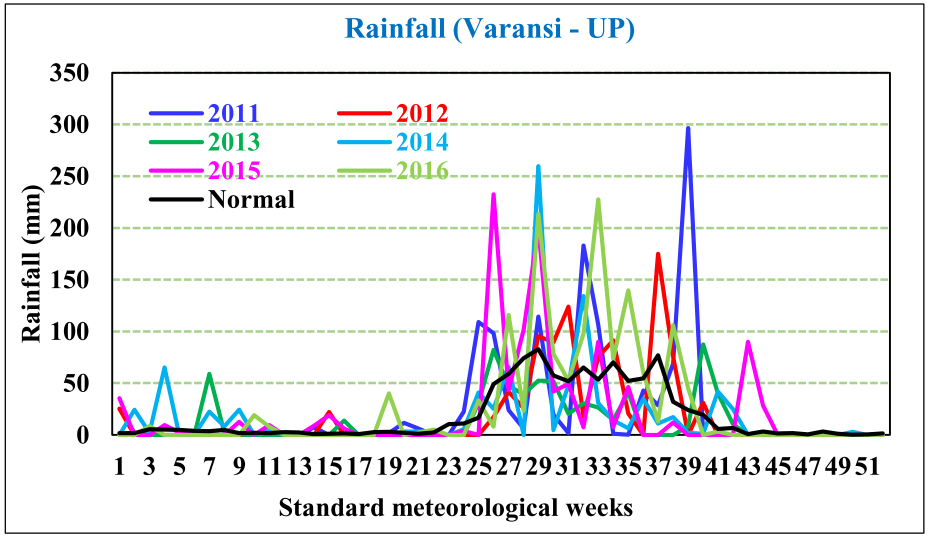
Annexure X

Actual and 'normal' of temperature (maximum, minimum and mean) and rainfall at study locations of tomato



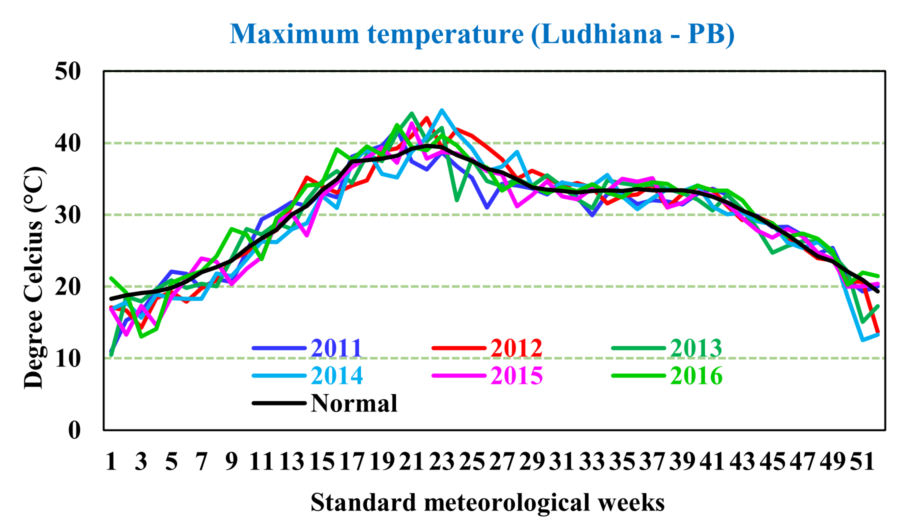


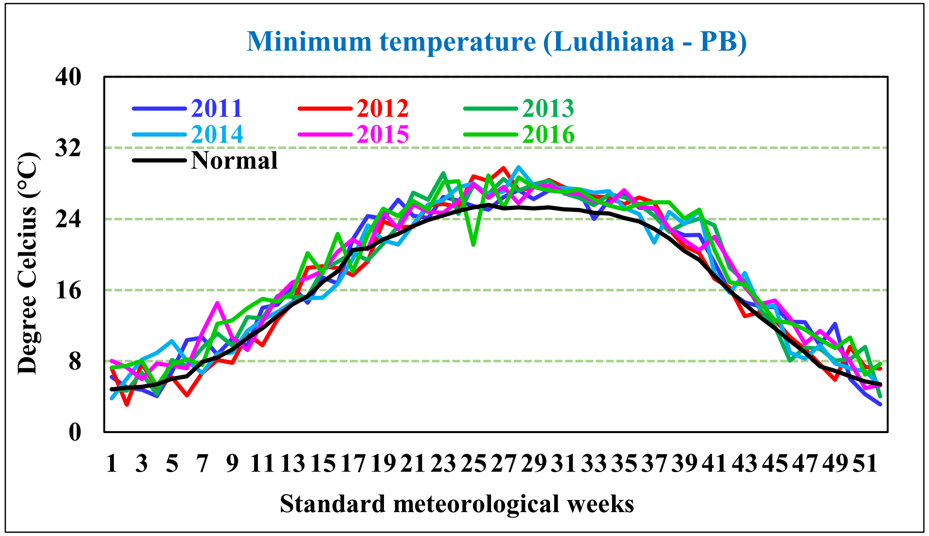


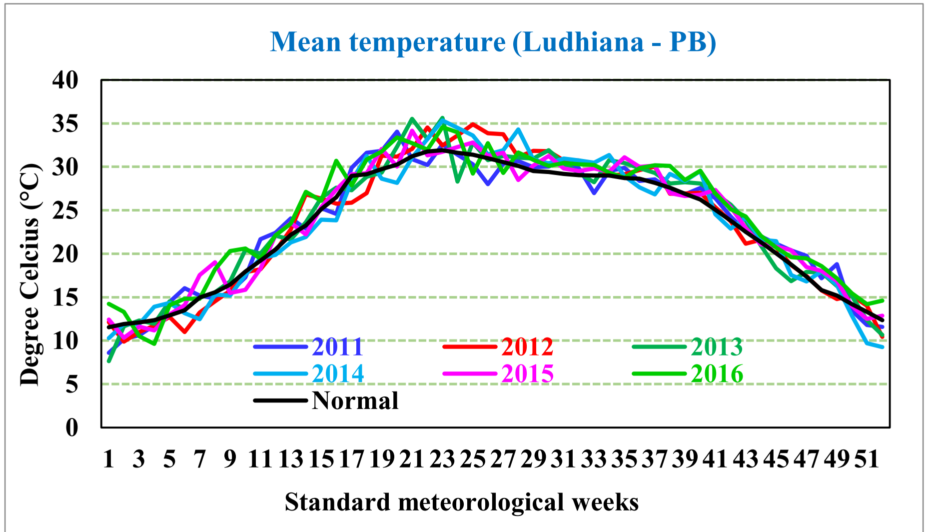


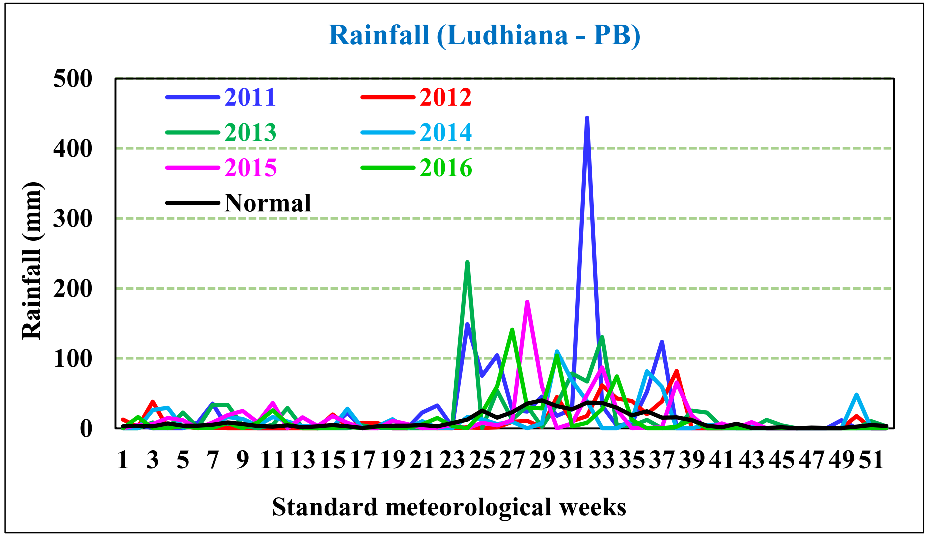
Annexure X

Actual and ‘normal’ of temperature (maximum, minimum and mean) and rainfall at study locations of tomato



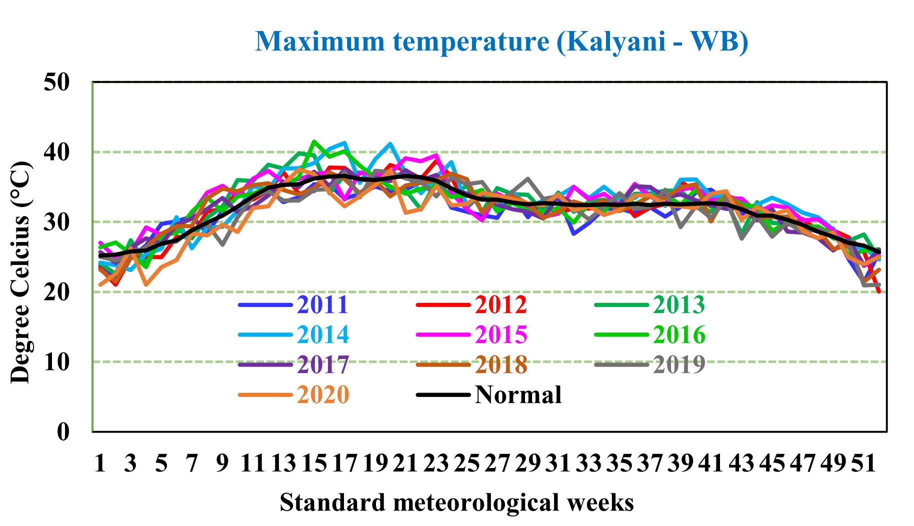


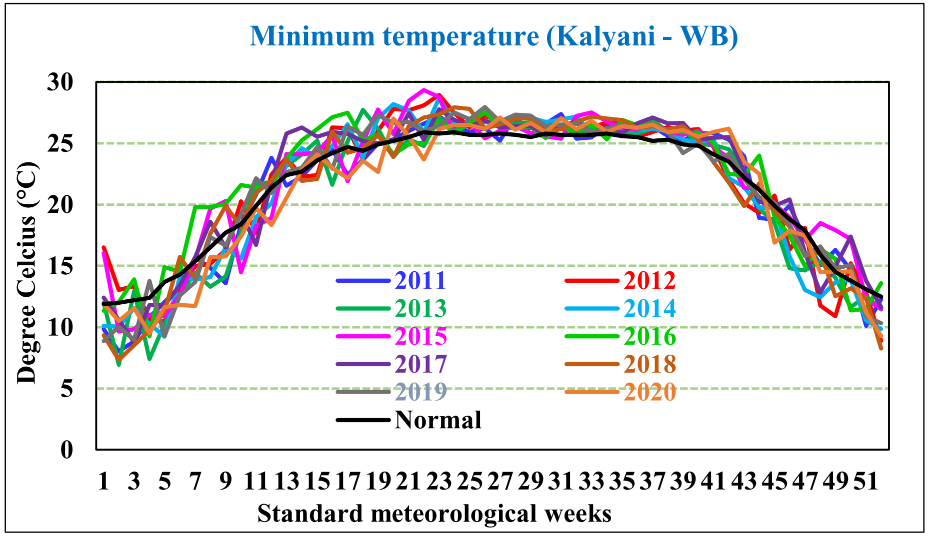


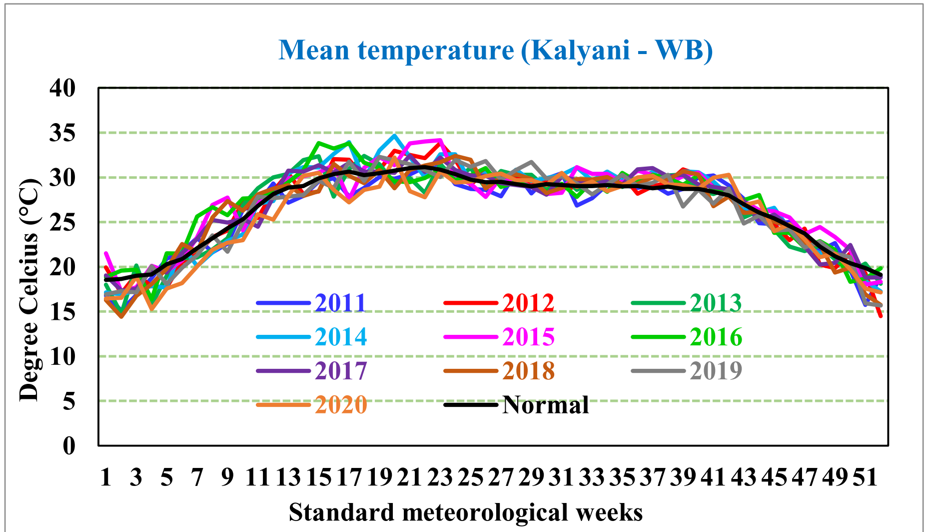


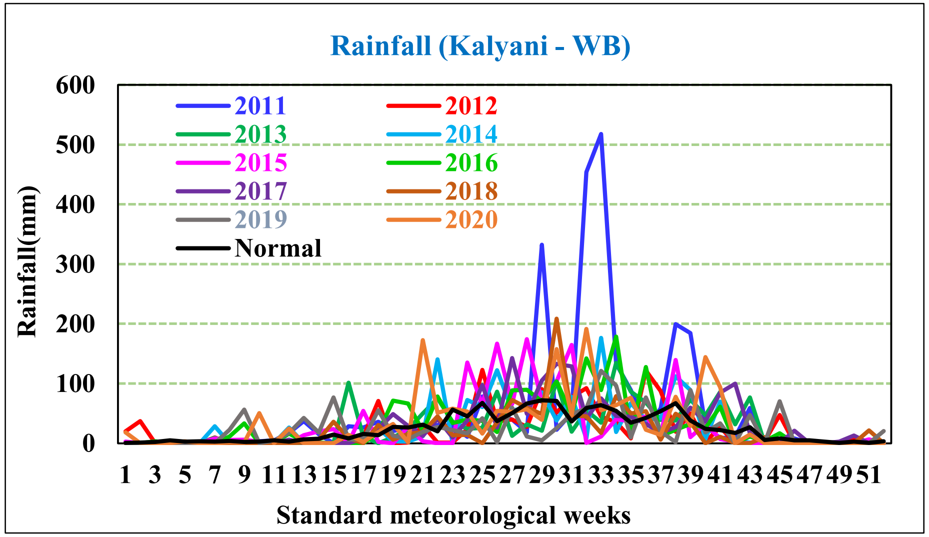
Annexure X

Actual and 'normal' of temperature (maximum, minimum and mean) and rainfall at study locations of tomato









Annexure XI

Scientific names of study insects and diseases covered under surveillance vis *a vis* their reporting units

Crop: Rice

S.No.	Common name	Scientific name	Reporting unit
INSECTS*			
1	Yellow stem borer	*Scirpophaga incertulas* (Walker)	% Dead heart or White ears
2	Pink stem borer	*Sesamia inferens* (Walker)	
3	White stem borer	*Scirpophaga innotata* (Walker)	
4	Dark headed borer	*Chilo polychrysus* (Meyrick)	
5	Striped stem borer	*Chilo suppressalis* (Meyrick)	
6	Swarming caterpillar	*Spodoptera mauritia* Boisdual	% Damaged leaves; No. of larvae/hill
7	Case worm	*Nymphula depunctalis* Stagnalis	% Damaged leaves
8	Rice horned caterpillar	*Melanitis leda ismene* Cramer	% Damaged leaves; No. of larvae/hill
9	Yellow hairy caterpillar	*Psalis pennatula* (Fabricius)	% Damaged leaves; No. of larvae/hill
10	Leaf folder	*Cnaphalocrocis medinalis* (Guenee)	% Damaged leaves
11	Gall midge	*Orseolia oryzae* Wood-Mason	% Silver shoots
12	Stink bug	*Oebalus pugnax* (Fabricius)	Nos./hill
13	Gundhi bug	*Leptocorisa acuta* (Thunberg)	Nos./hill
14	Black bug	*Scotinophora coaractata* Fabricius	Nos./hill
15	Blue beetle	*Leptisma pygmoea* Baly	Nos./hill
16	Hispa	*Dicladispa armigera* Olivier	Nos./hill
17	Leaf mite	*Olygonychus oryzae* (Hirst)	% Incidence
18	Panicle mite	*Steneotarsonemus spinkii* Smiley	% Incidence
19	Thrips	*Stenchaetothrips biformis* Bagnall	% Damaged leaves
20	Brown plant hopper	*Nilaparvata lugens* (Stal)	Nos./hill; % Damaged tillers; % Plant damage
21	White backed plant hopper	*Sogatella furcifera* (Horvath)	
22	Zig-zag leafhopper	*Recilia dorsalis (*Motschulsky*)*	
24	Green leafhopper	*Nephotettix virescens* (Distant); *N. nigropictus* (Distant)	Nos./hill
25	White leafhopper	*Cofana spectra* (Distant); *C. unimacultata* (Signoret)	Nos./hill
DISEASES			
1	Leaf blast	*Pyricularia oryzae* Cav.	% Severity
2	Sheath blight	*Rhizoctonia solani* Kühn	
3	Bacterial leaf blight	*Xanthomonas campestris* pv. *oryzae* (Ishiyama) Dye	
4	Brown spot	*Helminthosporium oryzae* (Breda de Haan)	
5	Sheath Rot	*Sarocladium oryzae* (Sawada)	
6	Bakanae	*Fusarium fujikuroi* Nirenberg; *F. moniliforme*	% damage
7	False smut	*Ustilaginoidea virens* (Cooke) Takah	

S.No.	Common name	Scientific name	Reporting unit
BENEFICIALS			
1	Lady bird beetles/ Coccinellids*	*Micraspis hirashimai* (Sasaji); *Harmonia octomaculata* (Fabricius); *Coccinella septempunctata* (Linnaeus)	Nos./hill
2	Web spinning spiders	*Tetragnatha*; *Argiope*; *Araenus*; *Oxyopes*	
3	Rove beetle*	*Paederus fuscipes* (Curtis)	
4	Ground beetle*	*Ophionea nigrofasciata* (Schmidt – Goebel)	
5	Wolf spider	*Pardosa pseudoannulata* (Boes. & Strand)	
6	Green mirid bugs*	*Cyrtorhinus lividipennis* (Reuter)	
* the reporting units for insect pests and beneficial insects mentioned in the table are for field level surveillance; when their catches in light trap are recorded the reporting units are total number of adult insects or beneficials/week/trap. *[https://ncipm.icar.gov.in/nicra2015/NICRAPDFs/Manuals/Manual%20for%20Rice%20Pest%20Surveillance.pdf]*			

Annexure XII

Scientific names of study insects and diseases covered under surveillance vis *a vis* their reporting units

Crop: Pigeonpea

S.No.	Common name	Scientific name	Reporting unit
INSECTS			
1	Leaf folder	*Grapholita (Cydla) critica* (Meyr)	Nos. larvae/plant
2	Pod borer	*Helicoverpa armigera* (Hubner)	
3	Lablab pod borer	*Adisura atkinsoni* (Moore)	
4	Blue butterfly	*Lampides boeticus* (Linn.)	
5	Plume moth	*Exelastis atomosa* (Walsingham)	
6	Legume (cowpea) pod borer	*Maruca testulalis* (Geyer)	% bud infestation
7	Blister beetle	*Mylabris spp*	Nos./plant
8	Ash/Grey weevil	*Myllocerus undecimpustulatus* (Faust)	
9	Cow bugs	*Otinotus oneratus* (Walker) *Oxyrachis tarandus* (Fabricius)	
10	Mealy bug	*Phenacoccus solenopsis (Tinsley);* *Paracoccus marginatus* (Williams & Granara de Willink)	% incidence & Severity grade
11	Scales	*Ceroplastodes cajani* (Maskell) *Icerya purchase* (Maskell)	
12	Pod sucking bugs	*Clavigralla gibbosa* (Spinola) *Clavigralla scutellaris* (Westwood)	Nos./plant
		Nezara viridula (Linn.)	
		Riptortus spp	
13	Podfly*	*Melanogromyza obtusa* (Malloch)	Nos./pod
14	Bruchids*	*Callosobruchus maculatus* (Fabricius)	
BENEFICIALS			
1	Coccinelids	*Coccinella magnifica* (Redtenbacher)	Nos./plant
2	Spiders	All groups of spiders	
DISEASES			
1	*Fusarium* Wilt	*Fusarium udum* (Butler)	% Incidence
2	*Phytophthora* Blight	*Phytophthora drechsleri* Tucker *f. sp. cajani*	
3	Sterility mosaic	Viral disease transmitted by eriophyid mite *Aceria cajani* Channabasavanna	
4	Yellow mosaic	Transmitted by whiteflies	
5	Phyllody	Mycoplasma - like organism	
6	*Macrophomina* stem canker	*Macrophomina phaseolina* (Tassi) Goid)	
7	*Alternaria* blight	*Alternaria alternata (Fr.)* Keissl	% Severity
8	Powdery mildew	*Leveillula taurica (Lév.)* G. Arnaud	
9	*Cercospora* leaf spot	*Cercospora cajani* Hennings; *Cercospora spp.*	

* Based on destructive sampling of pods.
[https://ncipm.icar.gov.in/nicra2015/NICRAPDFs/Manuals/Manual%20for%20Pigeonpea%20Pest%20Surveillance.pdf]

Annexure XIII

Scientific names of study insects and diseases covered under surveillance vis *a vis* their reporting units

Crop: Groundnut

S.No.	Common name	Scientific name	Reporting unit
INSECTS			
1	Aphid	*Aphis craccivora* (Koch)	% plant infestation; Severity grade
2	Thrips	*Scirtothrips dorsalis* (Hood), *Thrips palmi* (Karny)	Nos./3 leaves/plant; % plant infestation
3	Jassid	*Empoasca kerri* (Pruthi), *Bachlucha spp*	Nos./3leaves/plant ; % plant infestation
4	Leaf miner	*Aproaerema modicella* (Deventer)	No. of mines with larvae/plant; % plant infestation
5	Tobacco caterpillar	*Spodoptera litura* (Fabricius)	Nos. egg mass & gregarious larvae/plant; Nos. solitary larvae/plant; % plant infestation
6	Red hairy caterpillar	*Amsacta albistriga* (Walker); *A. moorei* (Butler)	Nos. larvae/plant
7	Semilooper	*Plusia orichalcea* (Fabricius)	
8	Defoliator (Heliothis)	*Helicoverpa armigera* (Hubner)	
BENEFICIALS			
1	Coccinelids	*Coccinella magnifica* (Redtenbacher)	Nos./plant
2	Spiders	All groups of spiders	
DISEASES			
1	Collar rot	*Aspergillus niger* (van Tieghem)	% Incidence
2	Stem rot	*Sclerotium rolfsii* (Saccardo)	
3	Dry root rot	*Macrophomina phaseolina* (Tassi) Goid	
4	Peanut bud necrosis disease (PBND)	*Tospo virus* transmitted by *Thrips palmi* Karny	
5	Peanut stem necrosis disease (PSND)	*Frankliniella schultzei ; Scirtothrips dorsalis ; Megalurothrips usitatus*	
6	Peanut mottle virus	Transmitted by aphids	
7	Peanut clump virus	Transmitted by the obligate fungal parasite *(Polymyxa graminis)*	
8	Early leaf spot	*Cercospora arachidicola* (Hori)	% Severity
9	Late leaf spot	*Phaeoisariopsis personata (Berkeley & Curtis)*	
10	Rust	*Puccinia arachidis* (Spegazzini)	
11	*Alternaria* leaf spot	*Alternaria alternata* (Fr.) Keissl; *A. arachidis* (Kulk) & *A. tenuissima (Kunze)* Wiltshire	
[https://ncipm.icar.gov.in/nicra2015/NICRAPDFs/Manuals/Manual%20for%20Groundnut%20Pest%20Surveillance.pdf]			

Annexure XIV

Scientific names of study insects and diseases covered under surveillance vis *a vis* their reporting units

Crop: Tomato

S.No.	Common name	Scientific name	Reporting unit
INSECTS			
1	Aphids	*Myzus persicae* (Sulzer) & *Aphis gossypii* (Glover)	Nos./5leaves/plant
2	Whiteflies	*Bemisia tabaci* (Gennadius)	
3	Thrips	*Thrips tabacii* (Lindeman), *Frankliniella schultzei* (Trybom)	
4	Leaf miner	*Liriomyza trifolii* (Burgess)	
5	Mites	*Tetranychus spp.*	
6	Tobacco caterpillar	*Spodoptera litura* (Fabricius)	Nos./plant
7	Mealybugs	*Maconellicoccus hirsutus* (Green); *Phenacoccus solenopsis* (Tinsley)	Severity grade
8	Fruit borer	*Helicoverpa armigera* (Hübner)	No.of larvae/plant; % fruit damage
BENEFICIALS			
1	Coccinelids	*Scymnus* sp., *Cheilomenes* sp. *and Illeis* sp. *Coccinella* sp.	Nos./plant
2	Spiders	All groups of spiders	
DISEASES			
1	Damping off	*Pythium aphanidermatum* (Edson) Fitzp	
2	Seedling blight		
3	Tomato Leaf Curl Virus		% Incidence
4	Bud blight	Groundnut Bud Necrosis Virus	
5	Tomato mosaic	TMV, ToMV, PVY, CMV	
6	Cucumo virus	CMV	
7	*Fusarium* wilt	*Fusarium oxysporum f.sp. lycopersici* (Fol)	
8	*Ralstonia* wilt	*Ralstonia solanacearum* (Smith)	
9	*Sclerotium* wilt	*Sclerotium rolfsii* (Saccardo)	
10	Early blight	*Alternaria solani* (Sorauer)	% Severity
11	Powdery mildew	*Oidium neolycopersici* (L. Kiss)	
12	*Septoria* leaf spot	*Septoria lycopersici* (Speg)	
13	Bacterial canker	*Clavibacter michiganensis* subsp. *michiganensis*	% Incidence
14	Late blight	*Phytophthora infestans* (Mont.) de Bary	
15	Buckeye rot	*Phytophthora nicotianae* var. *parasitica*	
16	Early blight	*Alternaria solani* (Sorauer)	
17	Bacterial spot	*Xanthomonas vesicatoria* (Doidge) Stevens	% Severity
18	Sun scald	*Xanthomonas albilineansi* (Ashby) Dowson	% Incidence
[https://ncipm.icar.gov.in/nicra2015/NICRAPDFs/Manuals/Manual%20for%20Tomato%20Pest%20Surveillance.pdf]			

Annexure XV

Assessment of impact of climate change: frequency of study insects in respect of locations

Crop: Rice

Location	*Kharif*	*Rabi*	*Summer*
Aduthurai (TN)	6	6	6
Chinsurah (WB)	6	-	6
Karjat (MH)	3	3	-
Kampasagar (TS)	8	8	-
Ludhiana (PB)	6	-	-
Mandya (KA)	3	-	3
Raipur (CG)	6	-	-
Insect abundance in light traps alone were considered			

Crop: Pigeonpea

Location	Insect	Disease
Anantapur (AP)	6	6
Gulbarga (KA)	6	8
Rahuri (MH)	5	2
Jabalpur (MP)	5	2
SK Nagar (GJ)	6	3
Vamban (TN)	5	5
Warangal (TS)	6	4

Crop: Groundnut

Location	Insect	Disease
Junagadh (GJ)	10	6
Jalgaon (MH)	10	8
Dharwad (KA)	8	4
Kadiri (AP)	6	8
Virudhachalam (TN)	10	5

Crop: Tomato

Location	*Kharif*		*Rabi*	
	Insect	Disease	Insect	Disease
Bengaluru (KA)	5	4	8	4
Rajendranagar (TS)	5	3	9	7
Rahuri (MH)	9	7	10	7
Raipur (CG)	7	12	7	7
Varanasi (UP)	8	9	8	9
Ludhiana (PB)	4	3	-	-
Kalyani (WB)	-	-	11	5

Annexure XVI

Assessment of impact of climate change: study insects *vis a vis* seasons

Crop: Rice

Kharif	*Rabi*	*Summer*
Black bug [TN]	Black bug [TN]	Black bug [TN]
Brown plant hopper [PB,TN,WB,CG,TS]	Brown plant hopper [TN, TS]	Brown plant hopper [TN, WB]
Caseworm [CG]	Coccinellid [TS]	Green leaf hopper [TN, WB, KA]
Coccinellid [TS]	Gall midge [TS]	Leaf folder [TN,WB]
Gall midge [CG, TS]	Green leaf hopper [TS, TN, MH]	White backed plant hopper [WB]
Green leaf hopper [MH,TN, WB, CG, KA,TS]	Green mirid bug [TS]	White leaf hopper [TN,WB]
Green mirid bug [TS]	Leaf folder [TN, MH,TS]	Yellow stem borer [TN, KA,WB]
Leaf folder [MH, TN,PB,WB,CG,TS]	White backed plant hopper [TS]	White stem borer [KA]
Pink stem borer [PB]	White leaf hopper [TN]	
White backed plant hopper [PB,WB, TS]	Yellow stem borer [TS, TN, MH]	
White leaf hopper [TN,WB]		
White stem borer [KA,PB]		
Yellow stem borer [MH,TN, PB,WB, KA, CG,TS]		
Insect names are arranged alphabetically; Superscripts indicate the states of occurrence: CG: Raipur; KA: Karnataka; MH: Maharashtra; PB: Punjab; TS: Telangana; WB: West Bengal		

Crop: Pigeonpea

Insect	Disease
Jassids [AP,KA,GJ,TS]	*Alternaria* blight [TN,KA]
Leaf folder [KA,TN,MP,GJ,MH,TS,AP]	*Cercospora* leaf spot [AP, KA,TN]
Legume pod borer (*Maruca vitrata*) [TN, KA,MP,GJ,TS,MH,AP]	*Fusarium* wilt [GJ,TN,TS,AP,KA,MP,MH]
Pod borer (*H. armigera*) [GJ, TN, KA, TS,MH, MP,AP]	*Macrophomina* stem canker [TS, KA,AP]
Pod sucking bug (*Clavigralla*) [KA,TS,GJ,TN,MH,MP,AP]	Phyllody [KA]
Spiders [GJ,KA,TN,MP,TS,MH,AP]	*Phyphthora* blight [MP, GJ, KA,AP]
	Powdery mildew [TS,TN, KA,AP]
	Sterility mosaic disease [TN,TS,MH, KA,GJ,AP]
Insect and diseases are listed alphabetically; Superscripts indicate the states of occurrence: GJ: Gujarat; KA: Karnataka; MH: Maharashtra; MP: Madhya Pradesh; TS: Telangana; TN: Tamil Nadu	

Crop: Groundnut

Insect	Disease
Aphid infestation [TN,MH,GJ]	*Alternaria* leaf spot [KA,GJ,MH,TN]
Aphid severity [GJ]	Collar rot [AP, GJ, MH, TN]
Jassid abundance [KA,AP,TN,GJ,MH]	Dry root rot [MH,AP,TN]
Jassid infestation [KA,TN,AP,GJ, MH]	Early leaf spot [GJ,MH,KA,AP]
Leaf miner abundance [MH,KA,AP,GJ,TN]	Late leaf spot [KA,GJ,AP,MH]
Leaf minor damage [TN,KA,GJ,MH,AP]	PBND [AP,MH]
Spodoptera abundance [TN,KA,MH,GJ]	PSND [TN,MH,GJ]
Spodoptera damage [TN,KA,MH,GJ]	Rust [KA,MH,AP,TN,GJ]
Thrips abundance [TN,AP,MH,GJ]	Stem rot [GJ,MH,AP,TN]
Thrips damage [KA,TN,AP, MH,GJ]	
Insect and diseases are arranged alphabetically; Superscripts indicate the states of occurrence: Junagadh (GJ); Jalgaon (MH); Dharwad (KA); Kadiri (AP); Virudhachalam (TN)	

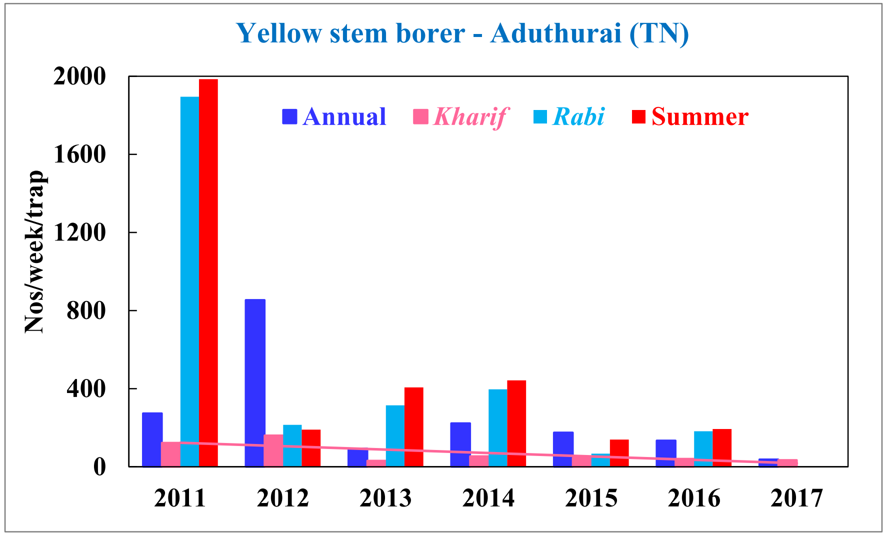
Crop: Tomato

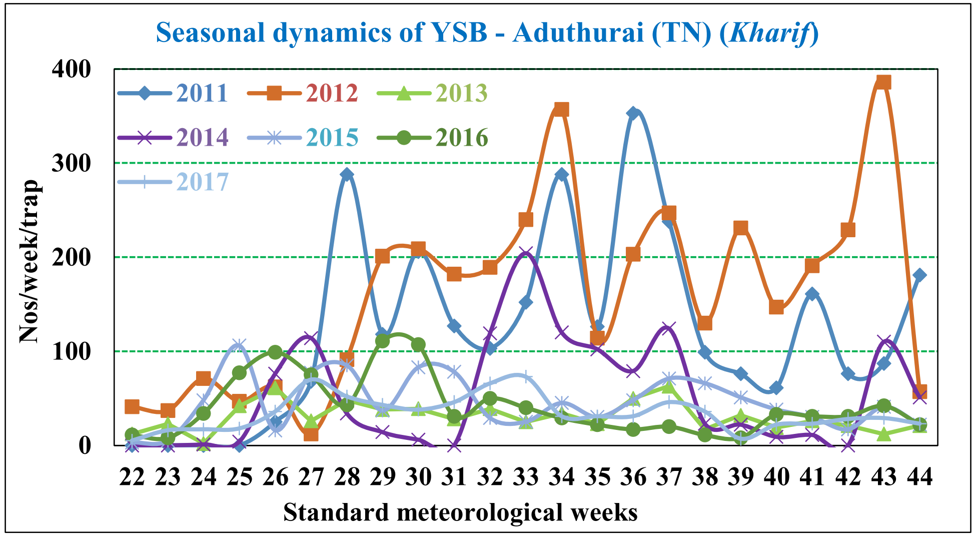
Kharif	
Insect	**Disease**
Aphids [CG, PB,UP,TS,KA,MH]	Bacterial canker – incidence [TS,CG]
Coccinellids [MH]	Bacterial canker – severity [CG, MH]
H. armigera – larval population [MH,TS,CG]	Bacterial spot - severity [CG,KA,UP,MH]
H. armigera - fruit damage [MH,PB,UP,CG]	Bacterial spot-incidence [CG]
Leaf miner [CG,UP,KA,PB,MH]	Bud blight [TS,CG]
Mealybug [UP]	Cucumo virus [MH]
Mites [TS,MH,CG,KA]	Early blight - incidence [PB]
Spiders [CG,KA,UP,TS,MH]	Early blight - severity [CG,KA,TS,UP,MH]
Spodoptera litura [UP]	*Fusarium* wilt [UP]
Thrips [UP,MH]	Late blight – incidence [PB]
Whiteflies [TS,KA,UP,PB,CG,MH]	Late blight – severity [PB,CG,UP]
	Powdery mildew [KA,MH]
	Ralstonia wilt [UP,CG]
	Sclerotium wilt [UP]
	Septoria leaf spot [CG,UP]
	Sun scald [CG]
	Tomato leaf curl [CG,KA,UP,MH]
	Tomato mosaic [UP,MH,CG]
Rabi	
Aphids [WB,UP,KA,MH,CG,TS]	Bacterial canker – incidence[TS]
Coccinellids [MH,WB]	Bacterial canker – severity[MH]
H. armigera - larval population [TS,KA,WB, CG,UP,MH]	Bacterial spot – severity [TS,MH,UP]
H. armigera -fruit damage [TS, CG, WB,KA,UP,MH]	Bacterial spot – incidence[TS]
Leaf miner [KA,WB,CG,MH,TS,UP]	Bud blight [CG, TS]
Mealybugs - severity [WB]	Cucumo virus [MH]
Mites [WB,MH, KA,TS]	Early blight - severity [WB,CG,KA,MH,TS,UP]
Spiders [CG,UP,WB,MH,KA,TS]	Late blight – incidence [UP,CG]
Spodoptera litura [KA,UP,MH,CG,WB,TS]	Late blight – severity [KA,UP]
Thrips [WB,MH,TS,UP]	Powdery mildew [MH,CG]
Whiteflies [WB,KA,CG,TS,MH,UP]	*Ralstonia* wilt [UP,WB]
	Sclerotium wilt [WB,UP]
	Septoria leaf spot [KA,UP, CG]
	Tomato leaf curl [WB,CG,MH,KA,UP,TS]
	Tomato mosaic [TS,CG,WB,MH,UP]

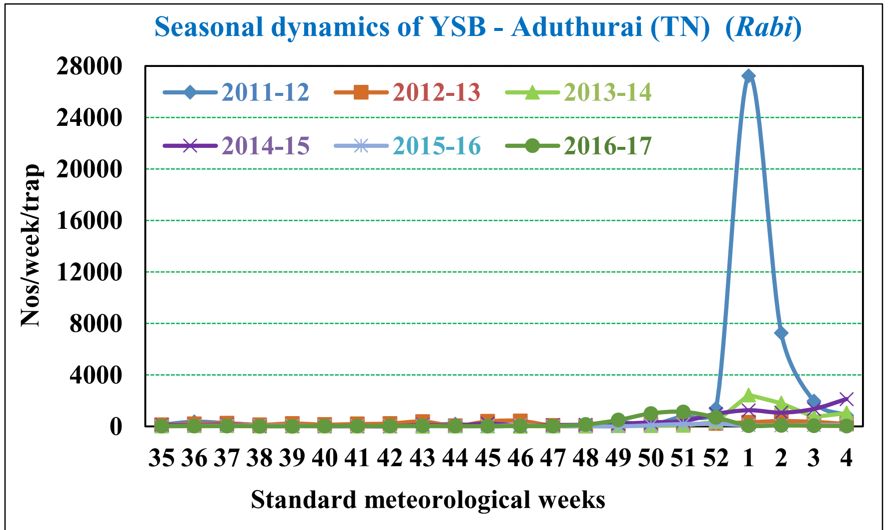
Insect and diseases are arranged alphabetically; Superscripts indicate the states of occurrence: CG: Chhattisgarh; KA: Karnataka; MH: Maharashtra; PB: Punjab; TS: Telangana; UP: Uttar Pradesh; WB: West Bengal

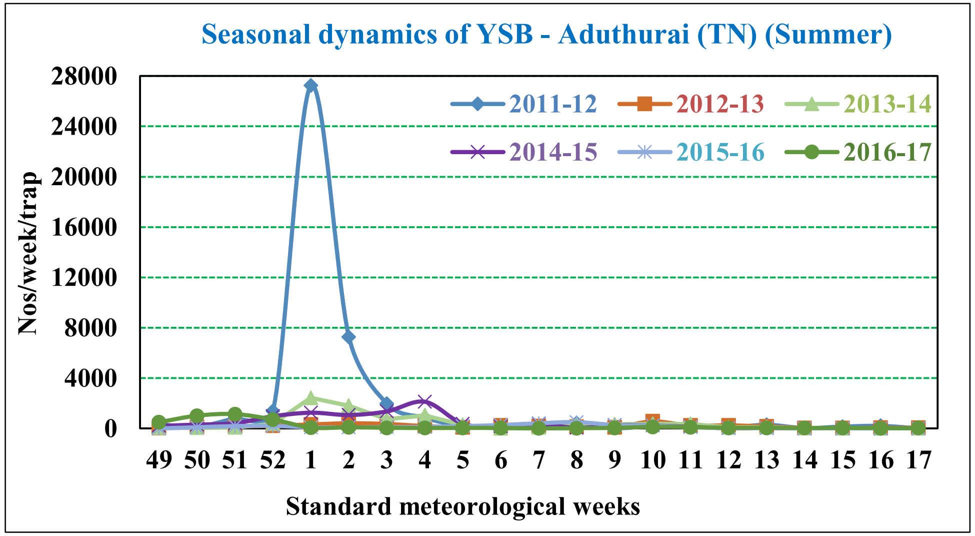
Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations
[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations

1. Yellow stem borer
Aduthurai (TN)





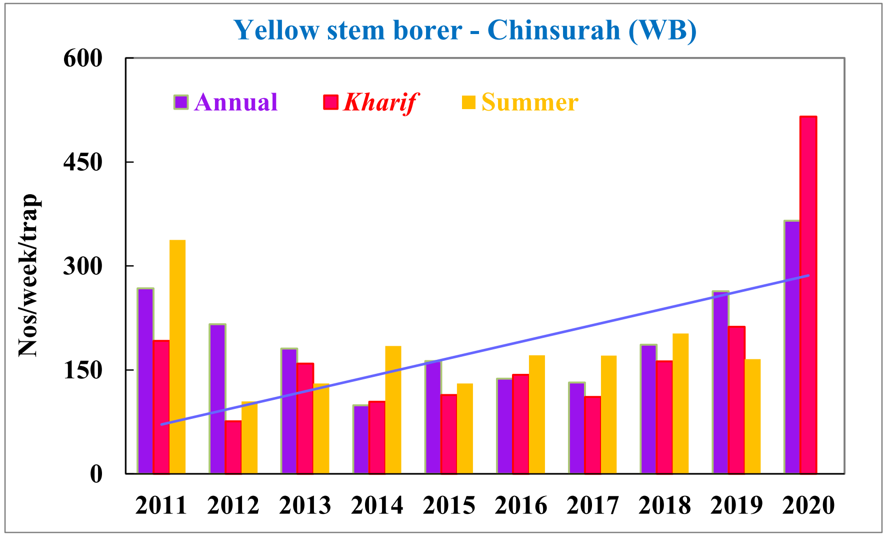


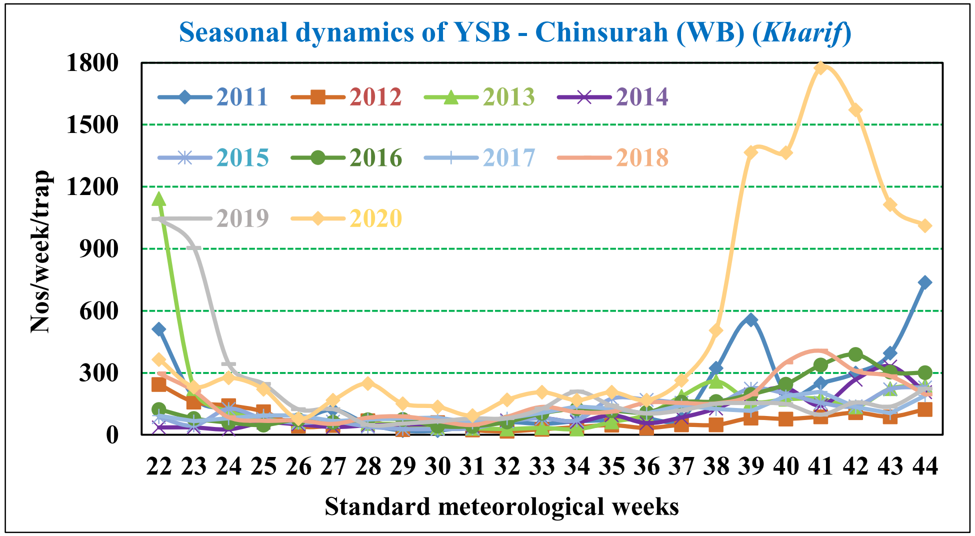


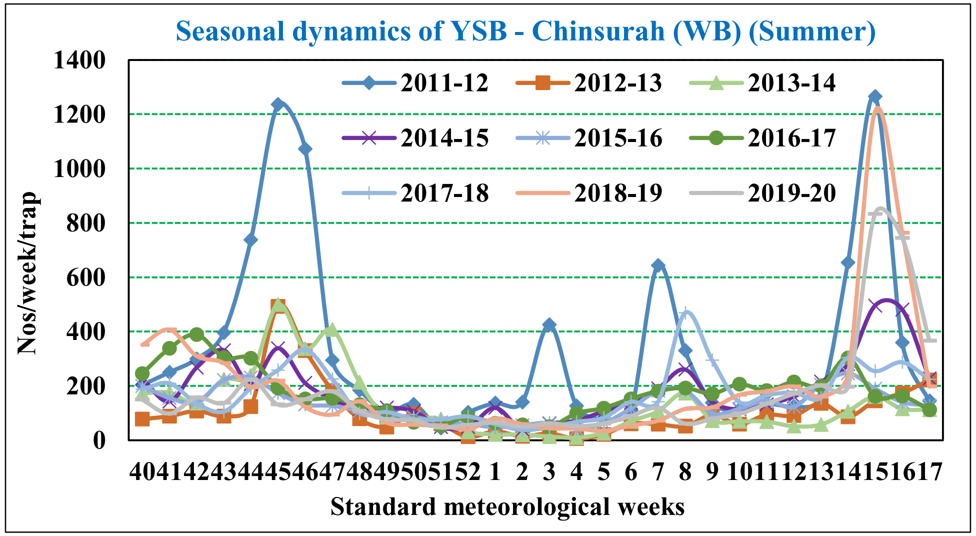
Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations

Chinsurah (WB)

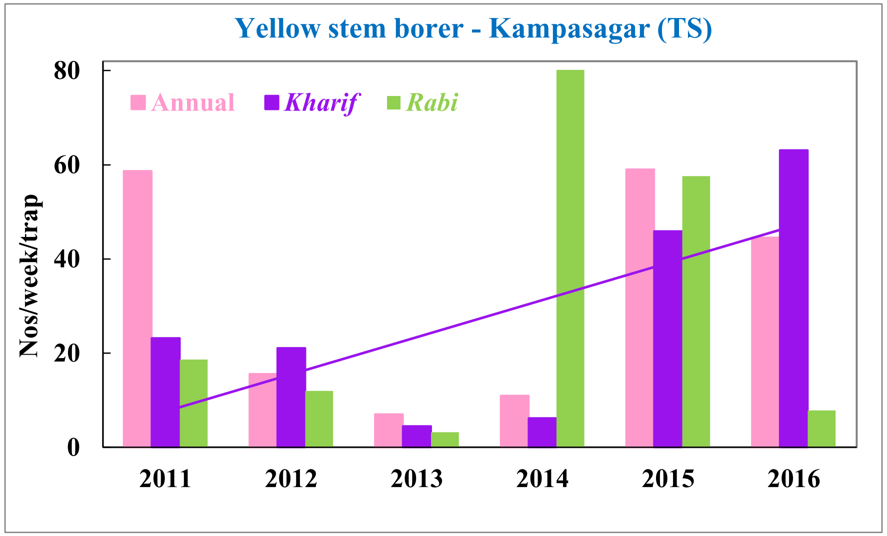


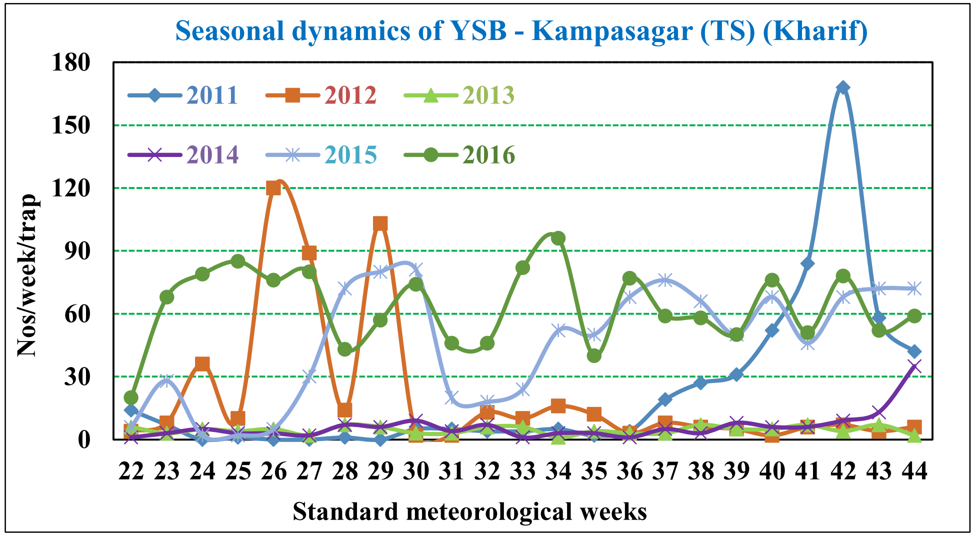


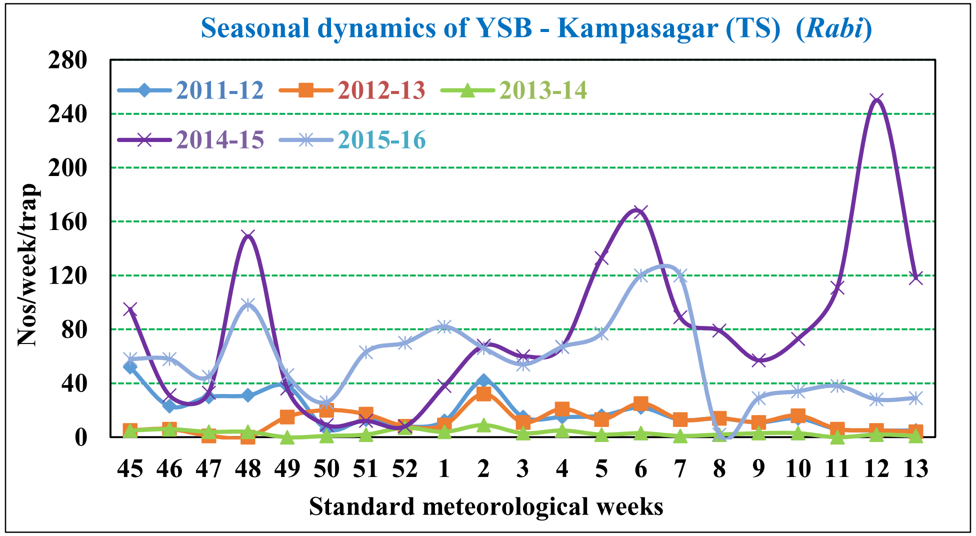


Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations
[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations

Kampasagar (TS)



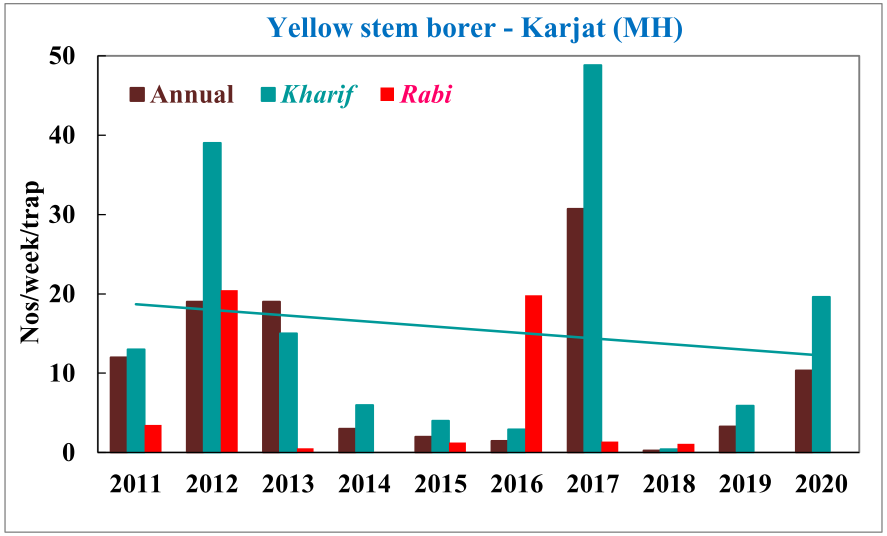


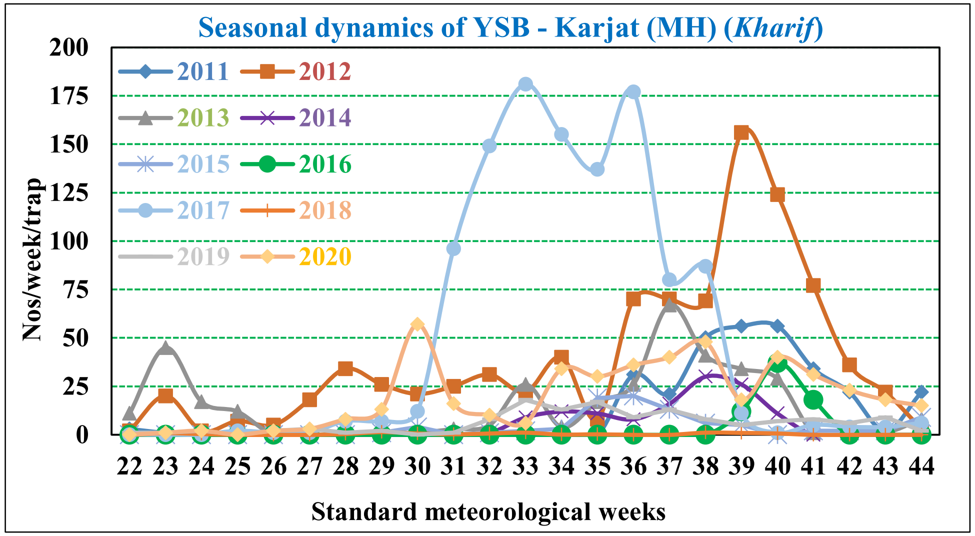


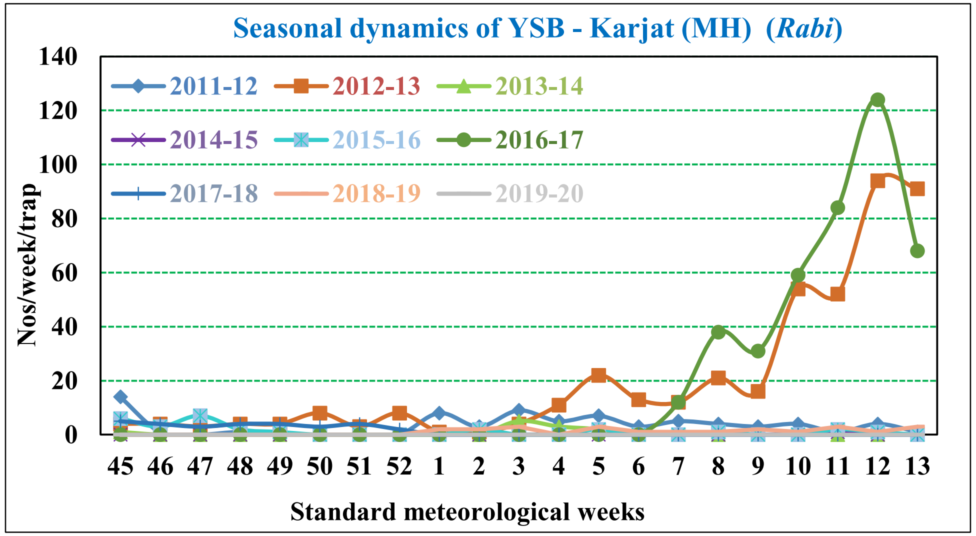
Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations

Karjat (MH)



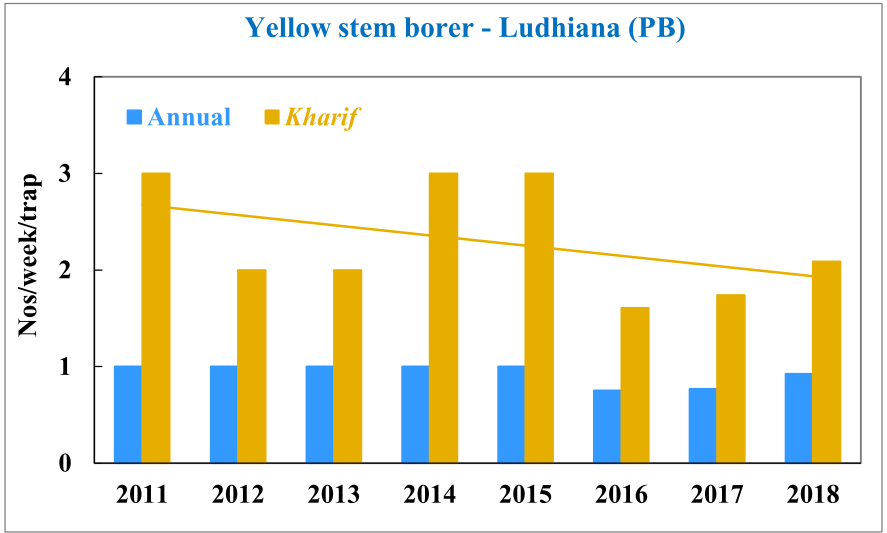


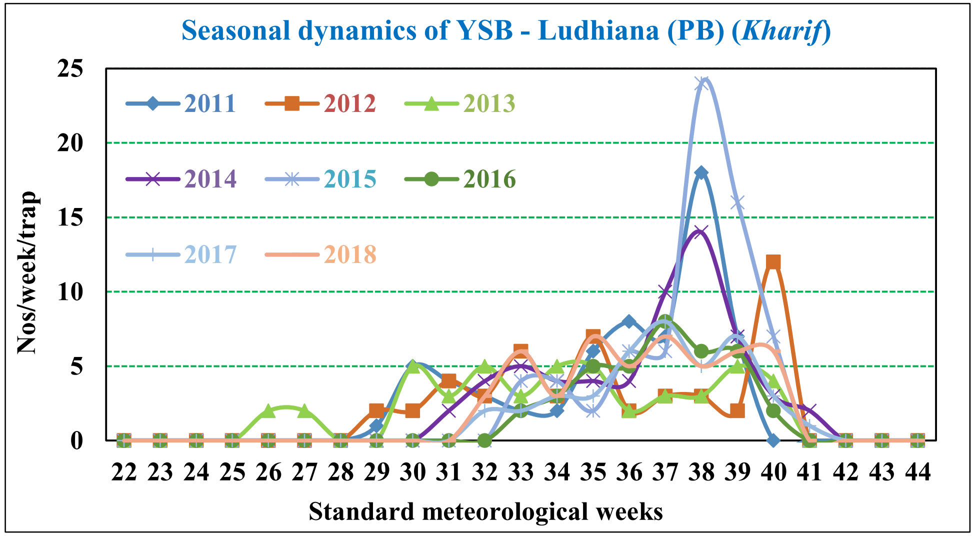


Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

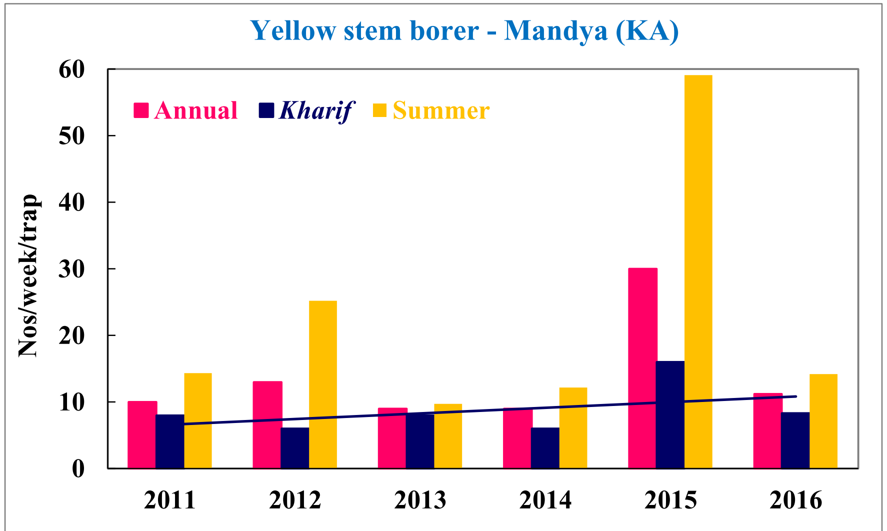
[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations

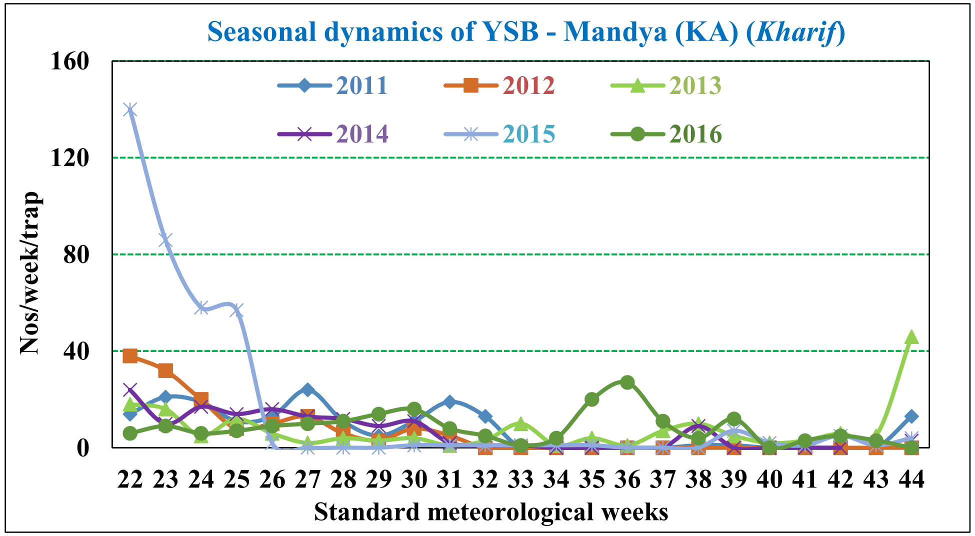
Ludhiana (PB)





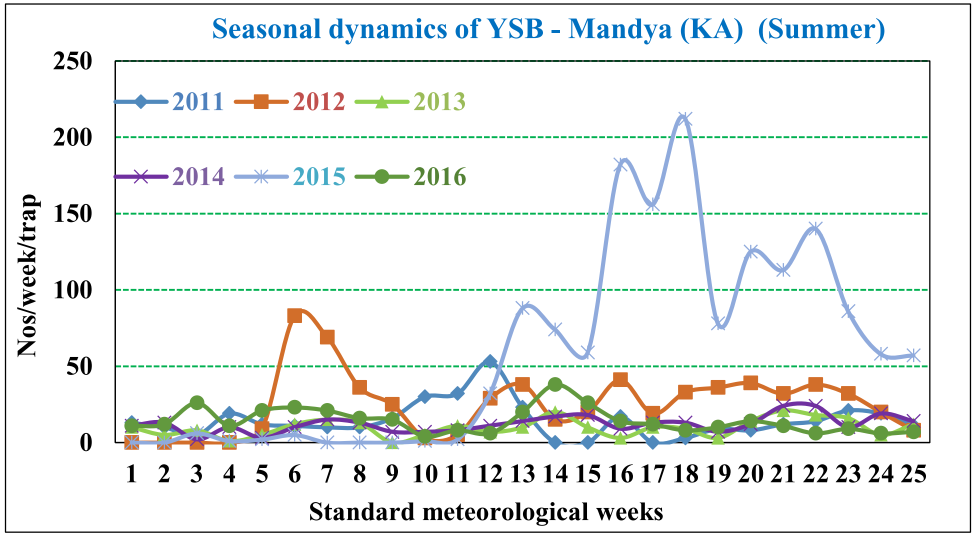
Mandya (KA)



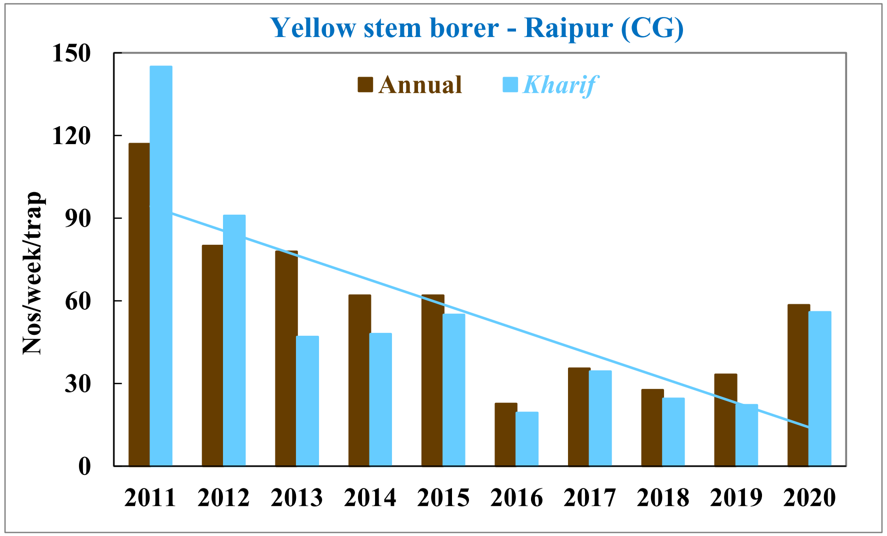


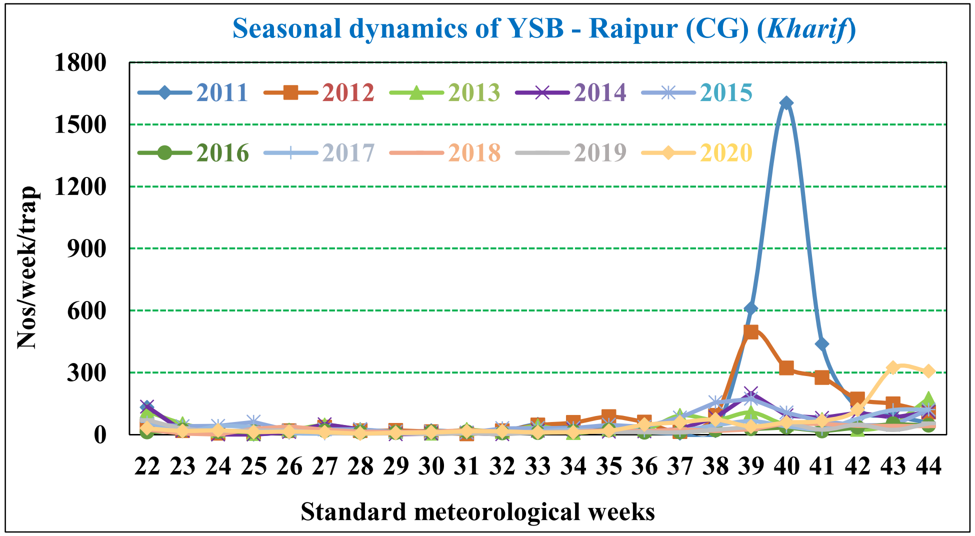
Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations



Raipur (CH)



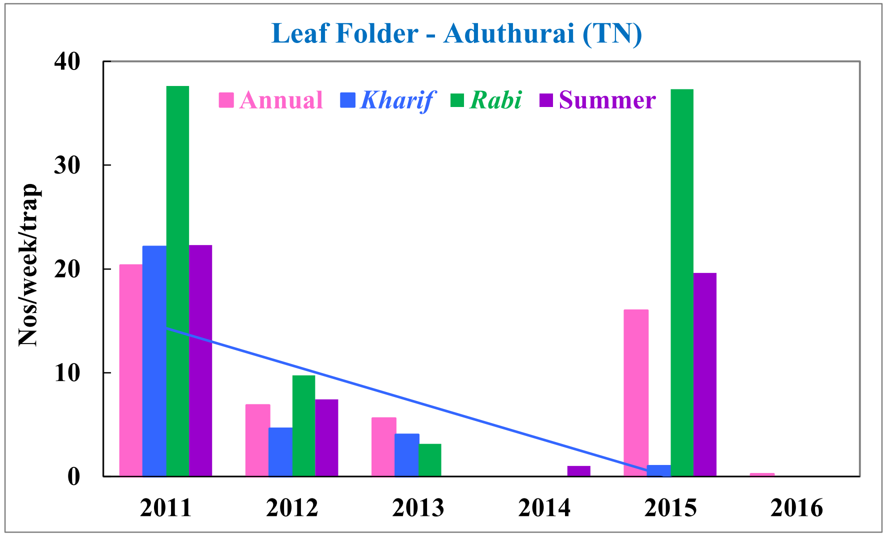


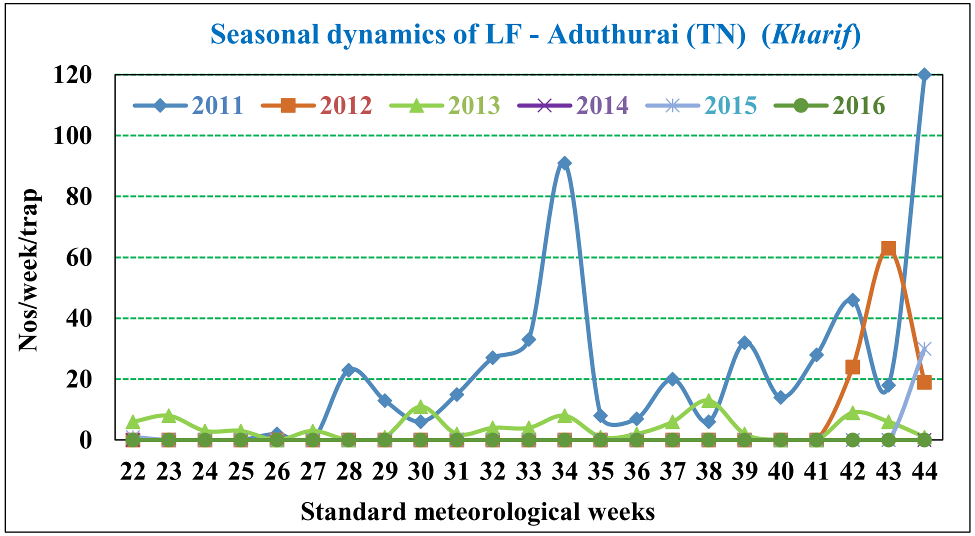
Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

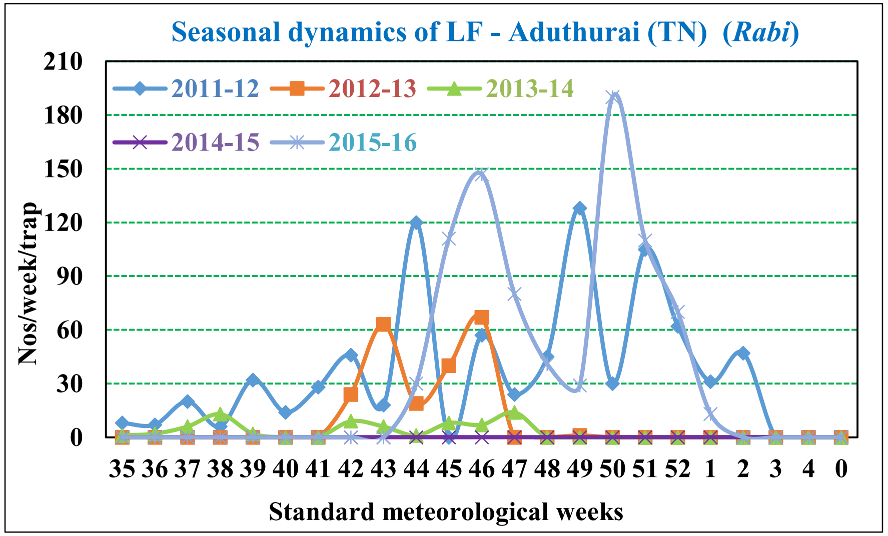
[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations

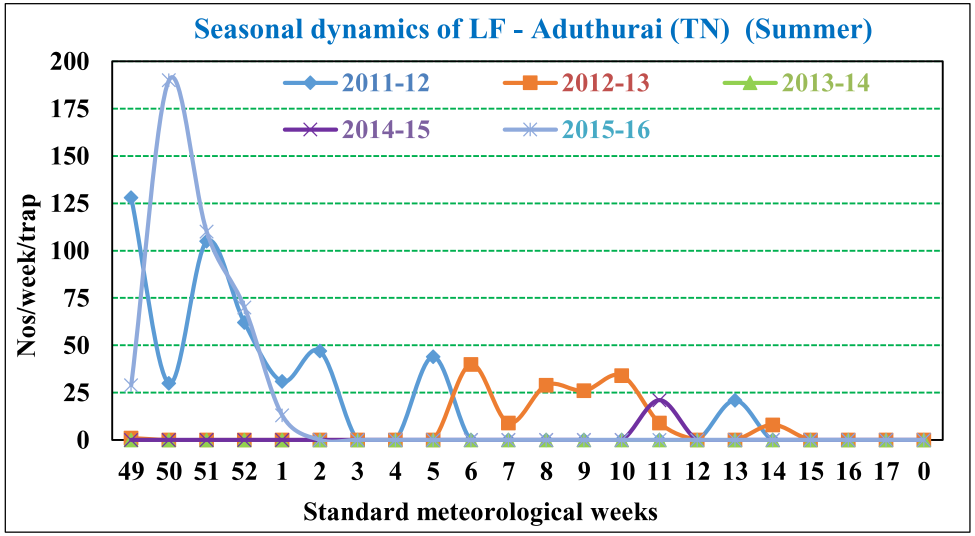
2. Leaf folder

Aduthurai (TN)





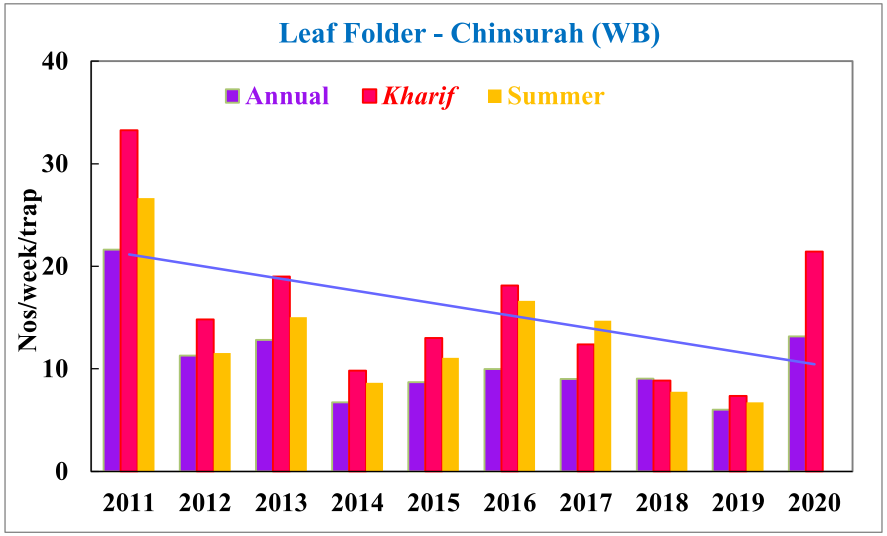


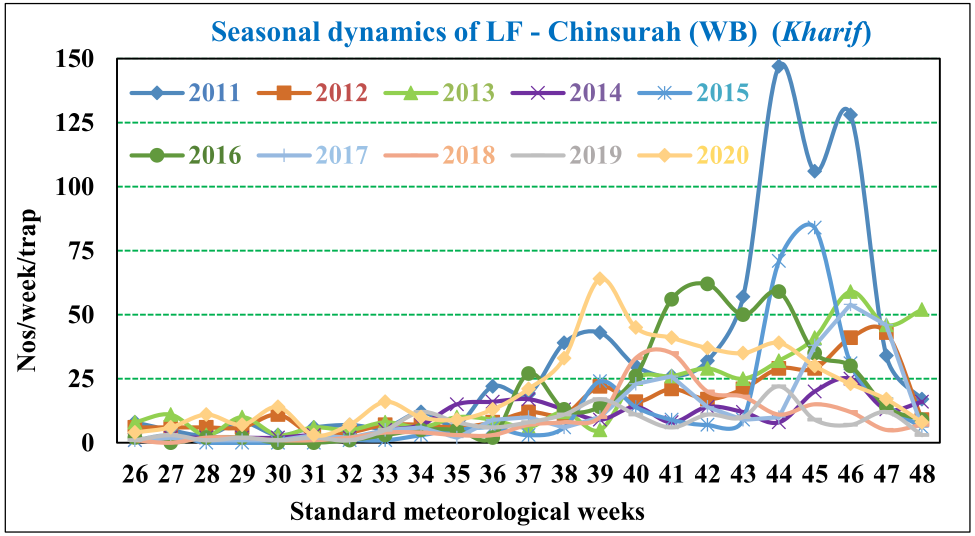


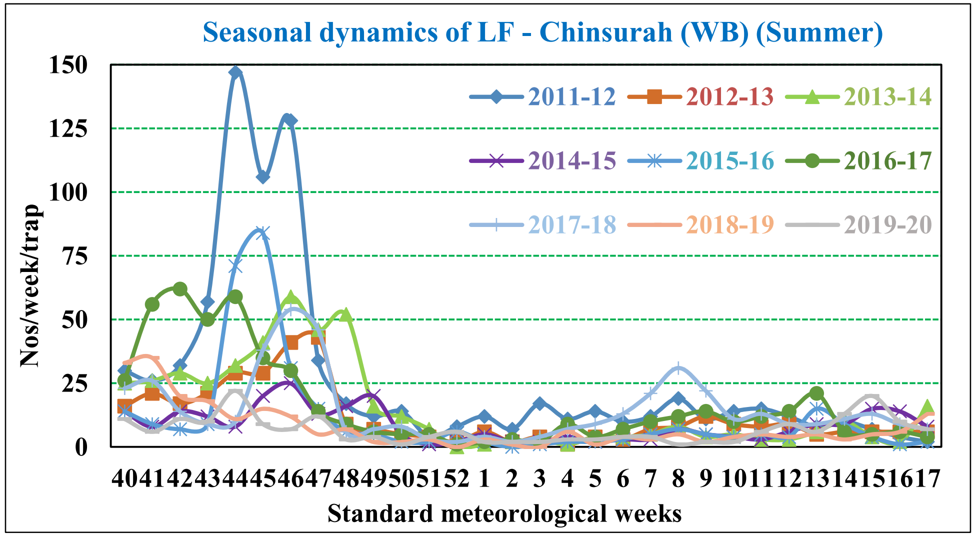
Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations

Chinsurah (WB)



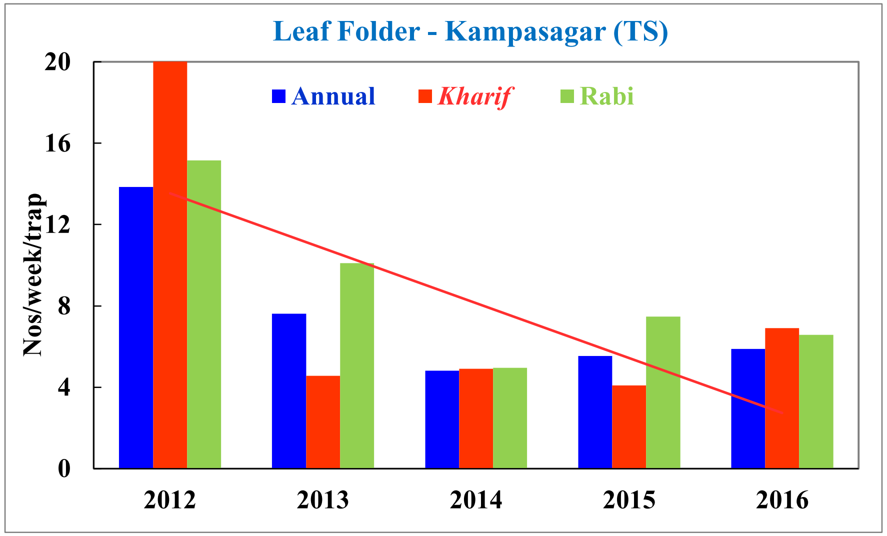


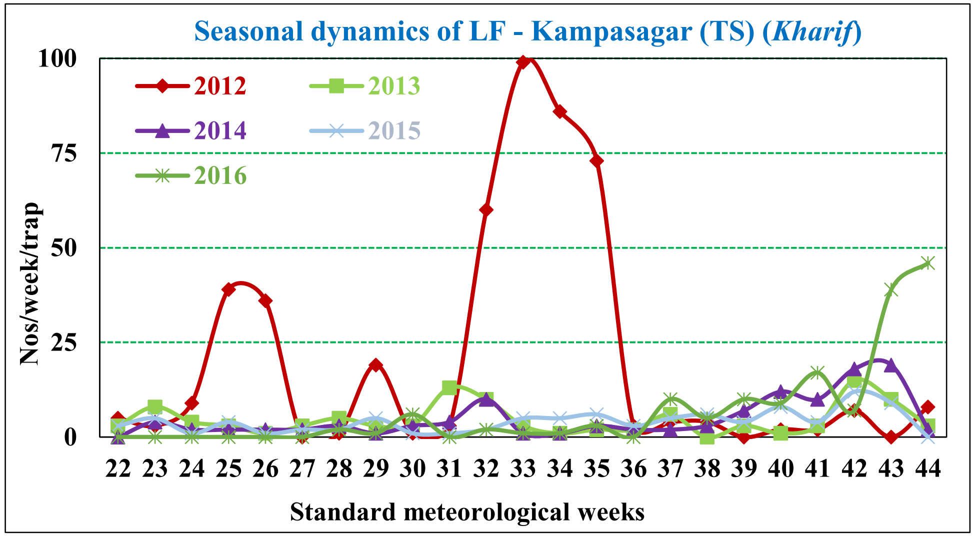


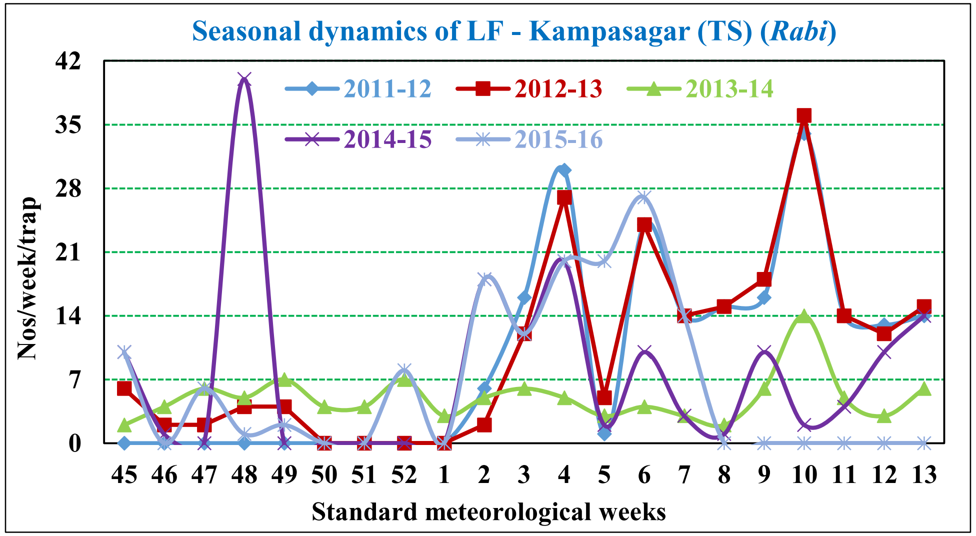
Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations

Kampasagar (TS)



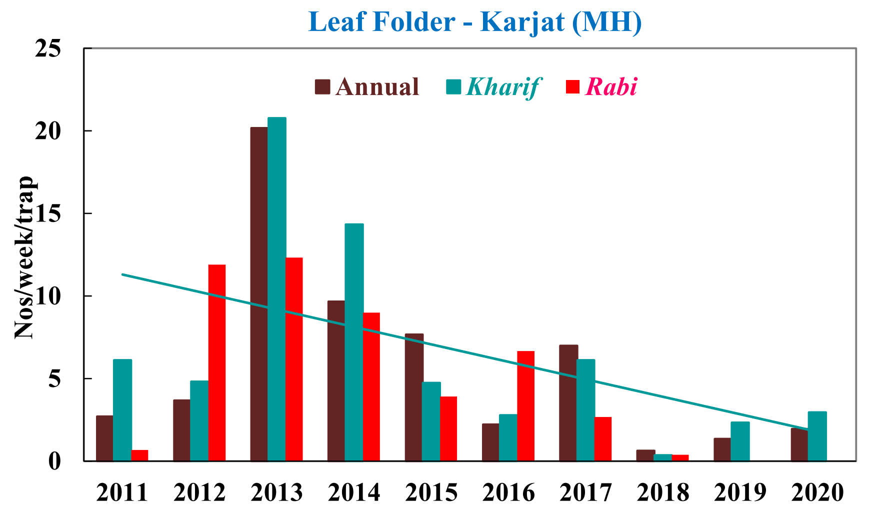


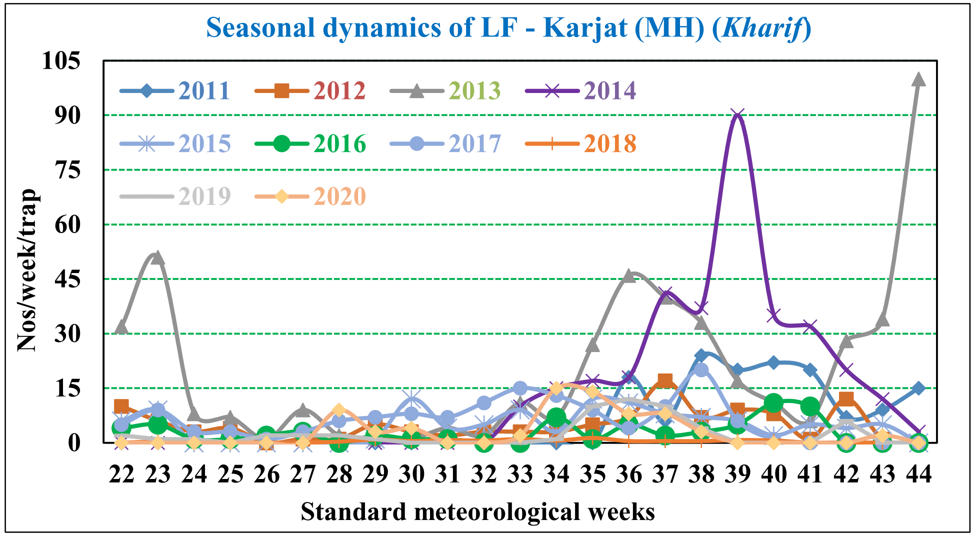


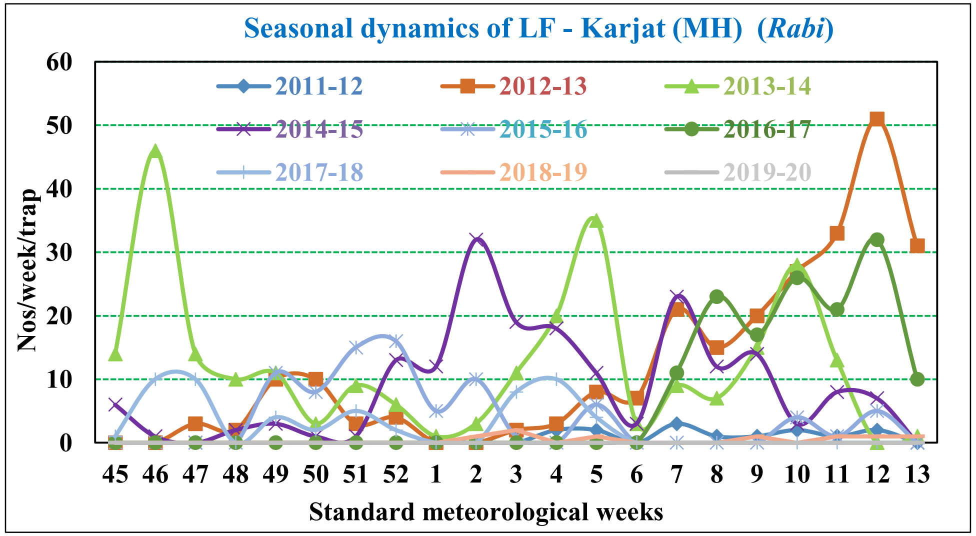
Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations

Karjat (MH)



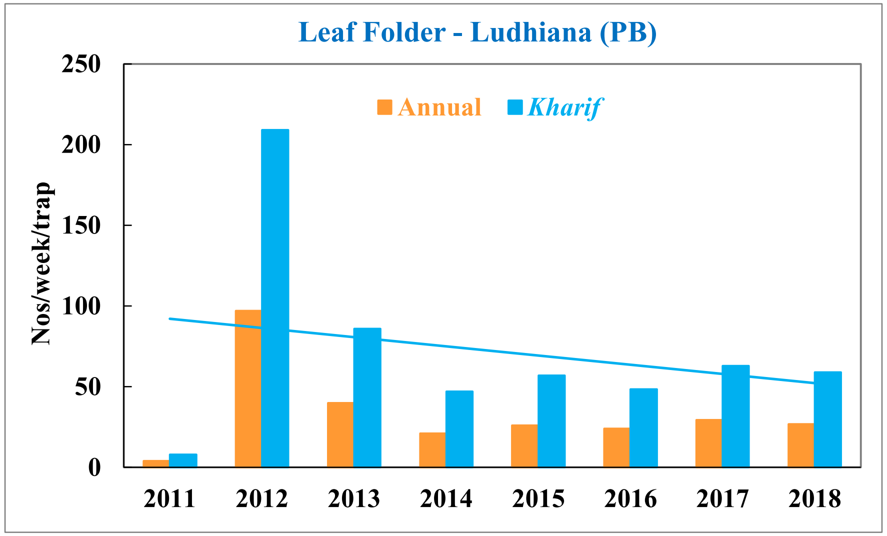


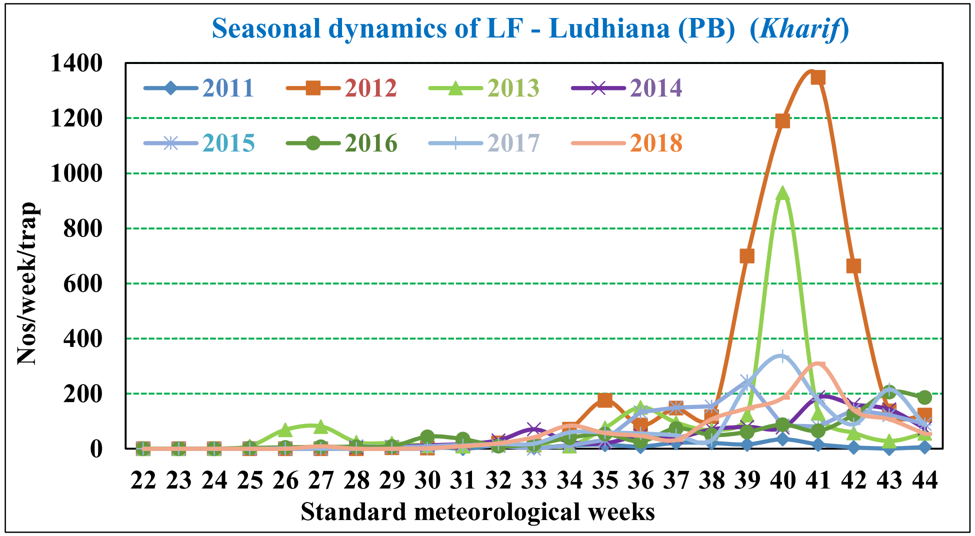


Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

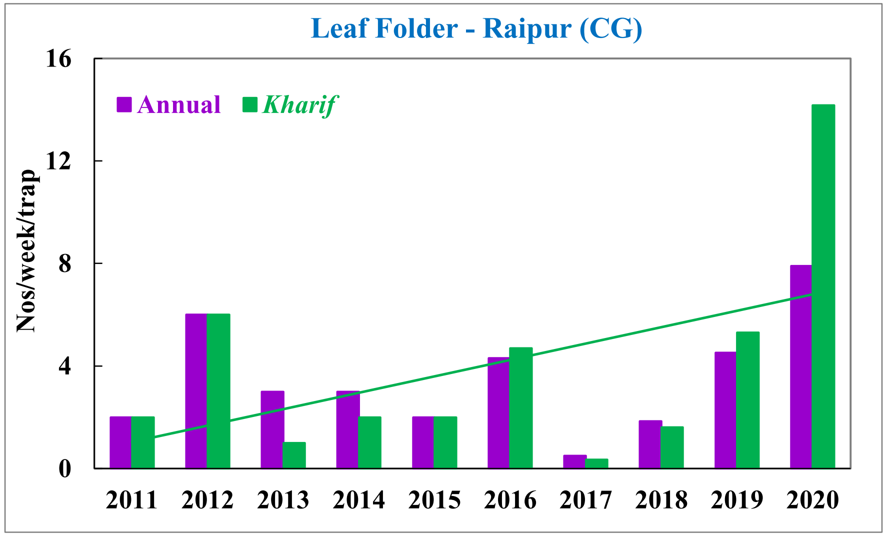
[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations

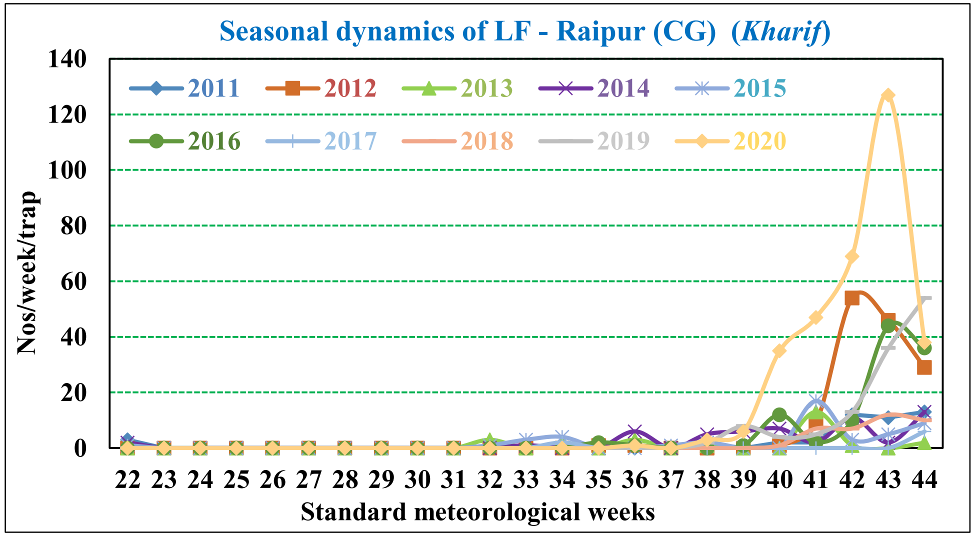
Ludhiana (PB)





Raipur (CG)



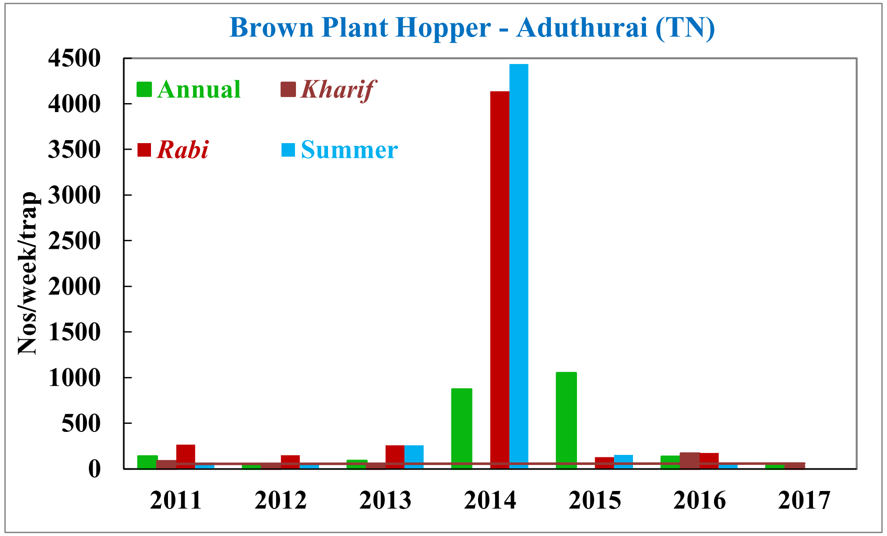


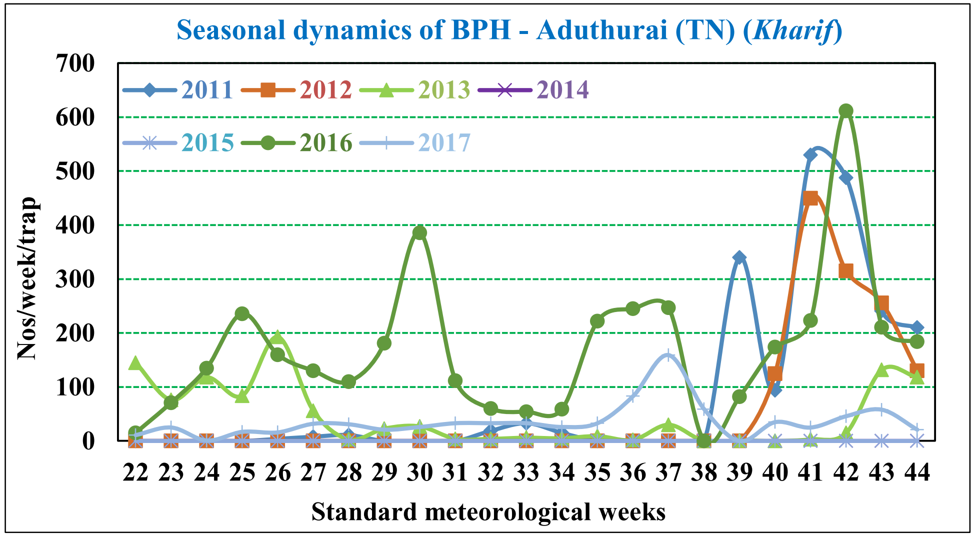
Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

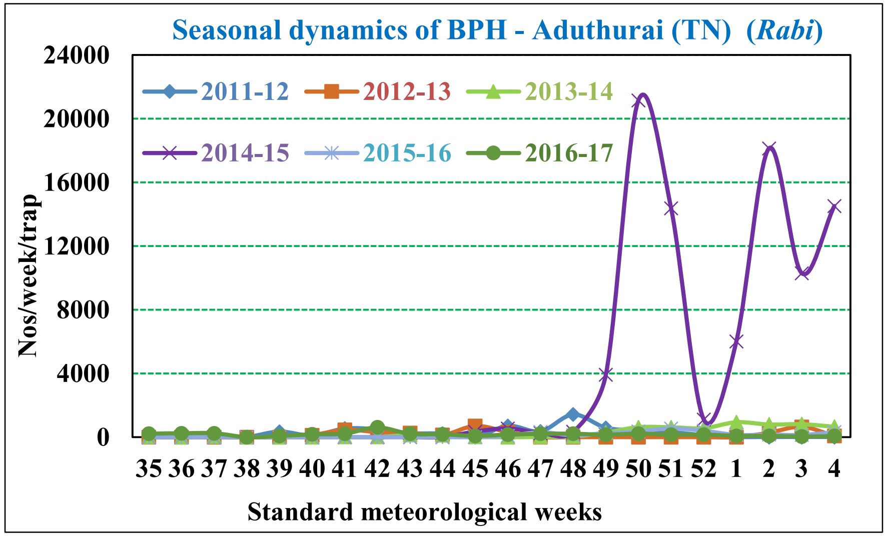
[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations

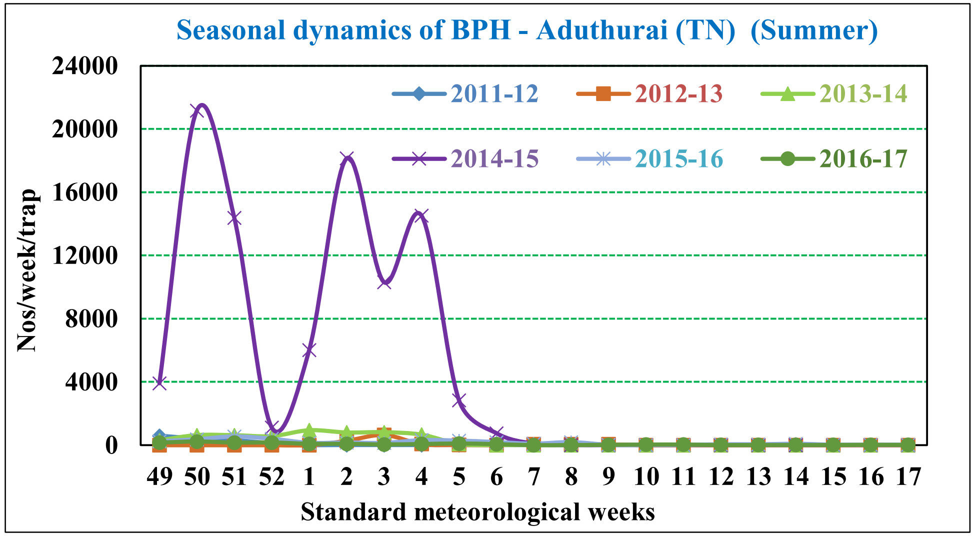
3. Brown plant hopper

Aduthurai (TN)





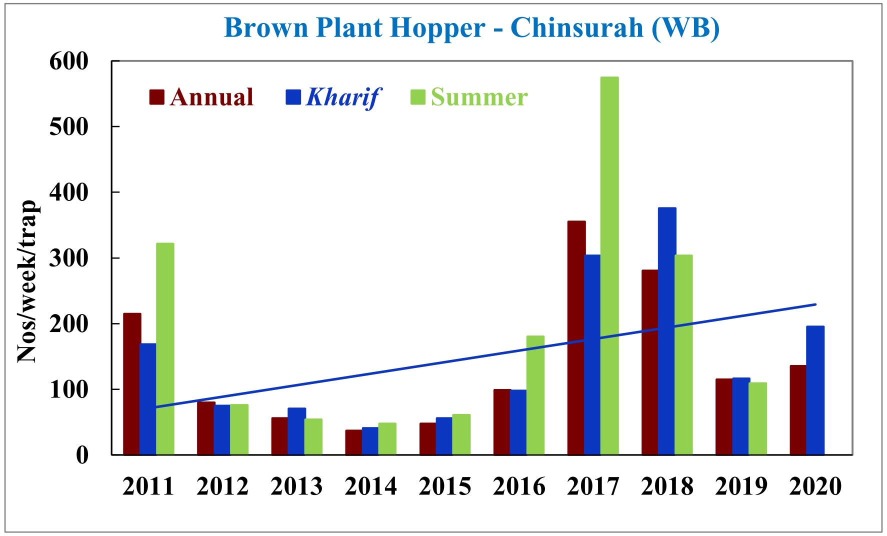


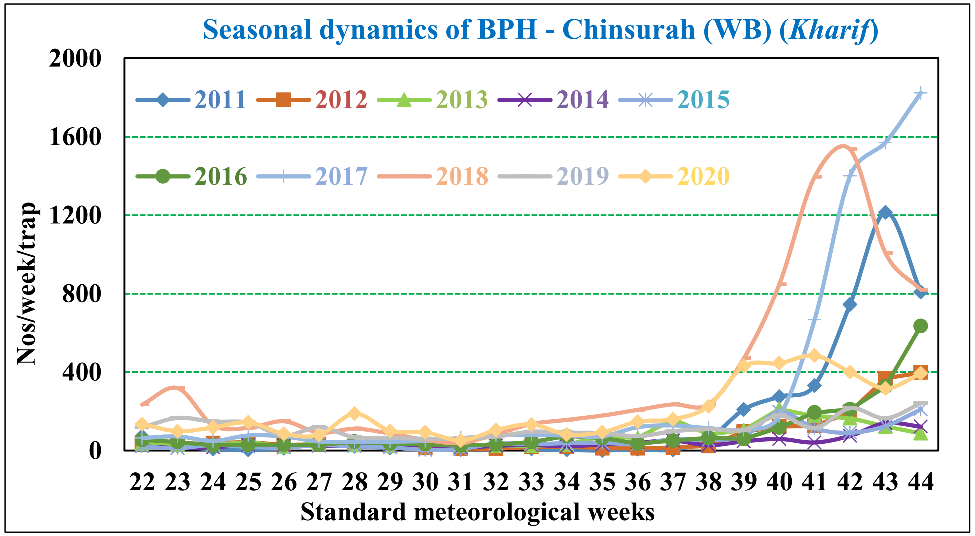


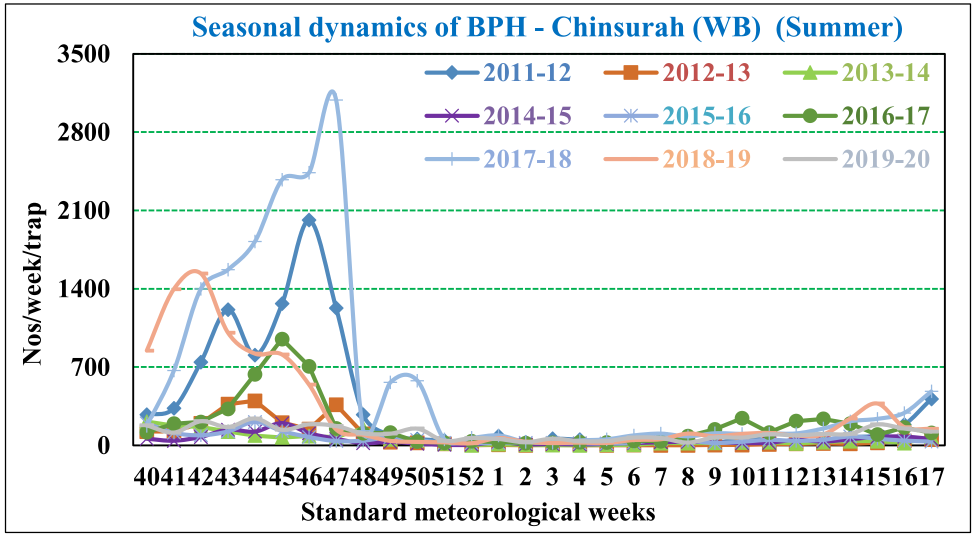
Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations

Chinsurah (WB)



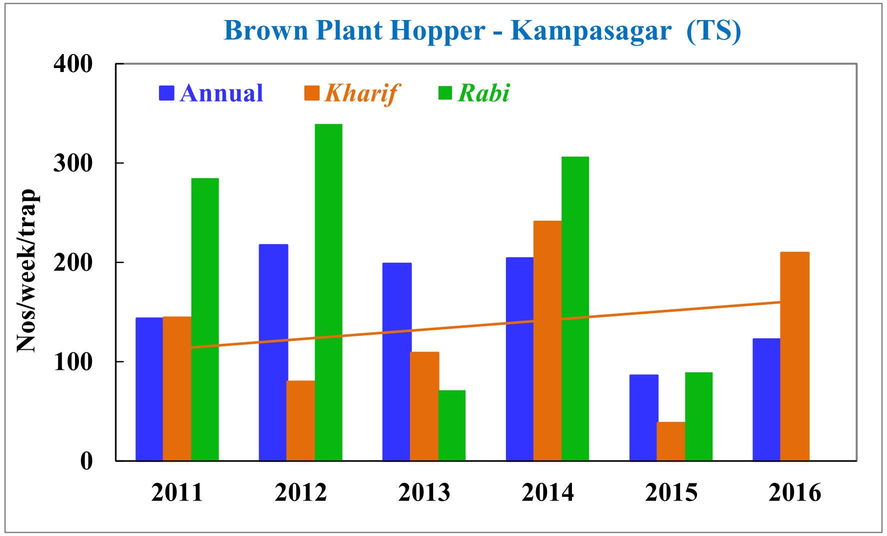


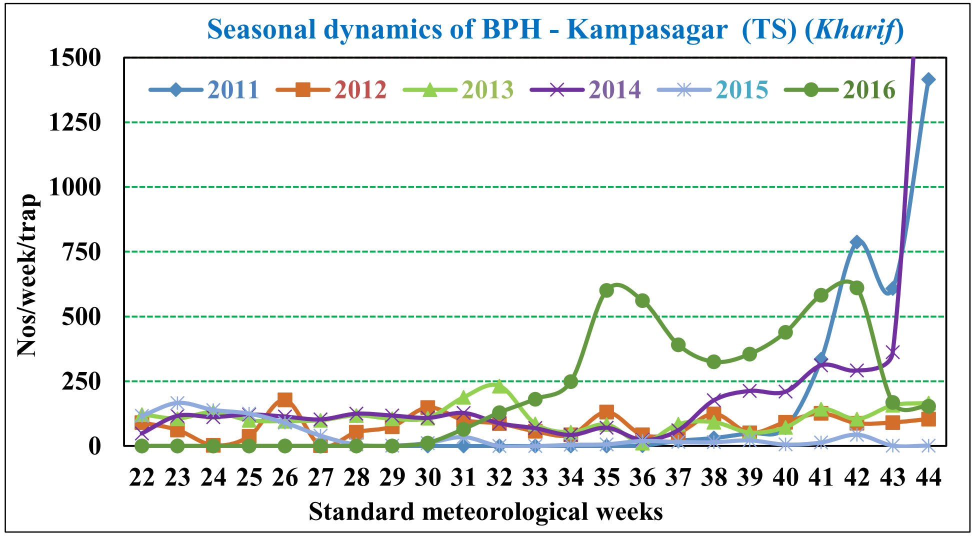


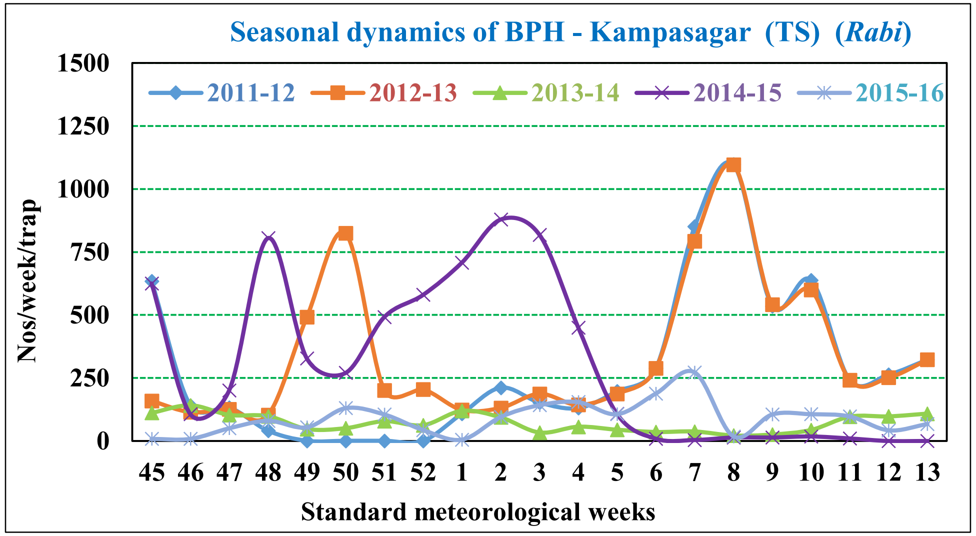
Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations

Kampasagar (TS)



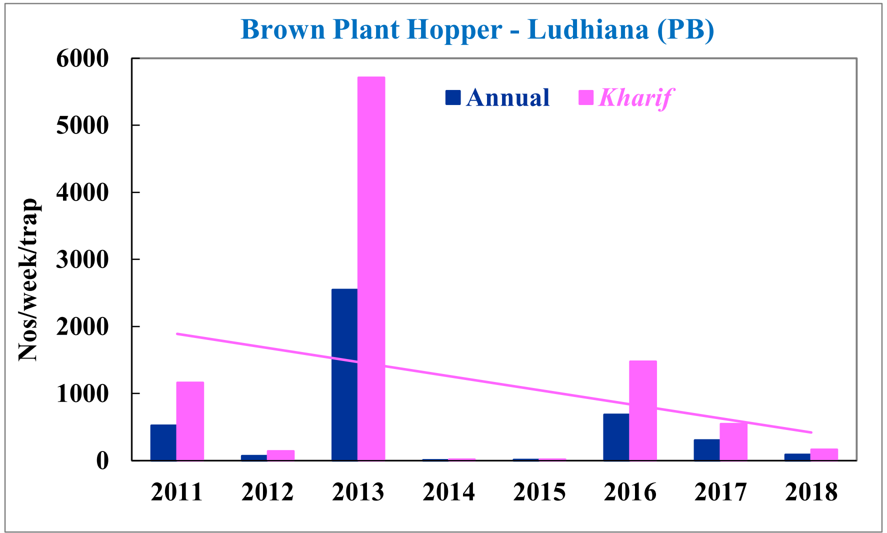


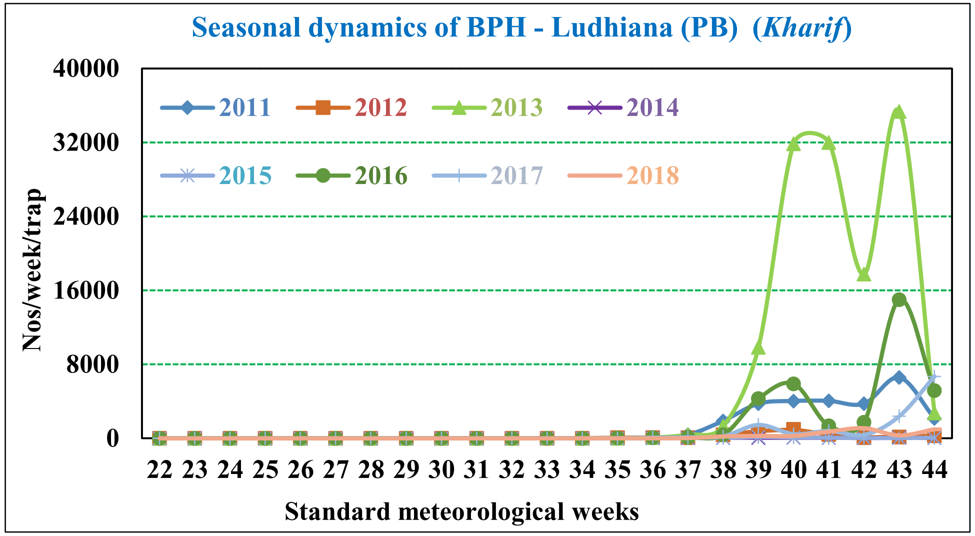


Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

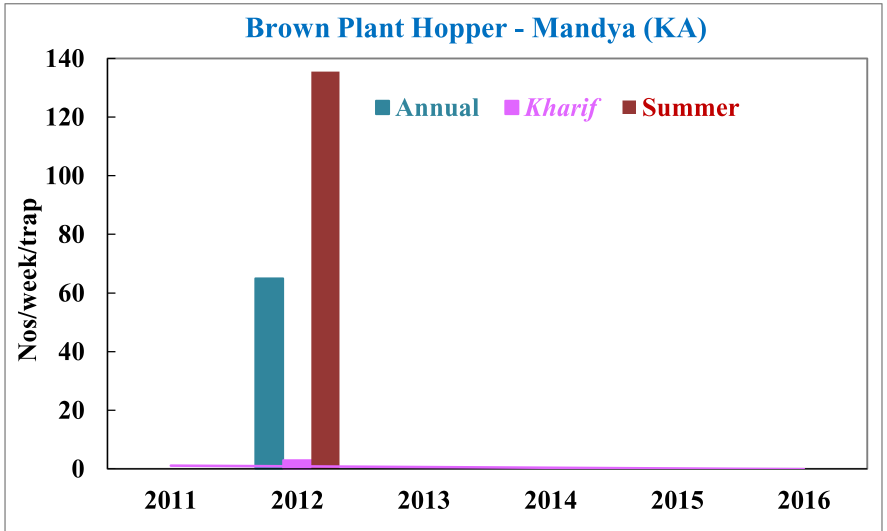
[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations

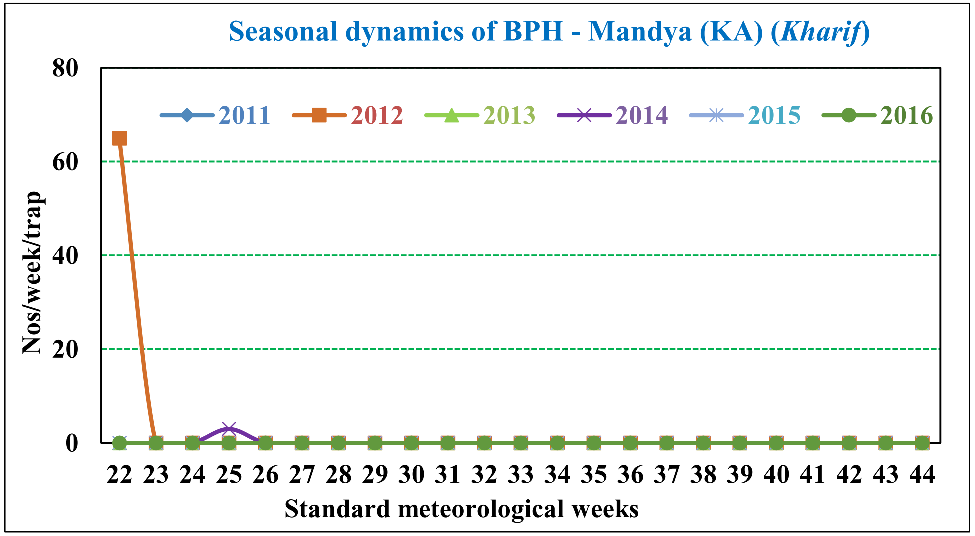
Ludhiana (PB)





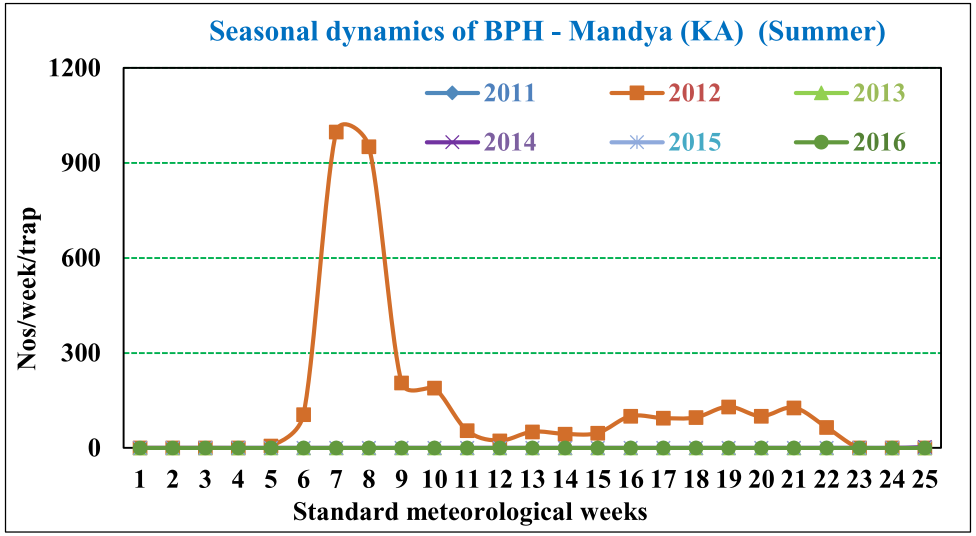
Mandya (KA)



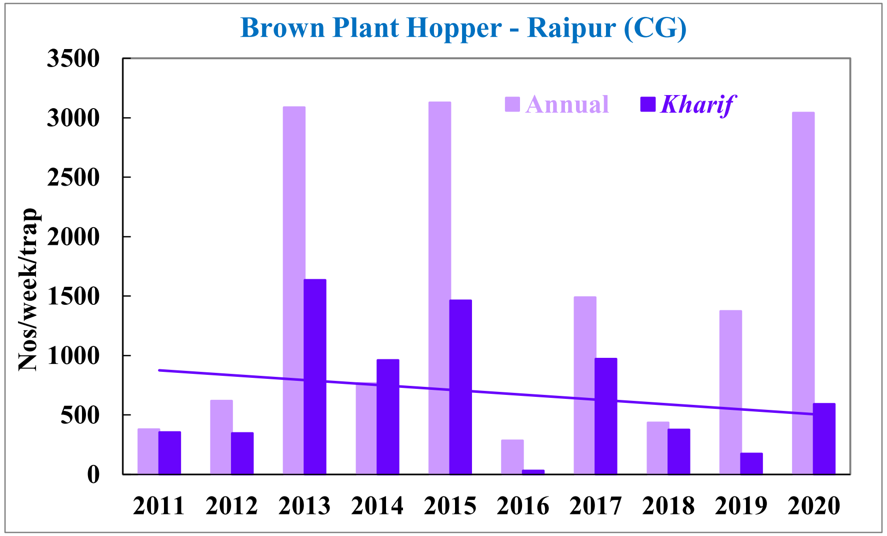


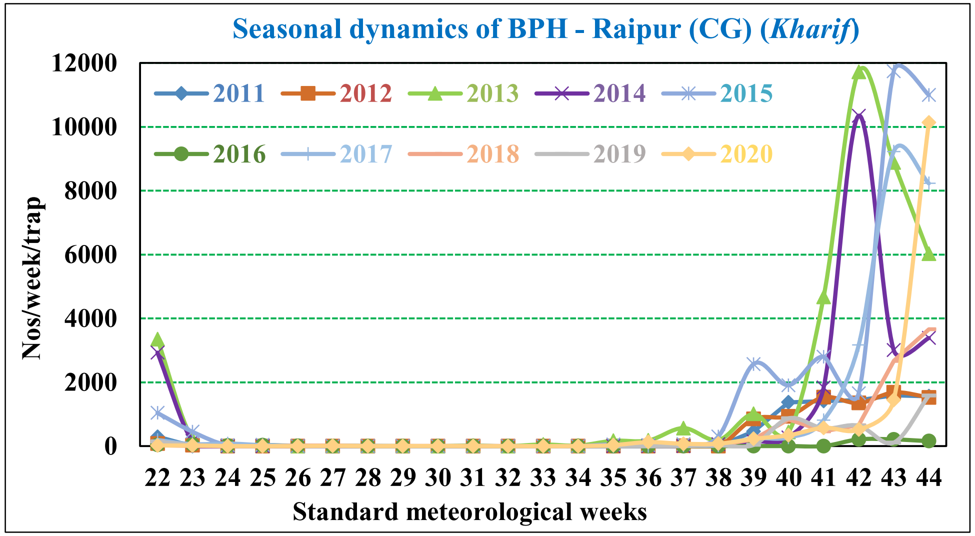
Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations



Raipur (CG)



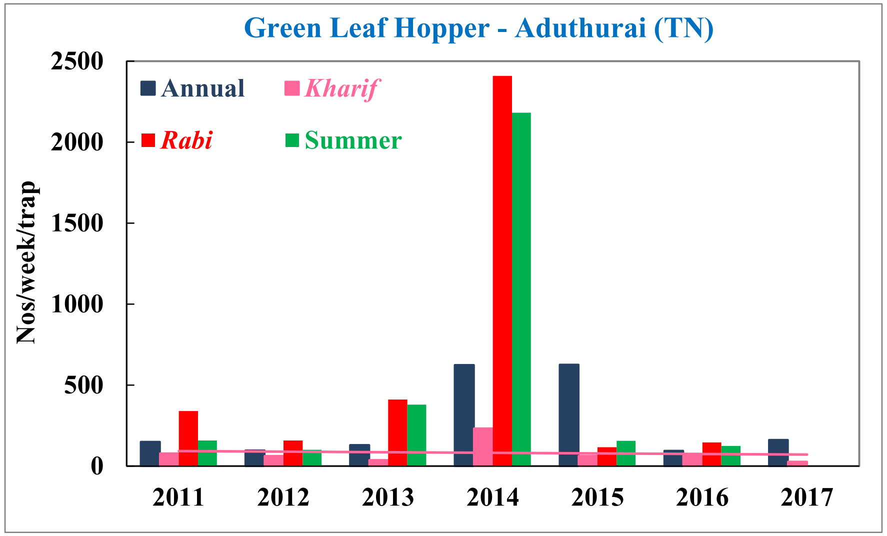


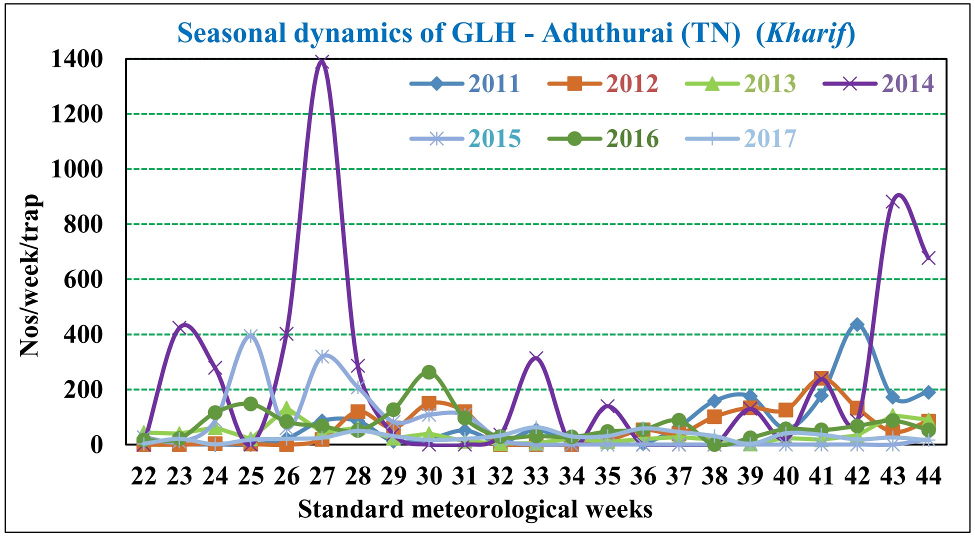
Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

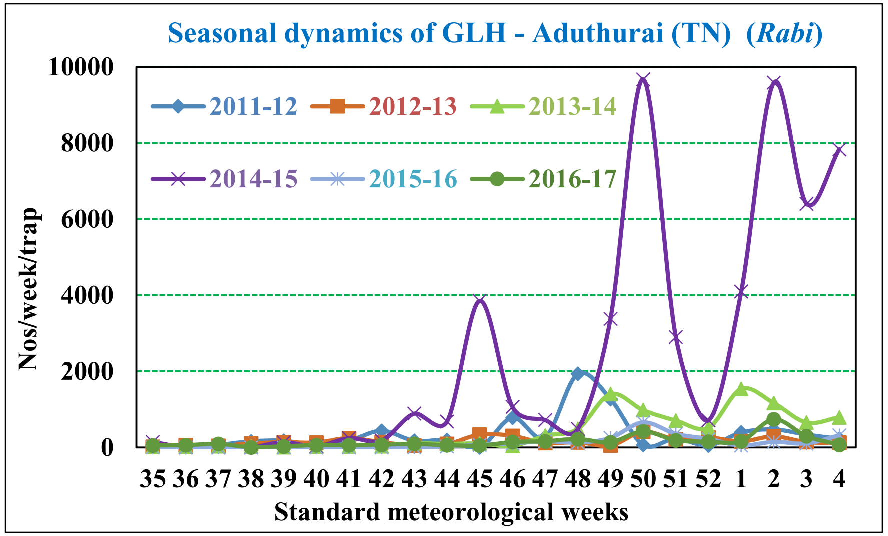
[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations

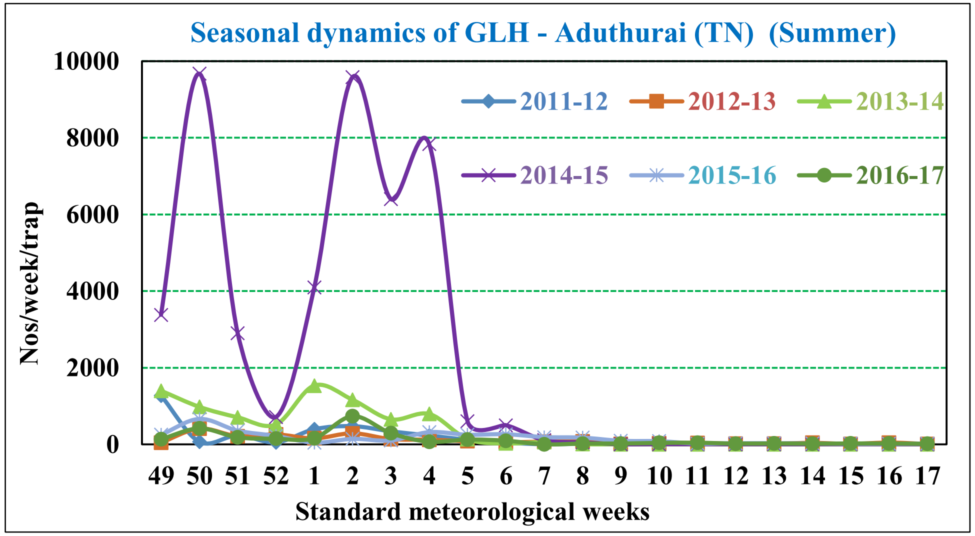
4. Green leaf hopper

Aduthurai (TN)





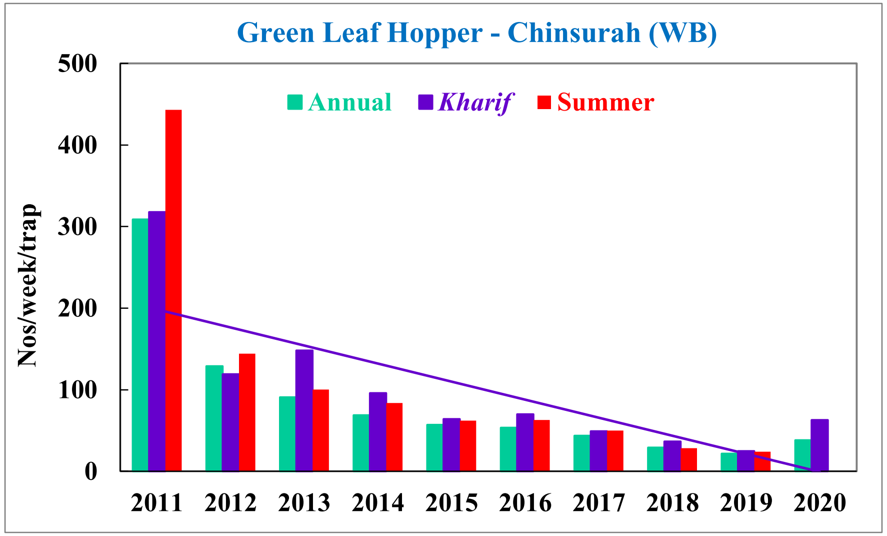


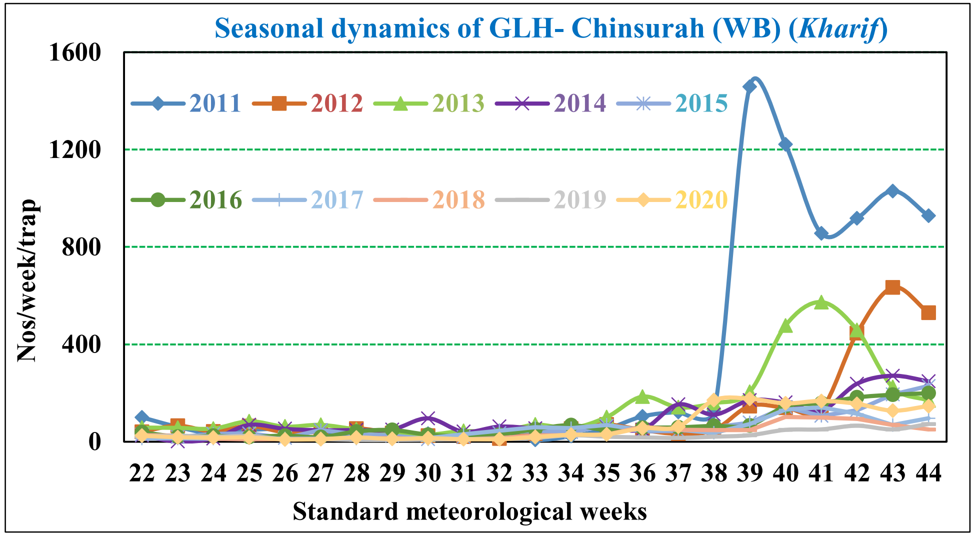


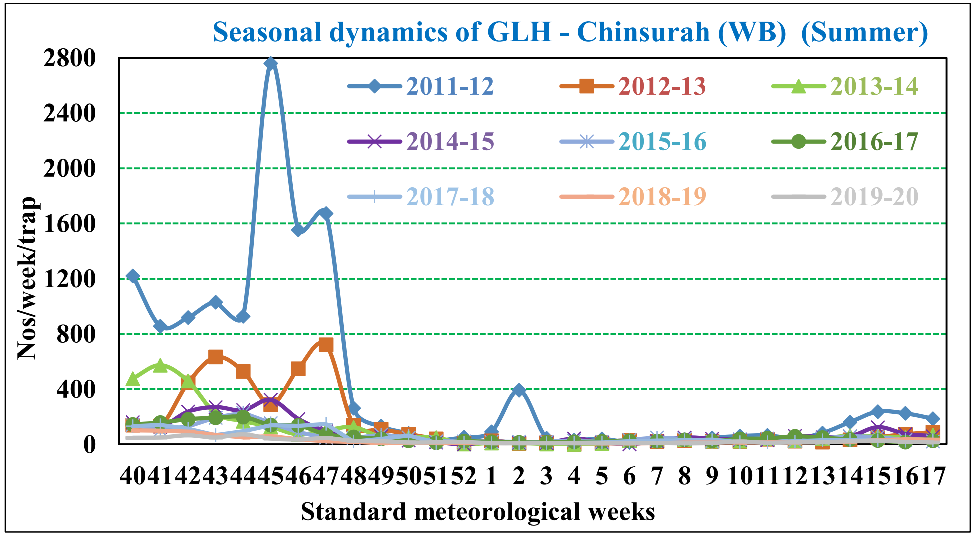
Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations

Chinsurah (WB)

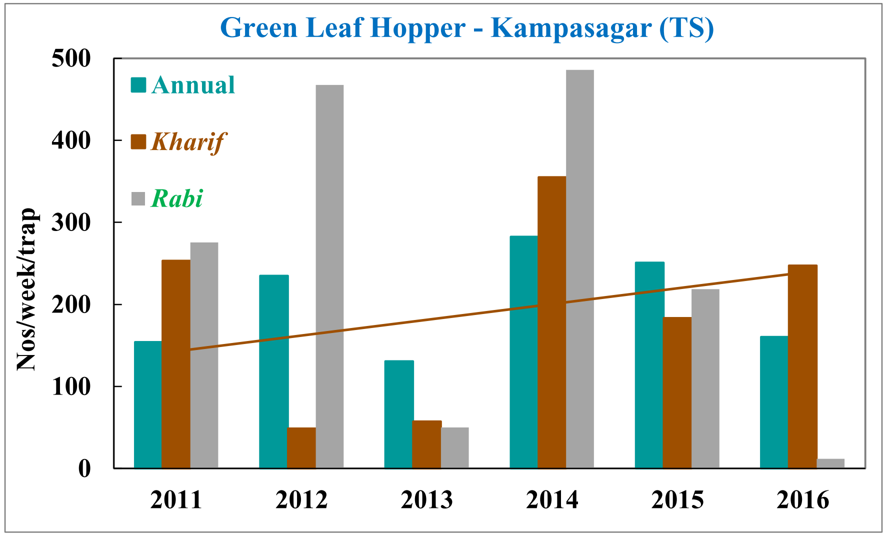


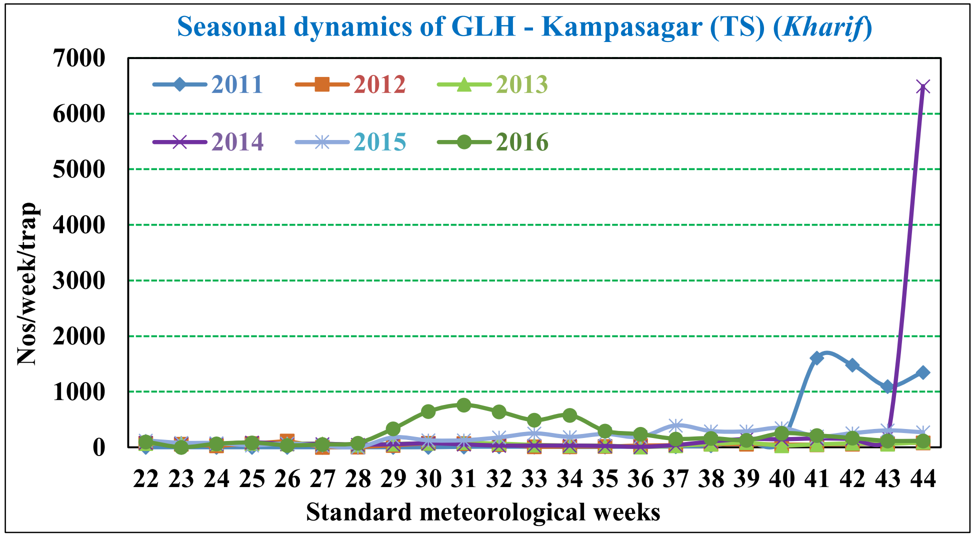


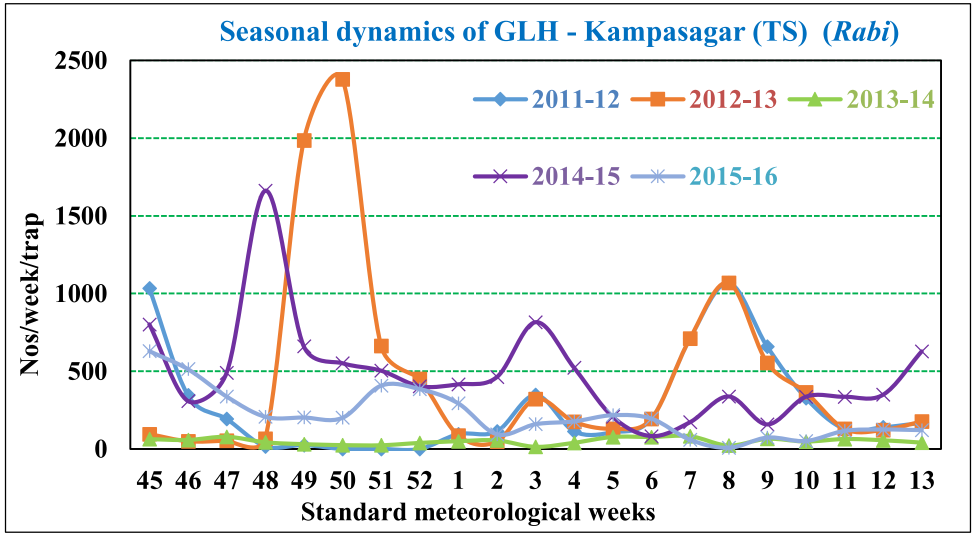


Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations
[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations

Kampasagar (TS)



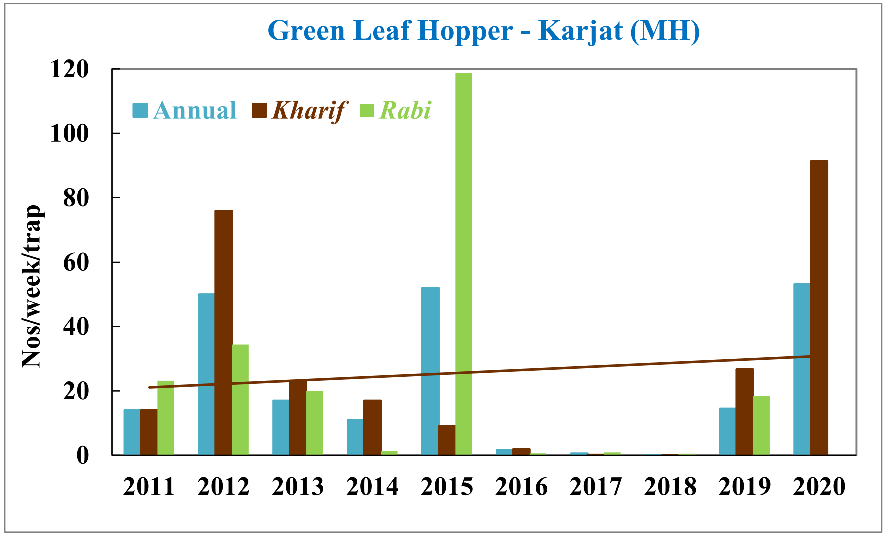


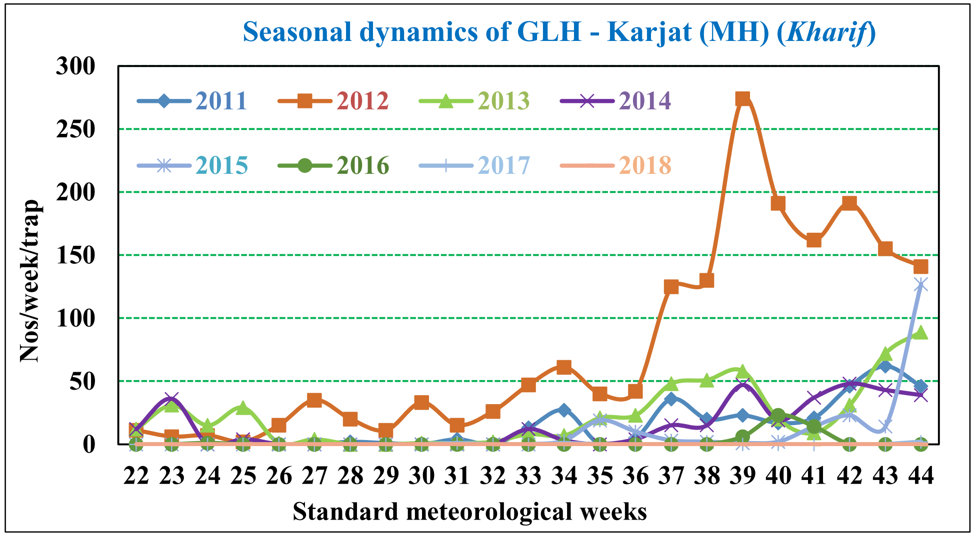


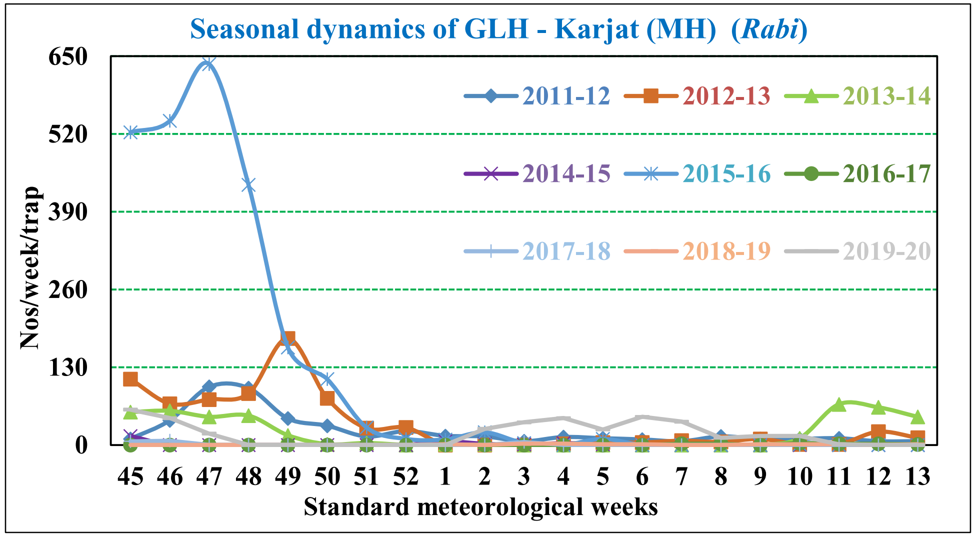
Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations

Karjat (MH)



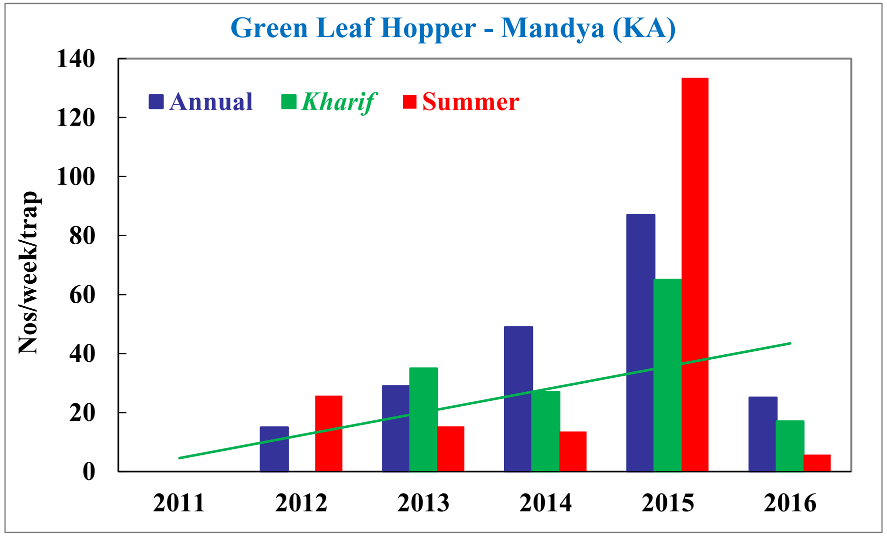


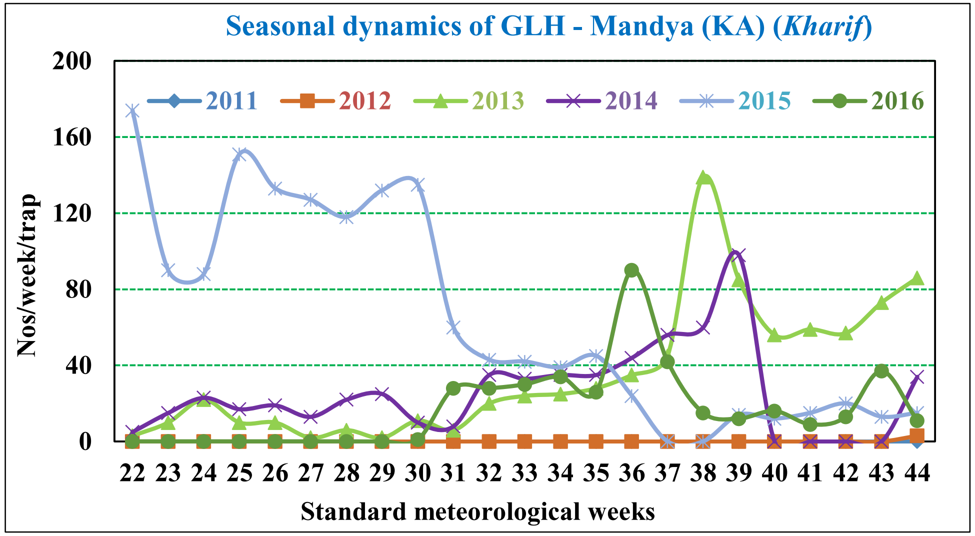


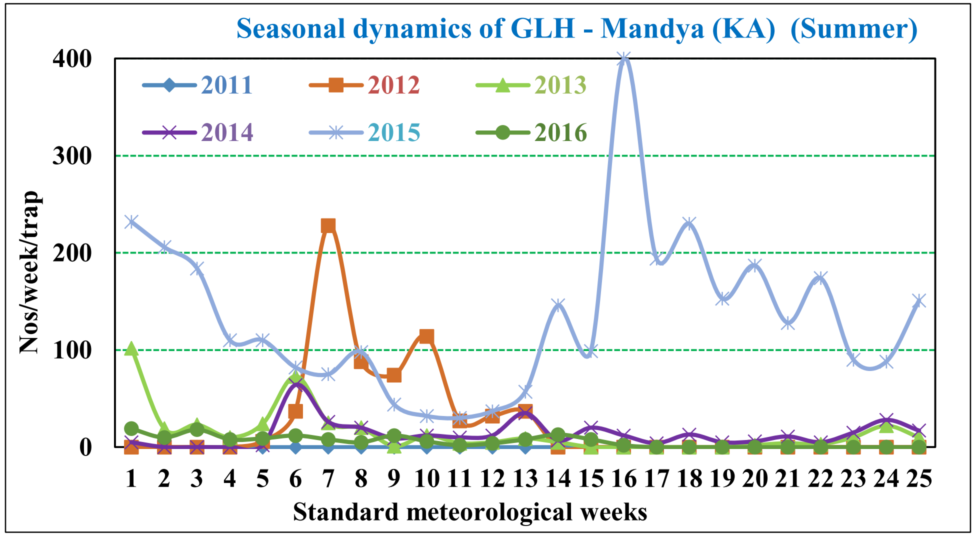
Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations

Mandya (KA)



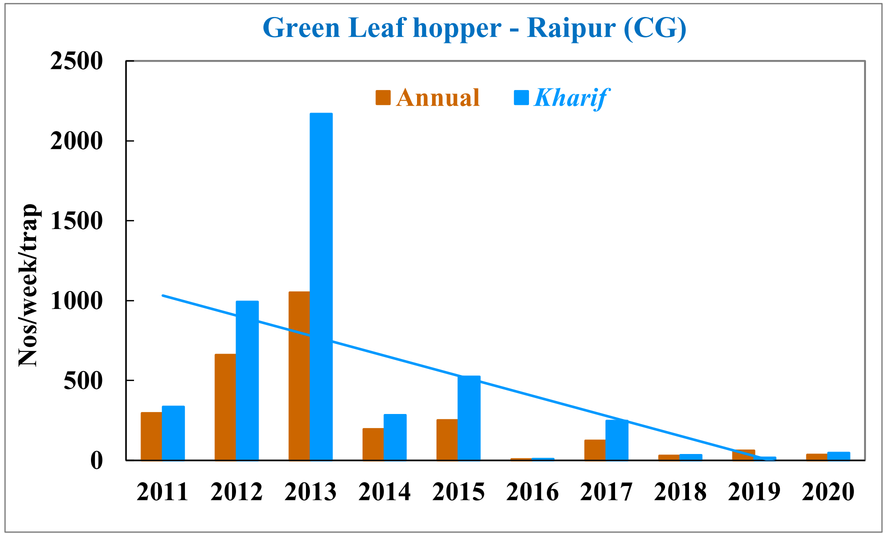


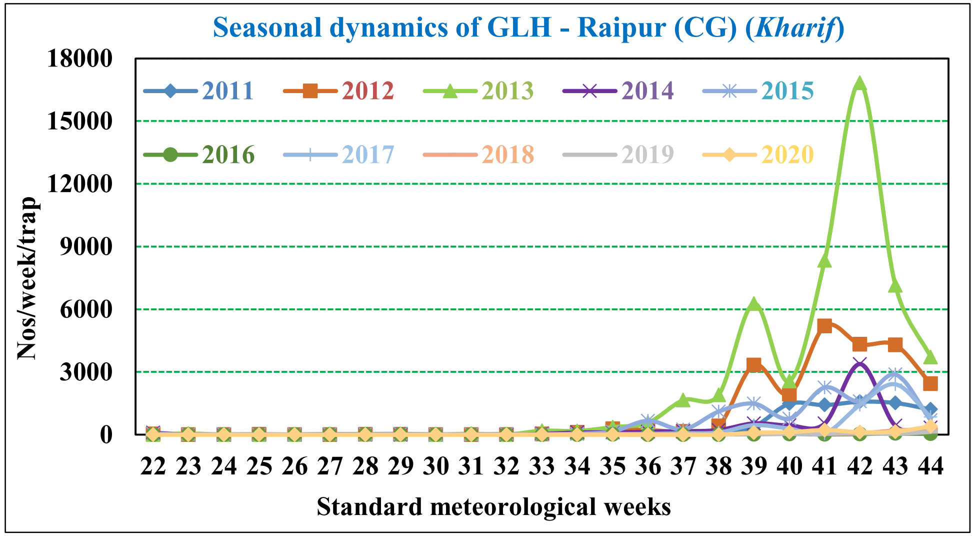


Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

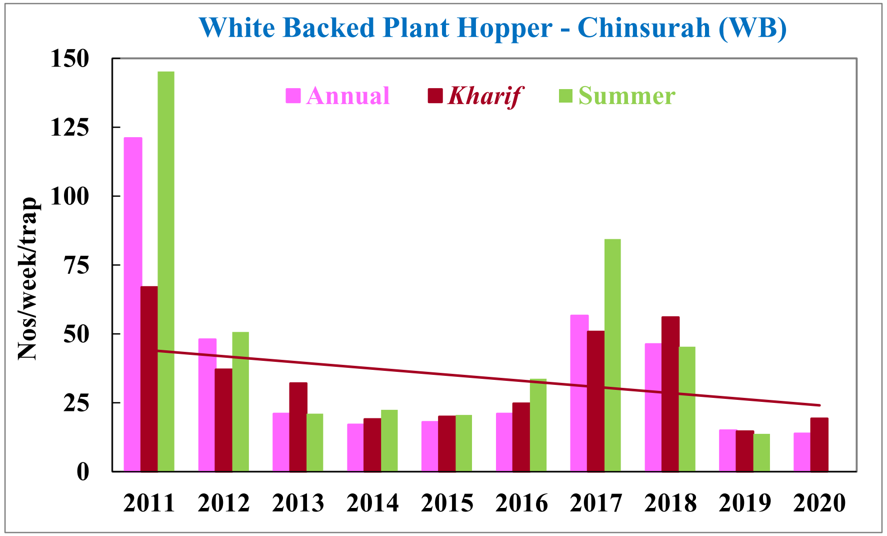
[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations

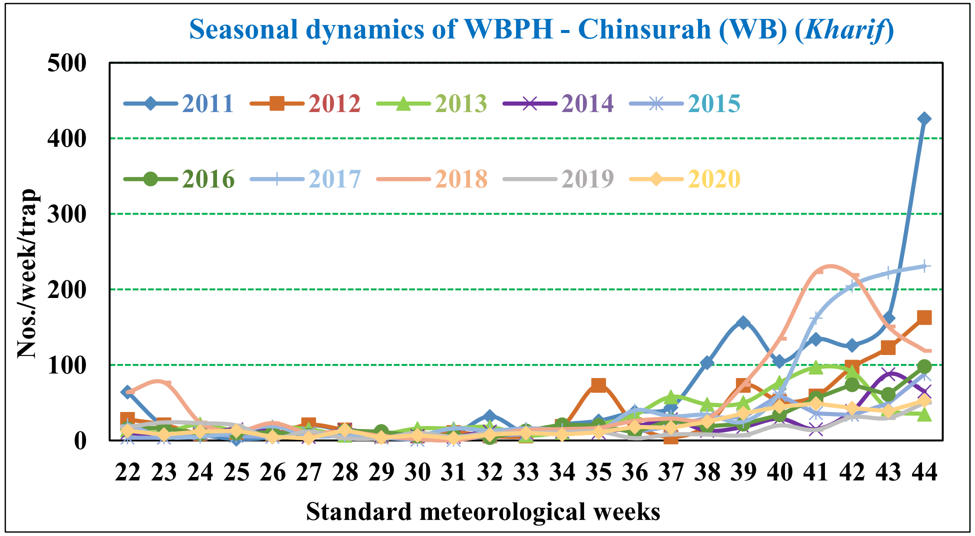
Raipur (CG)

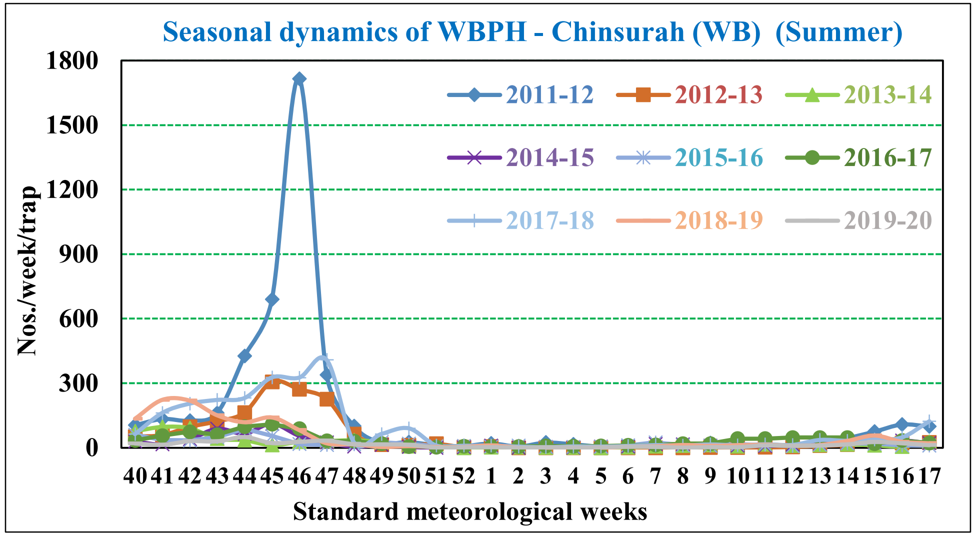




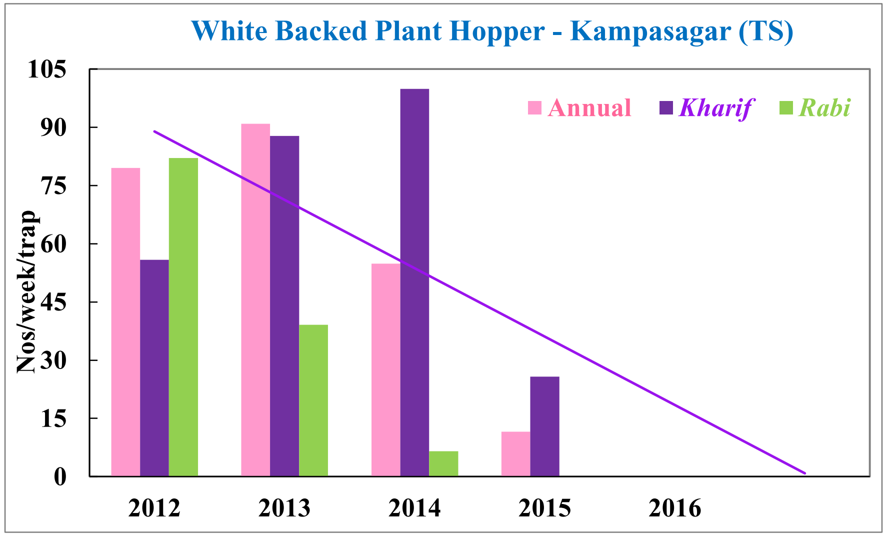
5. White backed plant hopper
Chinsurah (WB)

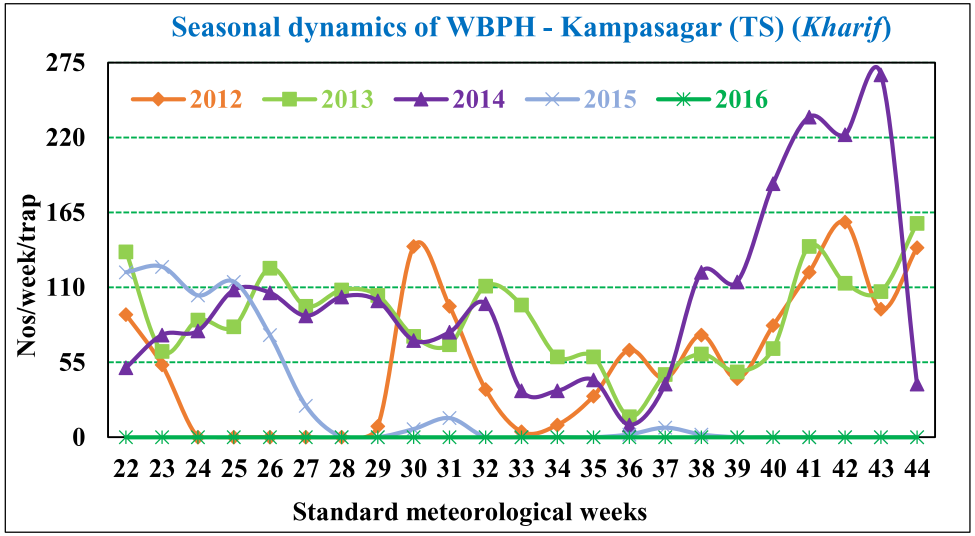






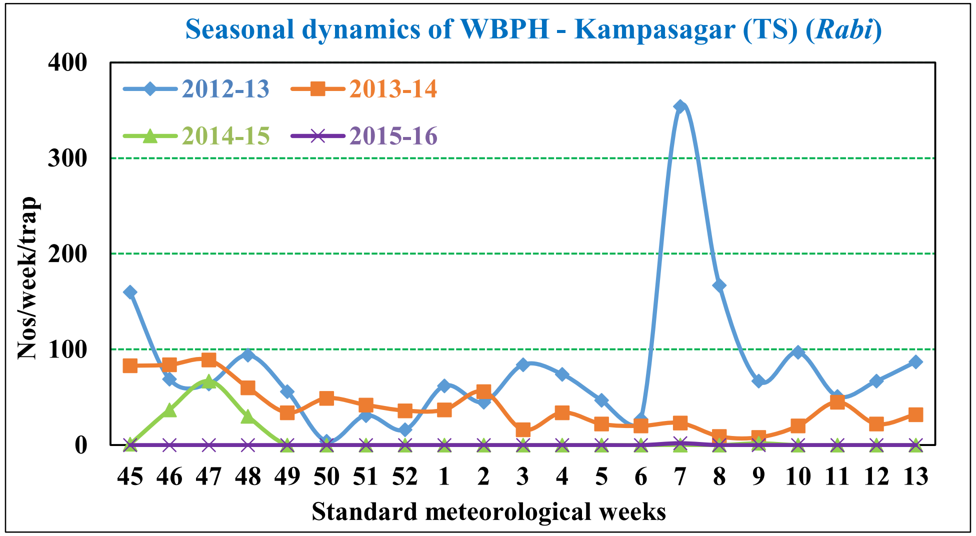
Kampasagar (TS)



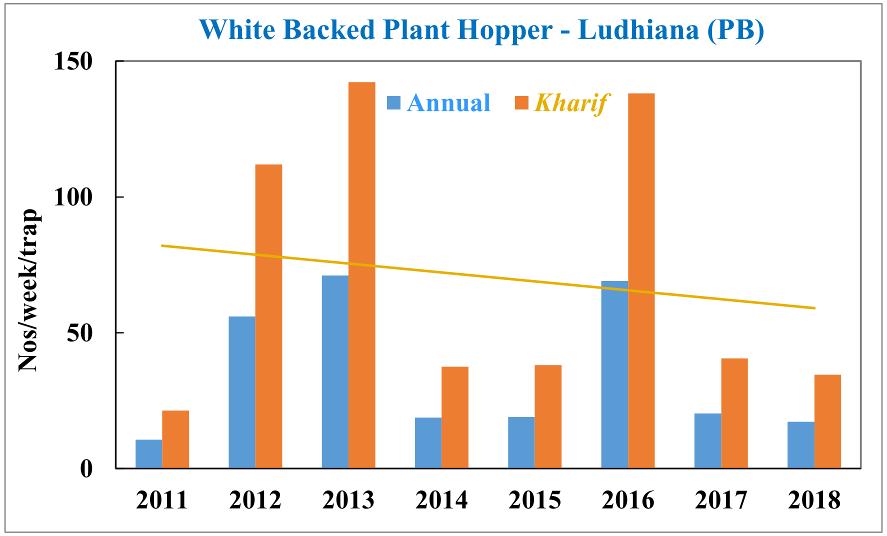


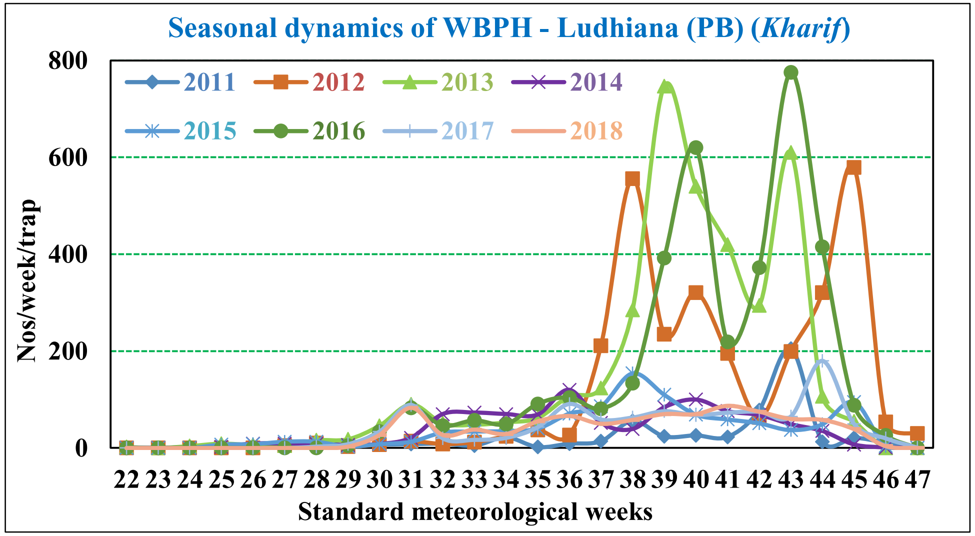
Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations



Ludhiana (PB)

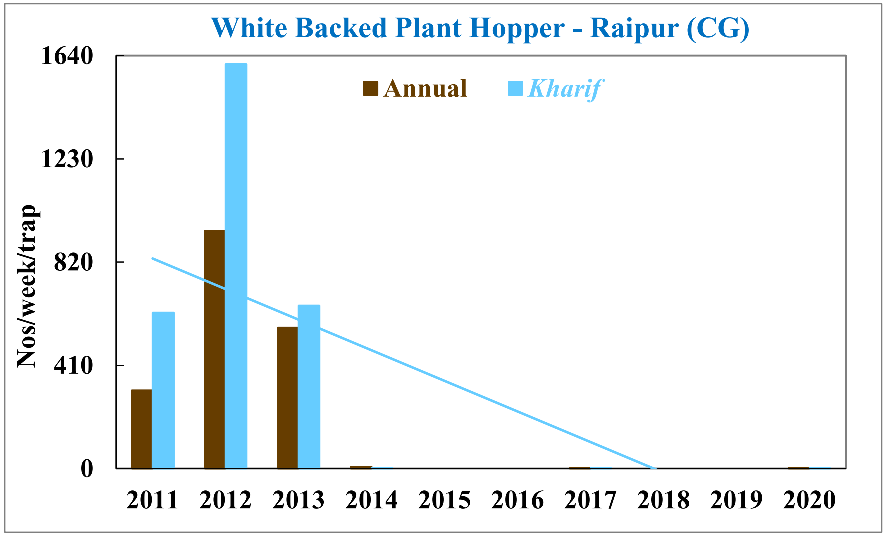


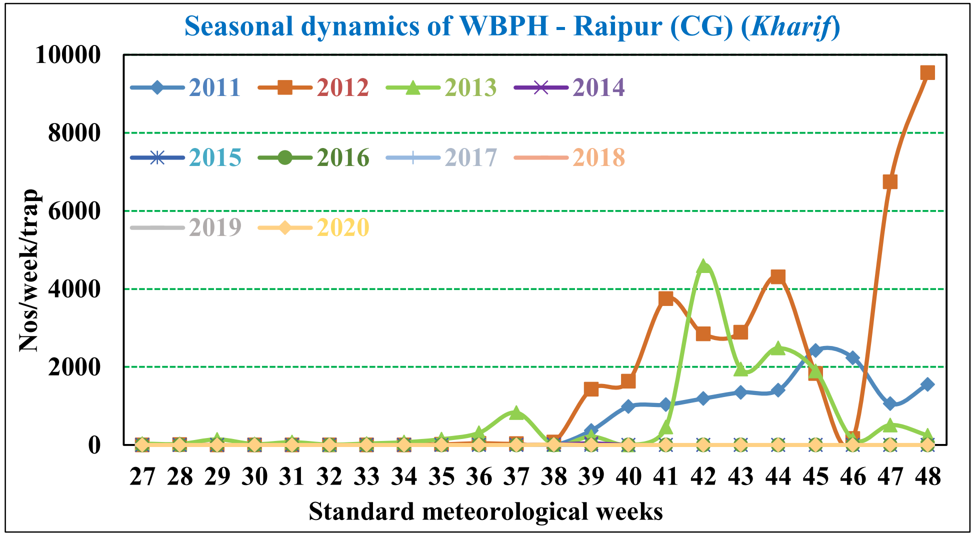


Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations

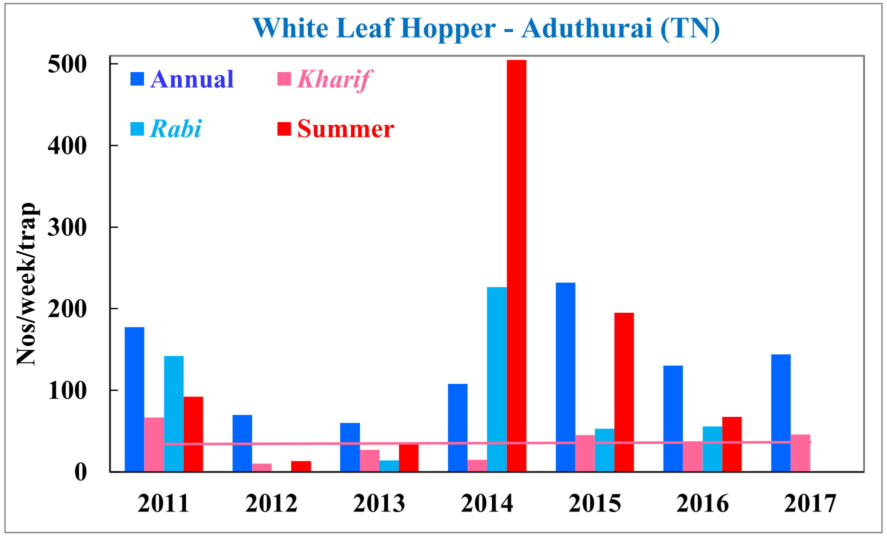
Raipur (CH)

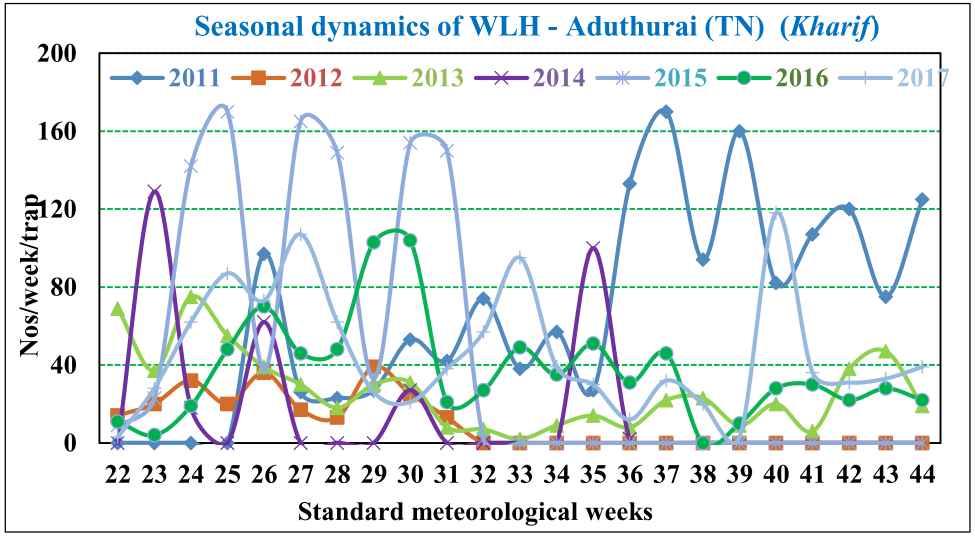




6. White leaf hopper

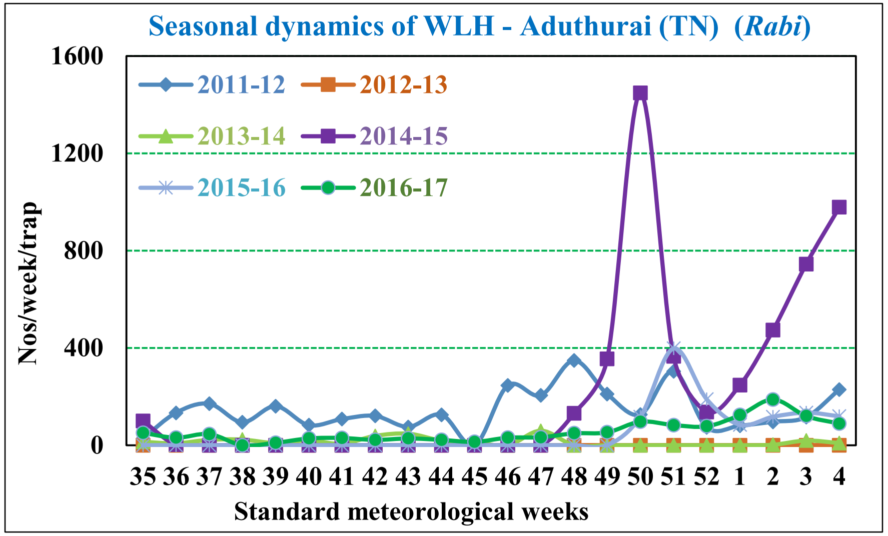
Aduthurai (TN)

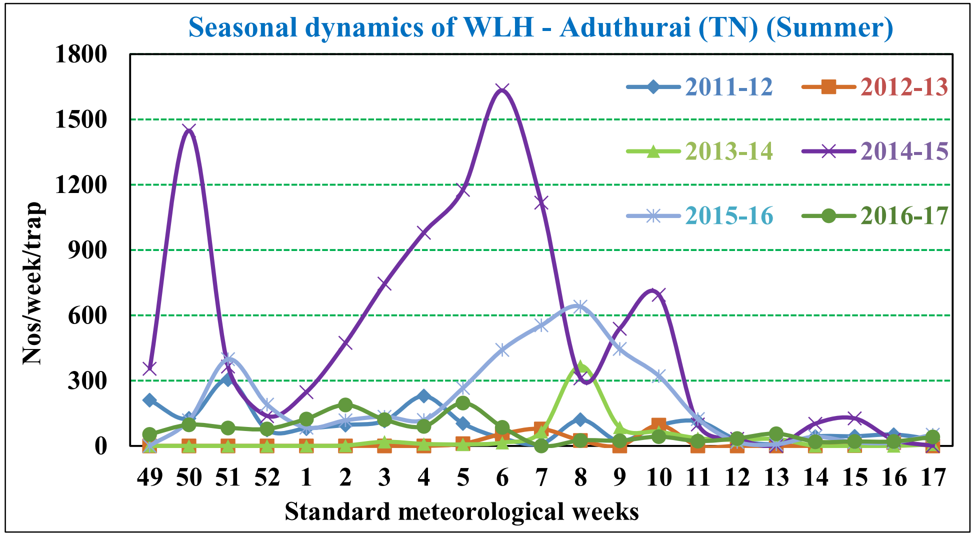




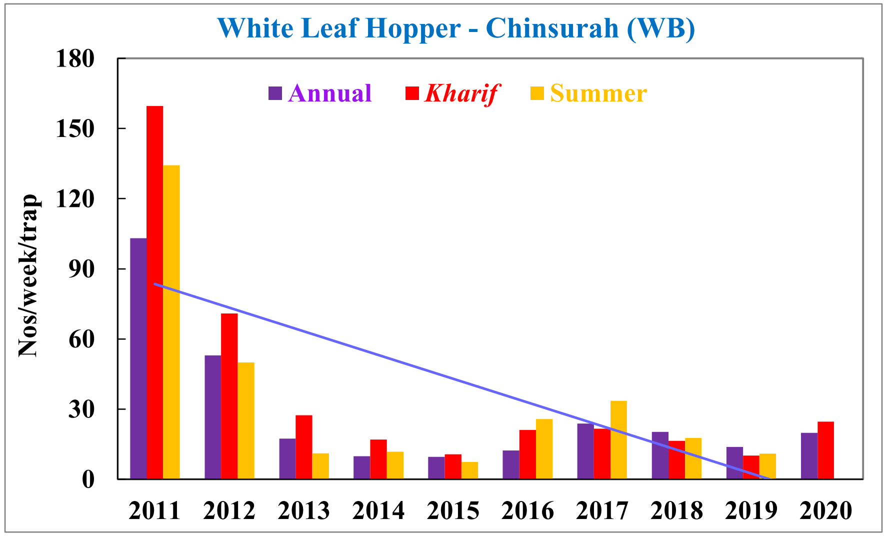
Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

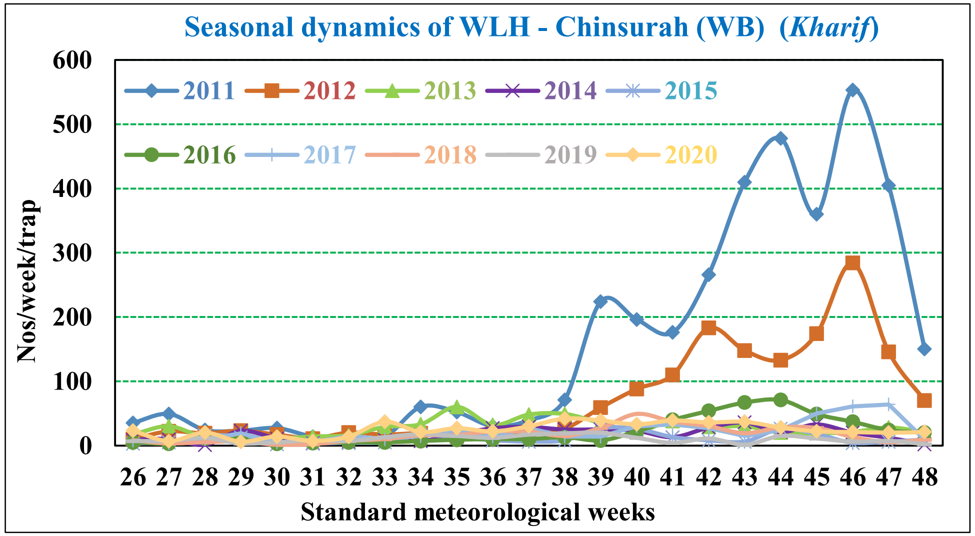
[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations





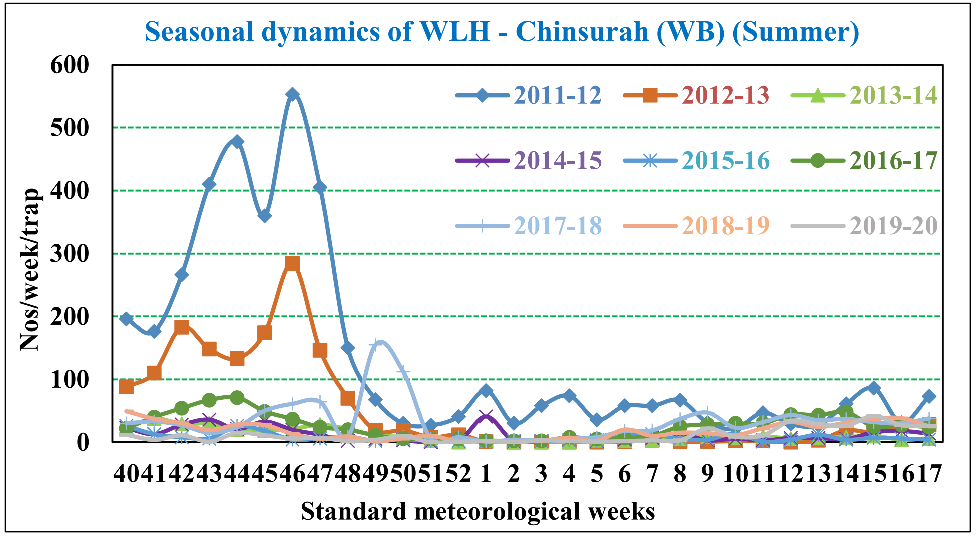
Chinsurah (WB)





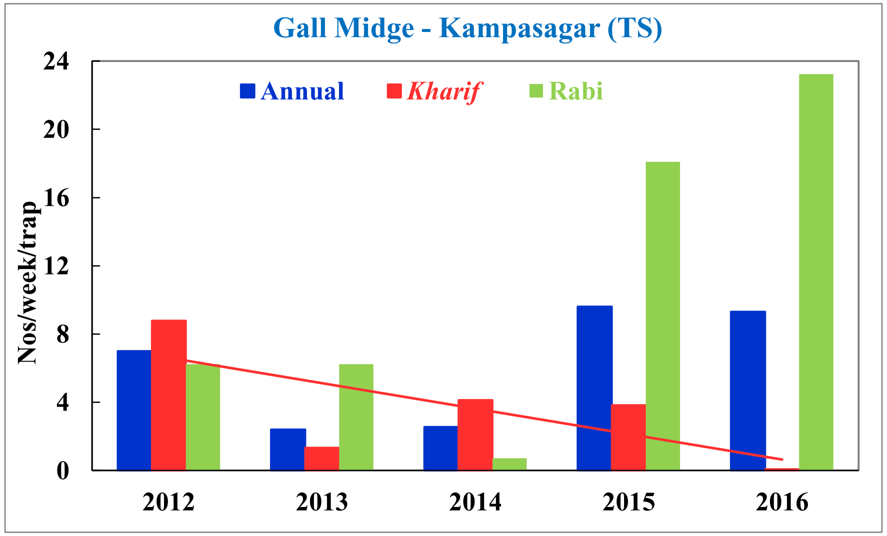
Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

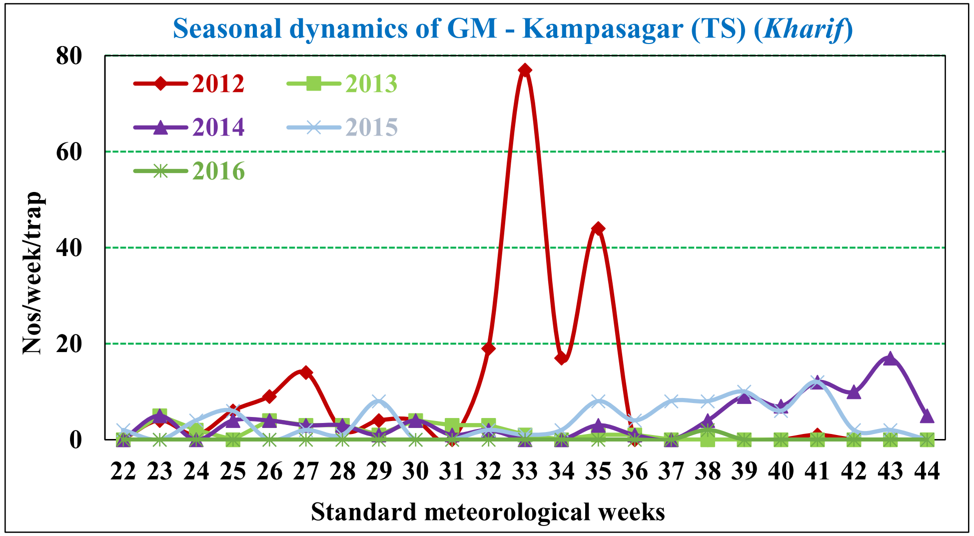
[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations



7. Gall midge

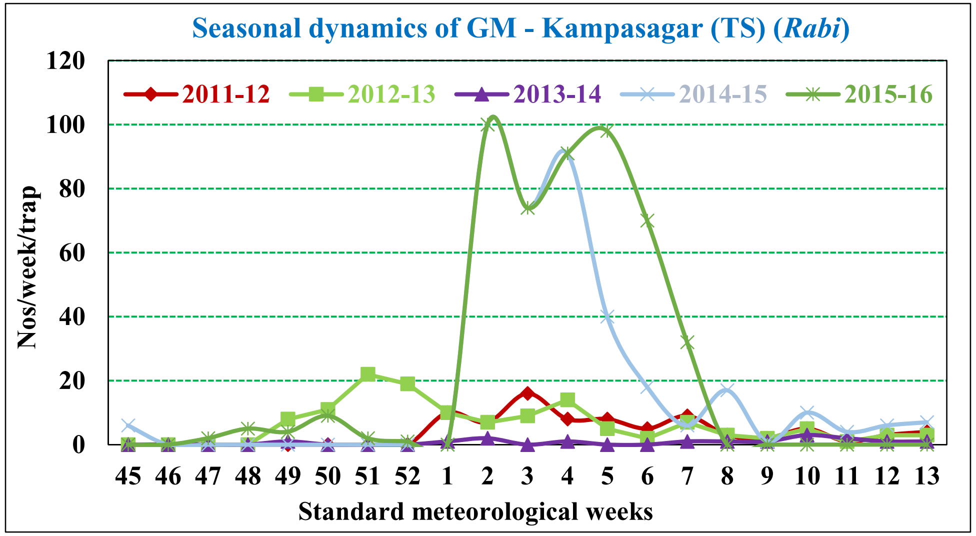
Kampasagar (TS)



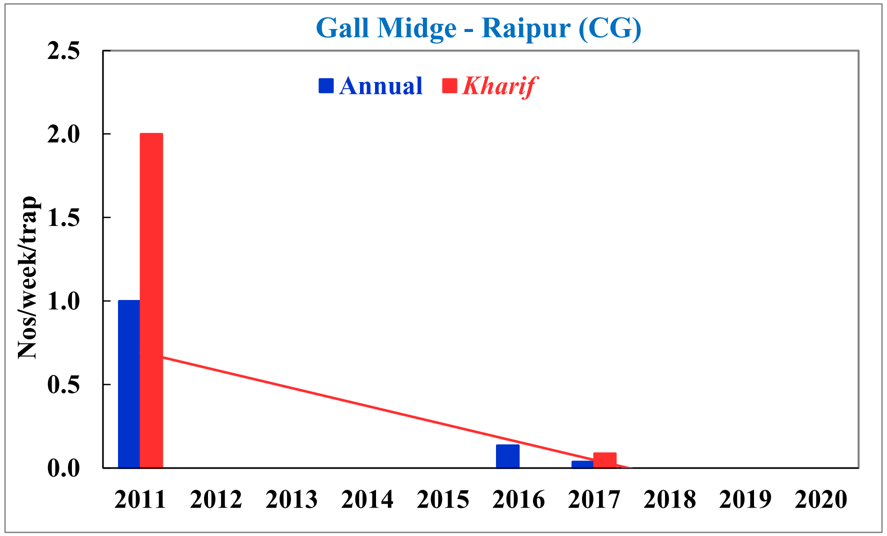


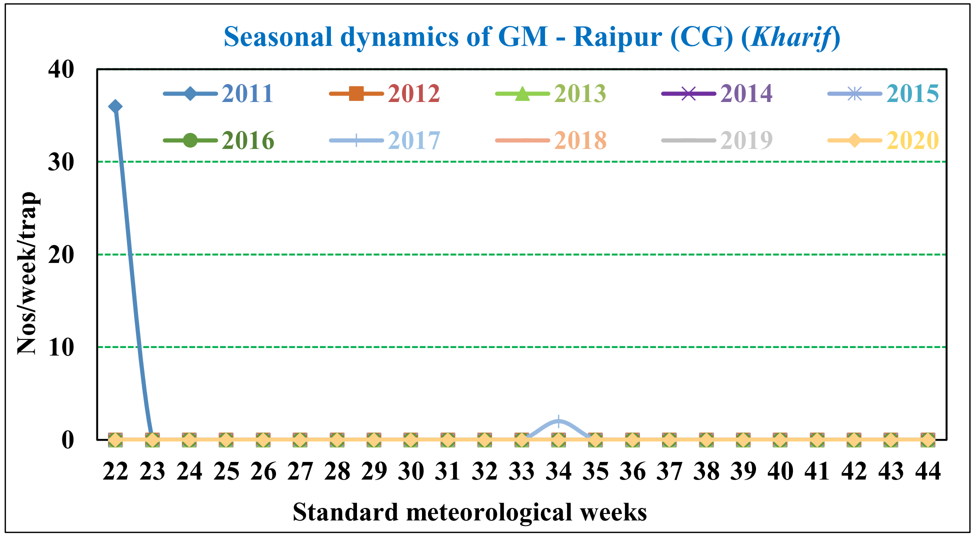
Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations



Raipur (CG)



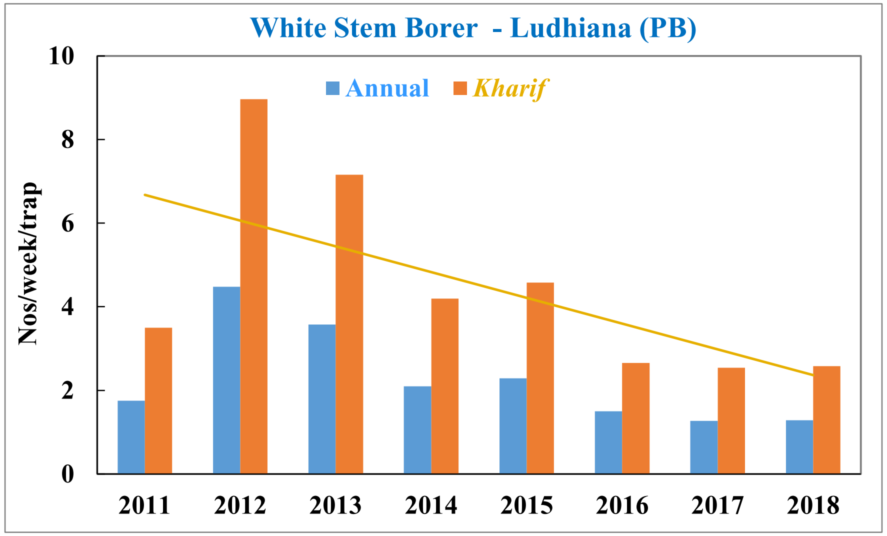


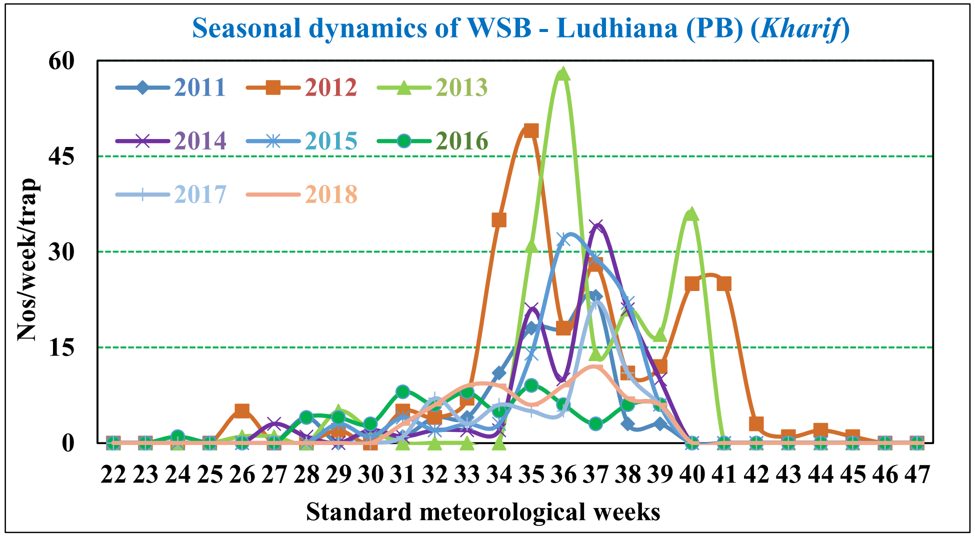
Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations

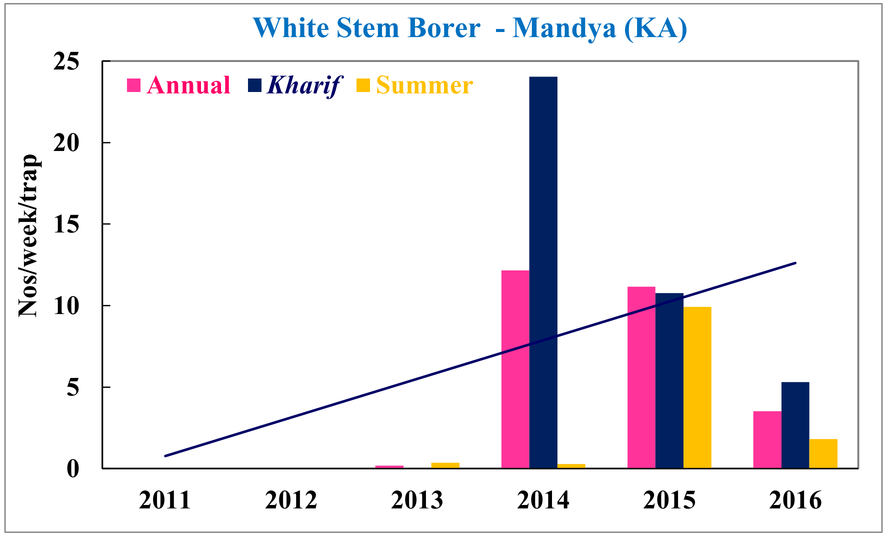
8. White stem borer

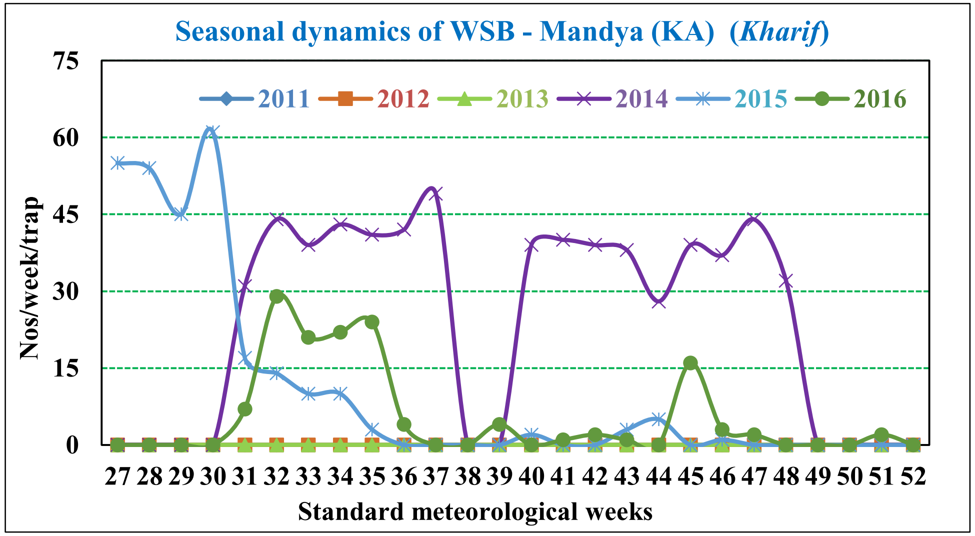
Ludhiana (PB)





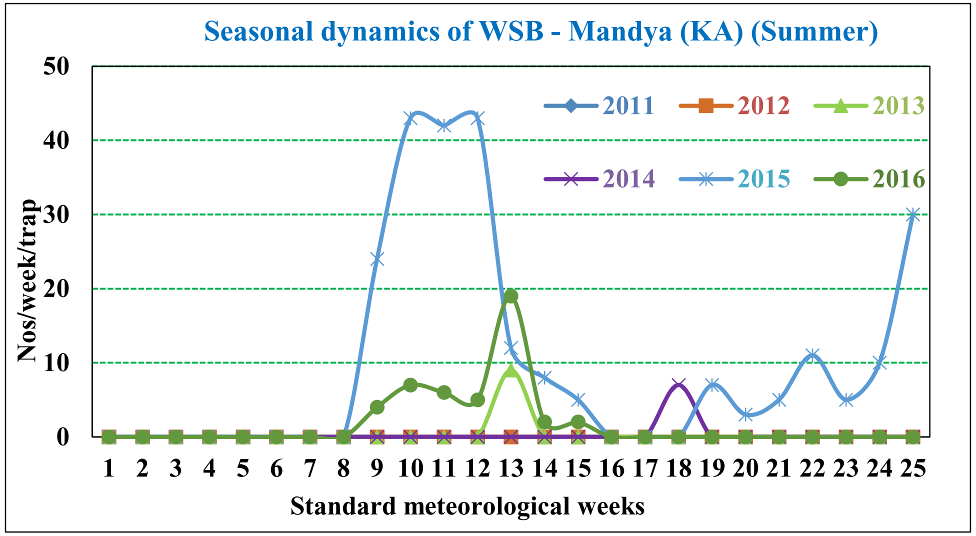
Mandya (KA)



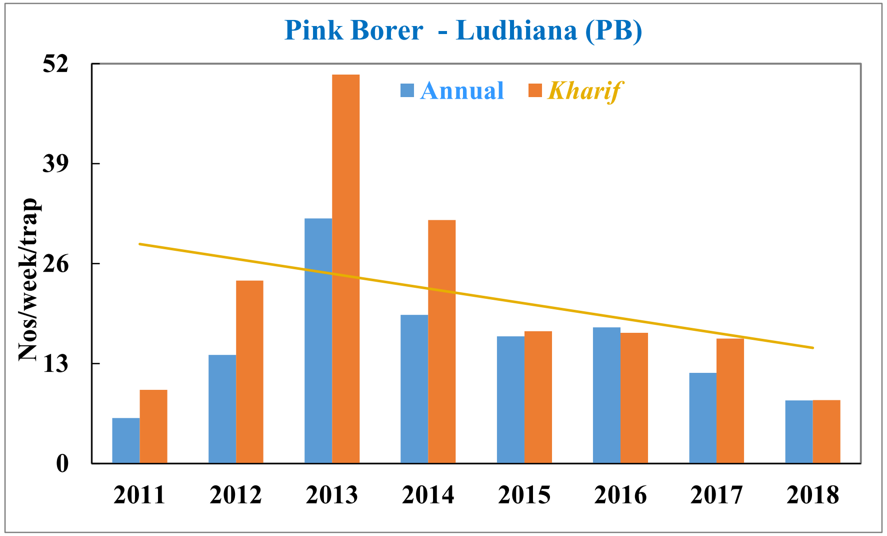


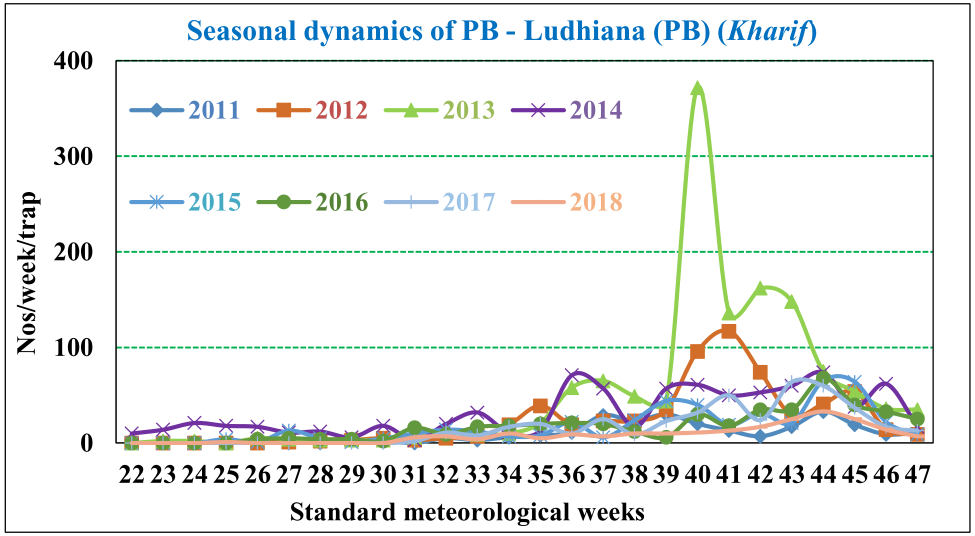
Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations



9. Pink borer- Ludhiana (PB)

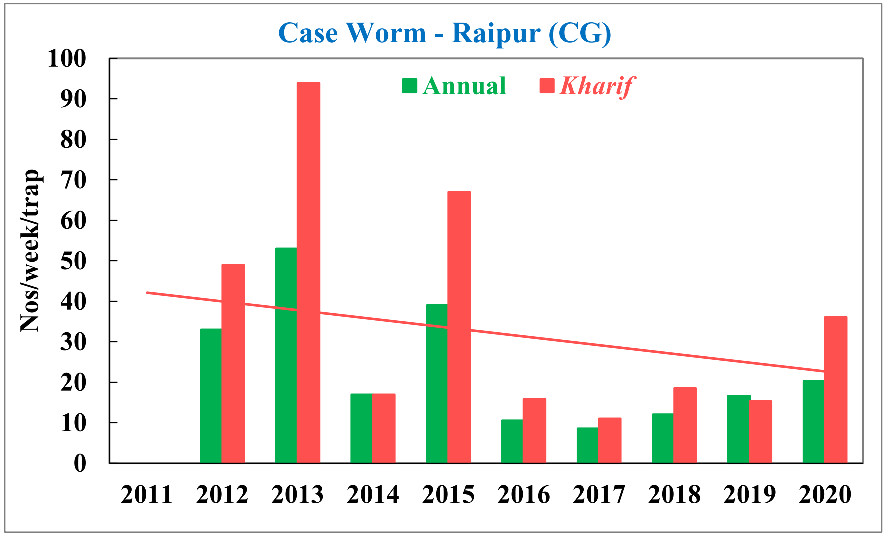


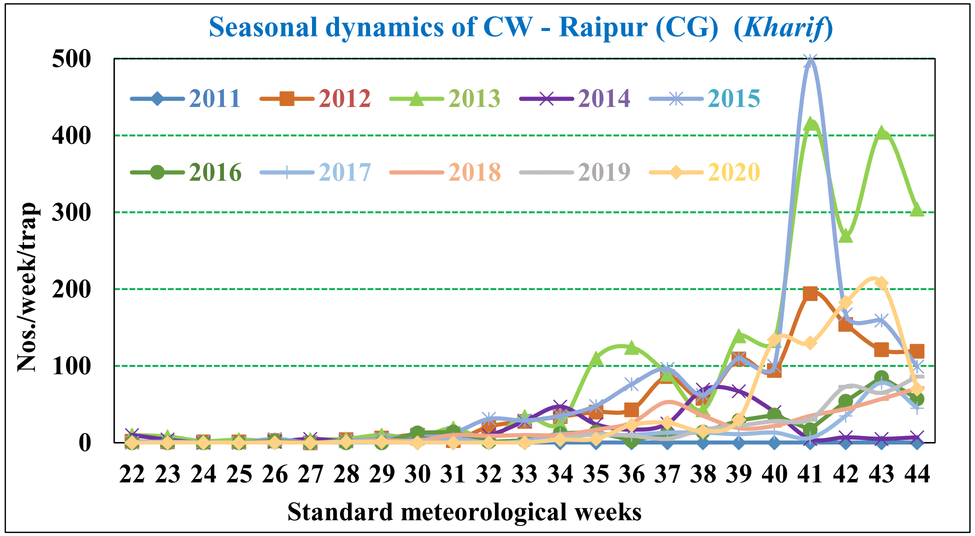


Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

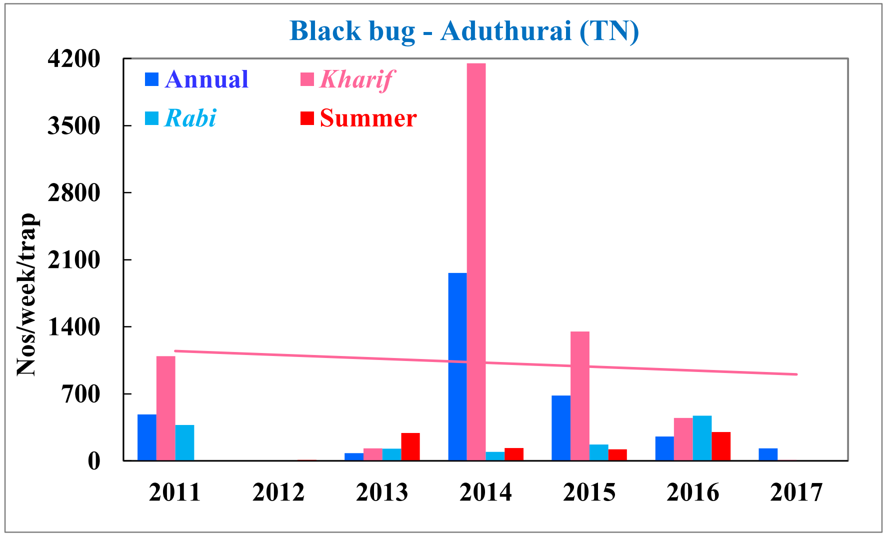
[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations

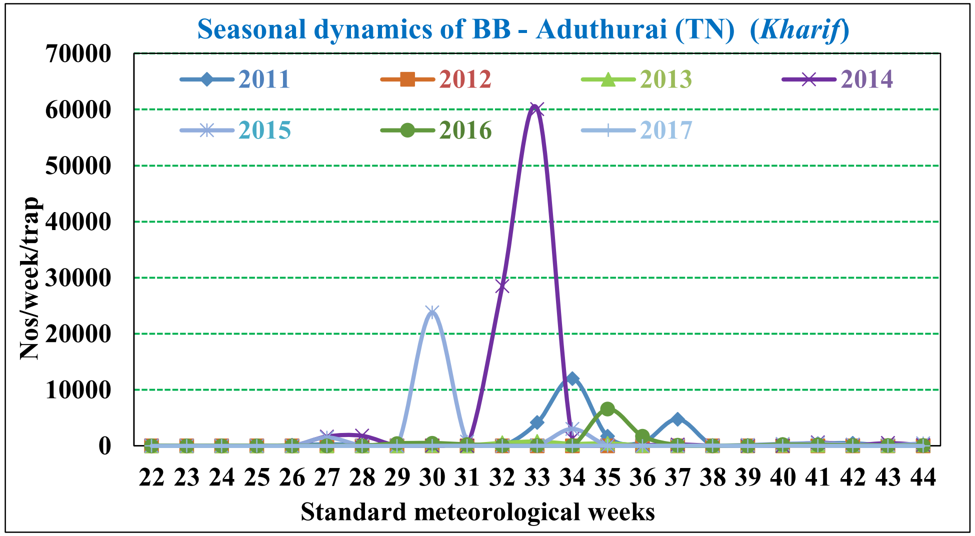
10. Case worm - Raipur (CG)





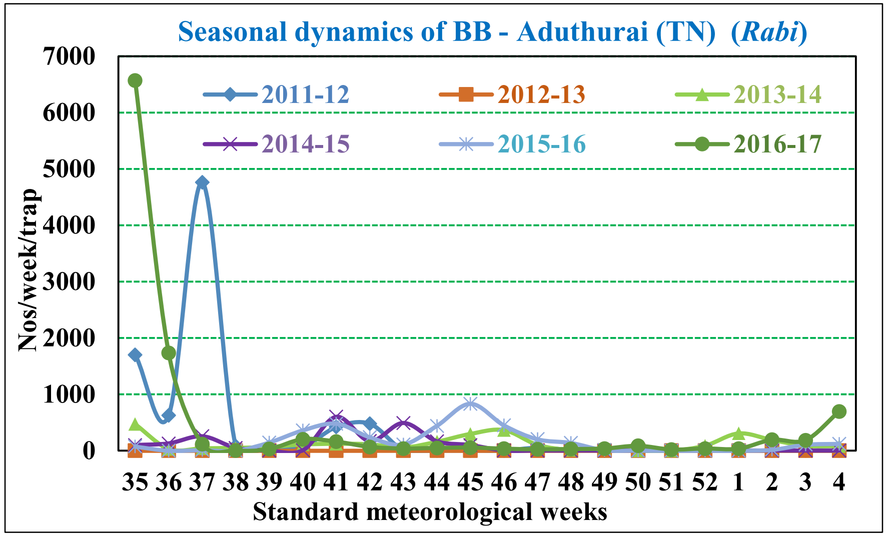
11. Black bug - Aduthurai (TN)

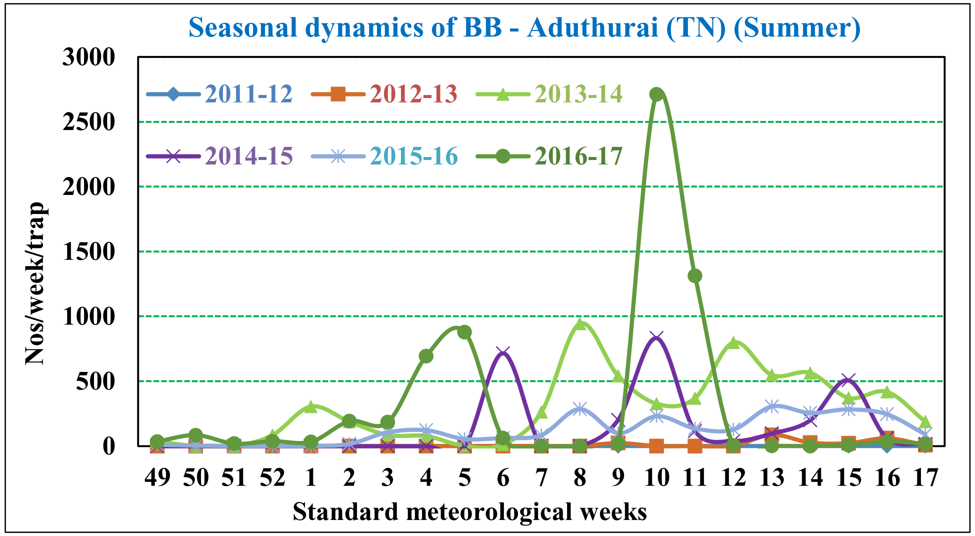




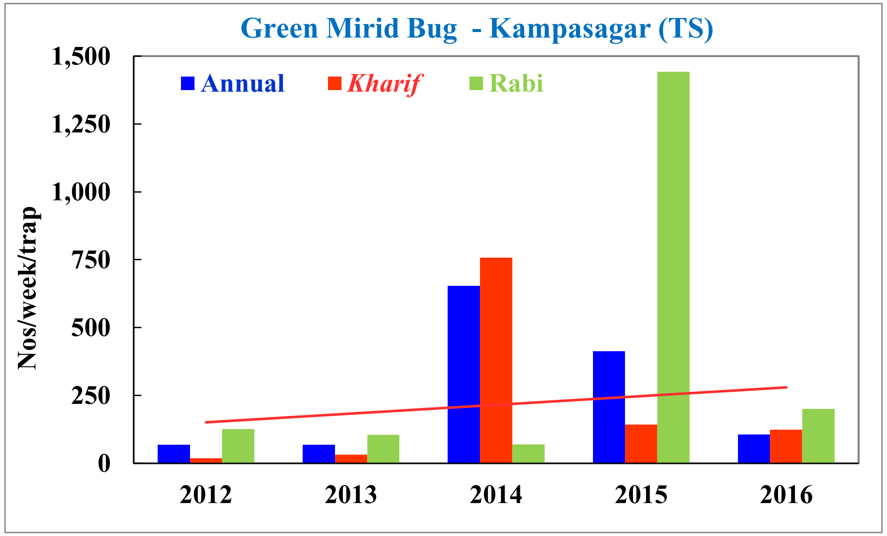
Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

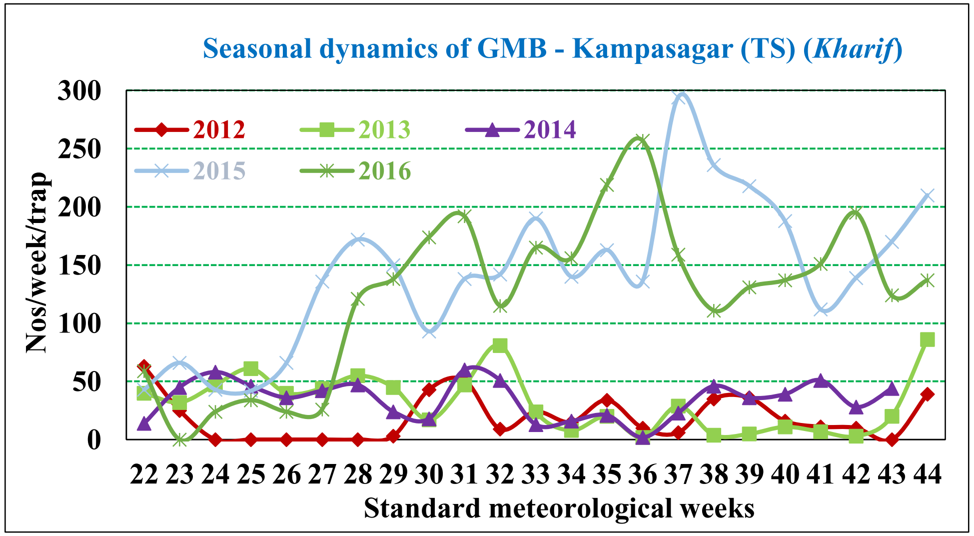
[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations





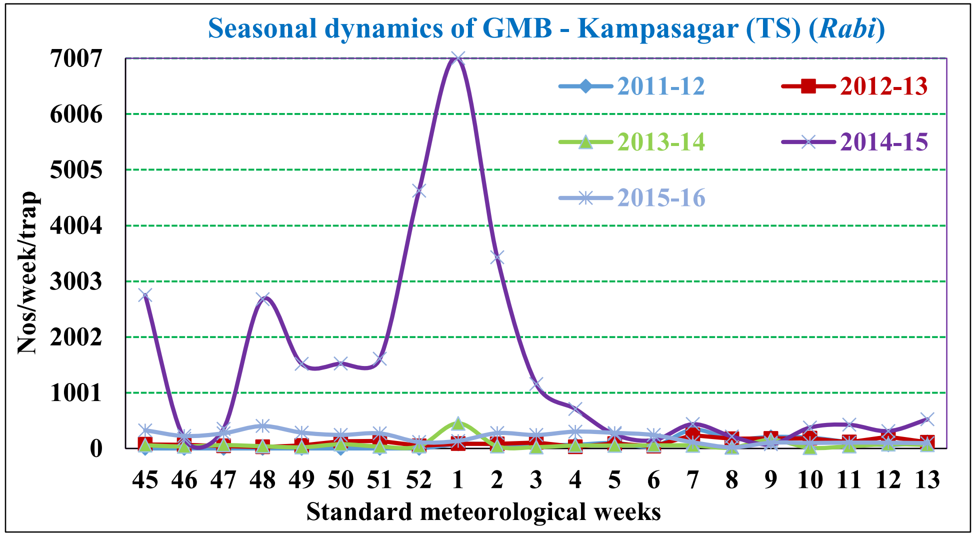
12. Green mirid bug - Kampasagar (TS)



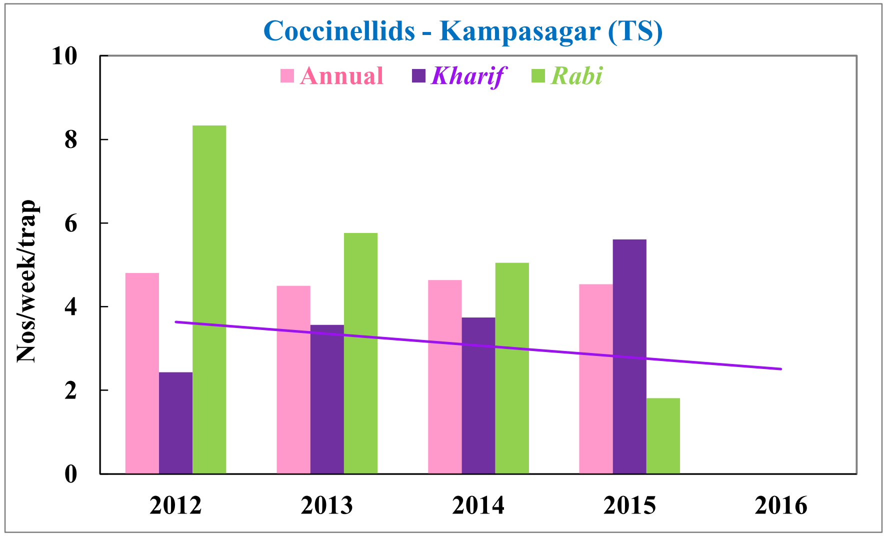


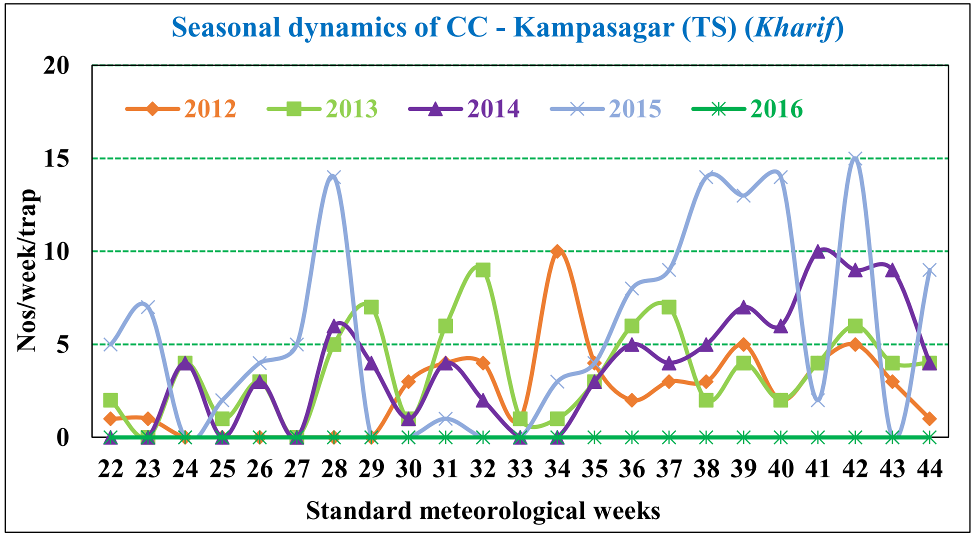
Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations



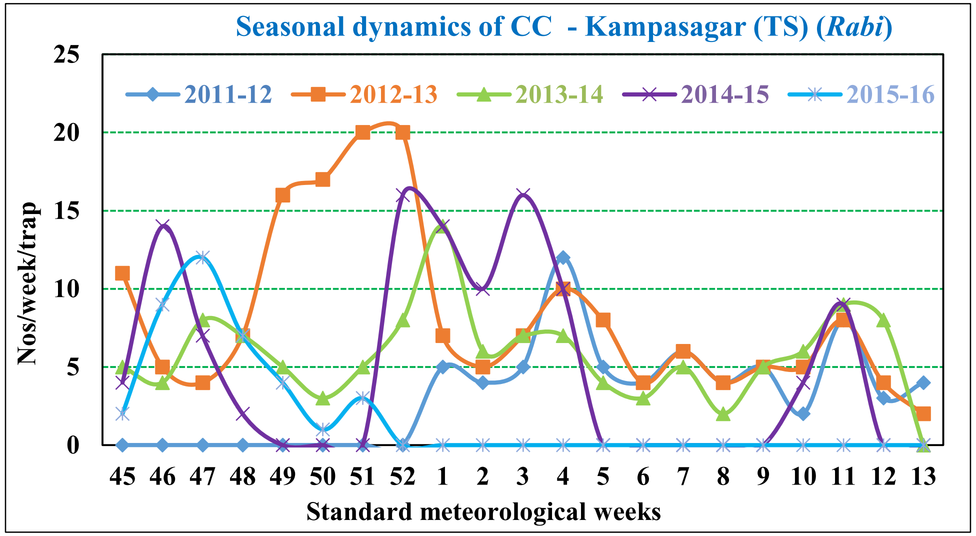
13. Coccinellids - Kampasagar (TS)





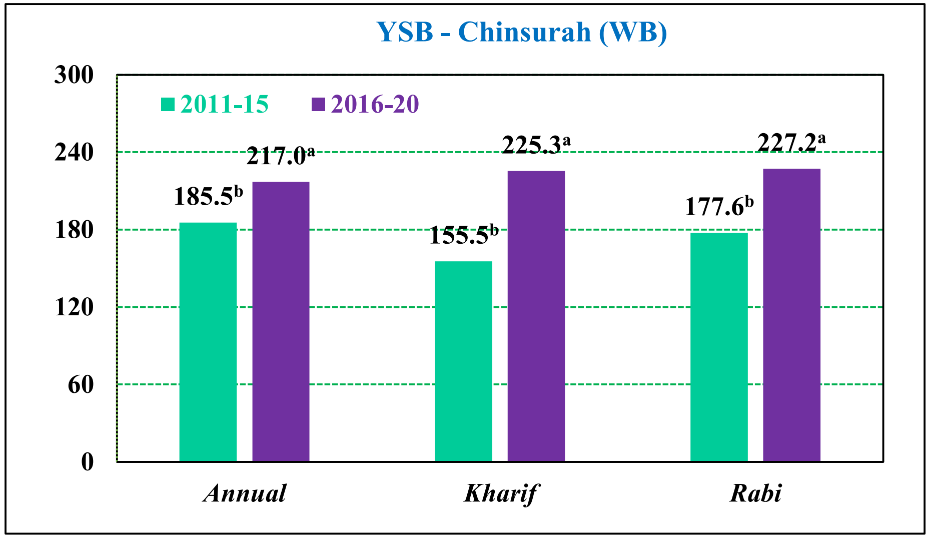
Annexure XVII : Seasonal dynamics of rice insects caught in light trap for study locations

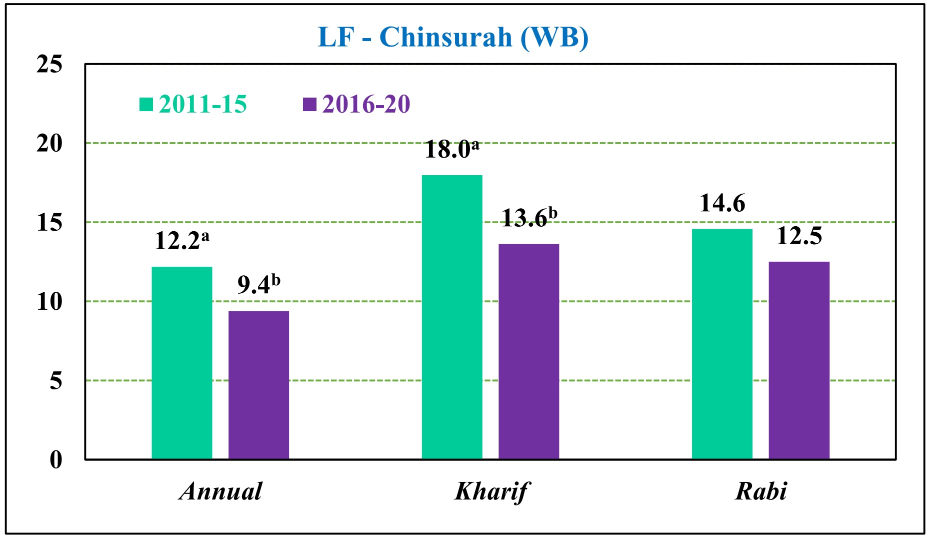
[Arranged insectwise covering status (bar graph) and dynamics (line graphs) for rice seasons as applicable to study locations

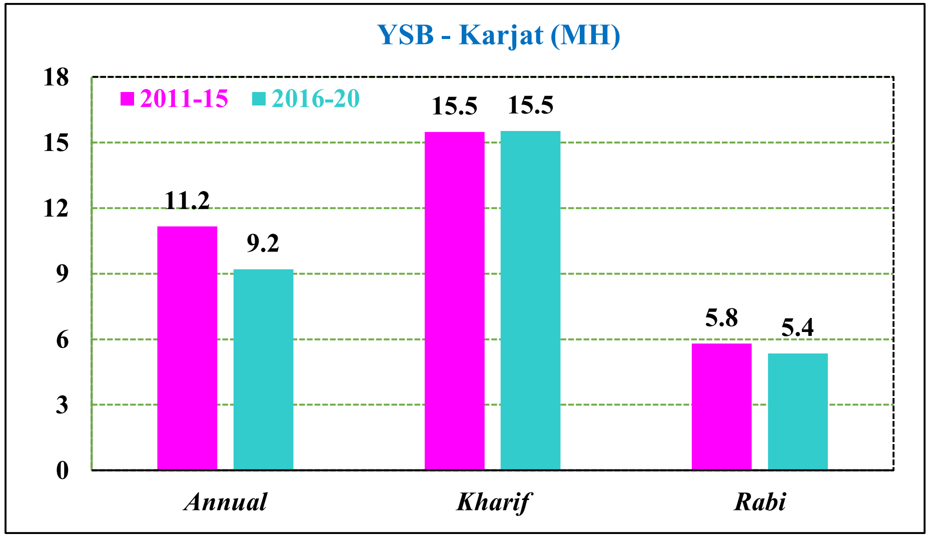


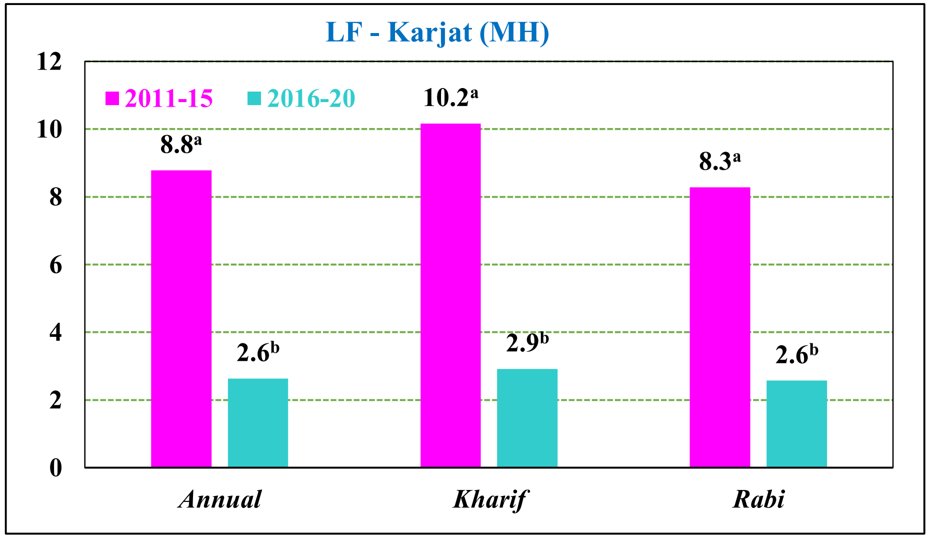
Note: Many legends and less lines shown in a graph denotes abundance/infestation (insects)/incidence/severity (diseases) very less or in traces, respectively

Annexure XVIII. Status of major lepidopterous and homopteran insects in respect of two half decades of 2011-2020
Abundance (y axis) (mean no./week/trap) based on annual and seasonal (*kharif* & *rabi*) light trap catches



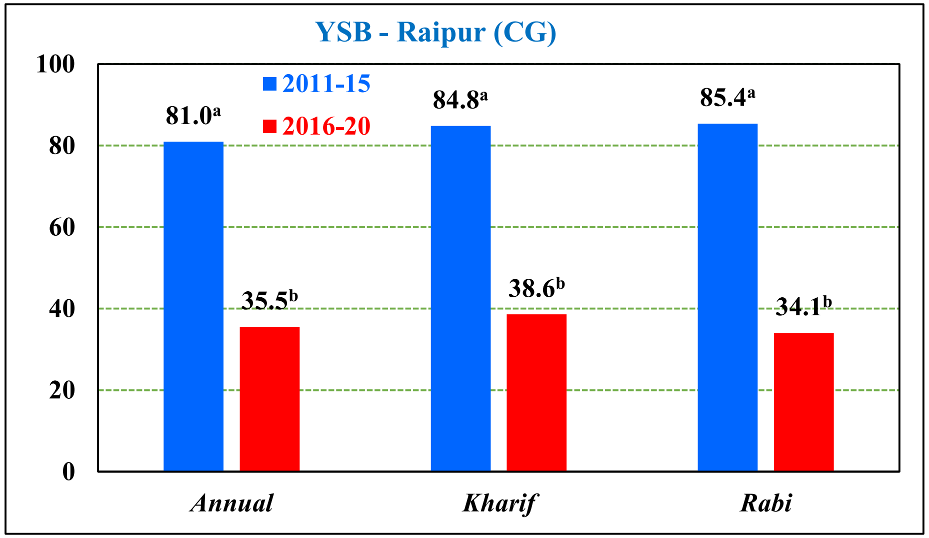


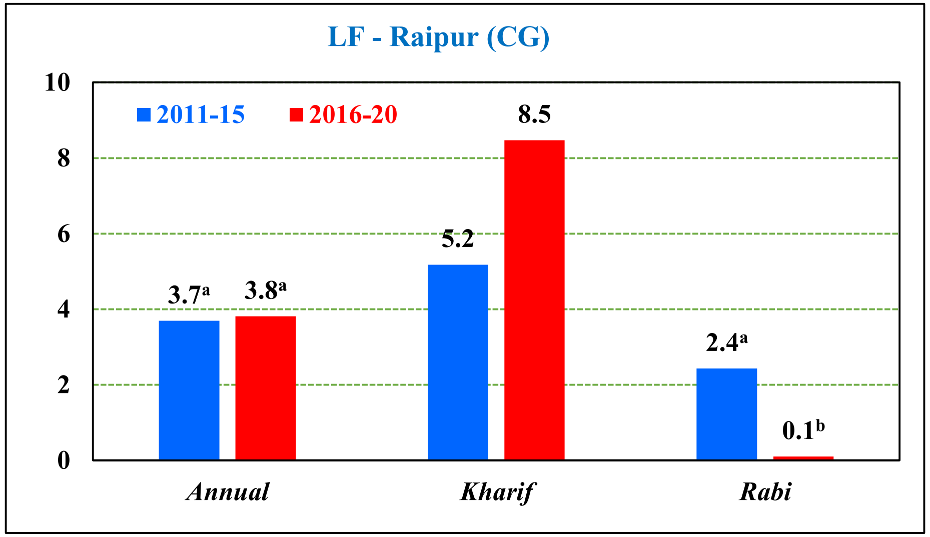


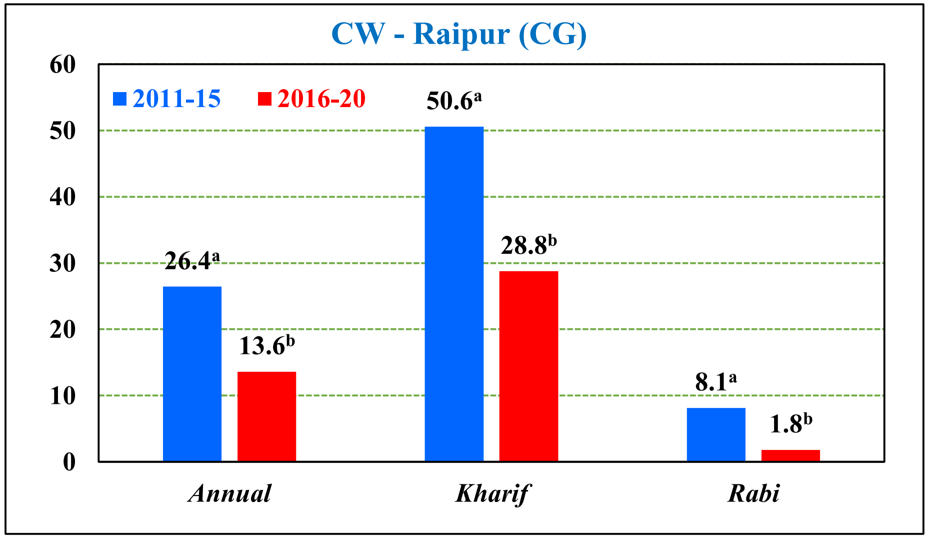


Annexure XVIII. Status of major lepidopterous and homopteran insects in respect of two half decades of 2011-2020

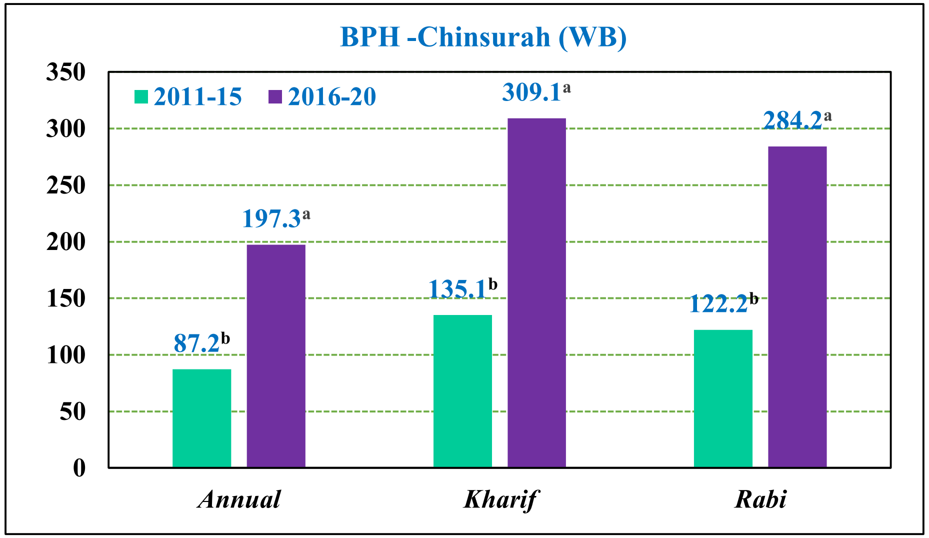
Abundance (y axis) (mean no./week/trap) based on annual and seasonal (*kharif* & *rabi*) light trap catches

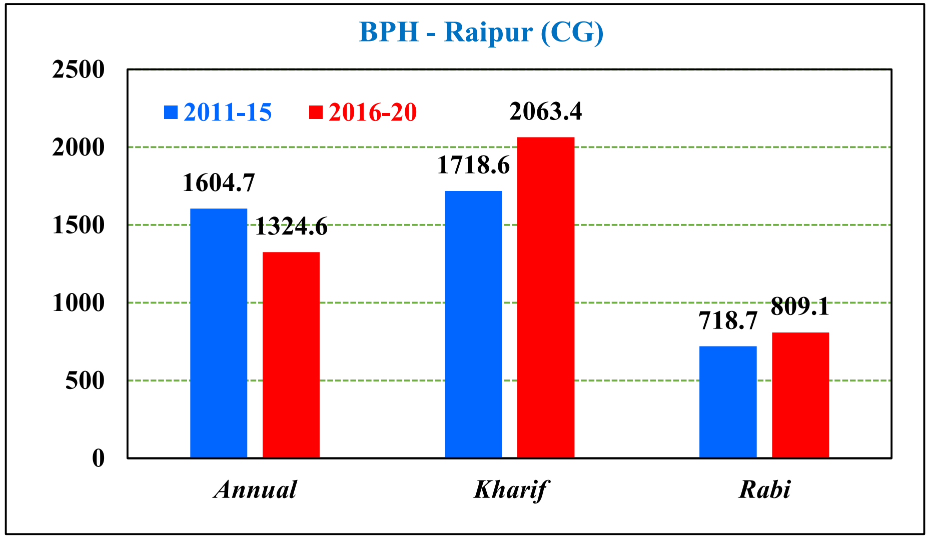


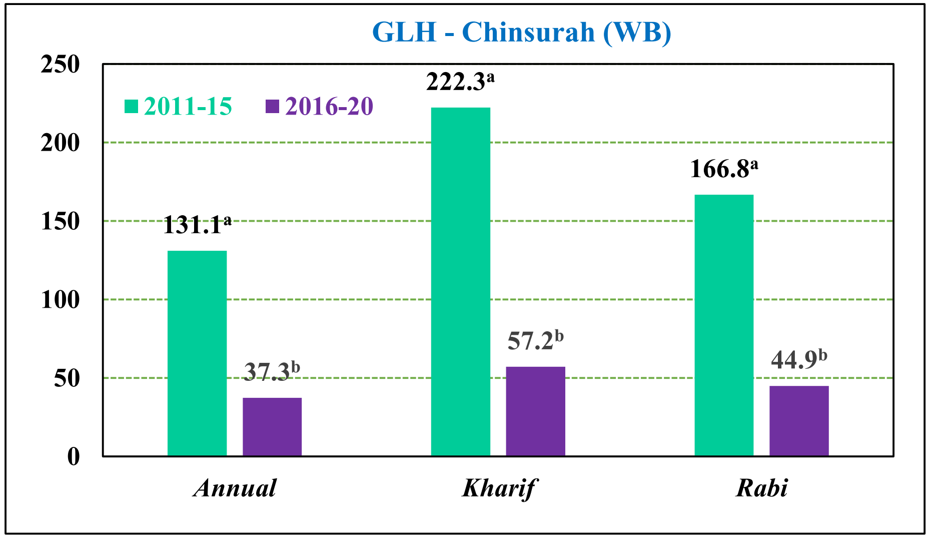


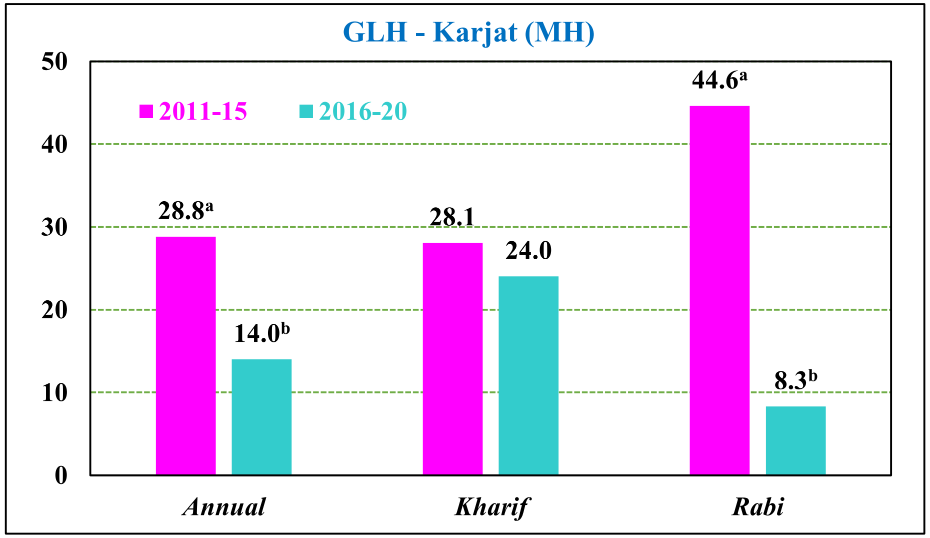


Annexure XVIII. Status of major lepidopterous and homopteran insects in respect of two half decades of 2011-2020
Abundance (y axis) (mean no./week/trap) based on annual and seasonal (*kharif* & *rabi*) light trap catches

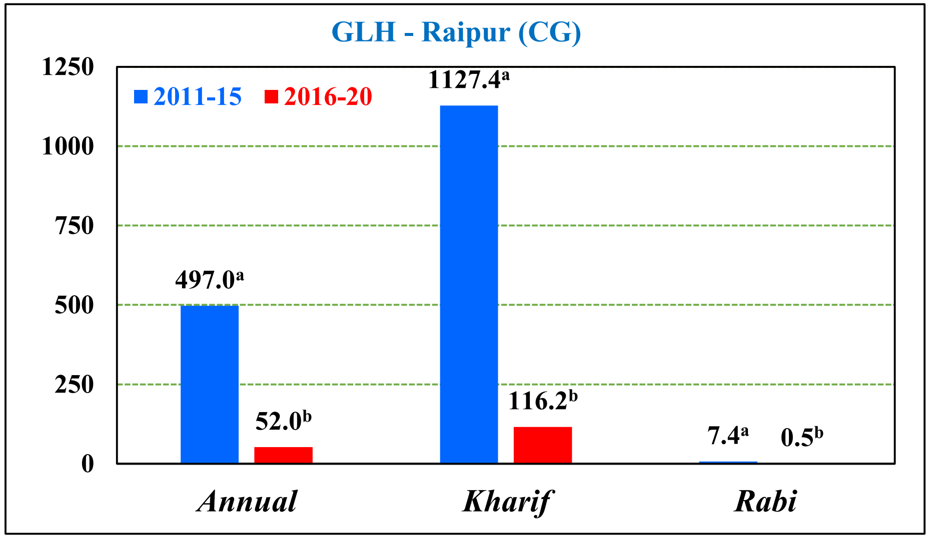


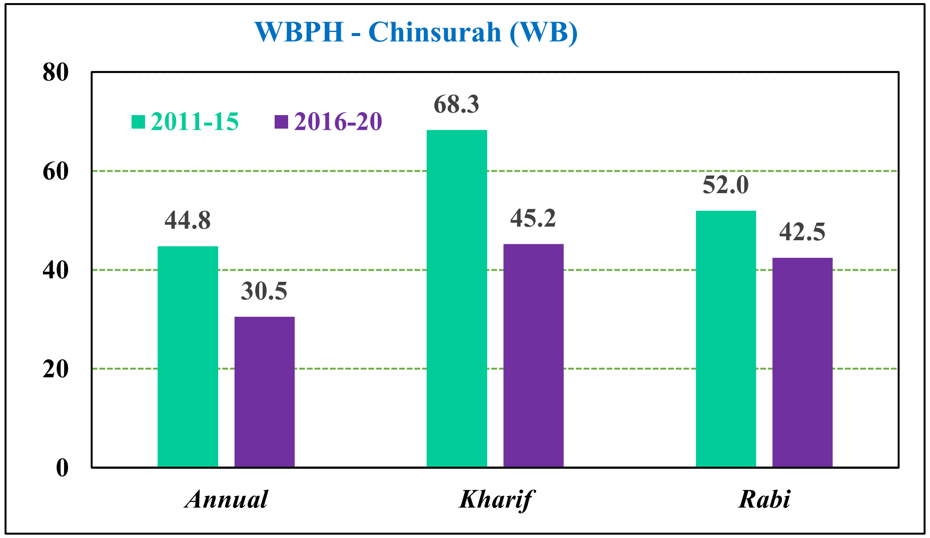


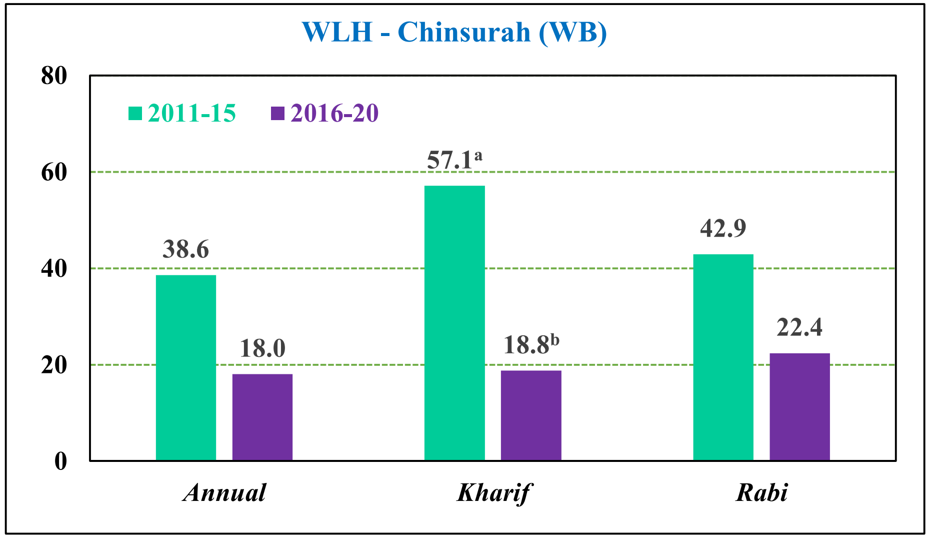




Annexure XVIII. Status of major lepidopterous and homopteran insects in respect of two half decades of 2011-2020
Abundance (y axis) (mean no./week/trap) based on annual and seasonal (*kharif* & *rabi*) light trap catches







Annexure XIX
Impact of climate change on rice insects - a listing and comparison across seasons

Location	*kharif*		*rabi*		summer	
	Adaptive	Vulnerable	Adaptive	Vulnerable	Adaptive	Vulnerable
Aduthurai (TN)	1. Leaf folder* 2. Yellow stem borer* 3. Green leaf hopper * 4. White leaf hopper * 5. Black bug	1. Brown plant hopper	1. Black bug 2. White leaf hopper* 3. Yellow stem borer* 4. Leaf folder* 5. Brown plant hopper* 6. Green leaf hopper*	-	1. Green leaf hopper* 2. Brown plant hopper* 3. Leaf folder 4. Yellow stem borer* 5. White leaf hopper	1. Black bug*
Chinsurah (WB)	1. White leaf hopper*	1. Green leaf hopper * 2. White backed plant hopper* 3. Yellow stem borer * 4. Brown plant hopper* 5. Leaf folder *			**1.** Leaf folder*	1. White leaf hopper 2. Green leaf hopper* 3. Yellow stem borer* 4. White backed plant hopper* **5.** Brown plant hopper*
Karjat (MH)	1. Yellow stem borer 2. Leaf folder 3. Green leaf hopper		1. Leaf folder*	1. Yellow stem borer* 2. Green leaf hopper*		
Kampasagar (TS)		1. Gall midge 2. Brown plant hopper* 3. Yellow stem borer 4. Coccinellid 5. White backed plant hopper 6. Leaf folder* 7. Green mirid bug 8. Green leaf hopper*	1. Green mirid bug* 2. Yellow stem borer* 3. Green leaf hopper	1. Gall midge 2. Brown plant hopper* 3. Coccinellids* 4. Leaf folder* 5. White backed plant hopper*		

Impact of climate change on rice insects - a listing and comparison across seasons

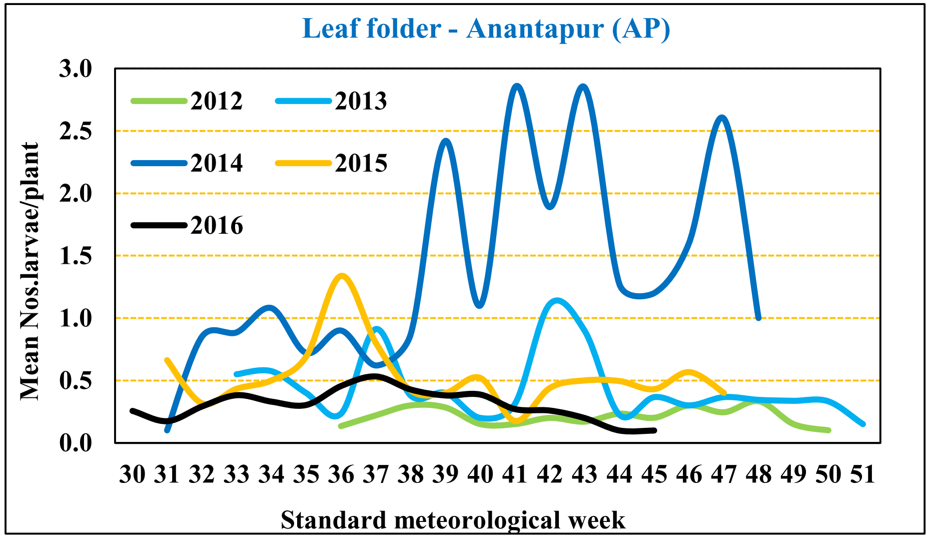
Location	*kharif*		*rabi*		summer	
	Adaptive	Vulnerable	Adaptive	Vulnerable	Adaptive	Vulnerable
Ludhiana (PB)	1. Brown planthopper 2. Pink stem borer 3. Leaf folder* 4. Yellow stem borer 5. White backed planthopper	1. White stem borer				
Mandya (KA)	1. White stem borer*	1. Yellow stem borer* 2. Green leaf hopper*				1. White stem borer* 2. Yellow stem borer* 3. Green leaf hopper*
Raipur (CG)	1. Gall midge	1. Caseworm 2. Brown planthopper* 3. Leaf folder* 4. Green leafhopper* 5. Yellow stem borer*				

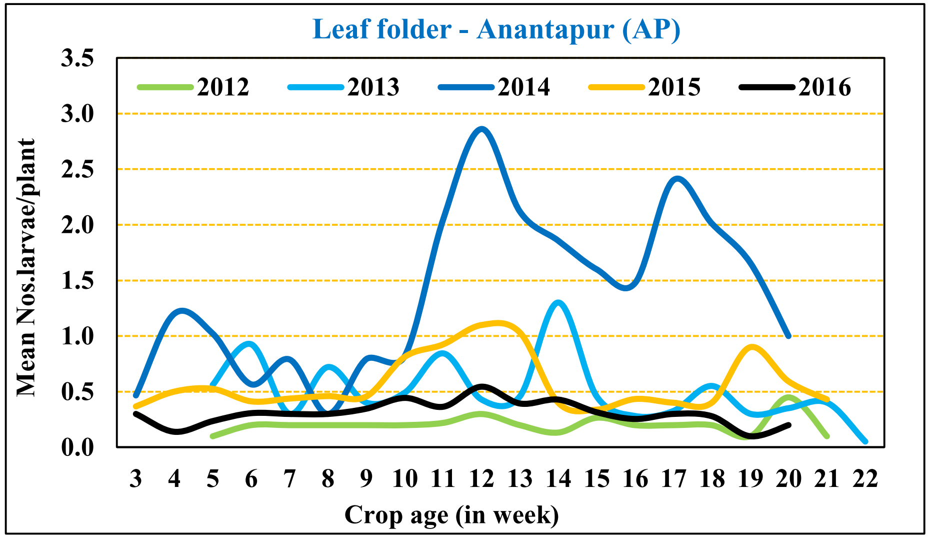
Insects have been listed along the order of importance for the cumulative impact of climate change based on species – climate change association index values; species with positive SAIs (Tables 26 & 27) are grouped under adaptation and the negative ones under vulnerability to climate change; symbol* associated with insects indicate the definitive influence of atleast one or all-climatic variables (MaxT, MinT, RF) having significant association with population dynamics irrespective of the significance of magnitude of climate change for the variables; insect without* specify the non significance of the association between population dynamics and climatic deviations of all three variables (MaxT., MinT., & RF)

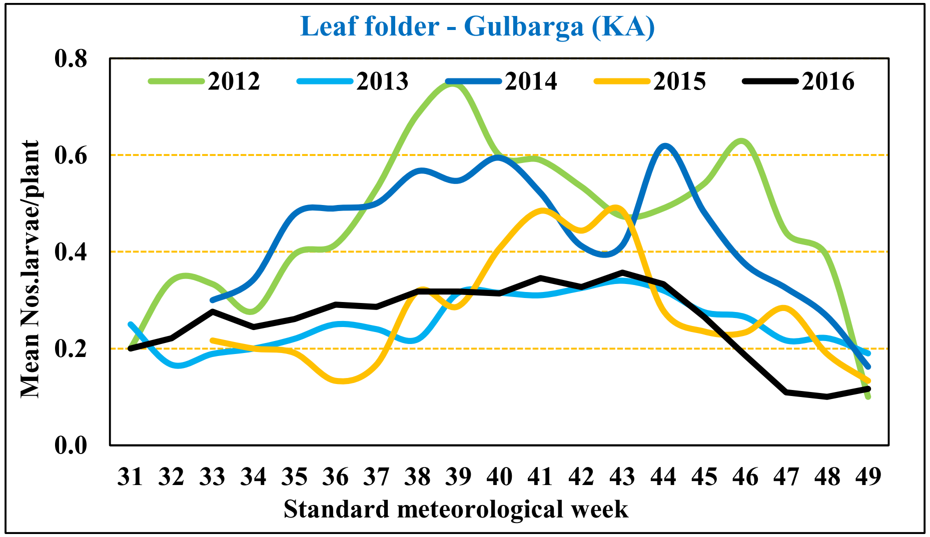
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

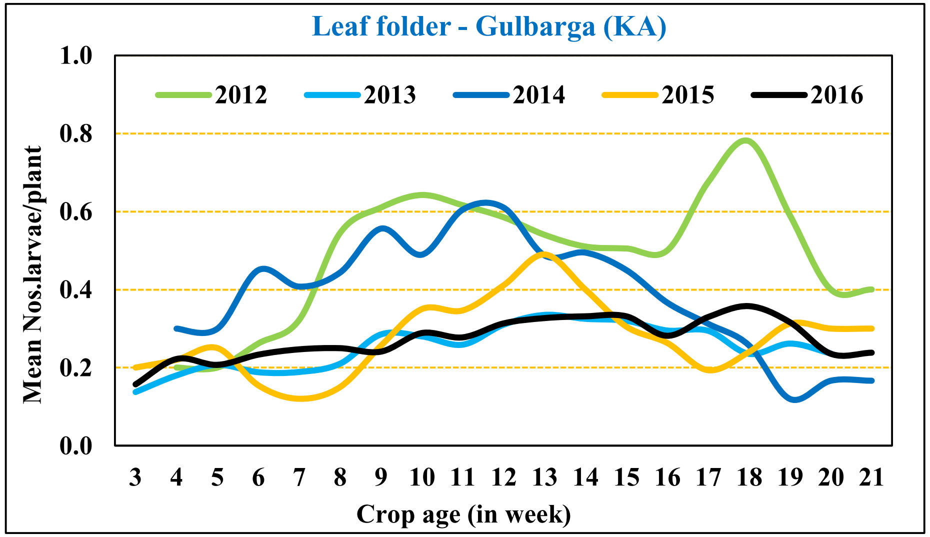
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



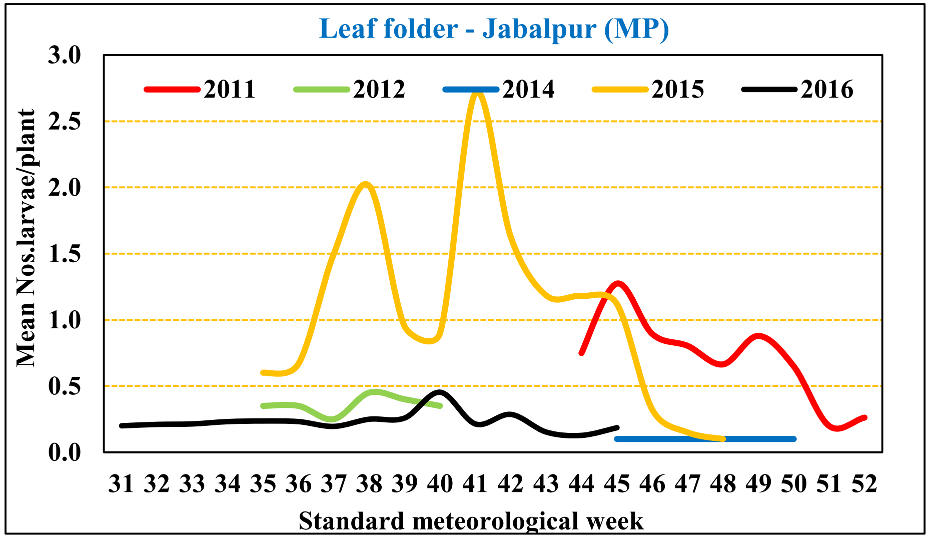


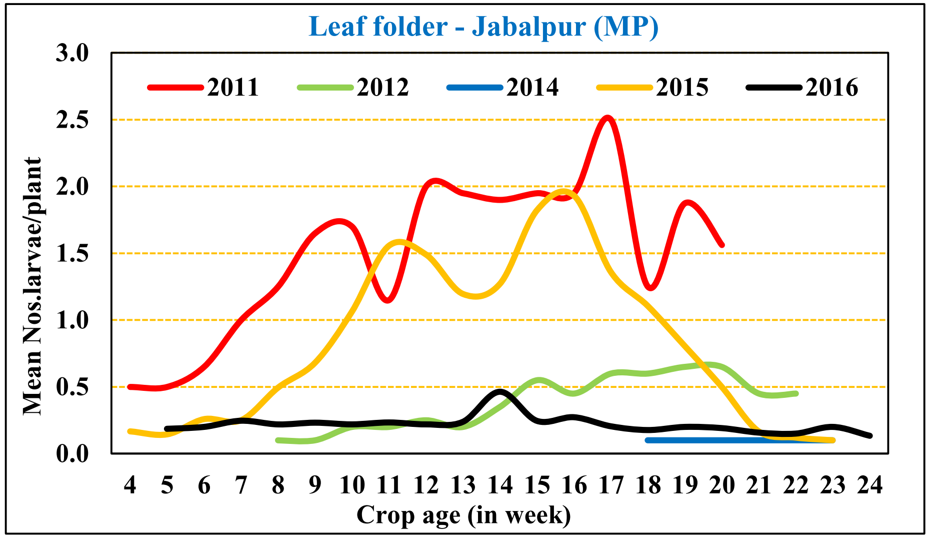


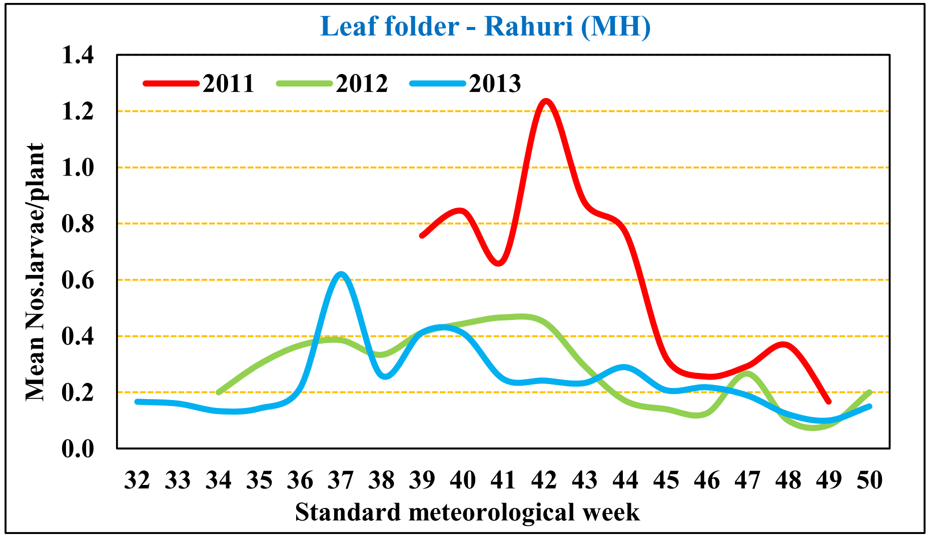


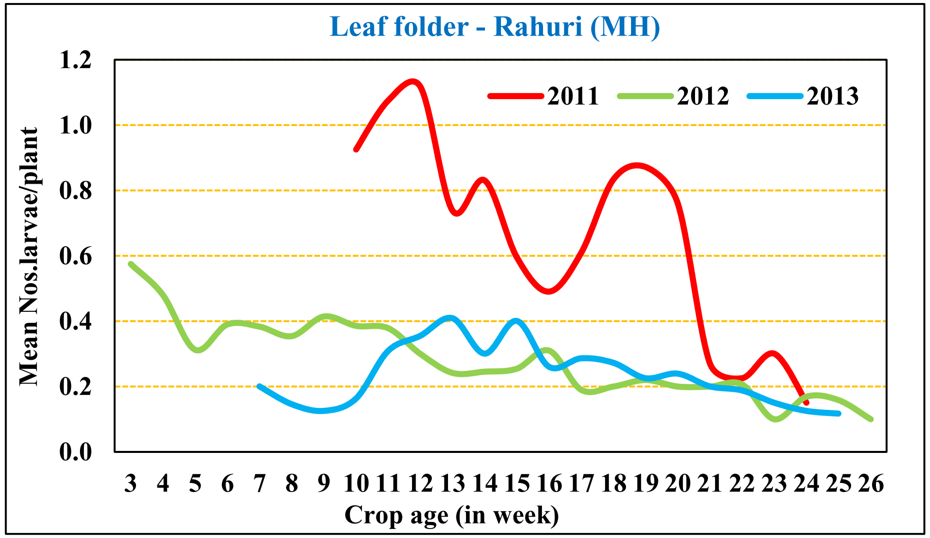
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | Seasonal dynamics based on crop age



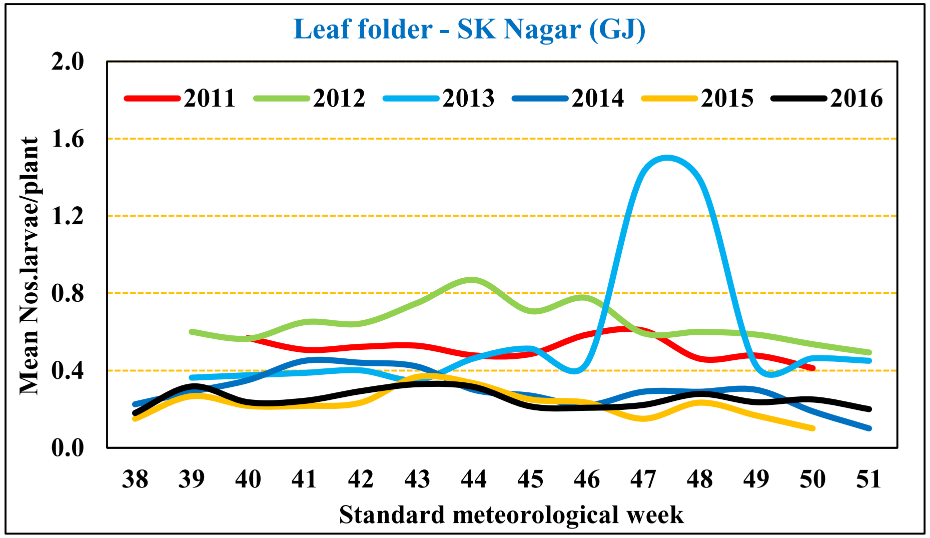


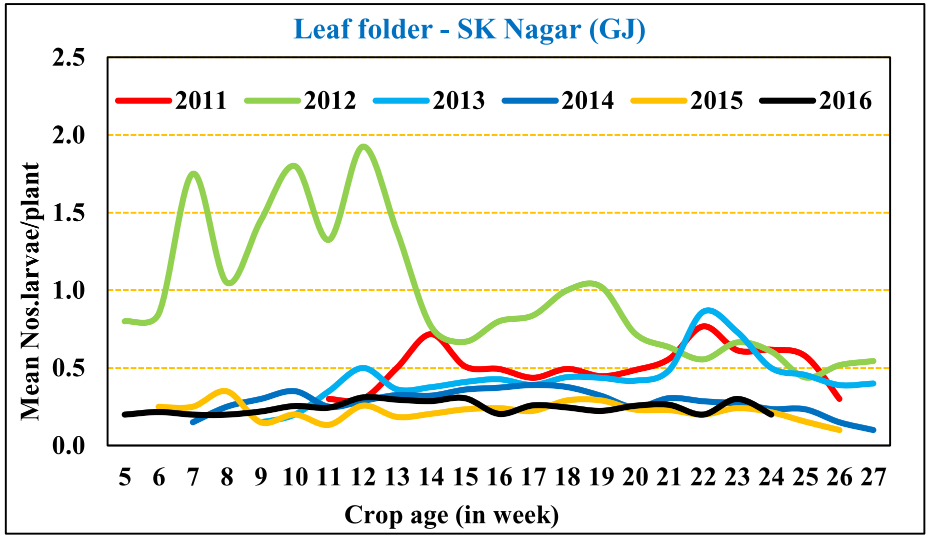


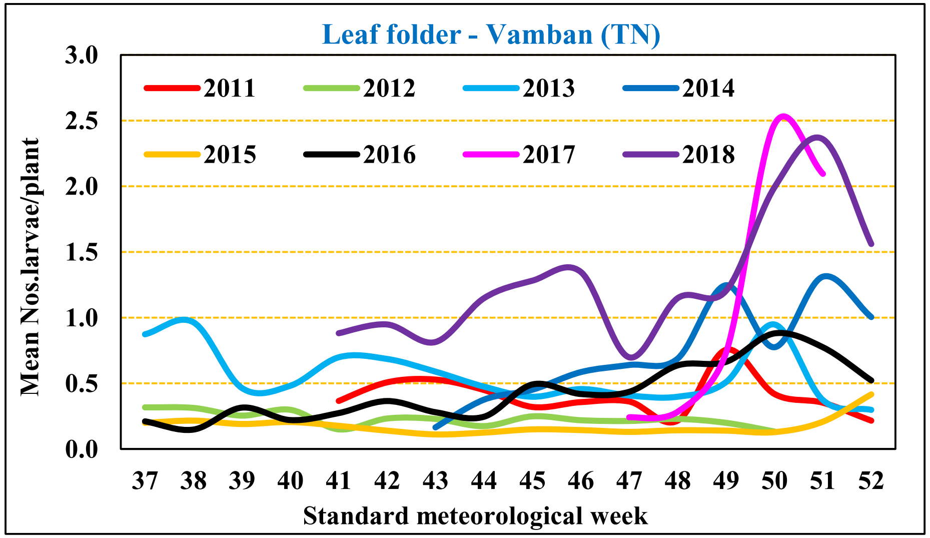


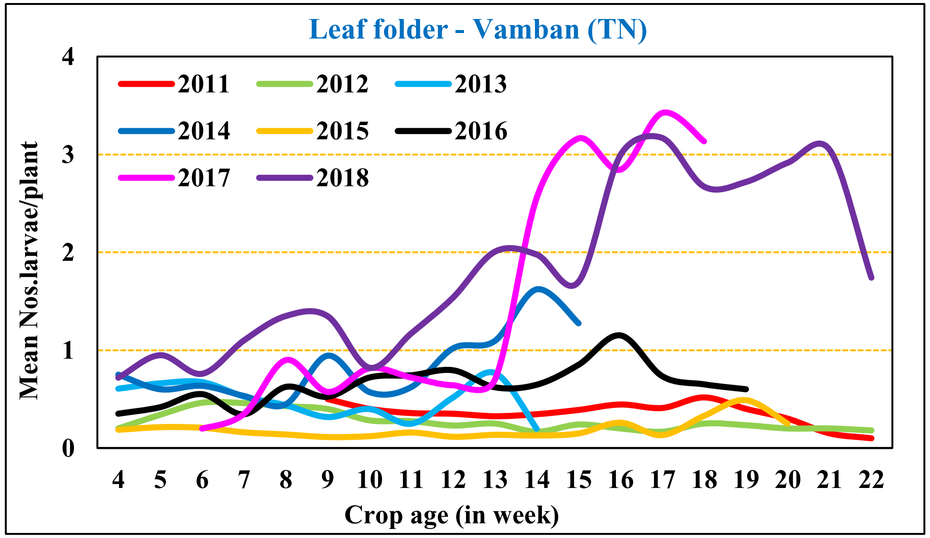
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**





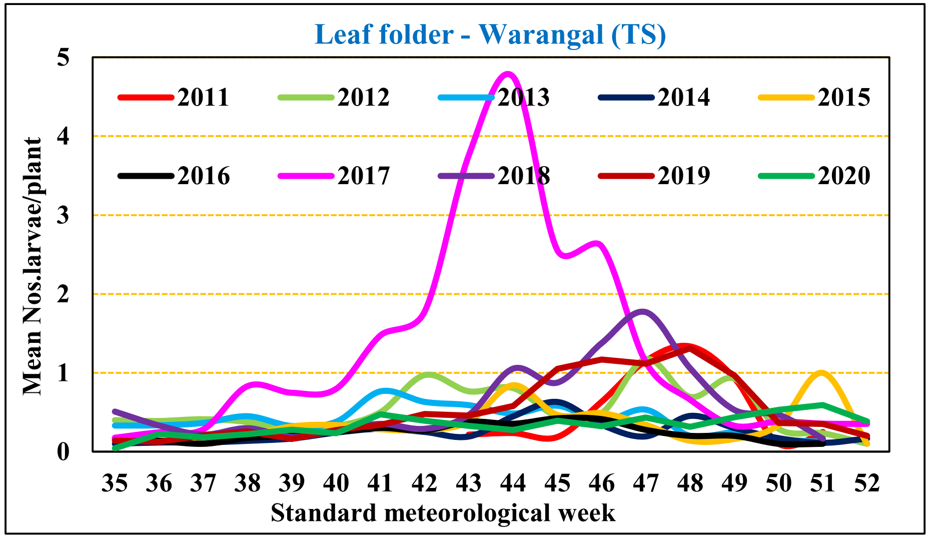


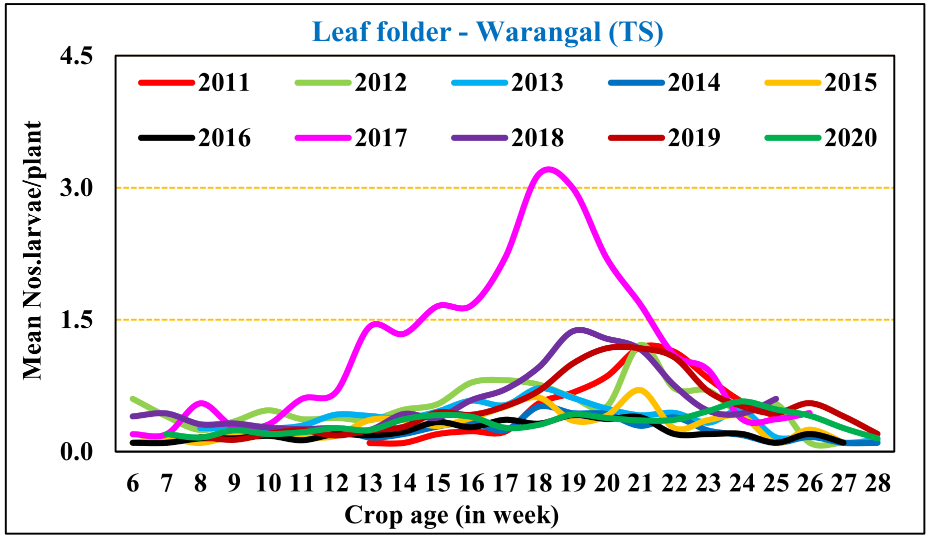


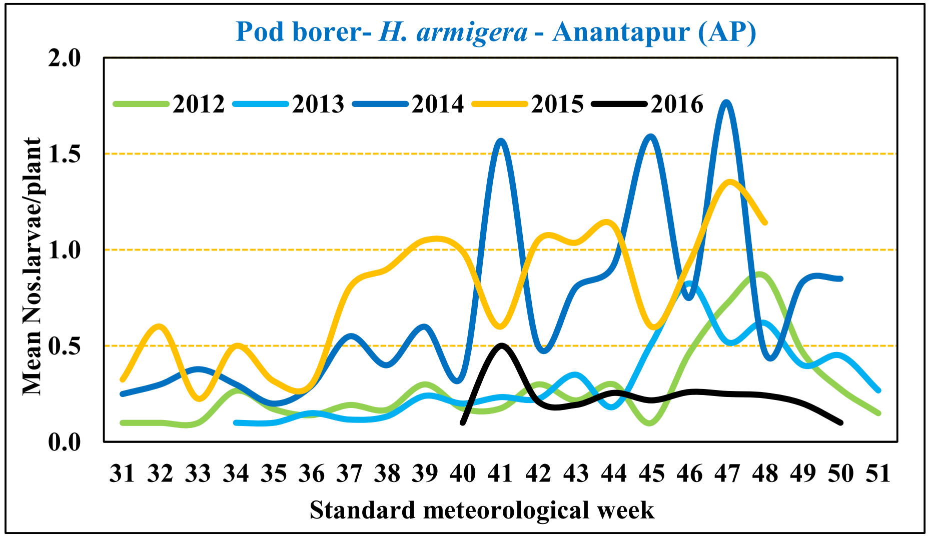
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

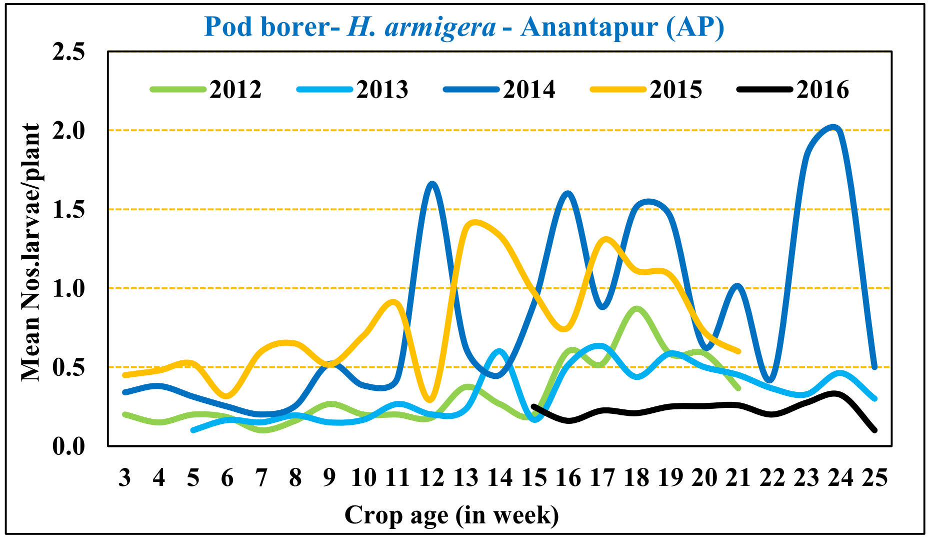
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





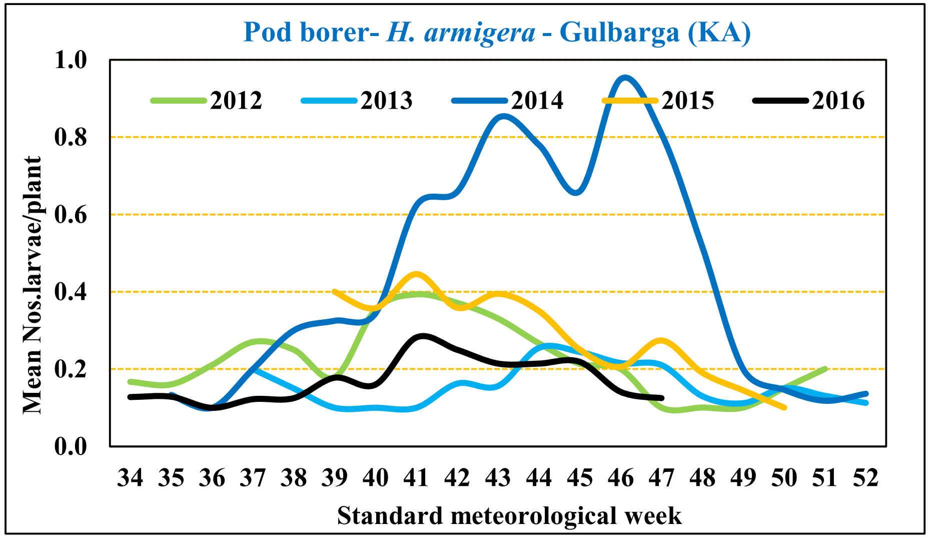


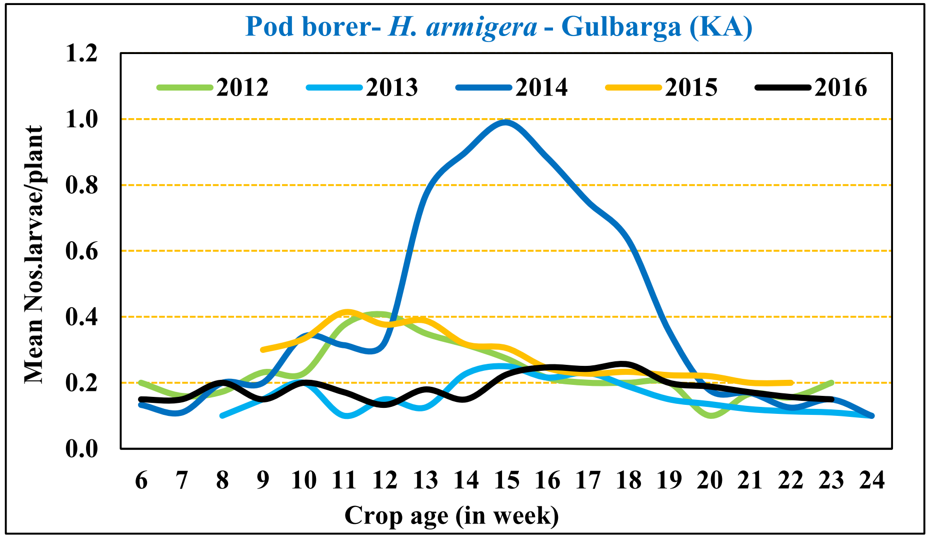


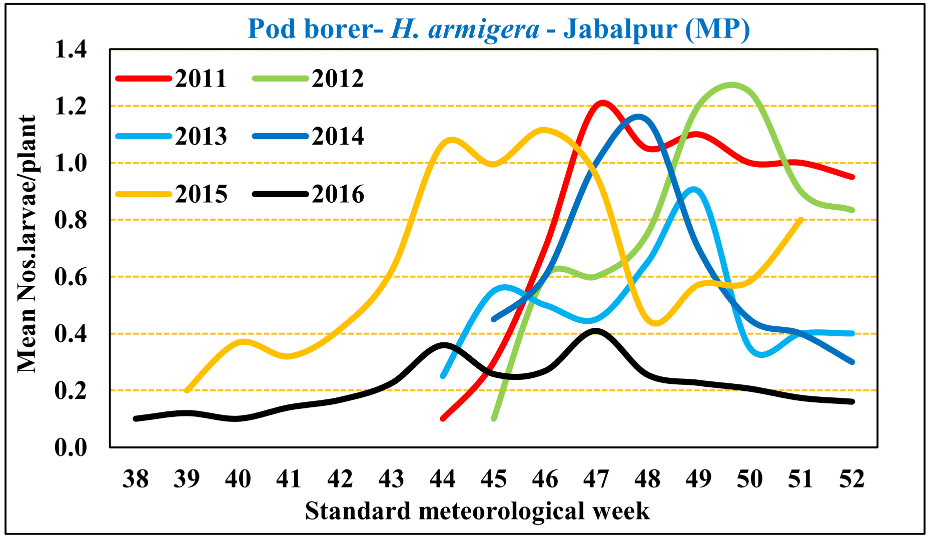
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

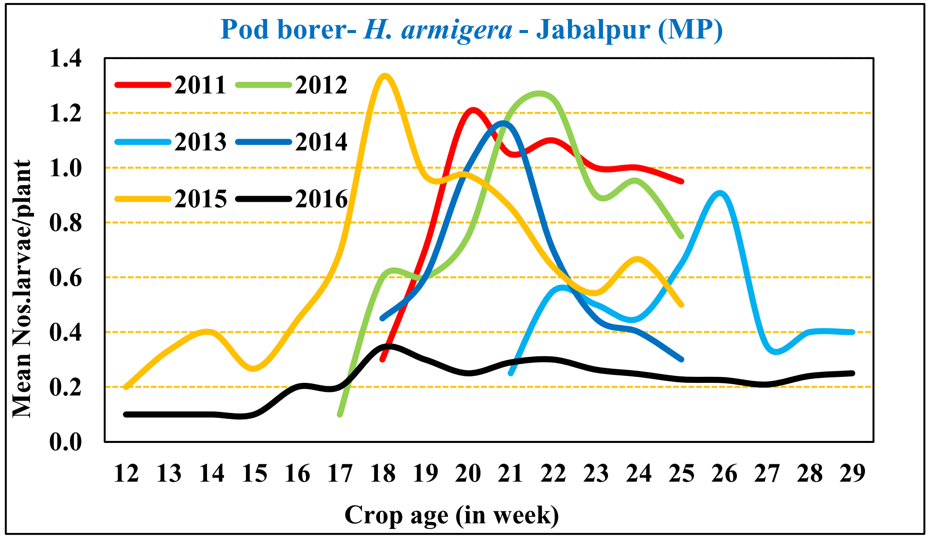
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





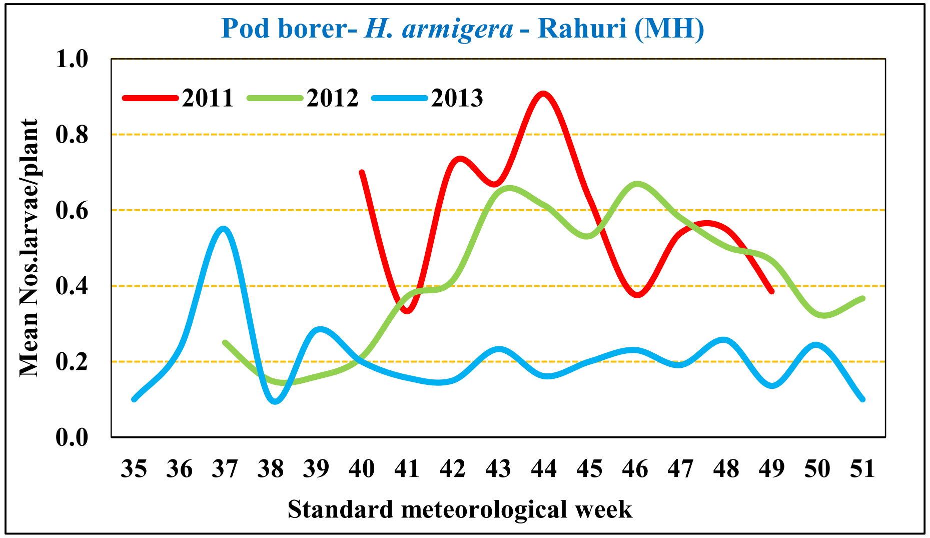


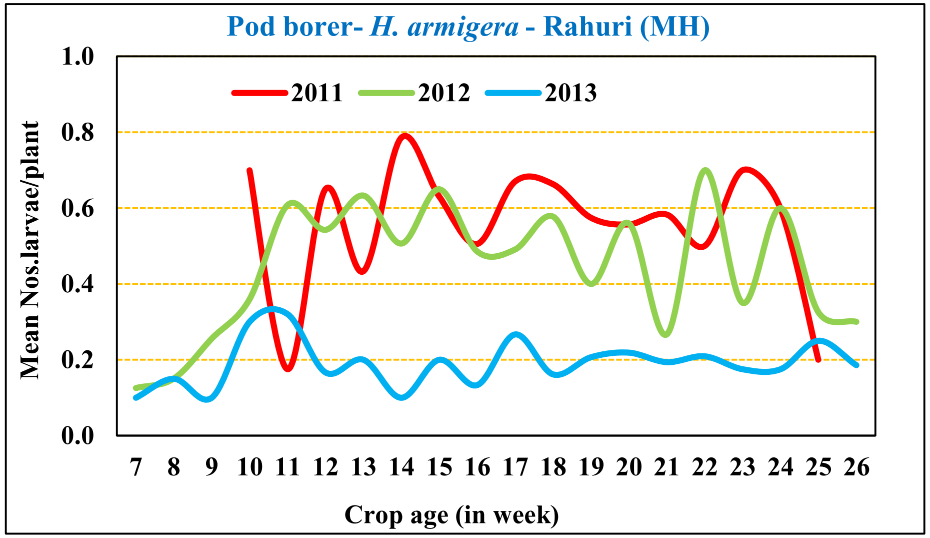


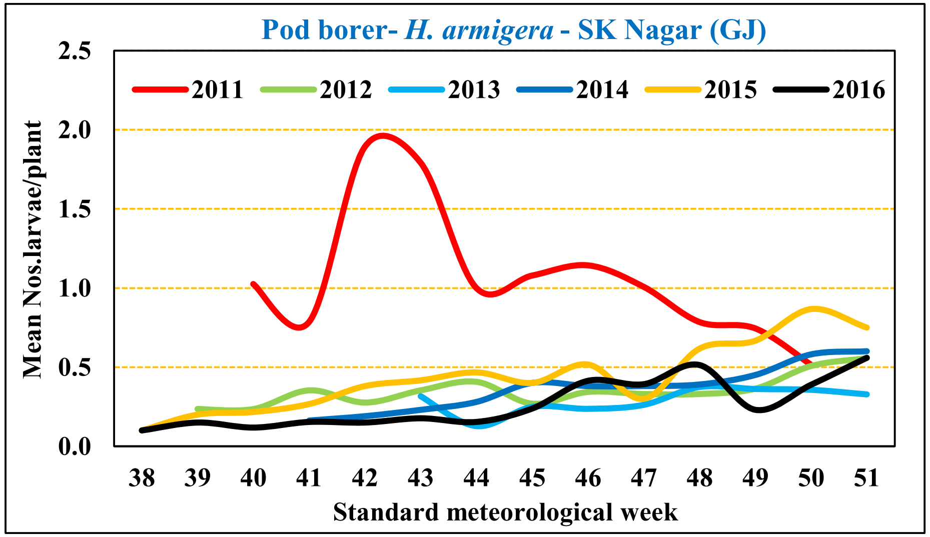
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

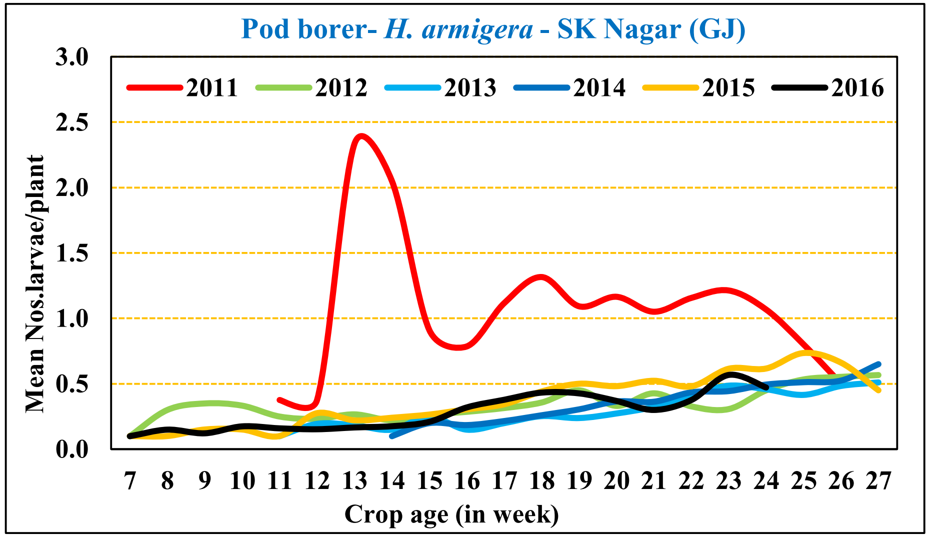
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





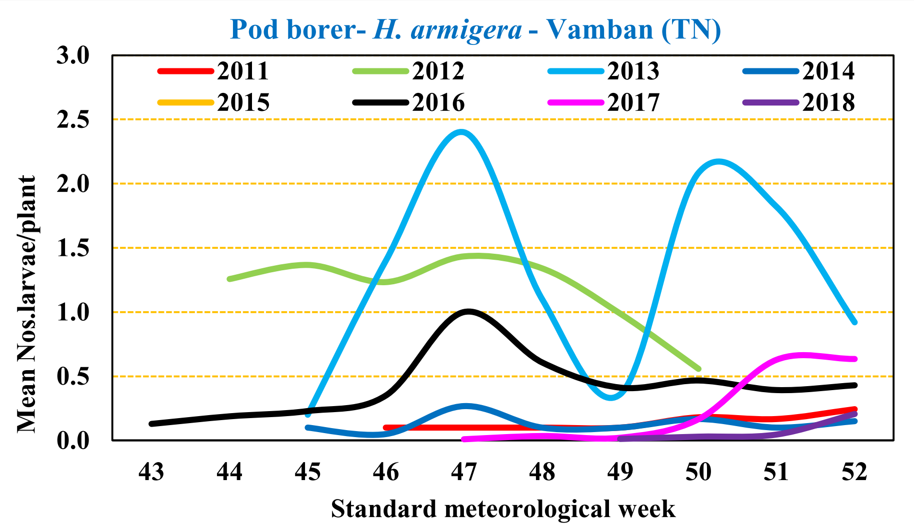


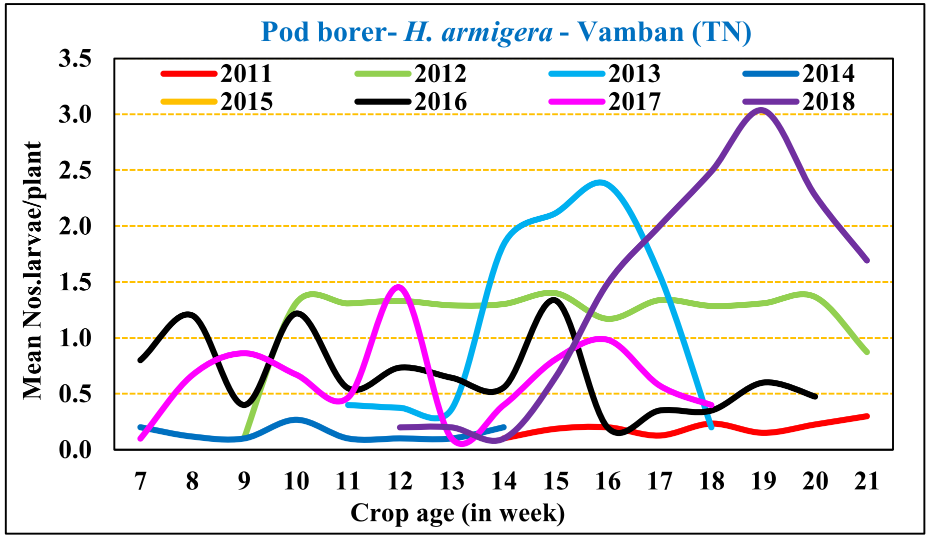


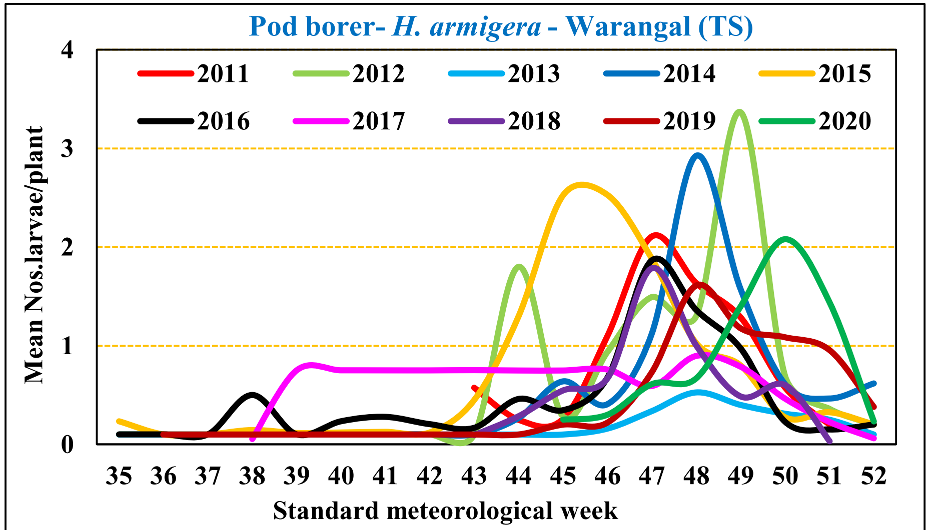
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

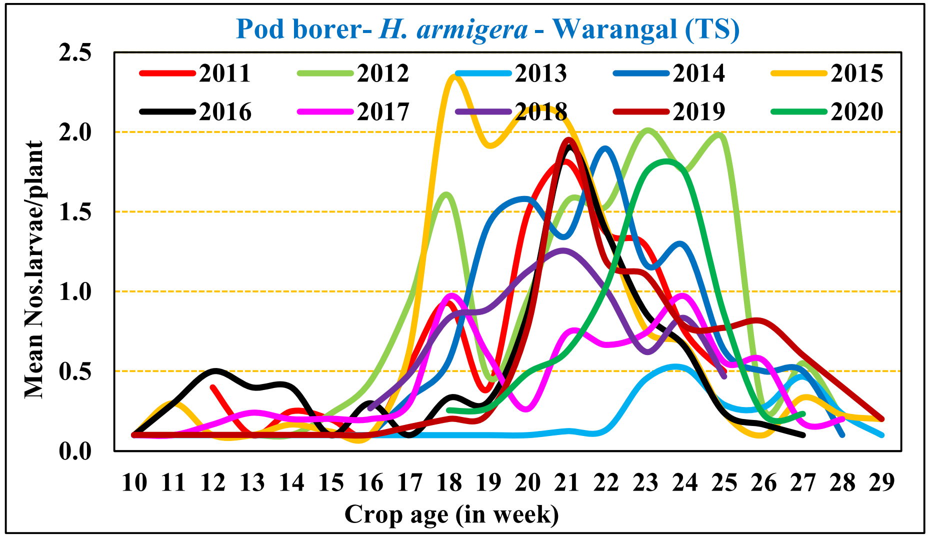
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





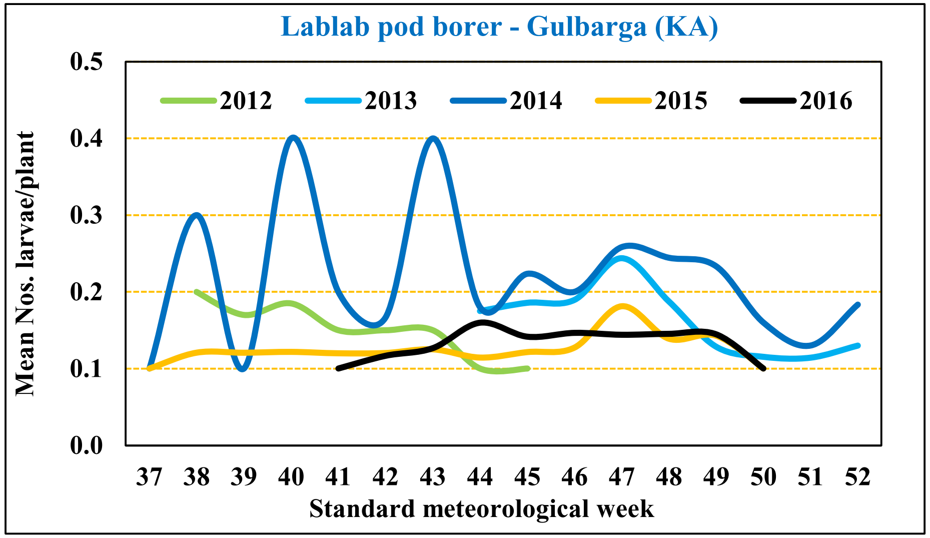


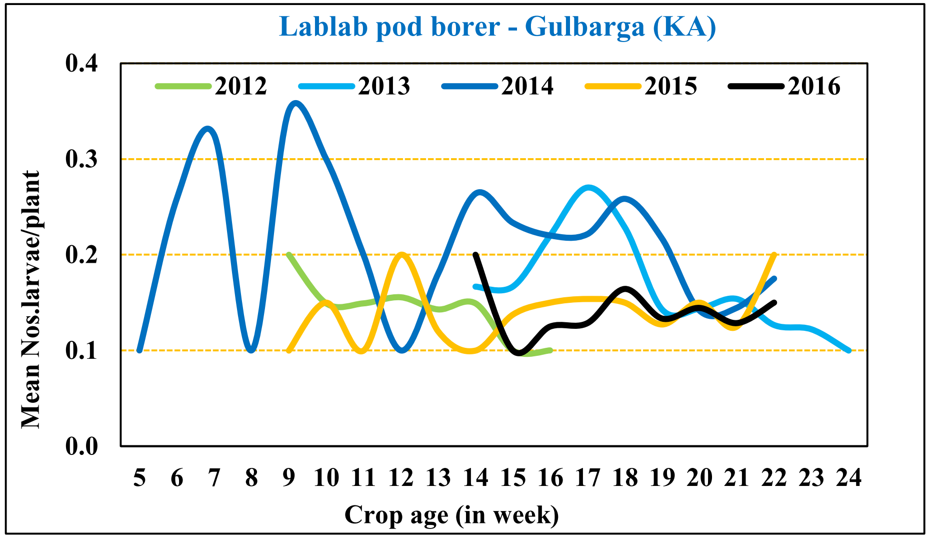


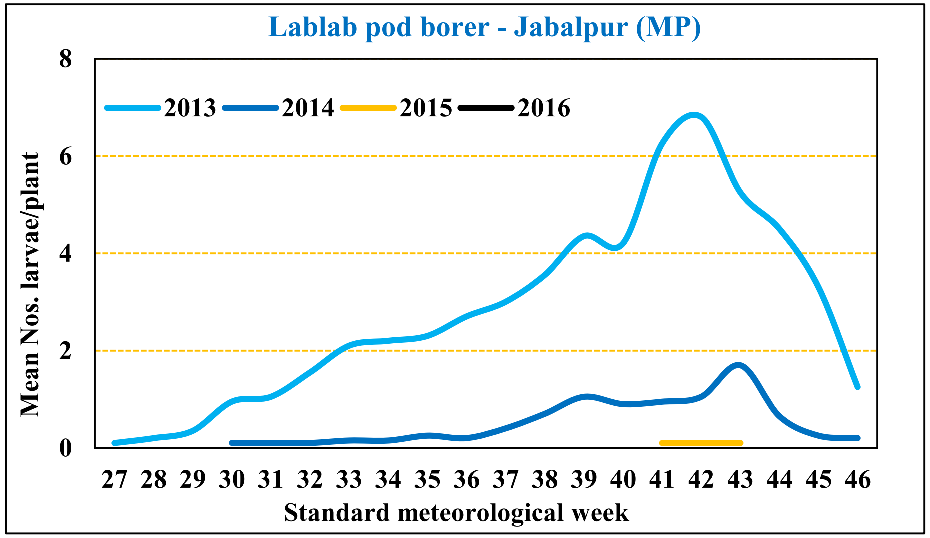
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

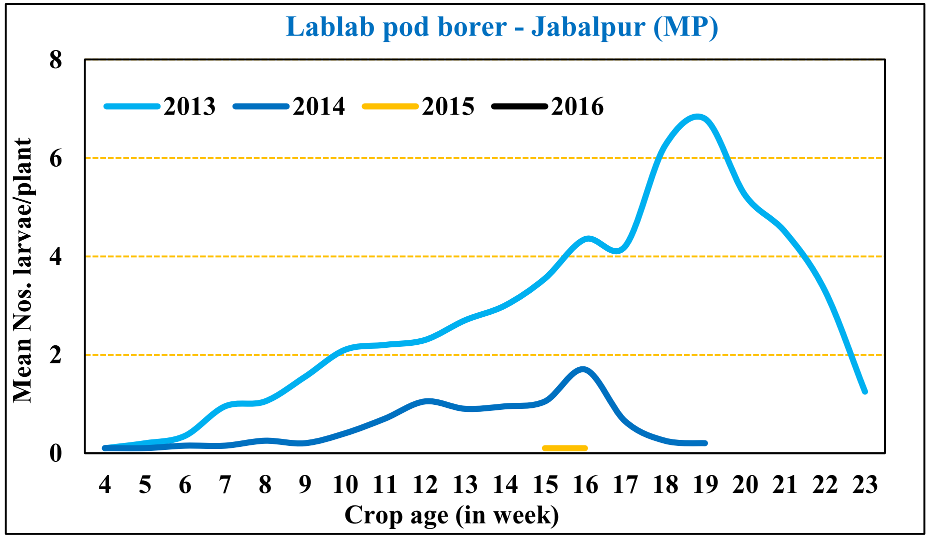
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





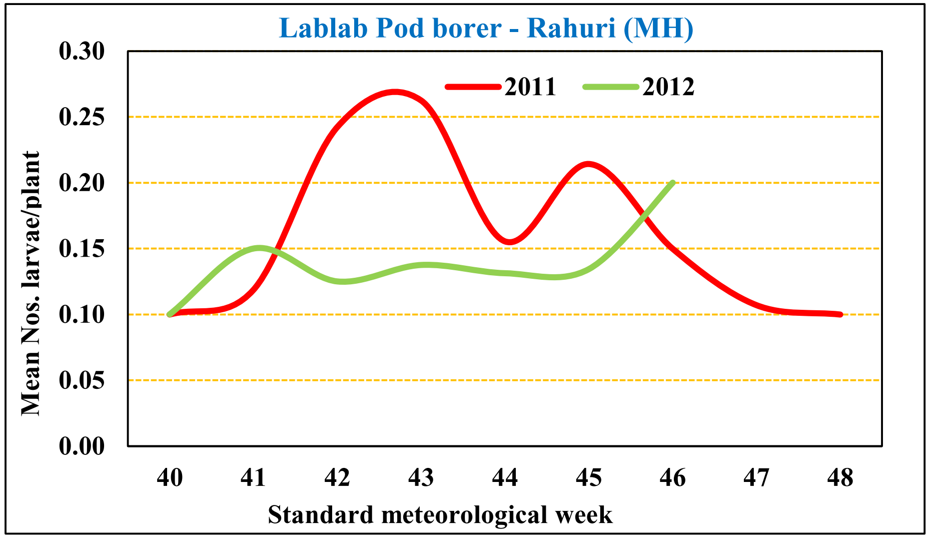


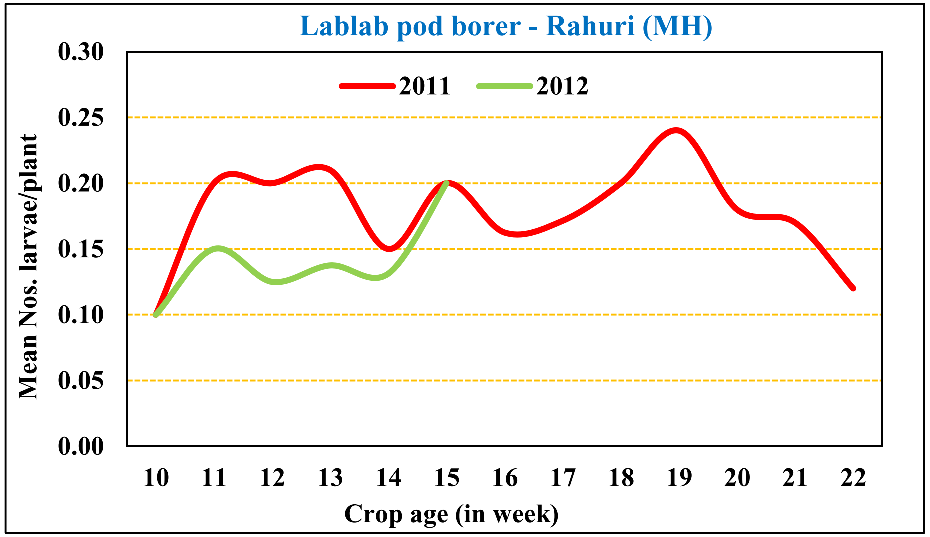


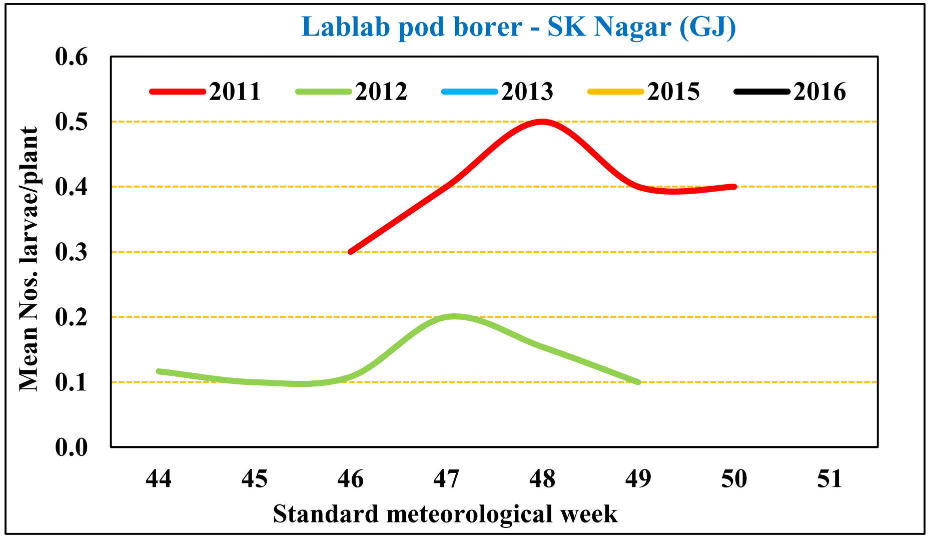
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

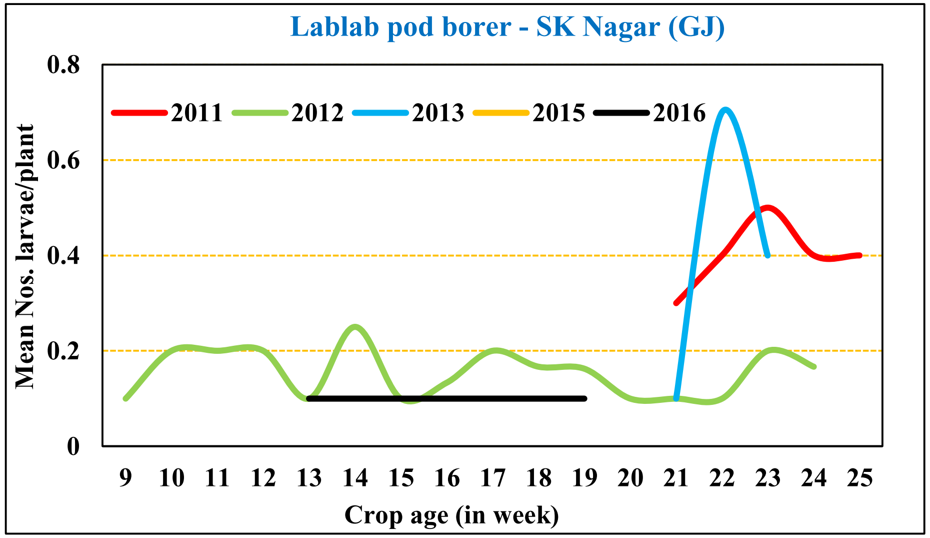
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





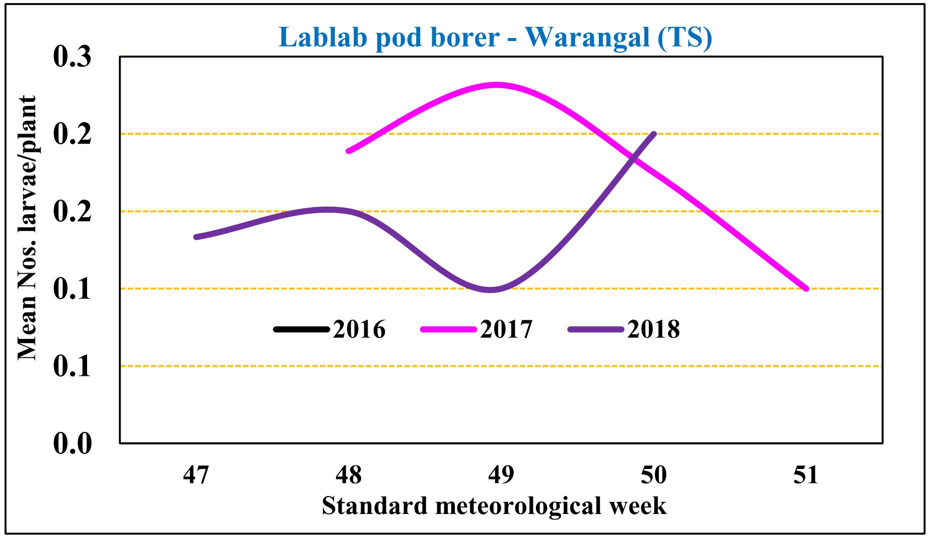


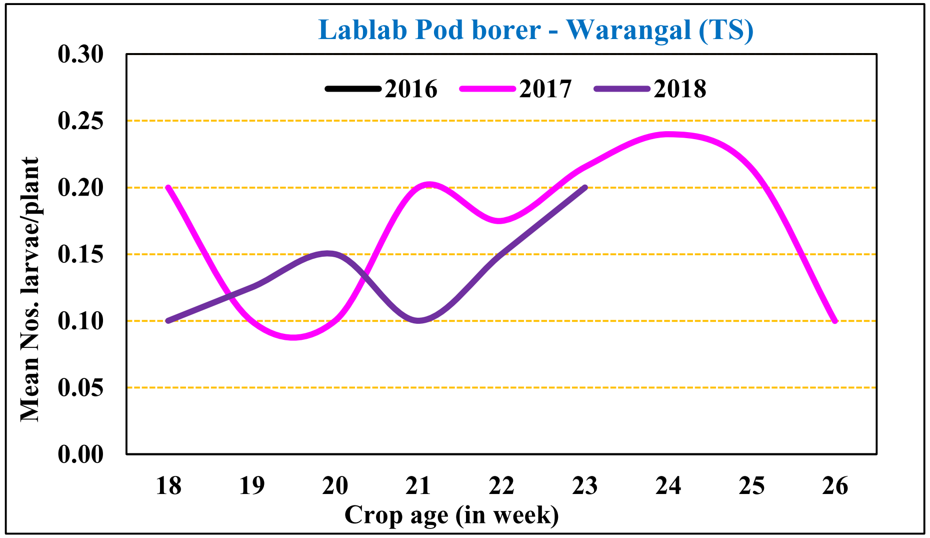


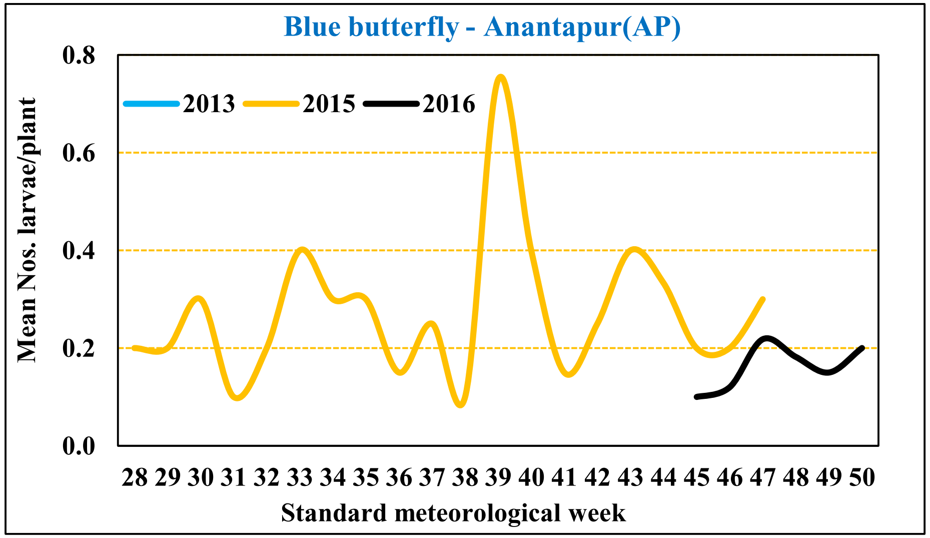
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

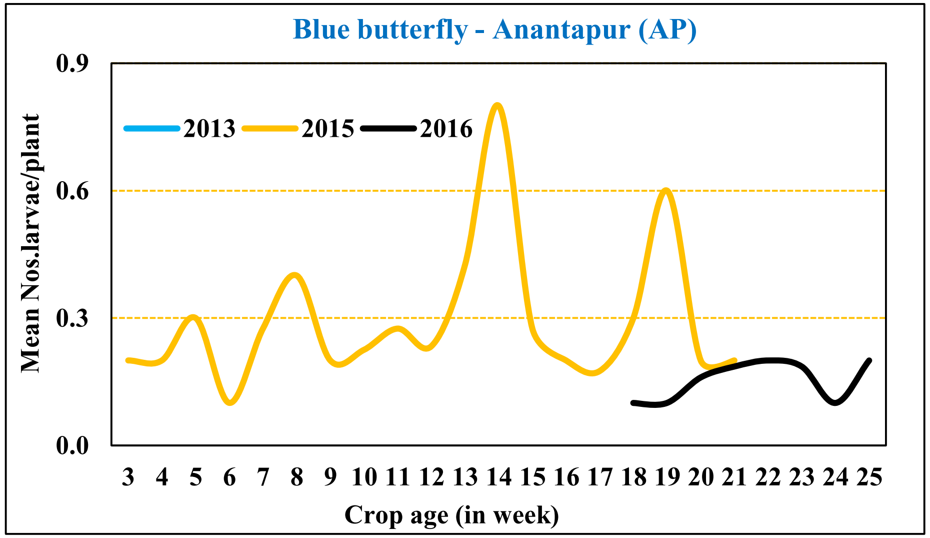
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





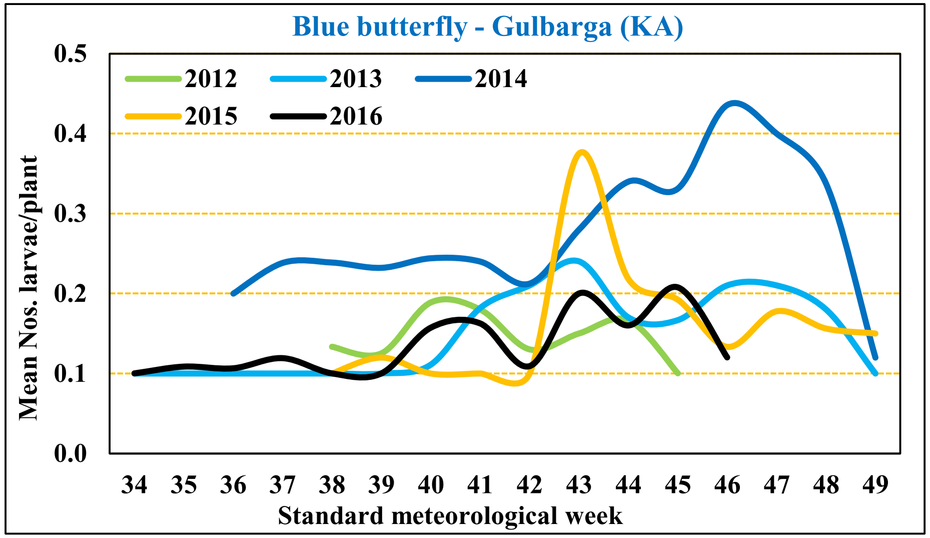


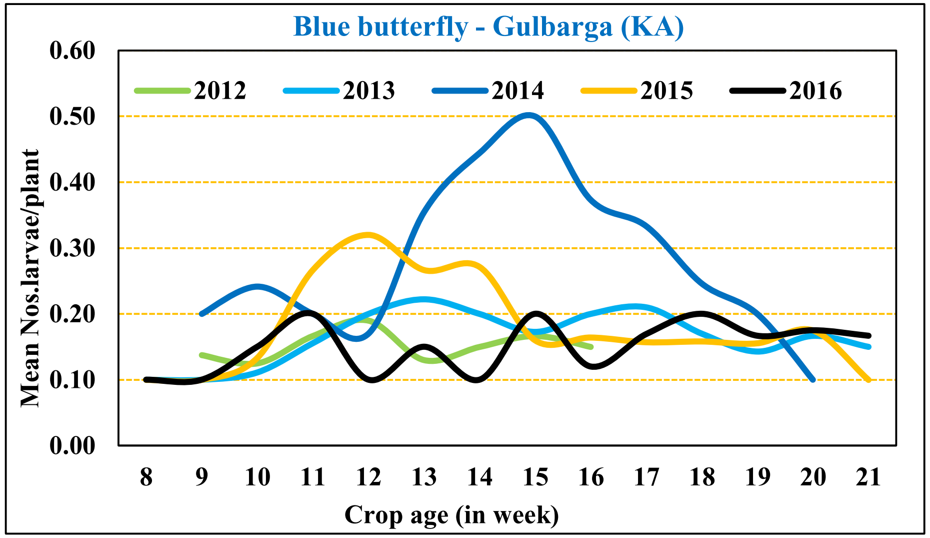


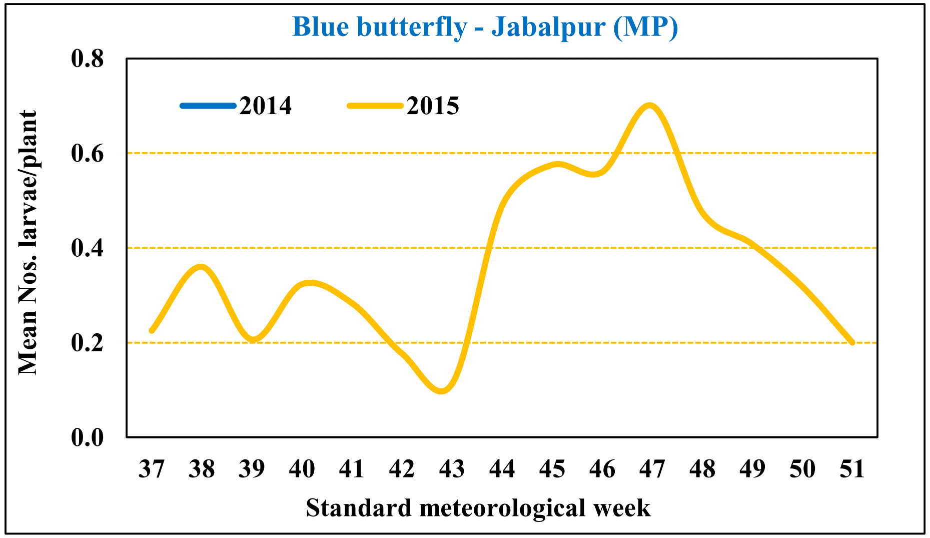
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

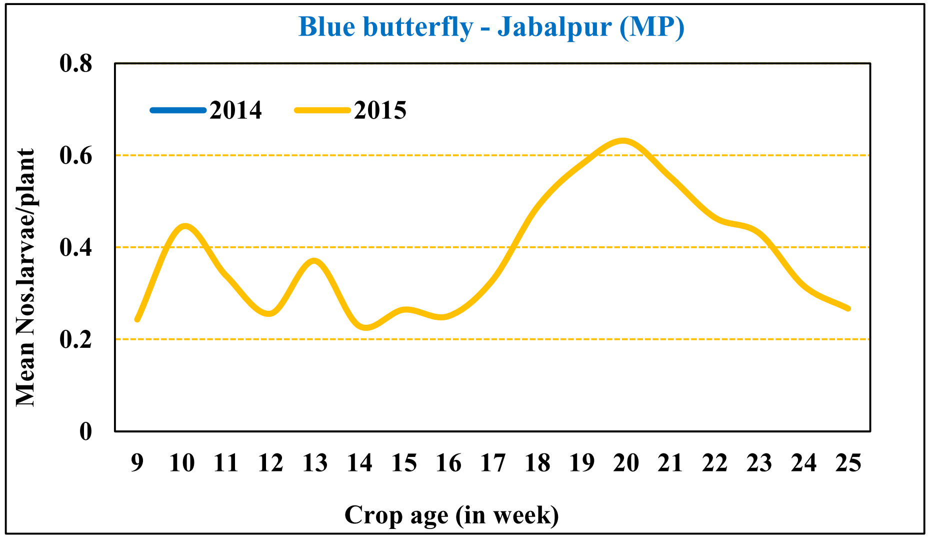
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



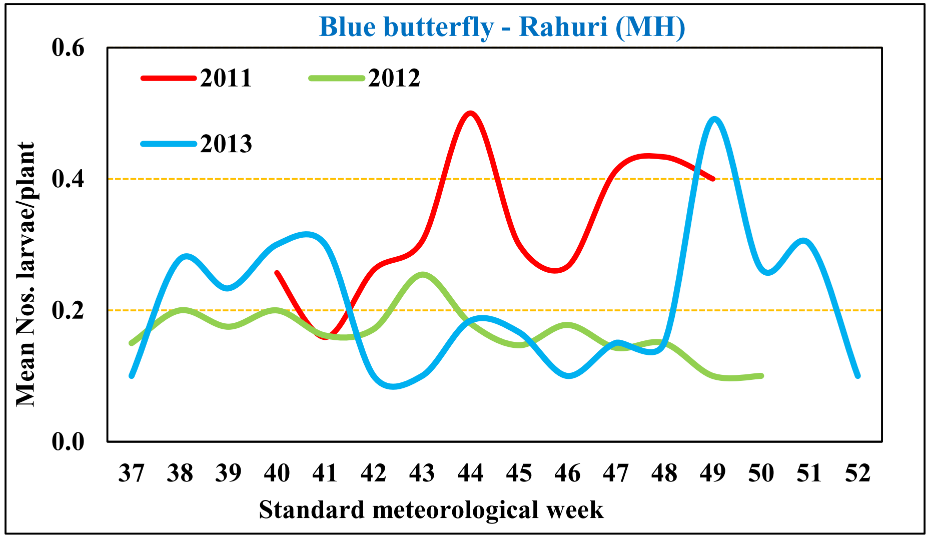


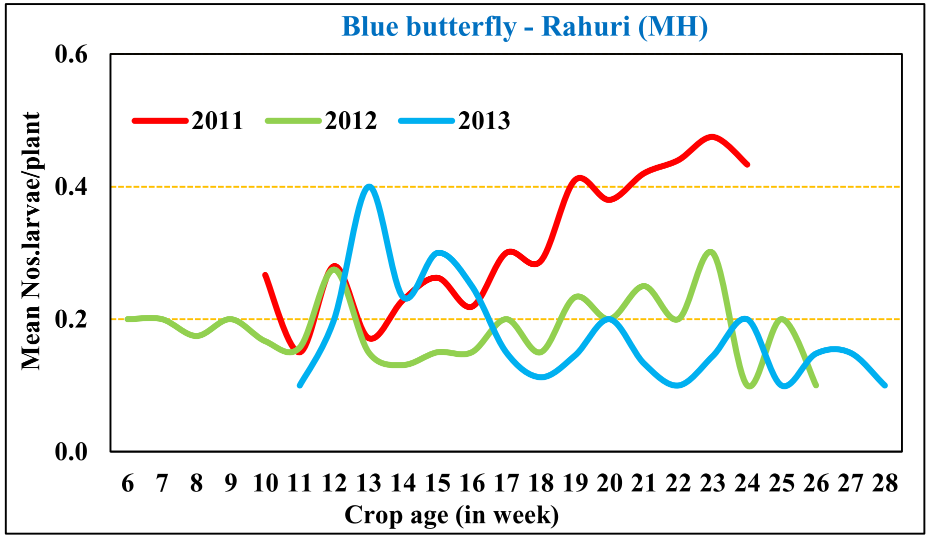


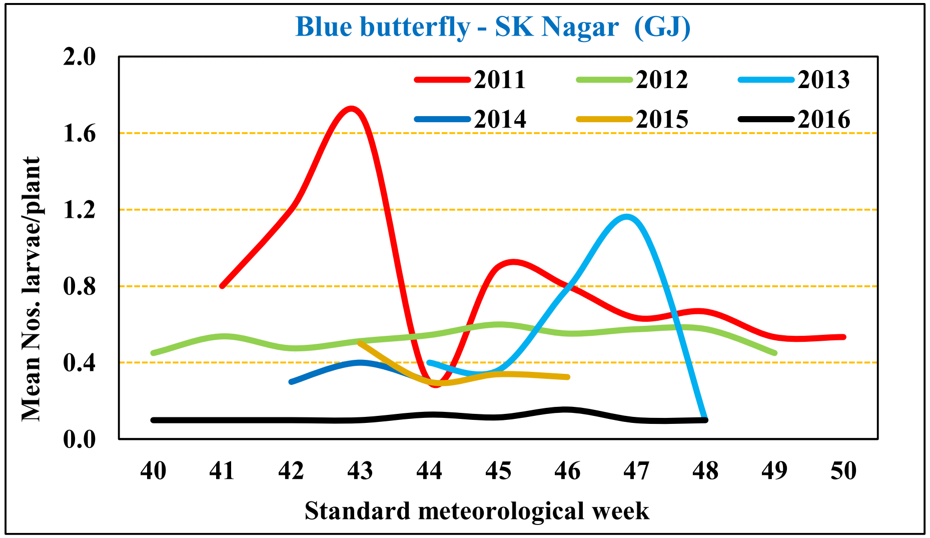


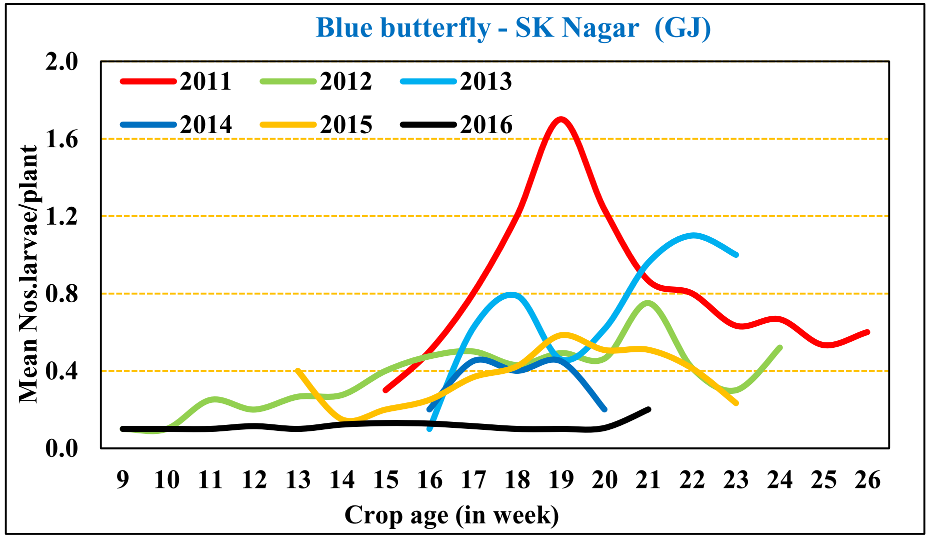
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**





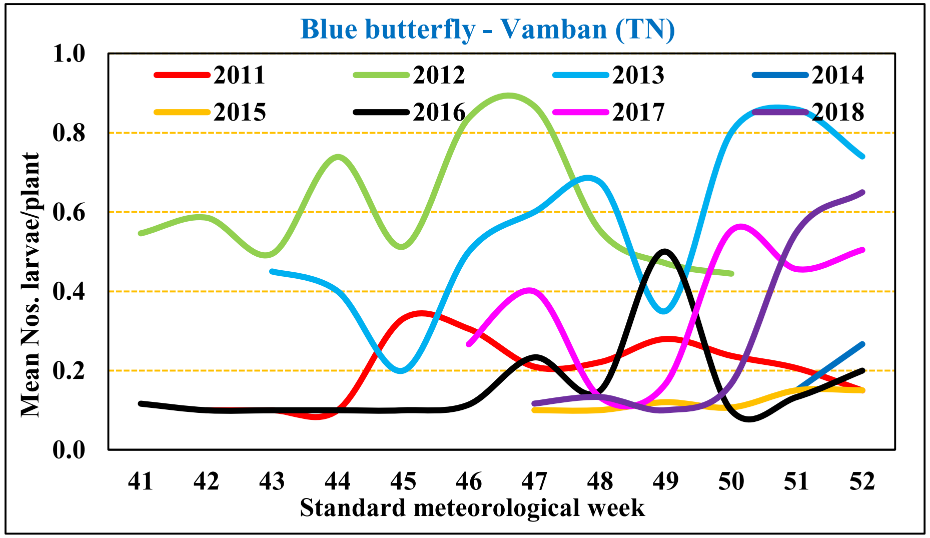


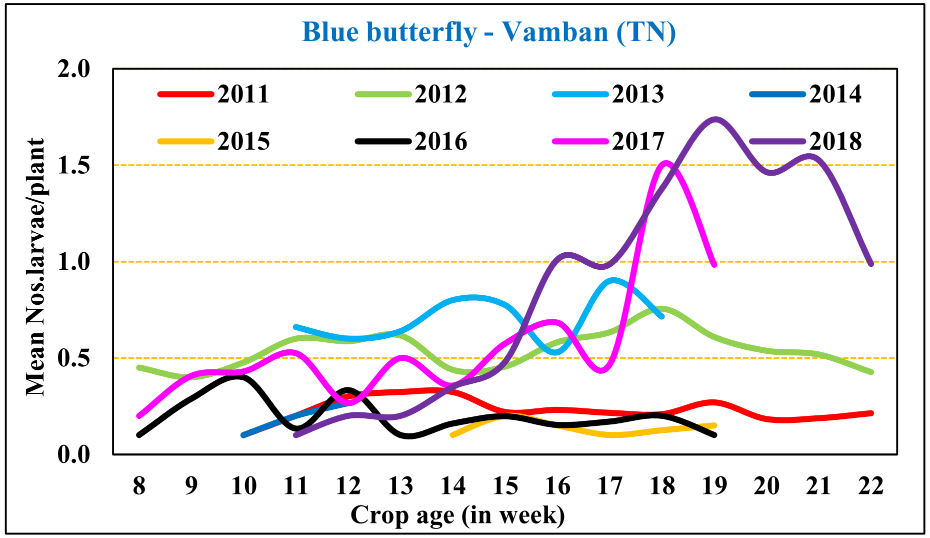


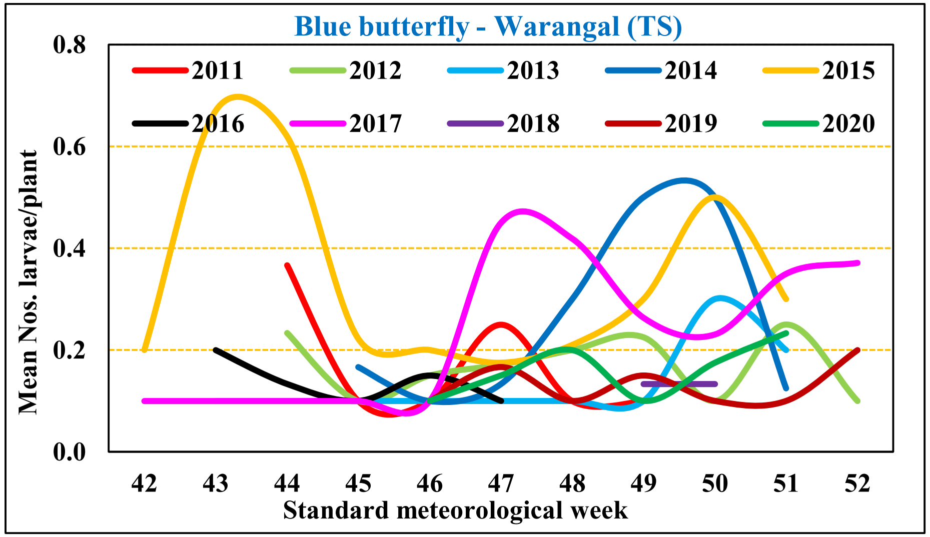
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

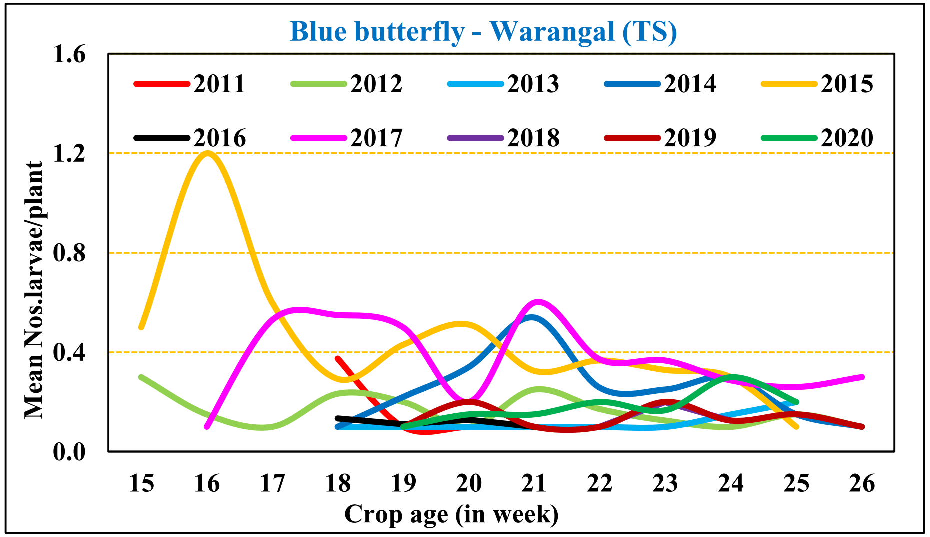
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





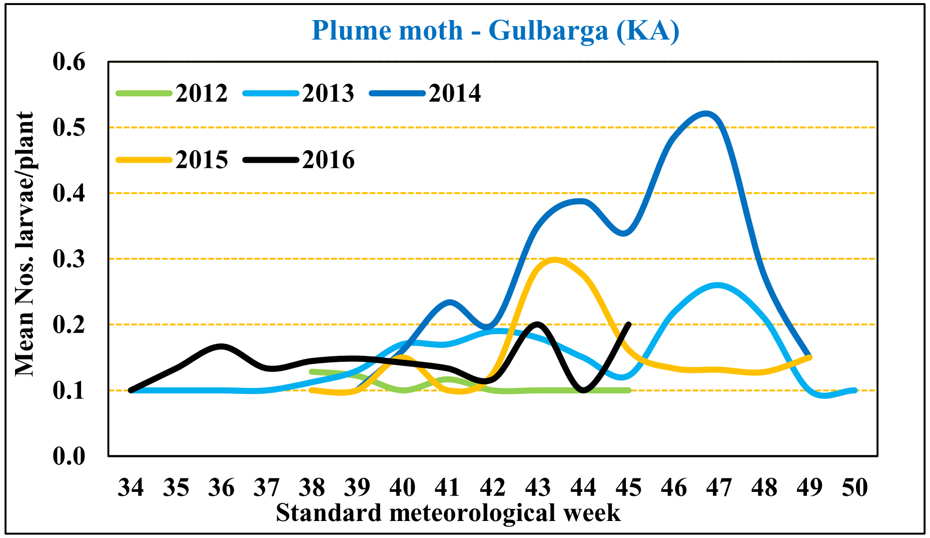


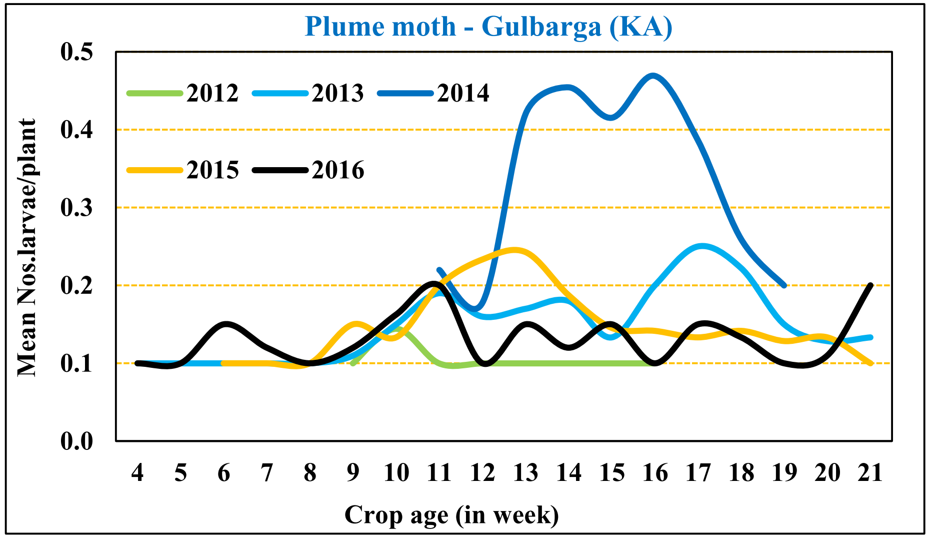


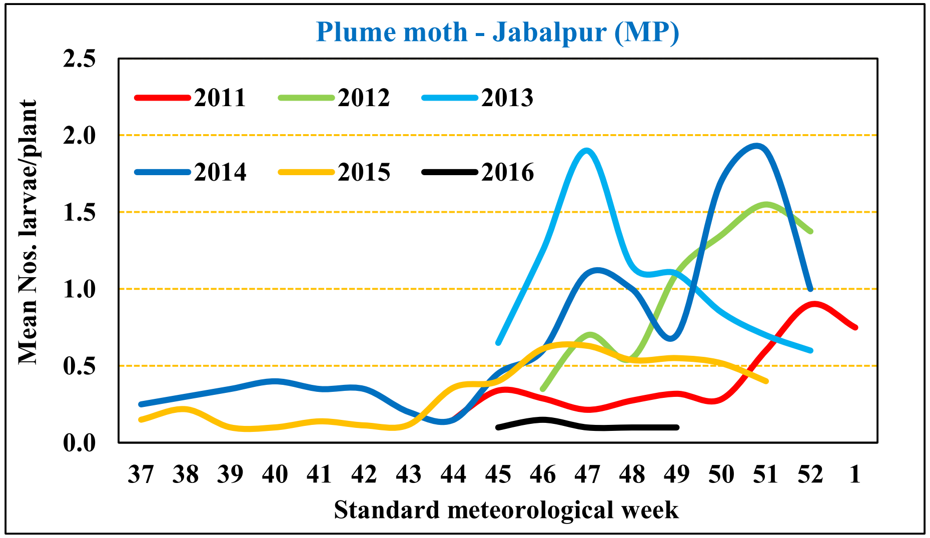
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

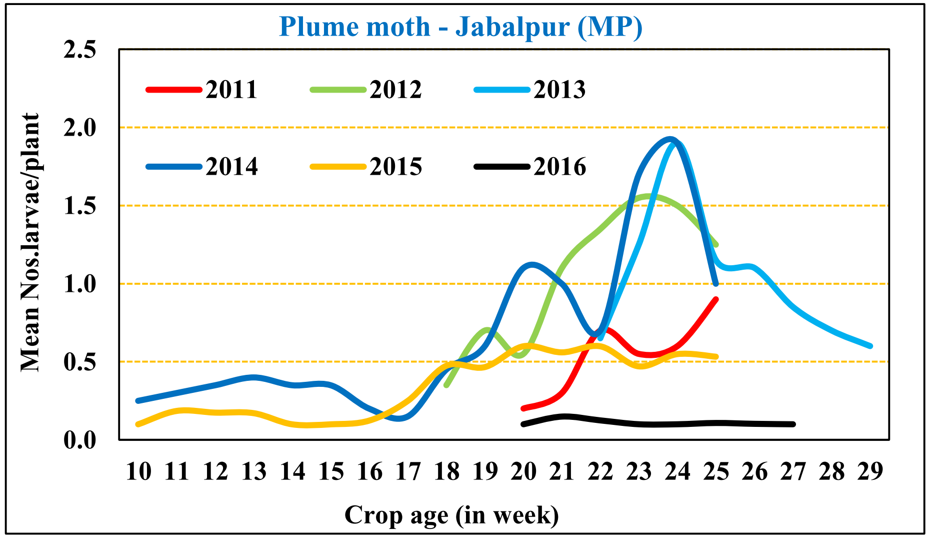
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



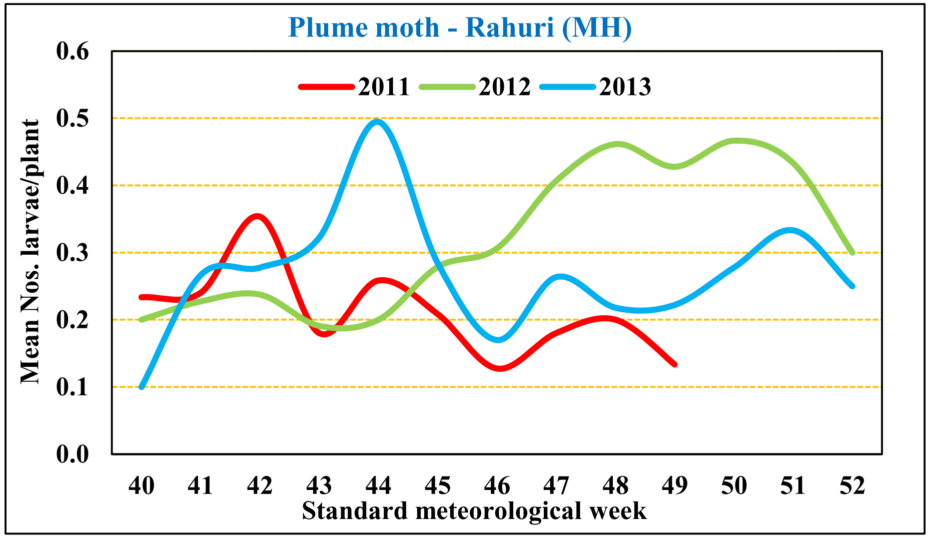


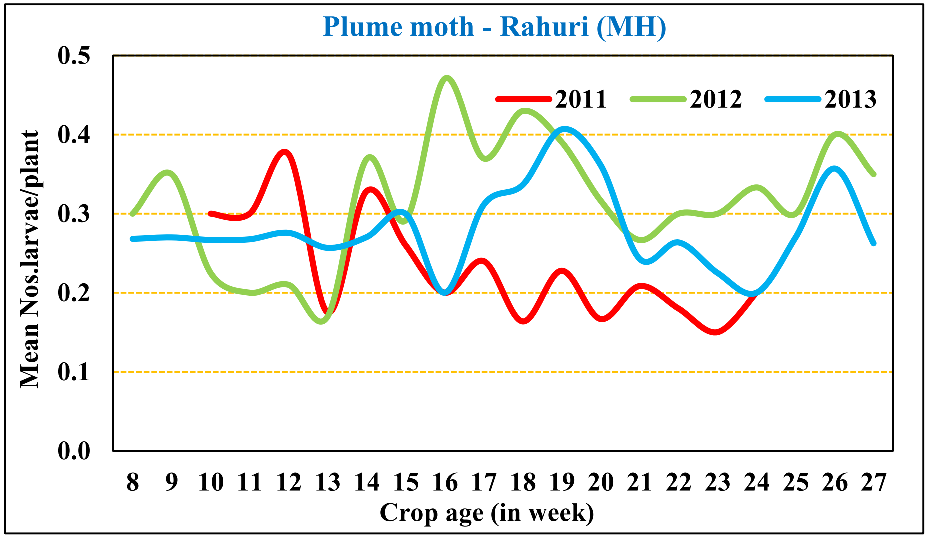


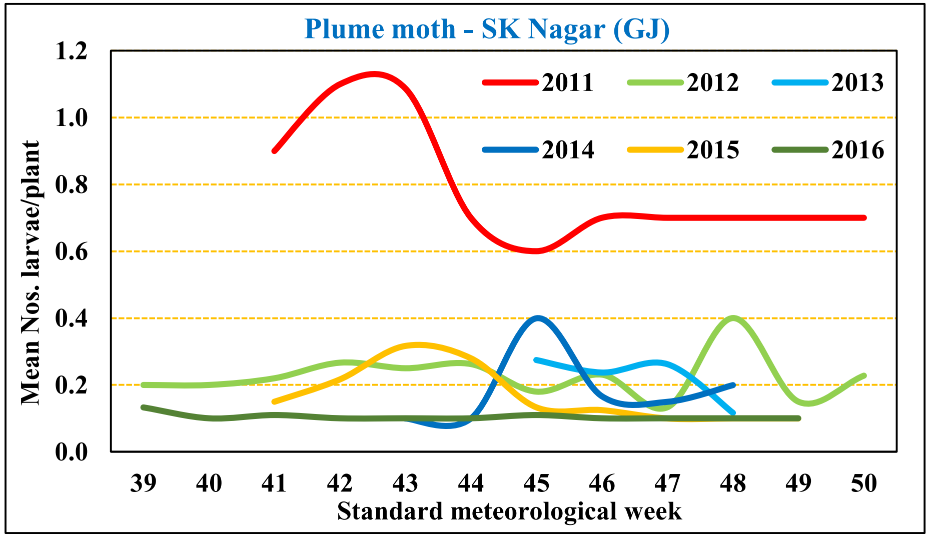


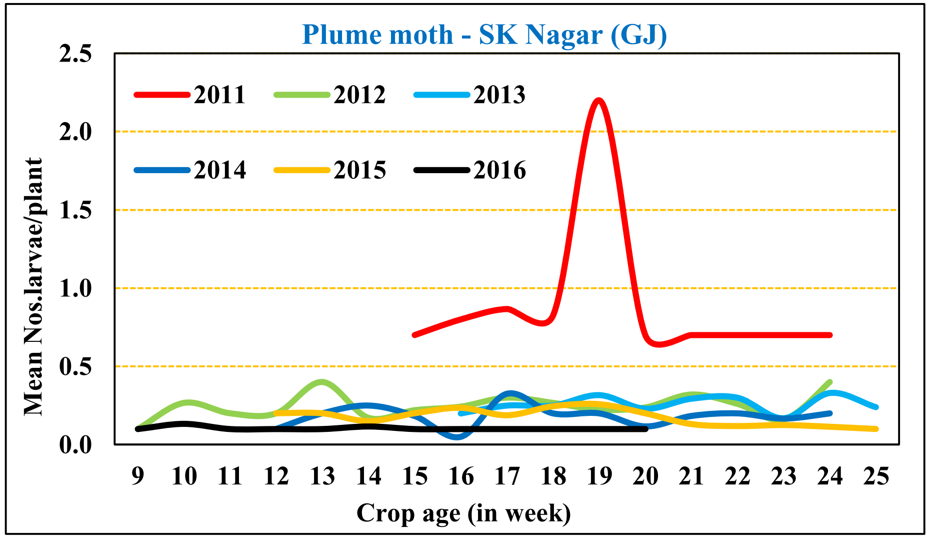
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**





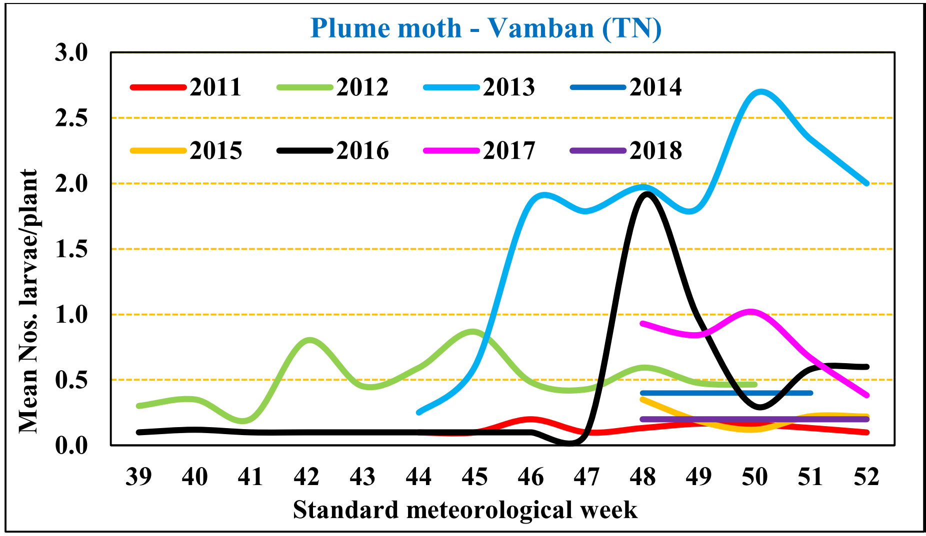


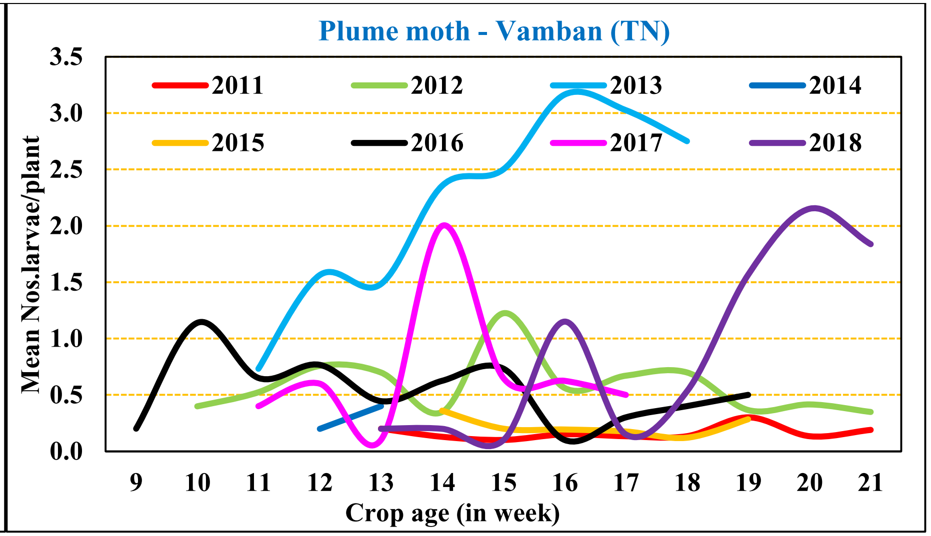


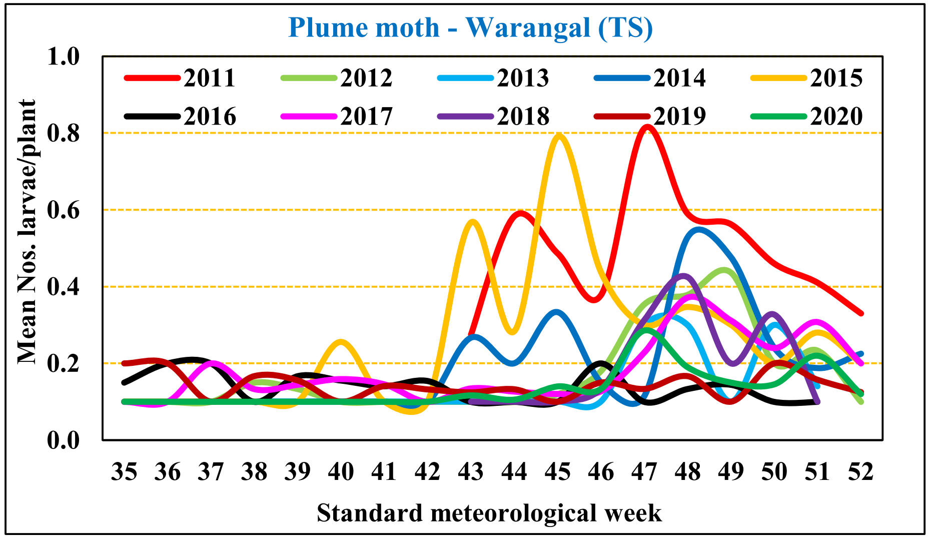
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

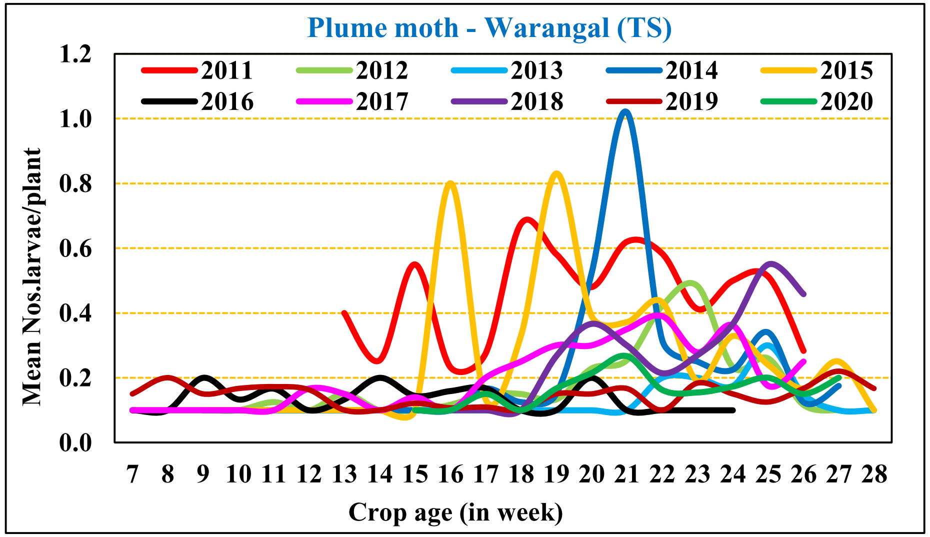
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



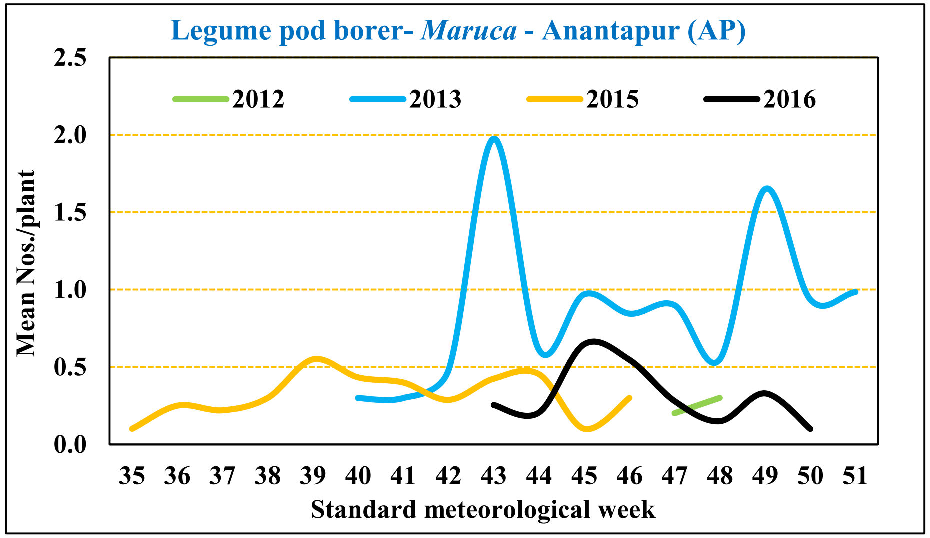


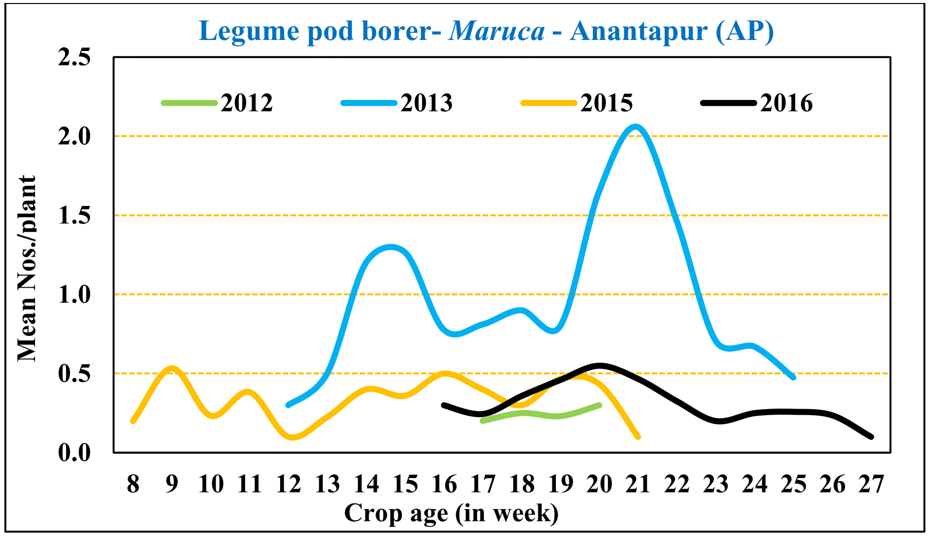


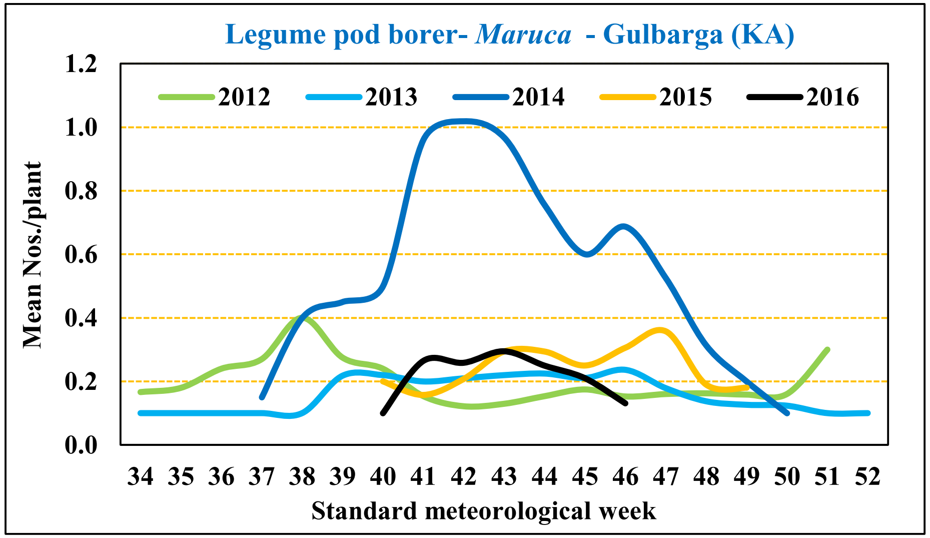


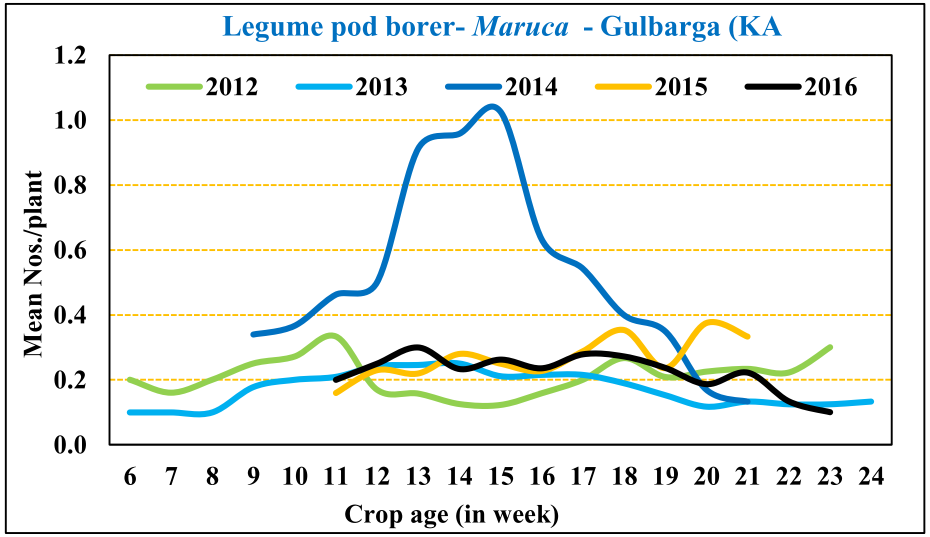
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**





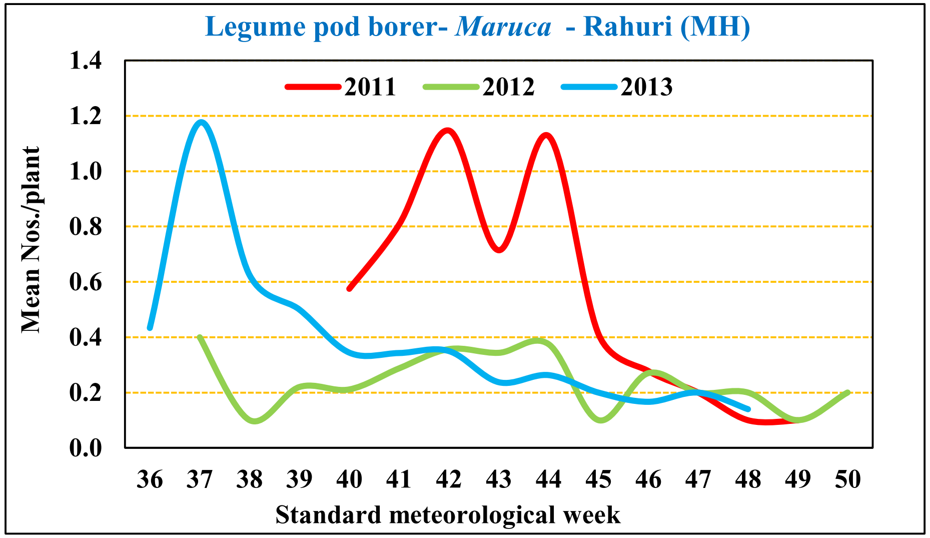


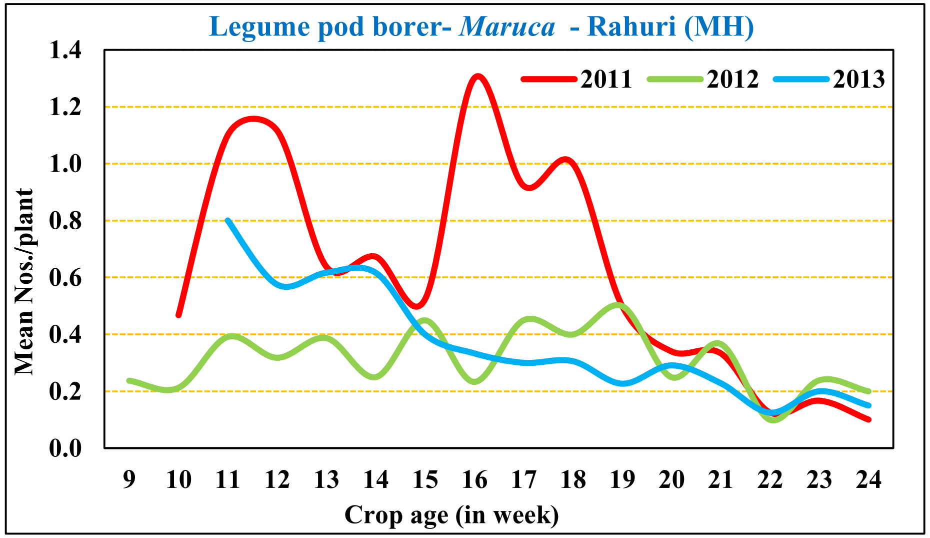


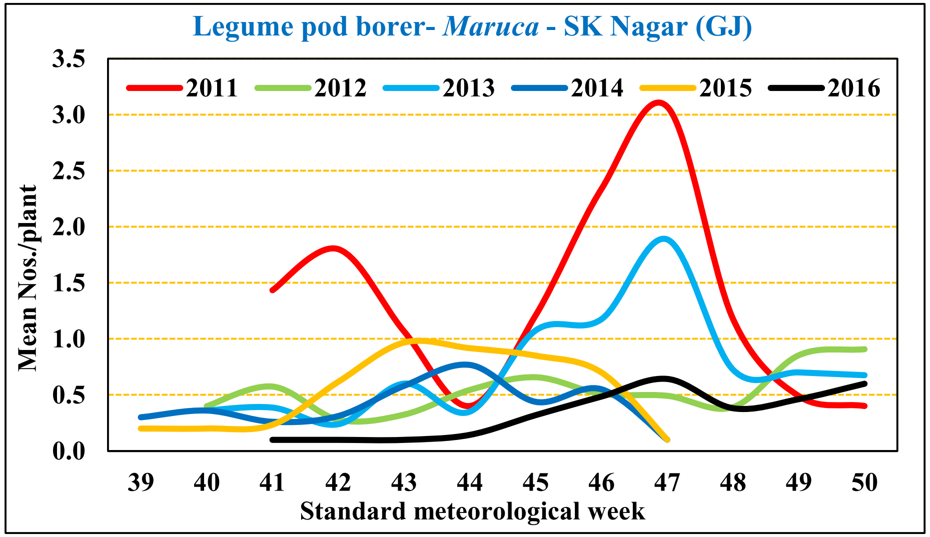
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

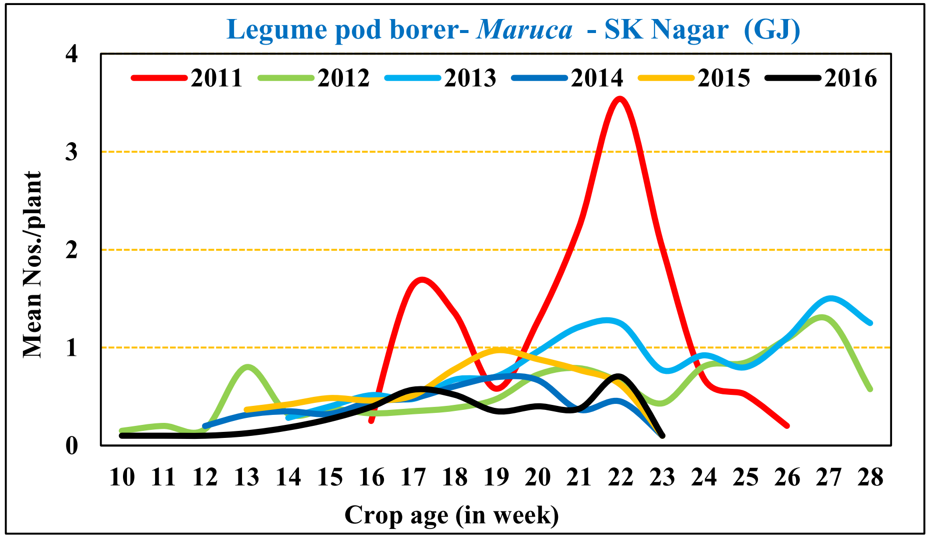
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





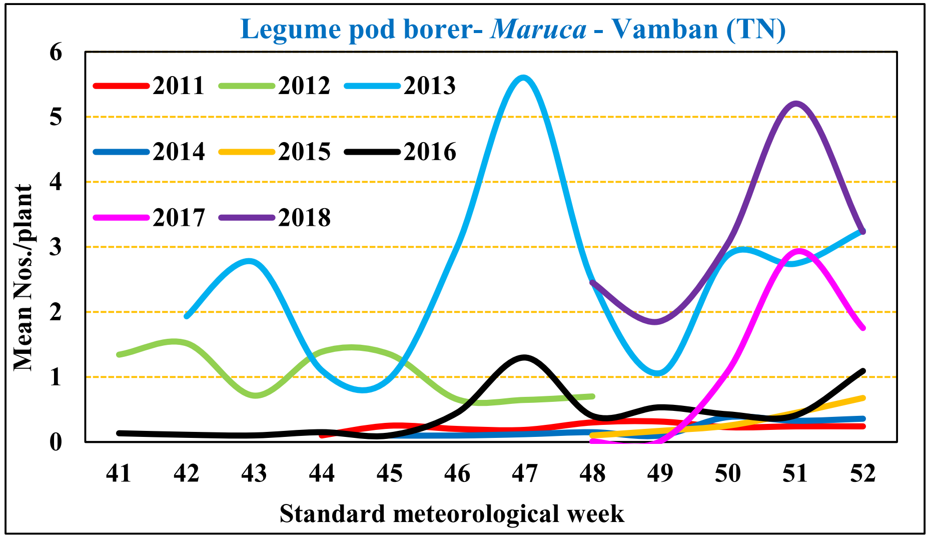


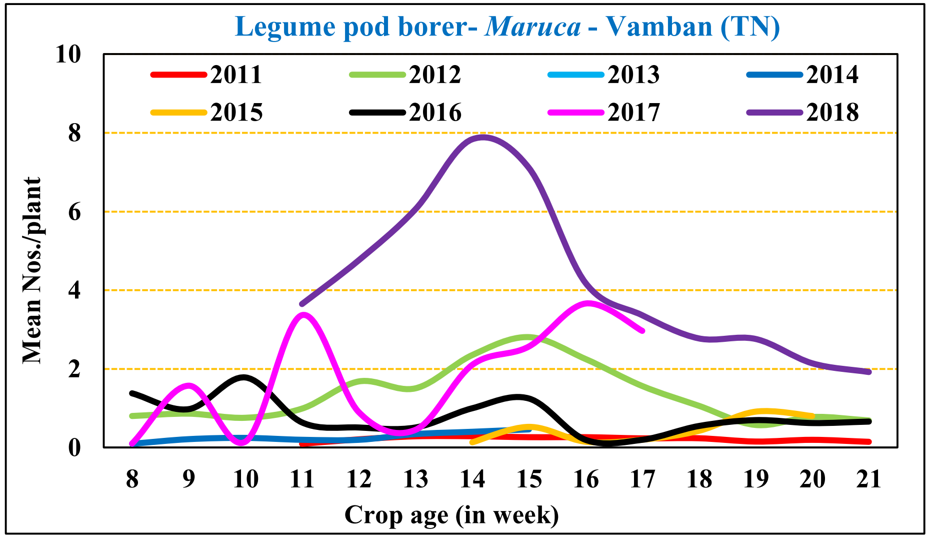


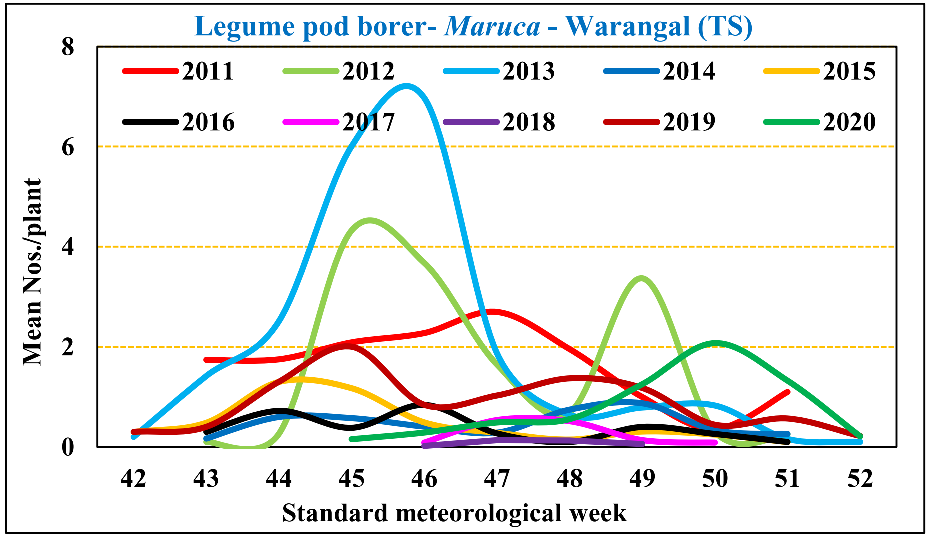
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

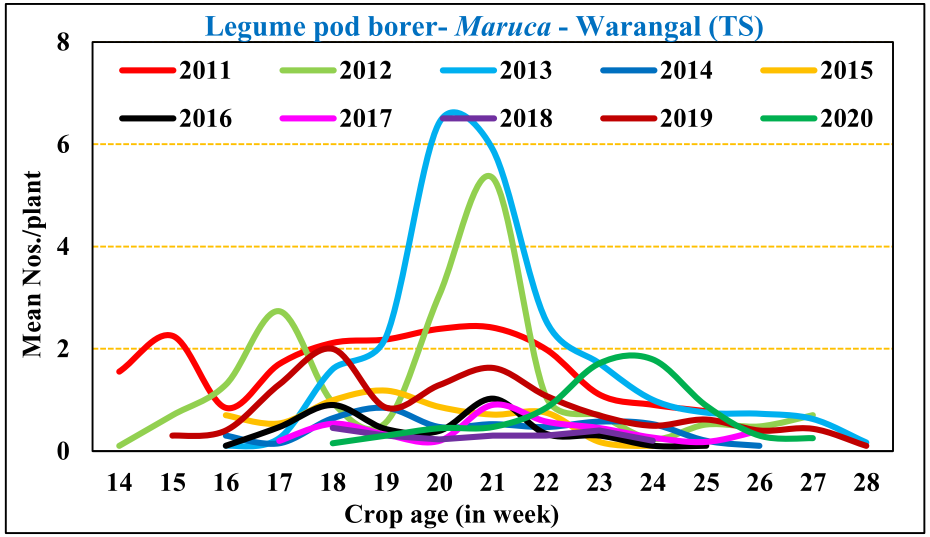
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





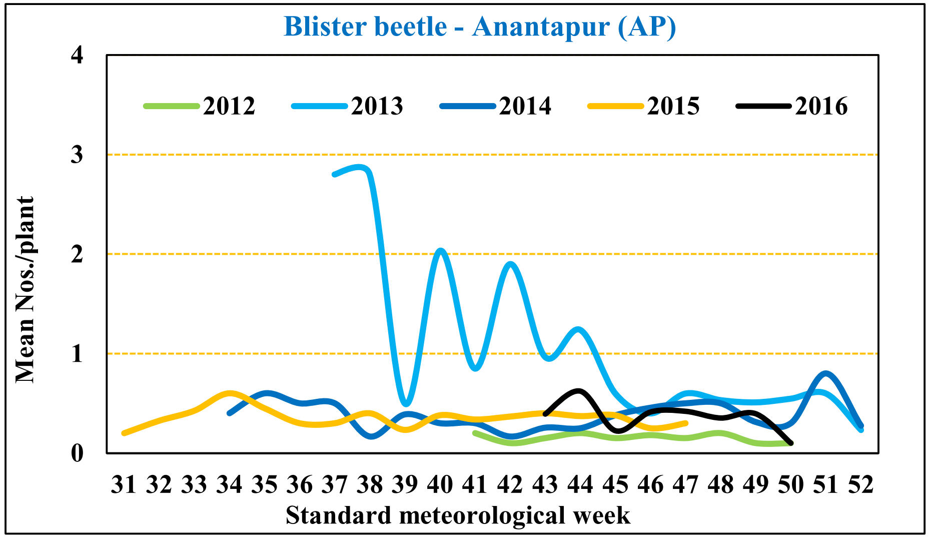


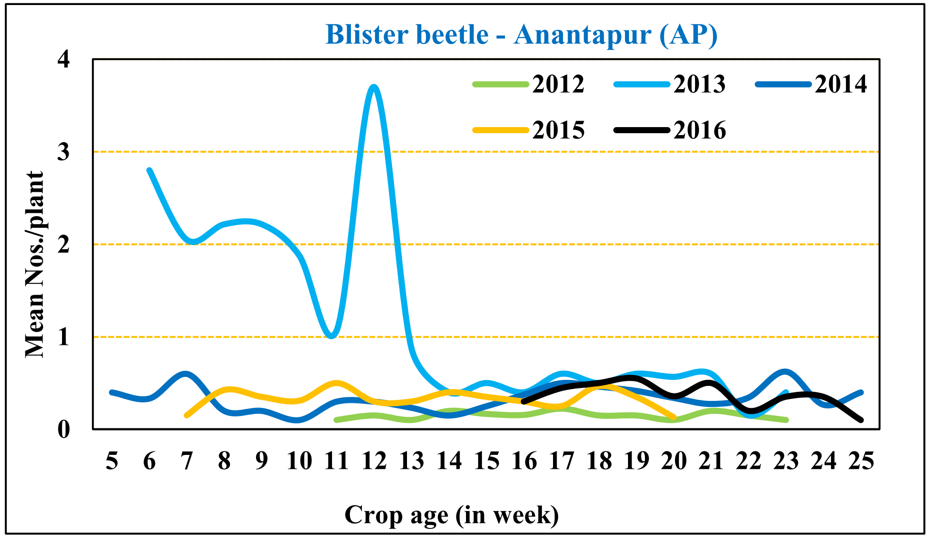


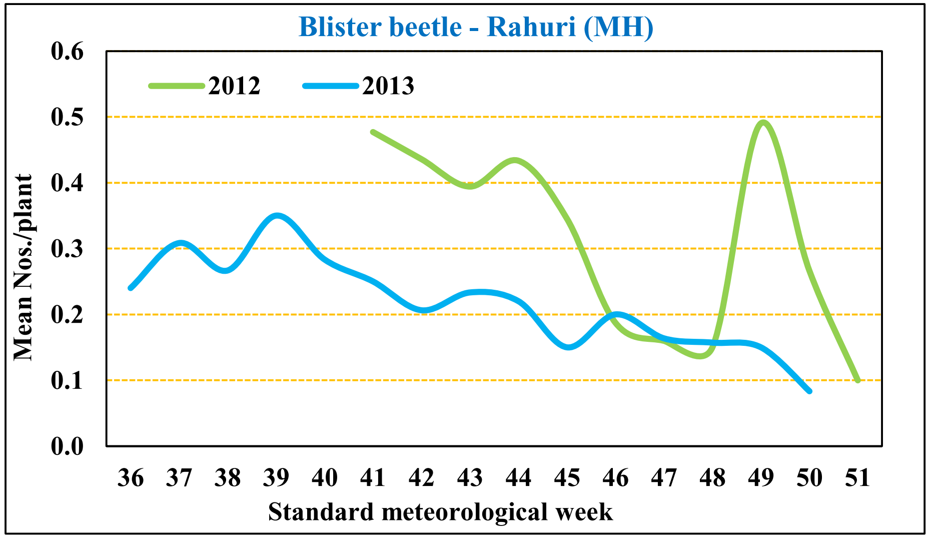
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

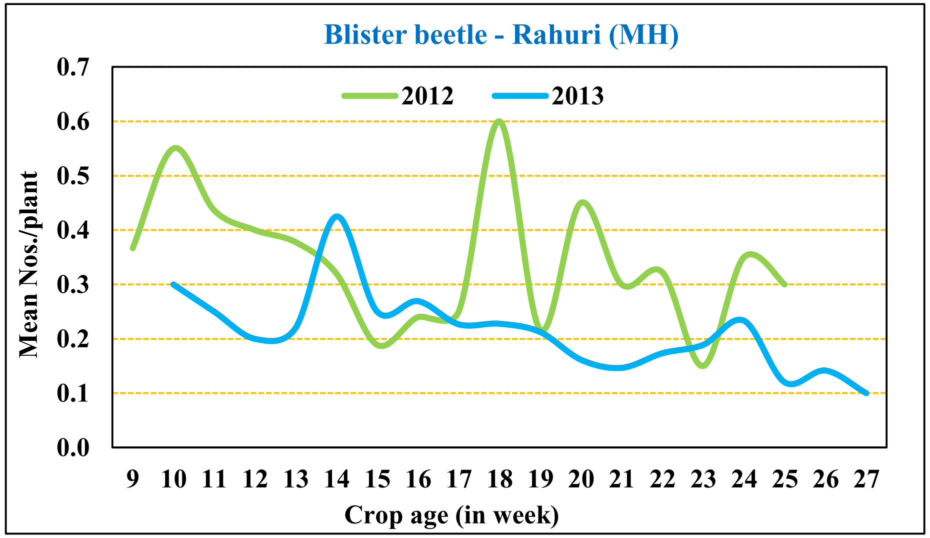
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



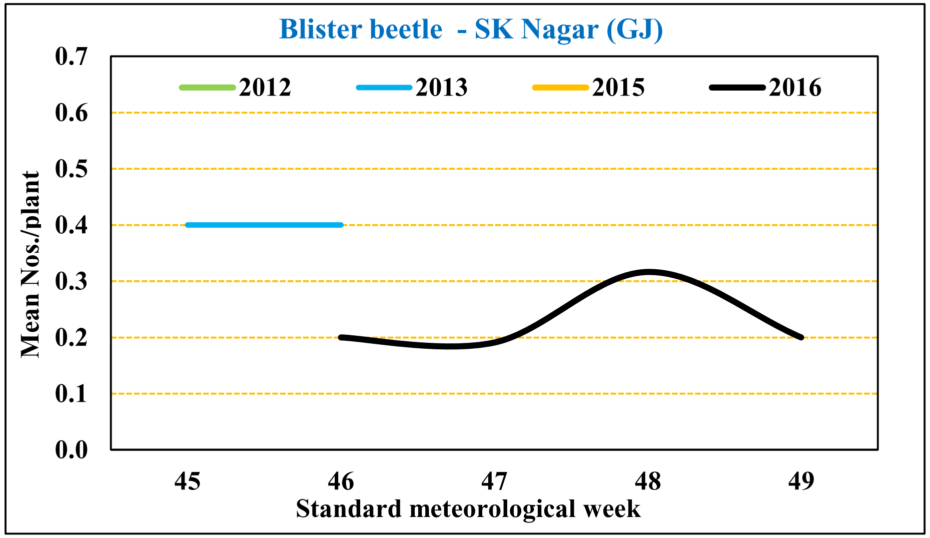


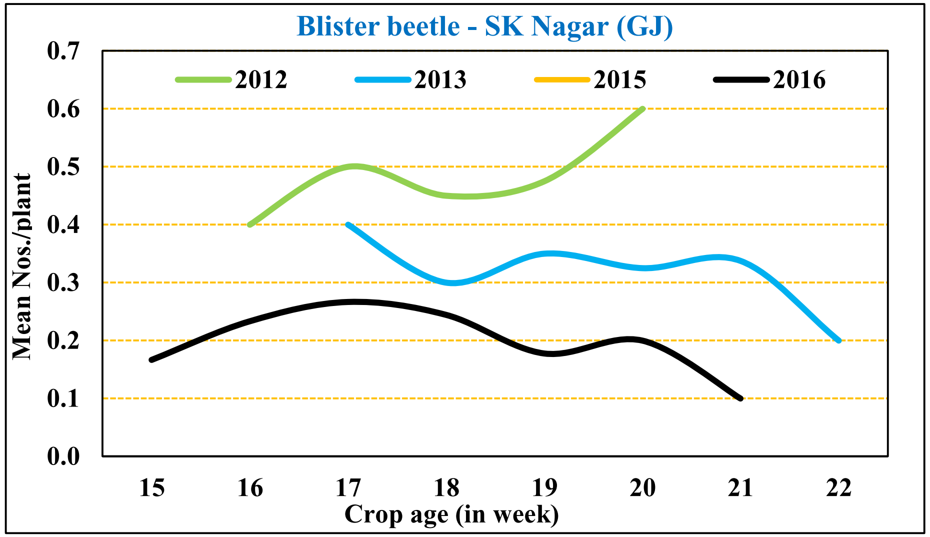


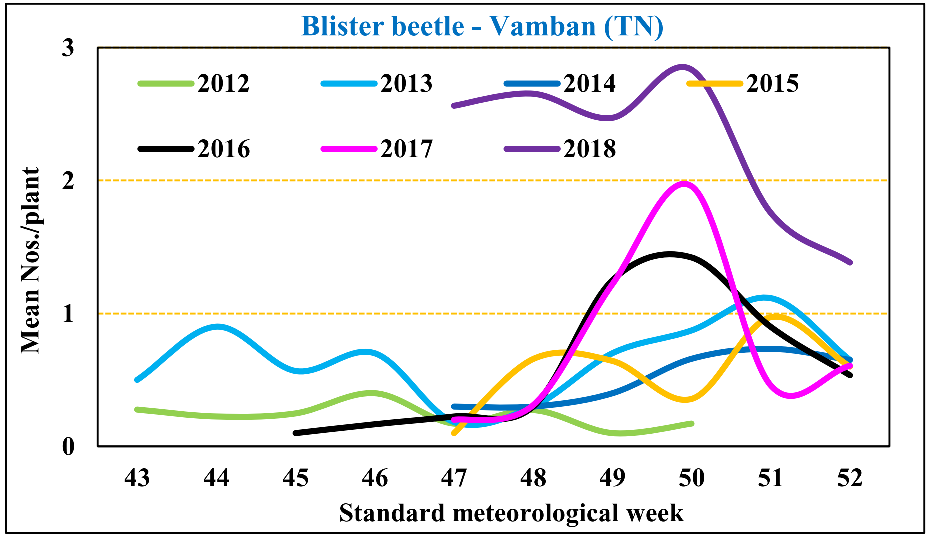


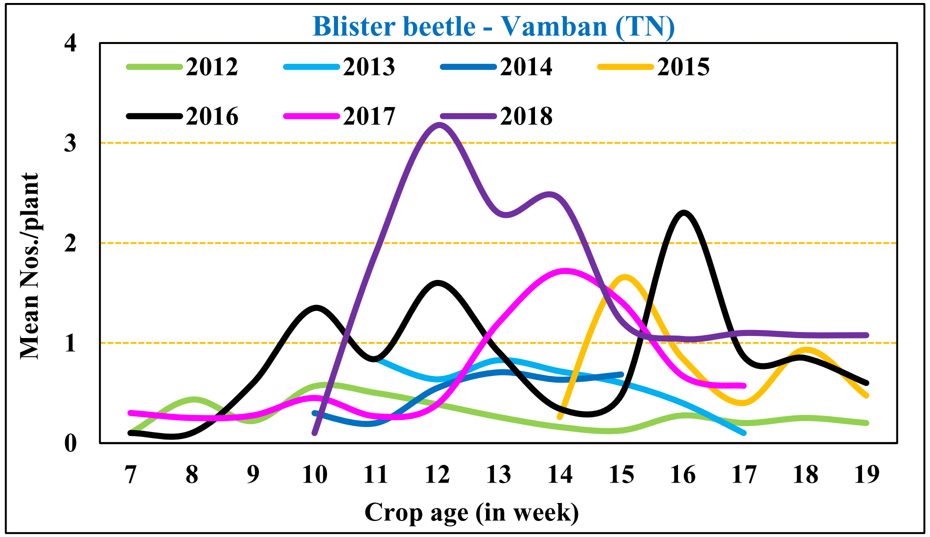
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**





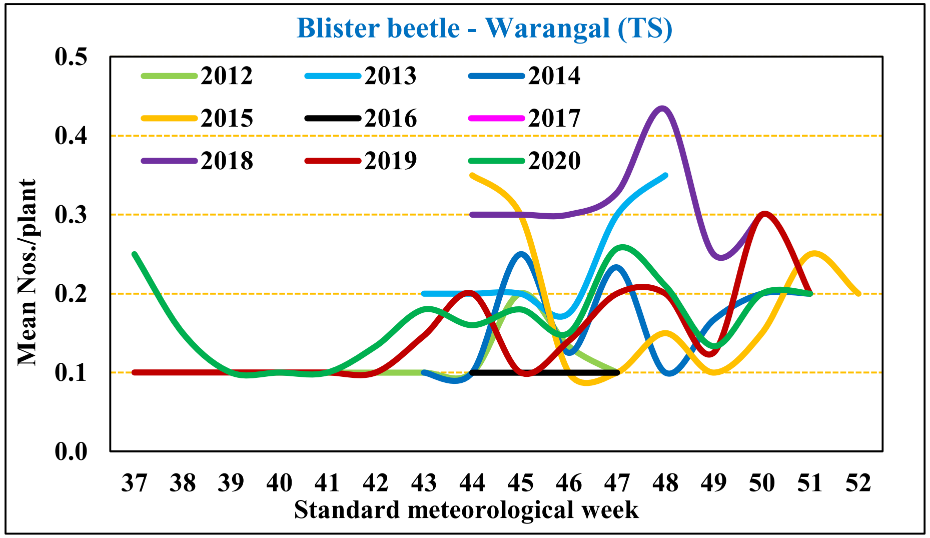


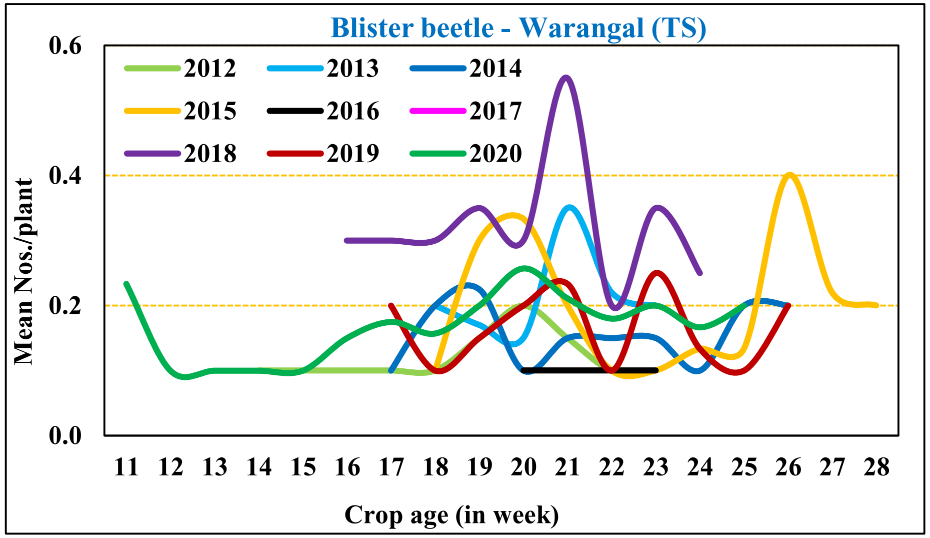


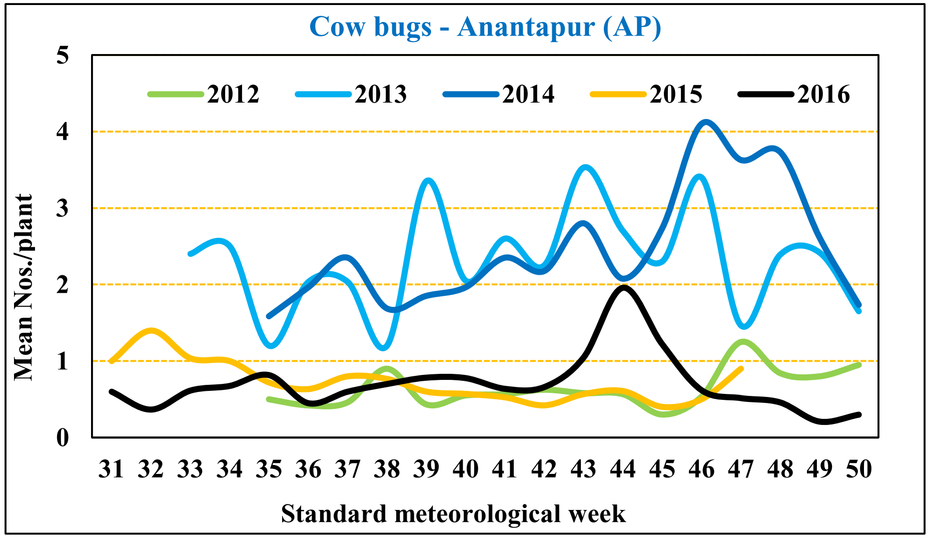
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

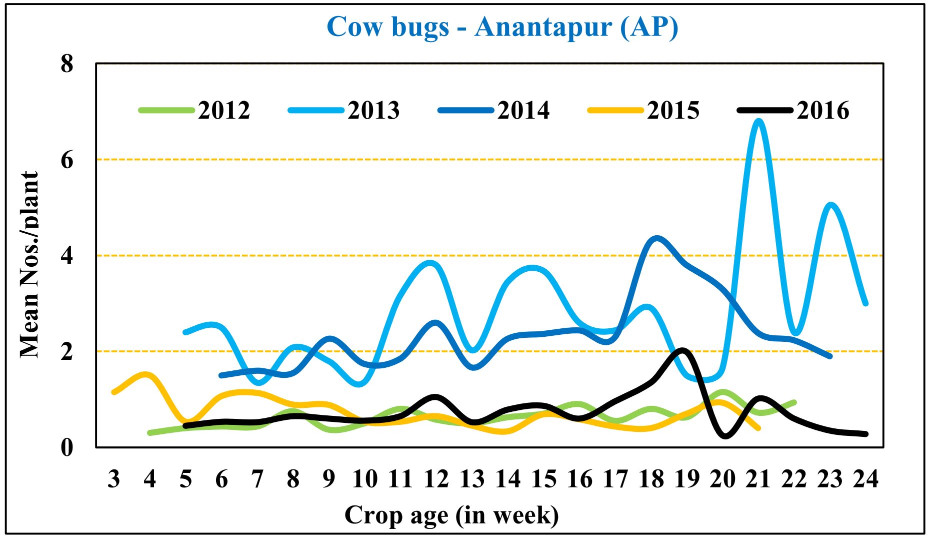
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





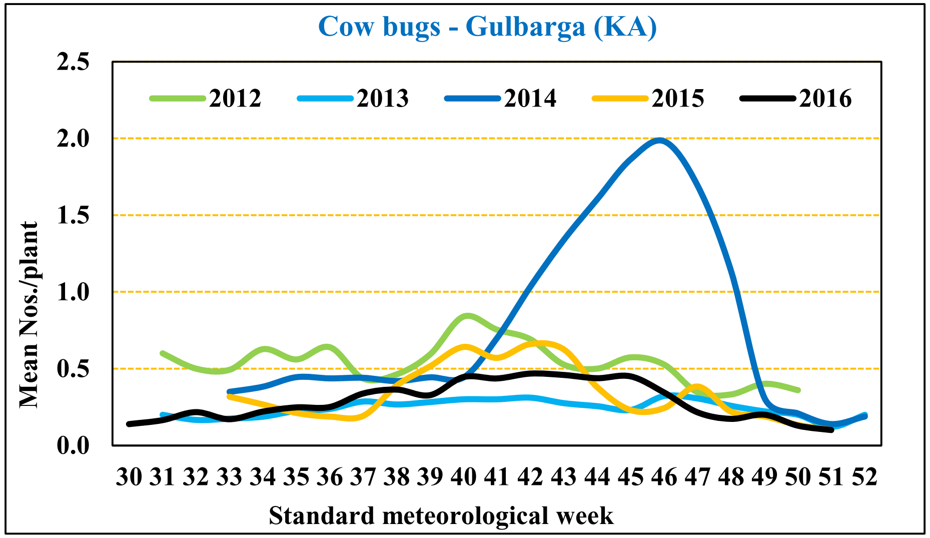


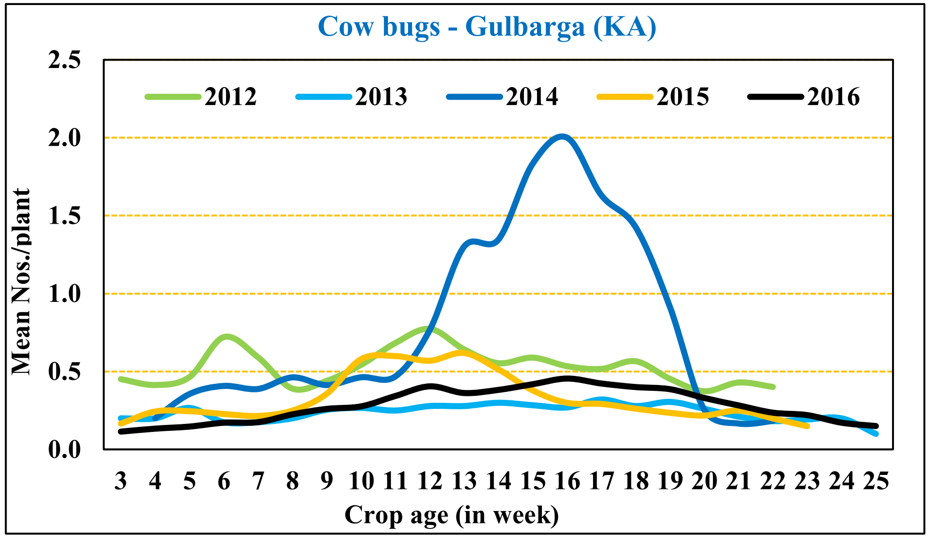


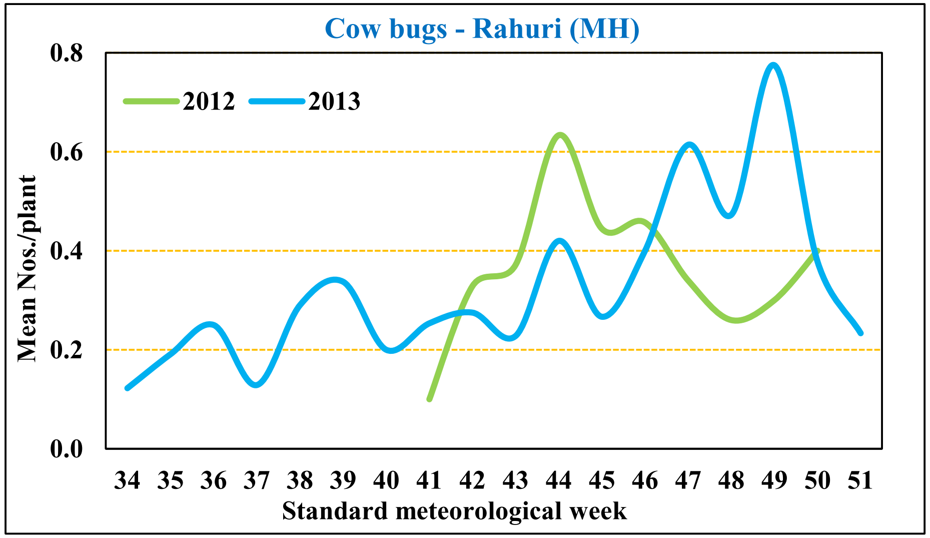
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

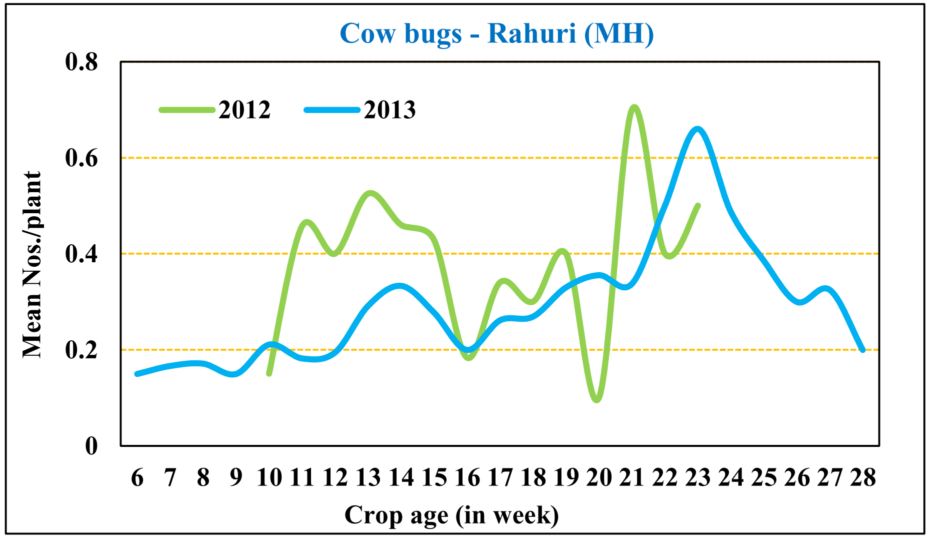
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





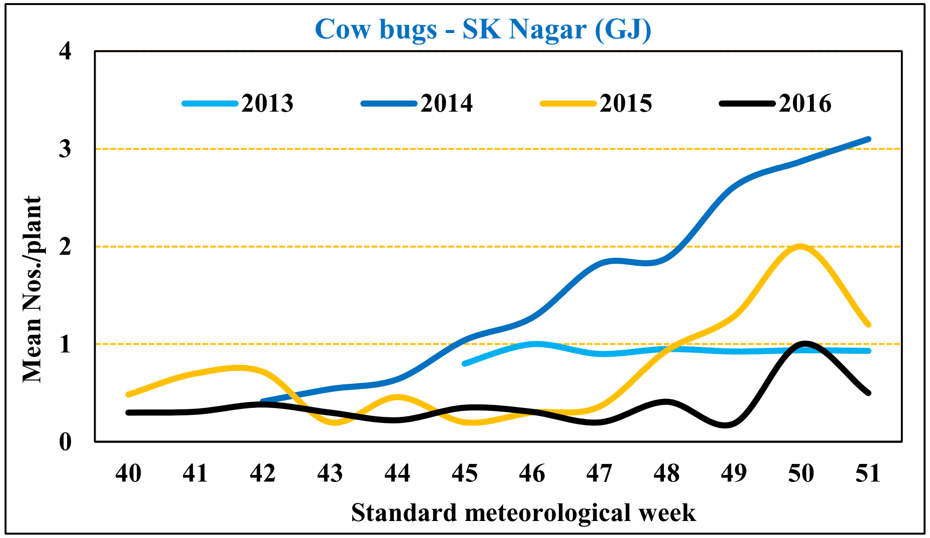


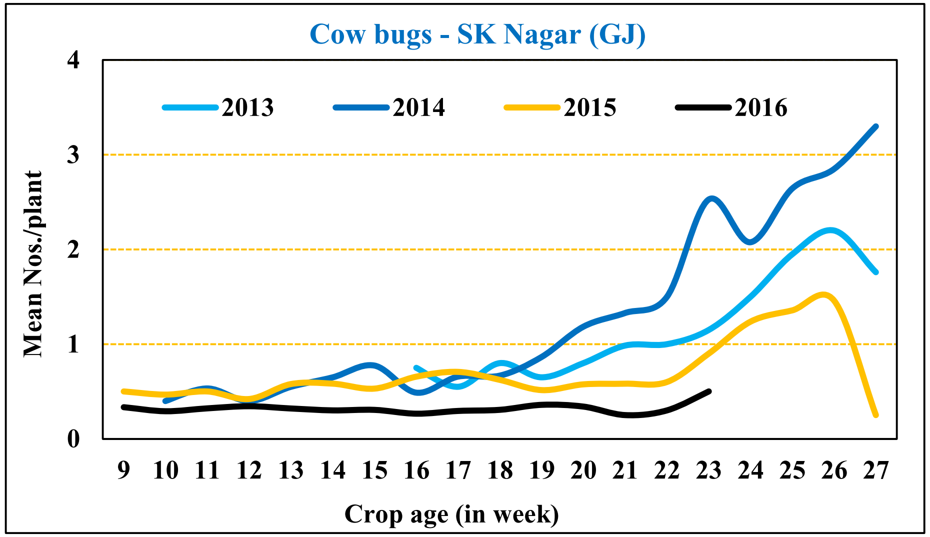


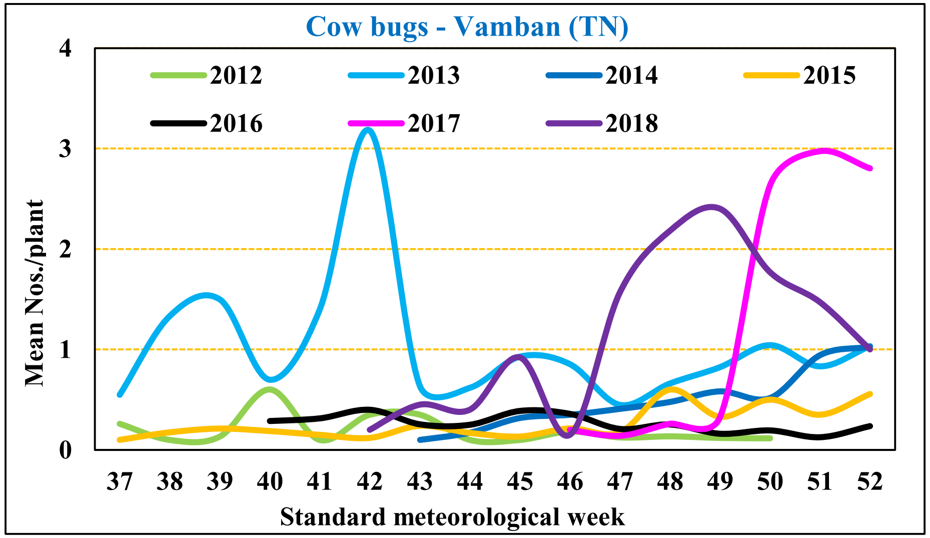
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

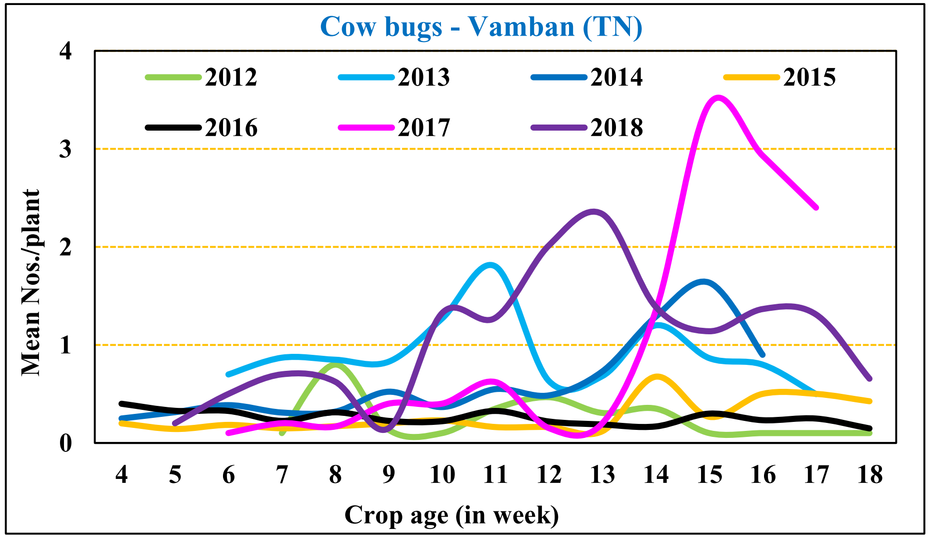
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





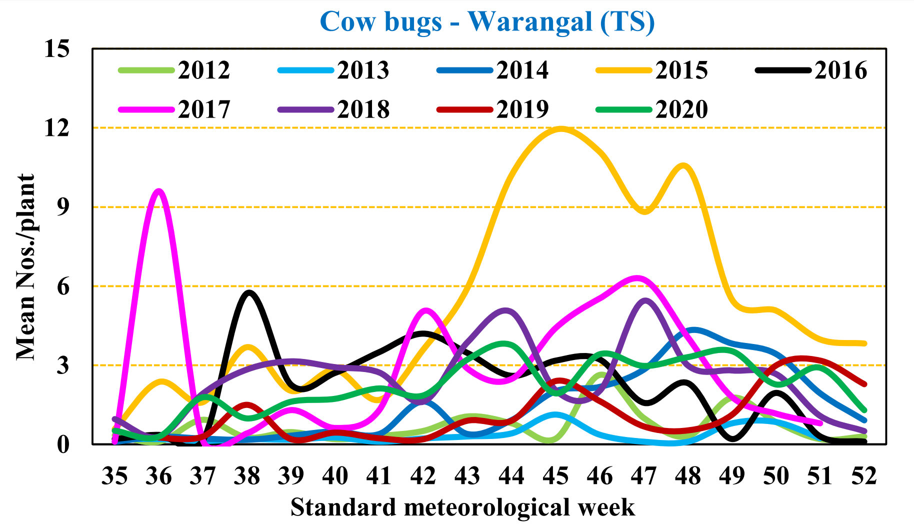


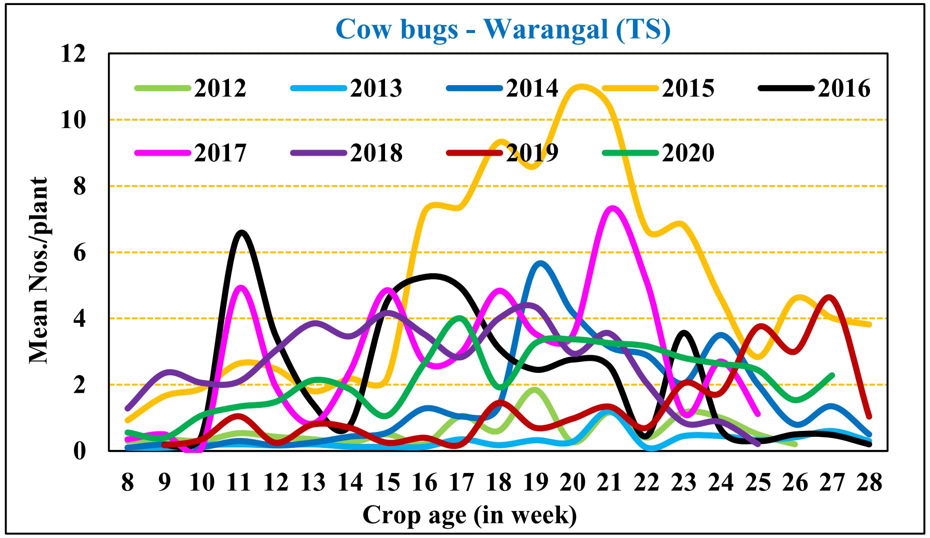


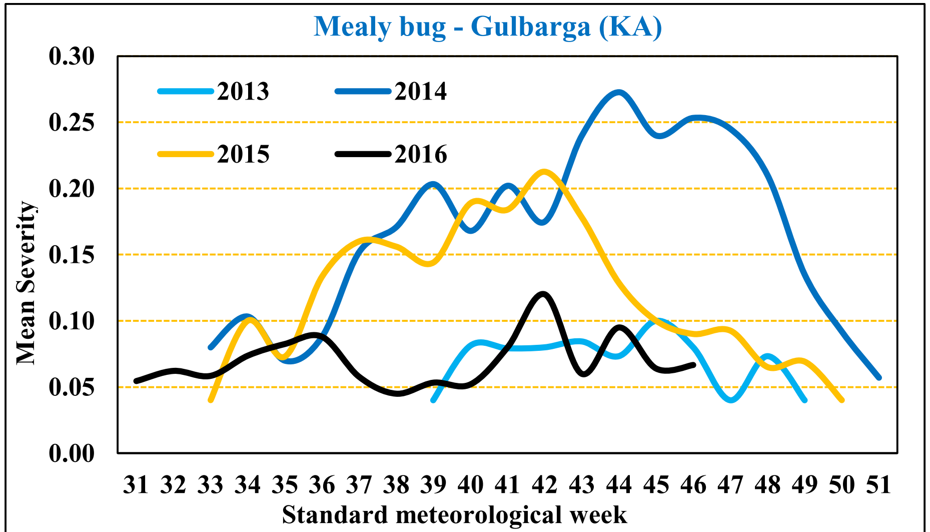
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

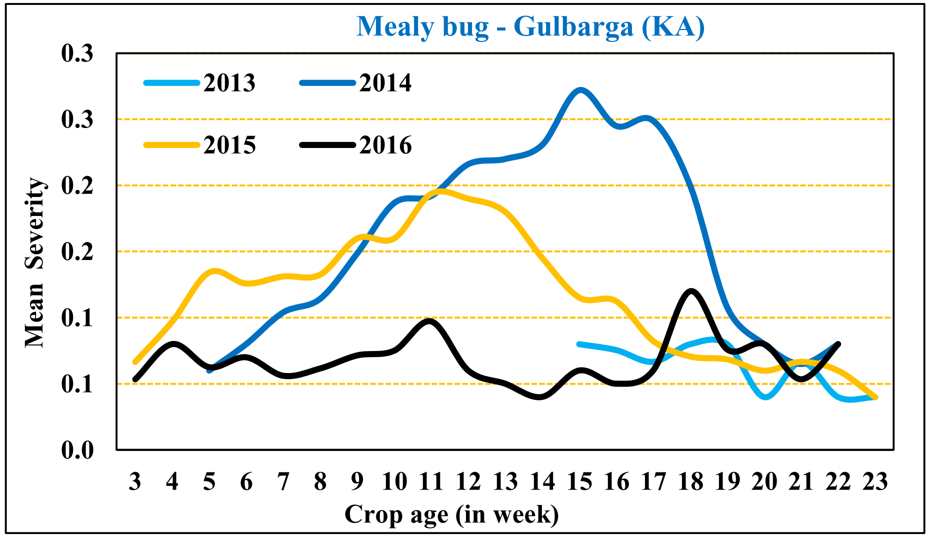
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





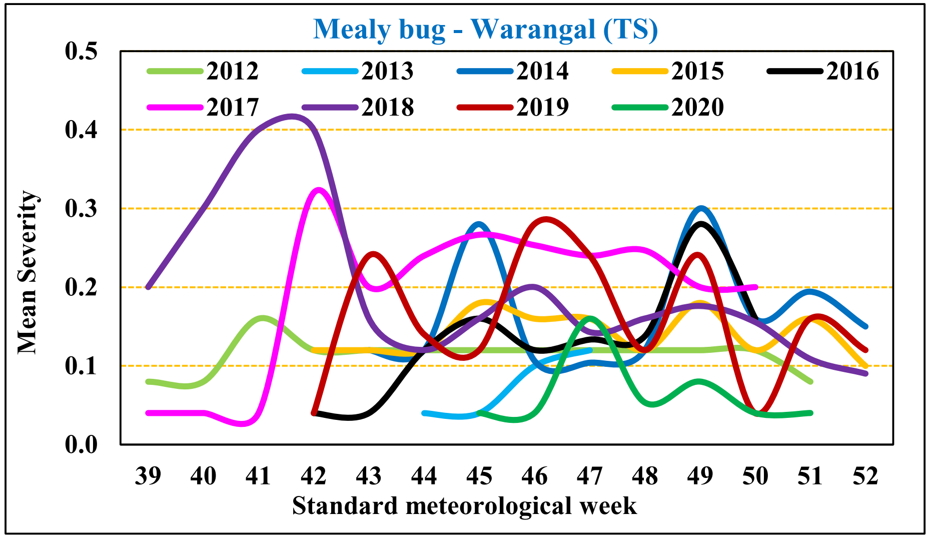


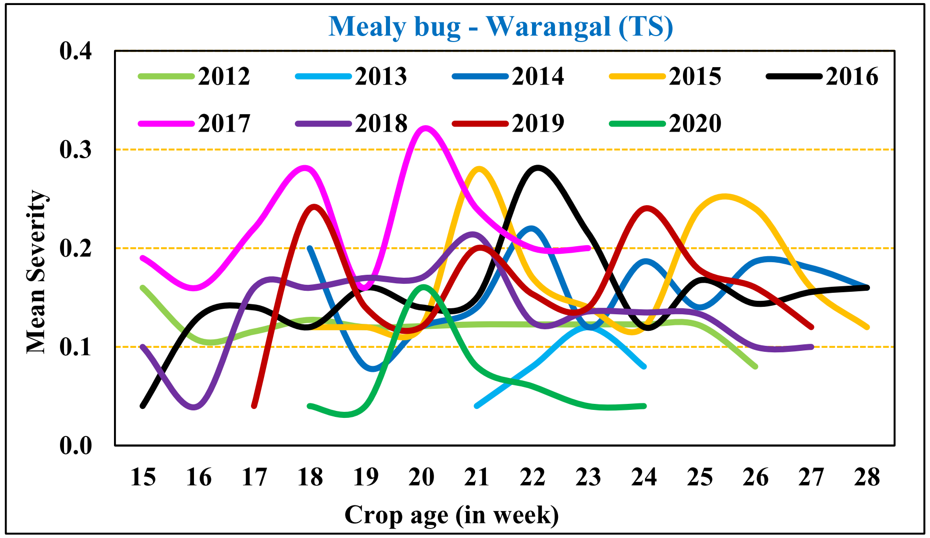


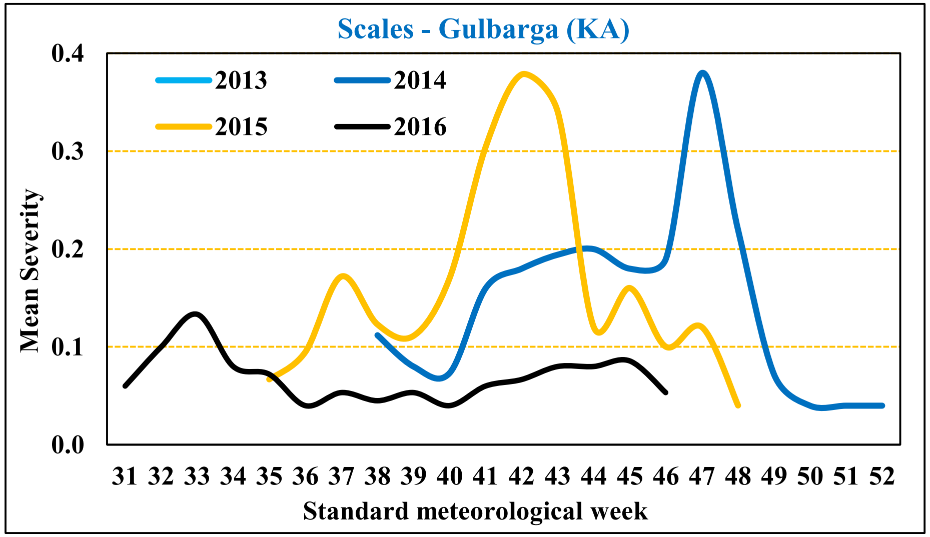
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

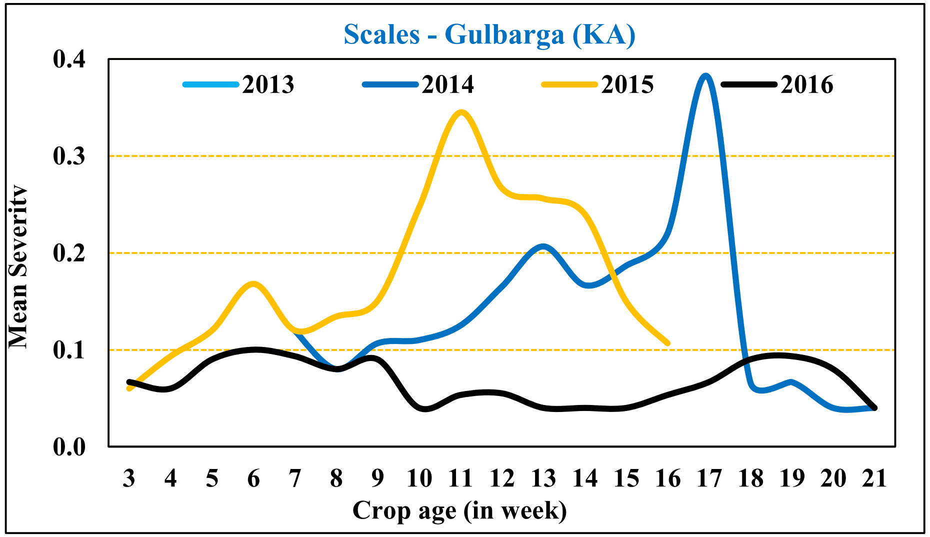
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





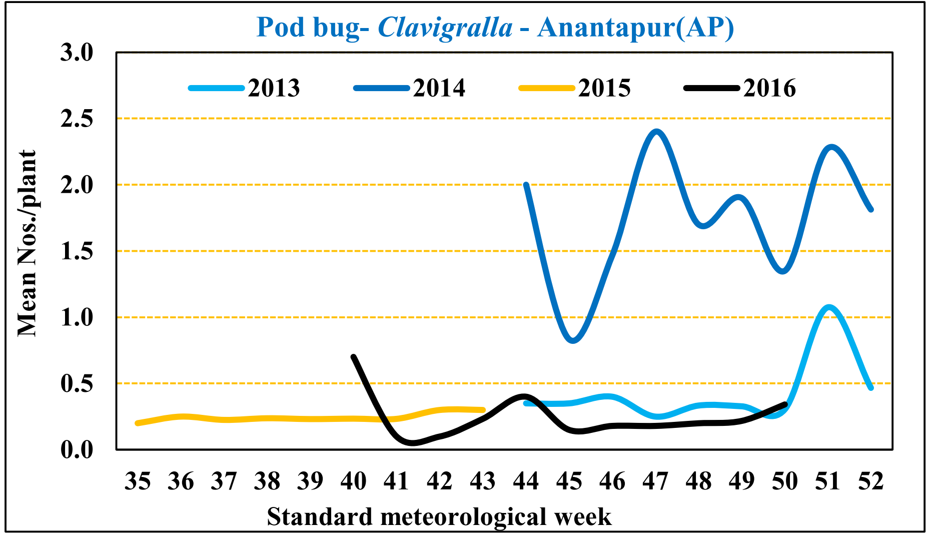


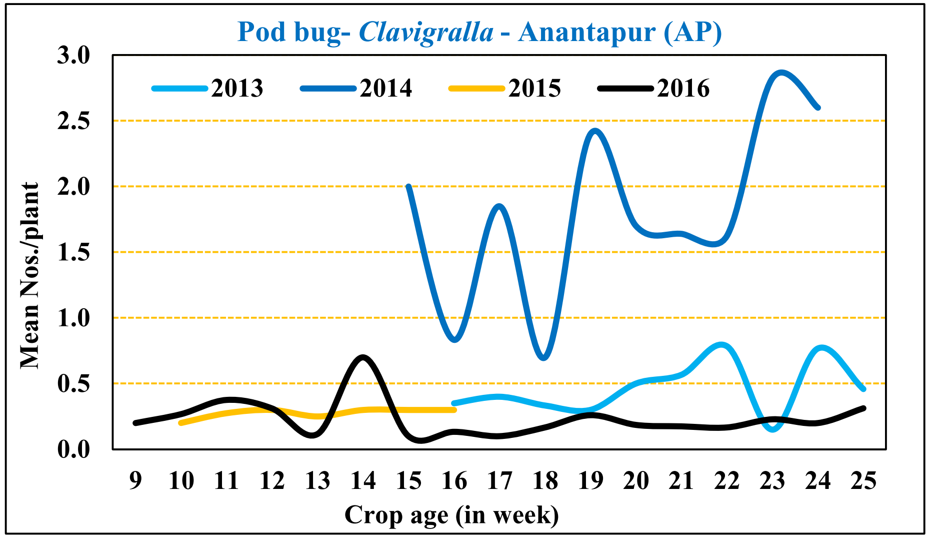


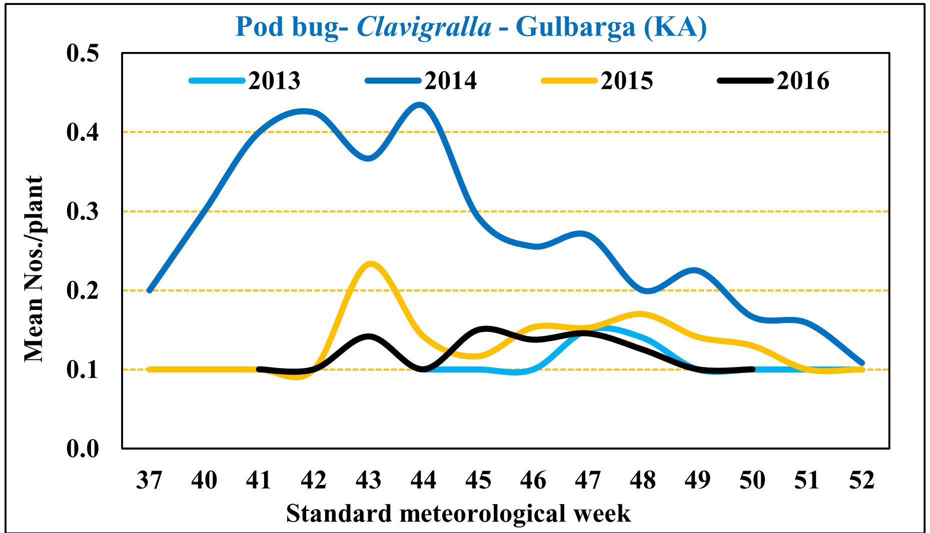
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

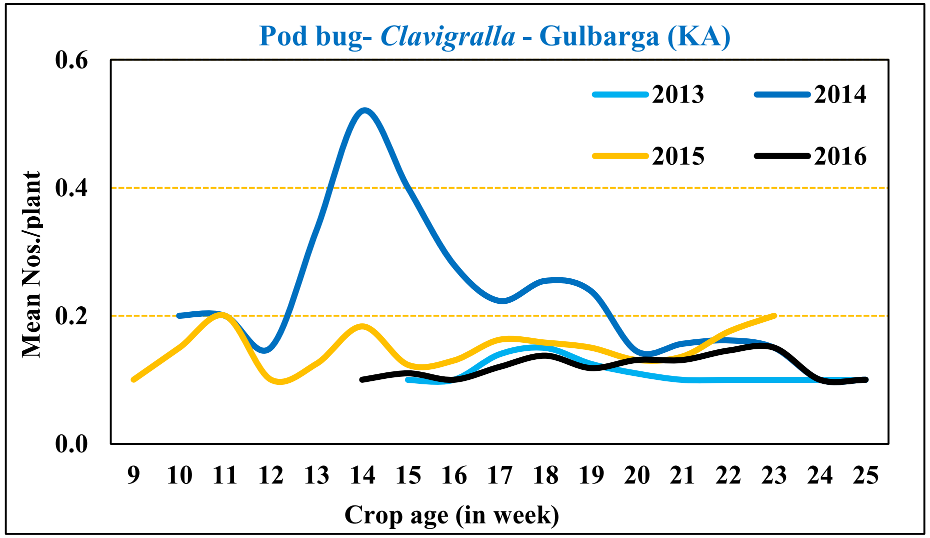
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





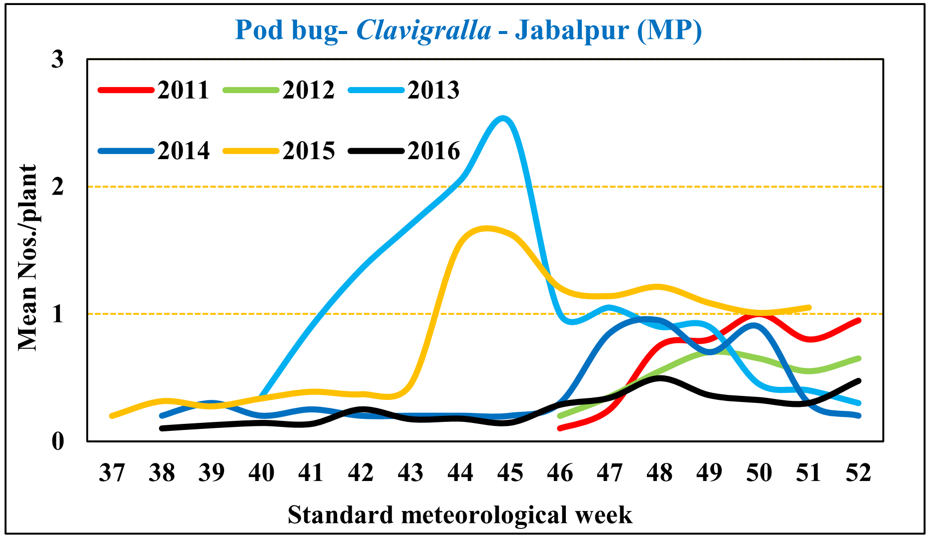


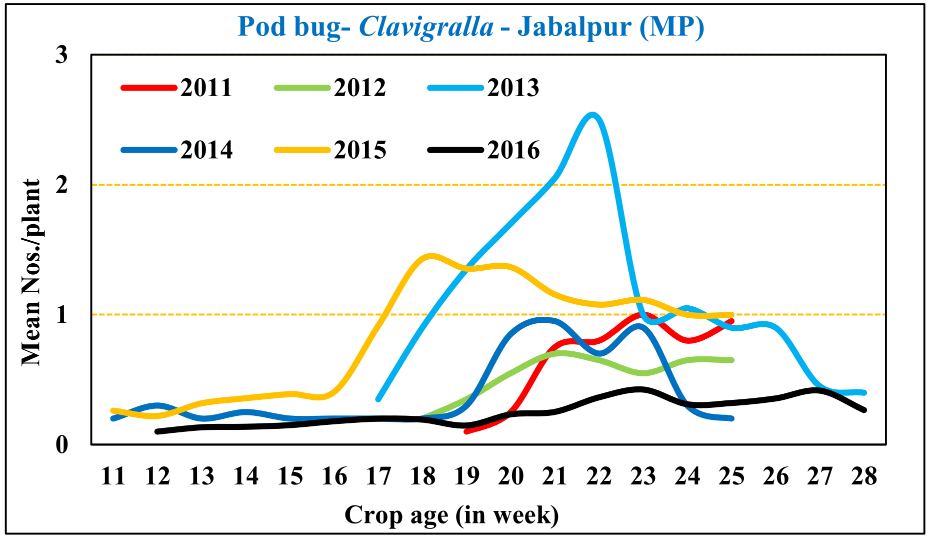


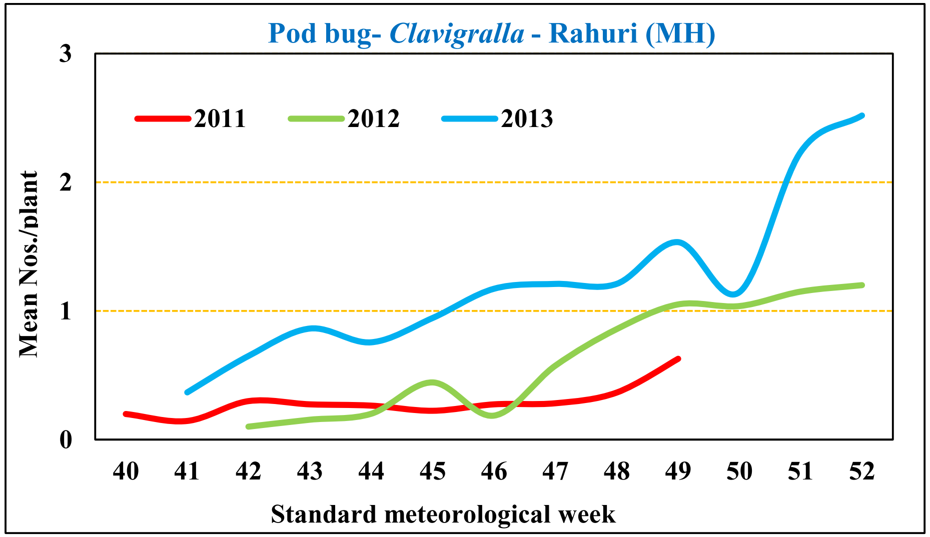
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

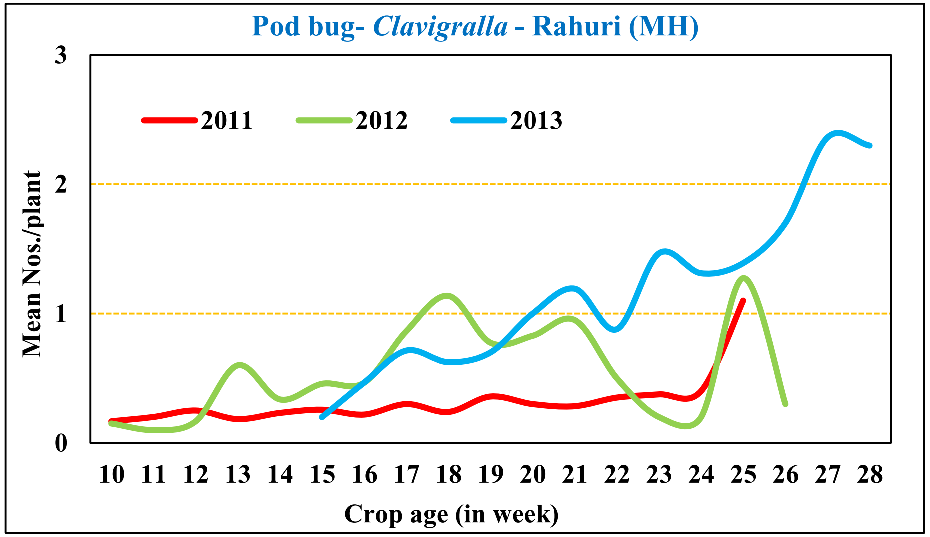
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





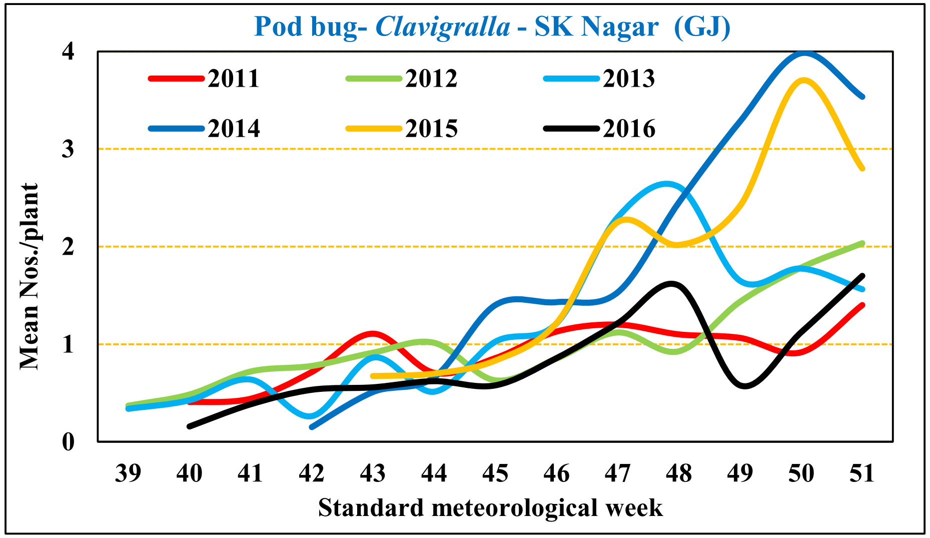


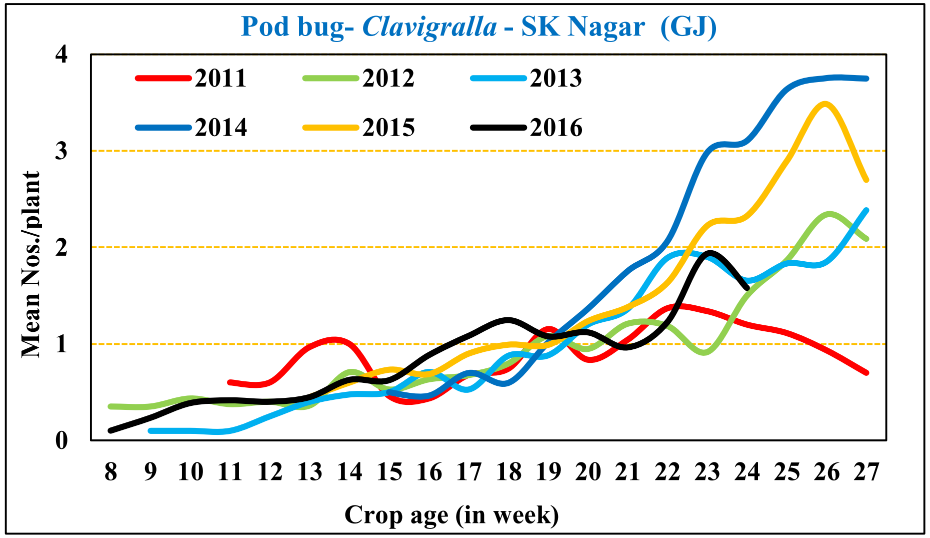


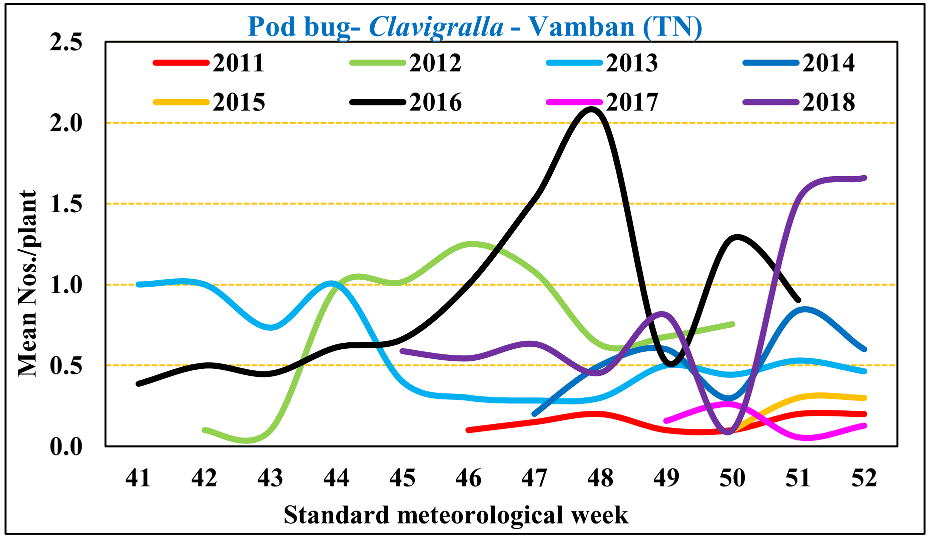
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

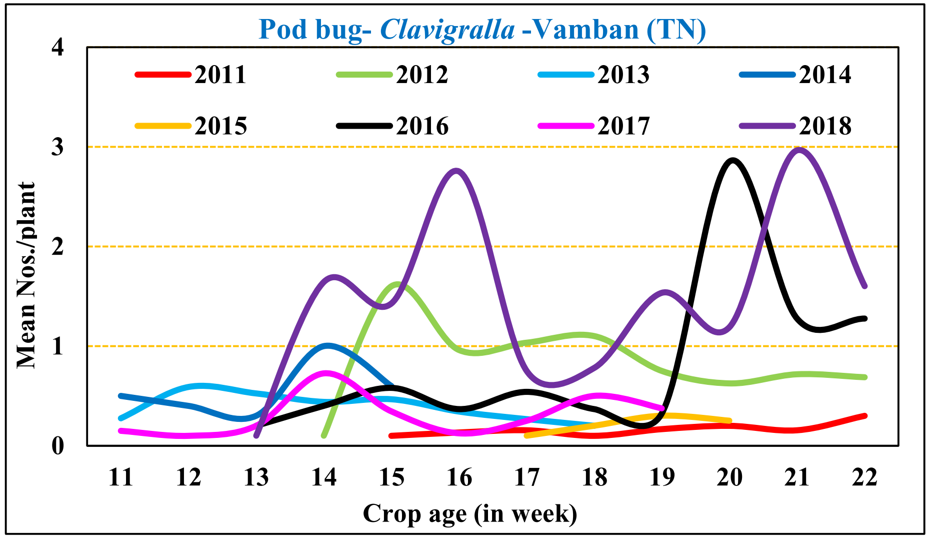
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



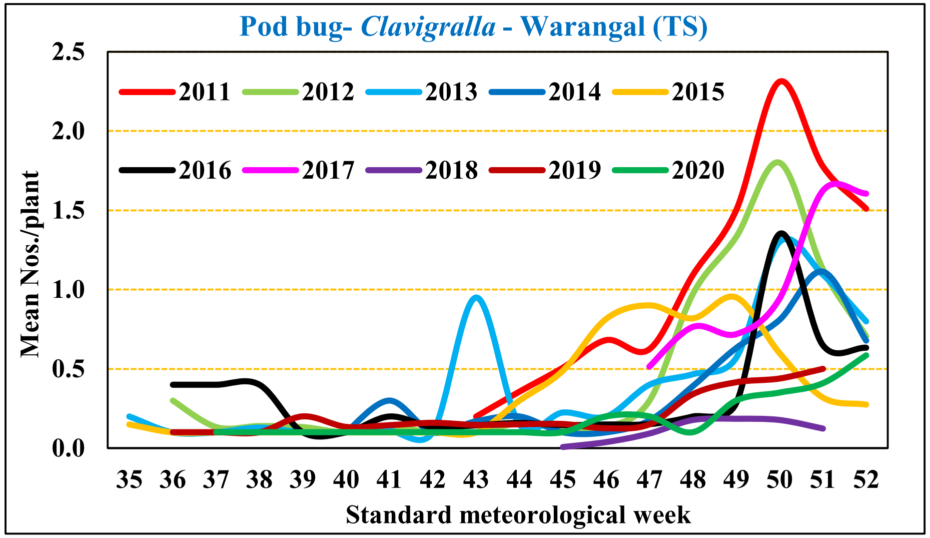


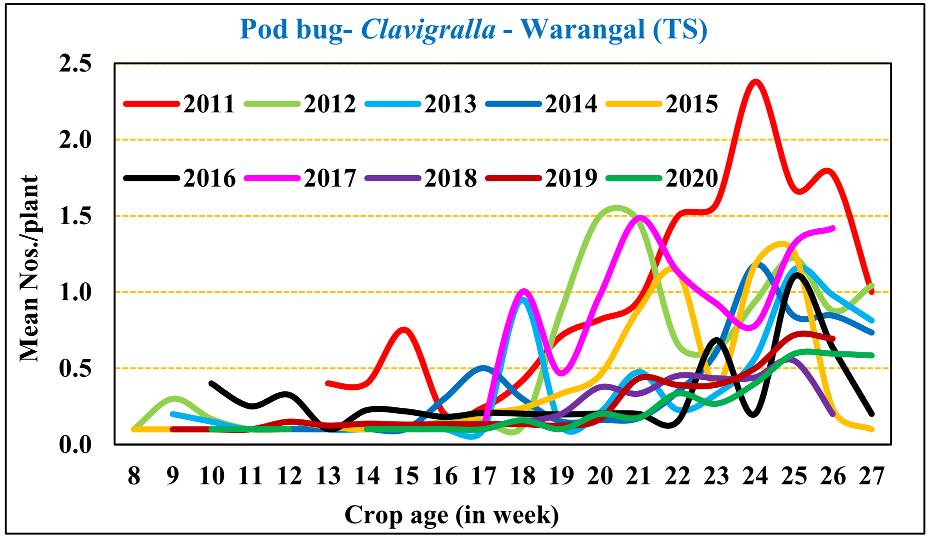


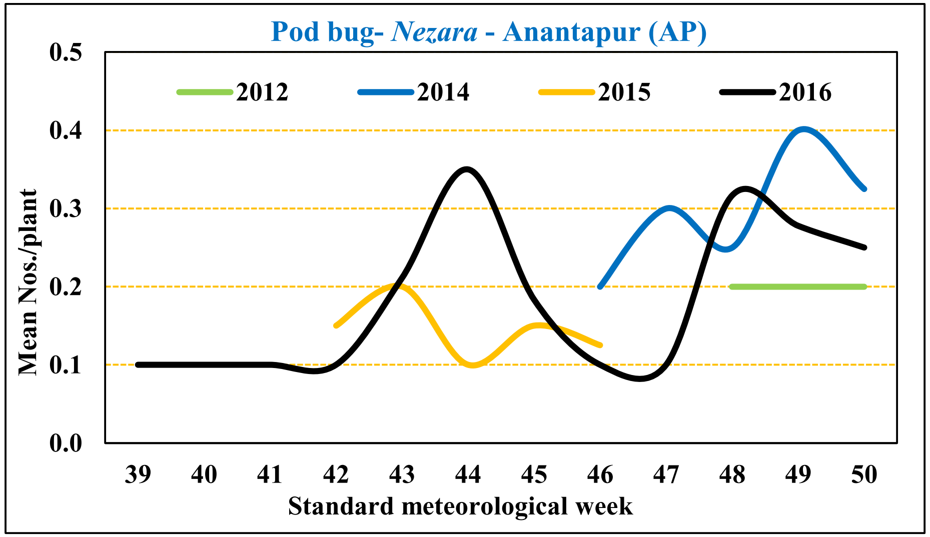


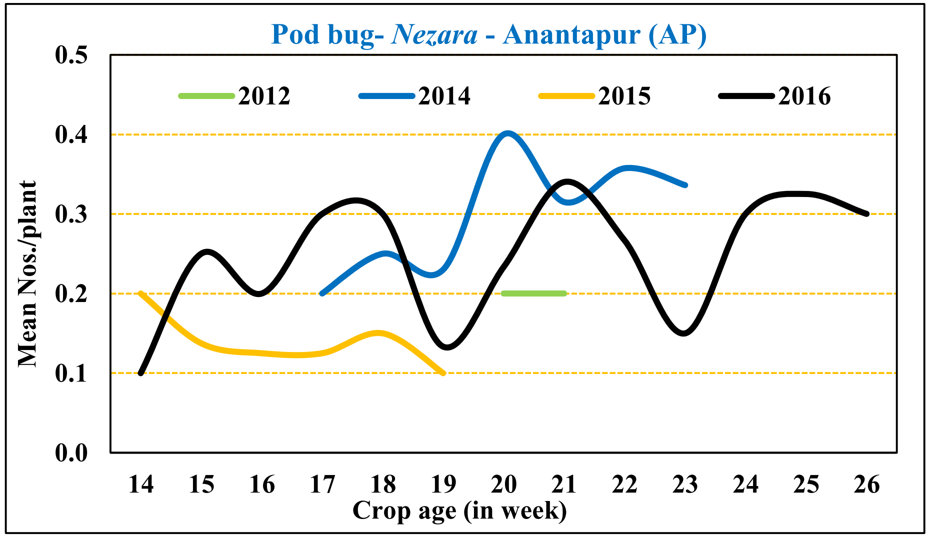
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



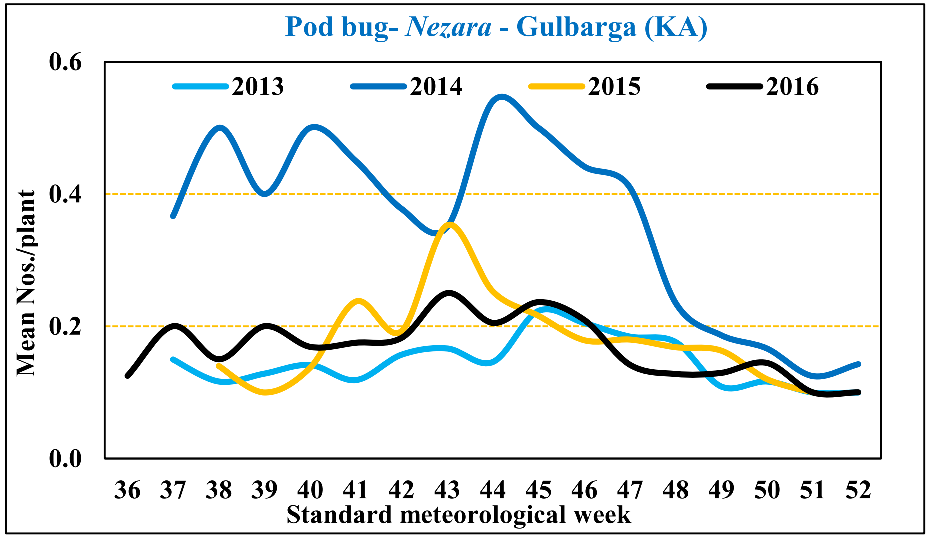


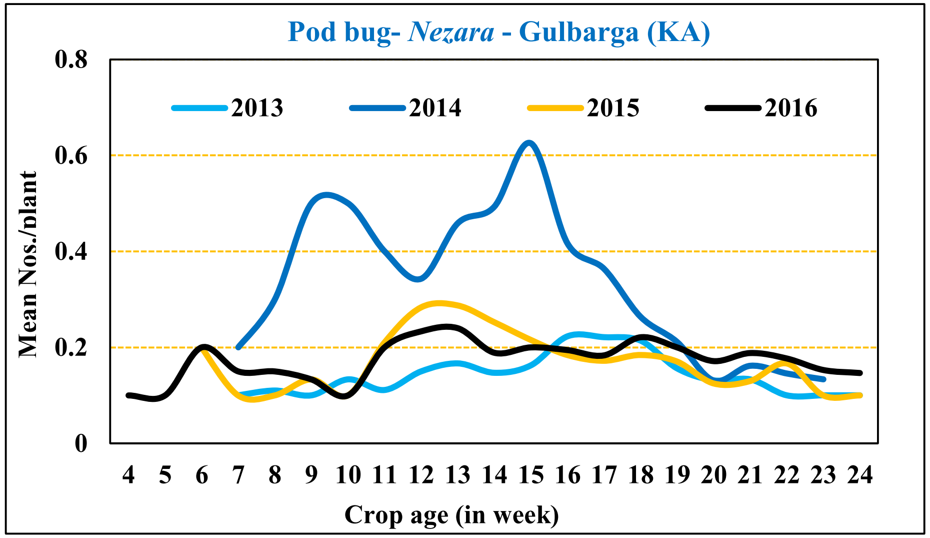


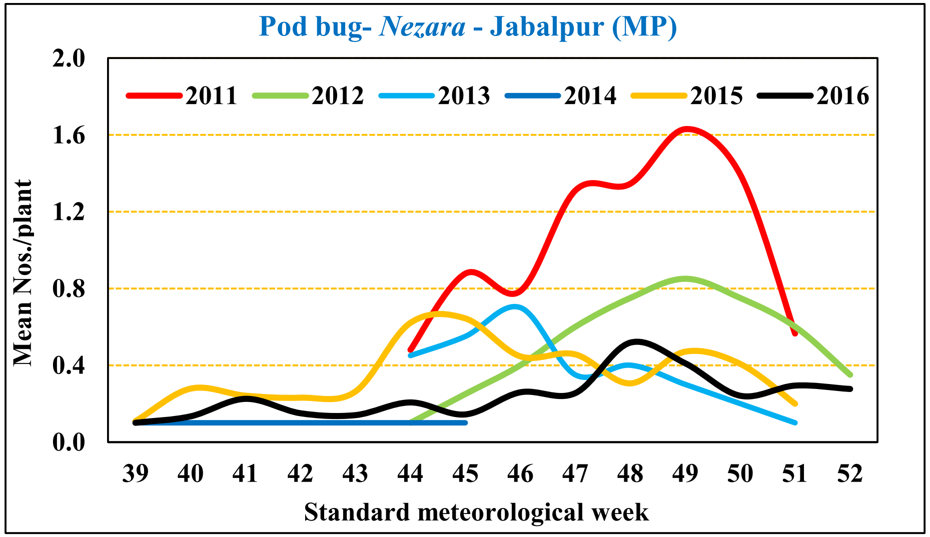


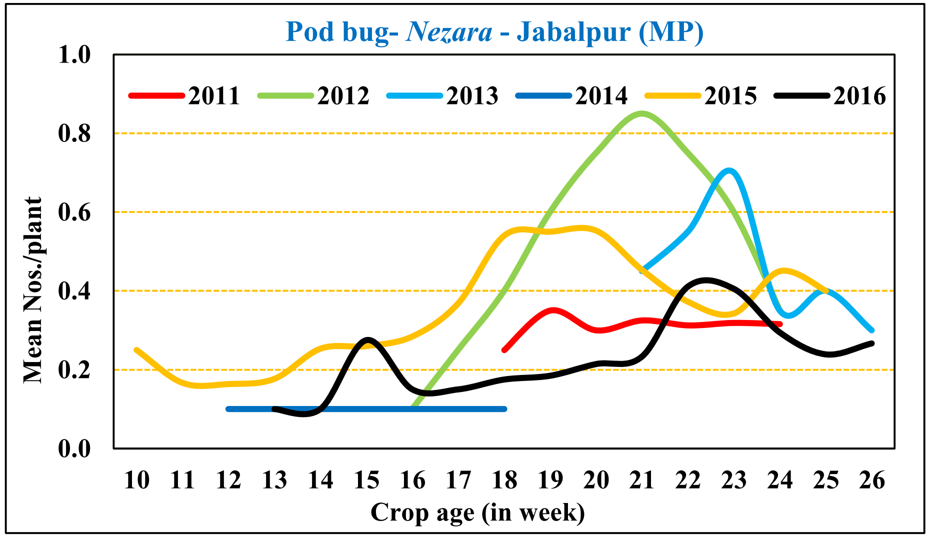
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**





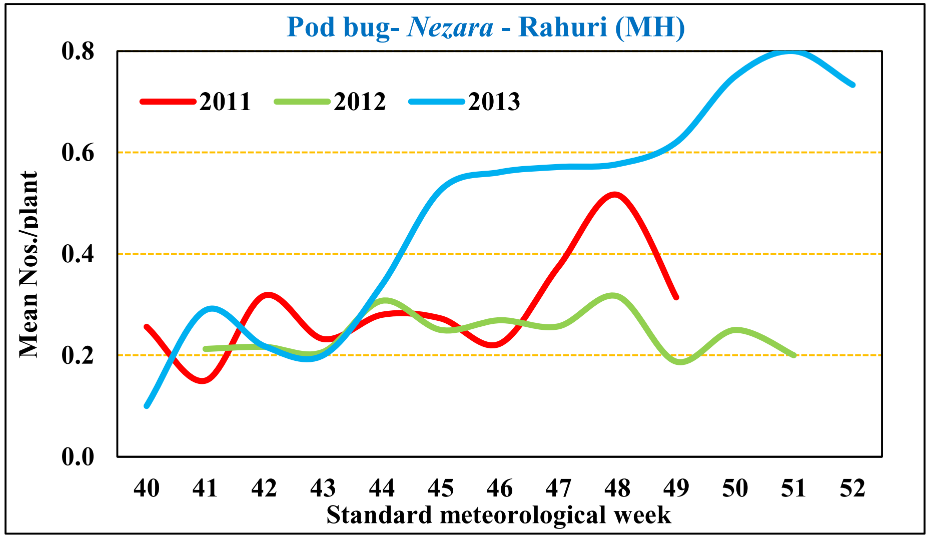


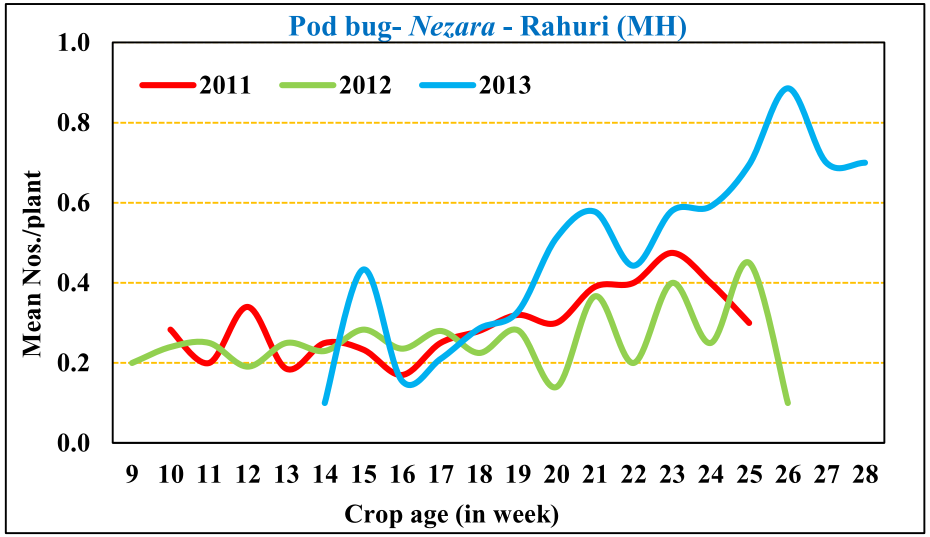


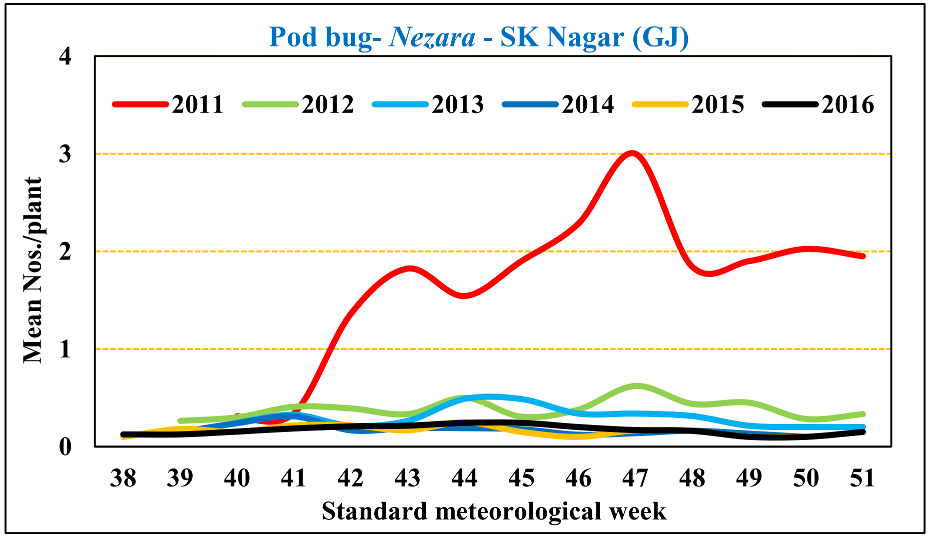
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

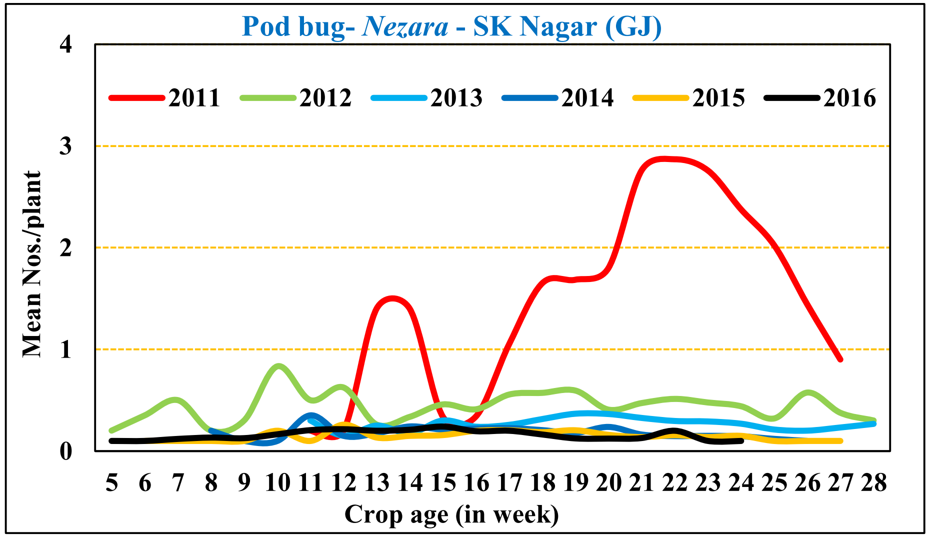
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





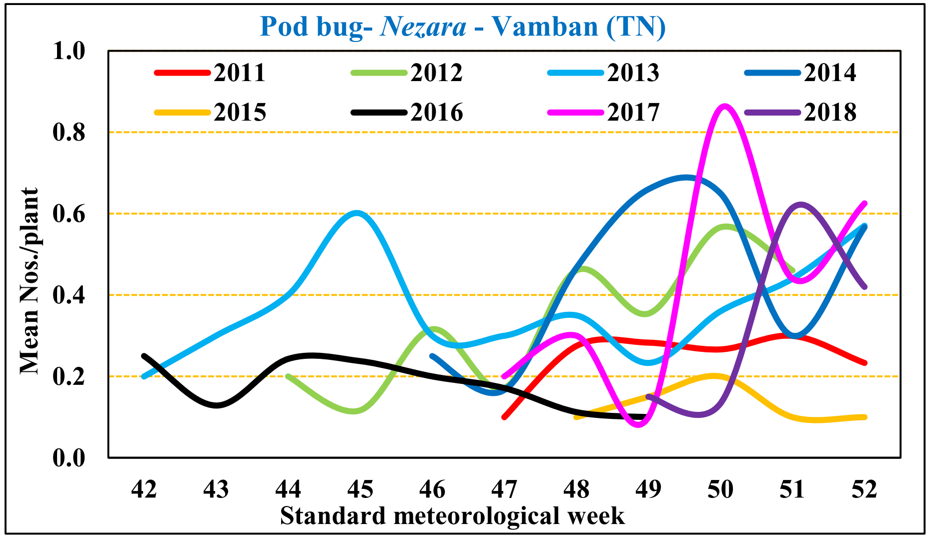


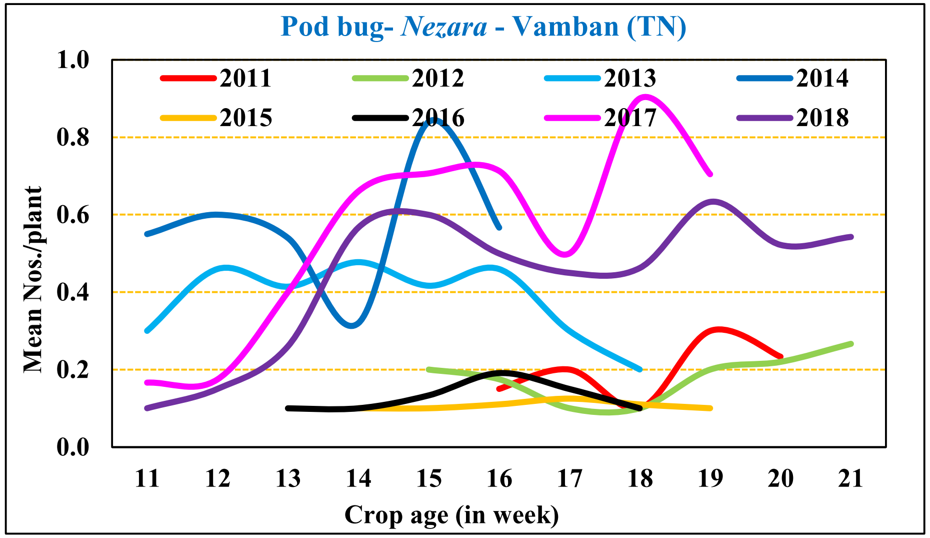


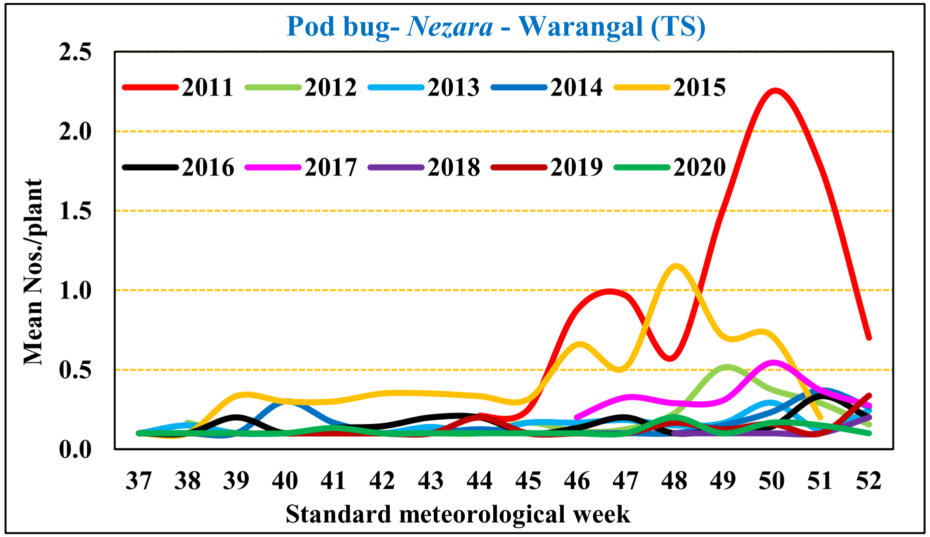
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

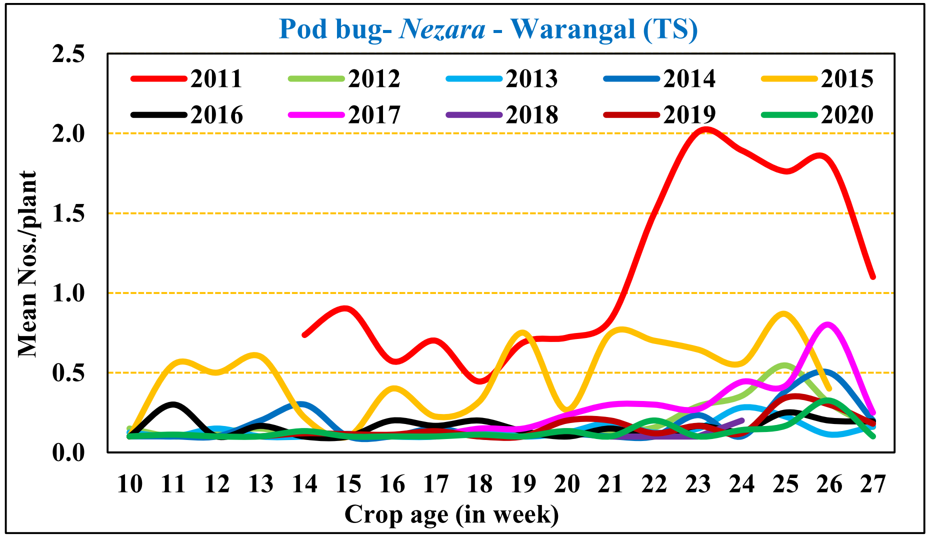
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





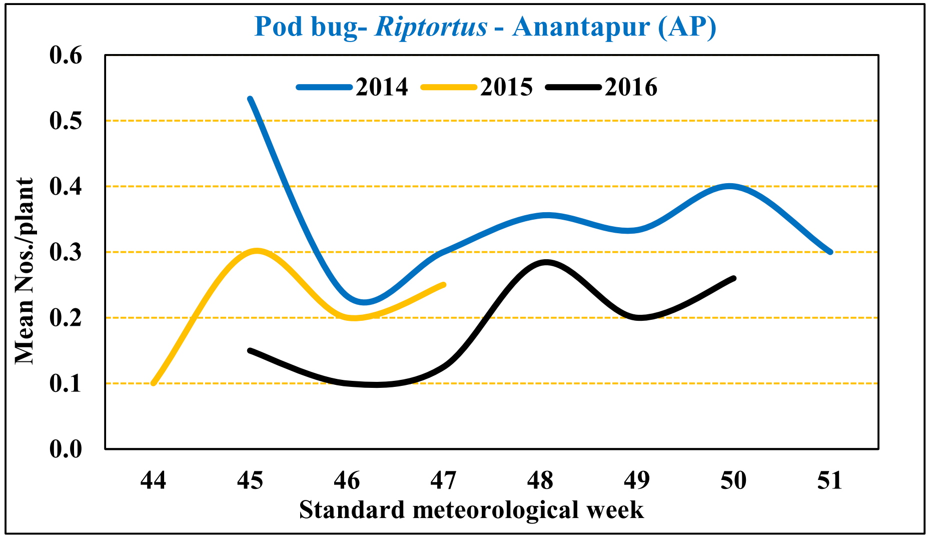


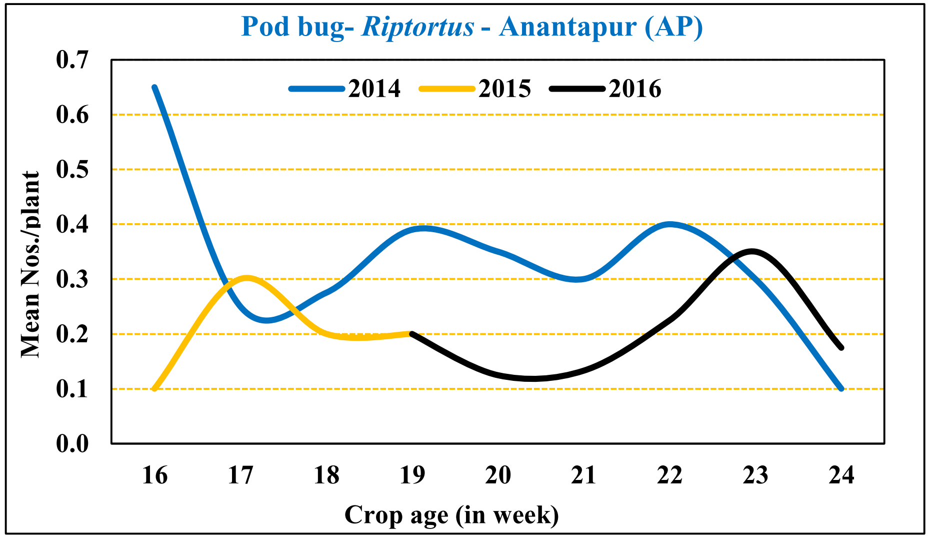


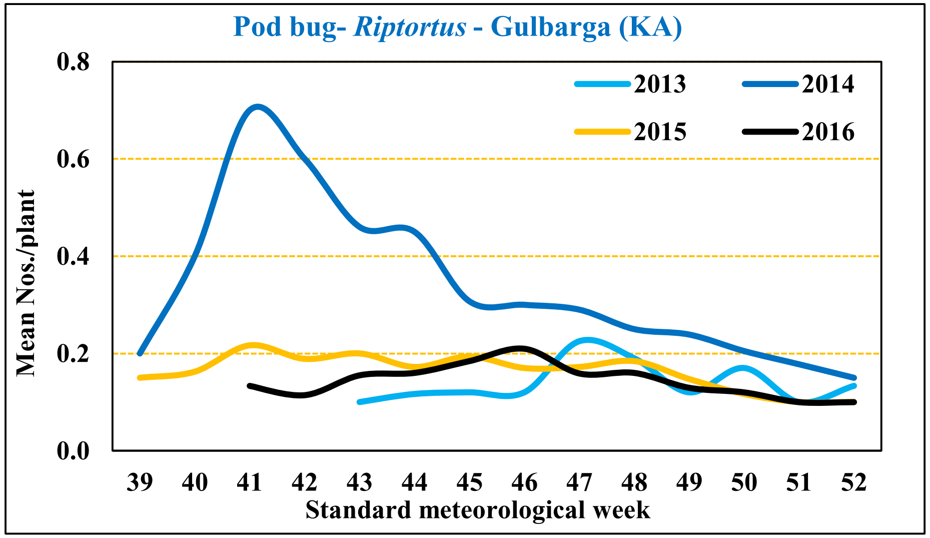
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

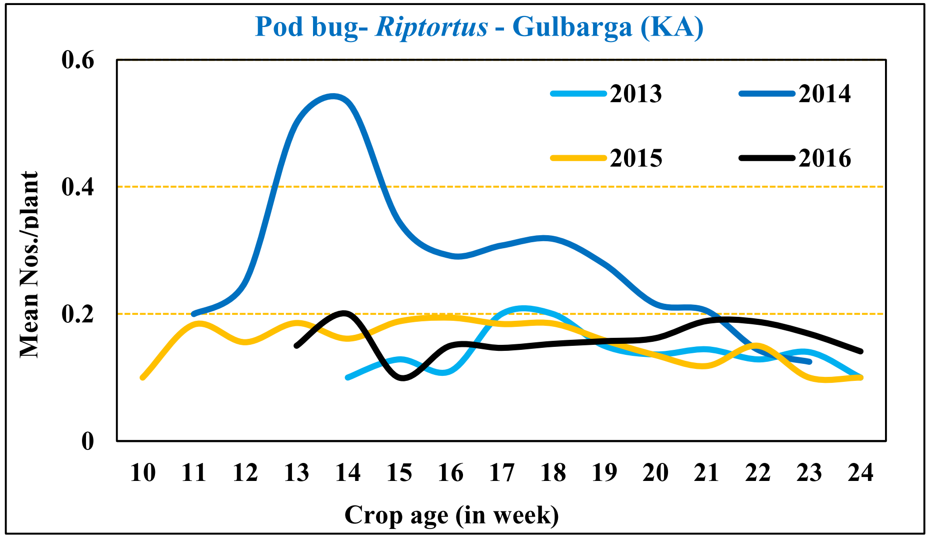
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





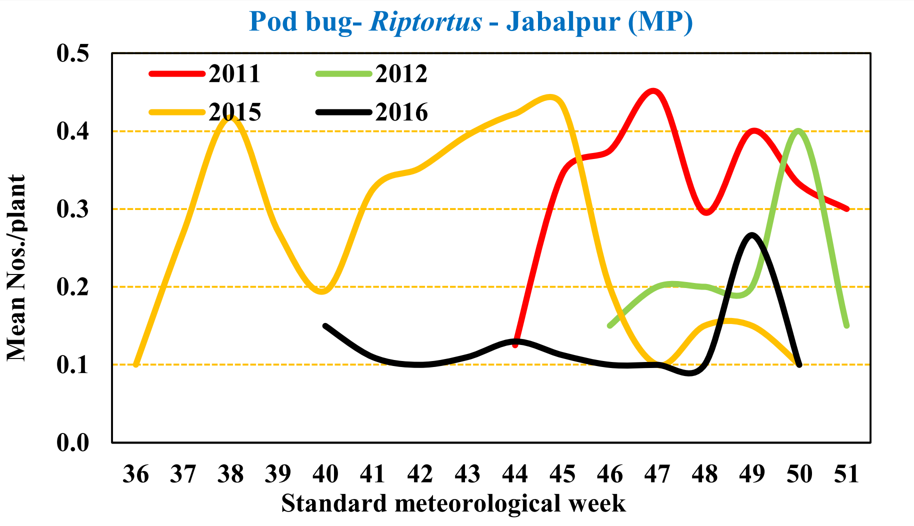


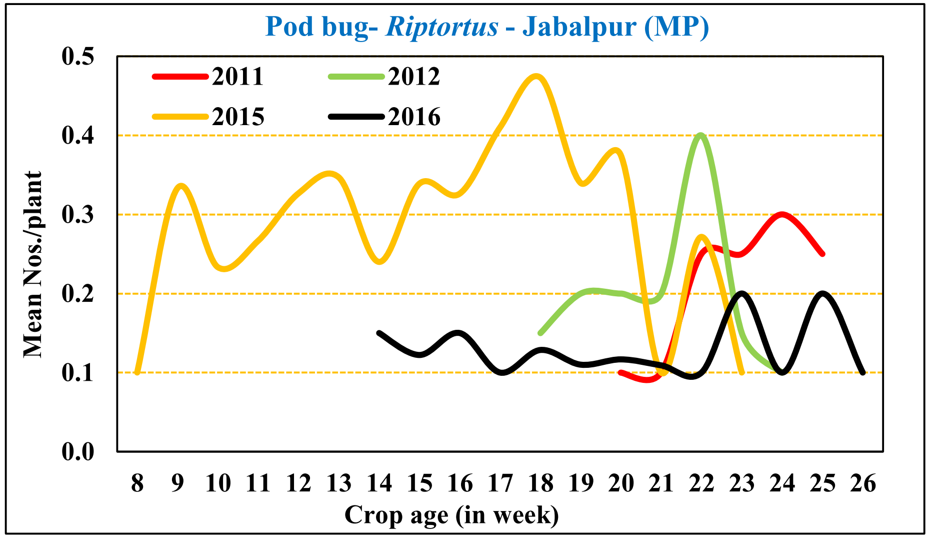


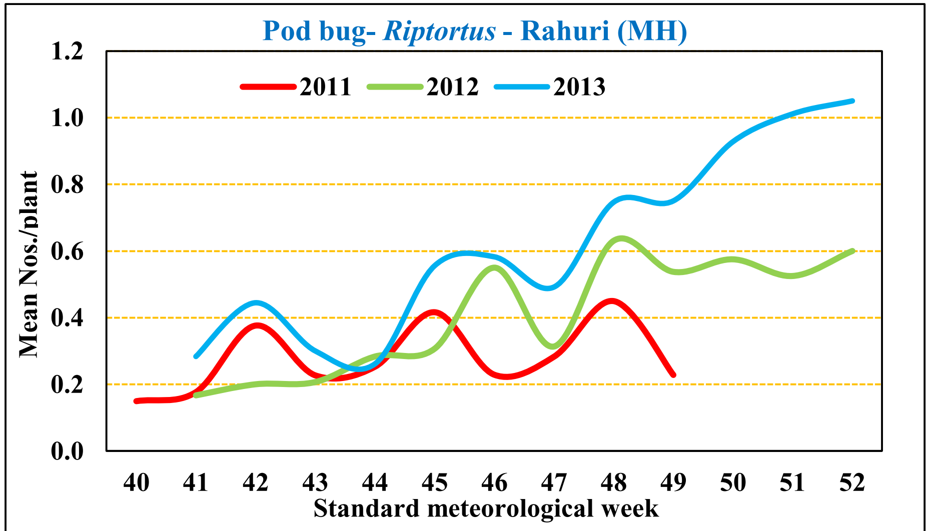
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

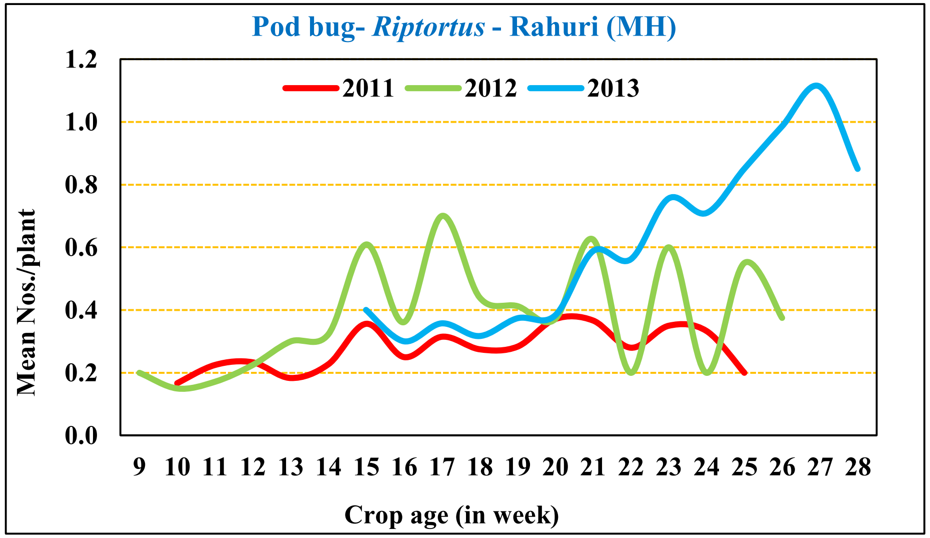
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





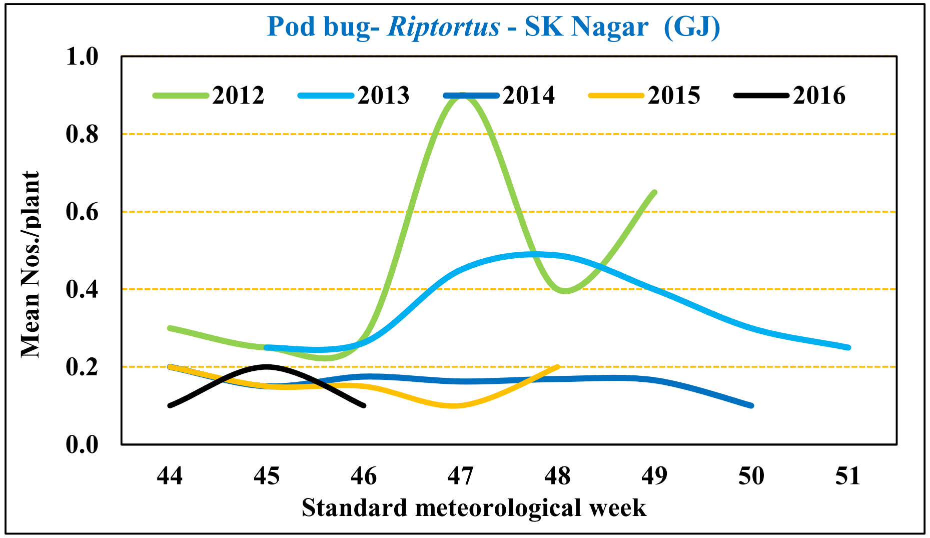


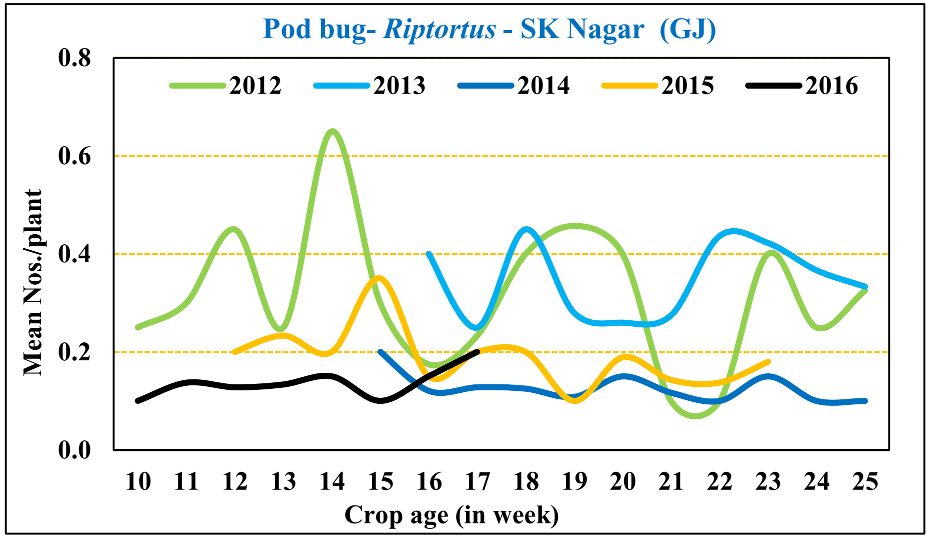


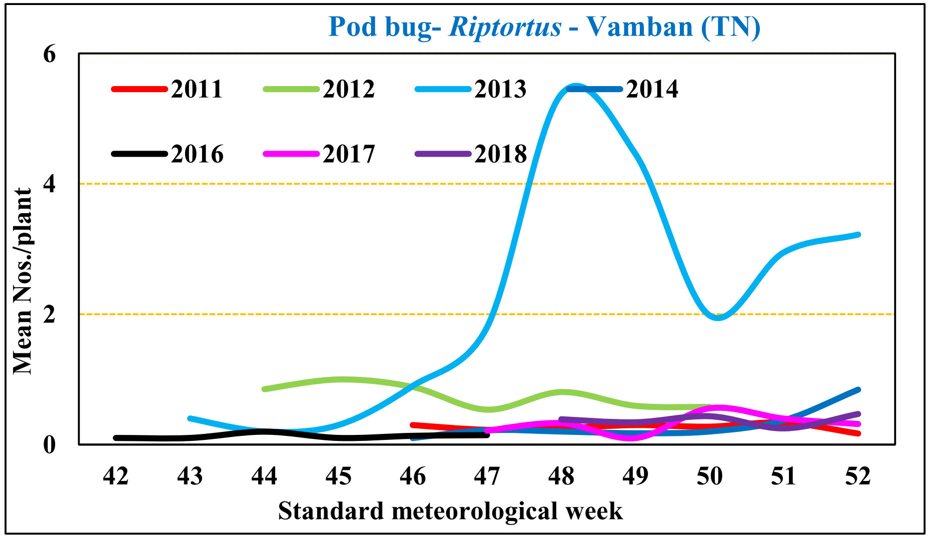
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

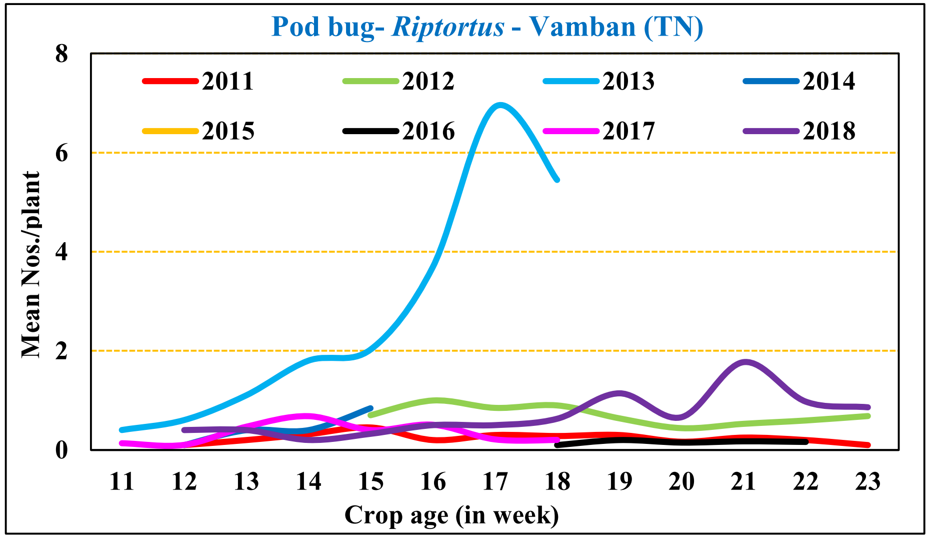
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



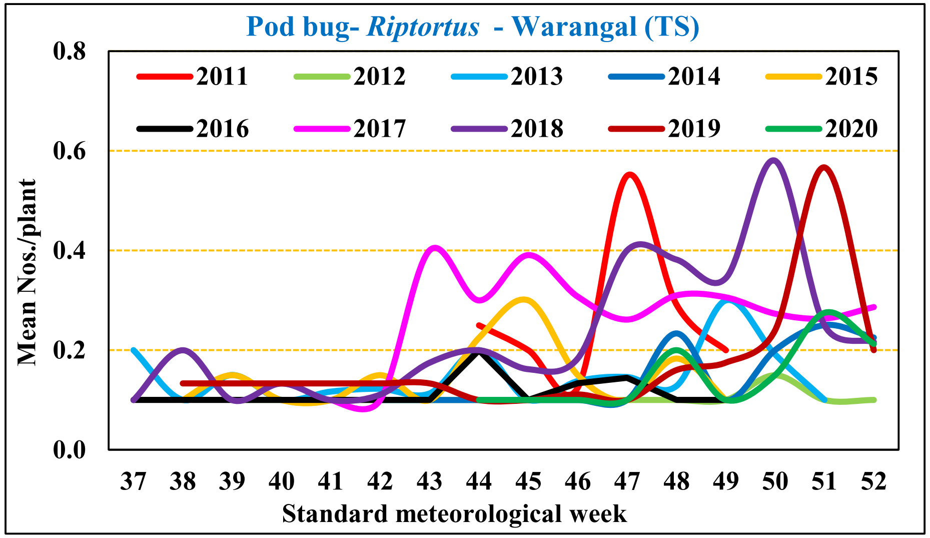


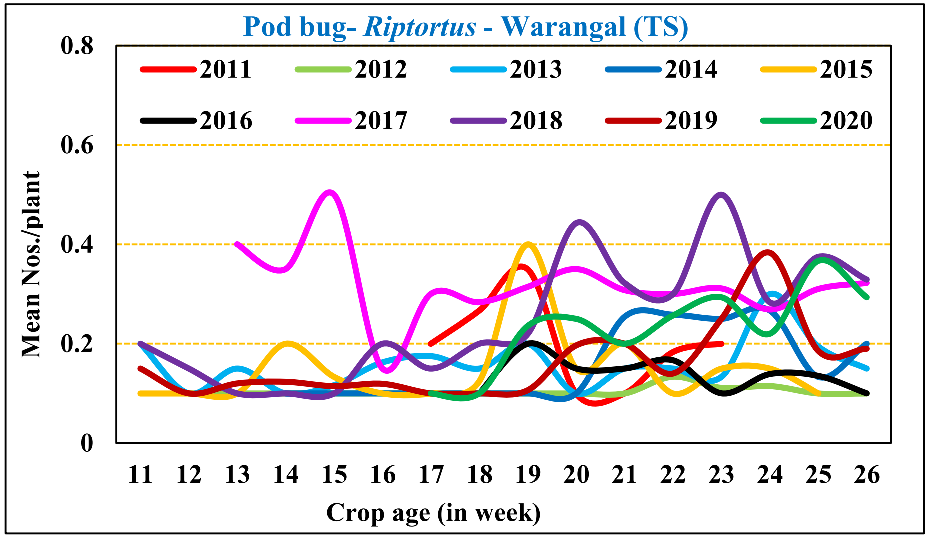


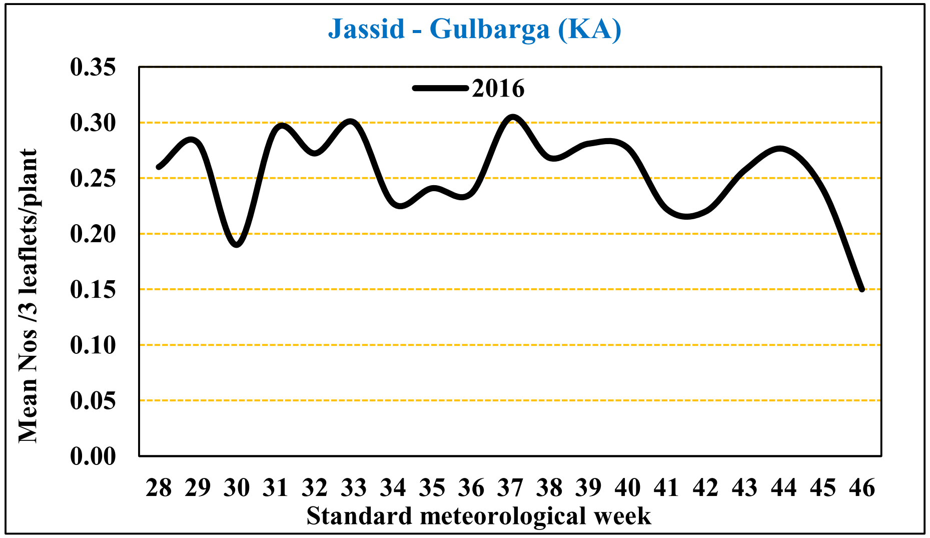


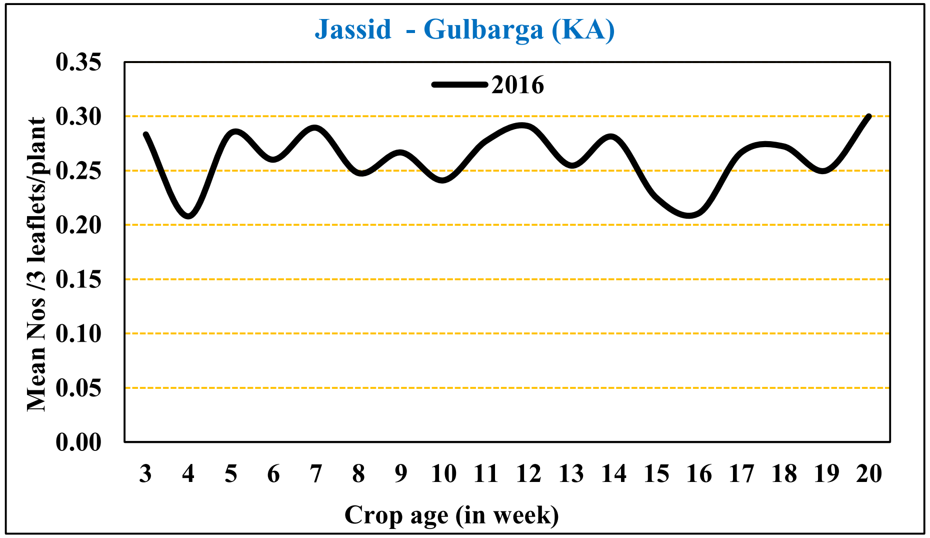
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | Seasonal dynamics based on crop age





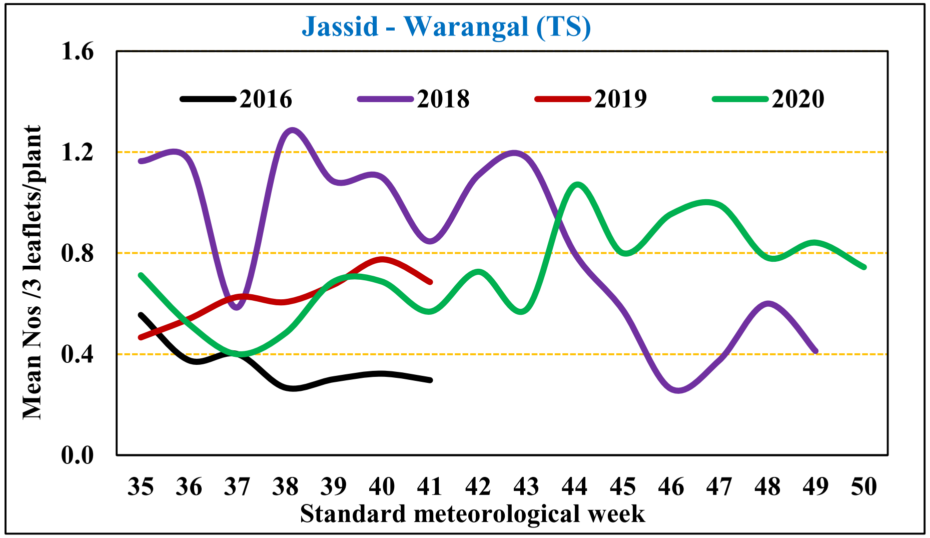


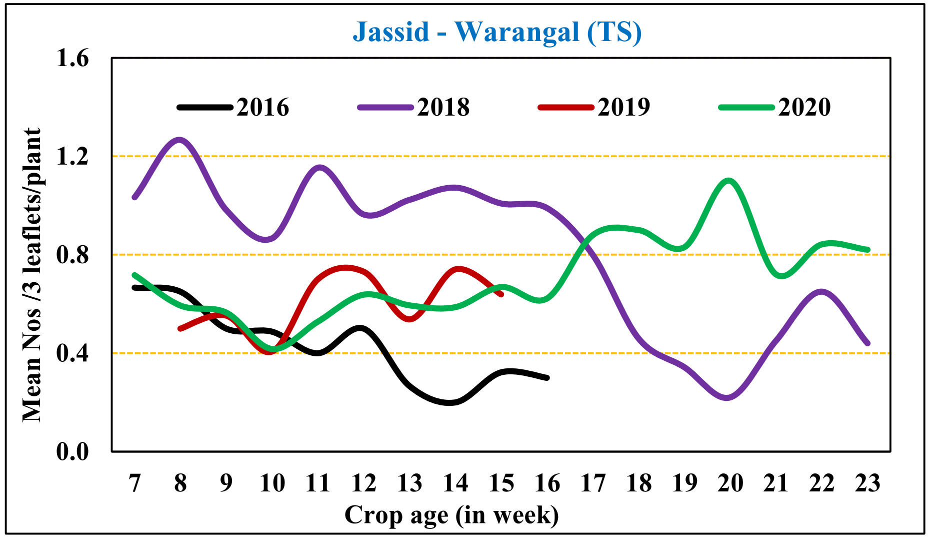


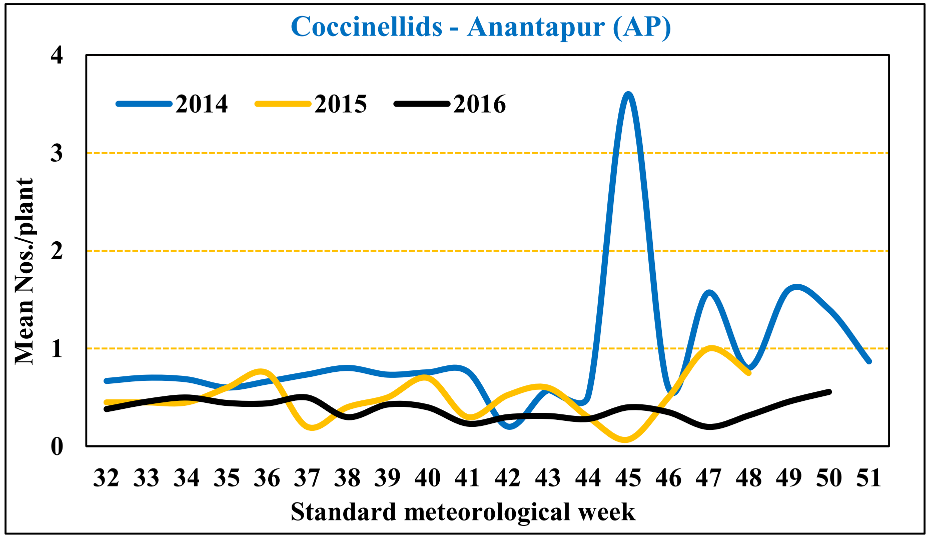
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

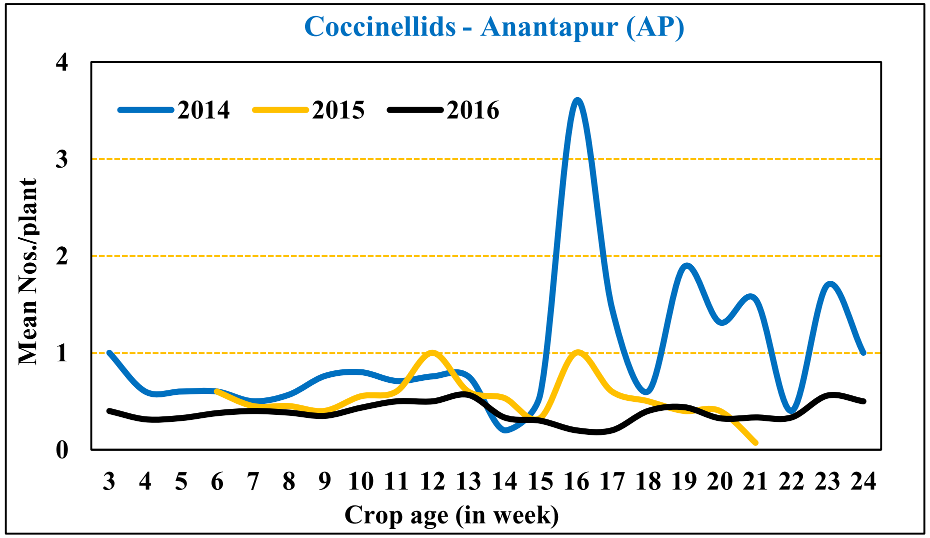
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



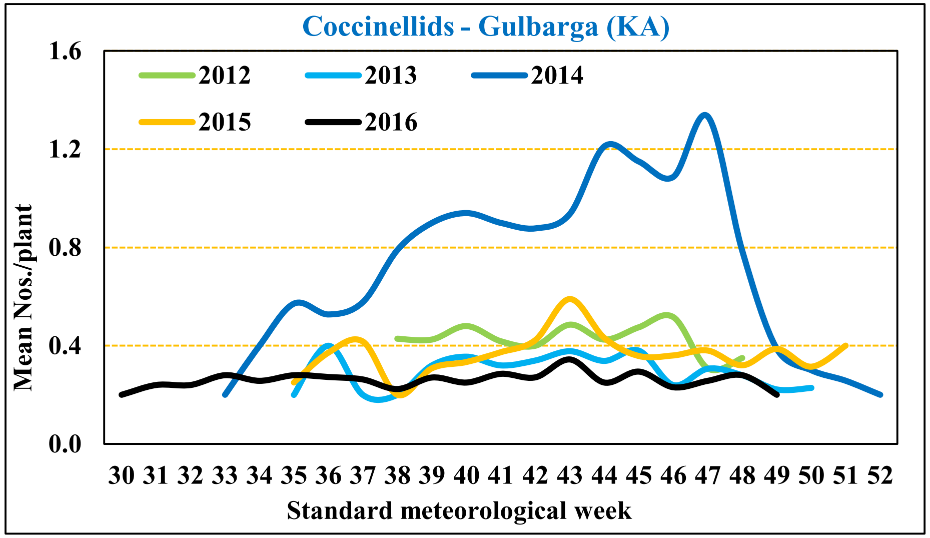


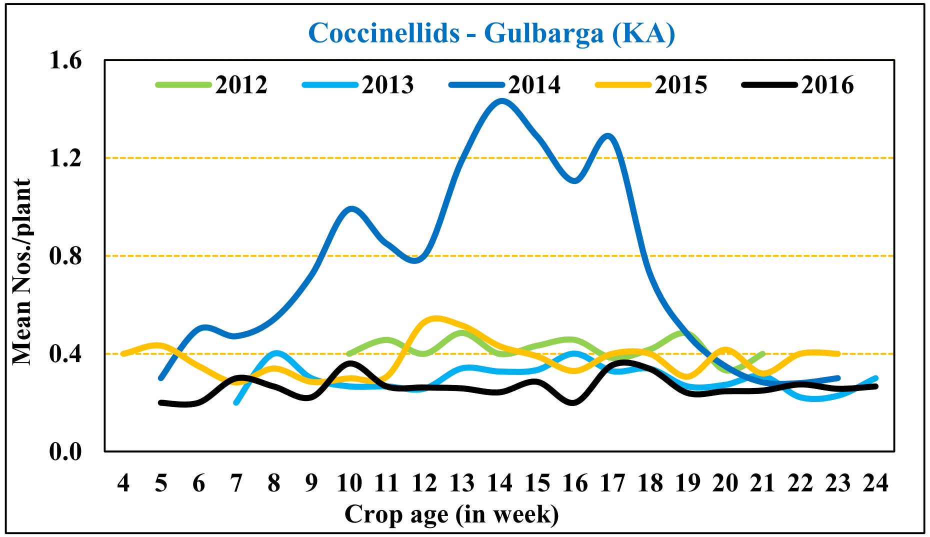


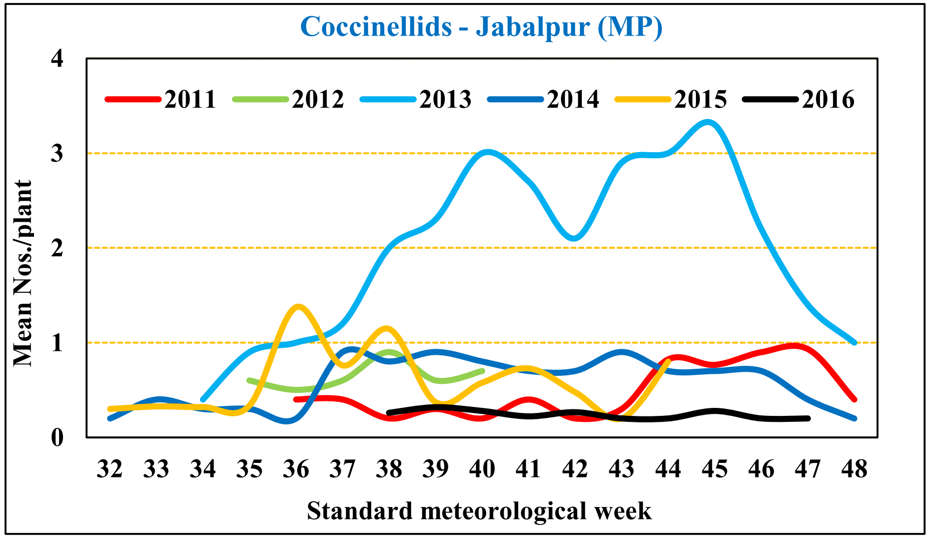


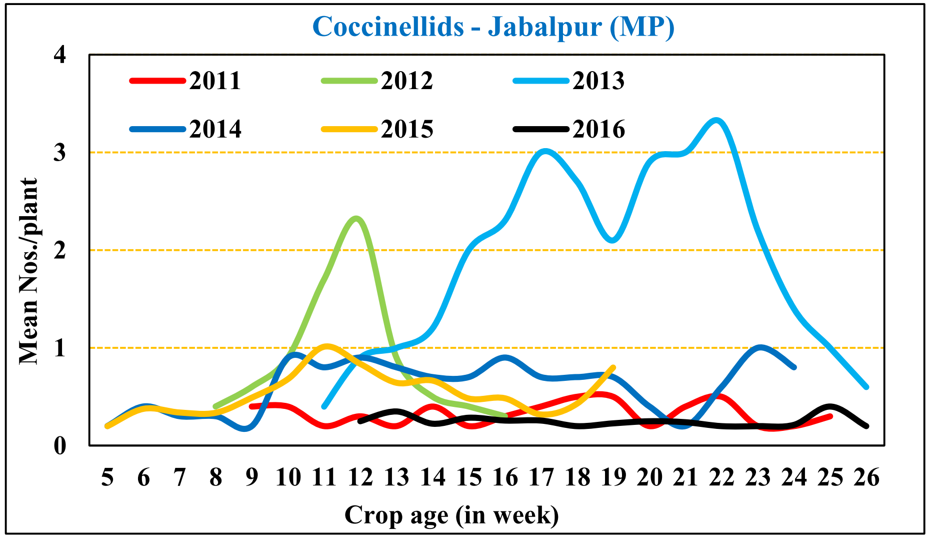
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | Seasonal dynamics based on crop age





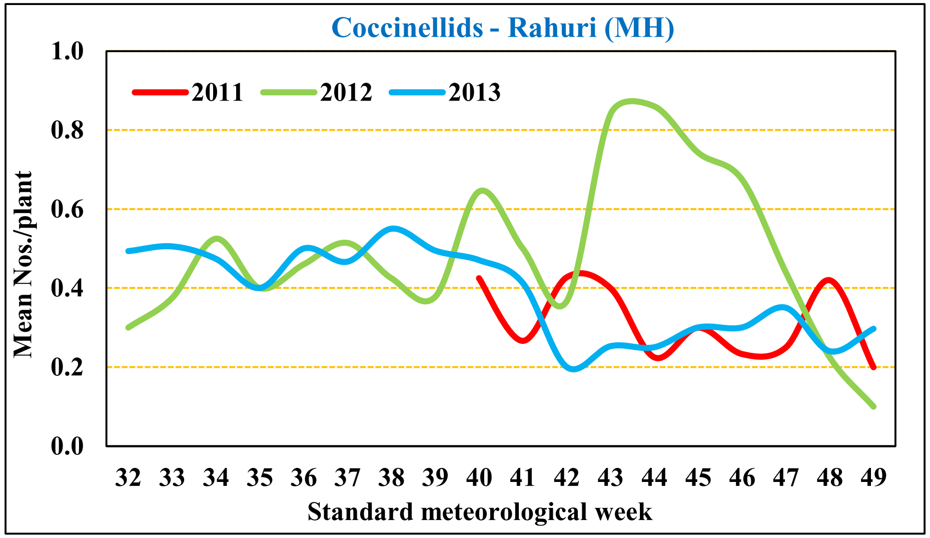


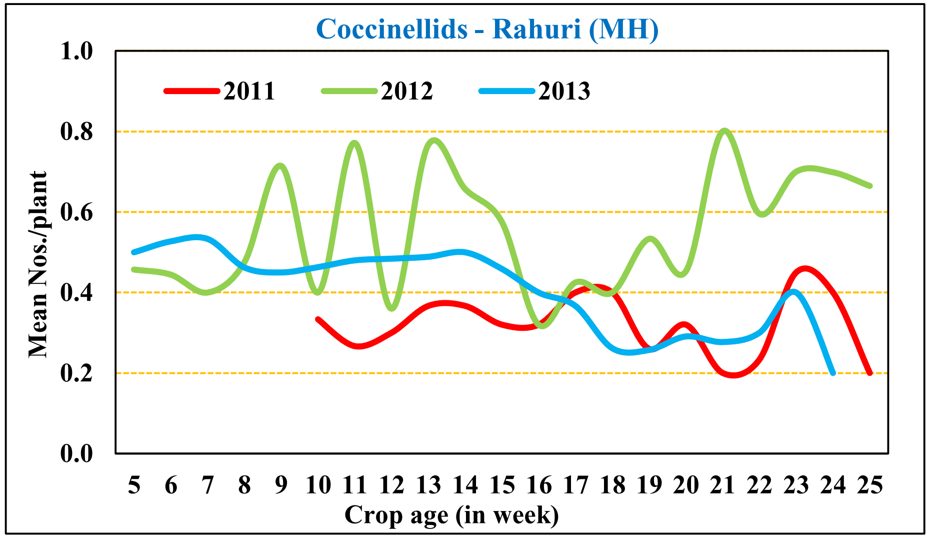


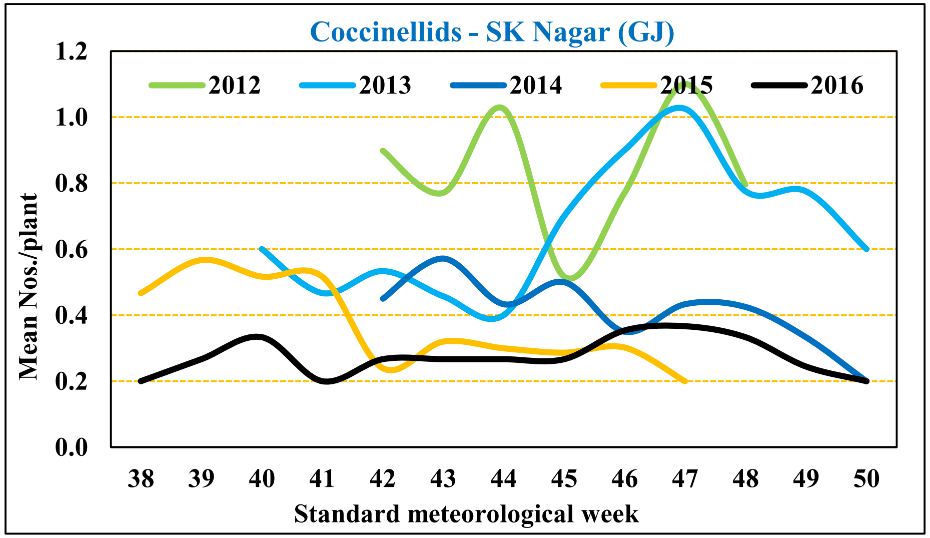
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

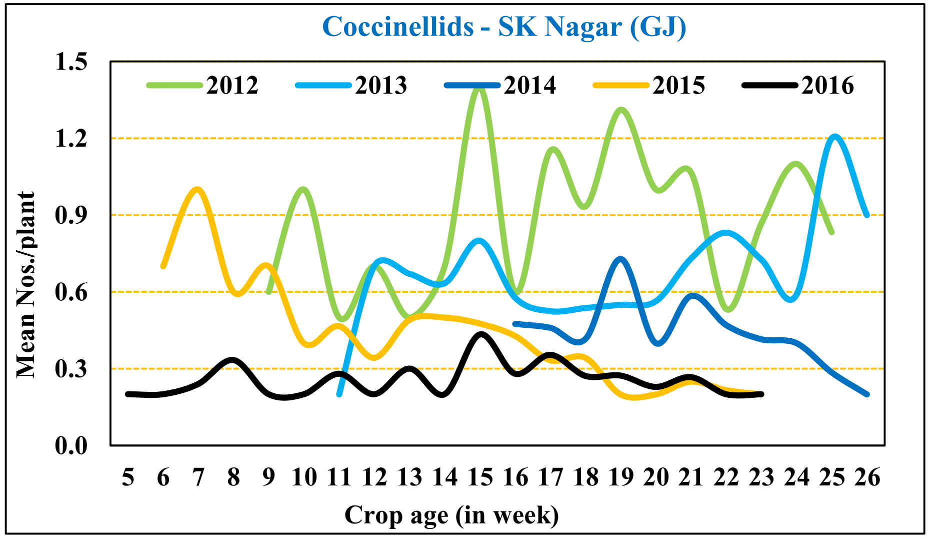
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





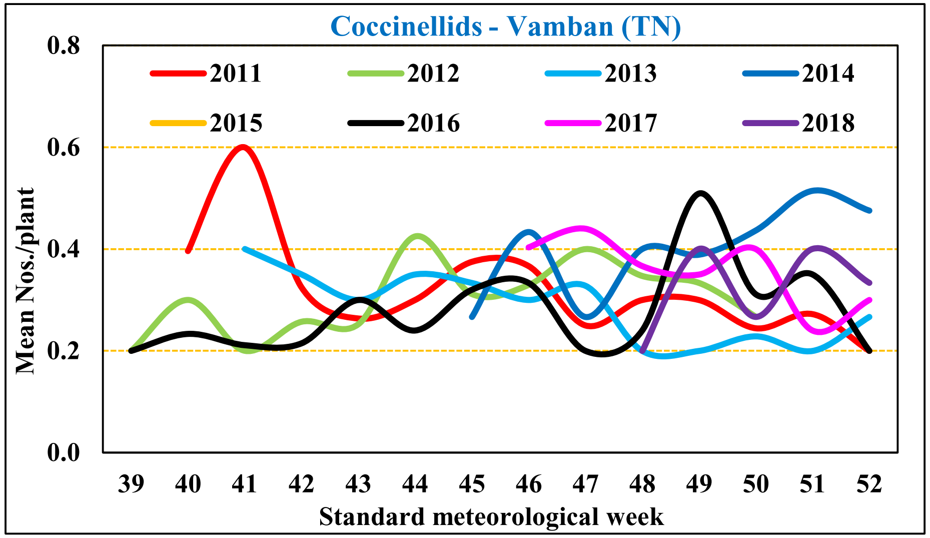


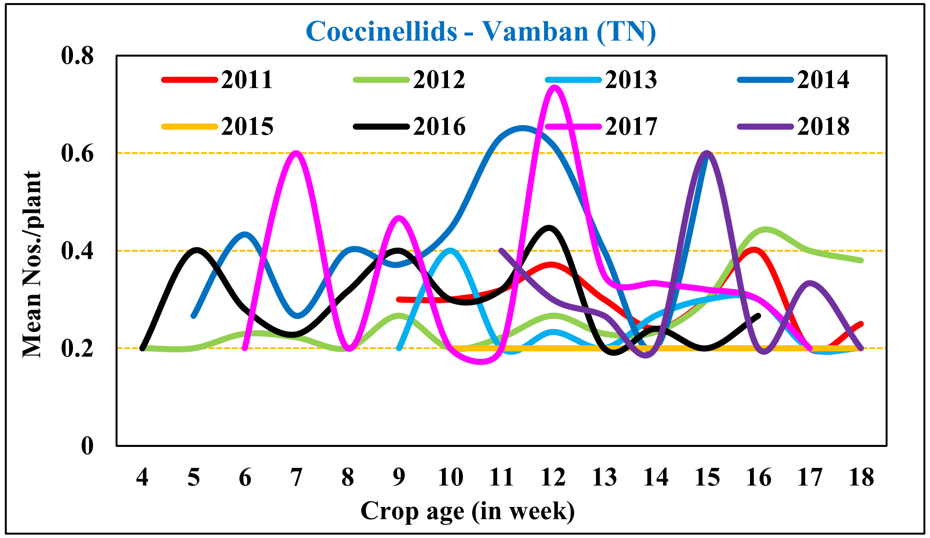


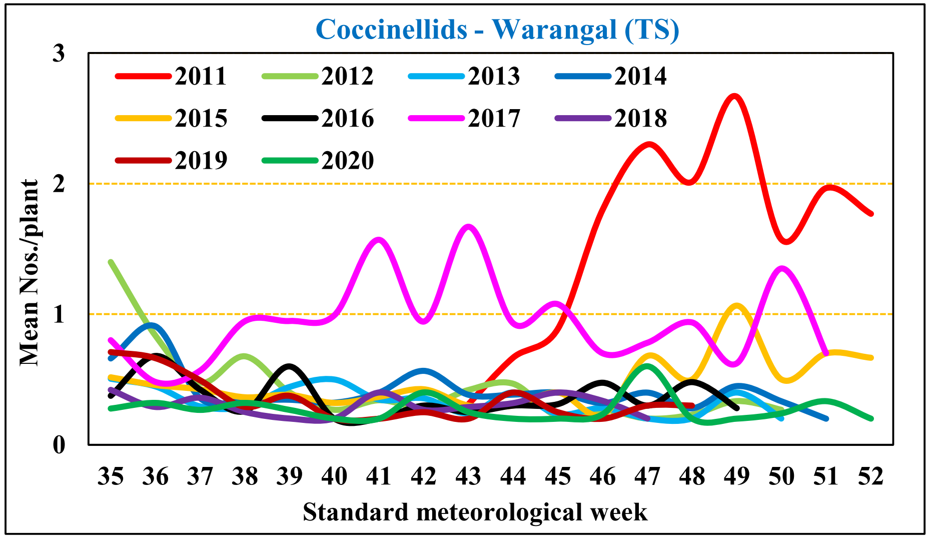
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

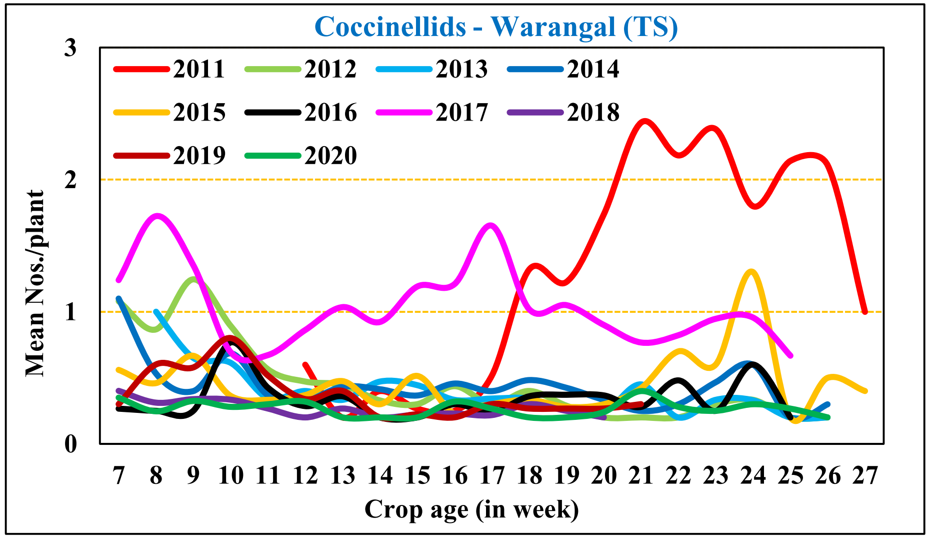
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





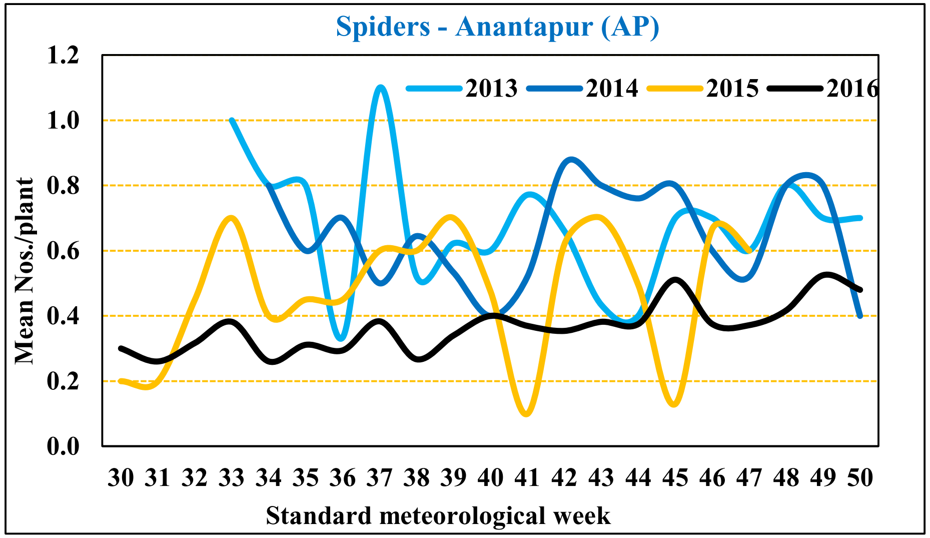


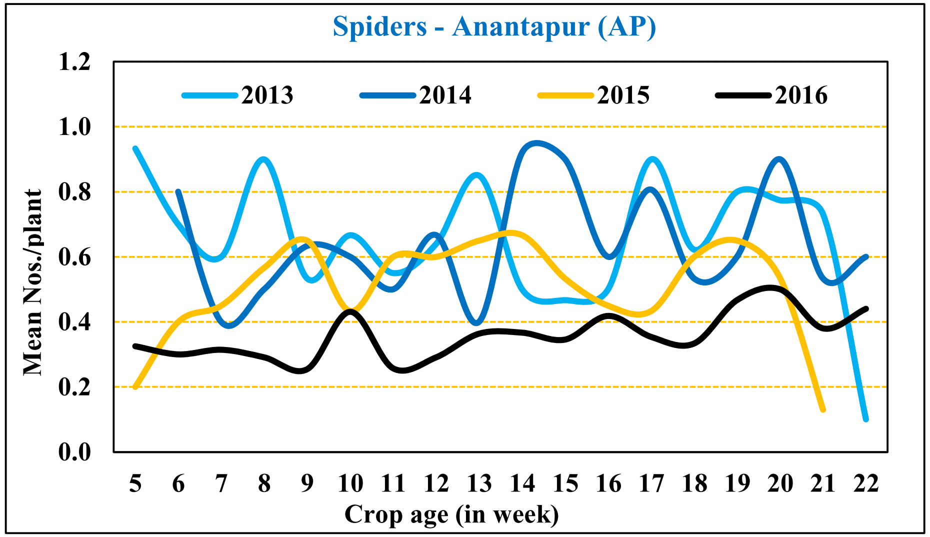


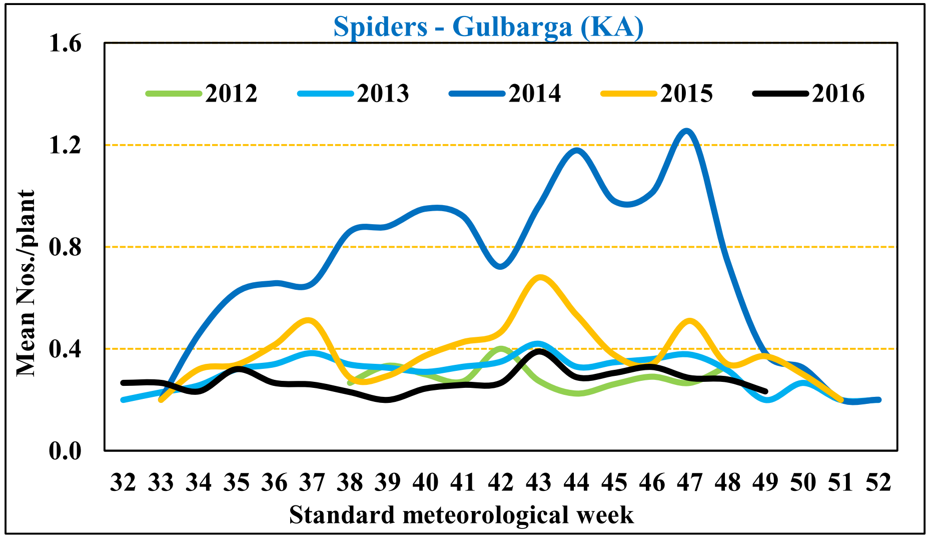
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

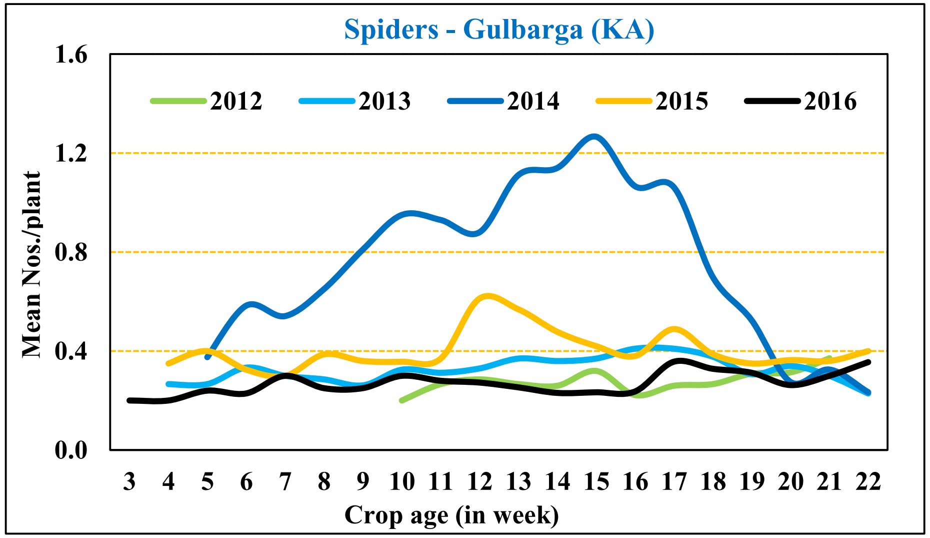
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





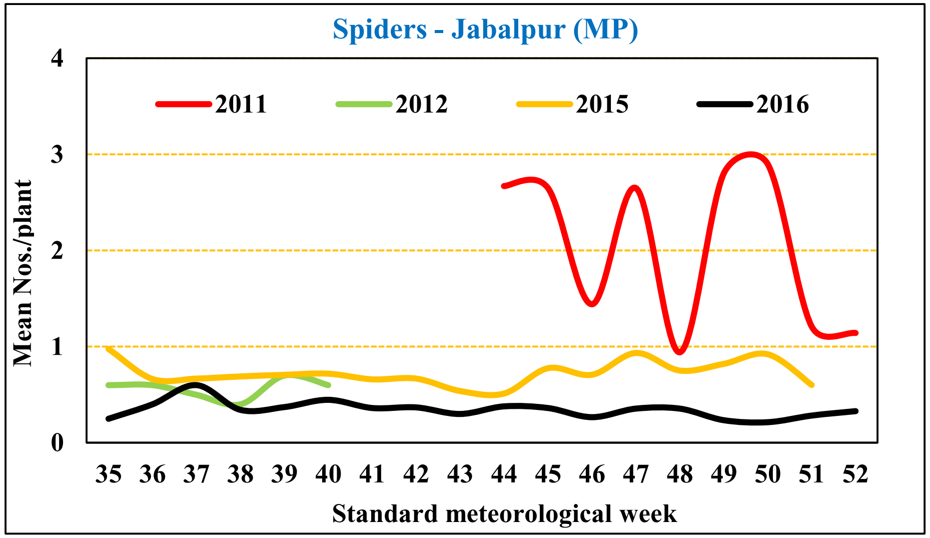


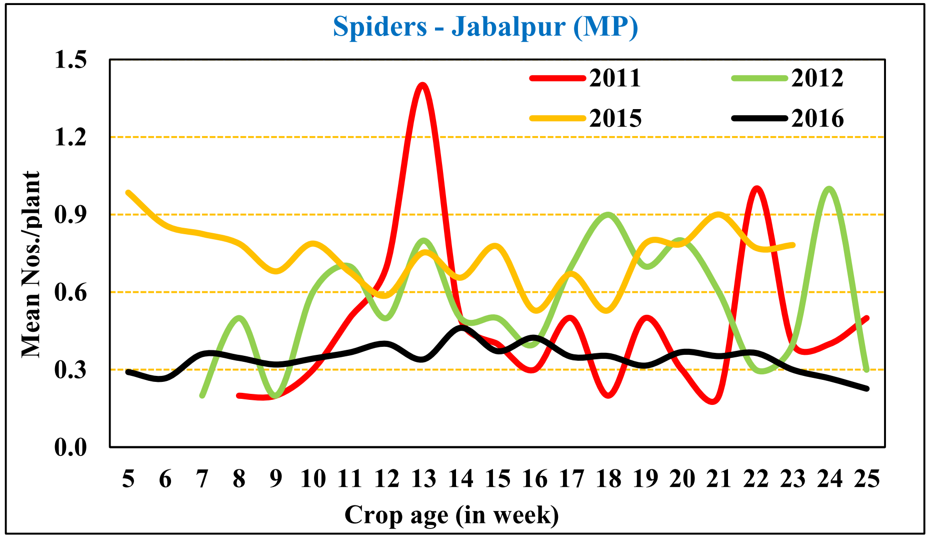


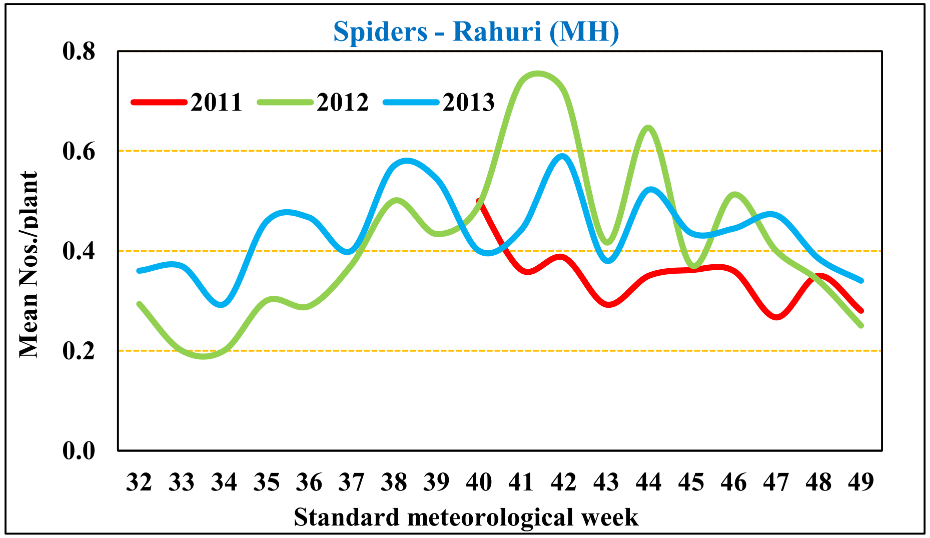
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

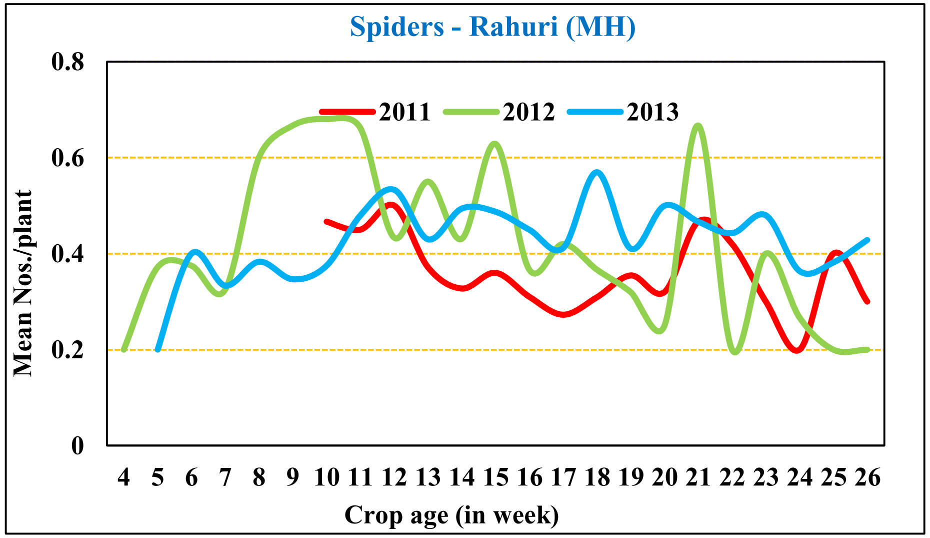
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





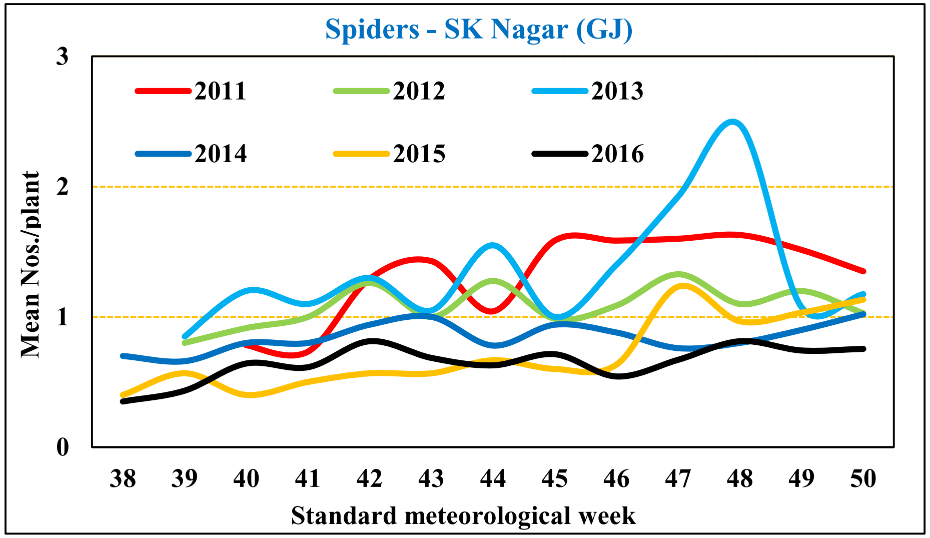


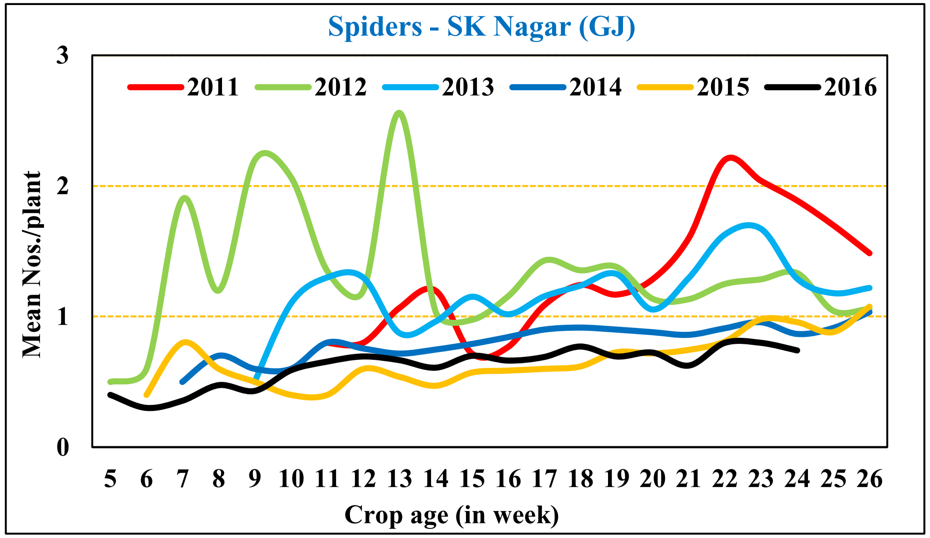


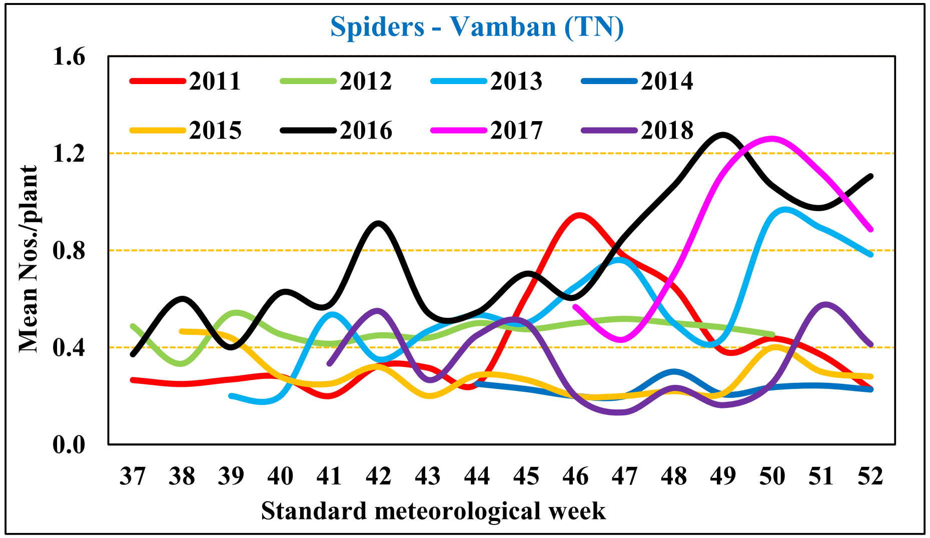
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

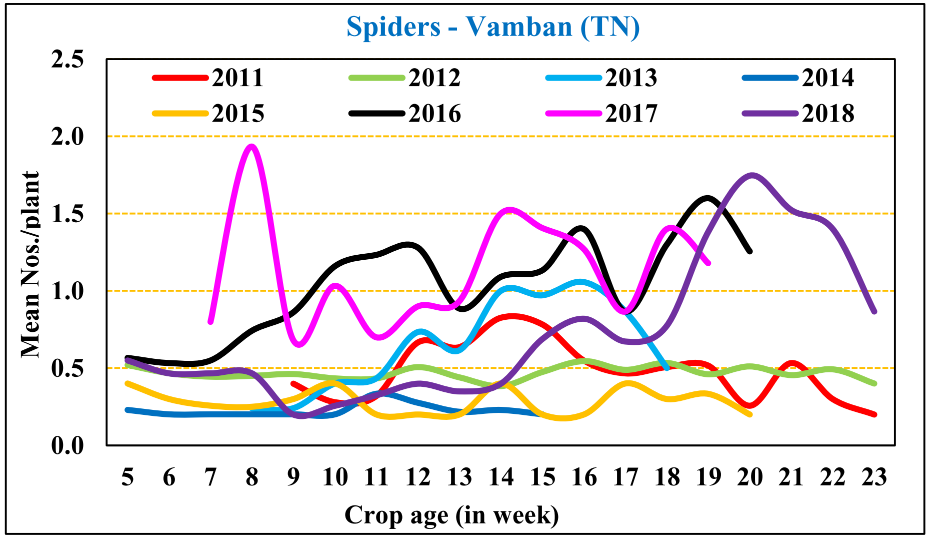
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





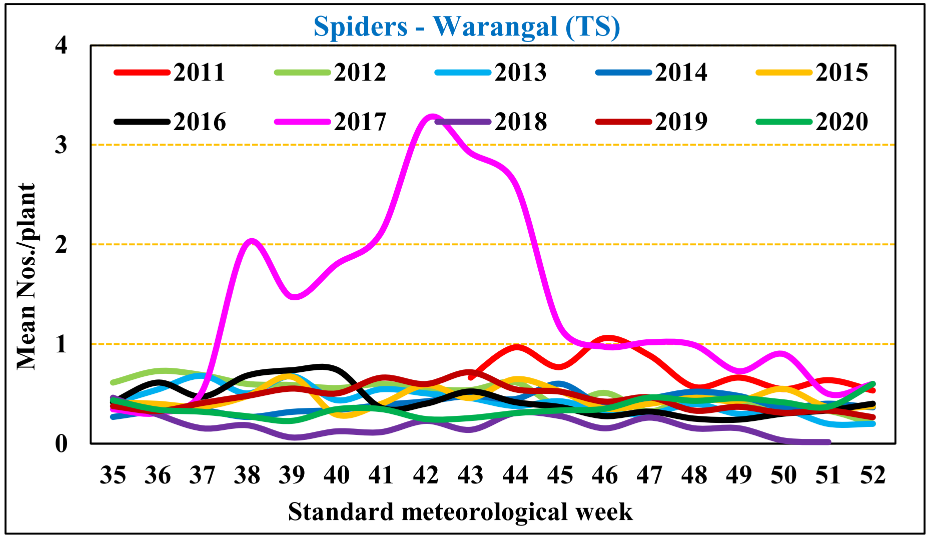


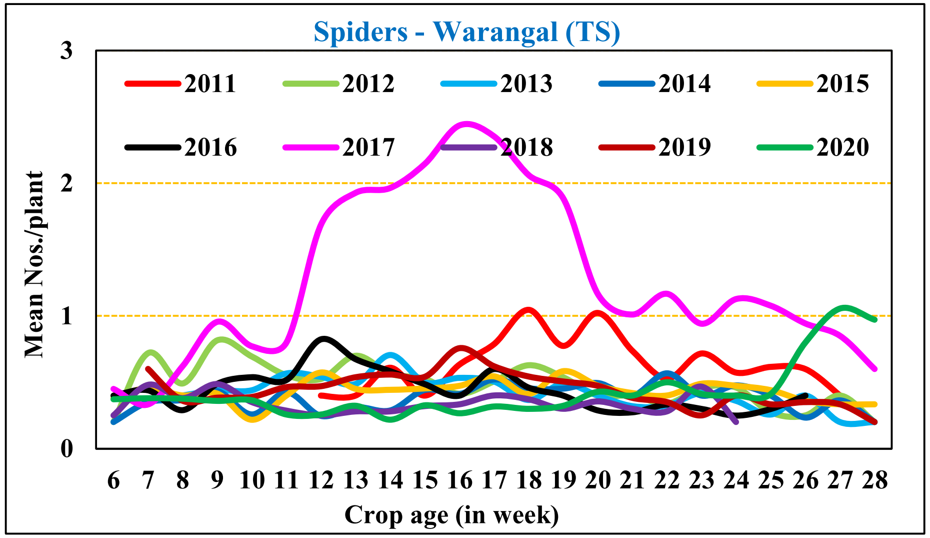


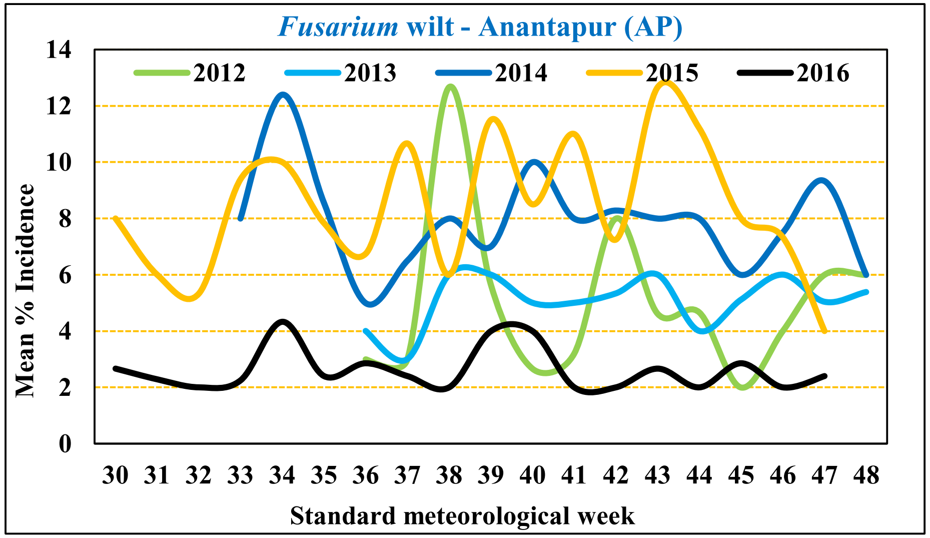
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

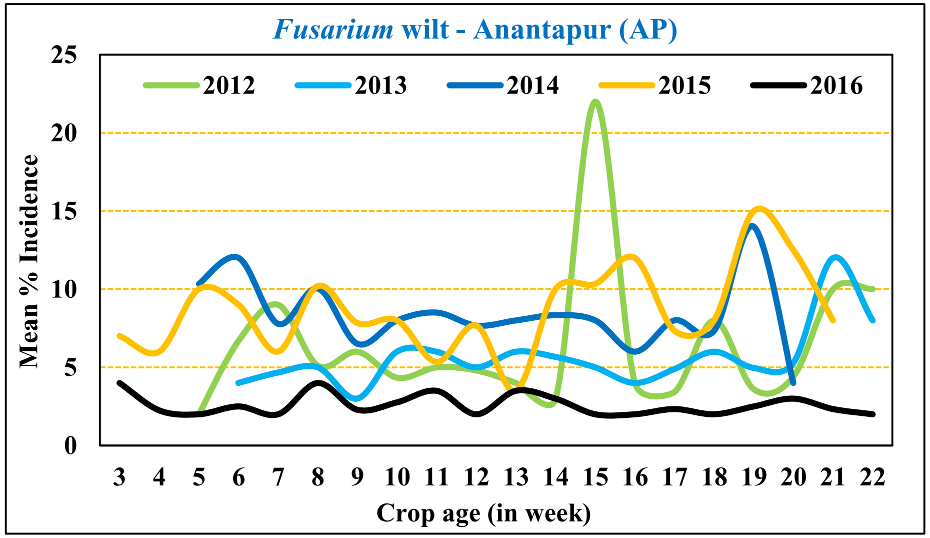
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





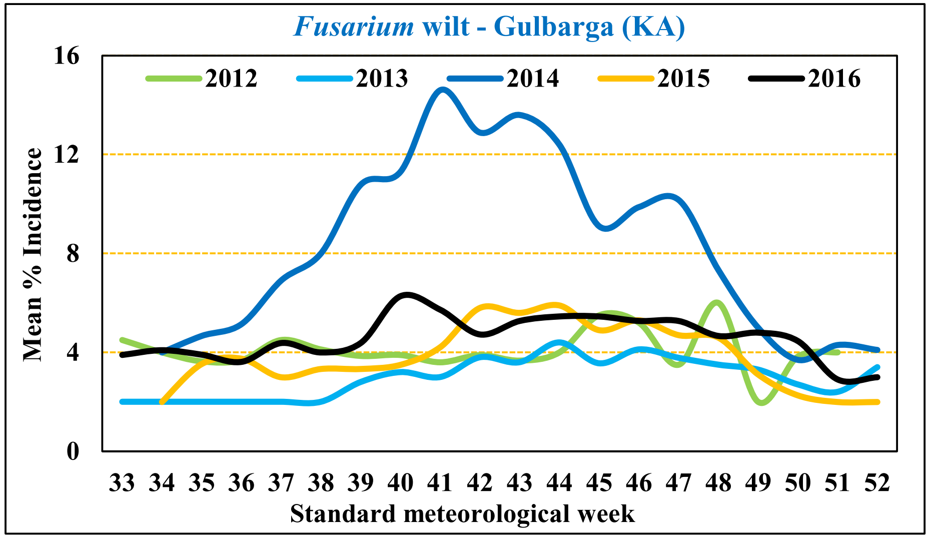


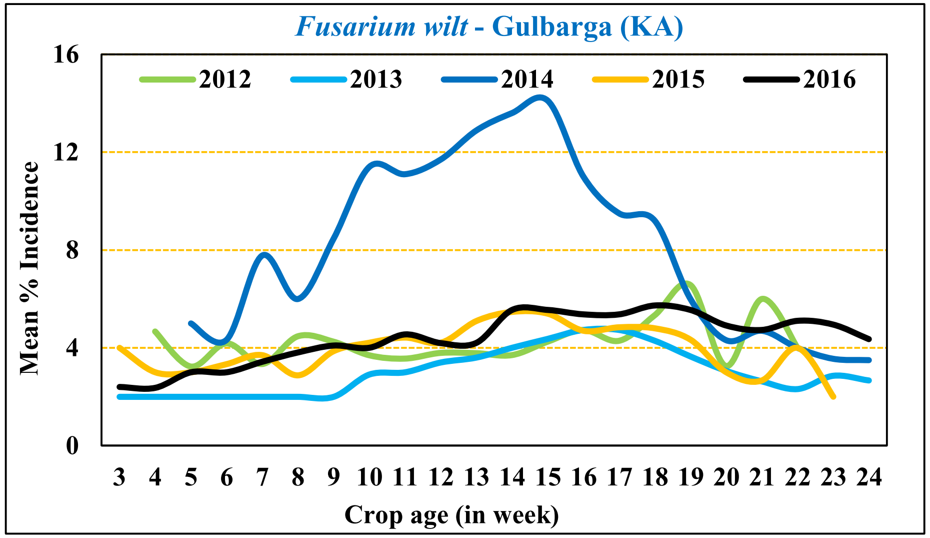


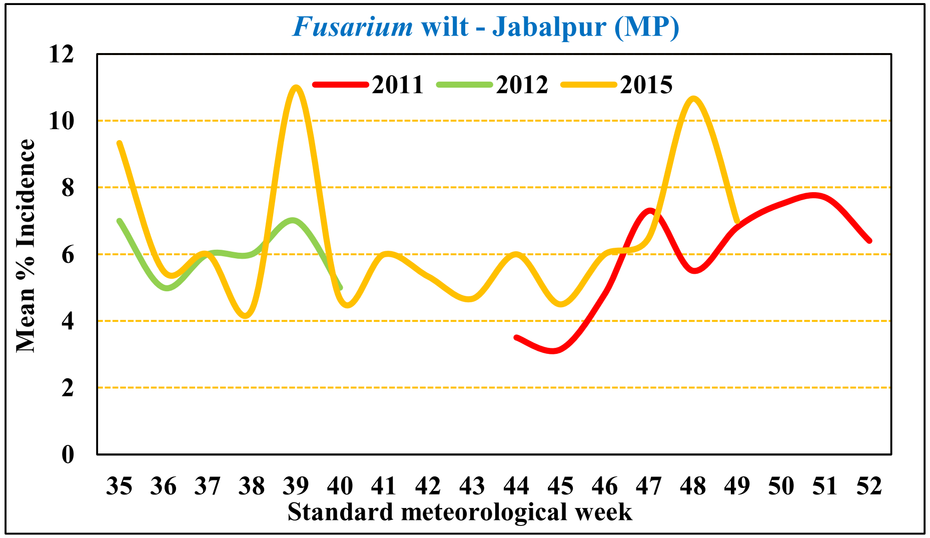
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

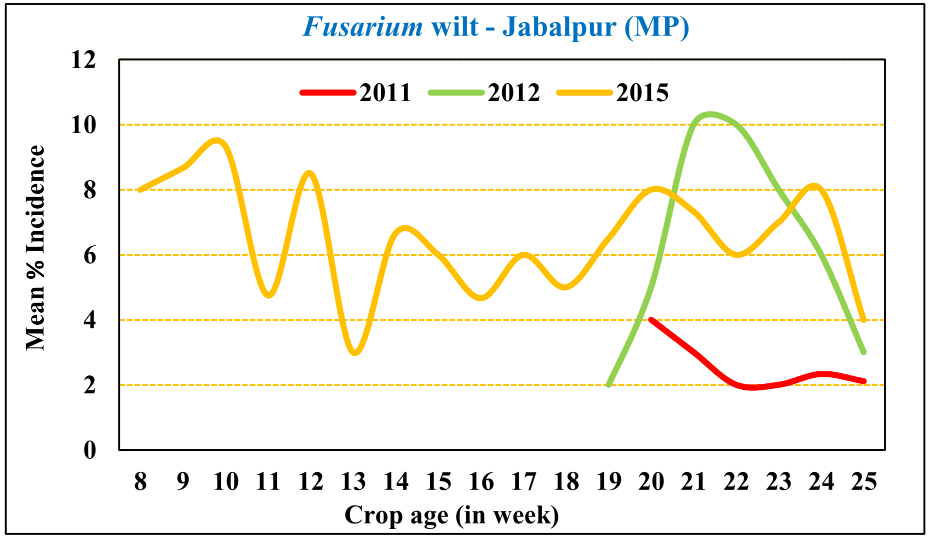
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



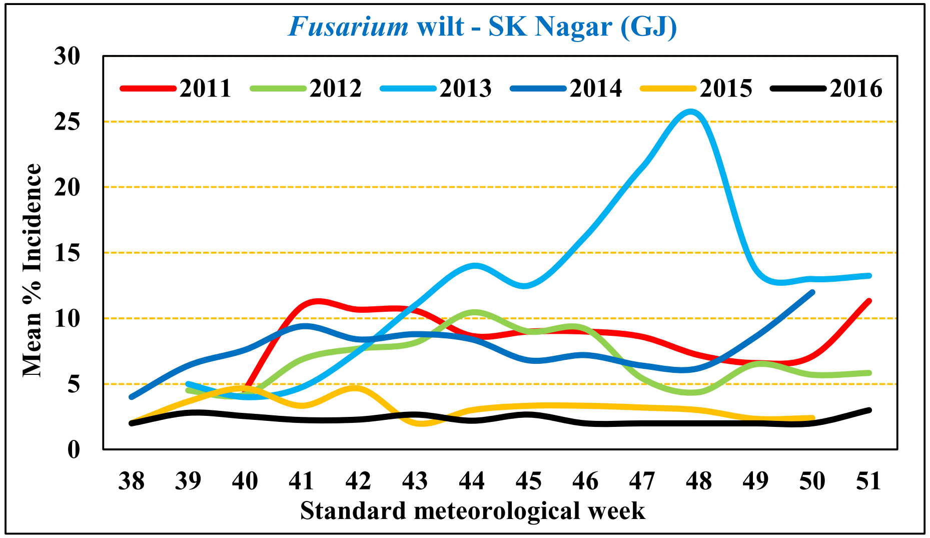


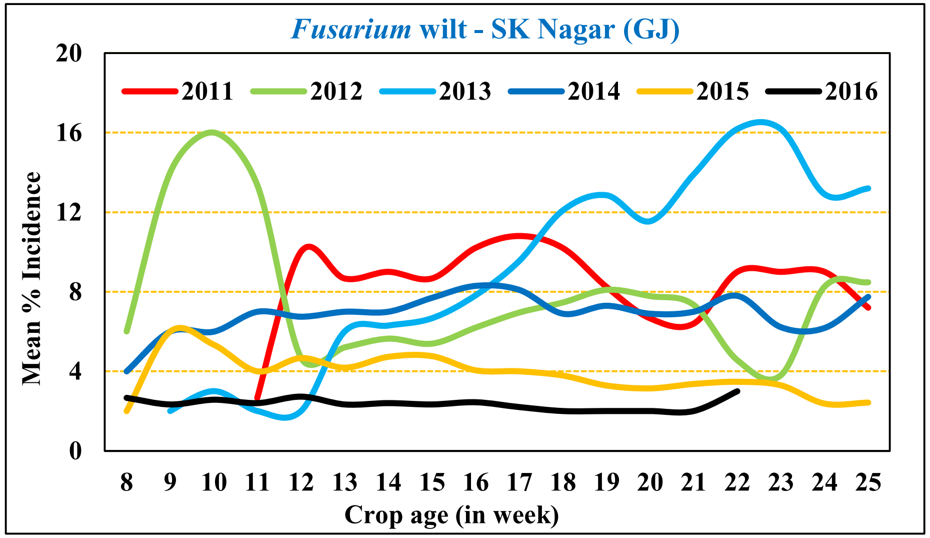


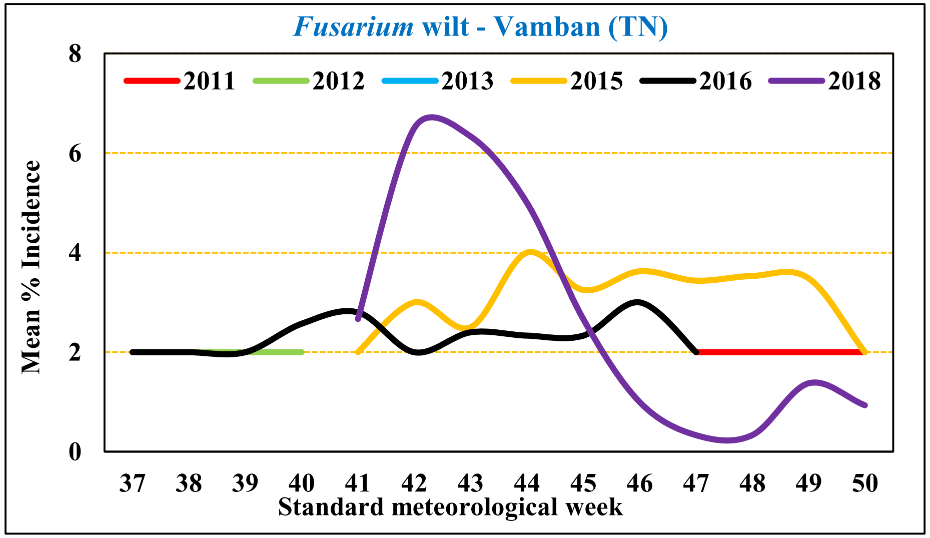


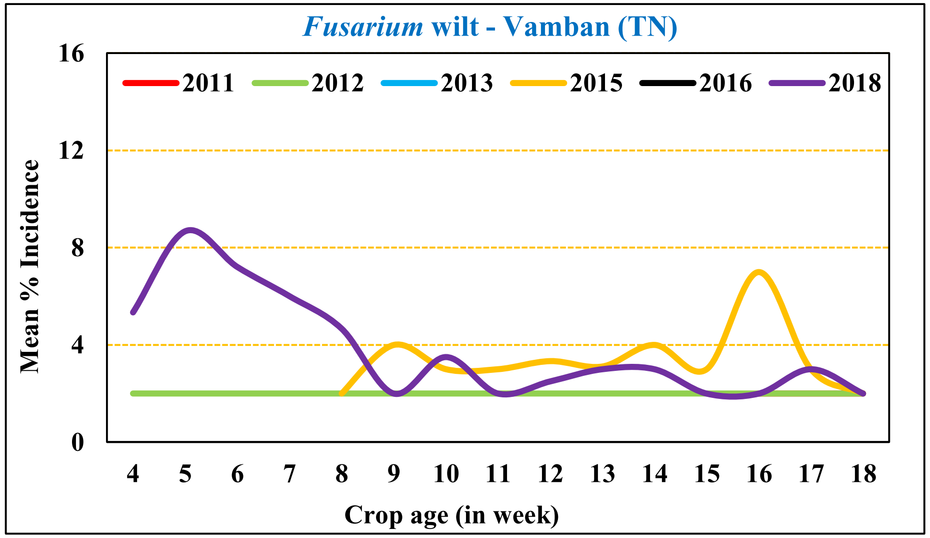
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



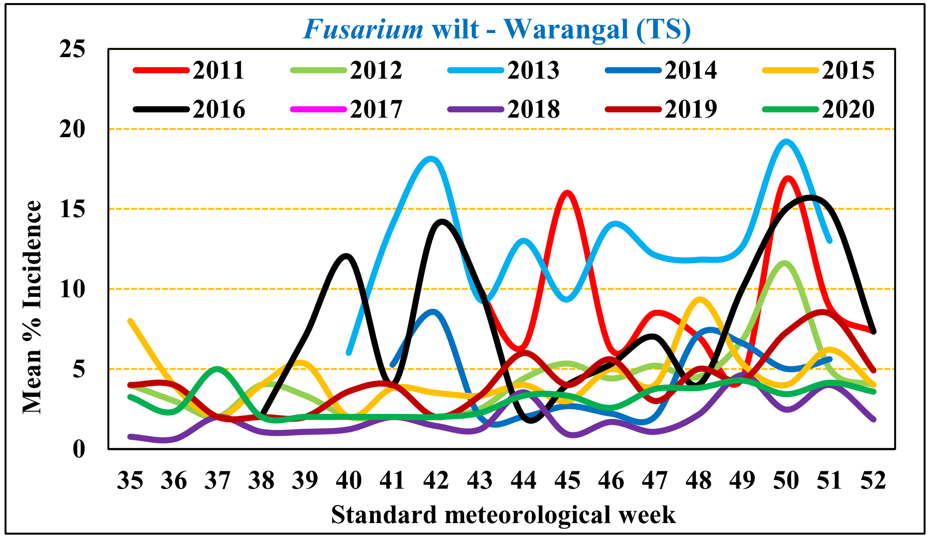


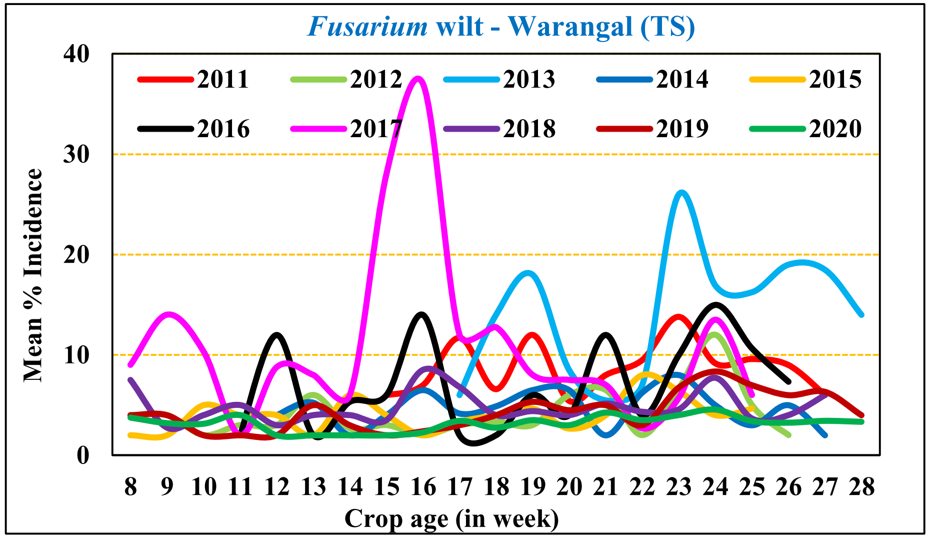


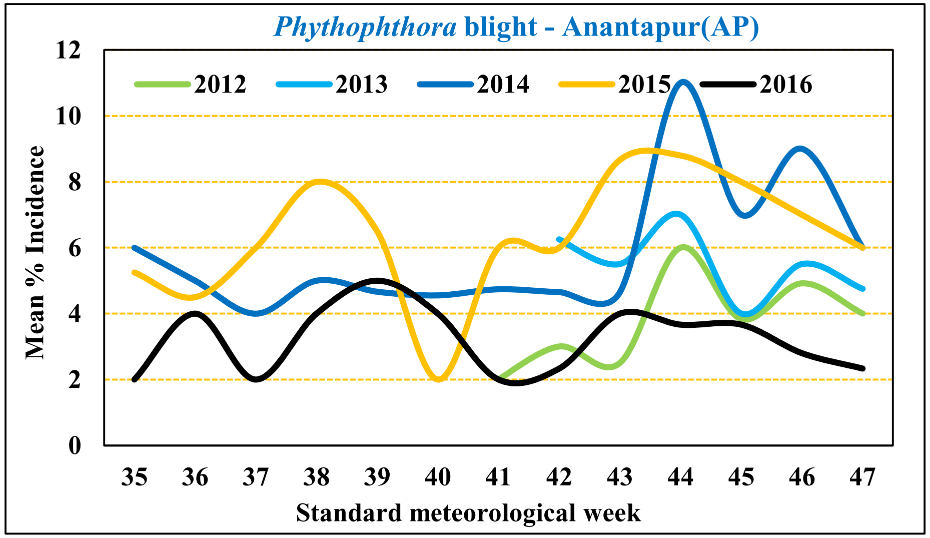


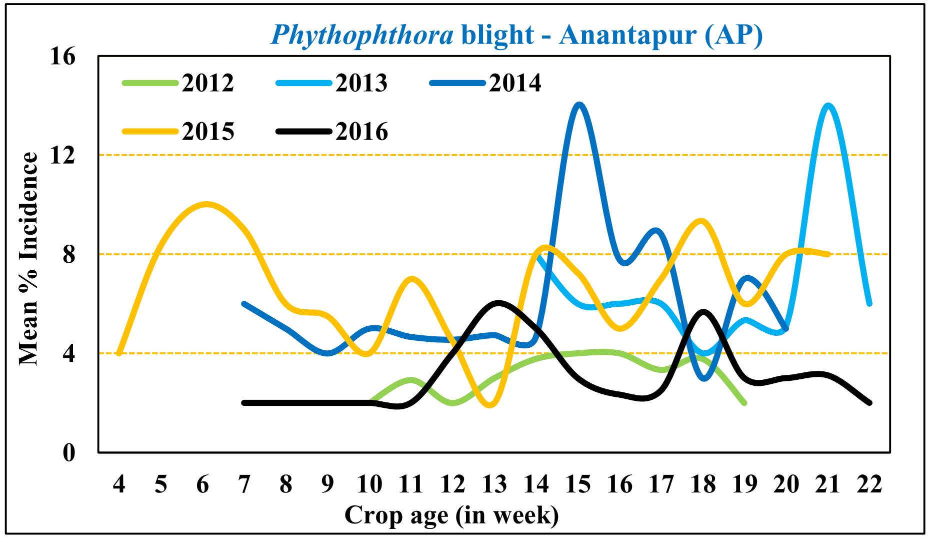
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**





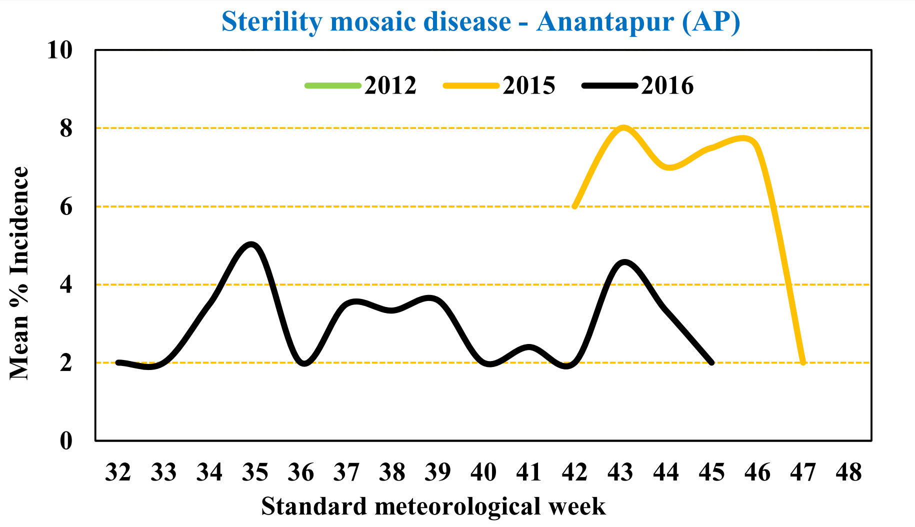


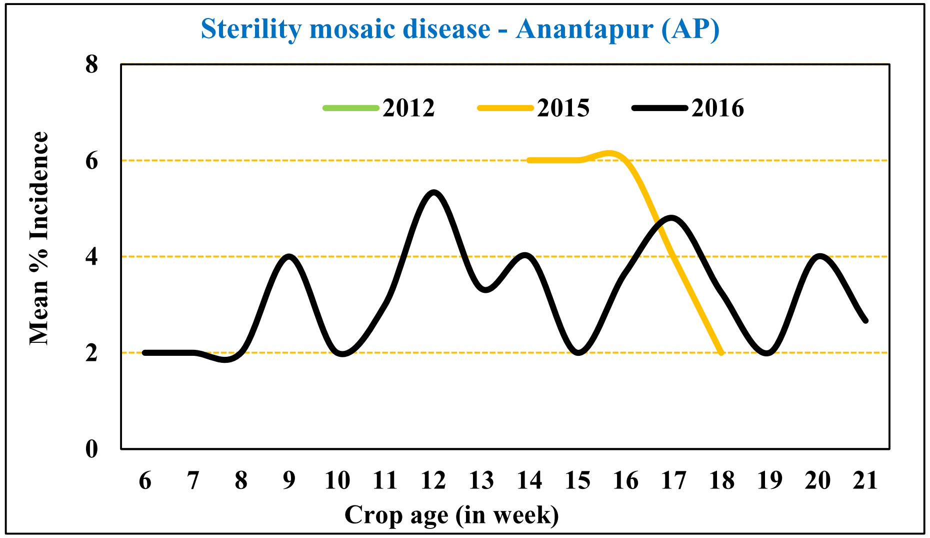


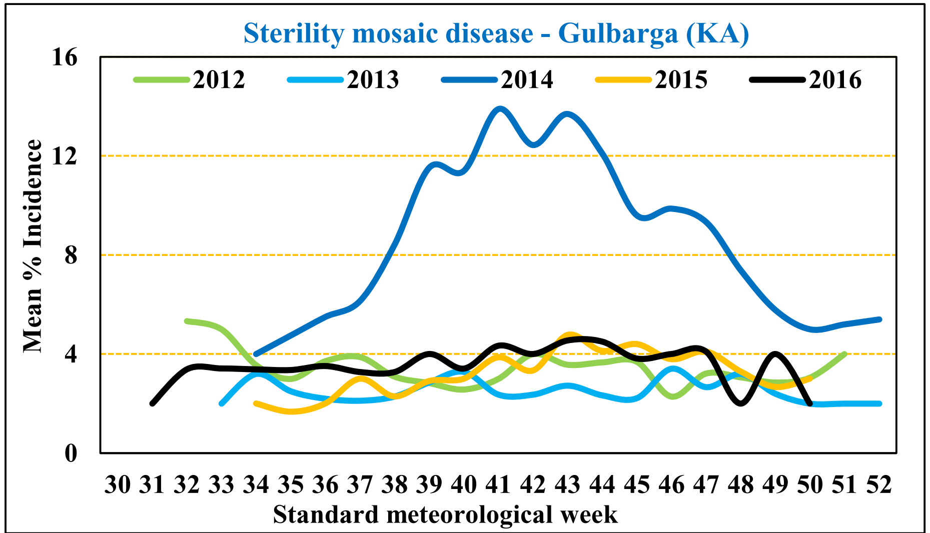
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

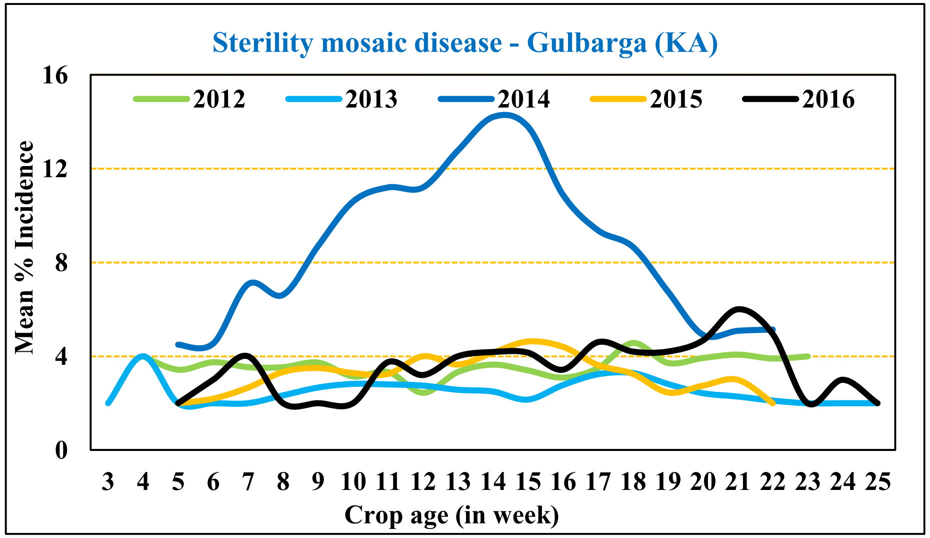
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



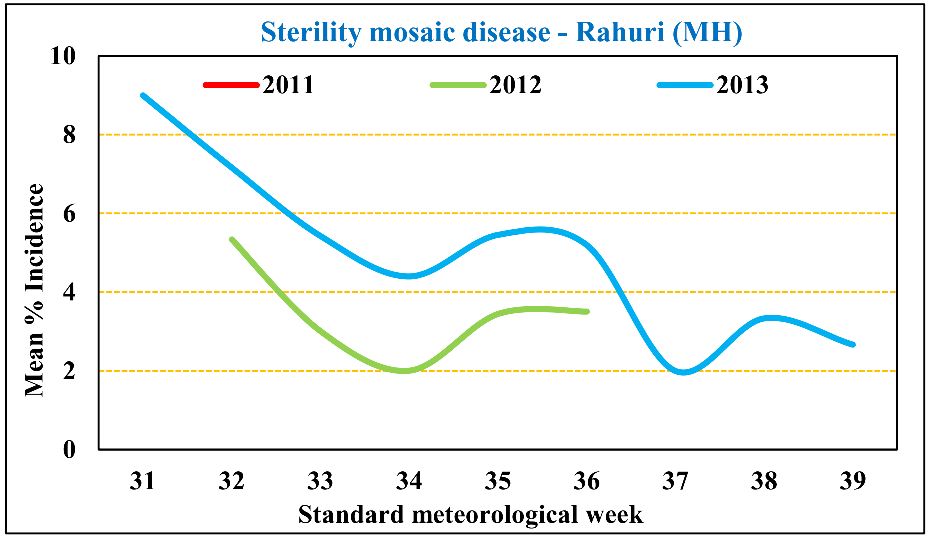


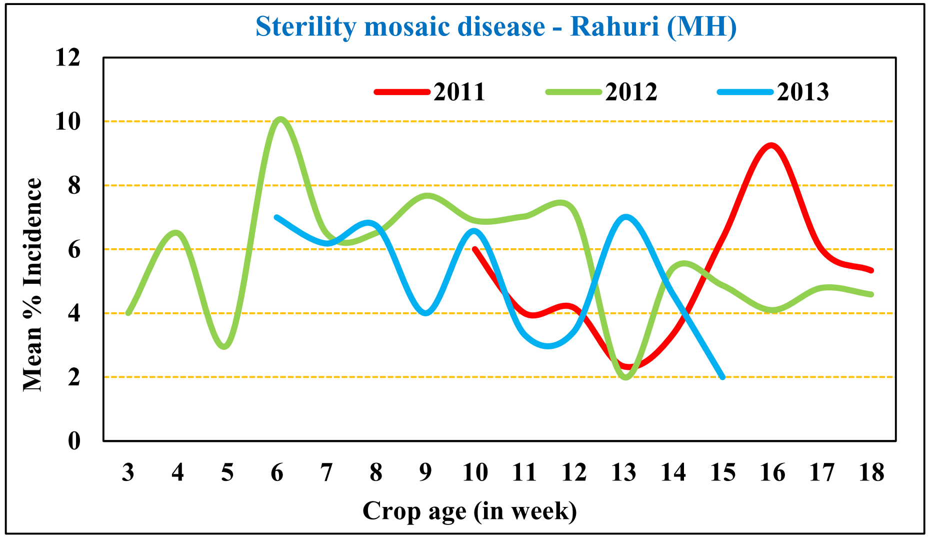


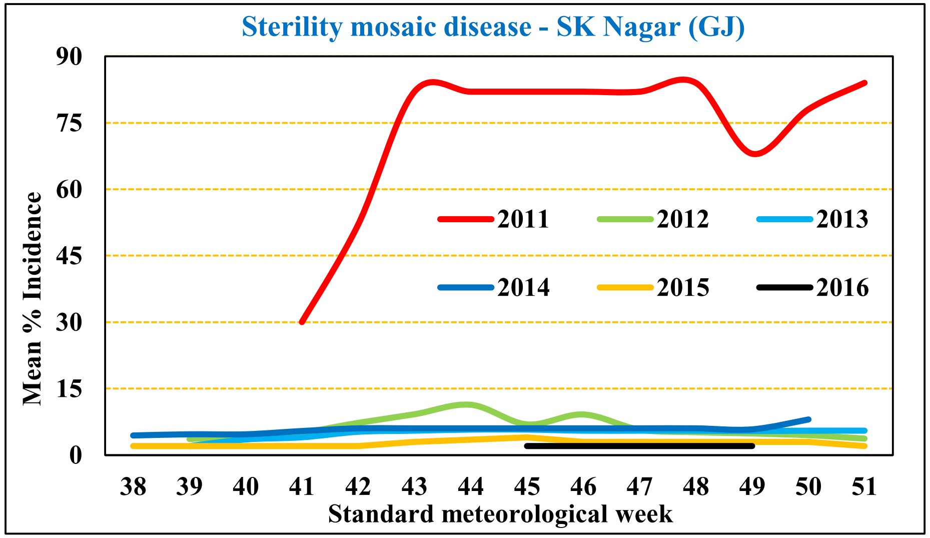


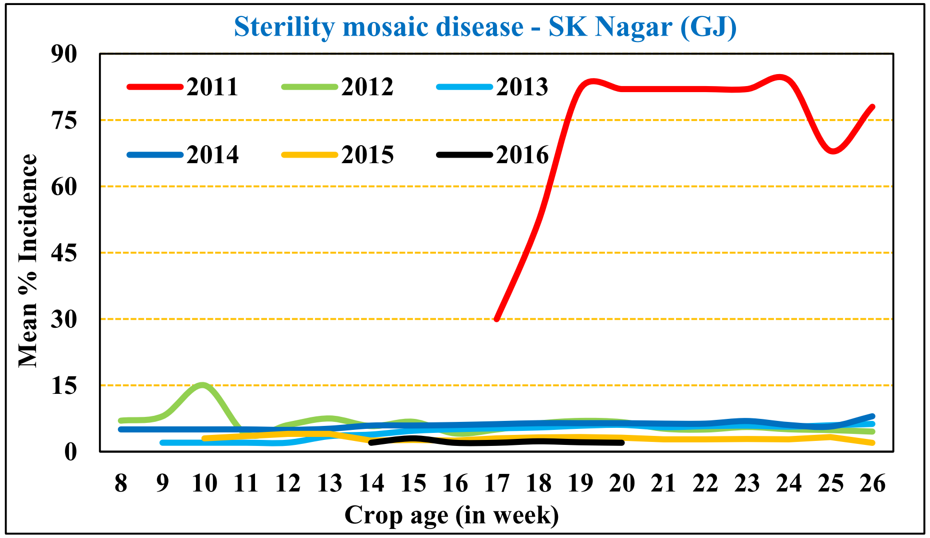
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks — **Seasonal dynamics based on crop age**



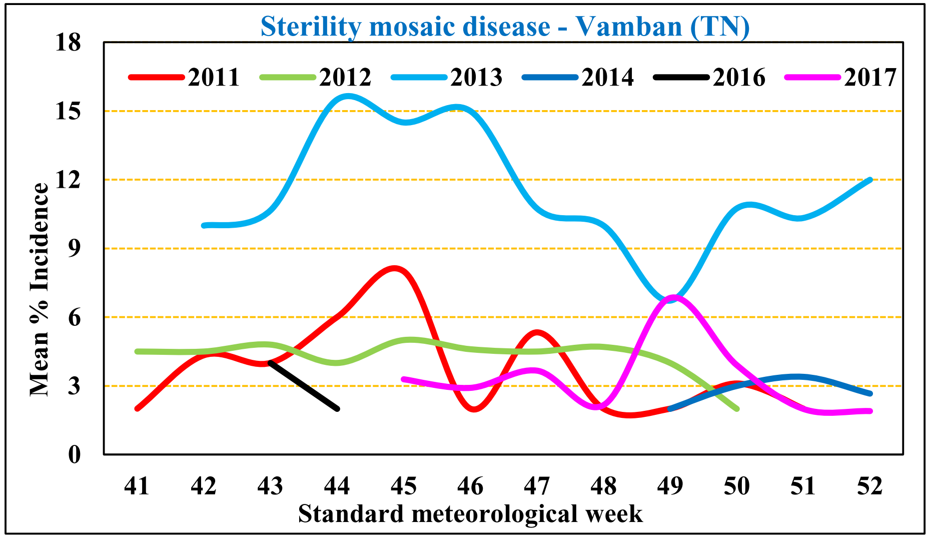


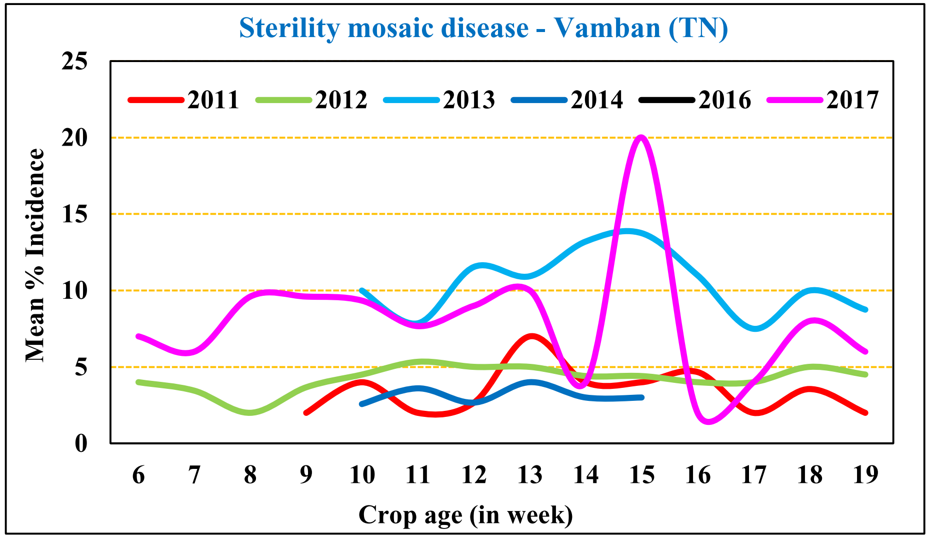


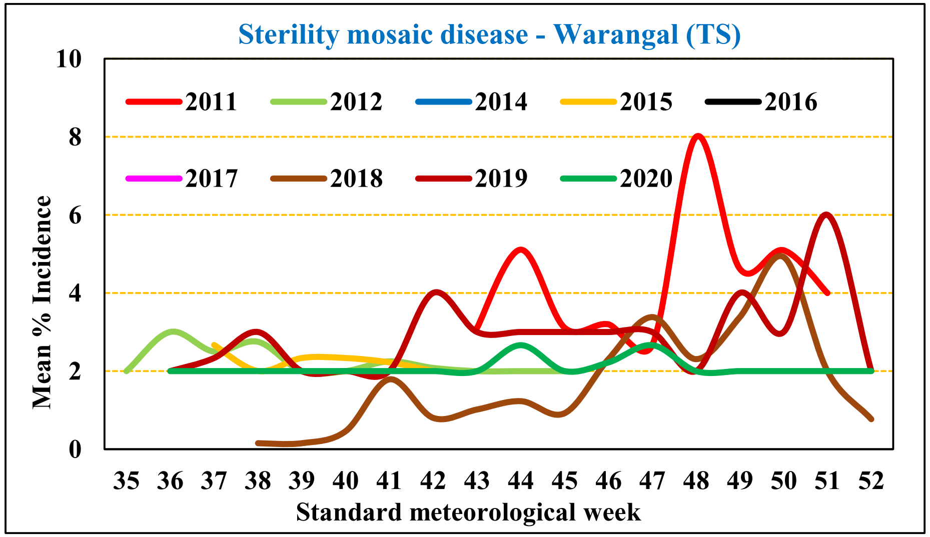


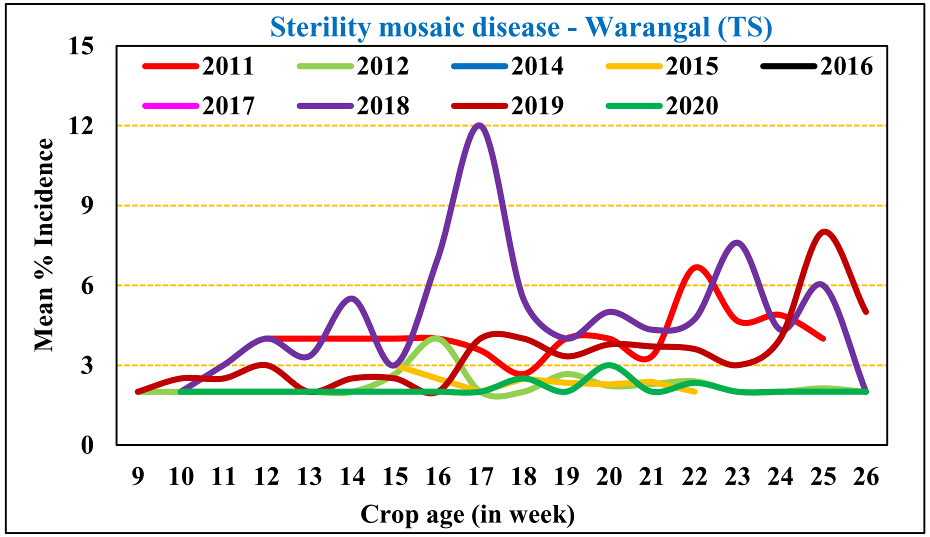
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



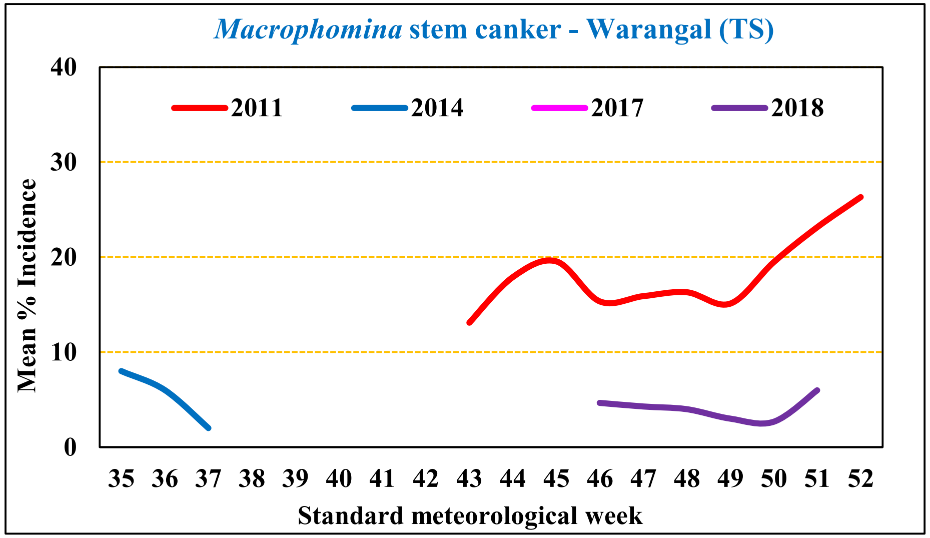


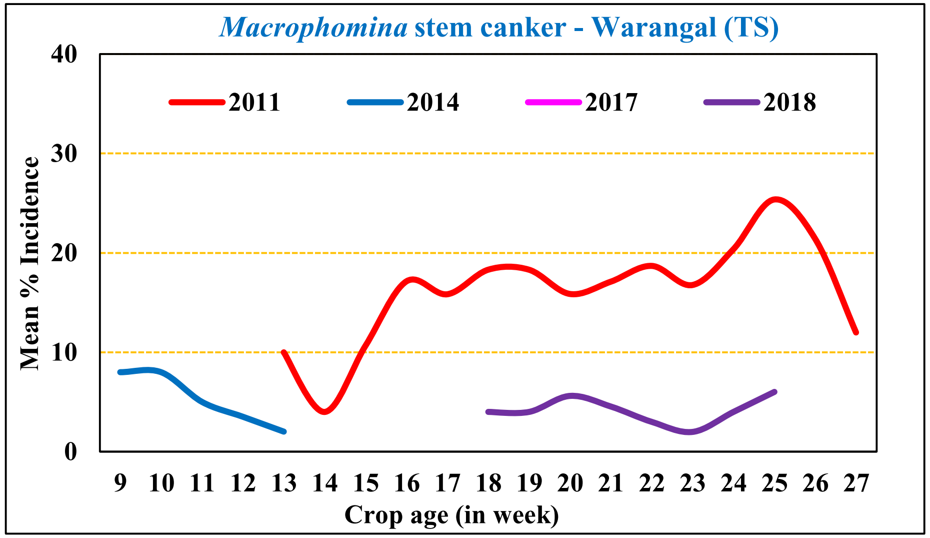


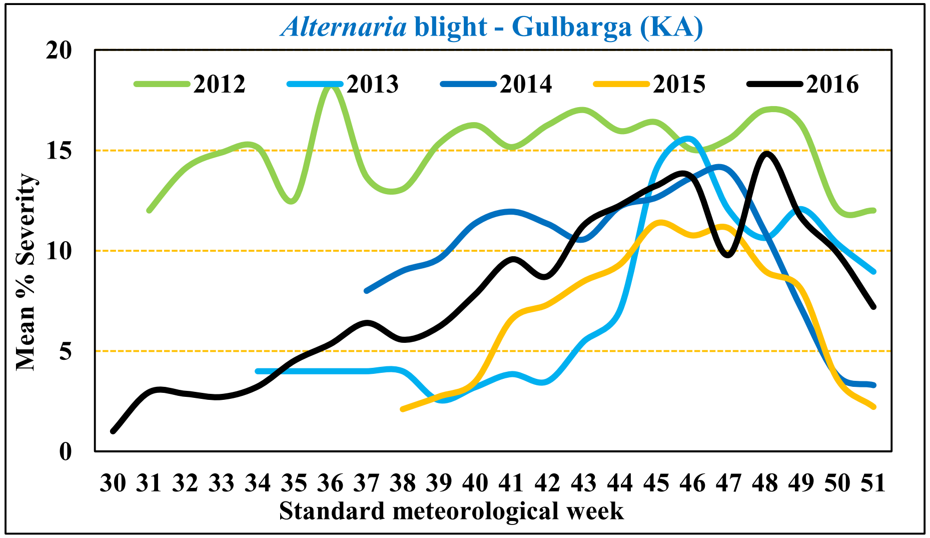


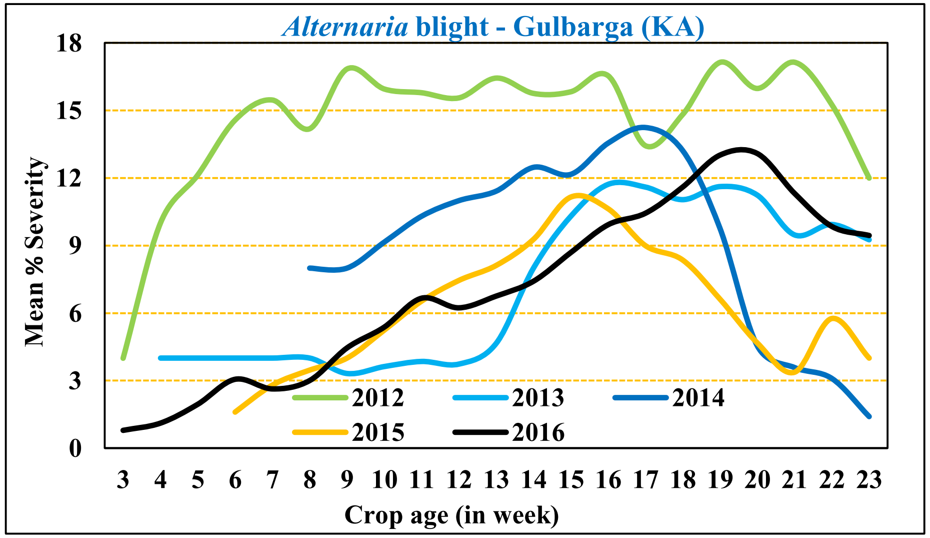
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



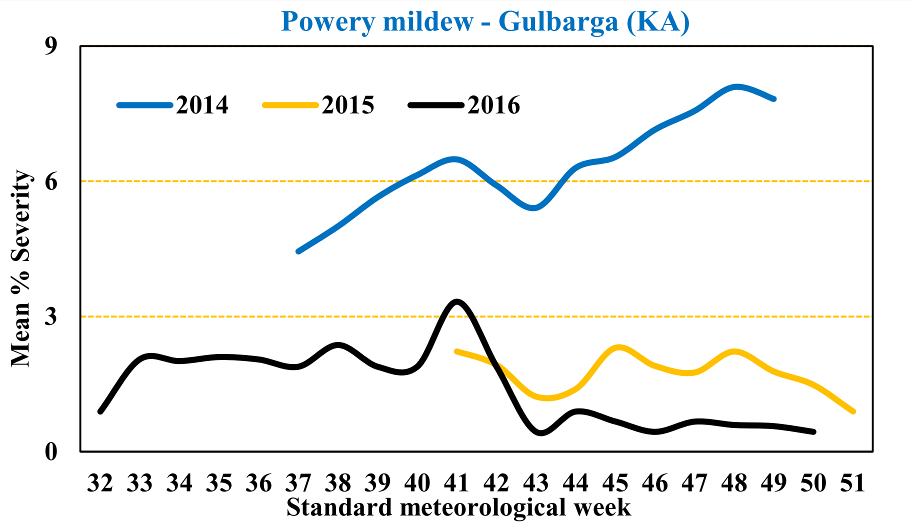


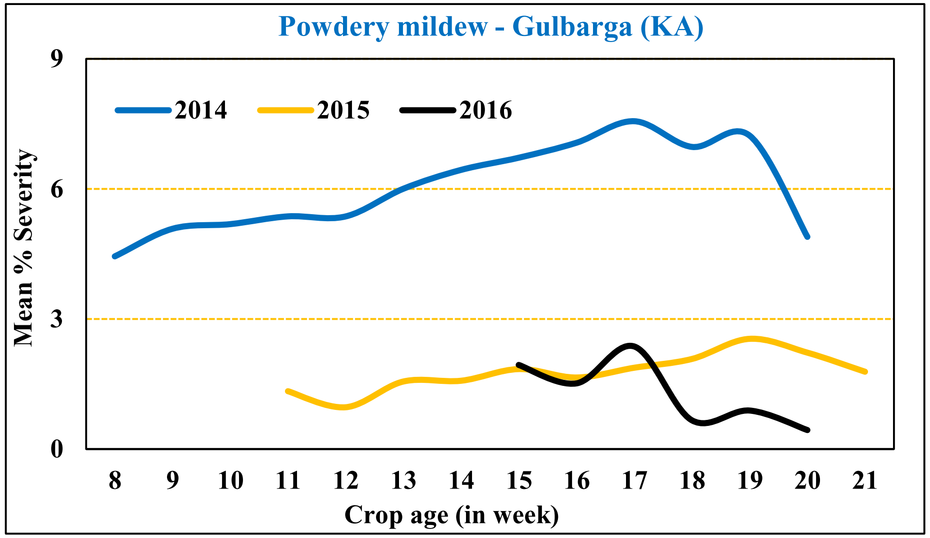


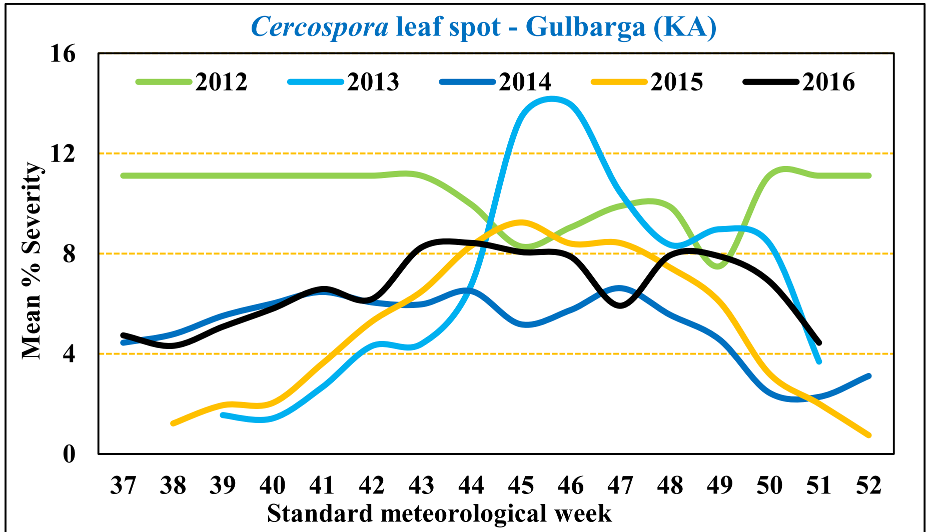


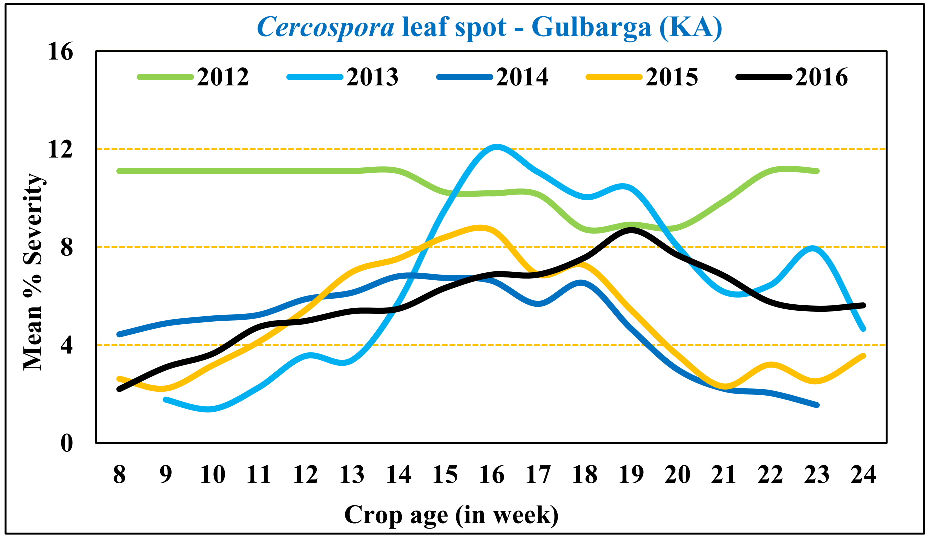
Annexure XX: Seasonal dynamics of insect pests and diseases of pigeonpea [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**









Note: *Many legends and less lines shown in a graph denotes abundance/infestation (insects)/incidence/severity (diseases) very less or in traces, respectively*

Annexure XXI

Impact of climate change on *kharif* pigeonpea insects and diseases - a listing

Location	Adaptive	Vulnerable
Anantapur (AP)	1. Jassids 2. *Cercospora* leaf spot 3. *Fusarium* wilt 4. Powdery mildew 5. Pod borer	1. Leaf folder 2. Sterility mosaic disease 3. Spiders* 4. *Phytophthora* blight 5. Legume pod borer 6. *Macrophomina* stem canker* 7. Pod sucking bug *
Gulbarga (KA)	1. Pod sucking bug* 2. Spiders* 3. Leaf folder* 4. Legume pod borer * 5. Pod borer* 6. Powdery mildew 7. *Fusarium* wilt*	1. Sterility mosaic disease 2. *Cercospora* leaf spot 3. *Macrophomina* stem canker 4. *Phytophthora* blight 5. *Alternaria* blight* 6. Jassids* 7. Phyllody*
Rahuri (MH)	1. Pod borer 2. Sterility mosaic disease	1. Pod sucking bug * 2. Leaf folder 3. Legume pod borer 4. *Fusarium* wilt 5. Spiders*
Jabalpur (MP)	1. Spiders* 2. Legume pod borer 3. Leaf folder* 4. Pod borer 5. *Fusarium* wilt	1. *Phytophthora* blight 2. Pod sucking bug*
S.K. Nagar (GJ)	1. Spiders* 2. Pod borer * 3. *Fusarium* wilt* 4. Pod sucking bug* 5. Legume pod borer 6. Leaf folder	1. *Phytophthora* blight 2. Sterility mosaic disease* 3. Jassids*
Vamban (TN)	1. Sterility mosaic disease* 2. *Alternaria* blight* 3. Pod borer 4. Powdery mildew* 5. Legume pod borer 6. Spiders* 7. *Fusarium* wilt 8. Leaf folder* 9. Pod sucking bug	1. *Cercospora* leaf spot*

Impact of climate change on *kharif* pigeonpea insects and diseases - a listing

Location	Adaptive	Vulnerable
Warangal (TS)	1. *Macrophomina* stem canker* 2. Sterility mosaic disease* 3. Powdery mildew* 4. Pod sucking bug* 5. Pod borer* 6. *Fusarium* wilt* 7. Legume pod borer* 8. Spiders	1. Leaf folder* 2. Jassids*

Insects and diseases have been listed along the order of importance for the cumulative impact of climate change based on species climate change association index values (Tables 40 & 41); Species with positive SAIs are grouped under adaptation and the negative ones under vulnerability to climate change; symbol * associated with insects/diseases indicate the definitive influence of at least one or all-climatic variables (MaxT, MinT, RF) having significant association with population dynamics irrespective of the significance of magnitude of climate change for the variables; insect/disease without * specify the non-significance of the association between population dynamics and climatic deviations of all three variables (MaxT., MinT., & RF)

Annexure XXII. Future status of *H. armigera* on pigeonpea - 2020

Locations	MaxT	MinT	RF	MaxT	MinT	RF	MaxT	MinT	RF	MaxT	MinT	RF
		RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5	
Vamban (TN)	-0.47* (31.3)	-0.66*** (23.6)	-0.08^{NS} (69.9)	-0.50* (31.2)	-0.64*** (23.6)	-0.10^{NS} (70.8)	-0.50* (31.4)	-0.66*** (23.7)	-0.10^{NS} (69.2)	-0.50* (31.4)	-0.66*** (23.7)	-0.10^{NS} (69.2)
Reddipalli (A.P)	-0.19^{NS} (30.0)	-0.07^{NS} (20.5)	0.02^{NS} (16.8)	-0.20^{NS} (30.0)	-0.09^{NS} (20.5)	0.02^{NS} (17.1)	-0.20^{NS} (29.8)	-0.11^{NS} (20.5)	0.06^{NS} (18.2)	-0.17^{NS} (30.0)	-0.11^{NS} (20.7)	0.06^{NS} (17.9)
Gulbarga (KA)	0.01^{NS} (30.84)	-0.27^{NS} (21.15)	0.05^{NS} (49.61)	-0.29^{NS} (30.84)	0.04^{NS} (21.17)	-0.09^{NS} (48.21)	-0.29^{NS} (30.84)	0.04^{NS} (21.11)	-0.09^{NS} (46.61)	-0.29^{NS} (30.84)	0.03^{NS} (21.23)	-0.09^{NS} (48.77)
Warangal (TS)	-0.23^{NS} (31.03)	-0.52** (20.78)	-0.40** (20.56)	-0.23^{NS} (31.12)	-0.52** (20.82)	-0.36^{NS} (20.12)	-0.21^{NS} (30.98)	-0.52** (20.73)	-0.40** (19.53)	-0.24^{NS} (31.13)	-0.52** (20.89)	-0.36^{NS} (20.26)
Jalgaon (MH)	0.10^{NS} (31.7)	0.15^{NS} (18.3)	0.15^{NS} (13.6)	0.10^{NS} (31.8)	0.15^{NS} (18.2)	0.14^{NS} (13.4)	0.12^{NS} (31.8)	0.13^{NS} (18.2)	0.14^{NS} (13.0)	0.10^{NS} (31.8)	0.15^{NS} (18.3)	0.14^{NS} (13.5)
Jabalpur (MP)	-0.27^{NS} (29.7)	-0.38^{NS} (14.8)	-0.45^{NS} (1.8)	-0.27^{NS} (29.8)	-0.38^{NS} (14.8)	-0.45^{NS} (1.8)	-0.27^{NS} (29.7)	-0.38^{NS} (14.7)	-0.45^{NS} (1.8)	-0.29^{NS} (29.8)	-0.38^{NS} (14.9)	-0.45^{NS} (1.8)
S.K. Nagar (GJ)	-0.42* (31.9)	-0.81*** (15.9)	-0.47* (35.0)	-0.41* (31.9)	-0.81*** (15.9)	-0.47* (33.8)	-0.41* (31.9)	-0.81*** (16.0)	-0.47* (37.0)	-0.41* (31.9)	-0.81*** (16.1)	-0.47* (34.6)

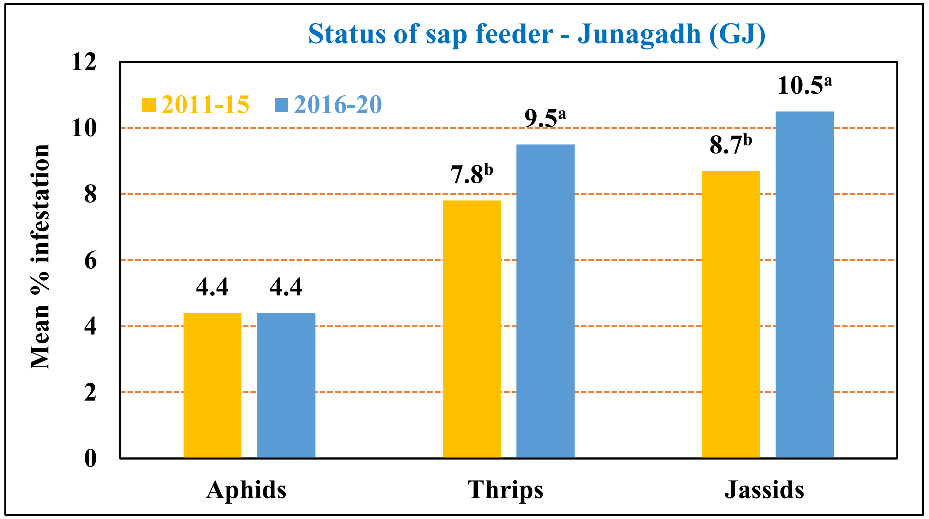
Annexure XXIII. Future status of *H.armigera* on pigeonpea - 2050

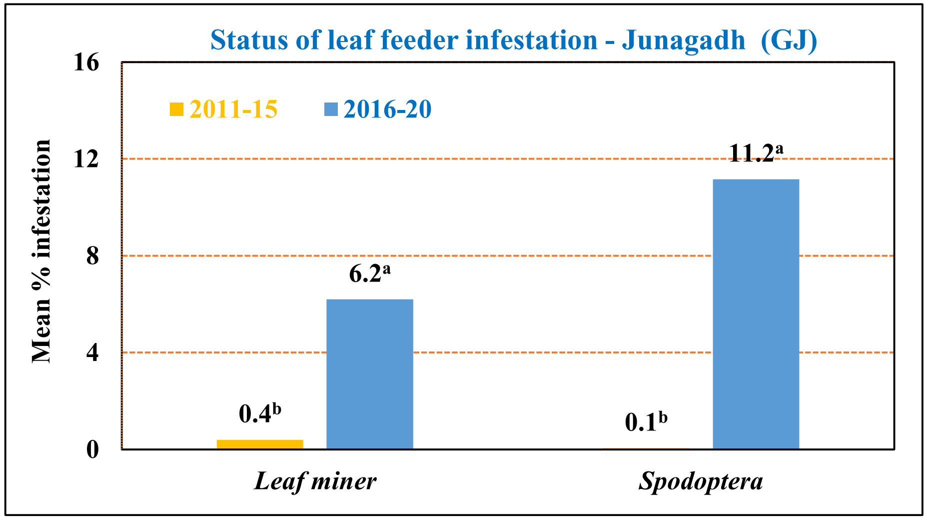
Locations	MaxT	MinT	RF	MaxT	MinT	RF	MaxT	MinT	RF	MaxT	MinT	RF
		RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5	
Vamban (TN)	-0.49* (31.5)	-0.66** (23.9)	-0.08^{NS} (72.4)	-0.47* (31.8)	-0.66** (24.2)	-0.08^{NS} (72.4)	-0.49* (31.6)	-0.66** (24.1)	-0.08^{NS} (73.1)	-0.49* (32.2)	-0.68*** (24.7)	-0.10^{NS} (74.1)
Reddipalli (A.P)	-0.15^{NS} (30.3)	-0.13^{NS} (20.9)	0.00^{NS} (18.1)	-0.18^{NS} (30.6)	-0.13^{NS} (21.3)	0.00^{NS} (18.2)	-0.17^{NS} (30.4)	-0.13^{NS} (21.1)	0.04^{NS} (18.7)	-0.17^{NS} (30.8)	-0.15^{NS} (22.0)	0.04^{NS} (19.9)
Gulbarga (KA)	-0.02^{NS} (31.1)	-0.33^{NS} (21.5)	-0.13^{NS} (51.0)	-0.06^{NS} (31.4)	-0.33^{NS} (21.8)	-0.13^{NS} (51.3)	-0.09^{NS} (31.3)	-0.34^{NS} (21.7)	-0.13^{NS} (49.2)	-0.01^{NS} (31.7)	-0.32 ^{NS} (22.4)	-0.13 ^{NS} (54.3)
Warangal (TS)	-0.17 ^{NS} (31.3)	-0.52** (21.2)	-0.40* (21.3)	-0.14 ^{NS} (31.7)	-0.51** (21.6)	-0.38* (21.3)	-0.16 ^{NS} (31.4)	-0.52** (21.5)	-0.40* (20.5)	-0.14 ^{NS} (32.0)	-0.51** (22.3)	-0.38* (22.8)
Jalgaon (MH)	0.13^{NS} (32.0)	0.15^{NS} (18.6)	0.15 ^{NS} (13.8)	0.13 ^{NS} (32.5)	0.15 ^{NS} (19.0)	0.15 ^{NS} (14.1)	0.13 ^{NS} (32.3)	0.14 ^{NS} (18.9)	0.14 ^{NS} (13.7)	0.09 ^{NS} (32.9)	0.14 ^{NS} (19.7)	0.15 ^{NS} (15.0)
Jabalpur (MP)	-0.25 ^{NS} (30.1)	-0.38 ^{NS} (15.2)	-0.45^{NS} (1.9)	-0.25^{NS} (30.6)	-0.38 ^{NS} (15.7)	-0.45^{NS} (1.9)	-0.25^{NS} (30.3)	-0.38 ^{NS} (15.6)	-0.45^{NS} (1.9)	-0.23^{NS} (30.9)	-0.38 ^{NS} (16.4)	-0.45^{NS} (2.1)
S.K. Nagar (GJ)	-0.39* (32.3)	-0.80*** (16.4)	-0.49* (35.1)	-0.39* (32.9)	-0.80*** (16.9)	-0.49* (35.1)	-0.39* (32.6)	-0.80*** (16.8)	-0.49* (38.4)	-0.38* (33.2)	-0.80*** (17.6)	-0.49* (37.5)

Annexure XXIV: Future status of *H.armigera* on pigeonpea - 2080

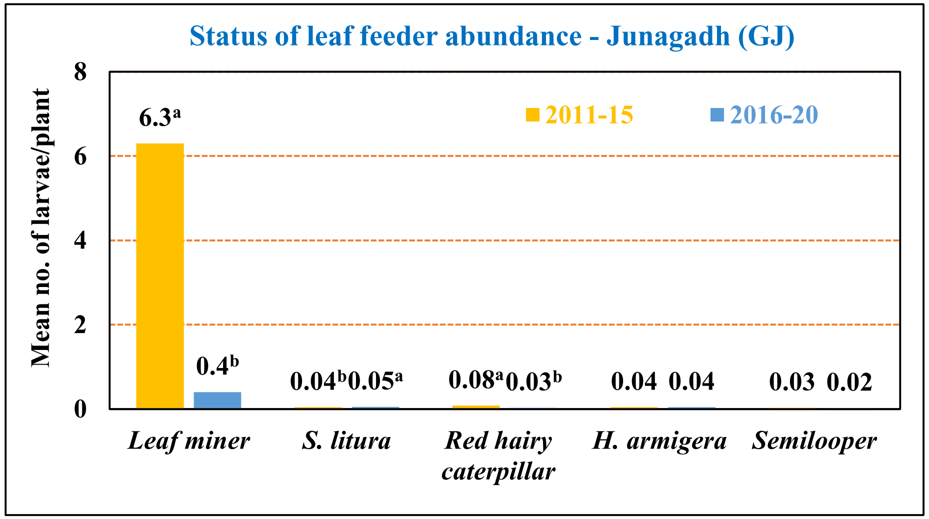
Locations	MaxT	MinT	RF	MaxT	MinT	RF	MaxT	MinT	RF	MaxT	MinT	RF
	RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
Vamban (TN)	-0.50* (31.5)	-0.66*** (23.9)	-0.10^{NS} (72.7)	-0.50* (32.2)	-0.67** (24.6)	-0.10^{NS} (74.4)	-0.50* (32.3)	-0.69*** (24.9)	-0.08^{NS} (77.7)	-0.49* (33.4)	-0.66** (26.0)	-0.08^{NS} (83.2)
Reddipalli (A.P)	-0.17^{NS} (30.3)	-0.13^{NS} (20.9)	0.04^{NS} (18.4)	-0.18^{NS} (31.0)	-0.13^{NS} (21.8)	0.00^{NS} (19.6)	-0.17^{NS} (31.0)	-0.15^{NS} (22.1)	0.04^{NS} (20.7)	-0.24^{NS} (31.8)	-0.15^{NS} (23.7)	0.04^{NS} (23.9)
Gulbarga (KA)	-0.09^{NS} (31.2)	-0.33^{NS} (21.5)	-0.15^{NS} (50.9)	-0.01^{NS} (31.8)	-0.34^{NS} (22.2)	-0.13^{NS} (54.1)	0.00^{NS} (31.8)	-0.30^{NS} (22.6)	-0.13^{NS} (53.6)	-0.02^{NS} (32.8)	-0.30^{NS} (23.8)	-0.10^{NS} (58.7)
Warangal (TS)	-0.25^{NS} (31.5)	-0.52** (21.2)	-0.40* (21.0)	-0.13^{NS} (32.1)	-0.51** (22.2)	-0.38* (22.4)	0.03^{NS} (31.9)	-0.51** (22.4)	-0.38* (23.1)	0.02^{NS} (33.2)	-0.51** (24.0)	-0.36^{NS} (24.1)
Jalgaon (MH)	0.12^{NS} (32.2)	0.14^{NS} (18.6)	0.15^{NS} (13.9)	0.12^{NS} (33.0)	0.14^{NS} (19.4)	0.15^{NS} (14.7)	0.12^{NS} (33.1)	0.13^{NS} (19.9)	0.14^{NS} (14.8)	0.09^{NS} (34.5)	0.13^{NS} (21.3)	0.15^{NS} (16.4)
Jabalpur (MP)	-0.25^{NS} (30.2)	-0.38^{NS} (15.2)	-0.45^{NS} (1.9)	-0.21^{NS} (31.1)	-0.38^{NS} (16.3)	-0.45^{NS} (2.1)	-0.21^{NS} (31.1)	-0.37^{NS} (16.7)	-0.45^{NS} (2.1)	-0.15^{NS} (32.5)	-0.33^{NS} (18.2)	-0.45^{NS} (2.3)
S.K. Nagar (GJ)	-0.38* (32.4)	-0.80*** (16.3)	-0.49* (35.1)	-0.38* (32.4)	-0.80*** (17.3)	-0.49* (38.5)	-0.39* (33.6)	-0.80*** (17.8)	-0.49* (47.0)	-0.37* (35.0)	-0.80*** (19.5)	-0.49* (49.1)

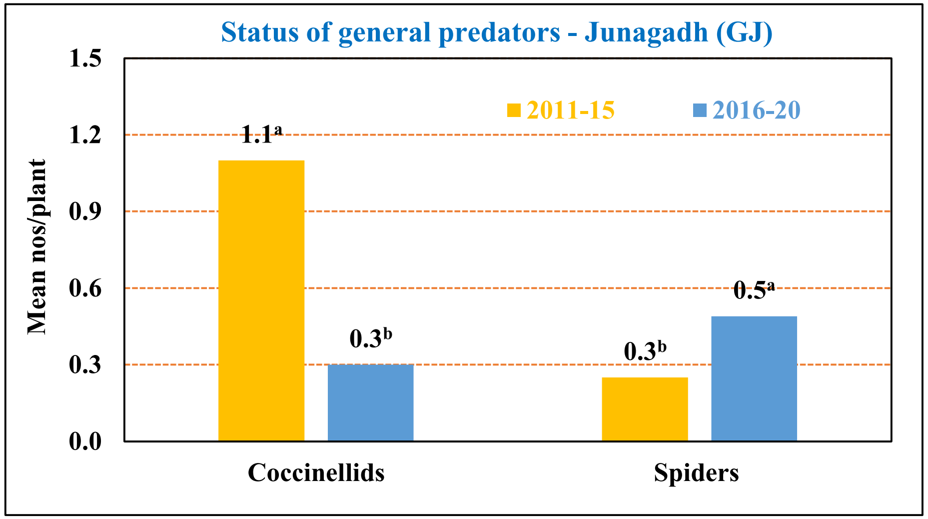
Annexure XXV: Status of major insects, predators and diseases of groundnut - half-decadal comparison [Junagadh (GJ)]



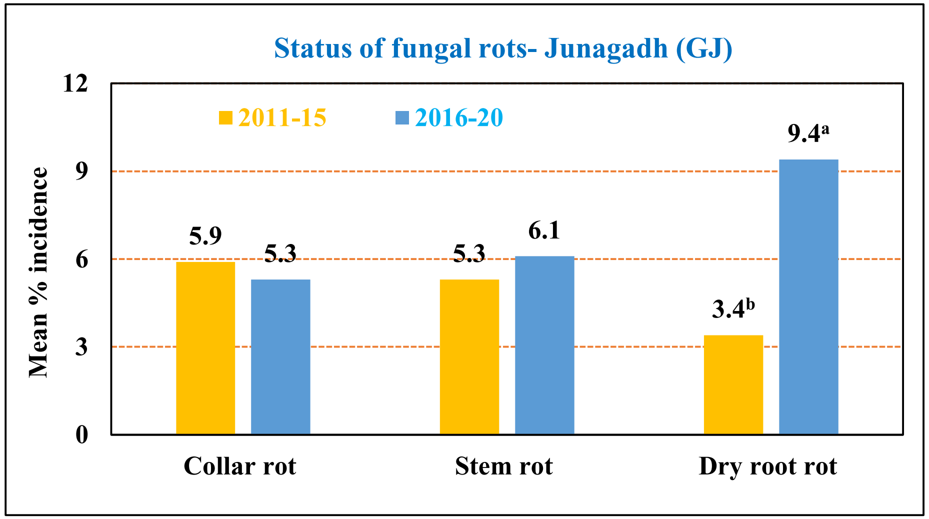


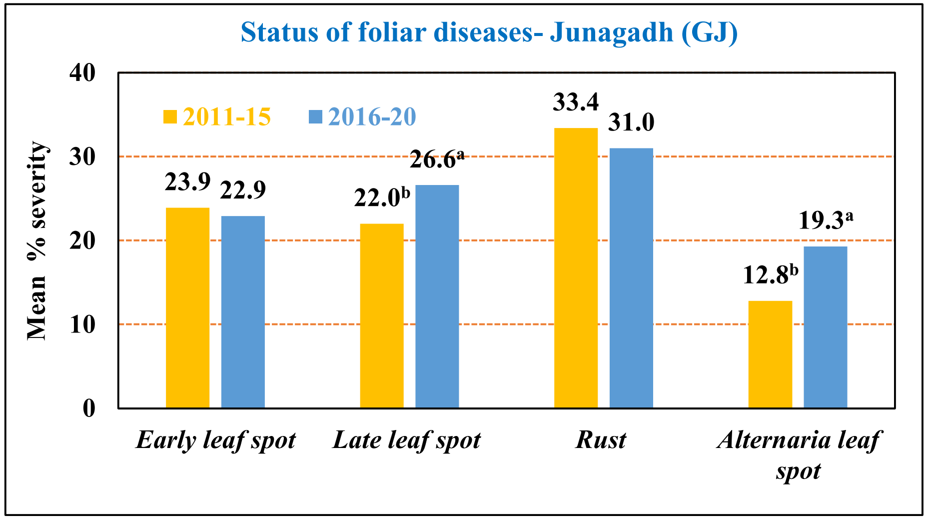
Annexure XXV: Status of major insects, predators and diseases of groundnut - half-decadal comparison [Junagadh (GJ)]



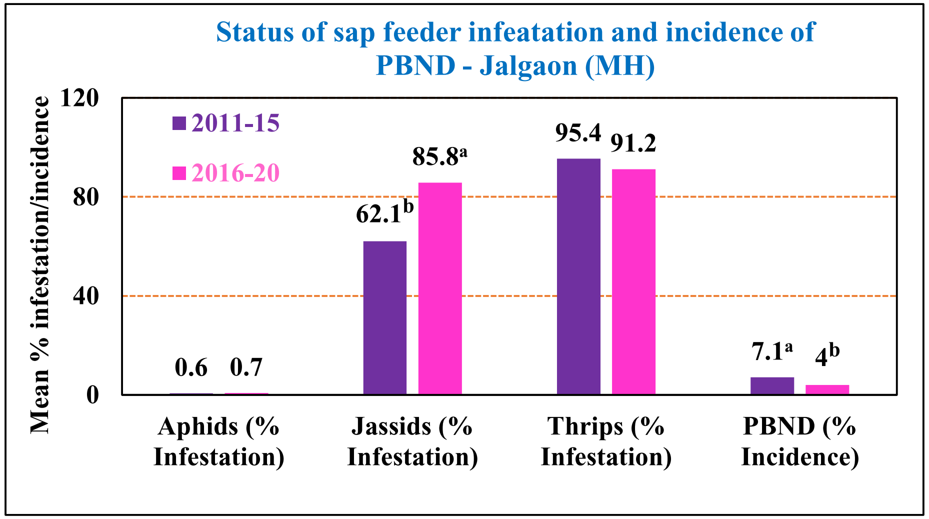


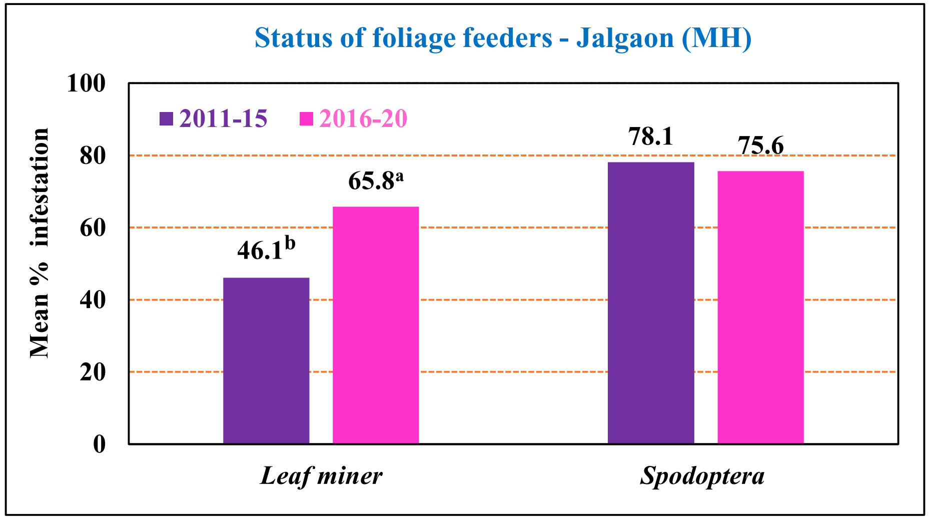
Annexure XXV: Status of major insects, predators and diseases of groundnut - half-decadal comparison [Junagadh (GJ)]

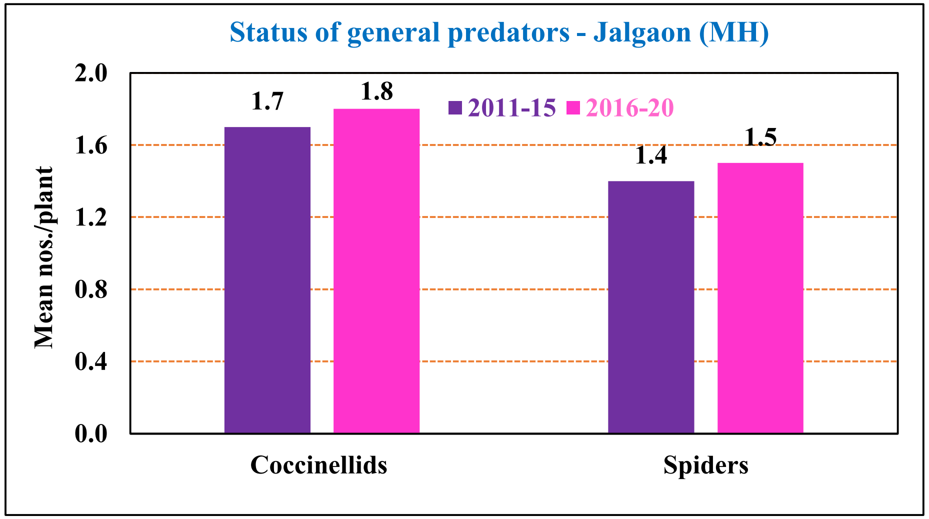




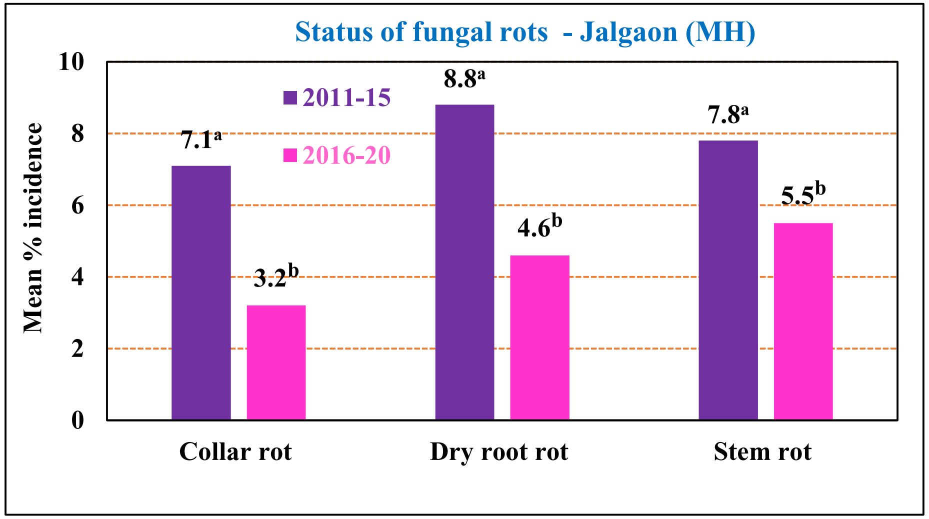
Annexure XXVI: Status of major insects, predators and diseases of groundnut - half-decadal comparison [Jalgaon (MH)]

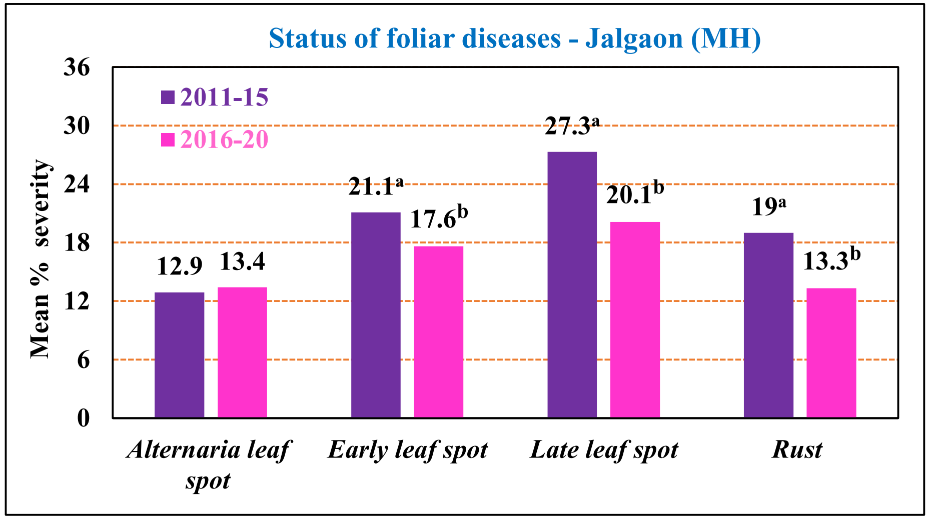






Annexure XXVI: Status of major insects, predators and diseases of groundnut - half-decadal comparison [Jalgaon (MH)]

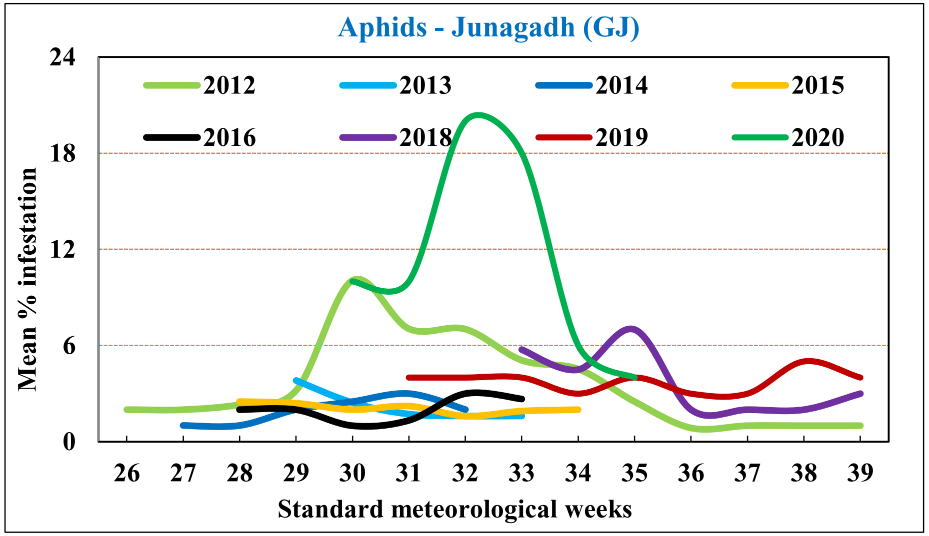


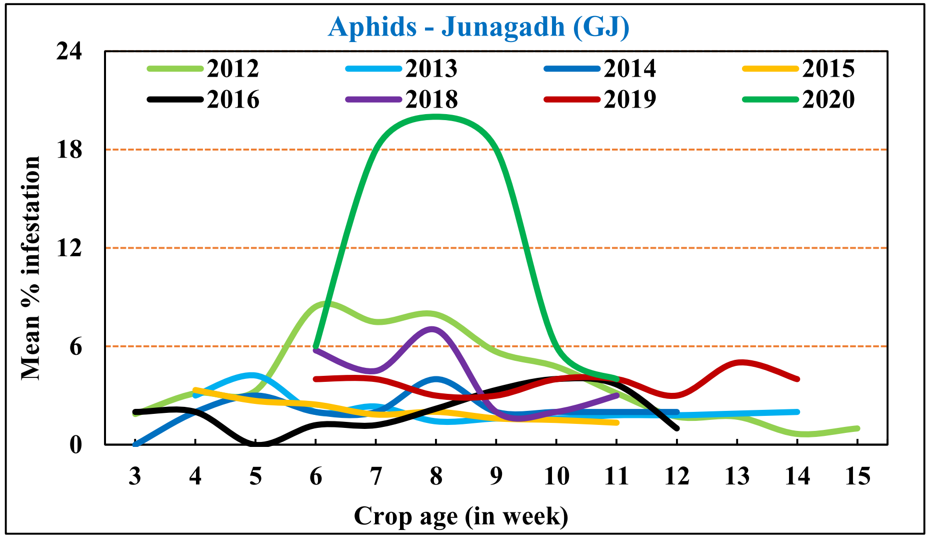


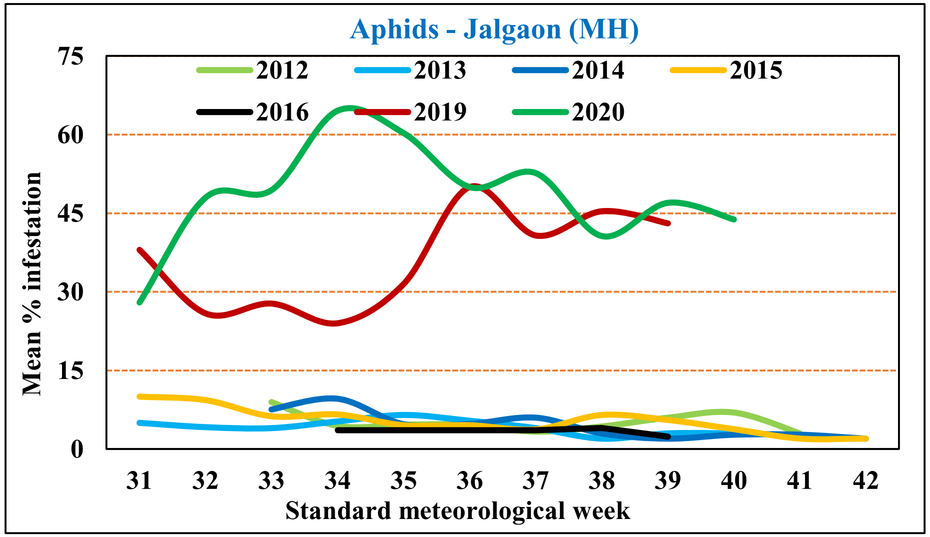
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

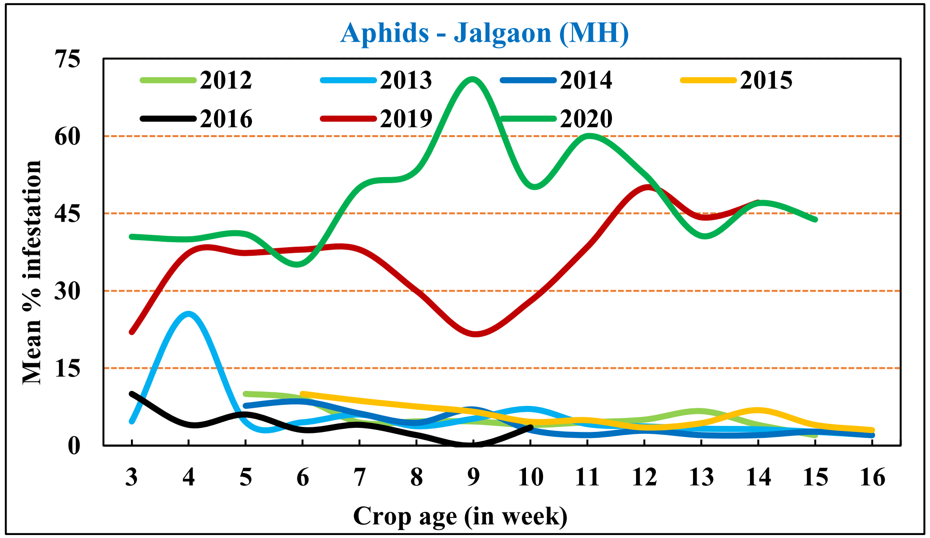
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





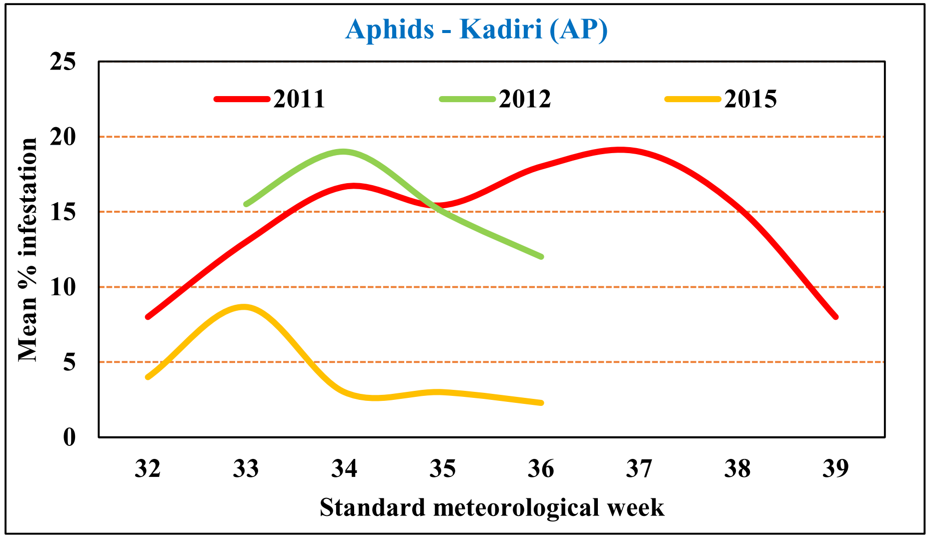


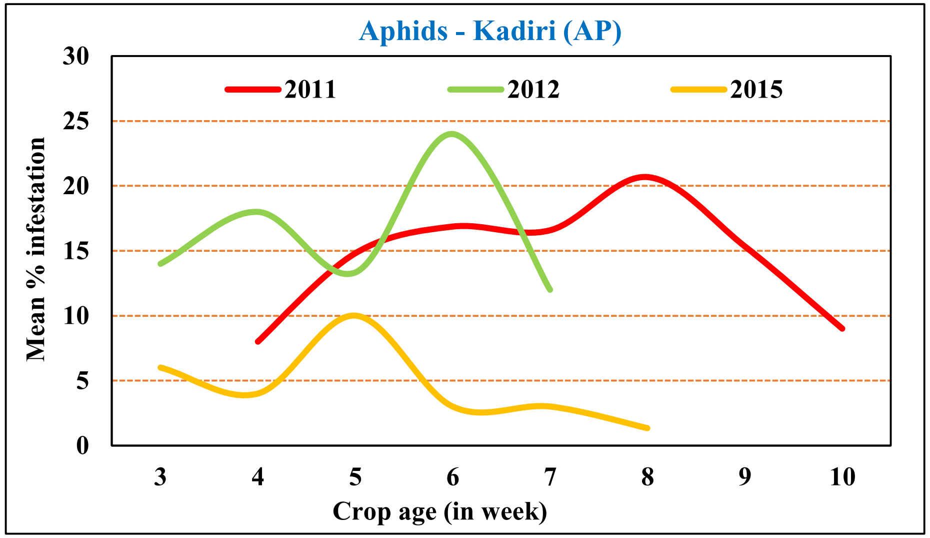


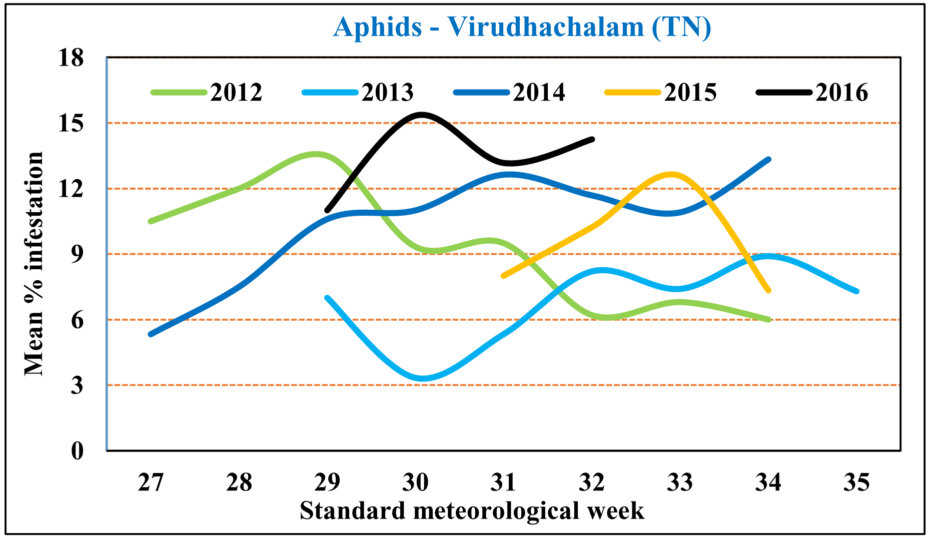
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

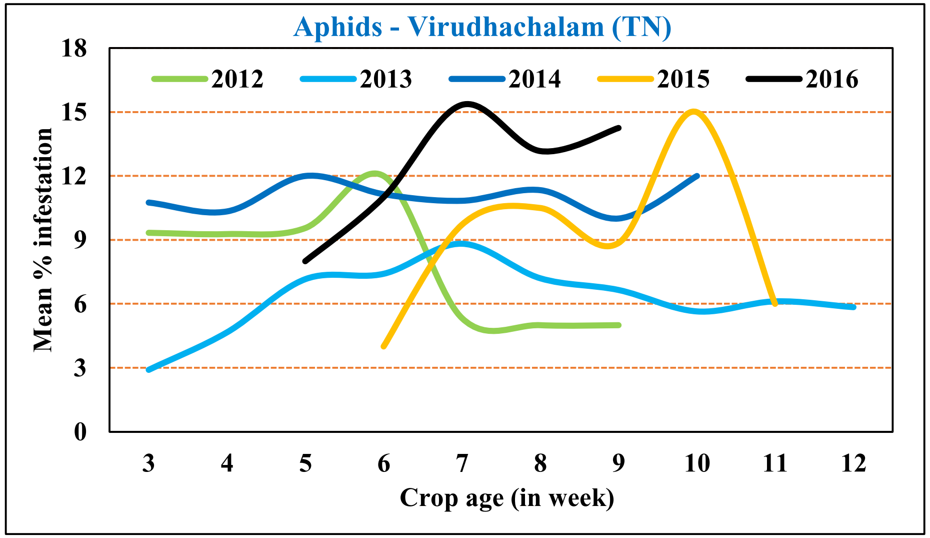
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





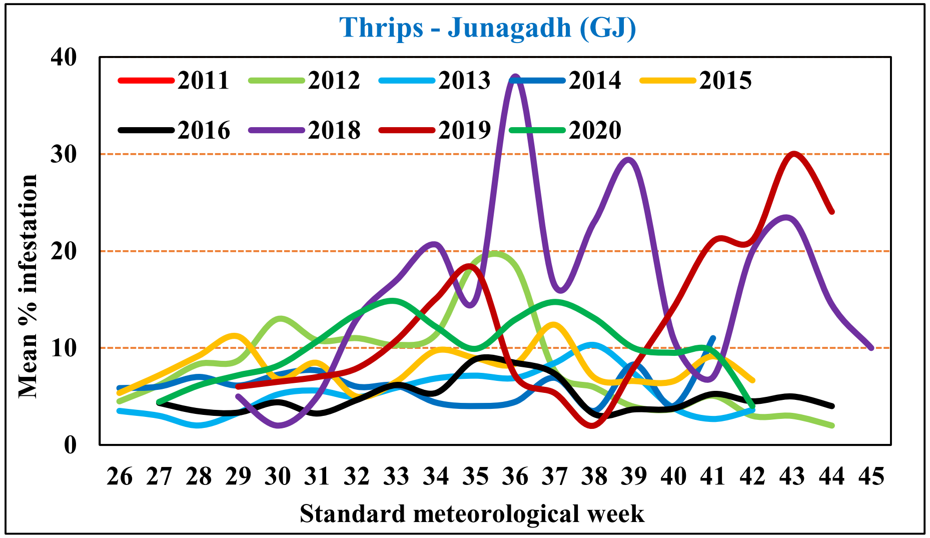


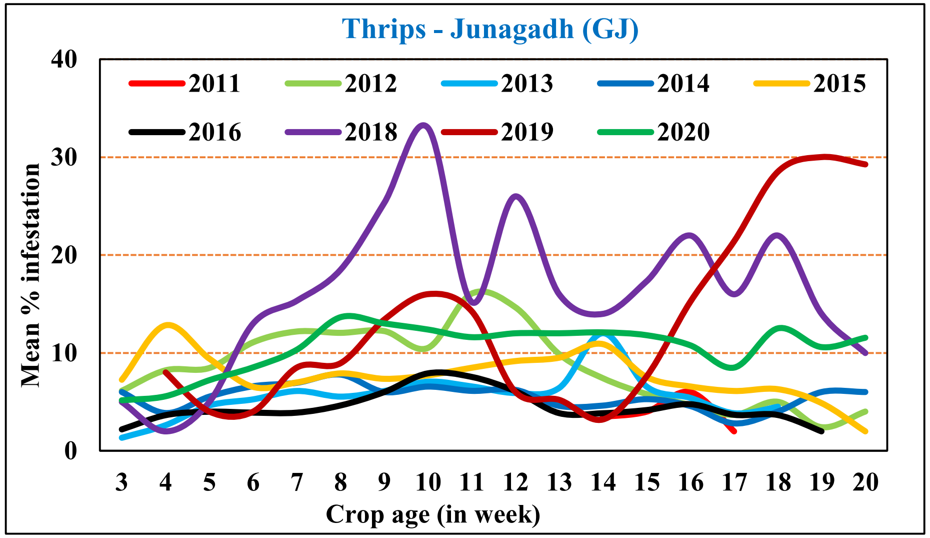


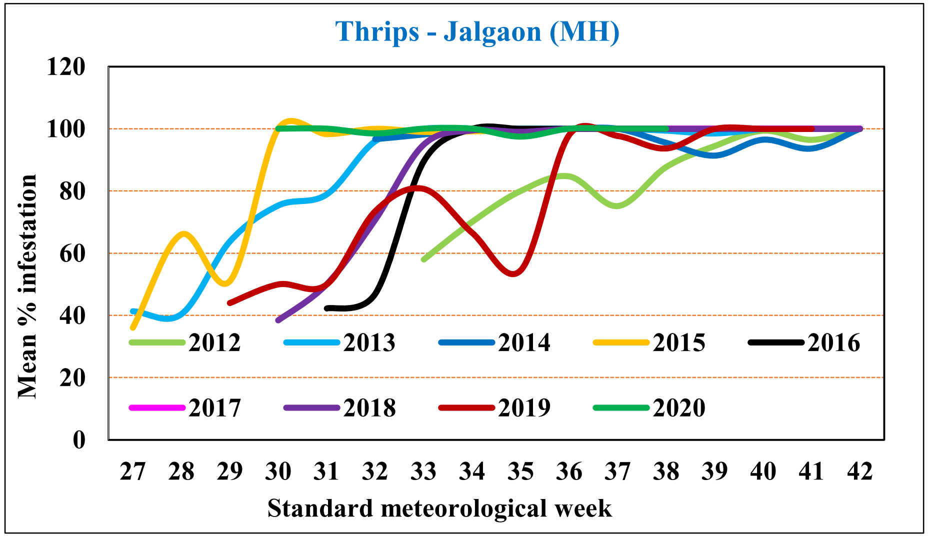
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

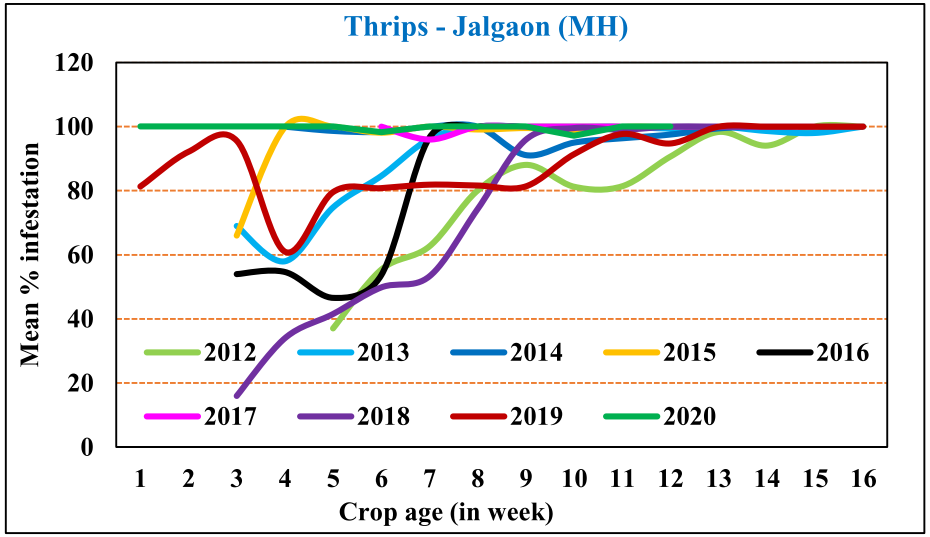
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





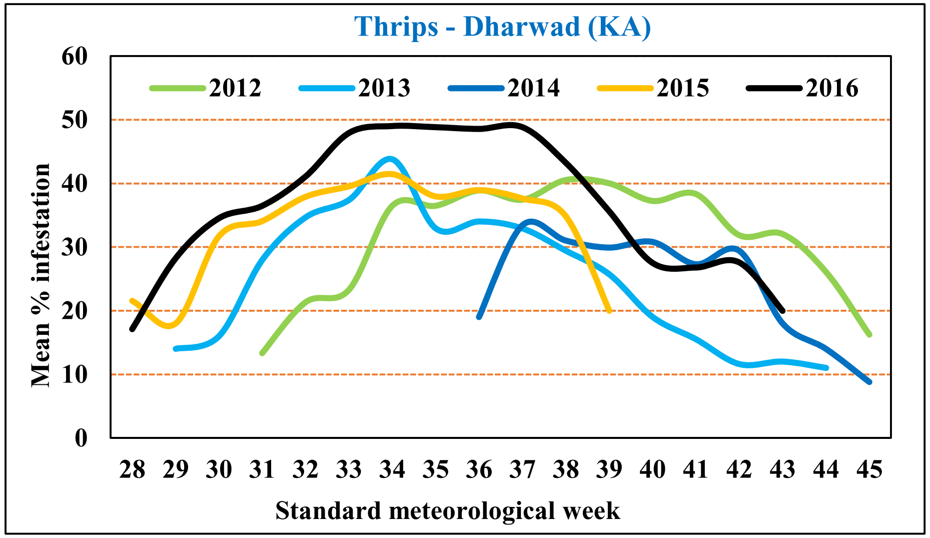


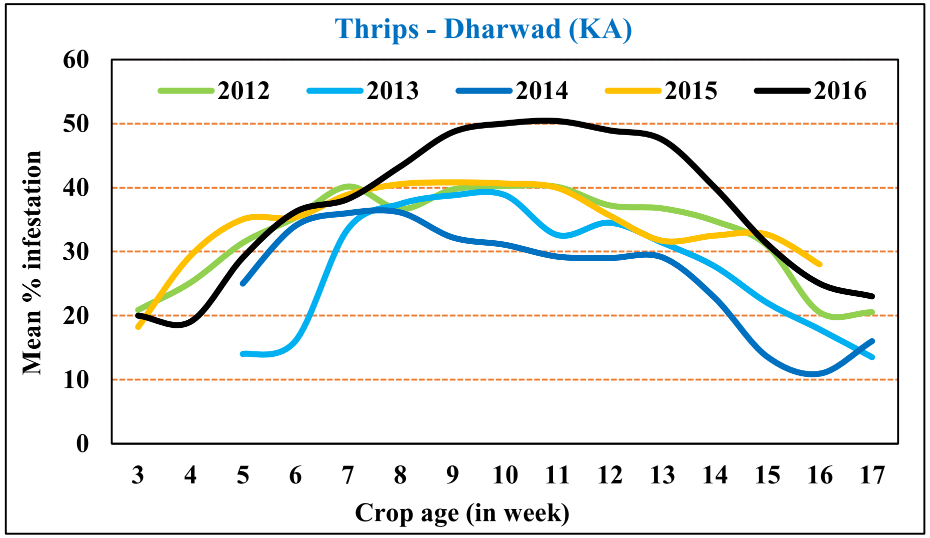


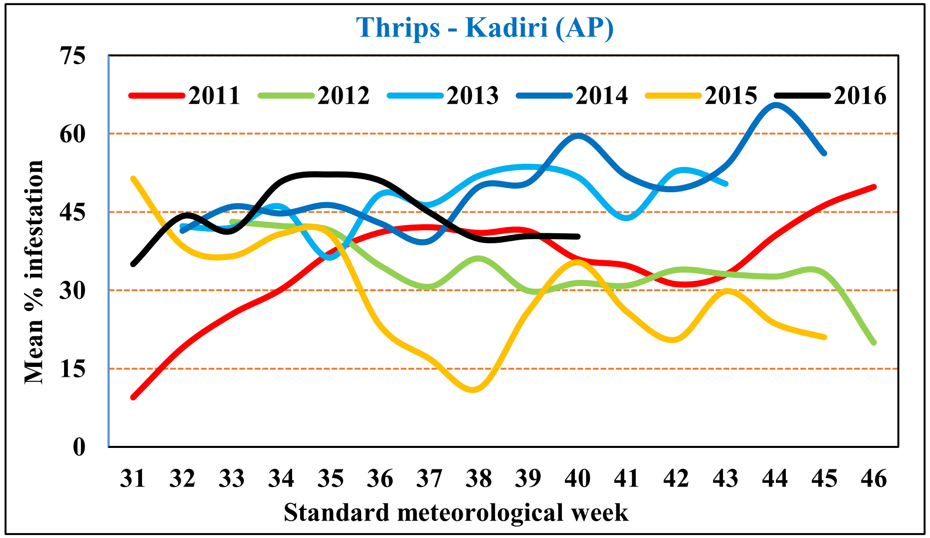
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

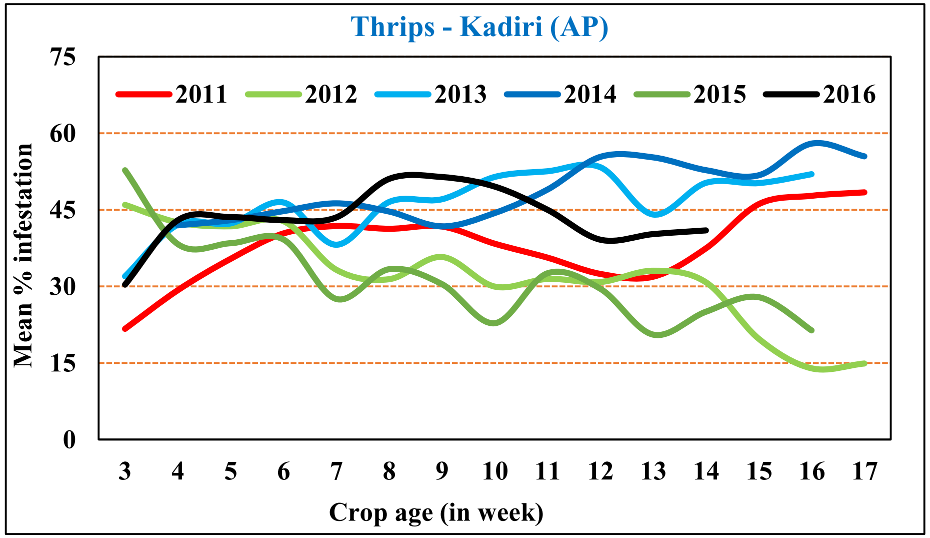
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



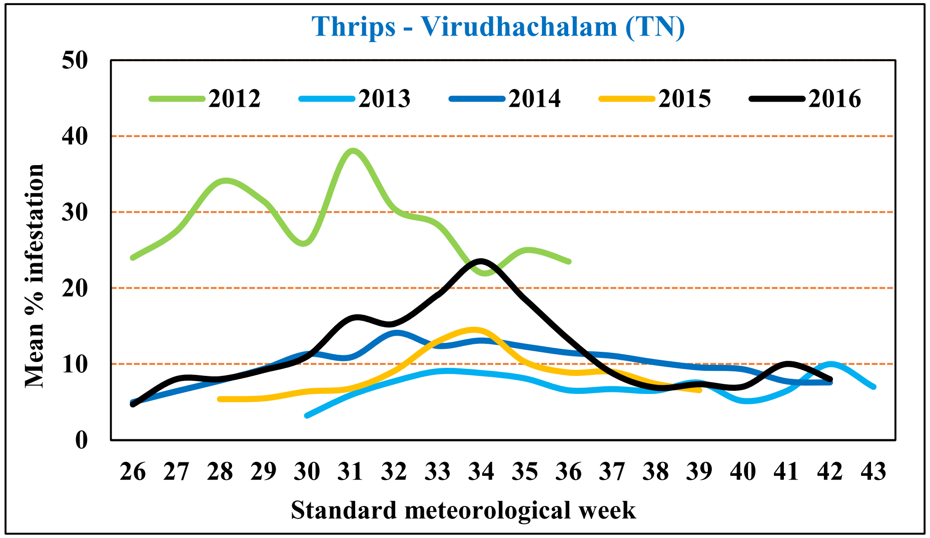


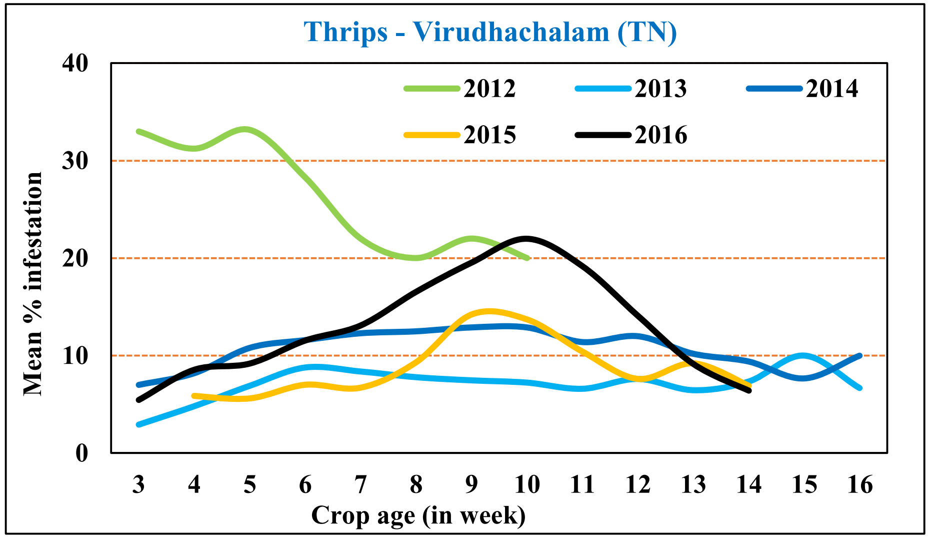


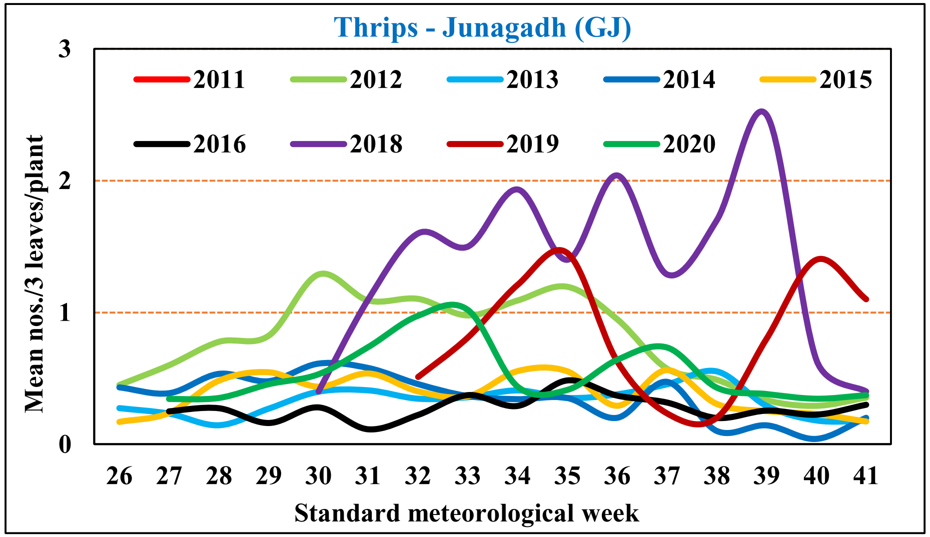


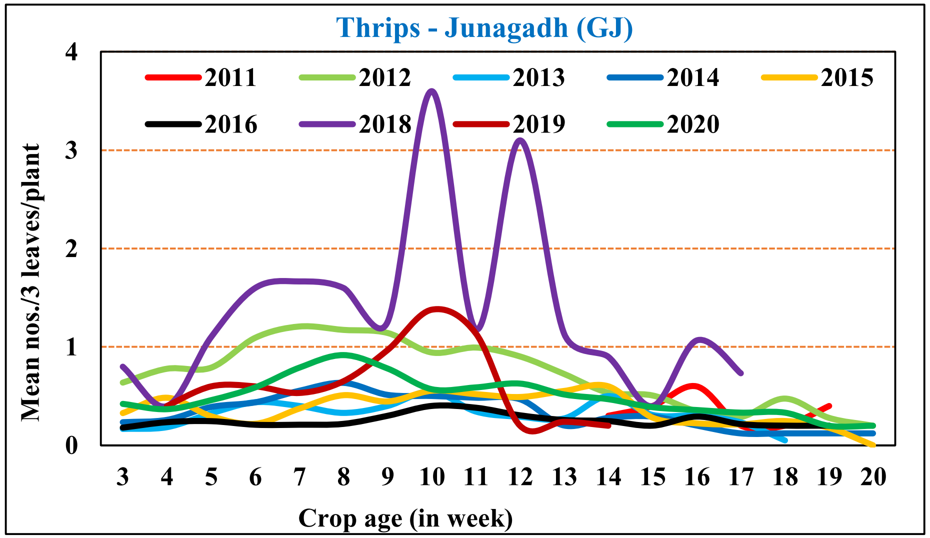
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**





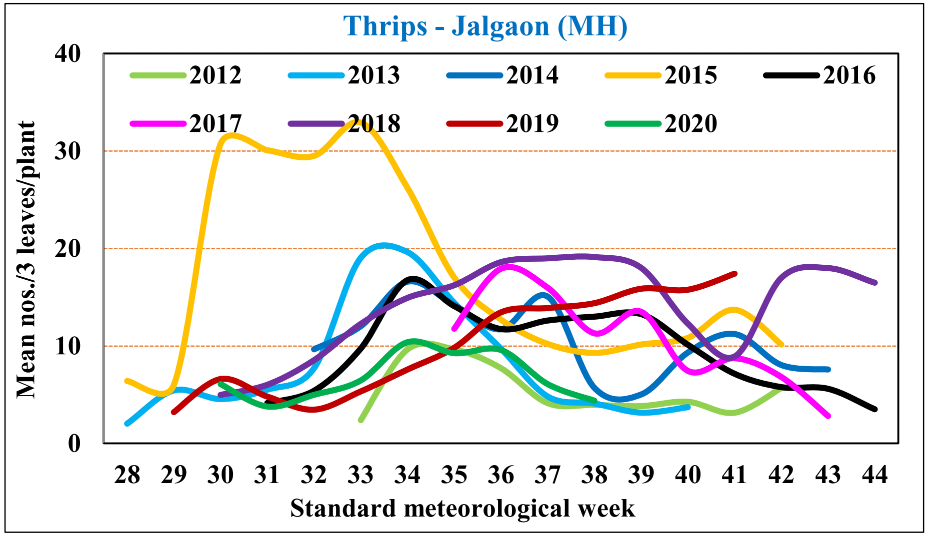


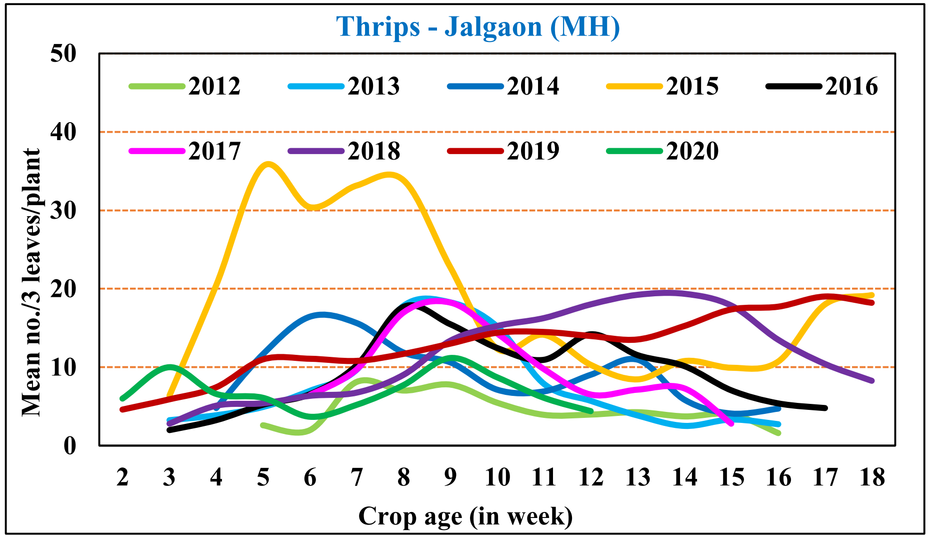


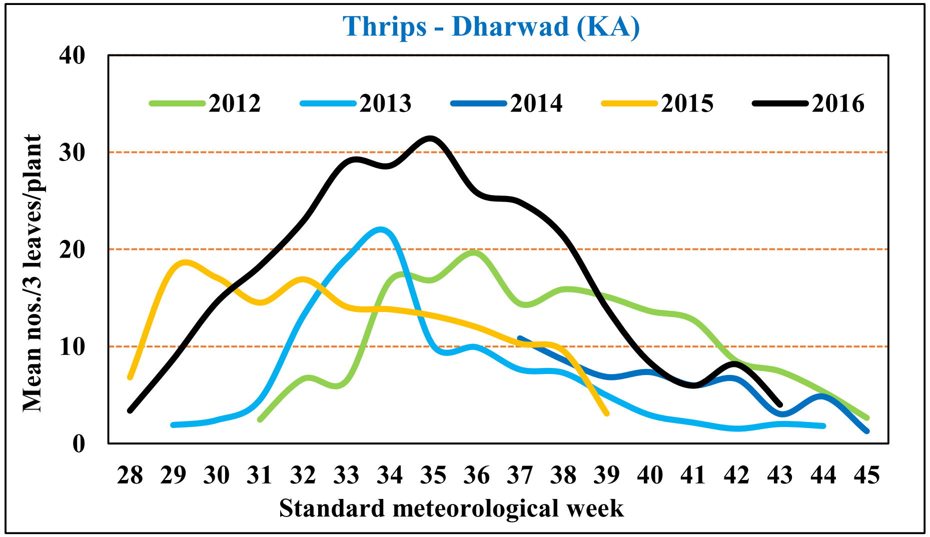
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

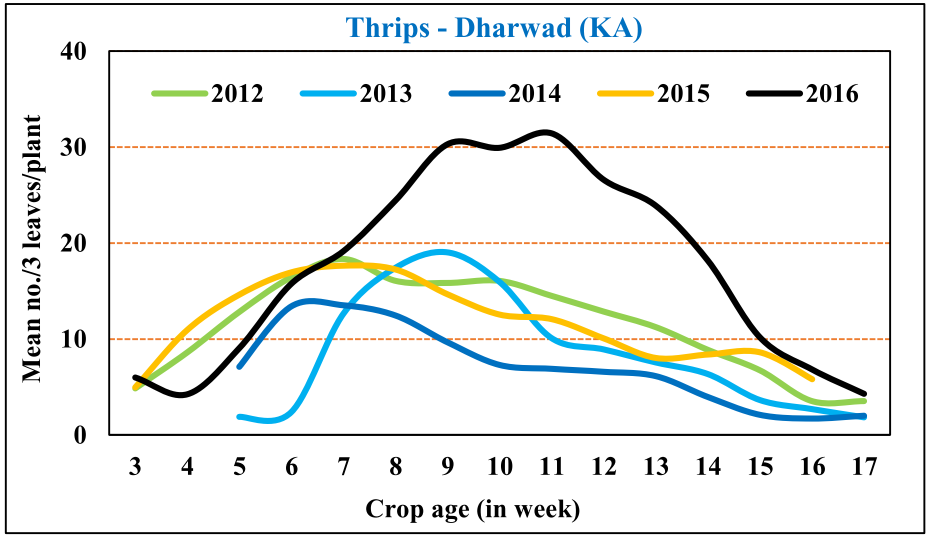
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





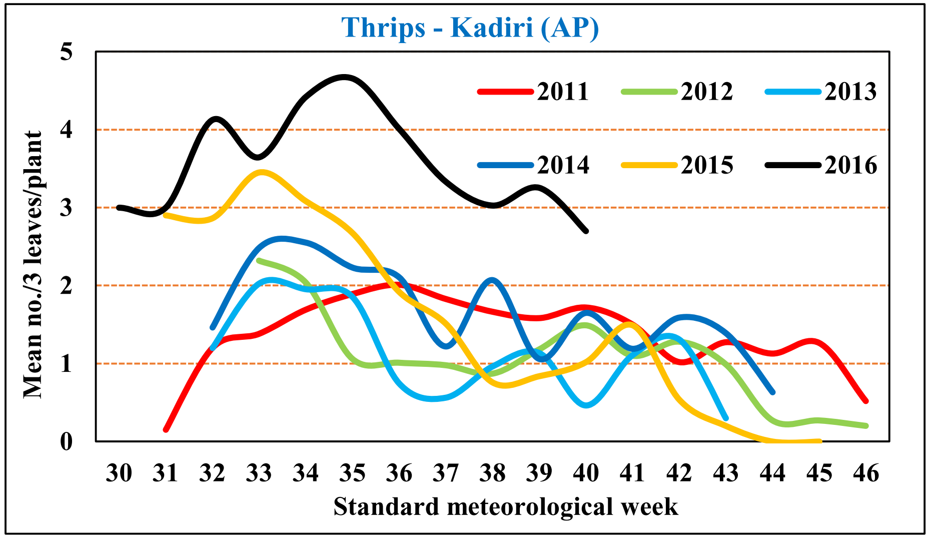


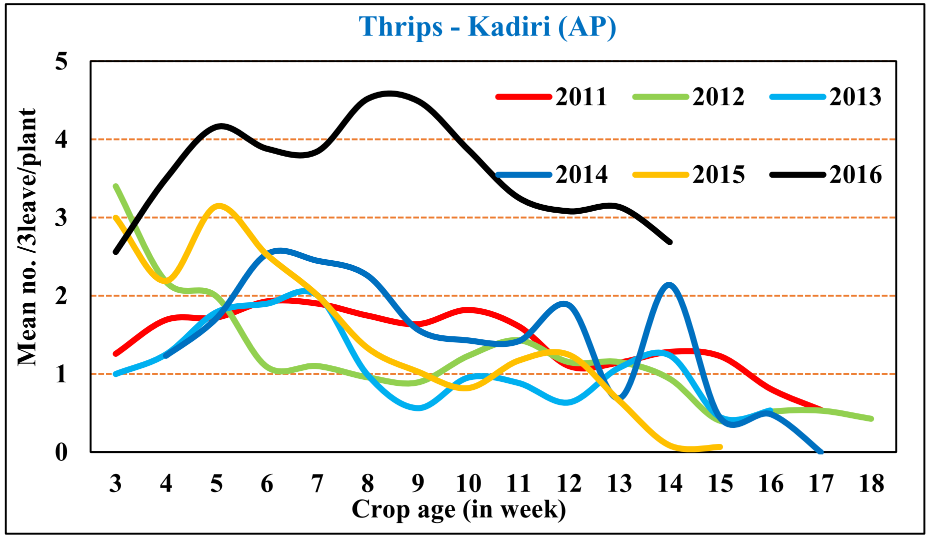


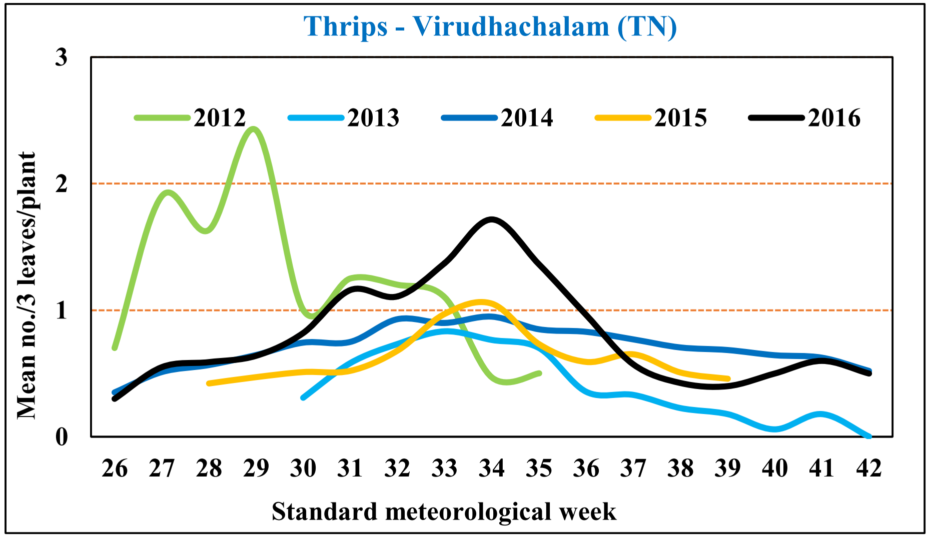
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

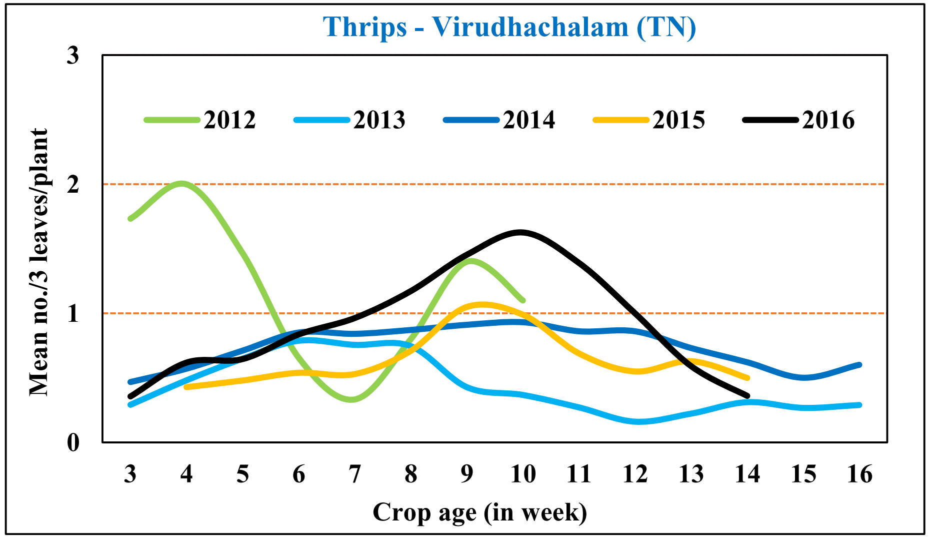
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





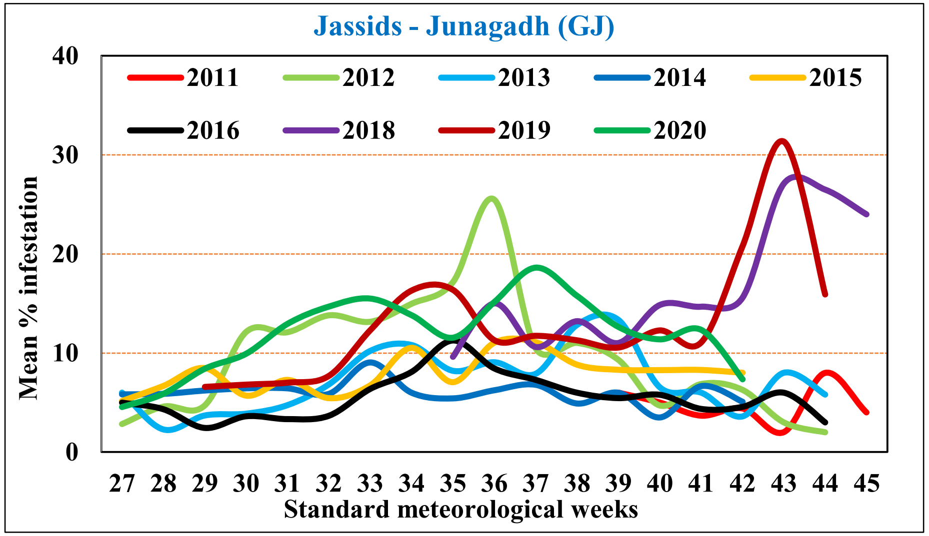


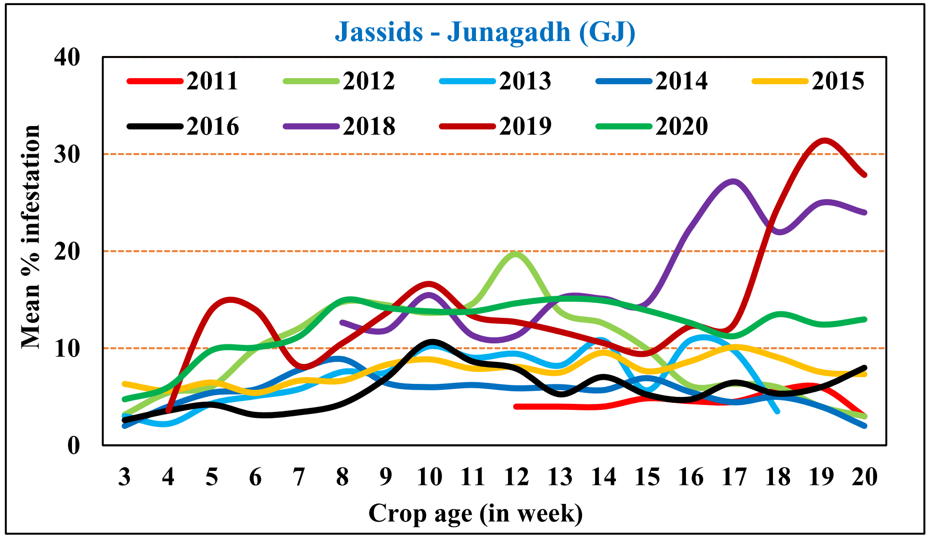


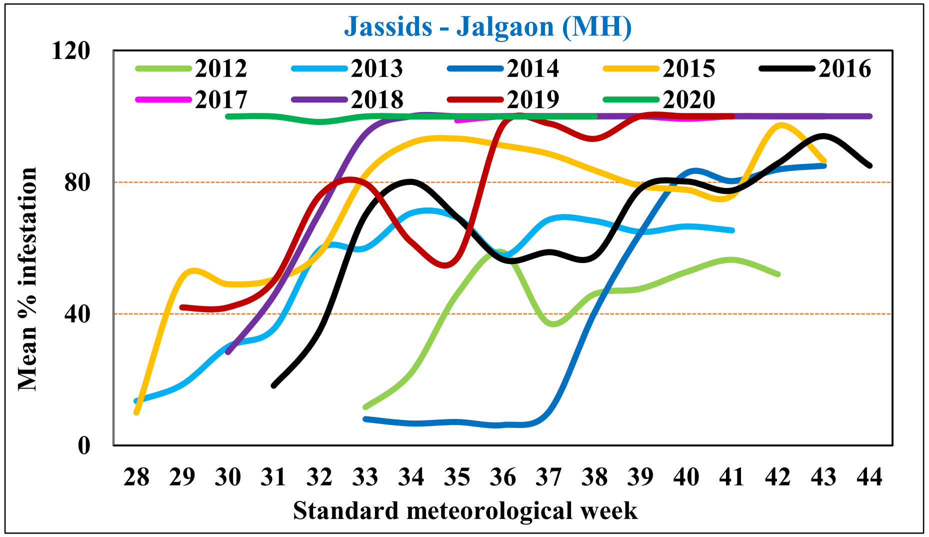
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

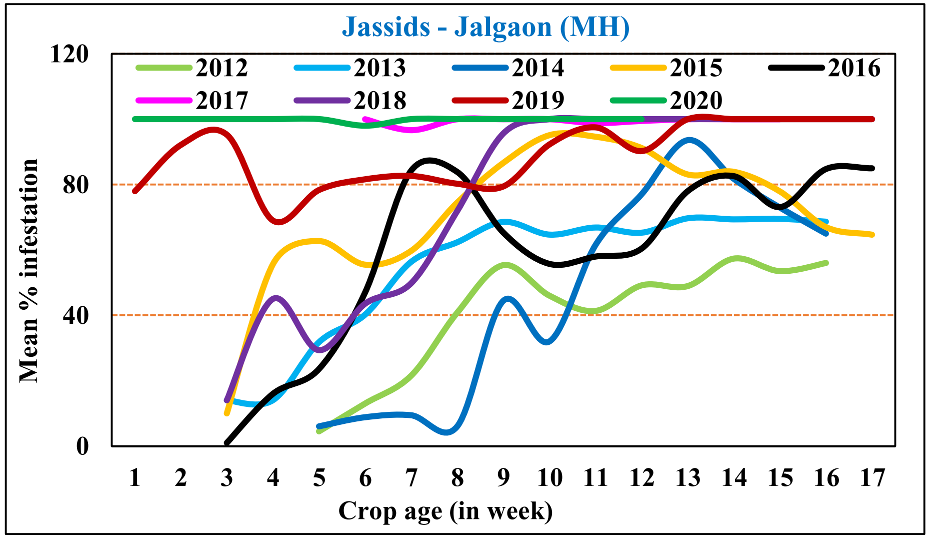
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



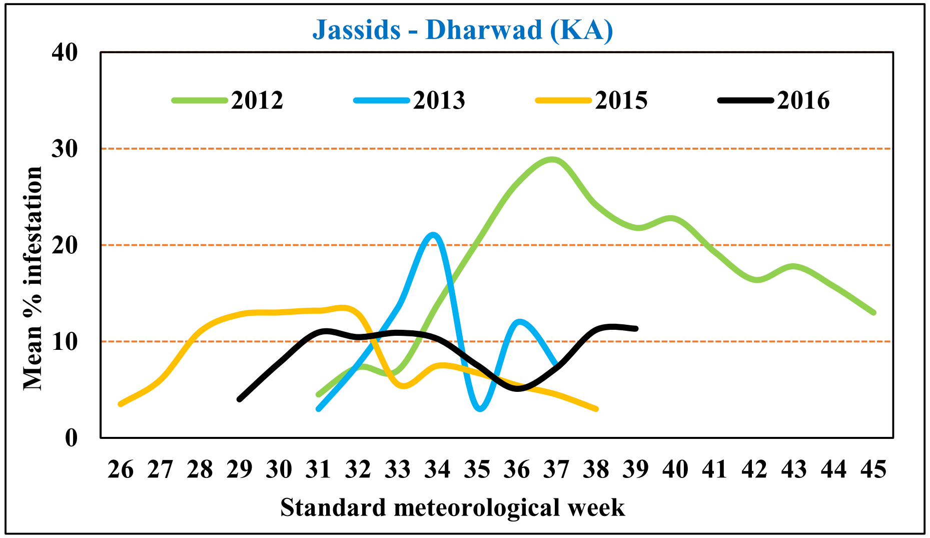


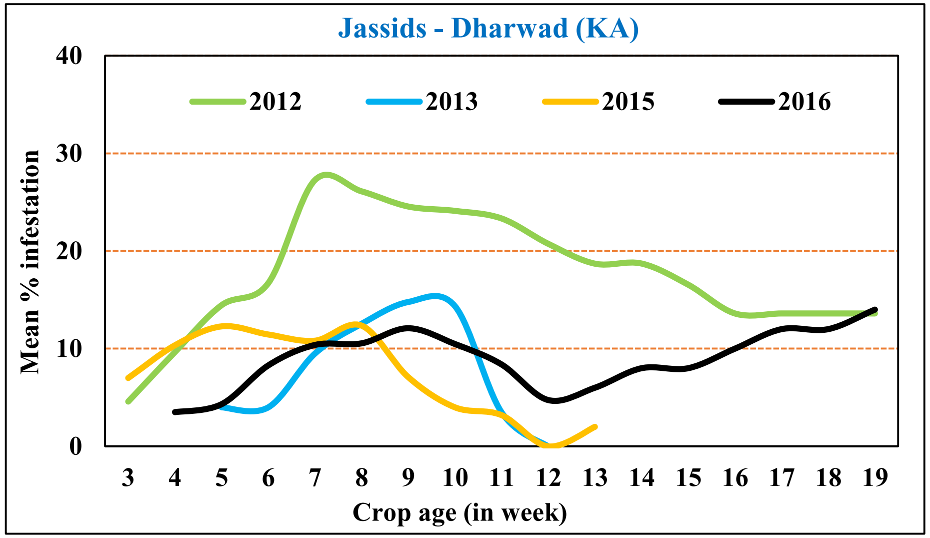


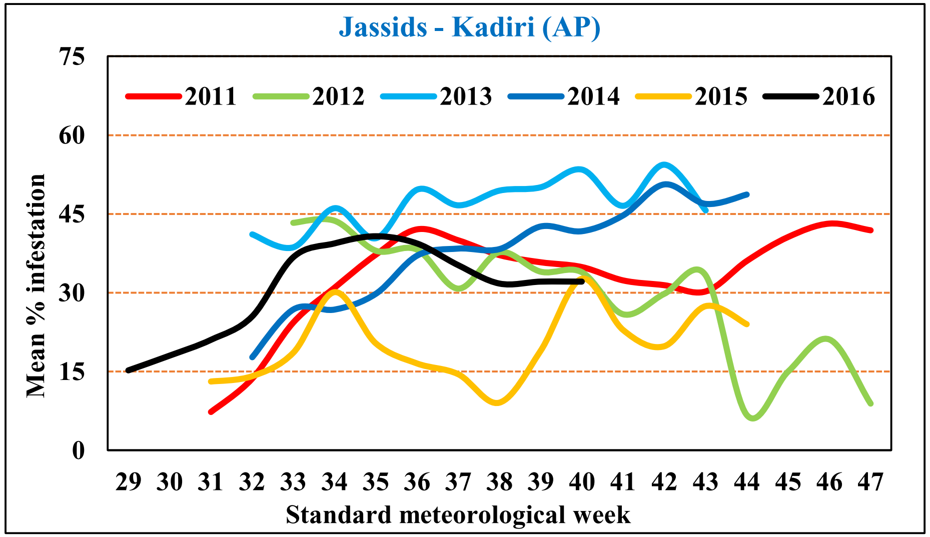


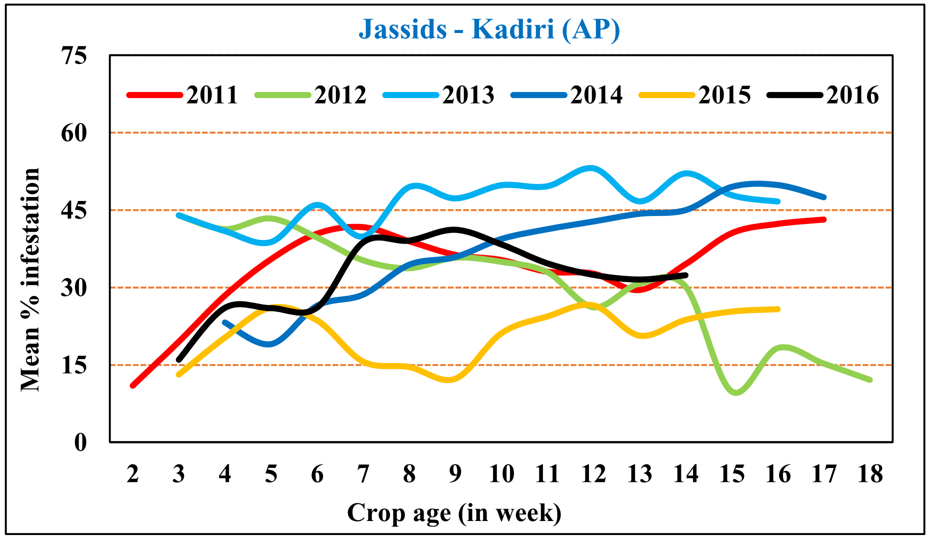
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



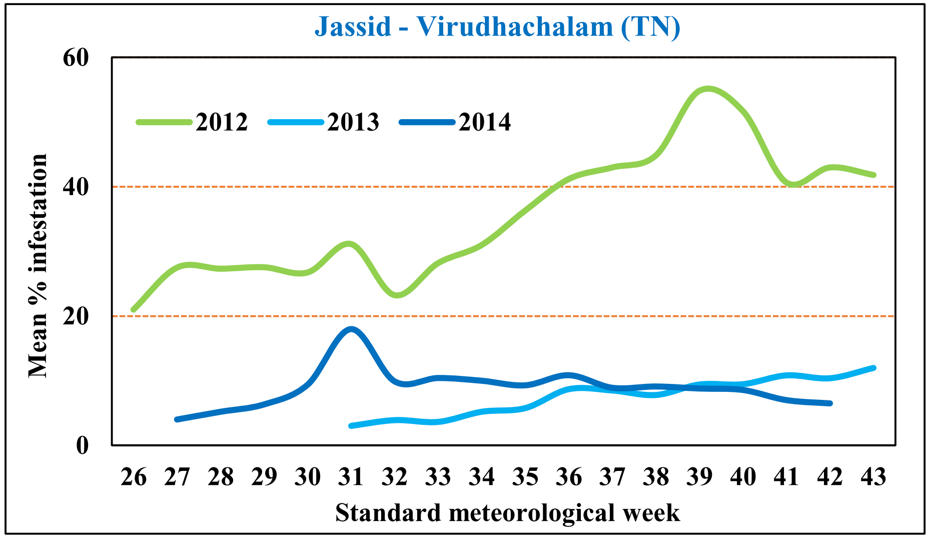


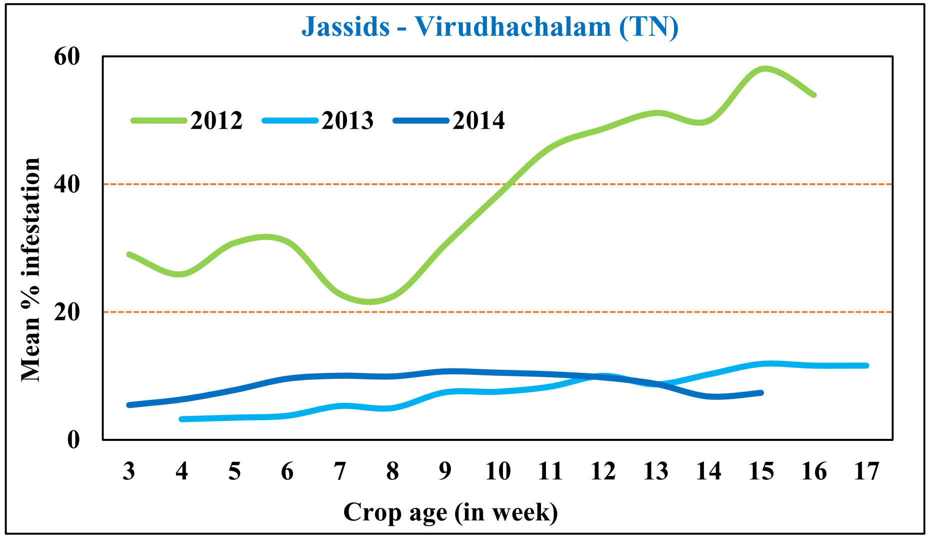


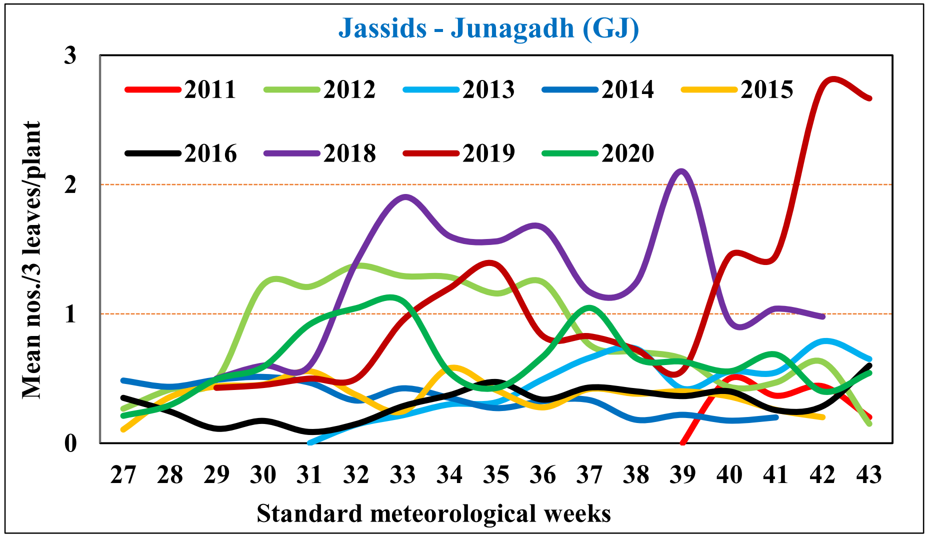


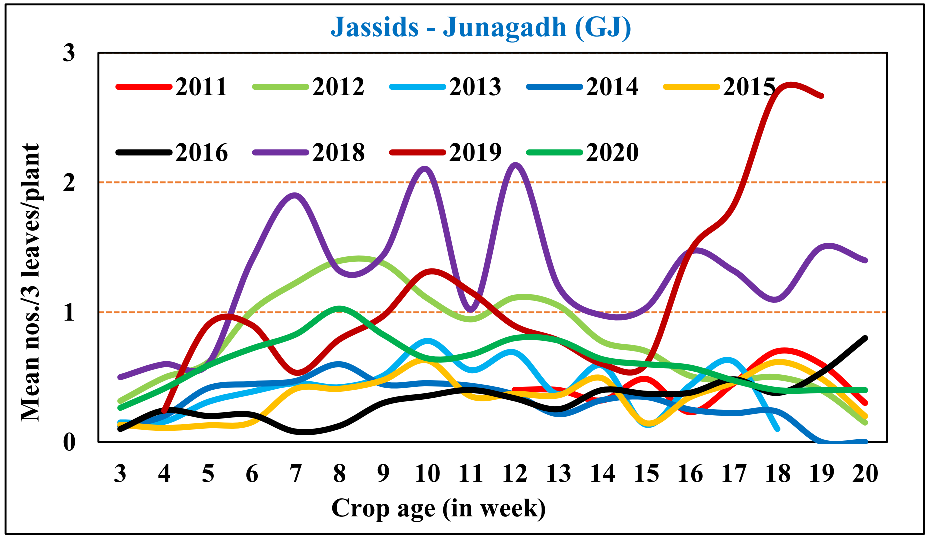
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



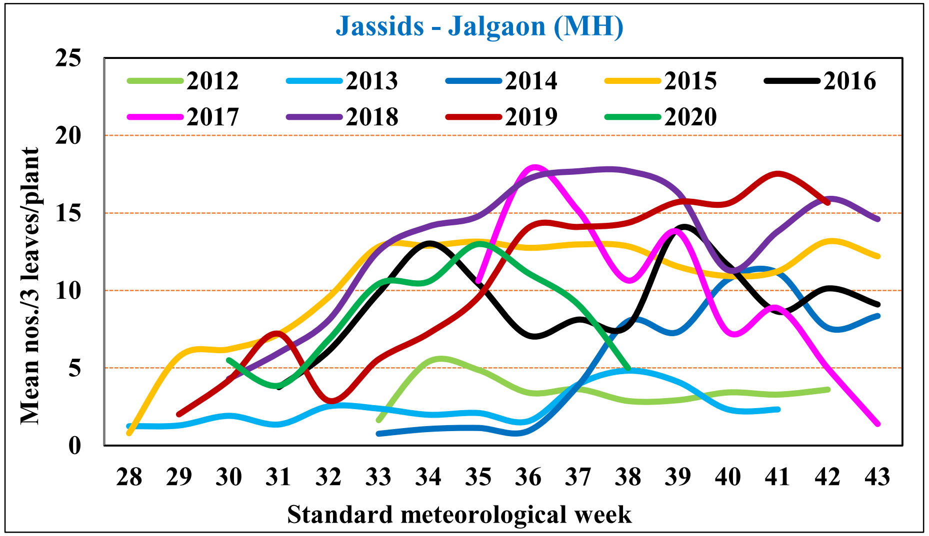


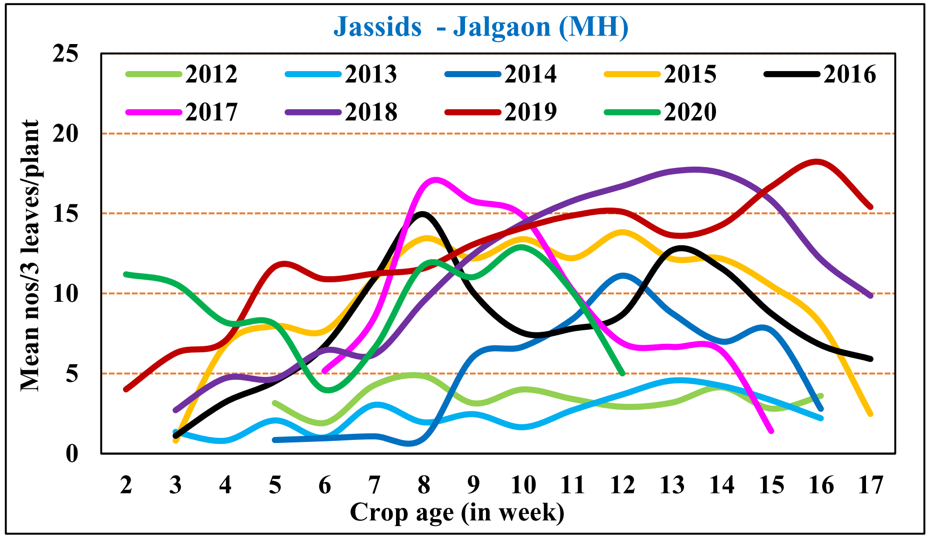


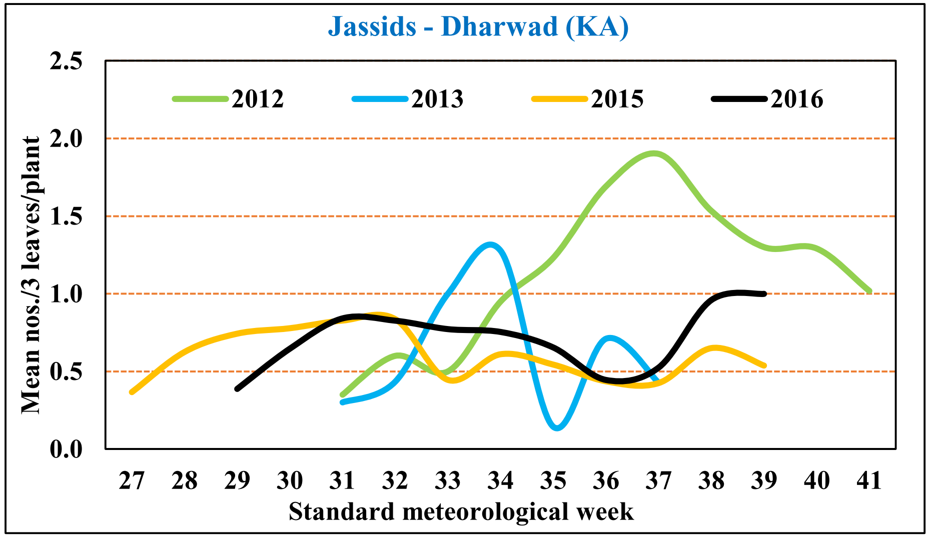


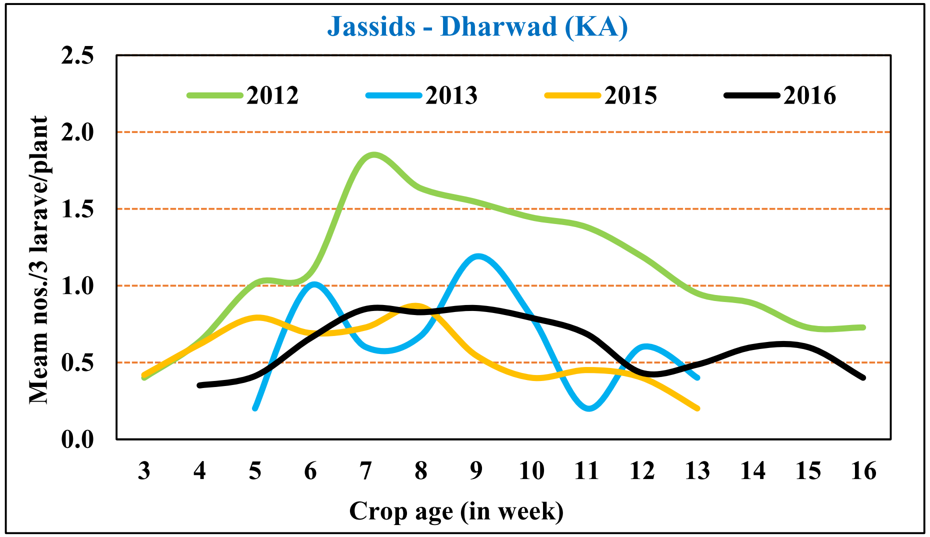
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**





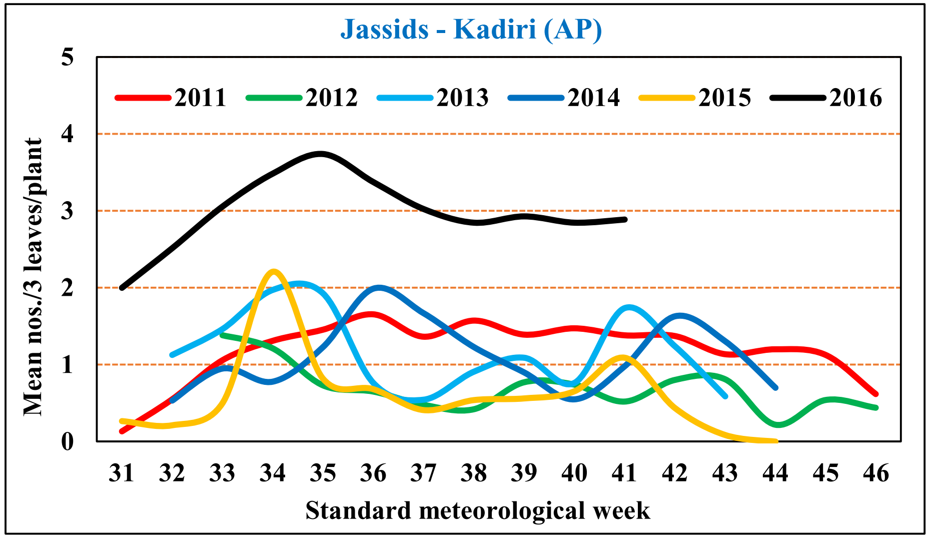


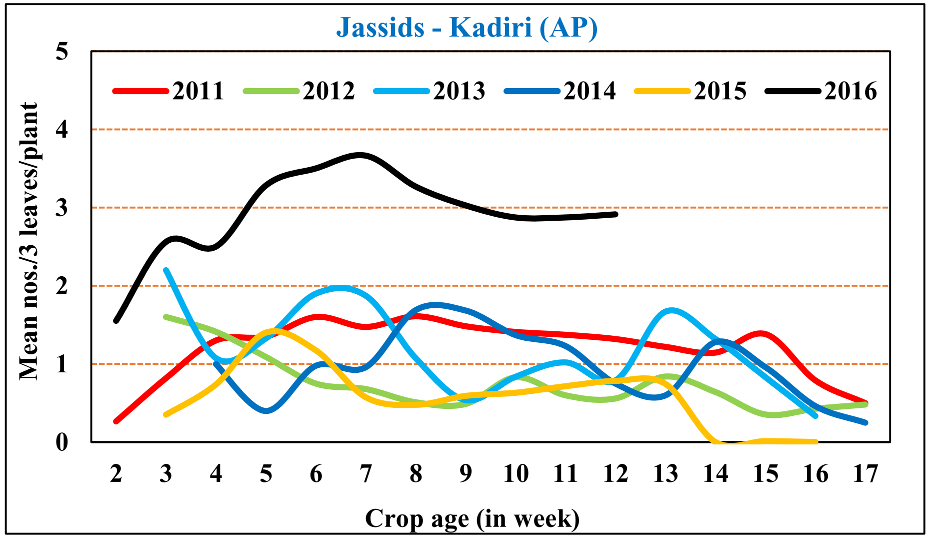


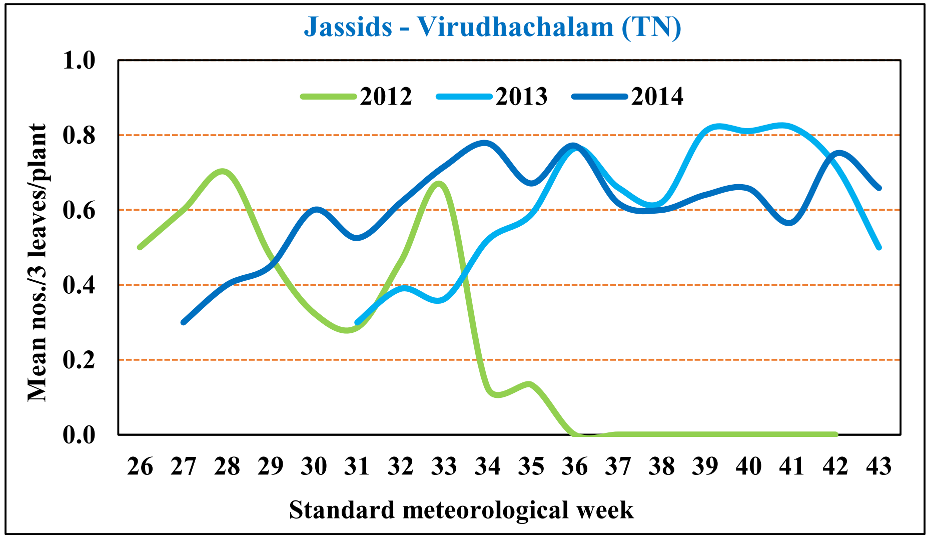
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

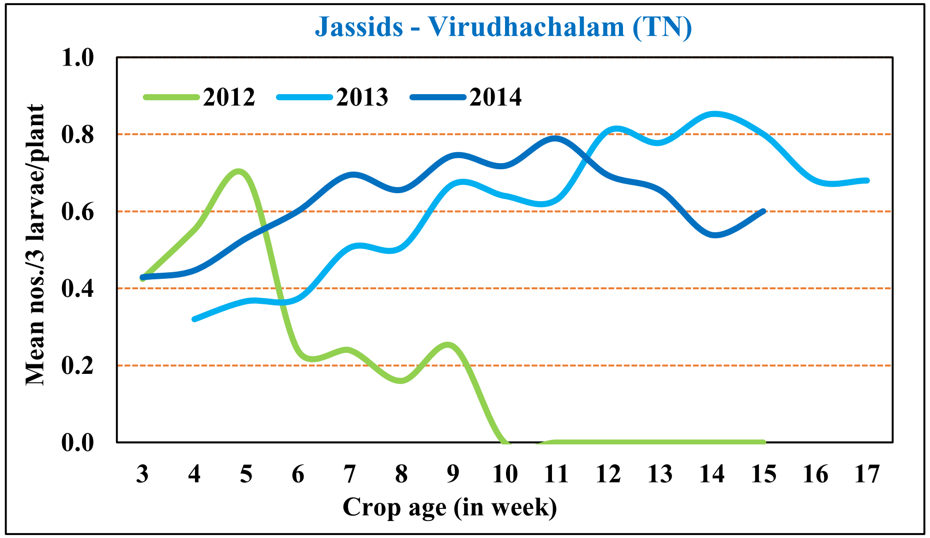
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





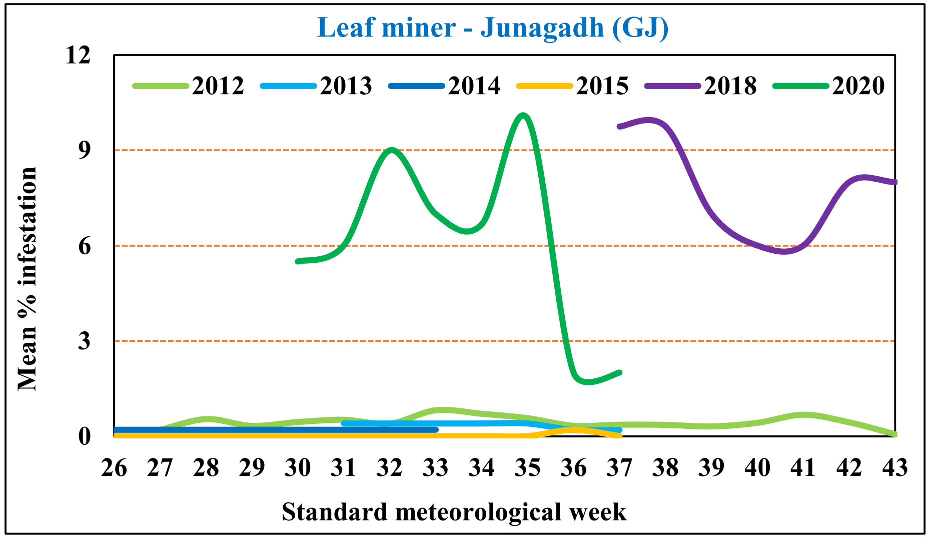


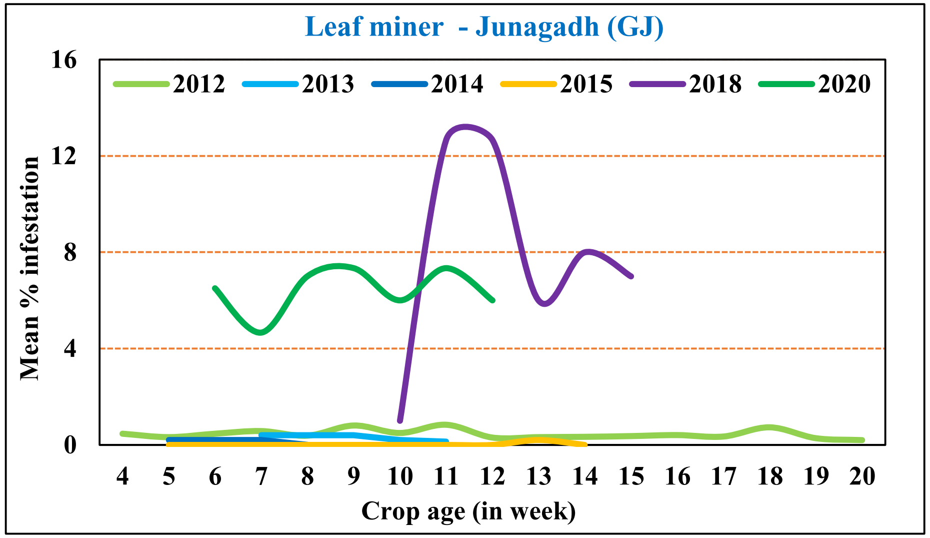


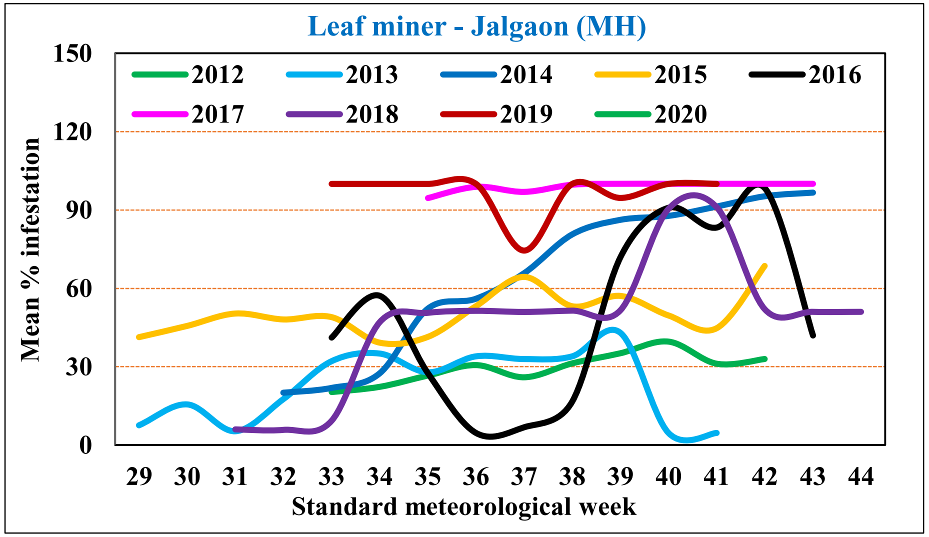
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

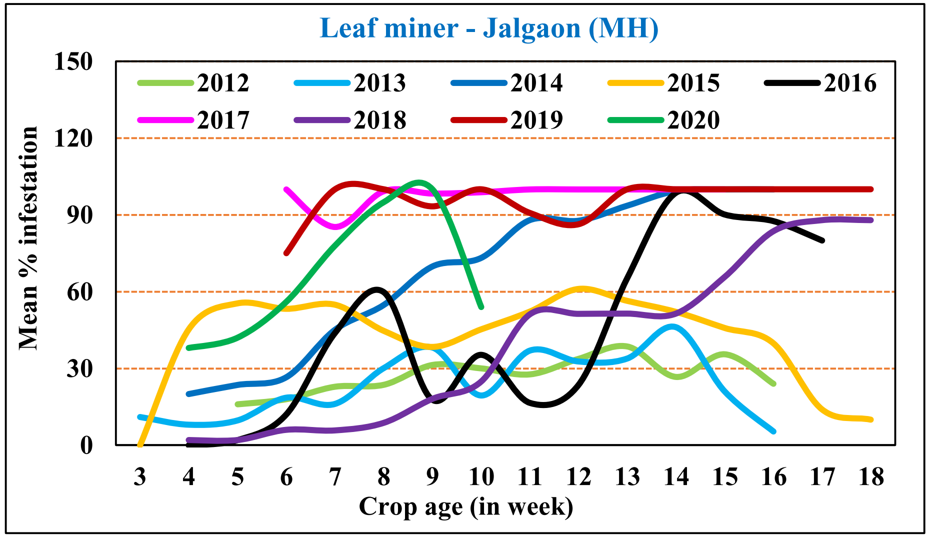
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





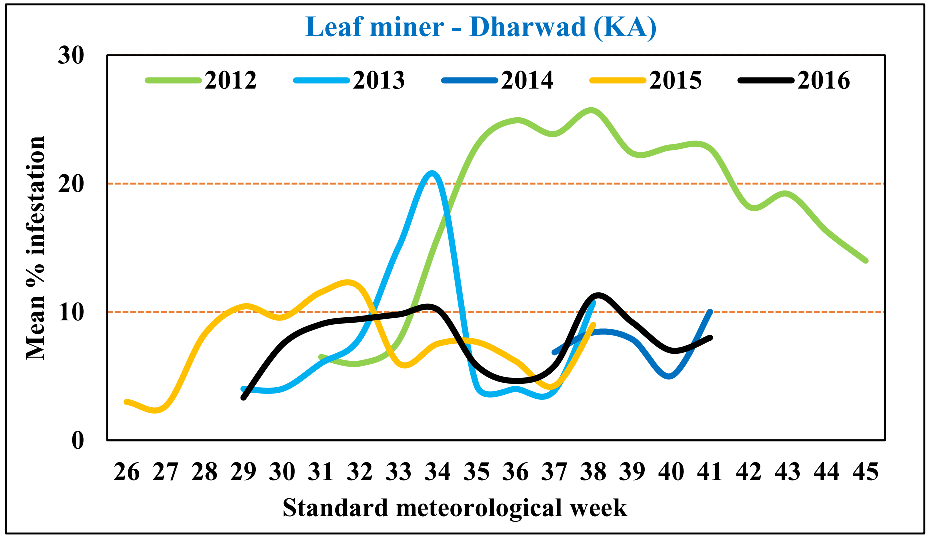


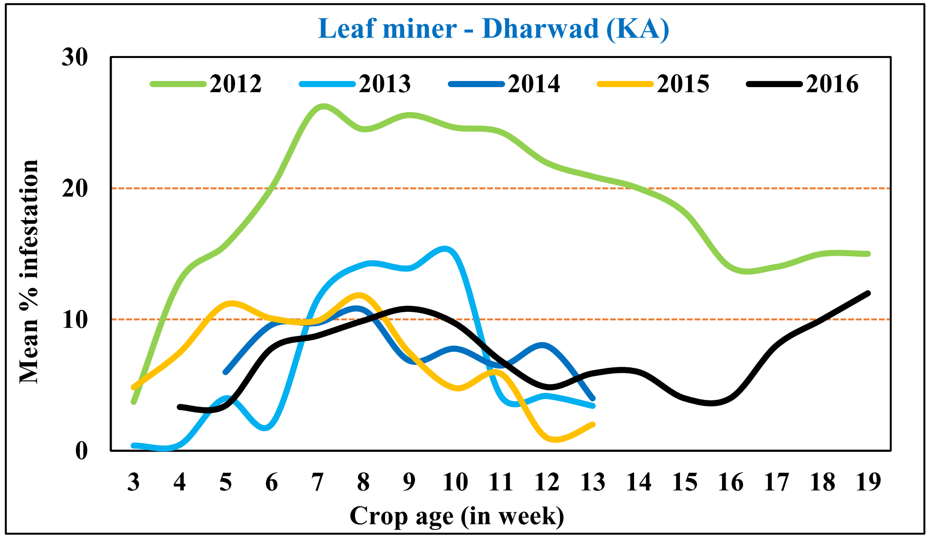


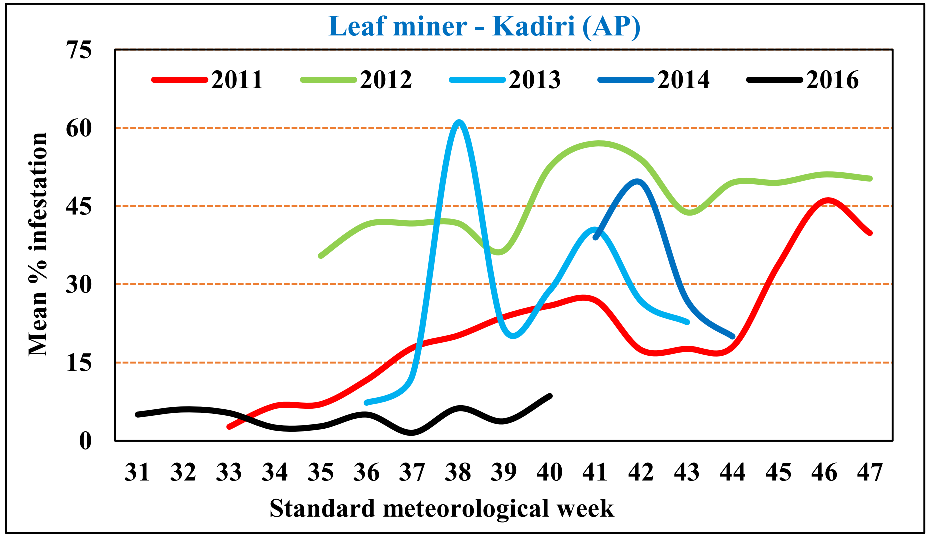
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

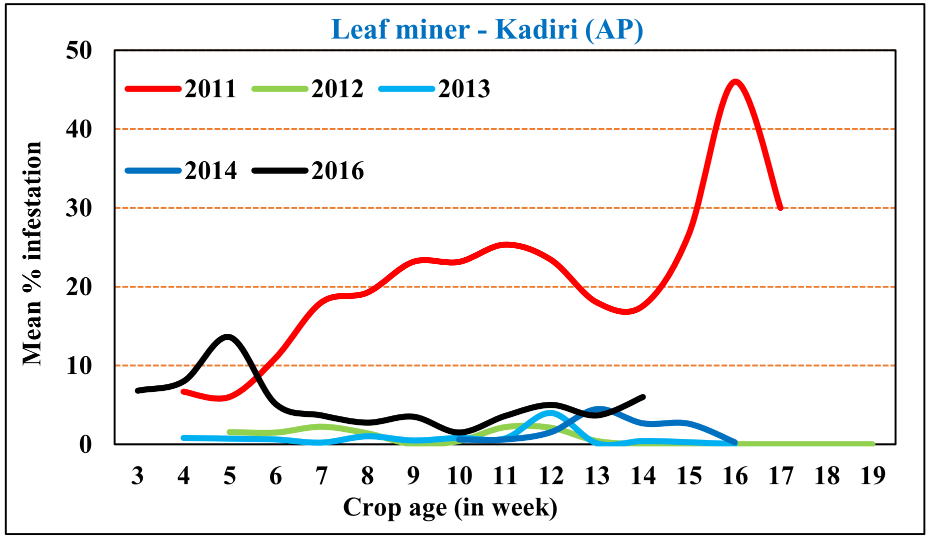
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





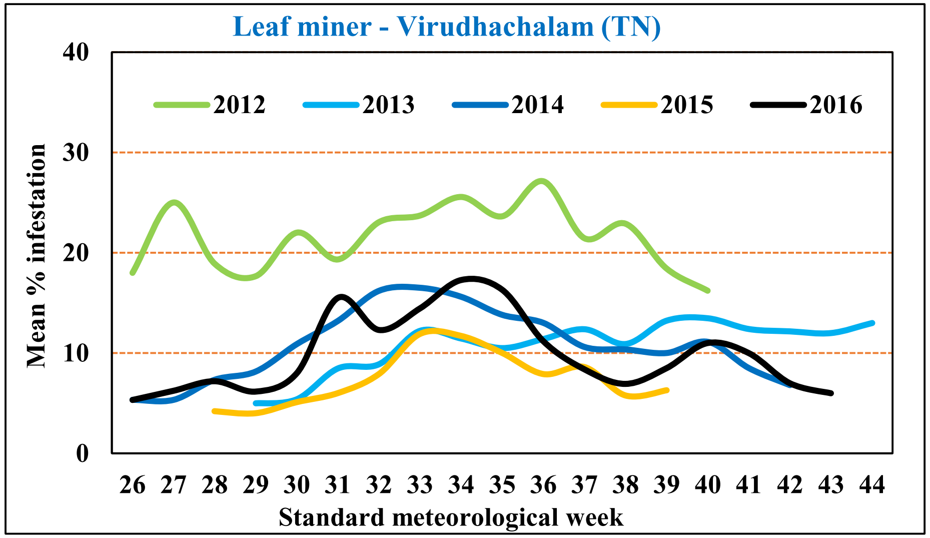


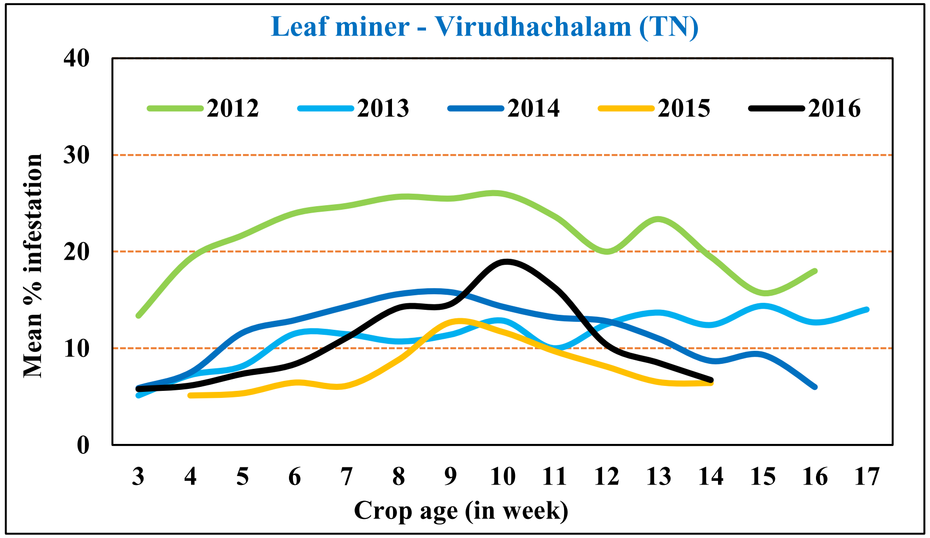


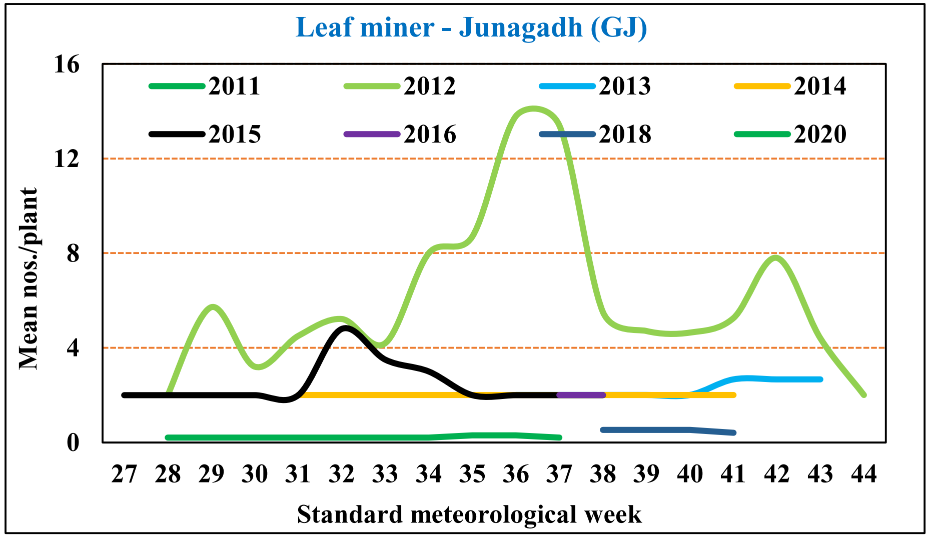
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

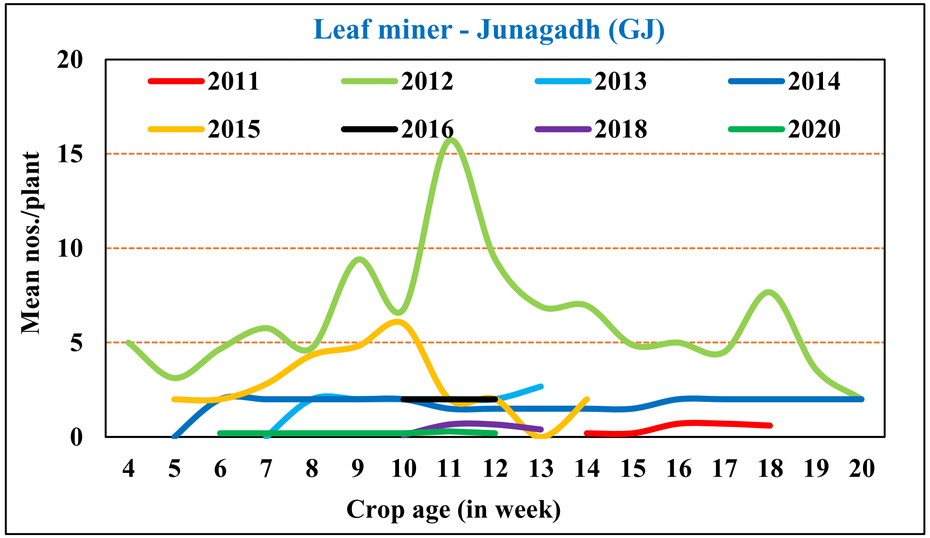
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



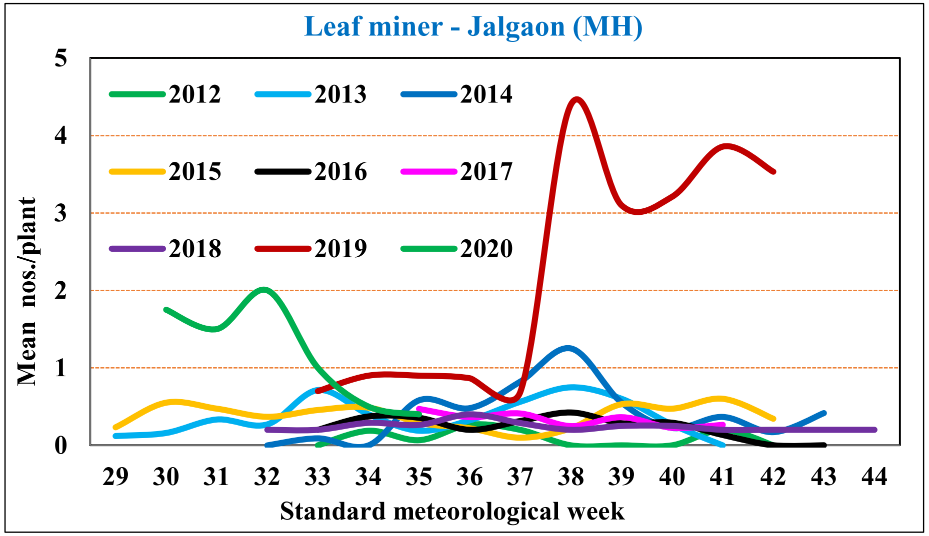


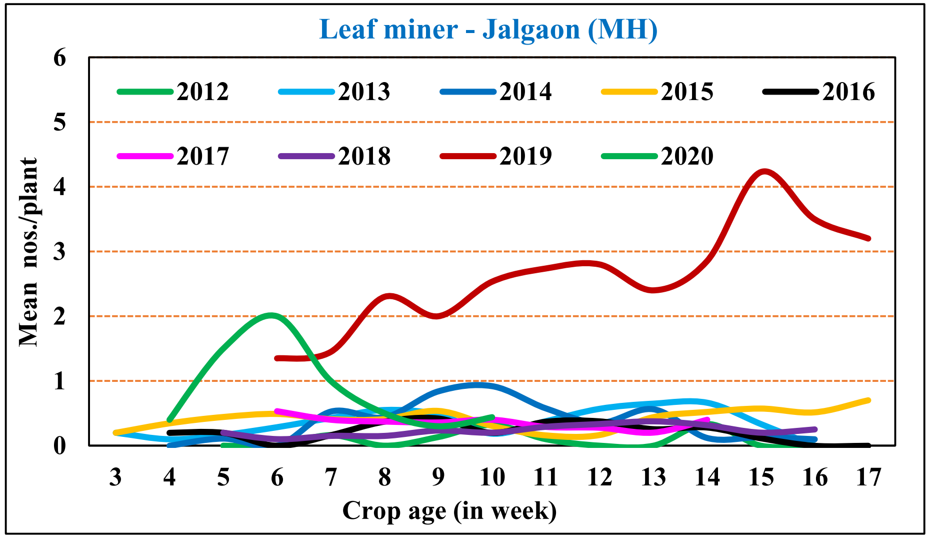


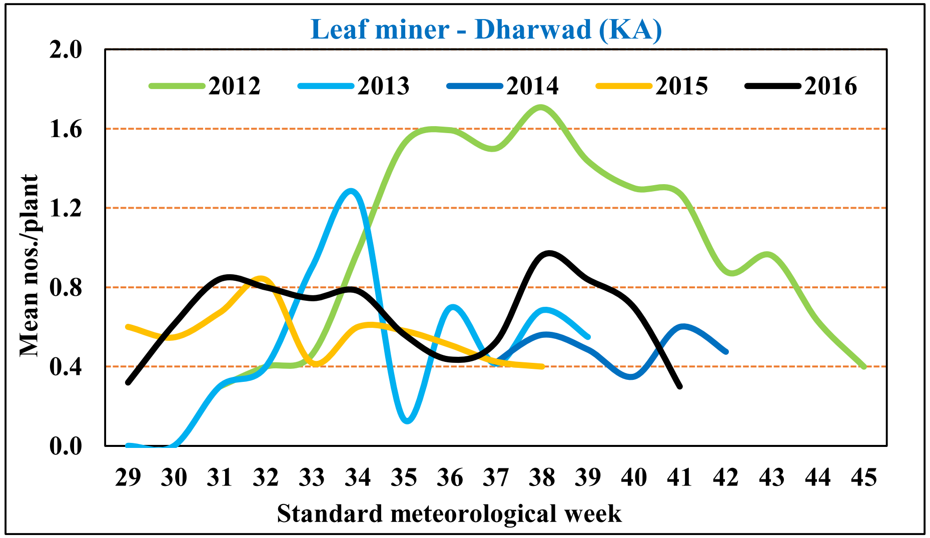


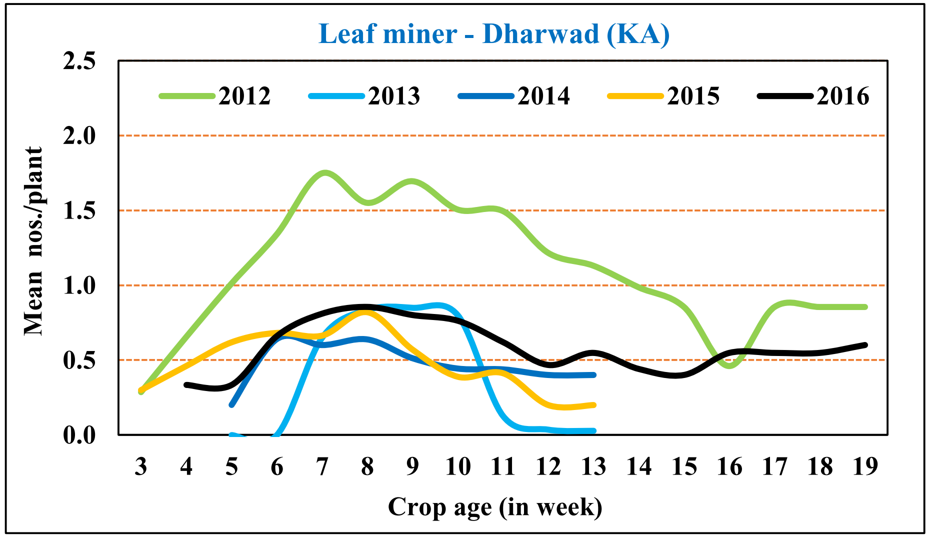
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks — **Seasonal dynamics based on crop age**





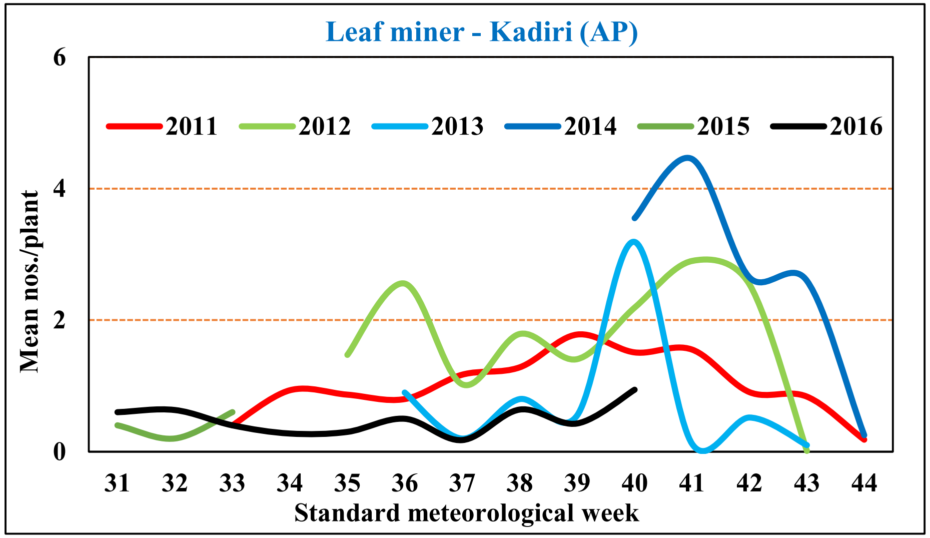


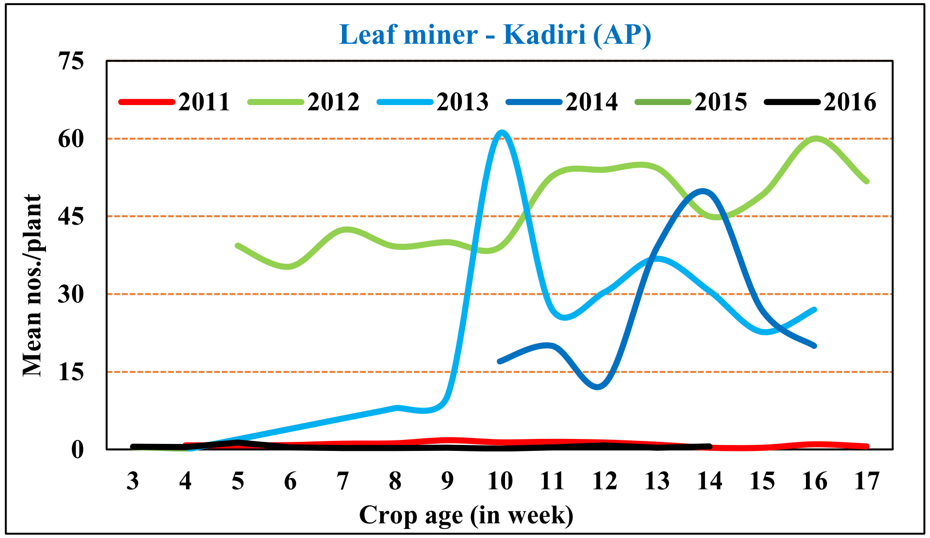


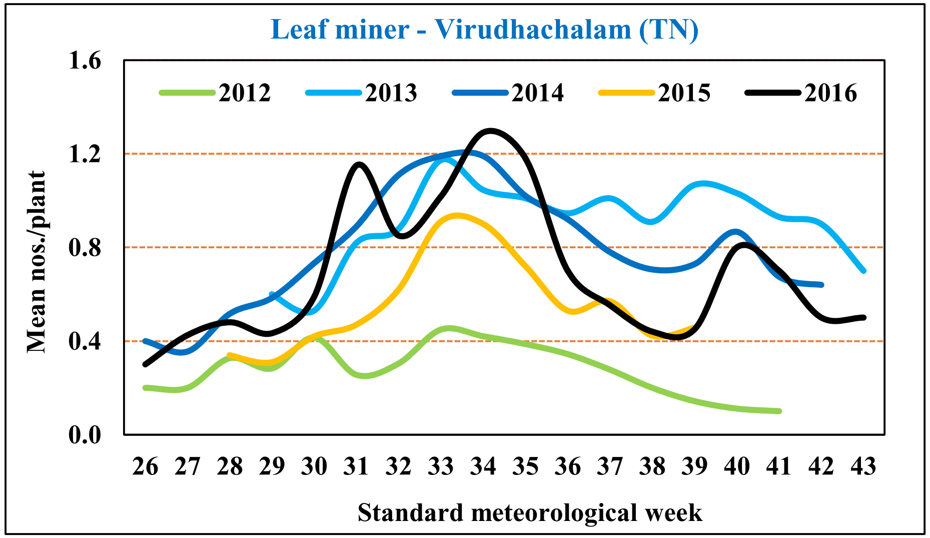
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

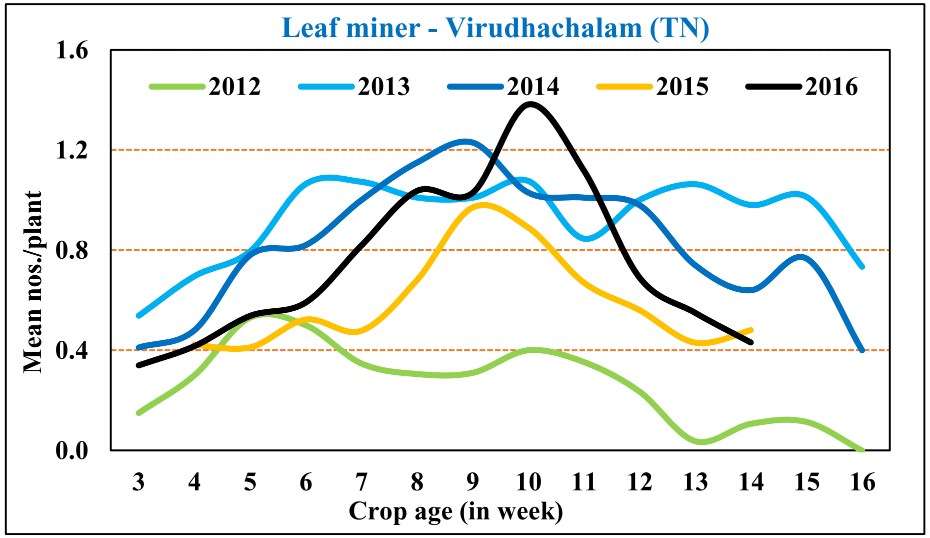
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



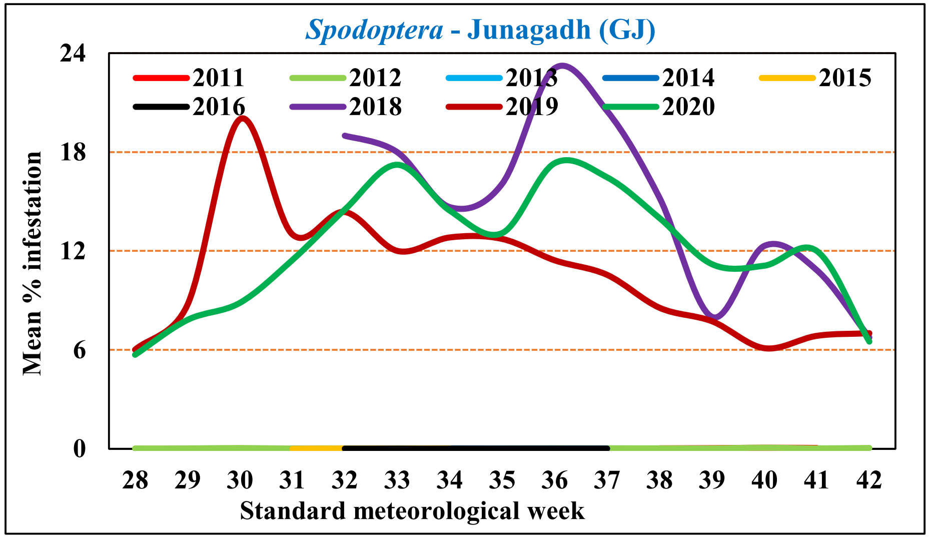


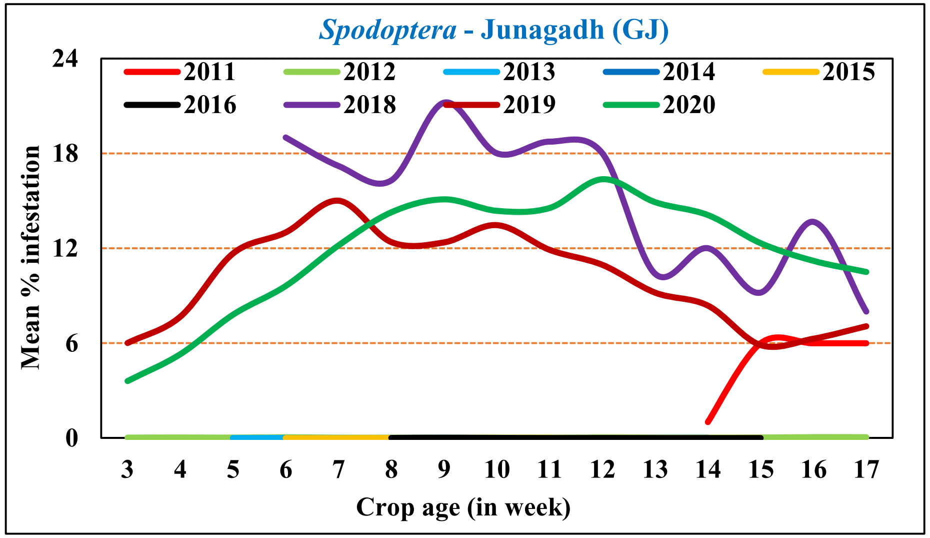


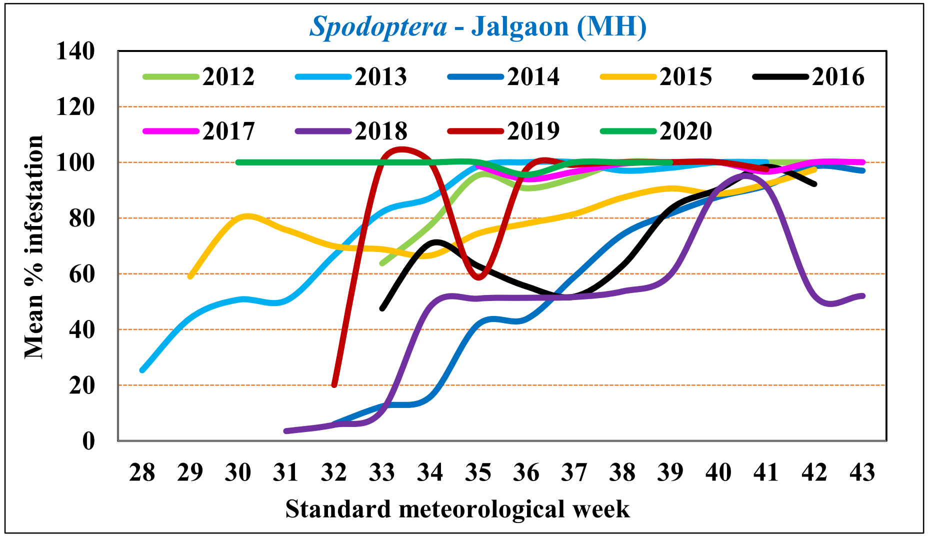


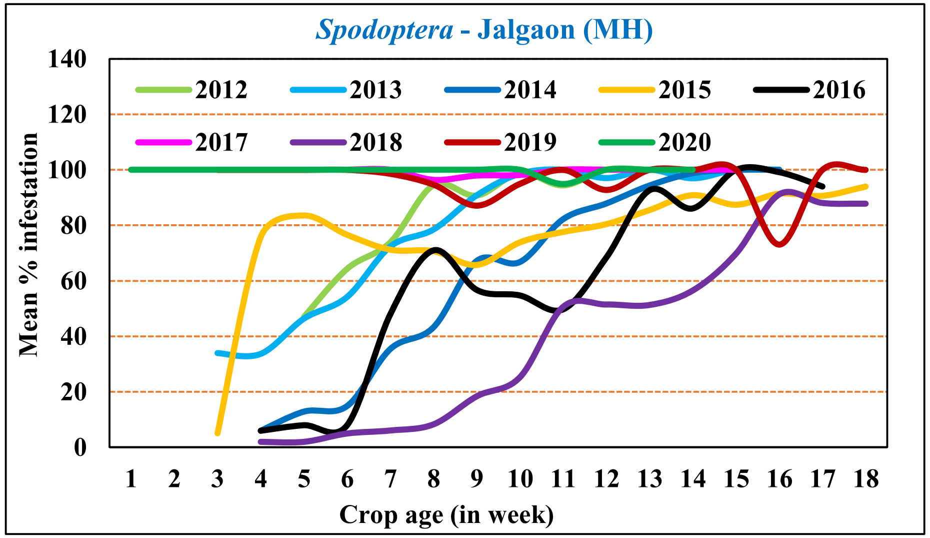
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



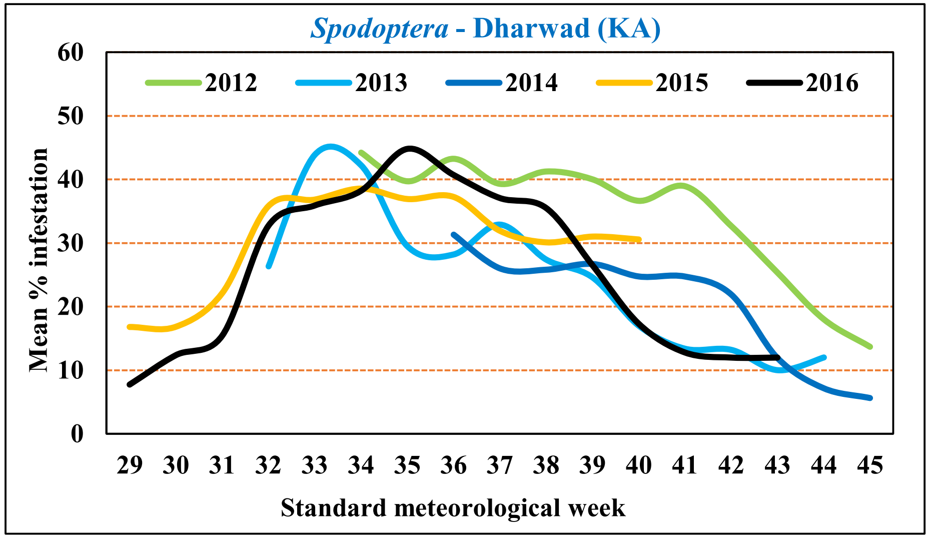


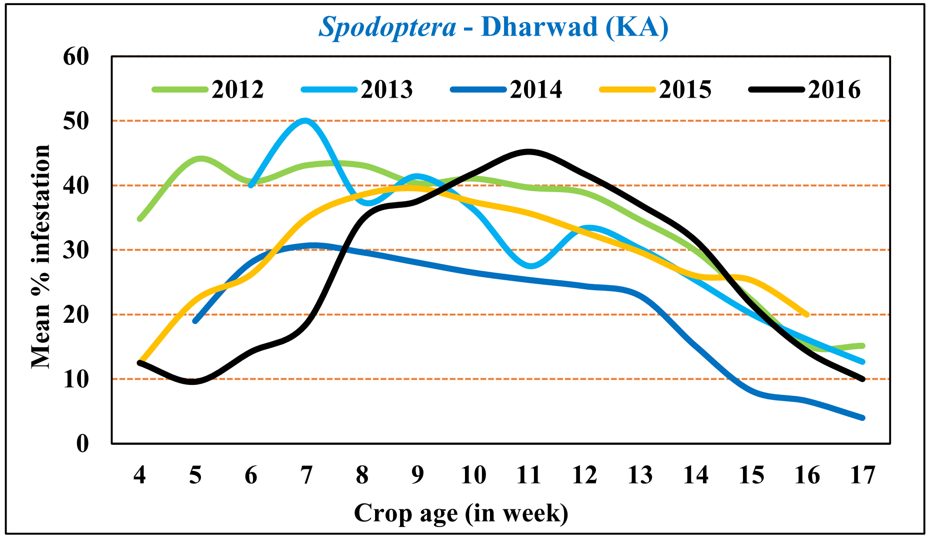


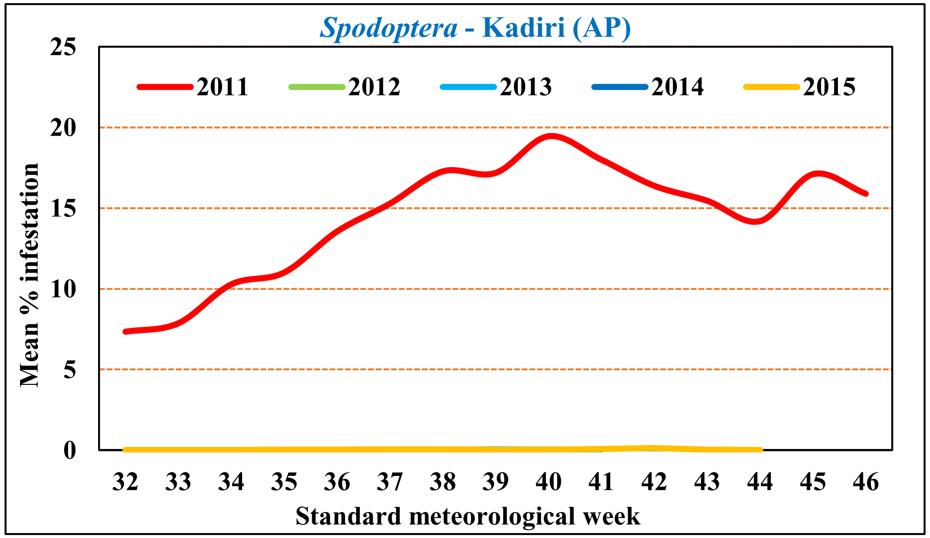


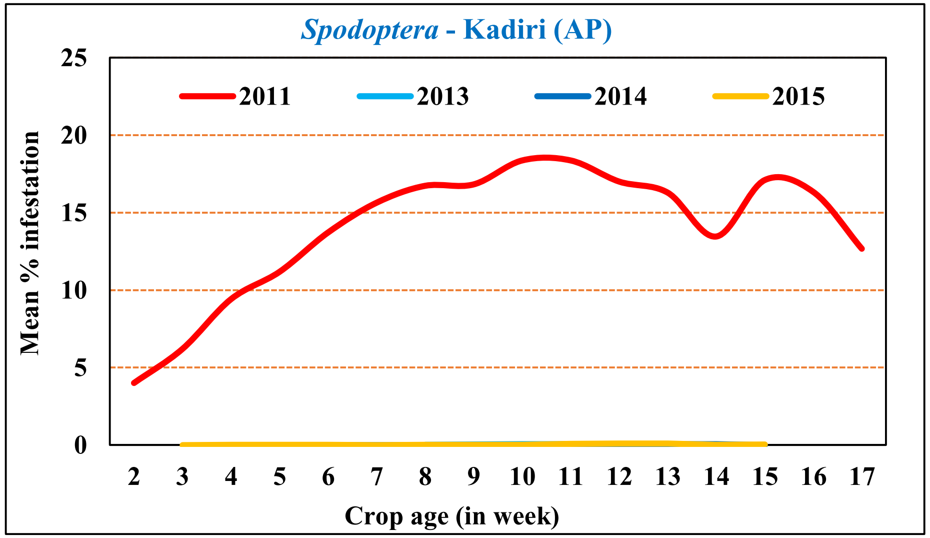
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**





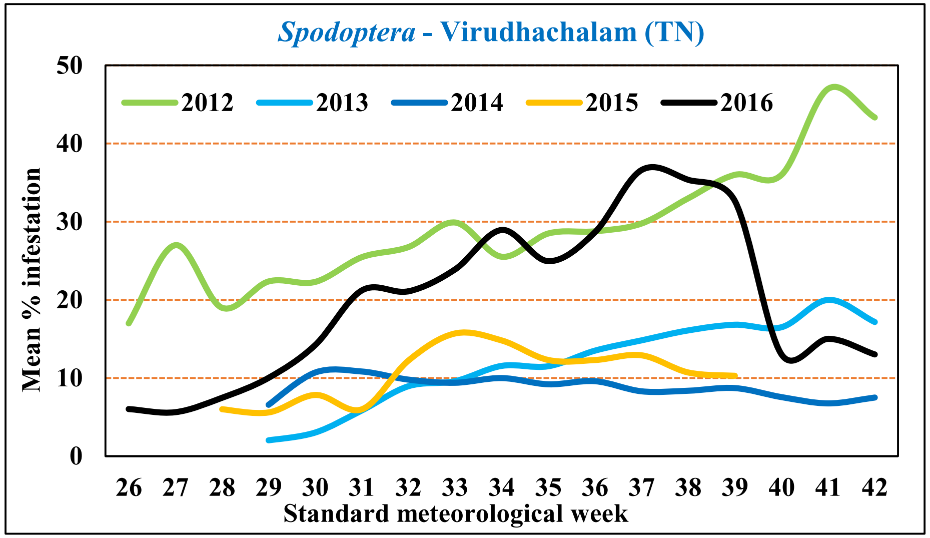


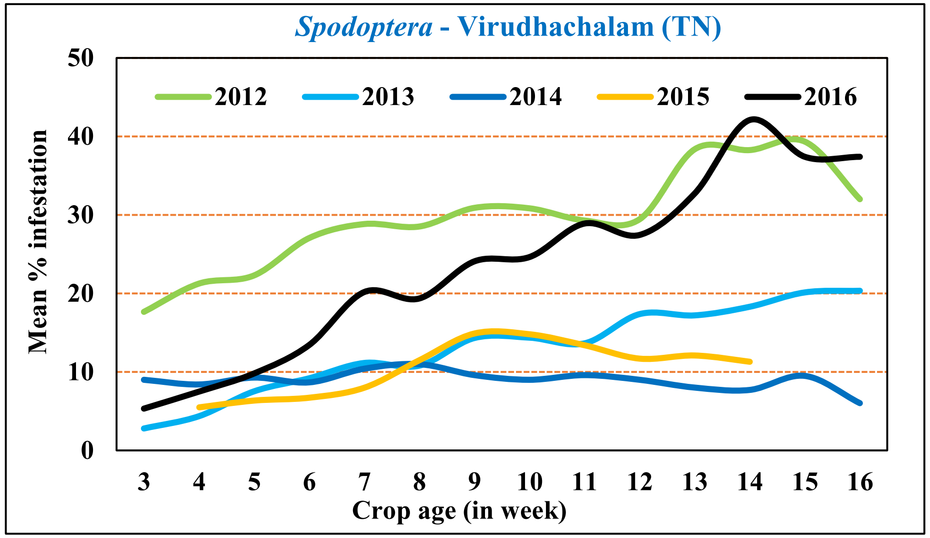


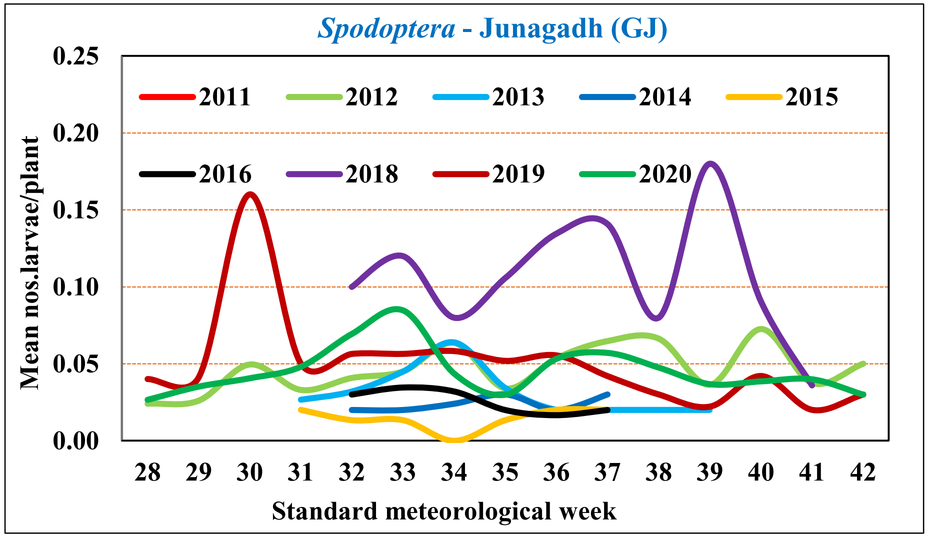
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

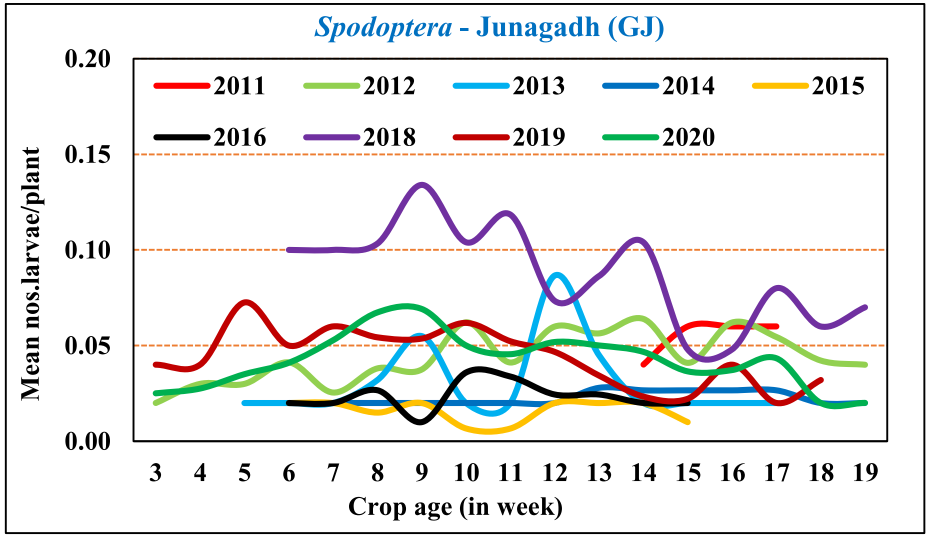
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





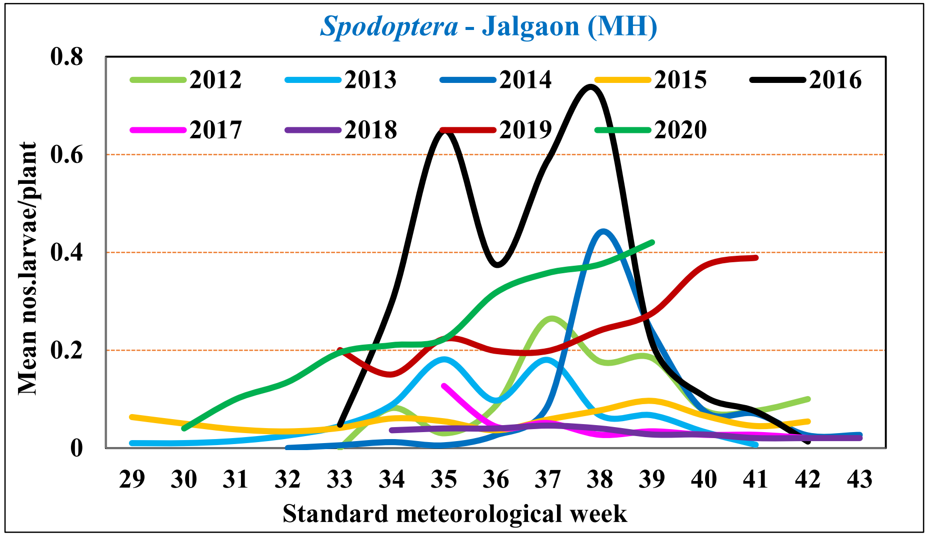


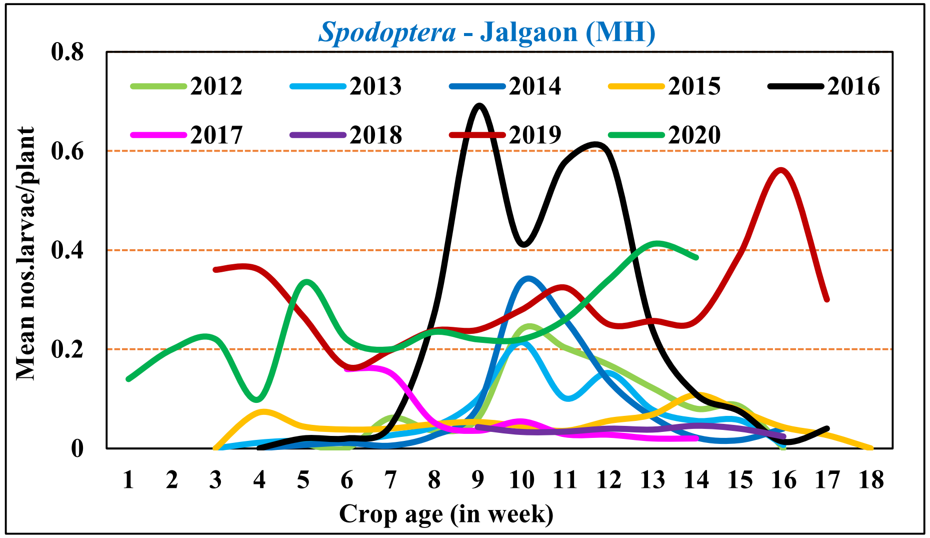


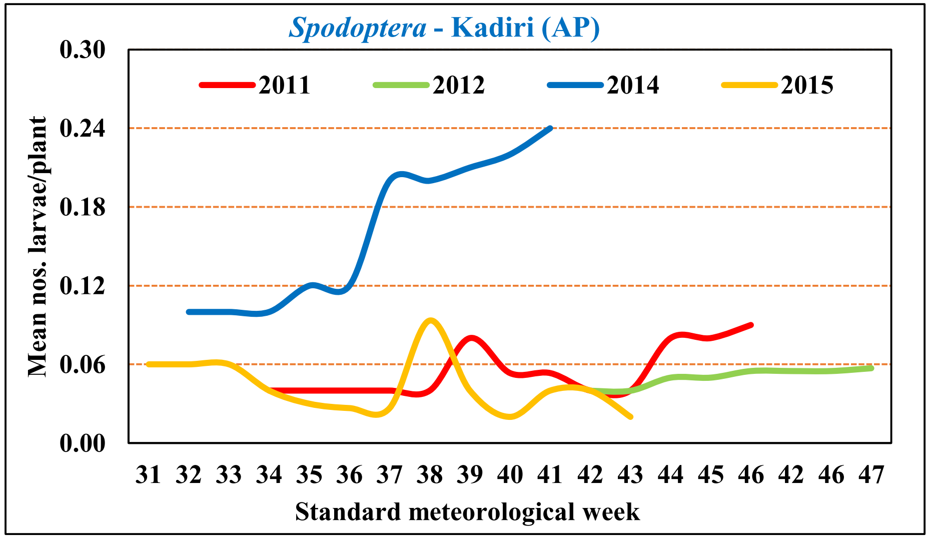
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

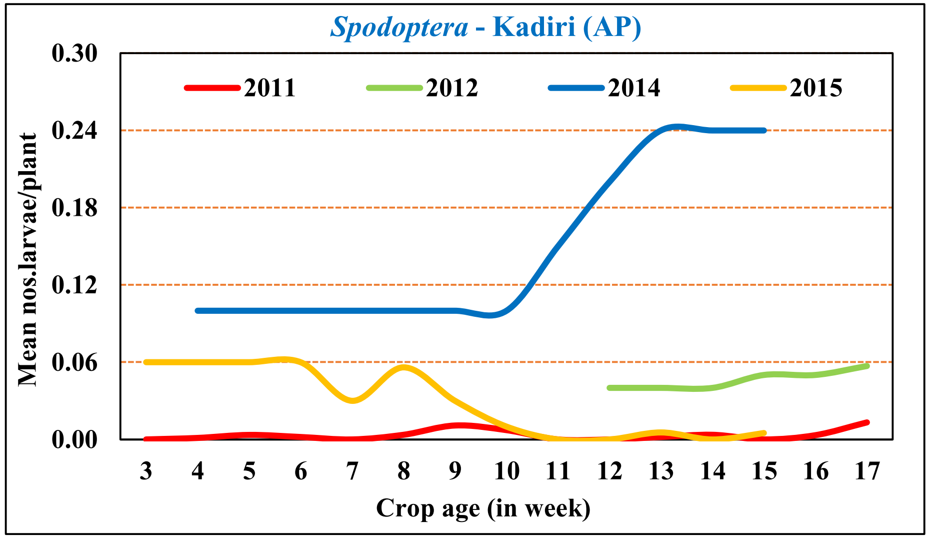
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



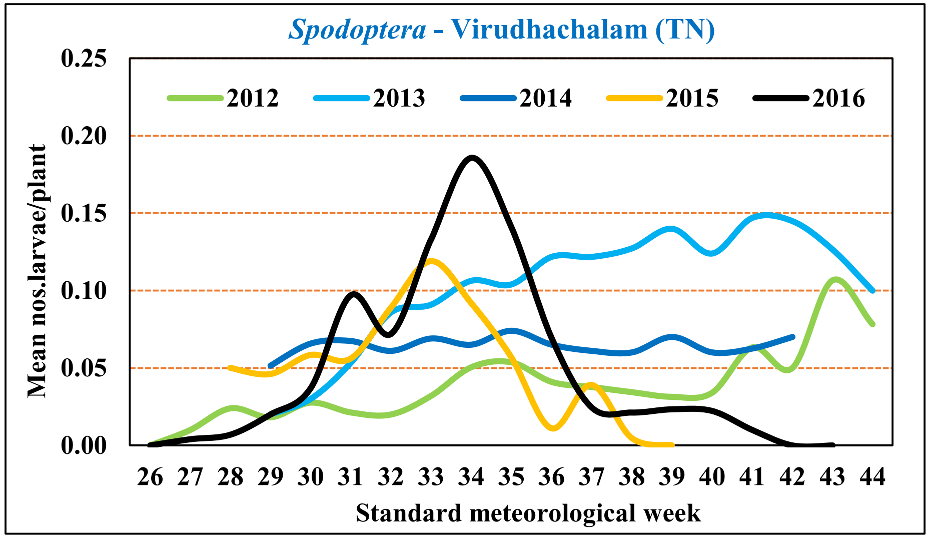


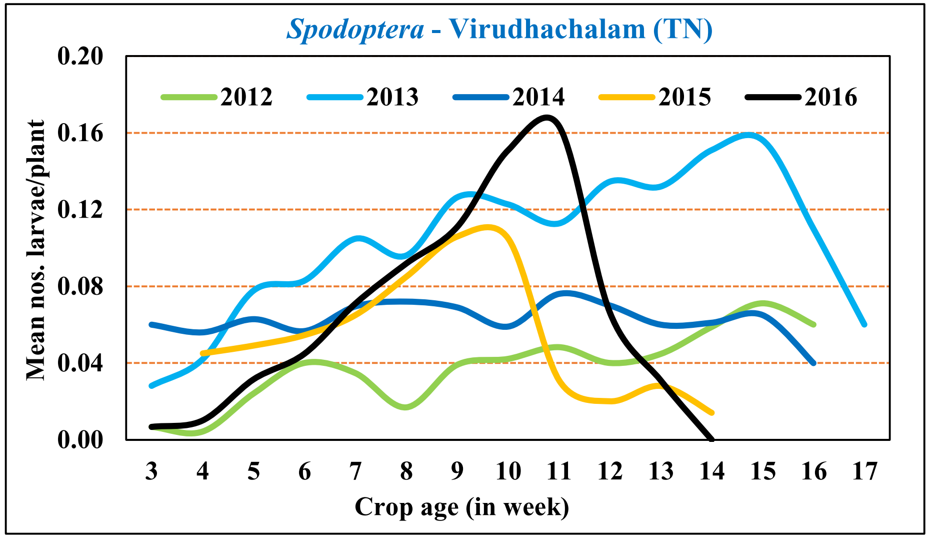


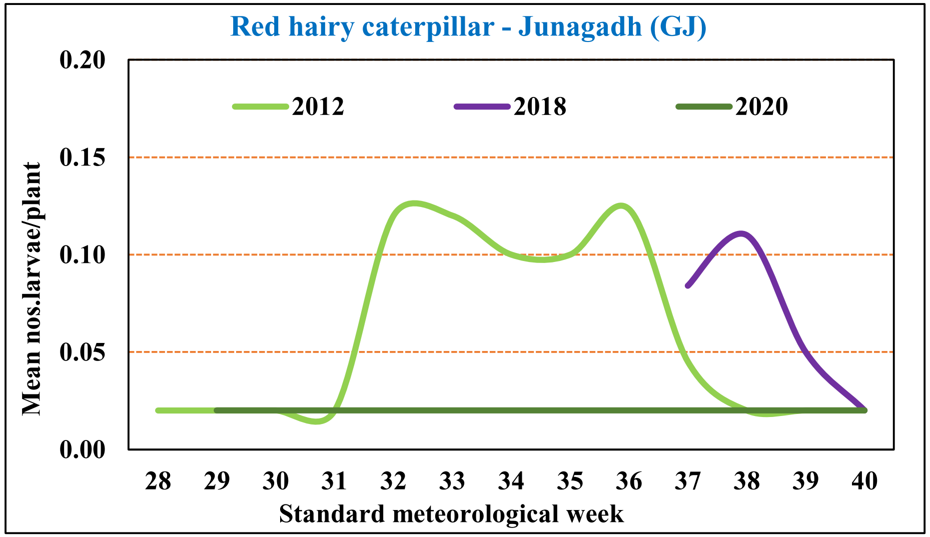


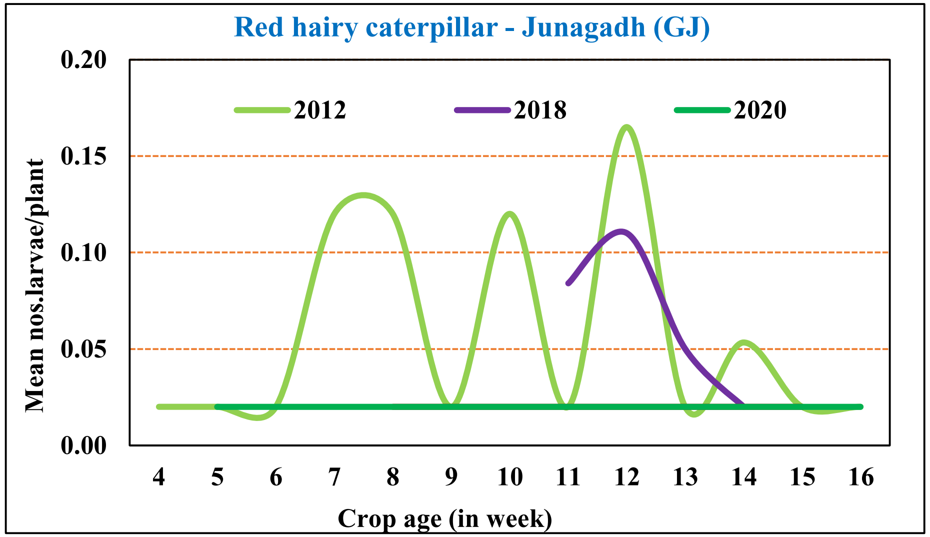
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**





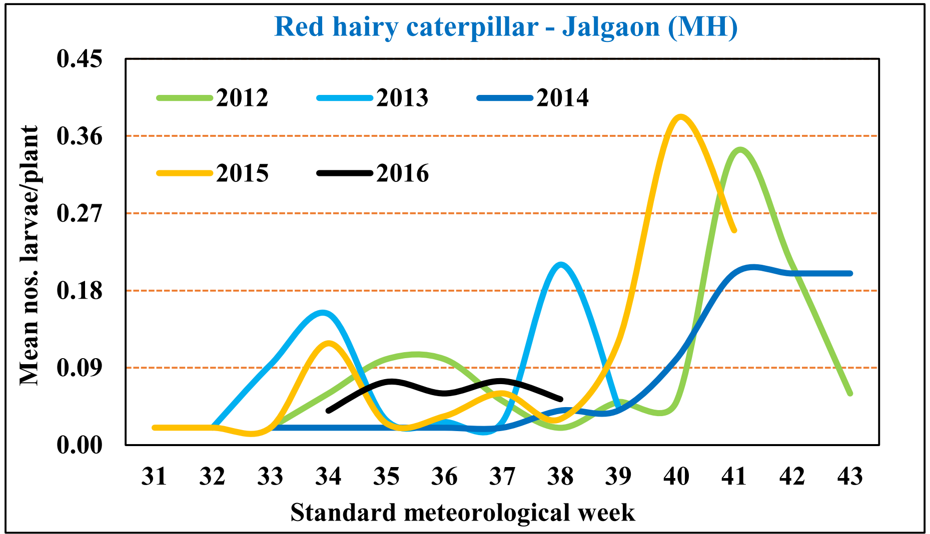


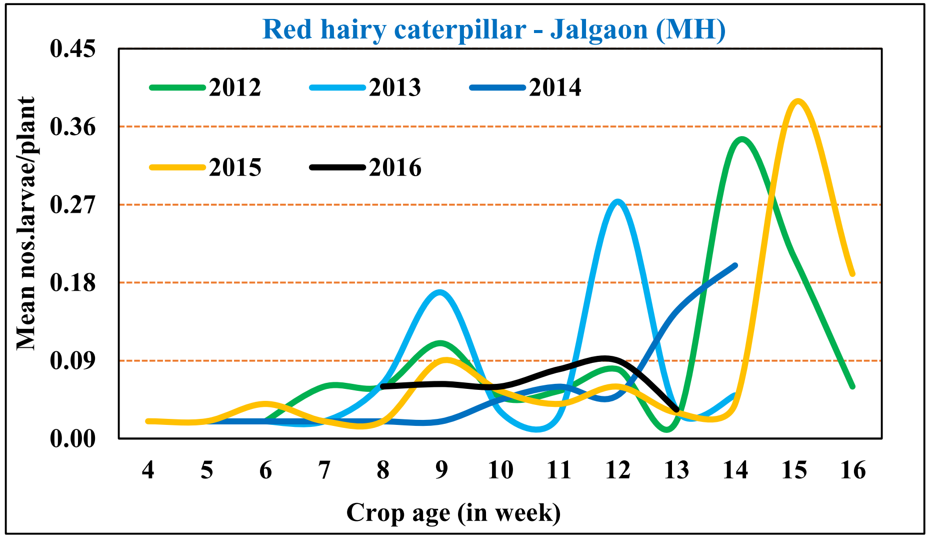


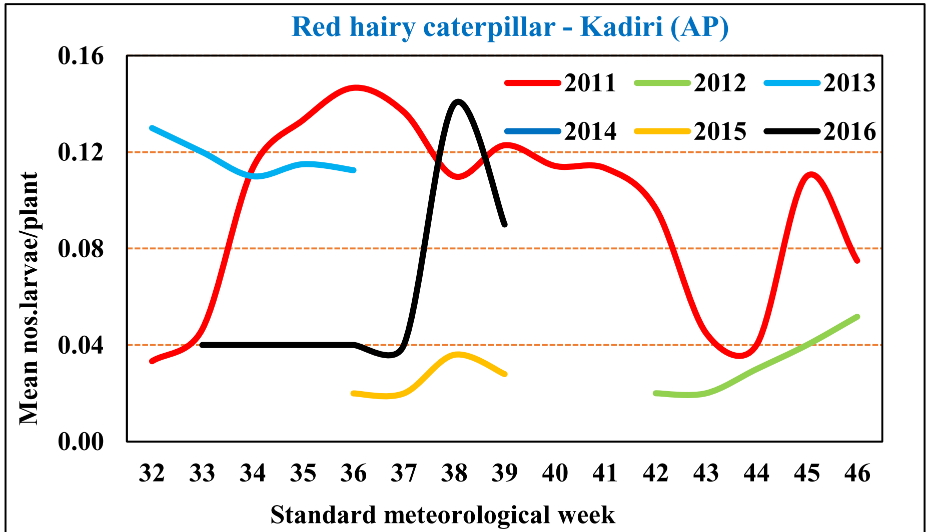
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

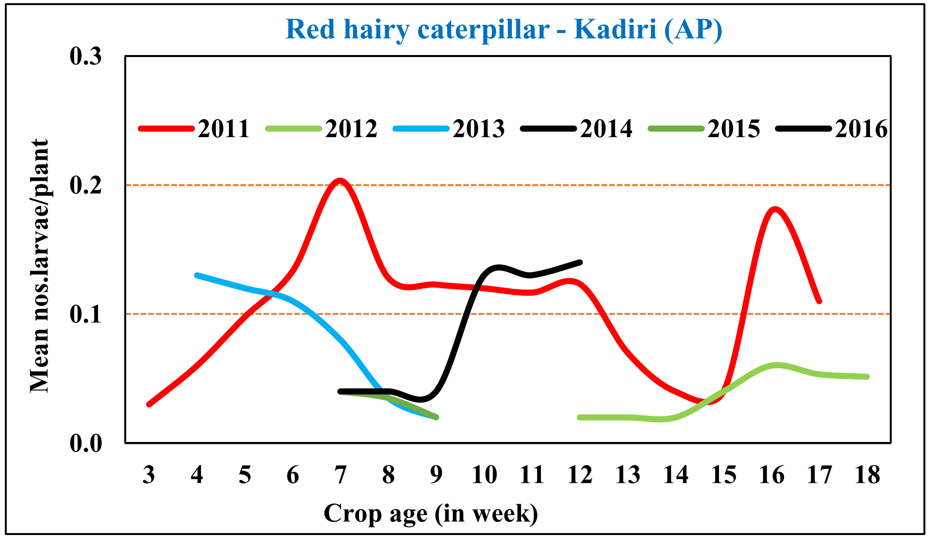
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





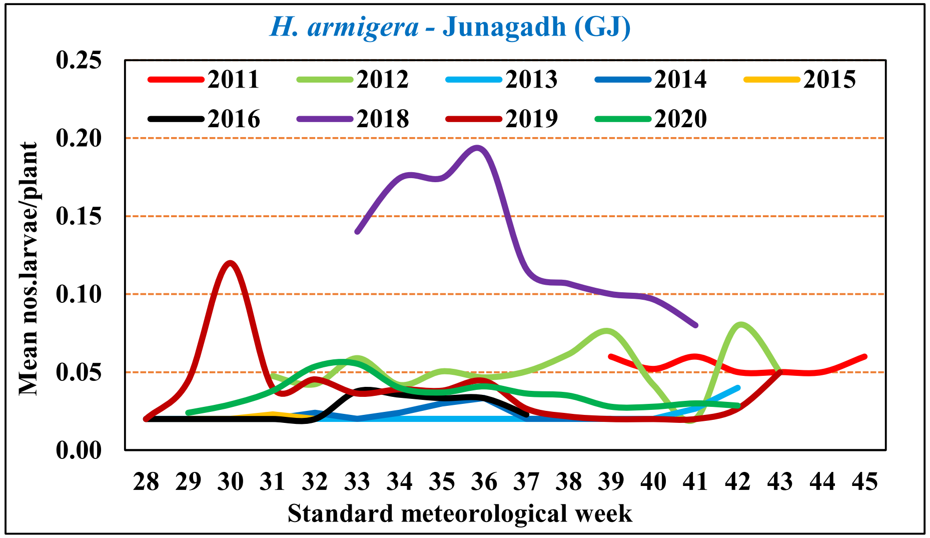


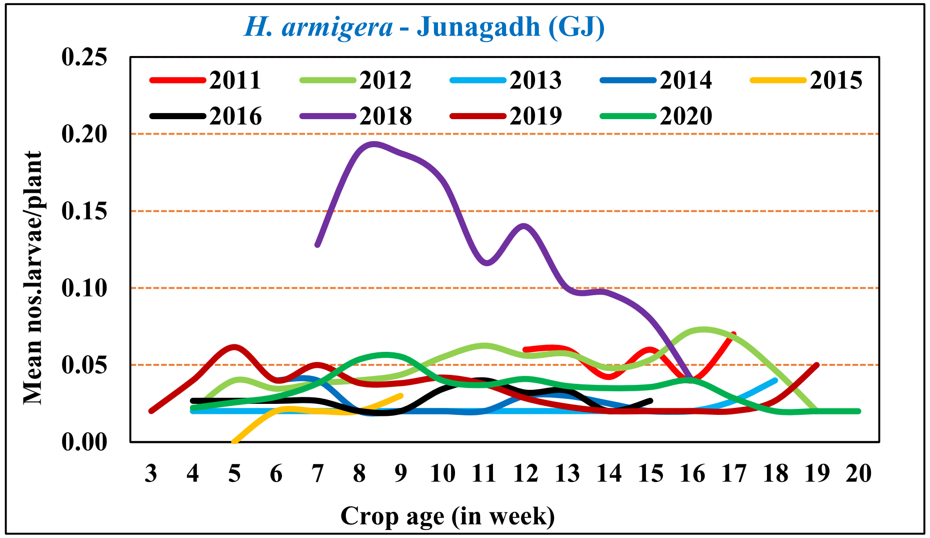


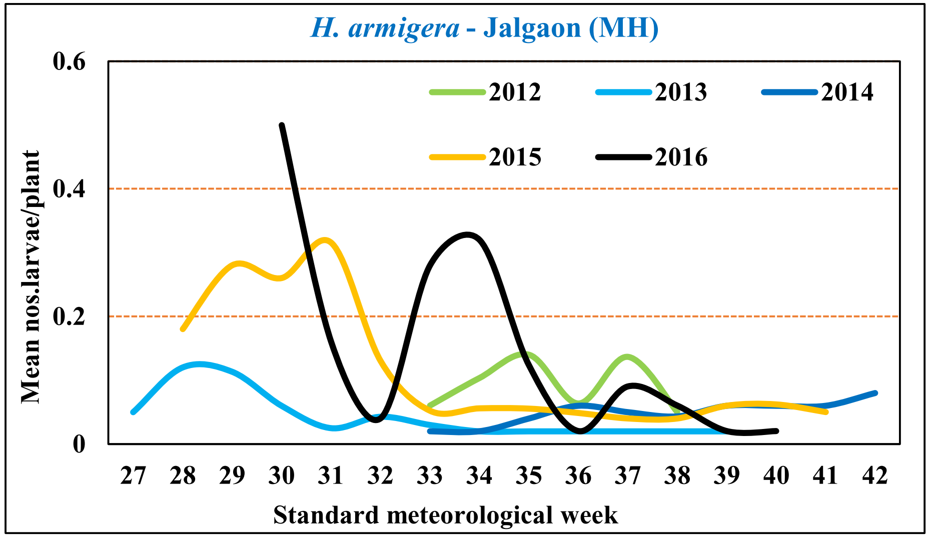
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

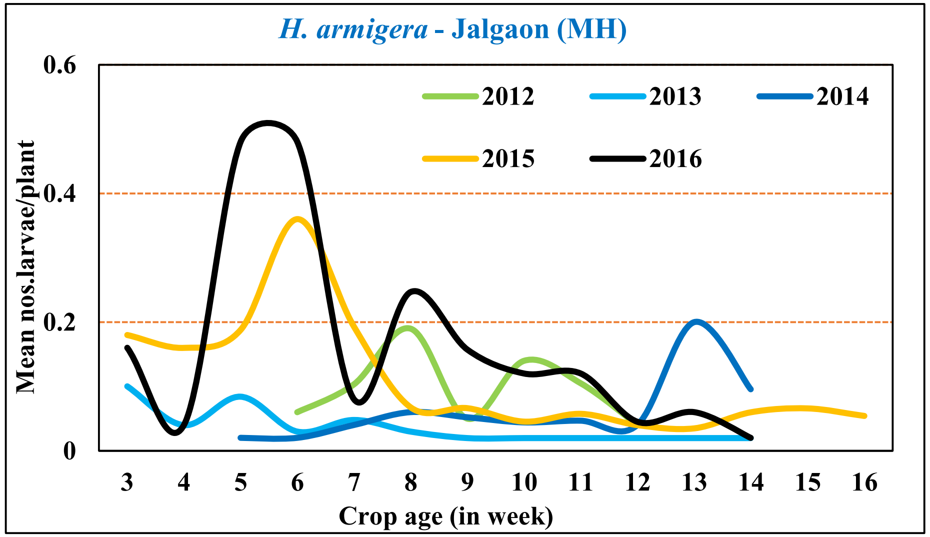
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



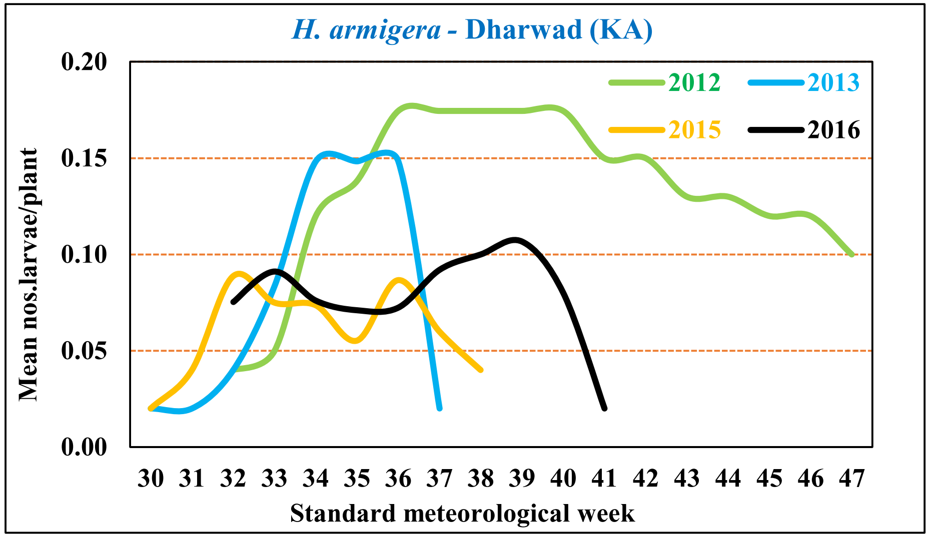


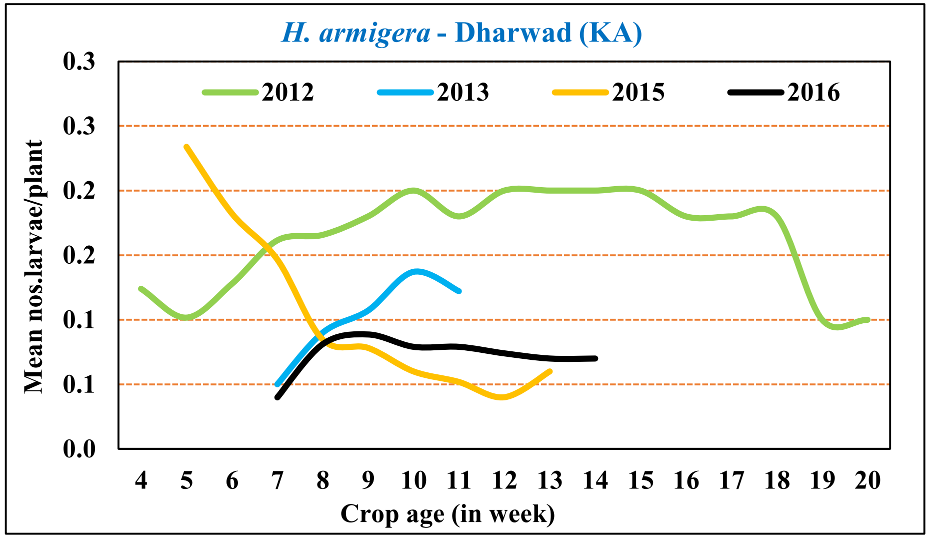


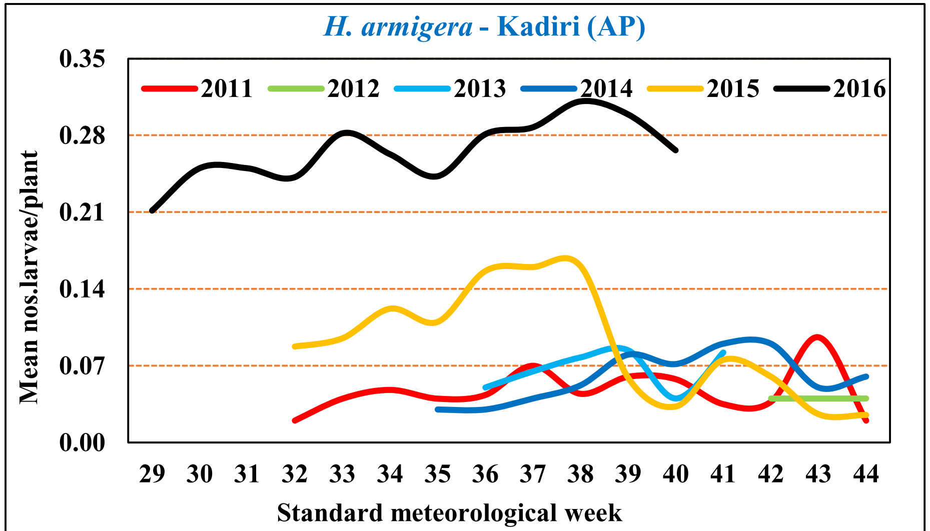


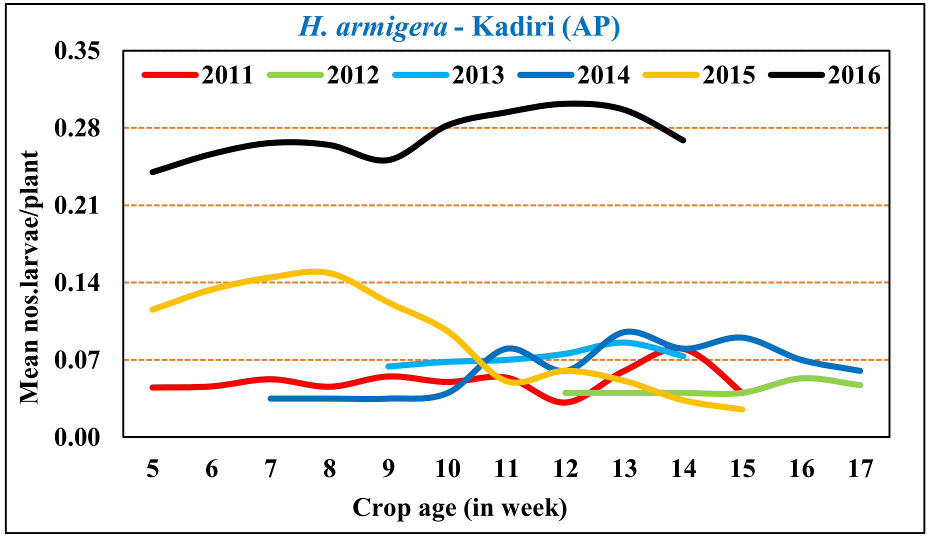
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks — **Seasonal dynamics based on crop age**





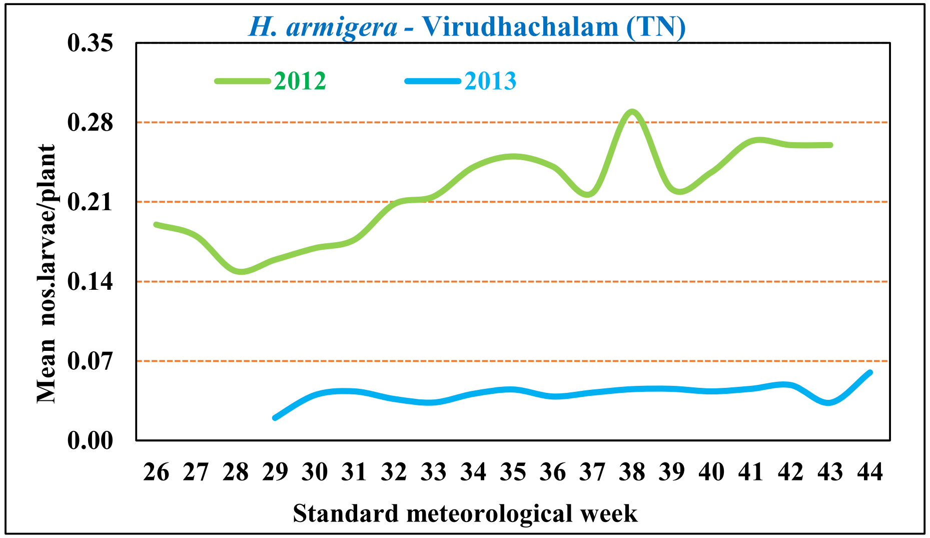


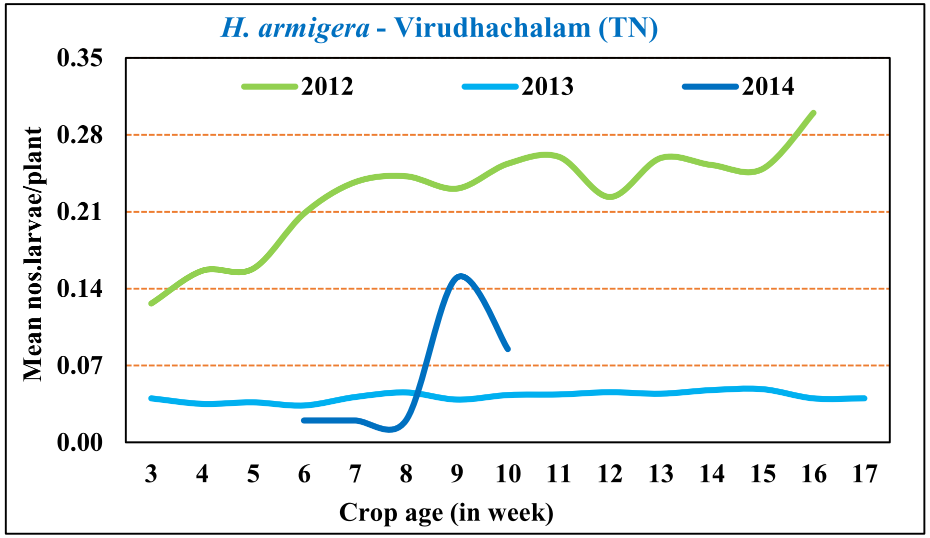


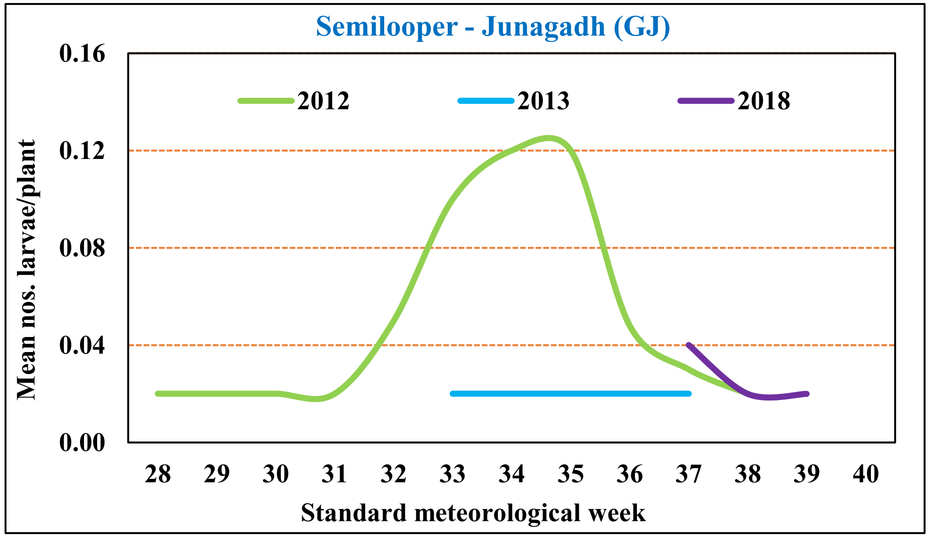
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

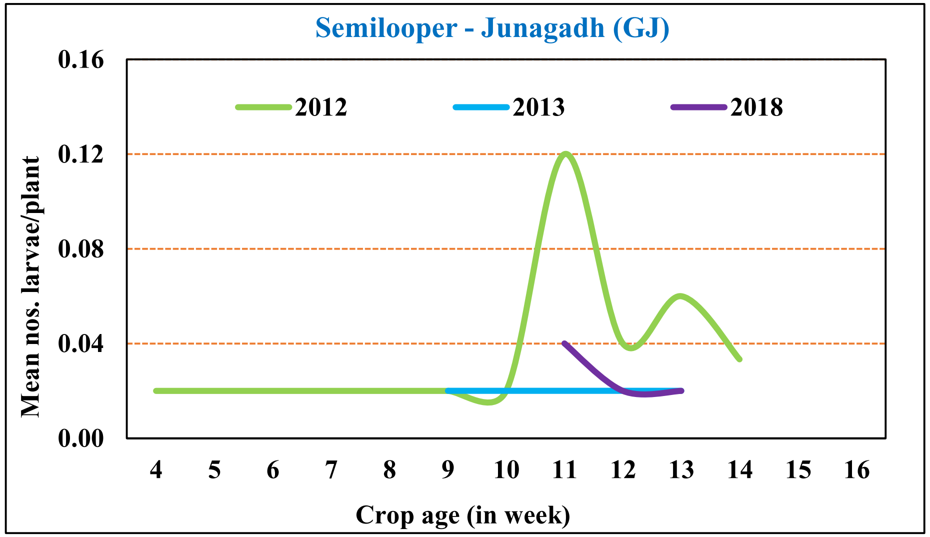
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





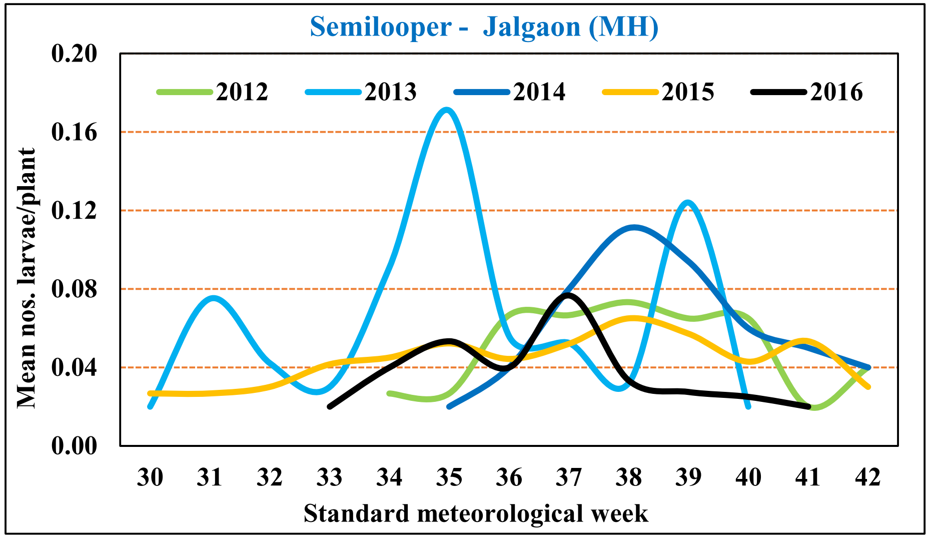


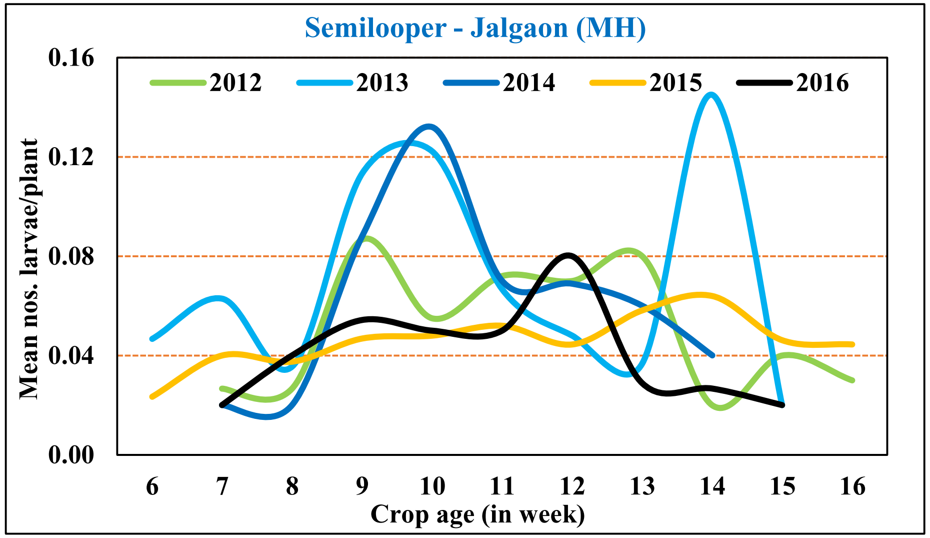


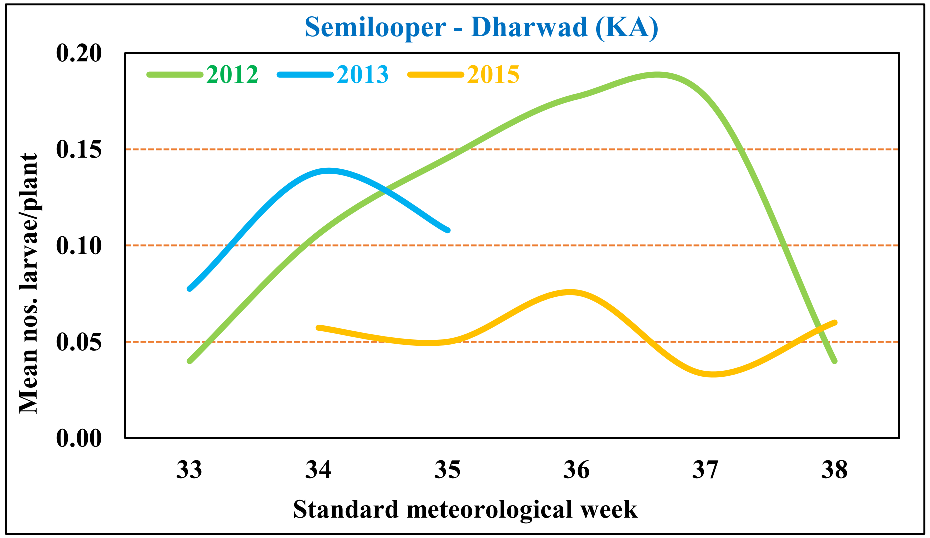
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

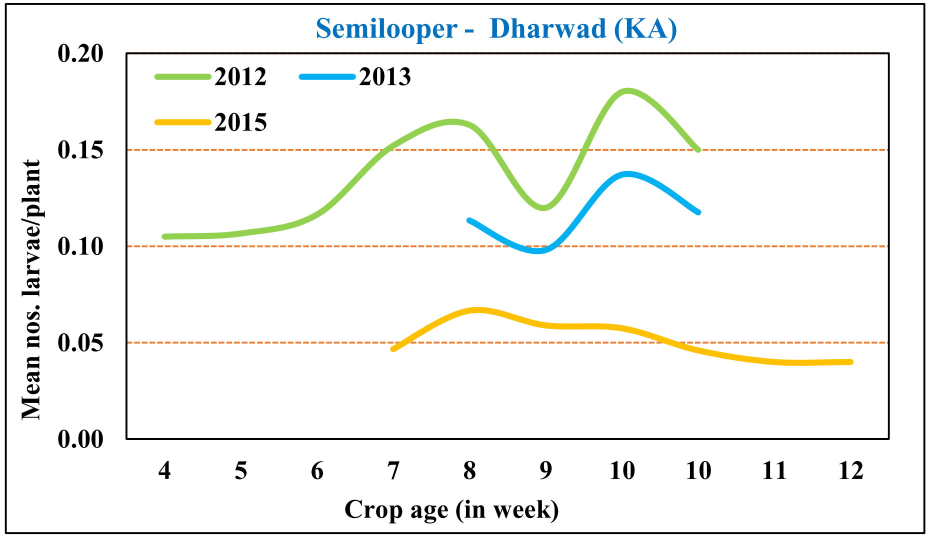
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



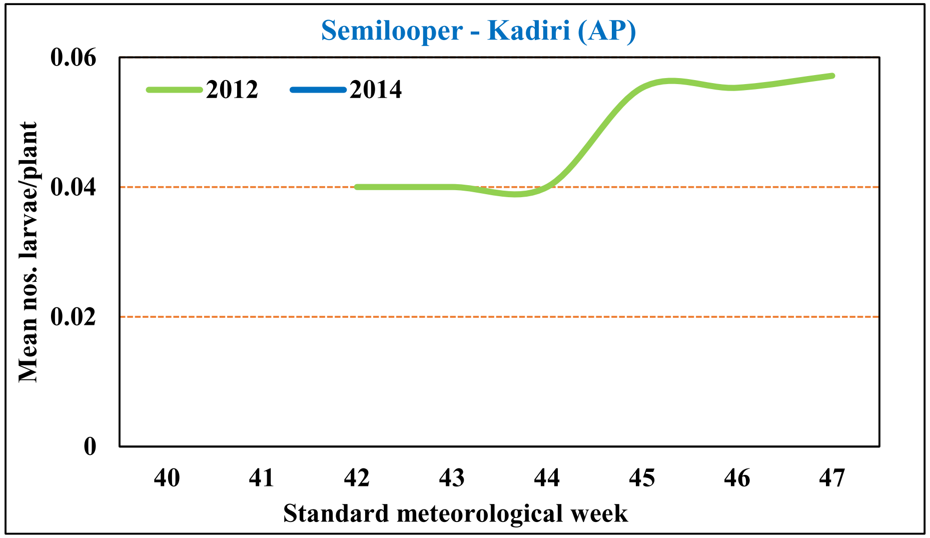


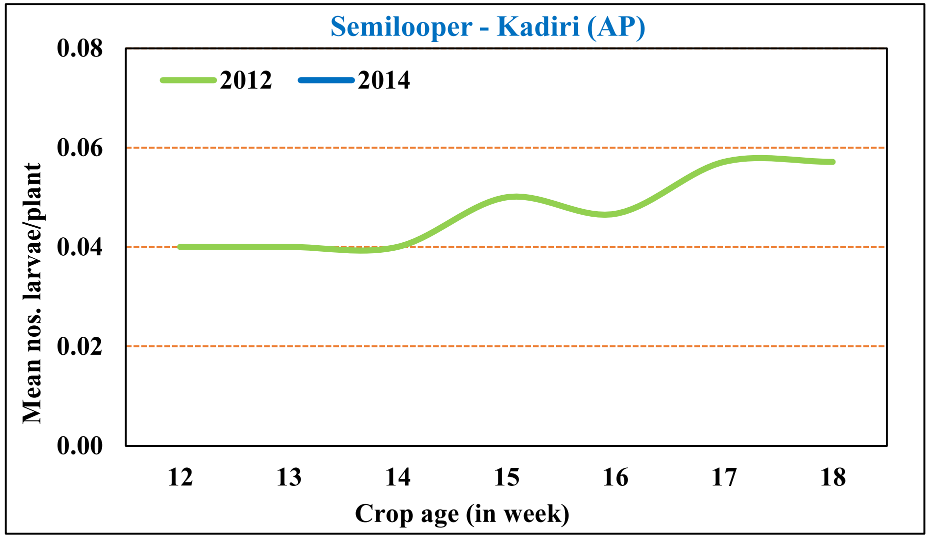


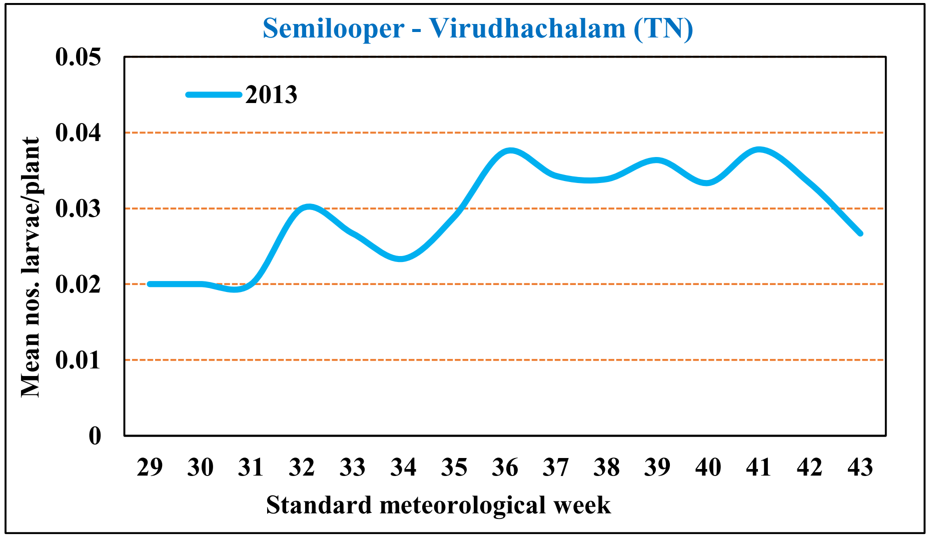


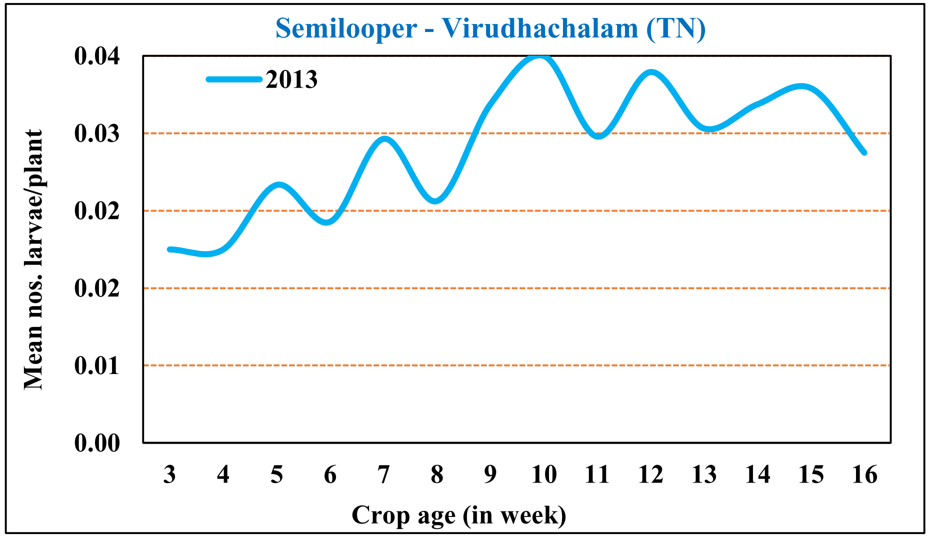
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | Seasonal dynamics based on crop age





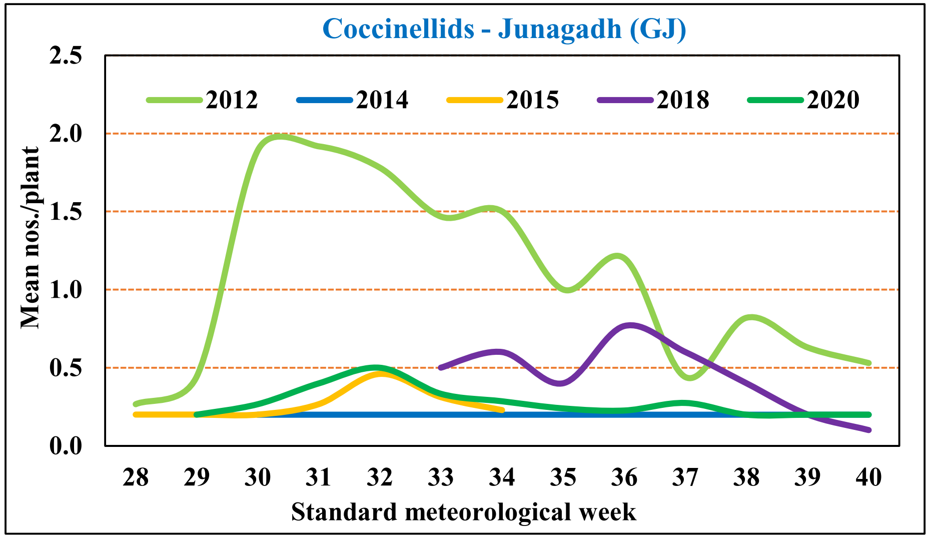


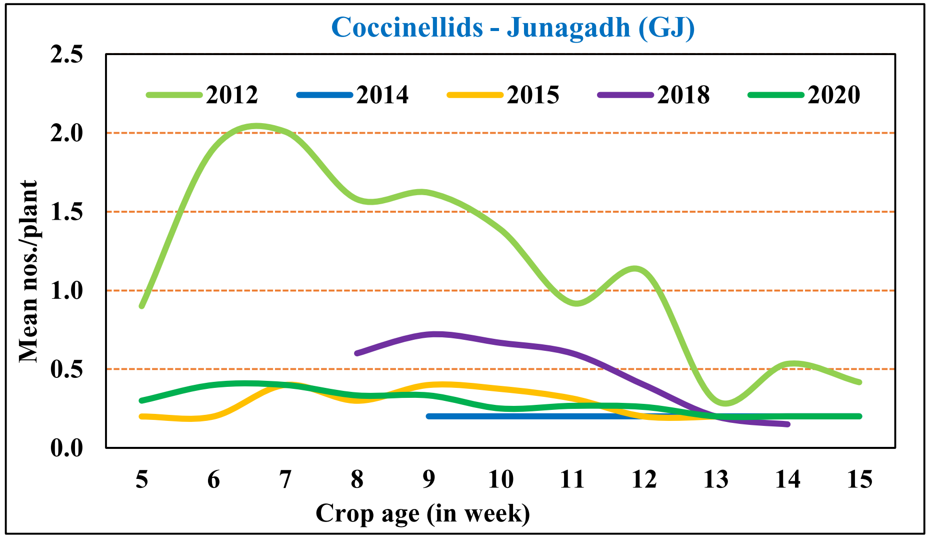


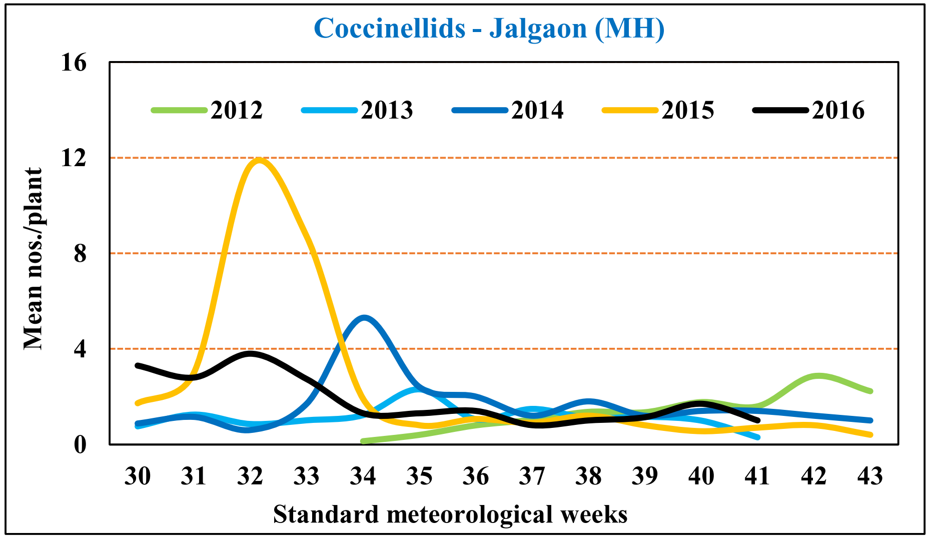
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

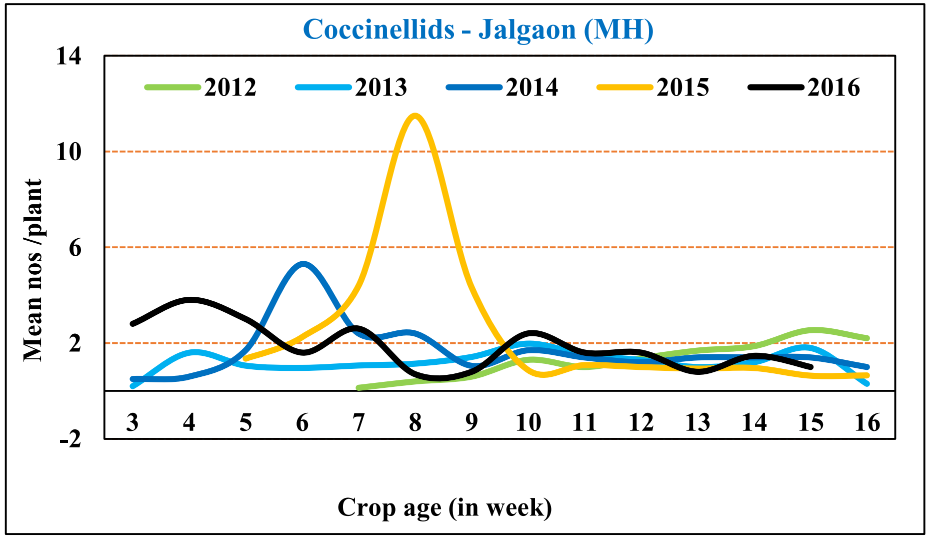
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





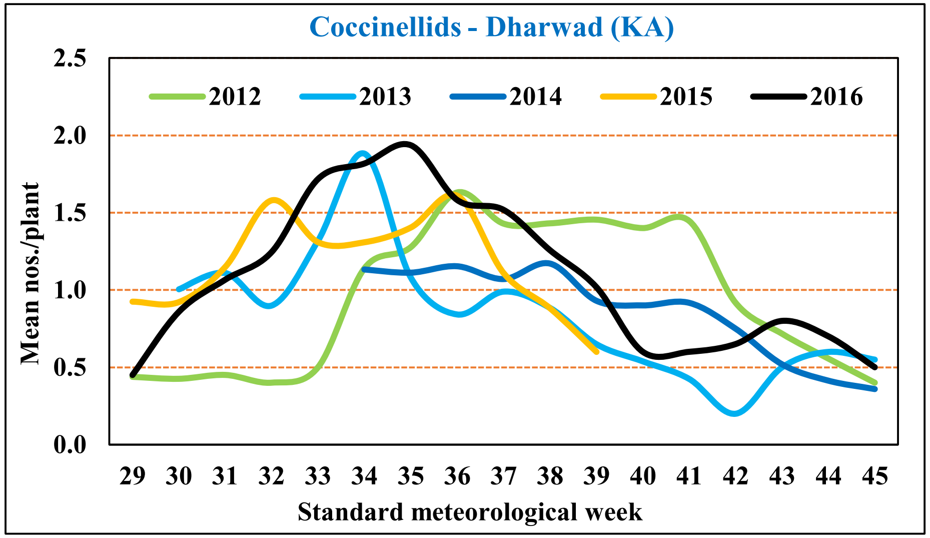


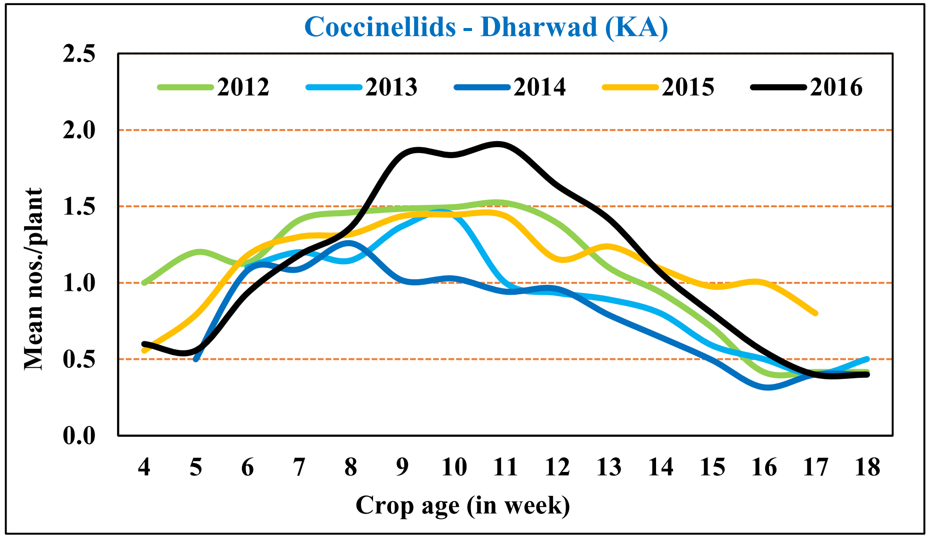


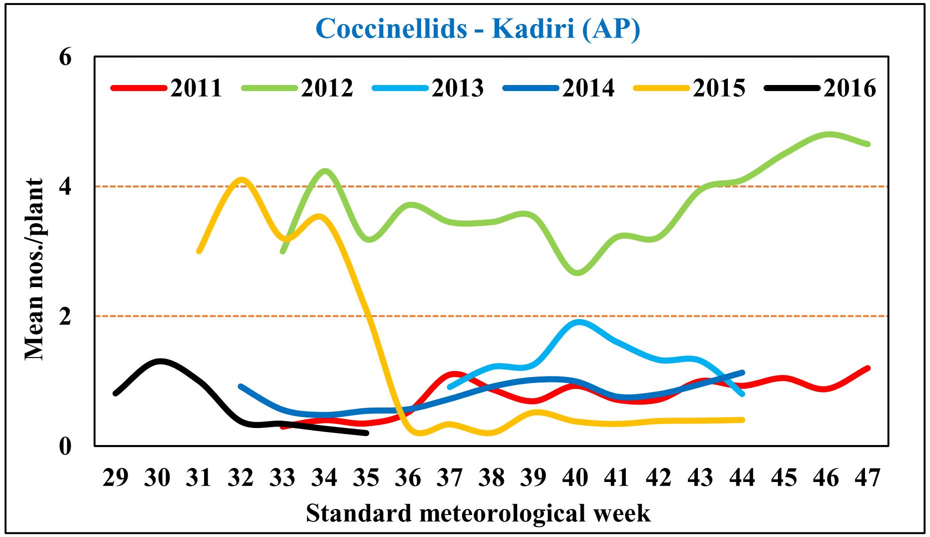
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

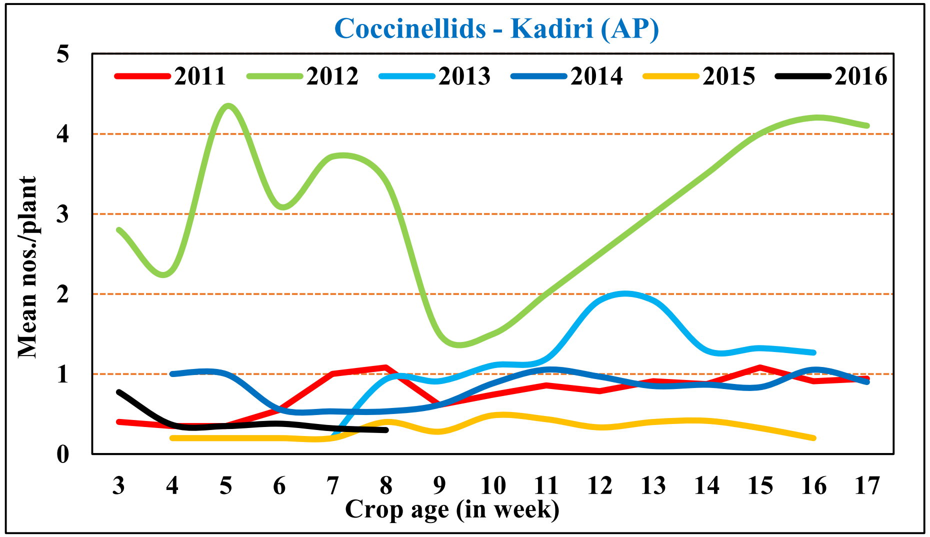
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





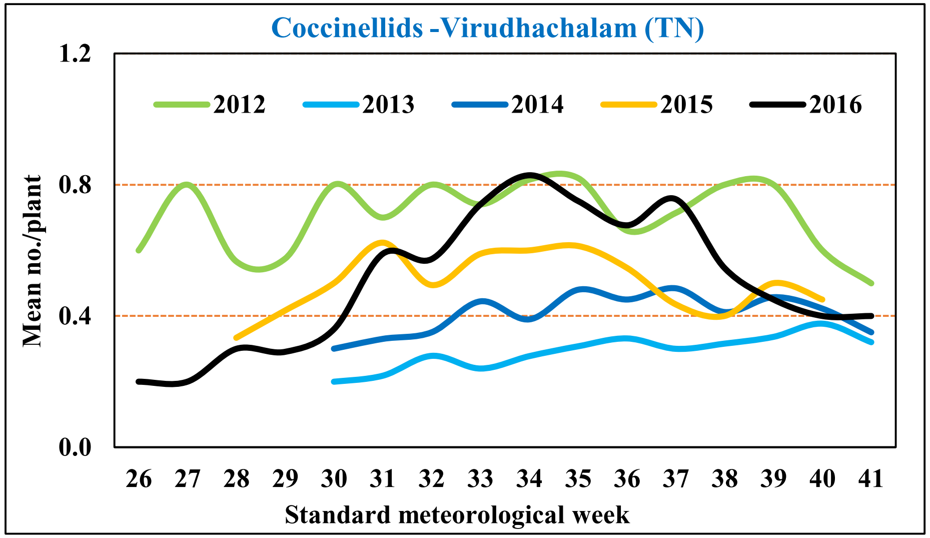


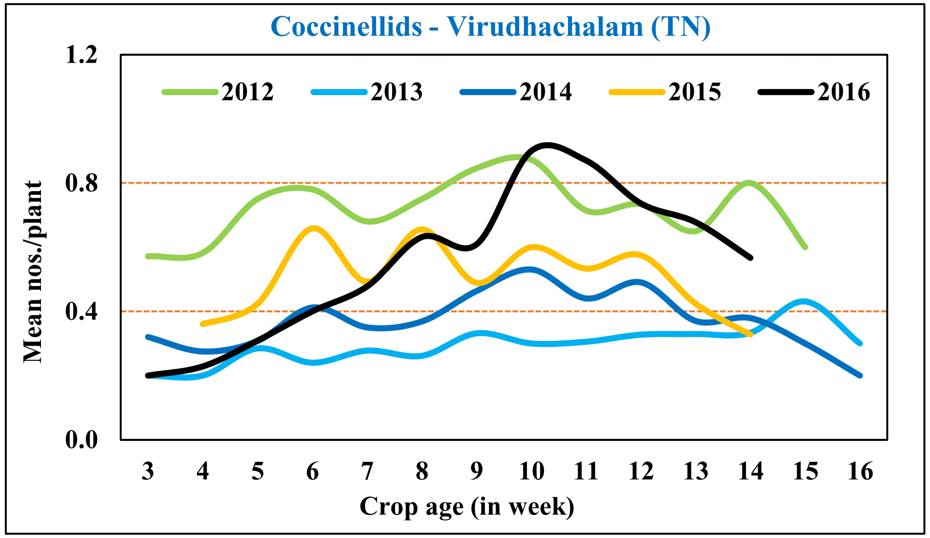


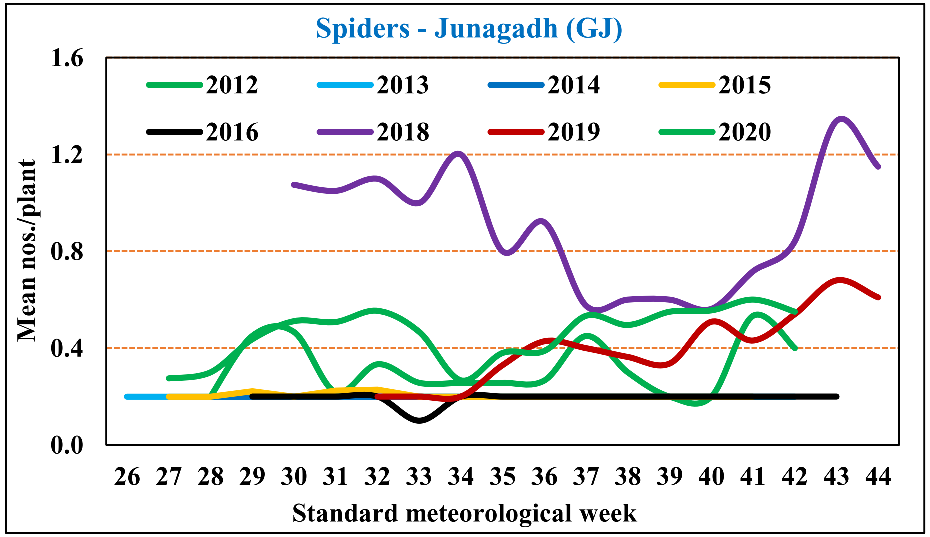
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

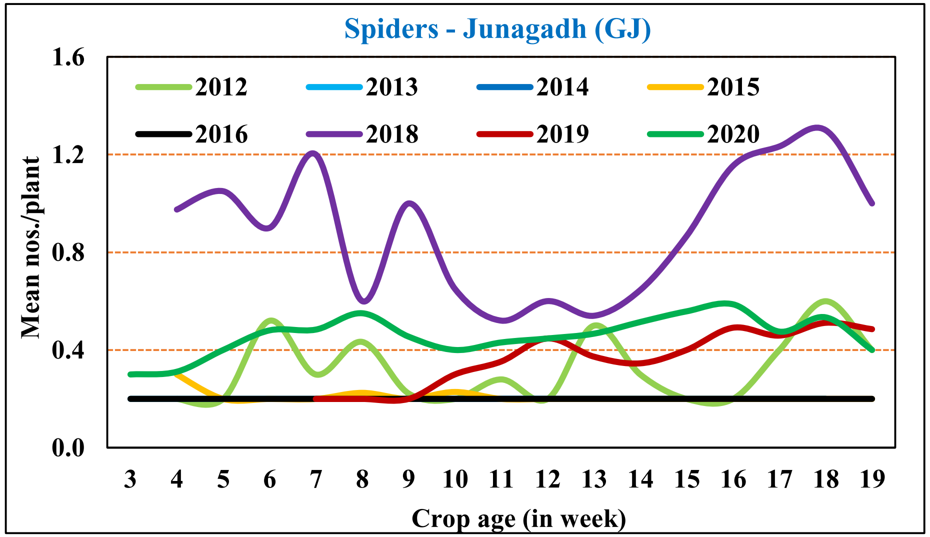
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



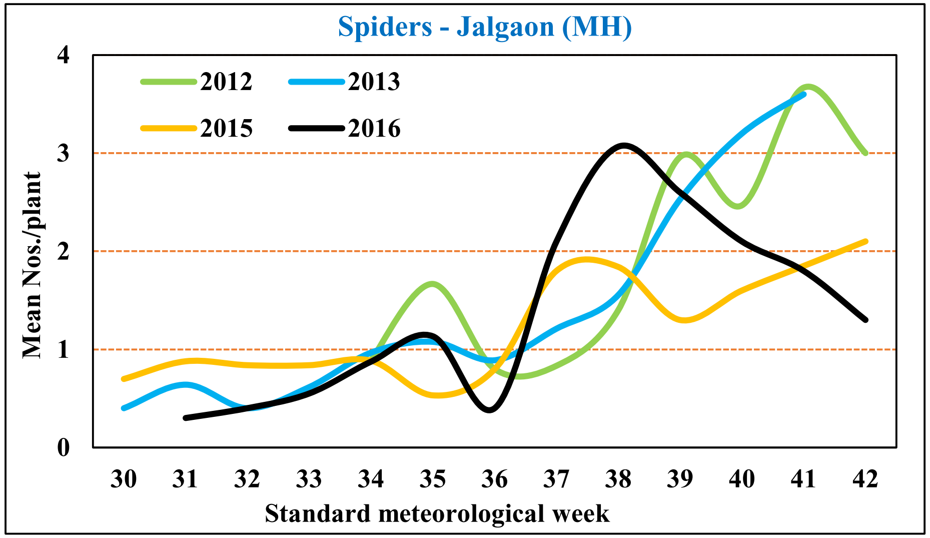


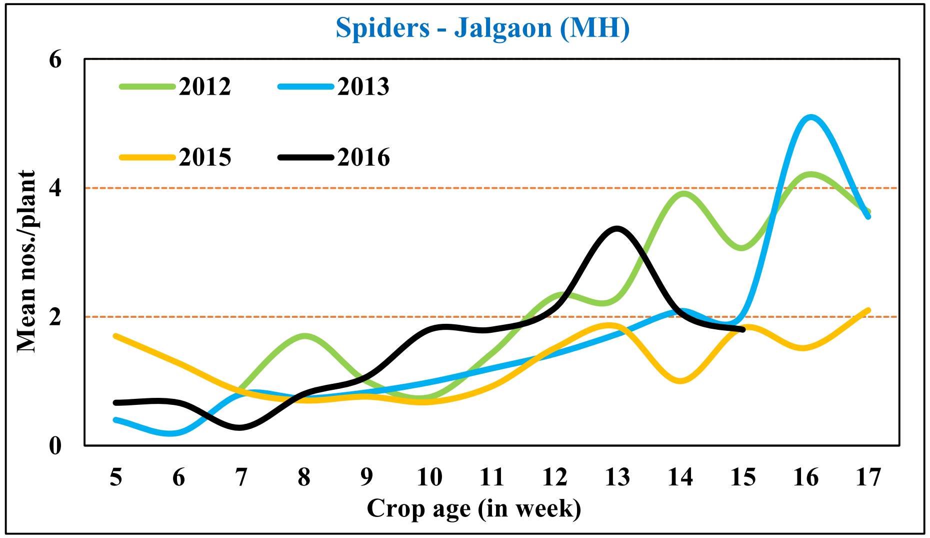


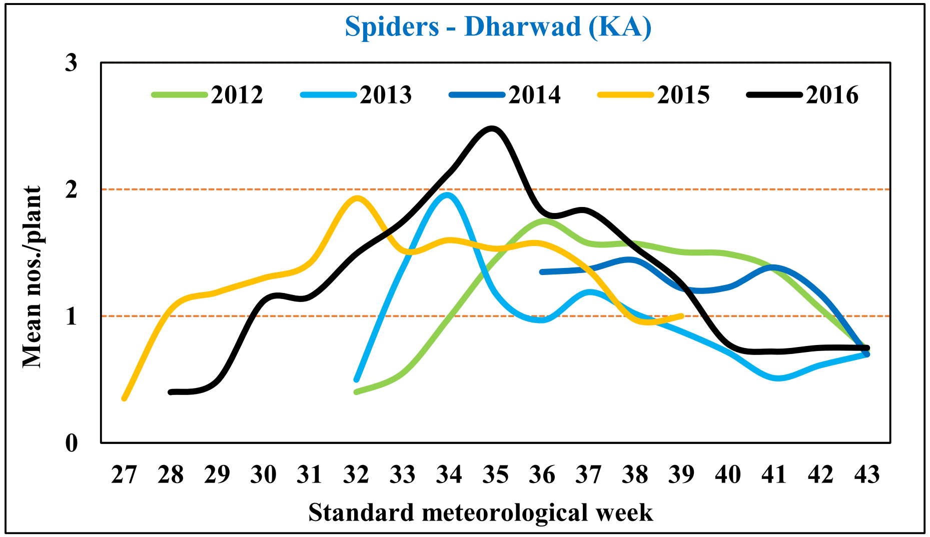


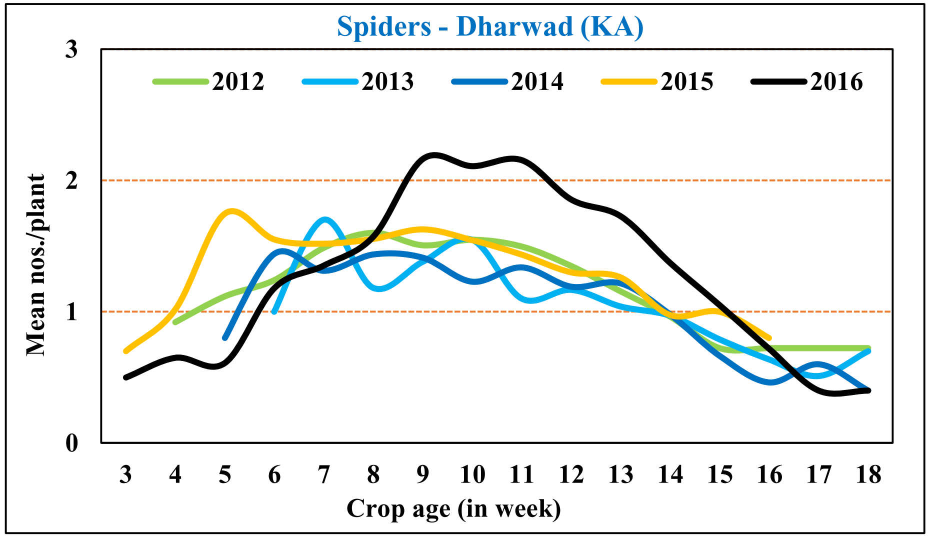
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | Seasonal dynamics based on crop age





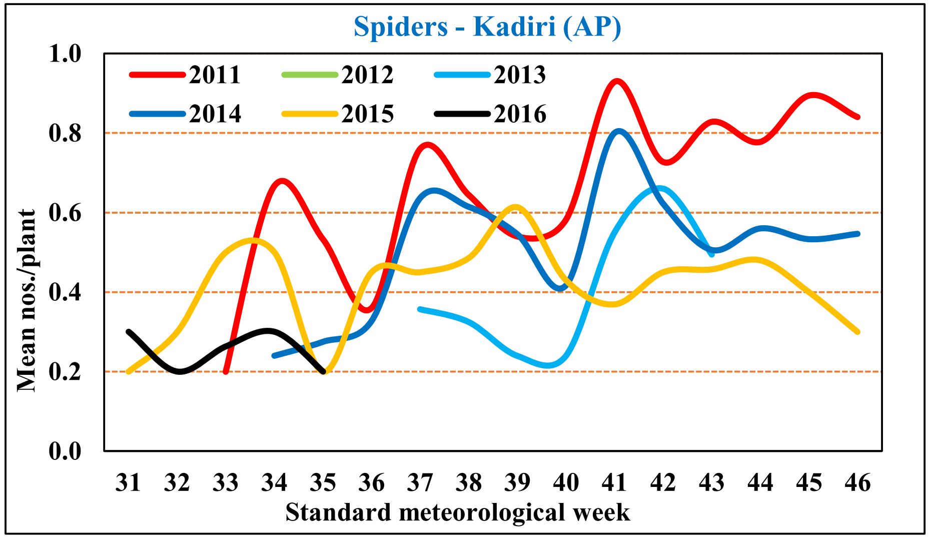


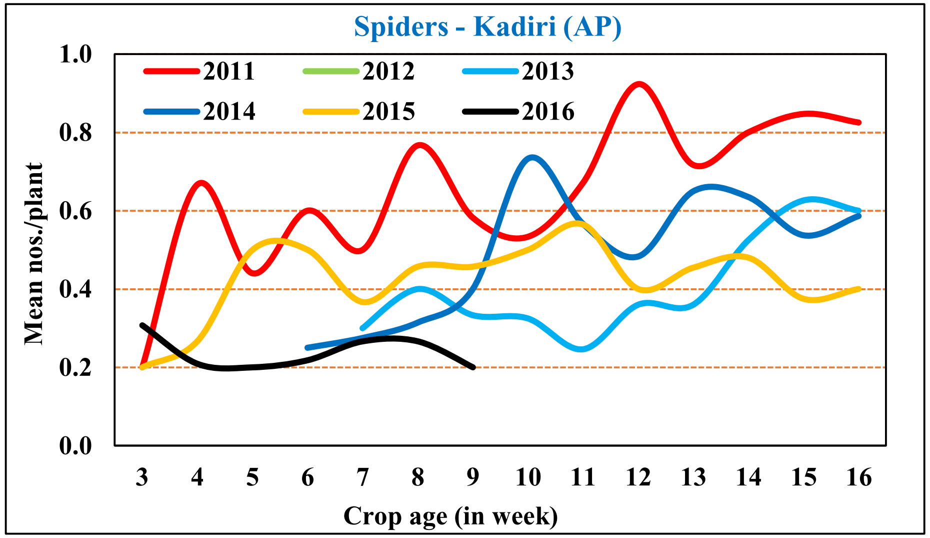


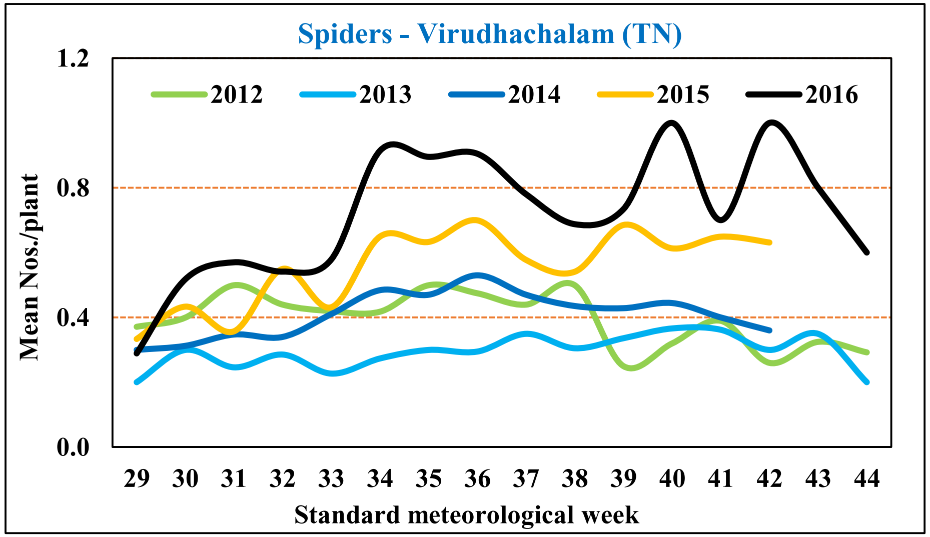
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

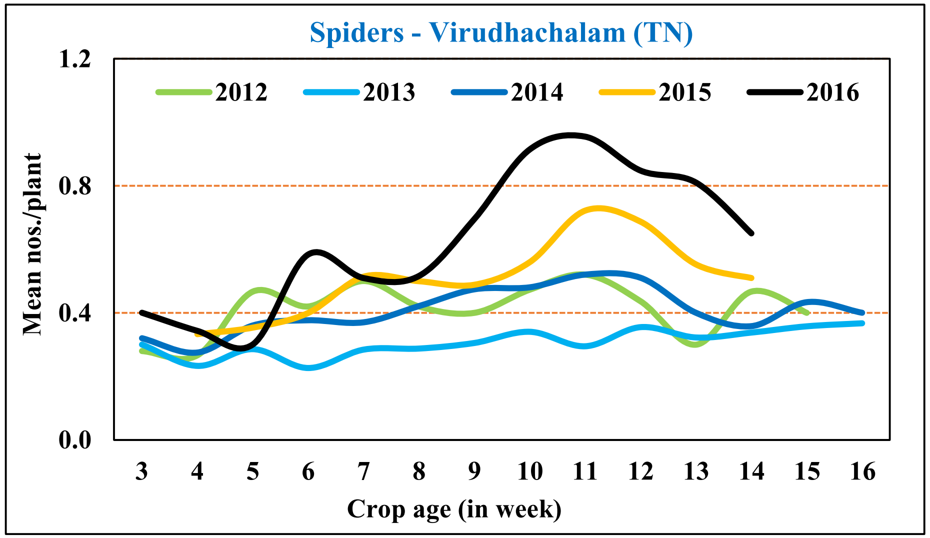
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





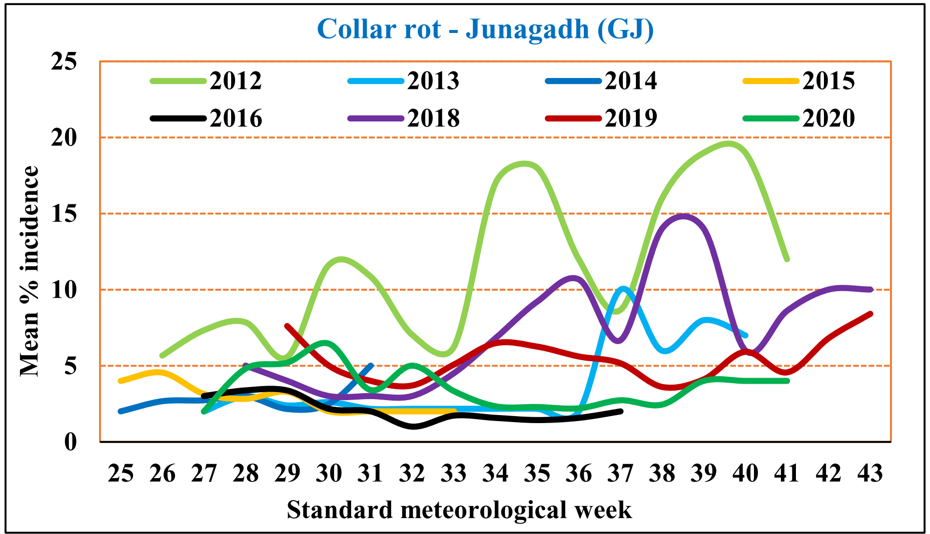


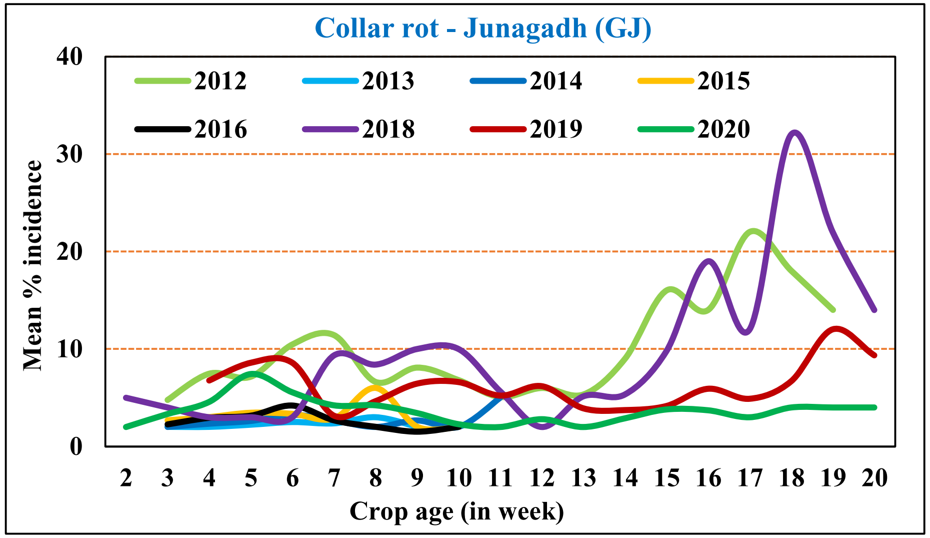


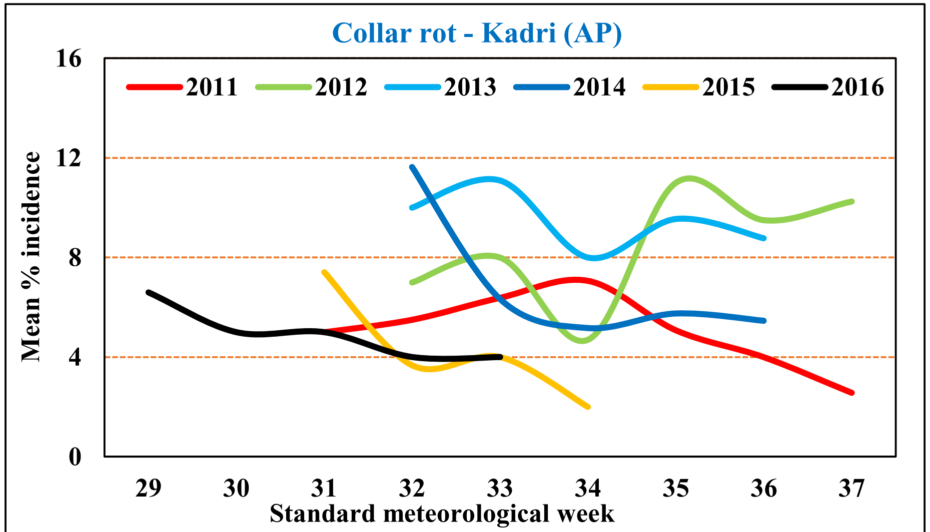
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

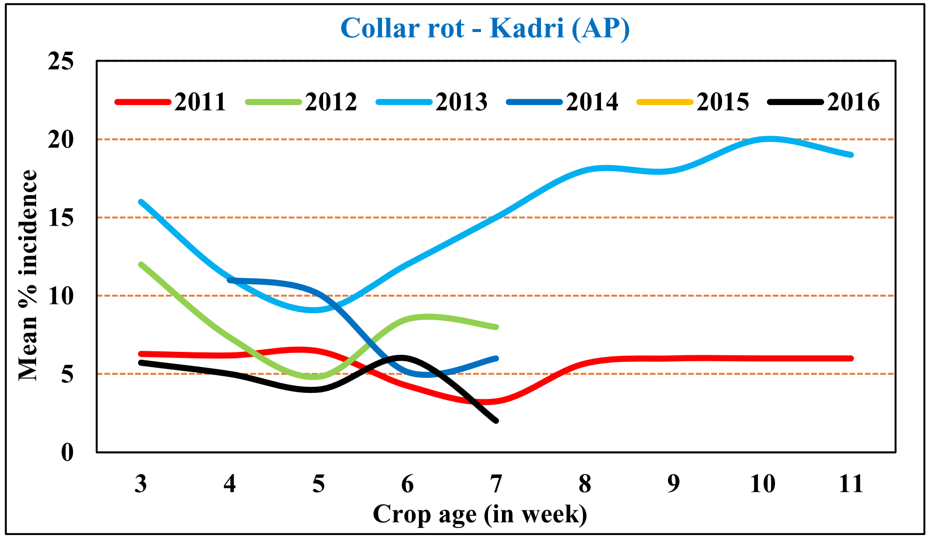
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



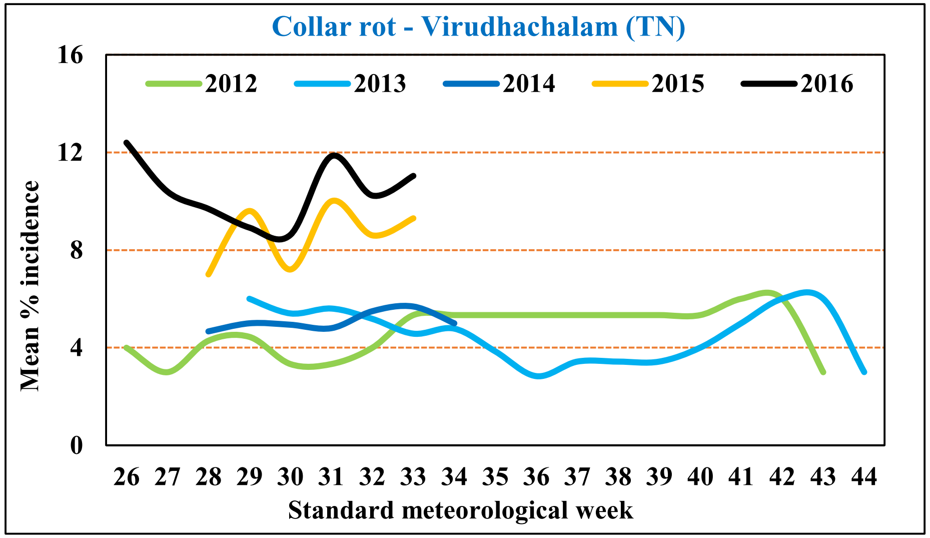


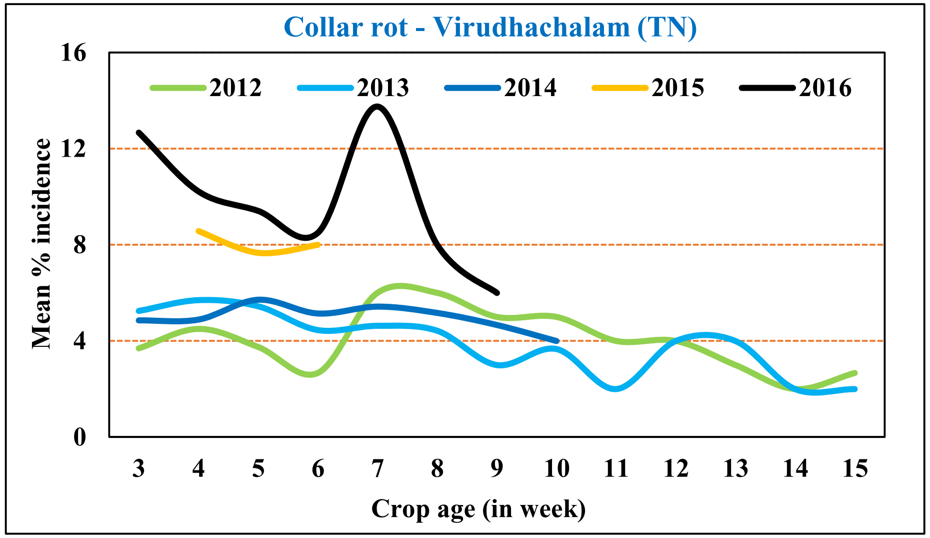


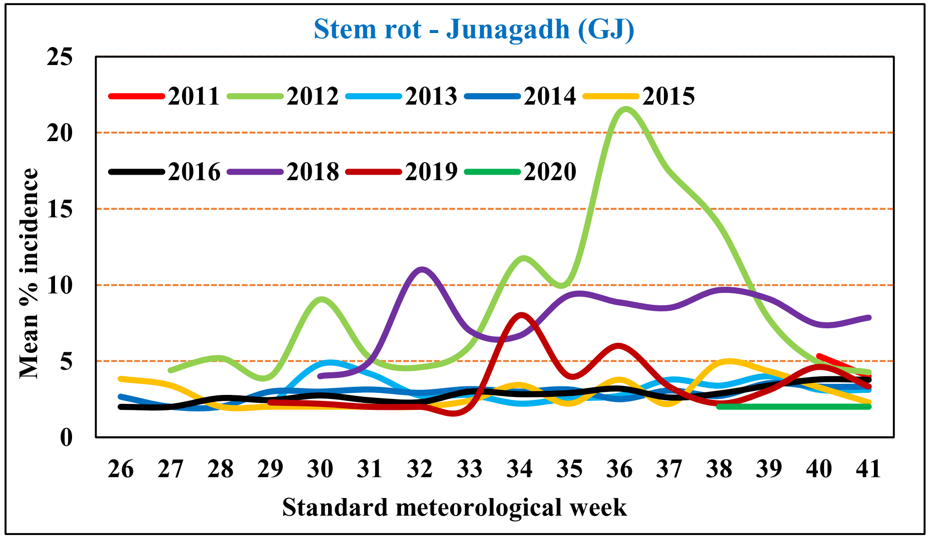


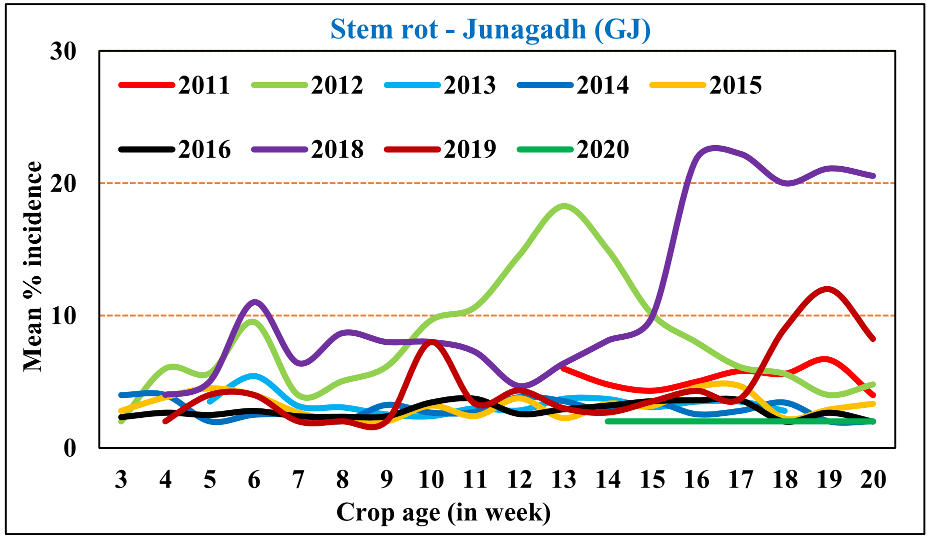
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



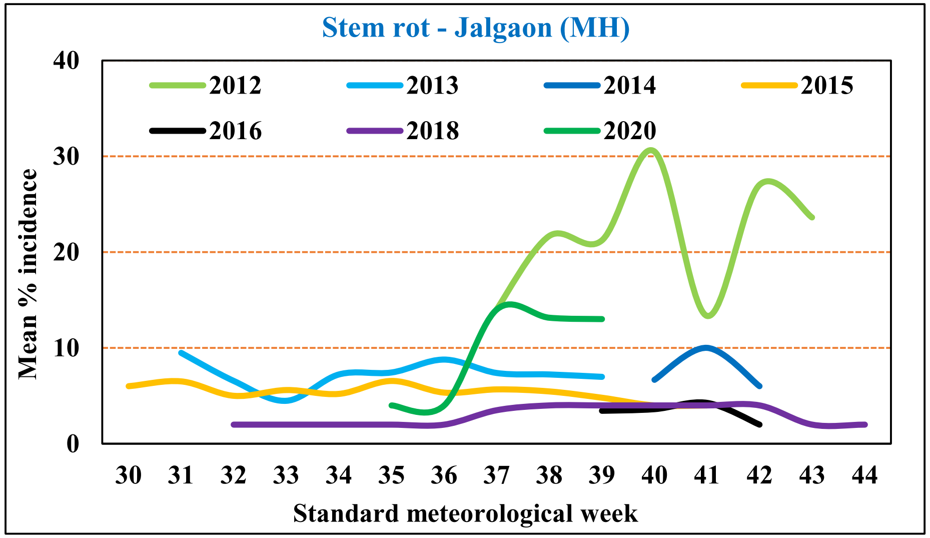


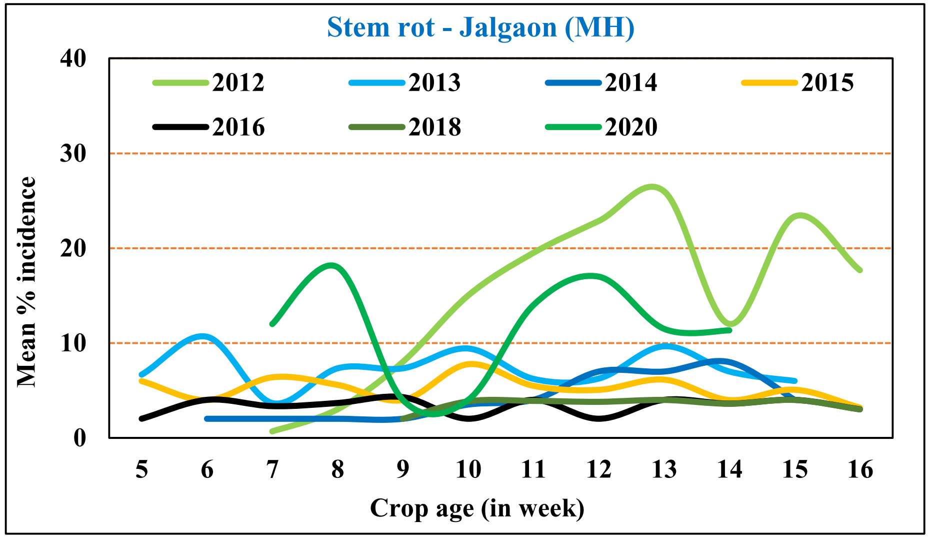


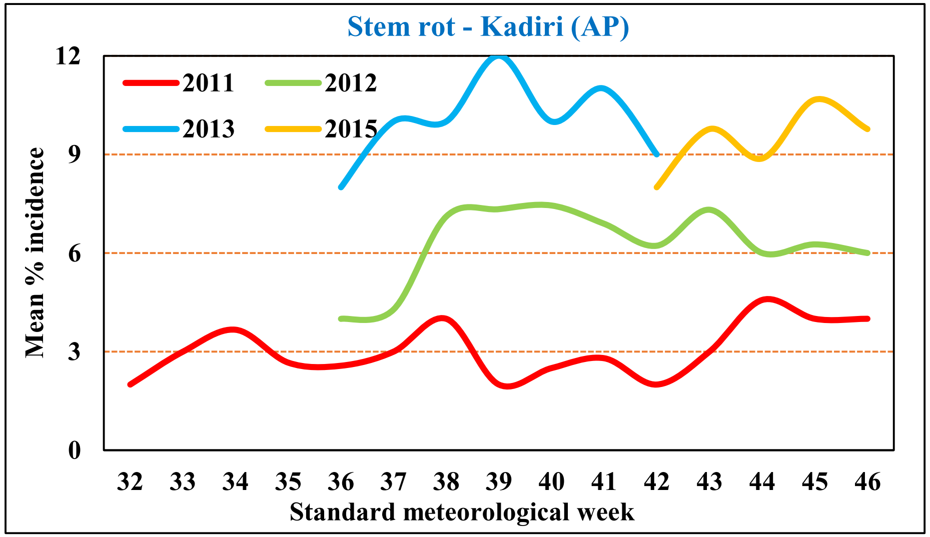


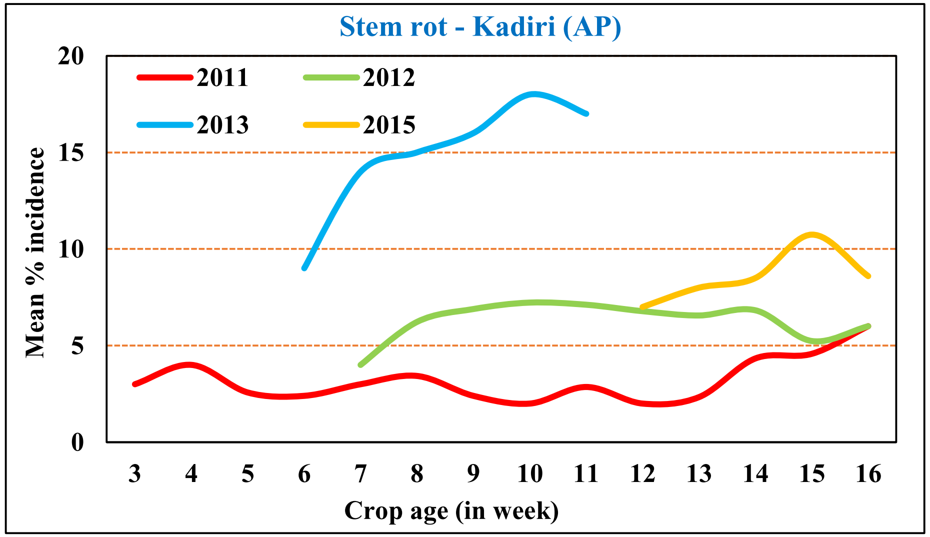
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**





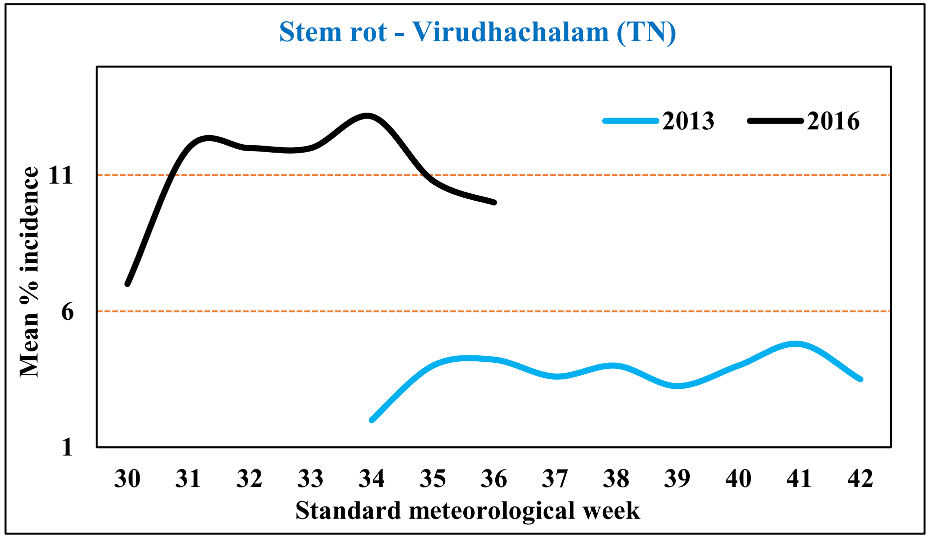


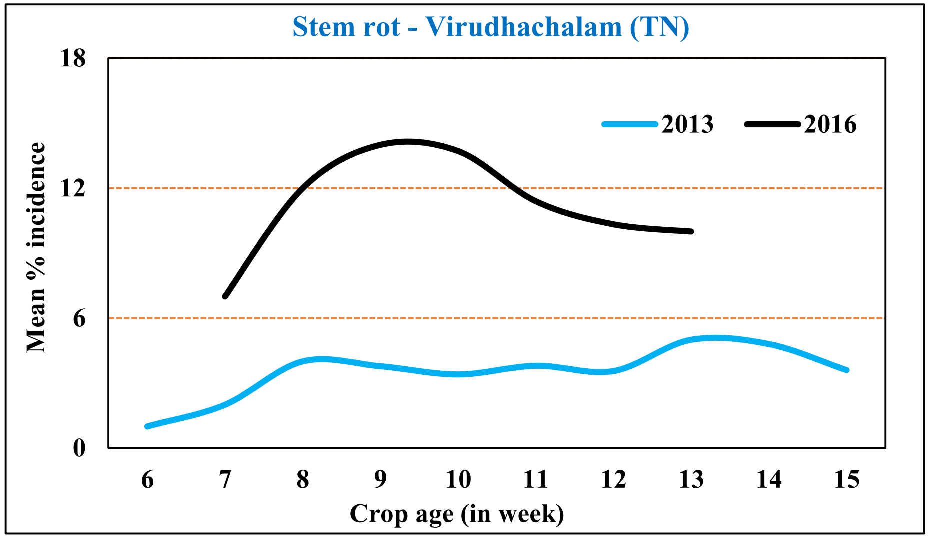


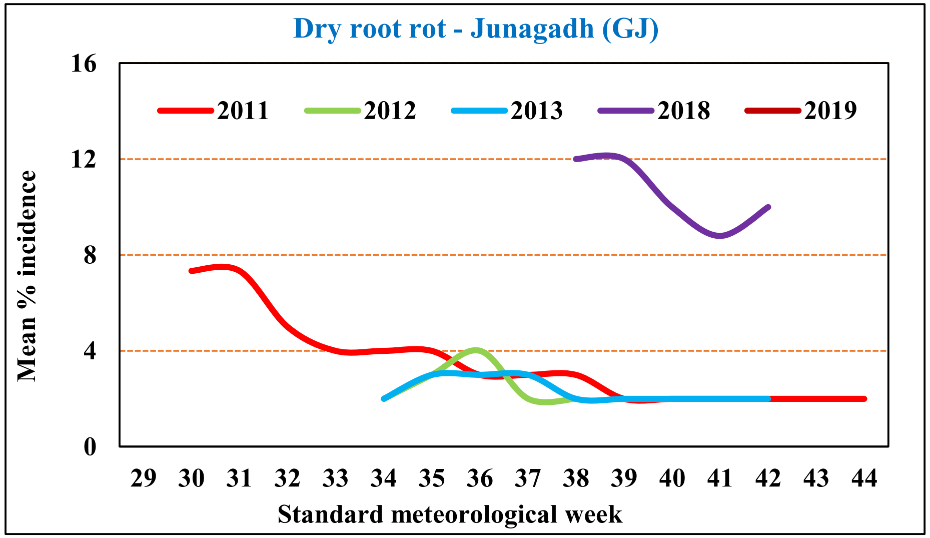
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

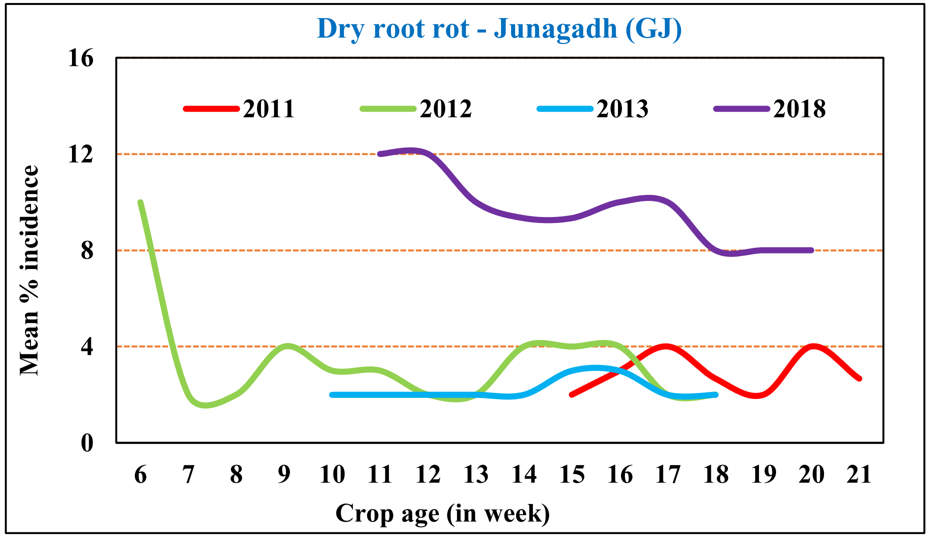
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





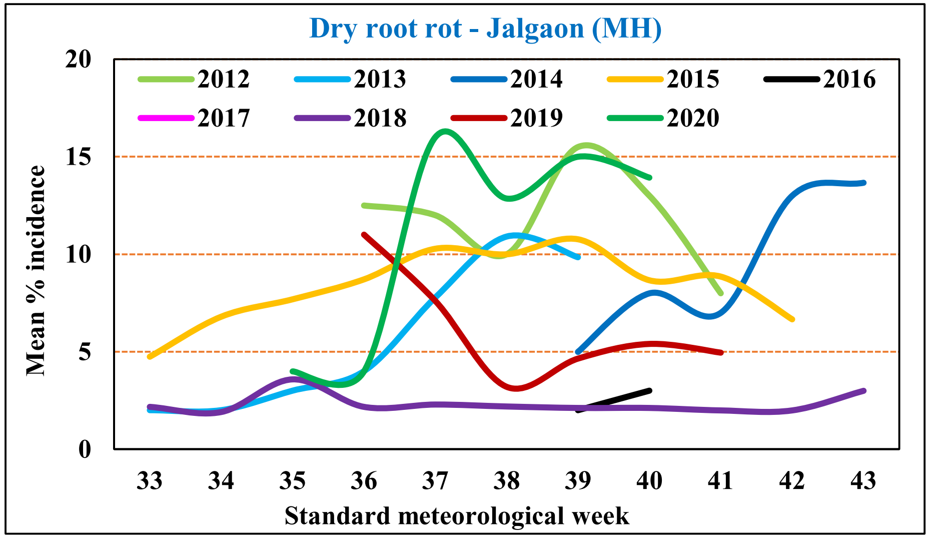


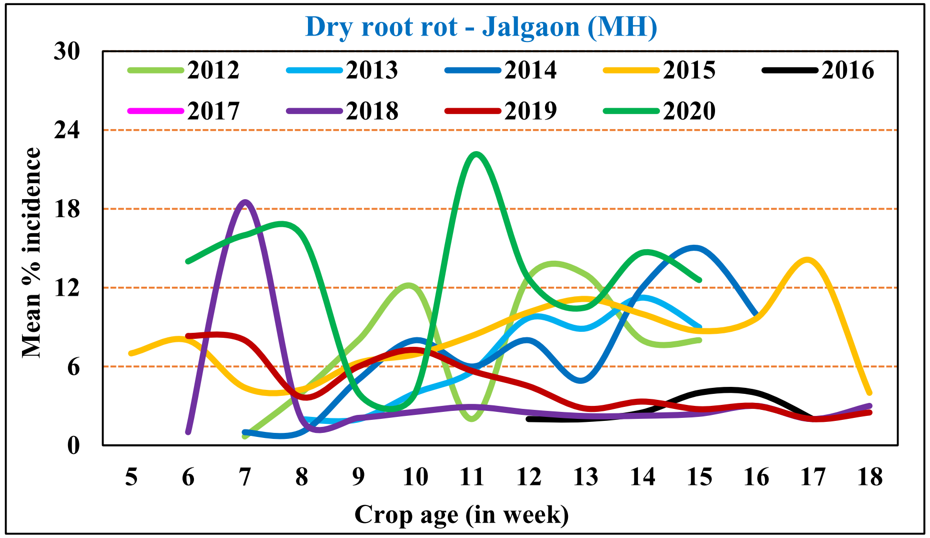


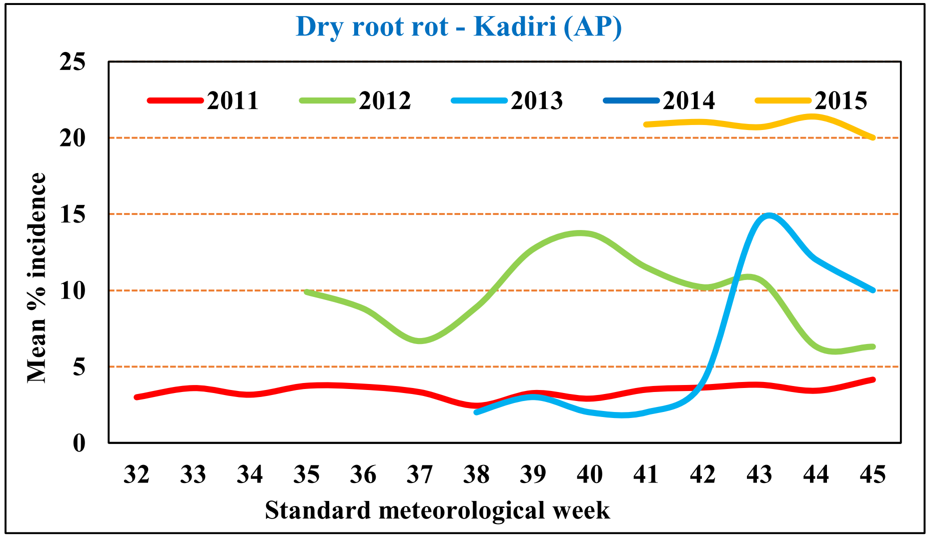
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

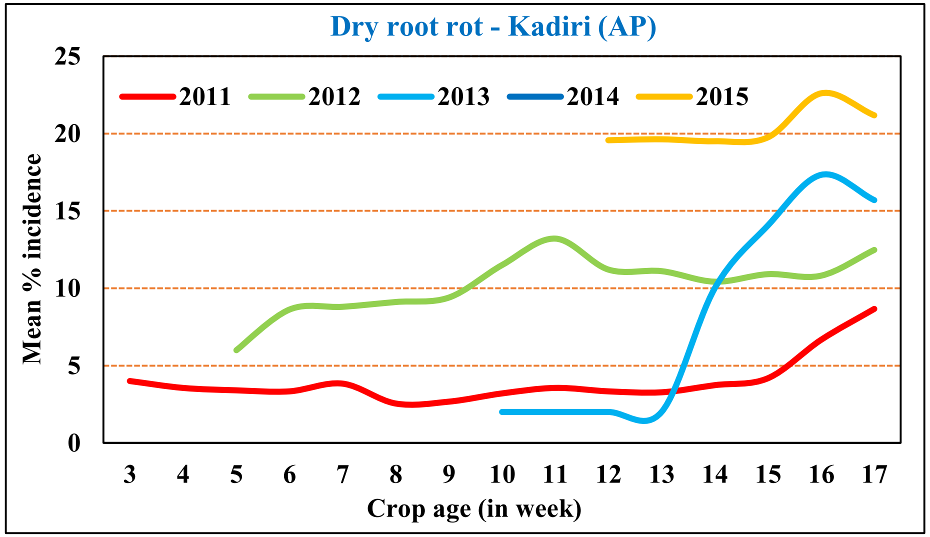
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





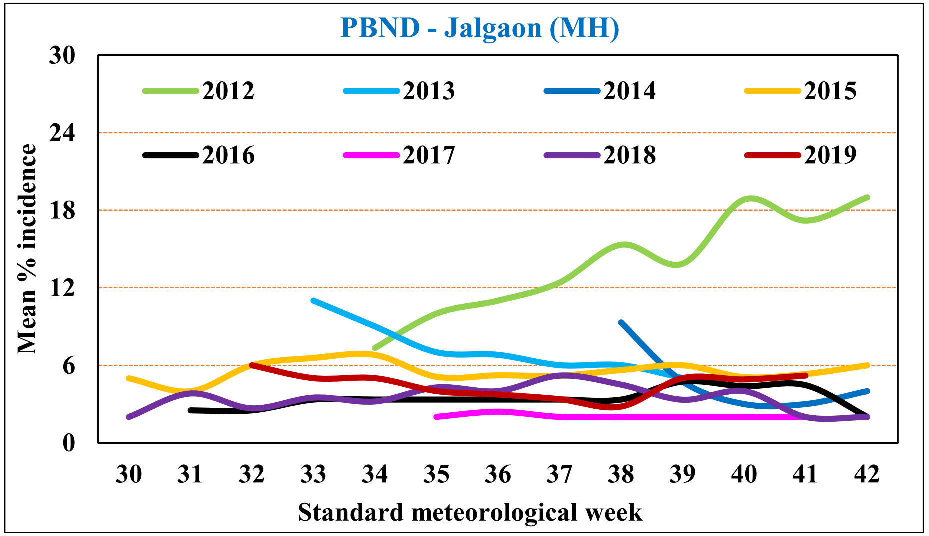


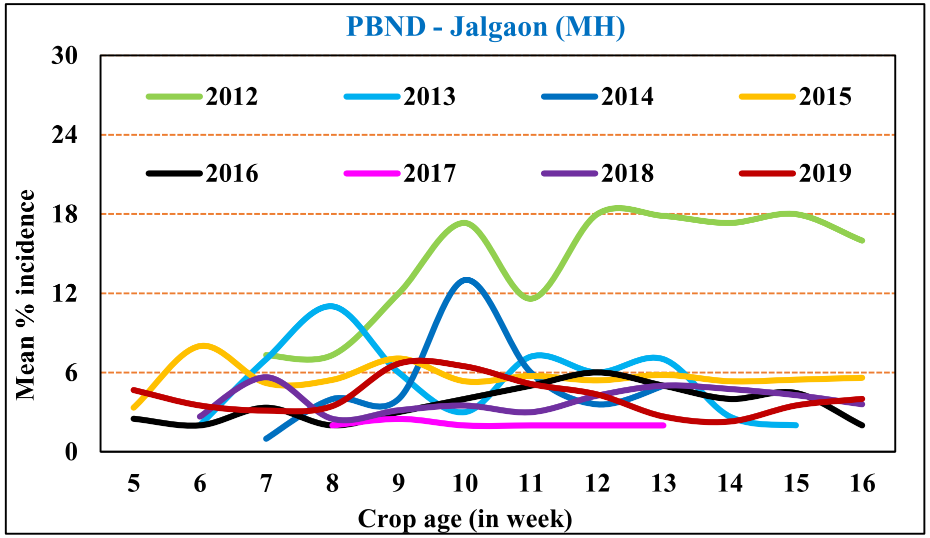


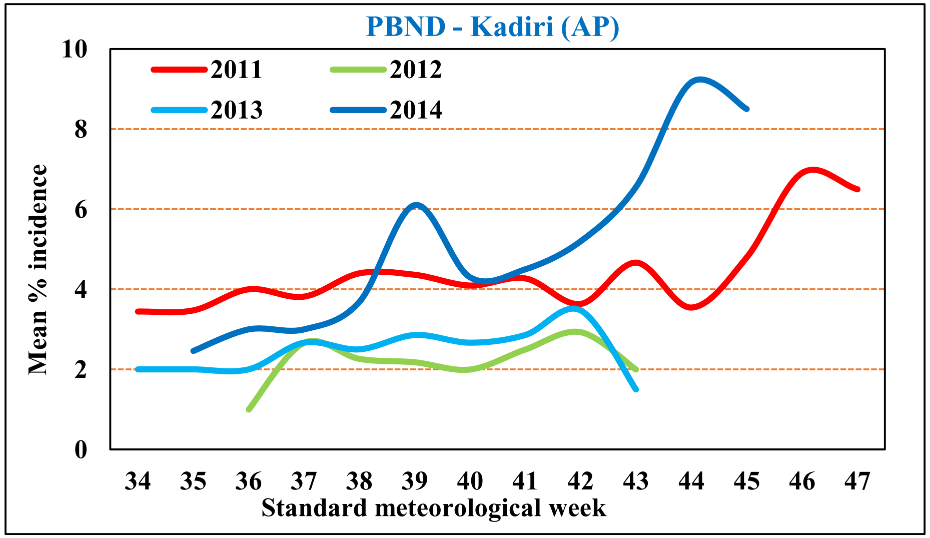
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

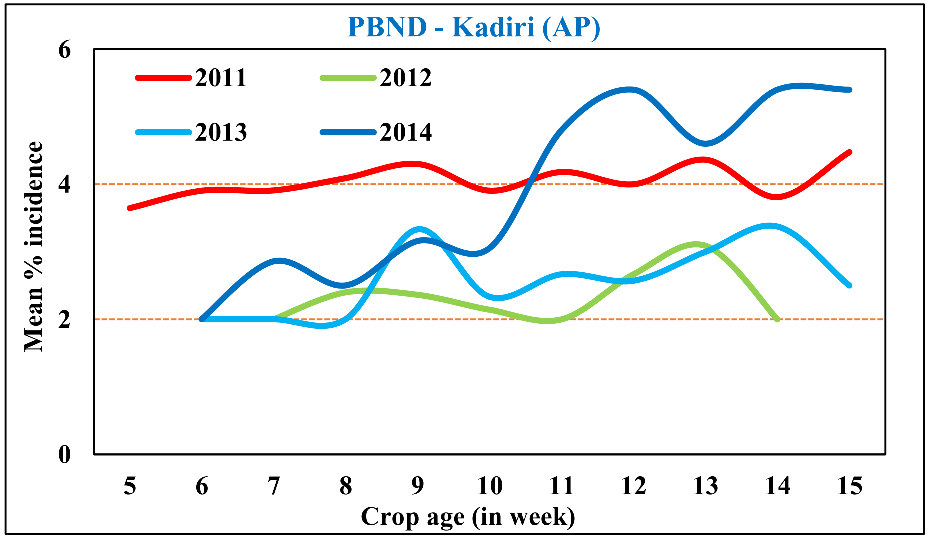
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





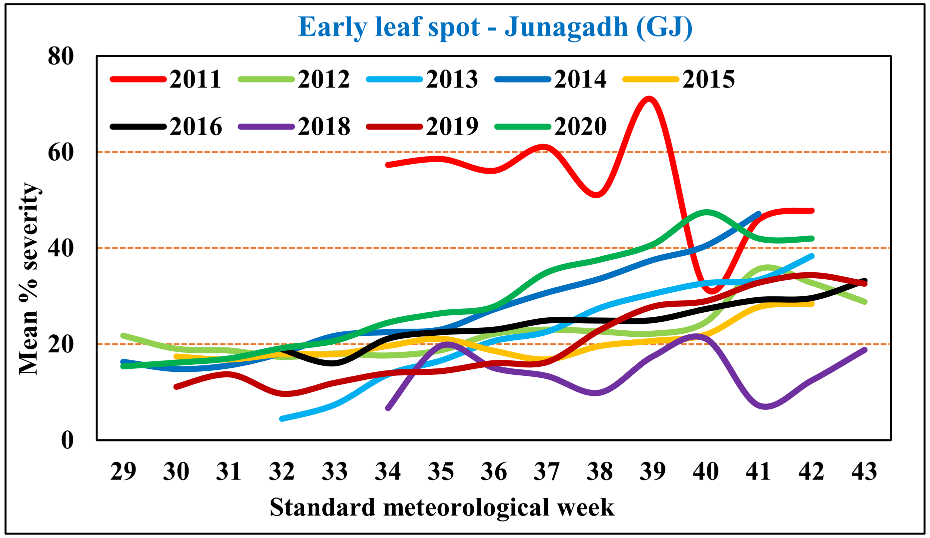


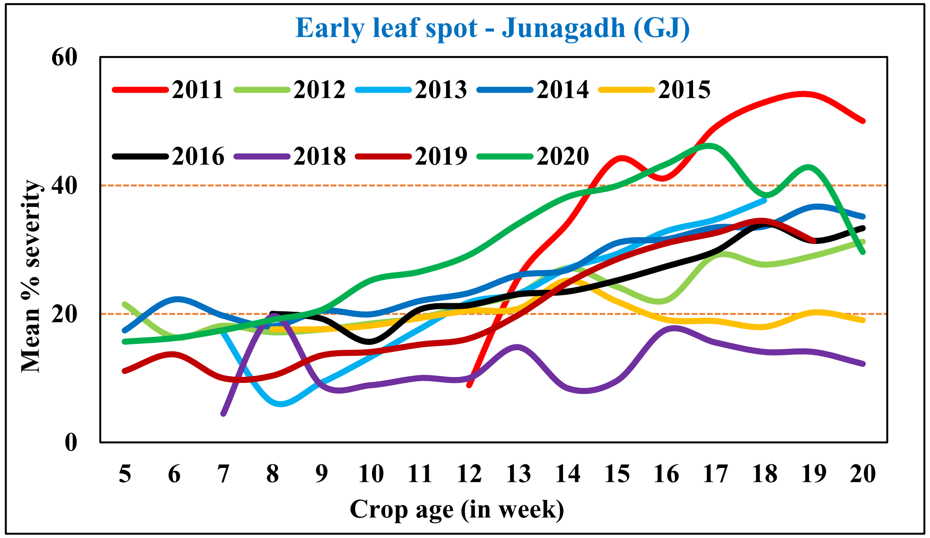


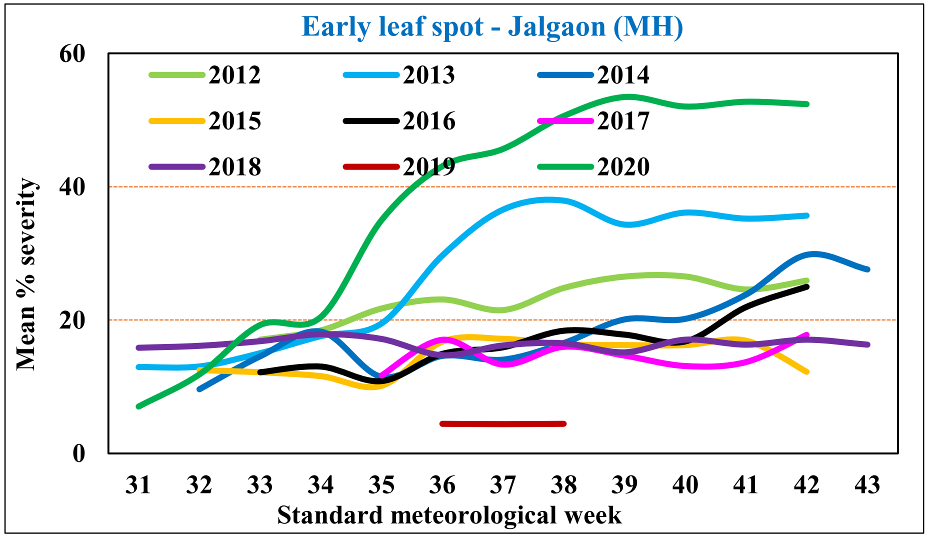
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

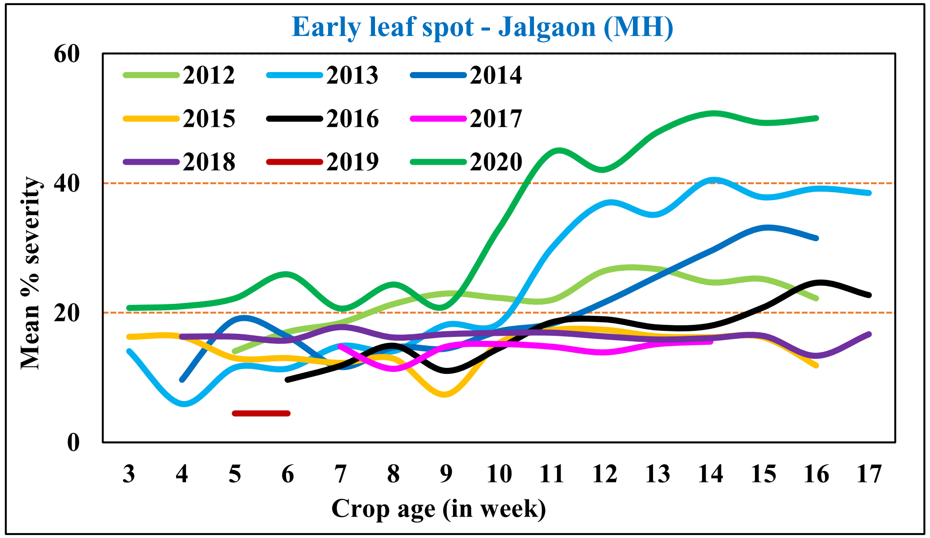
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





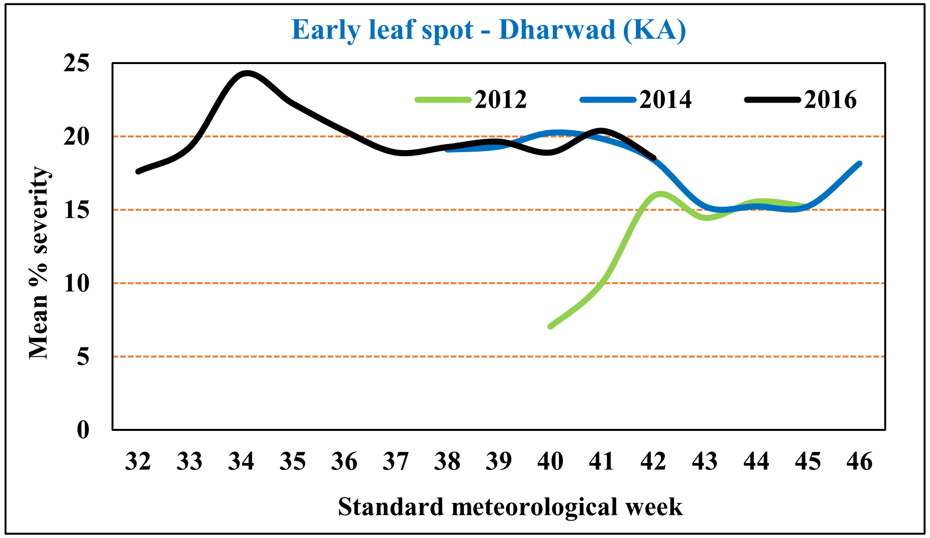


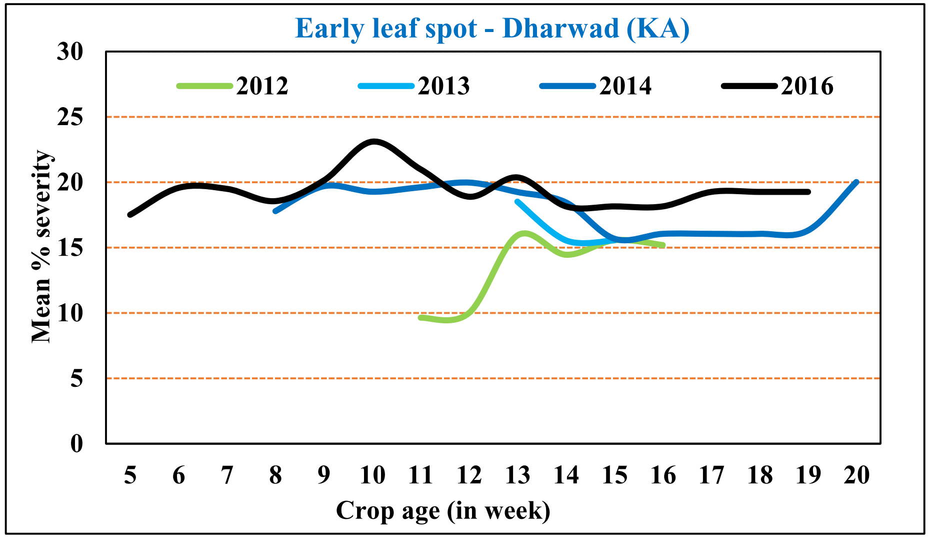


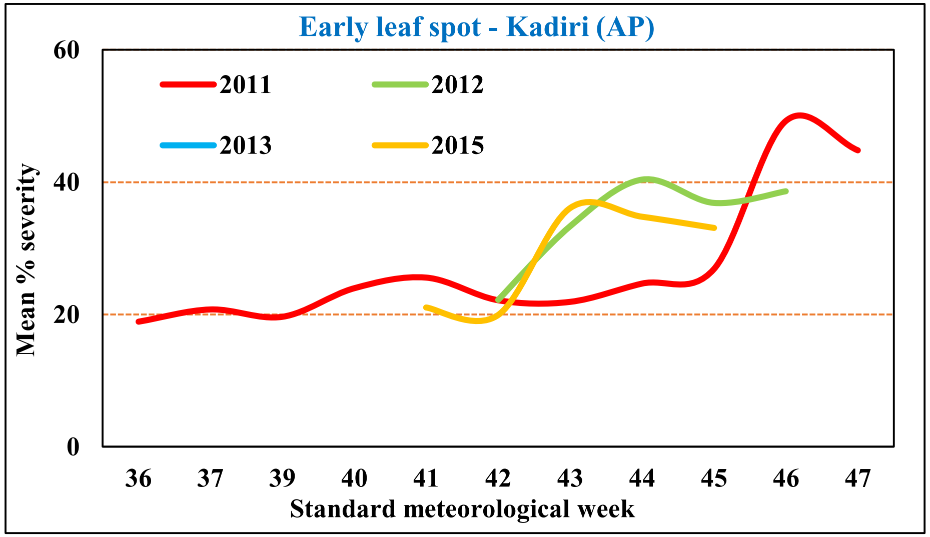
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

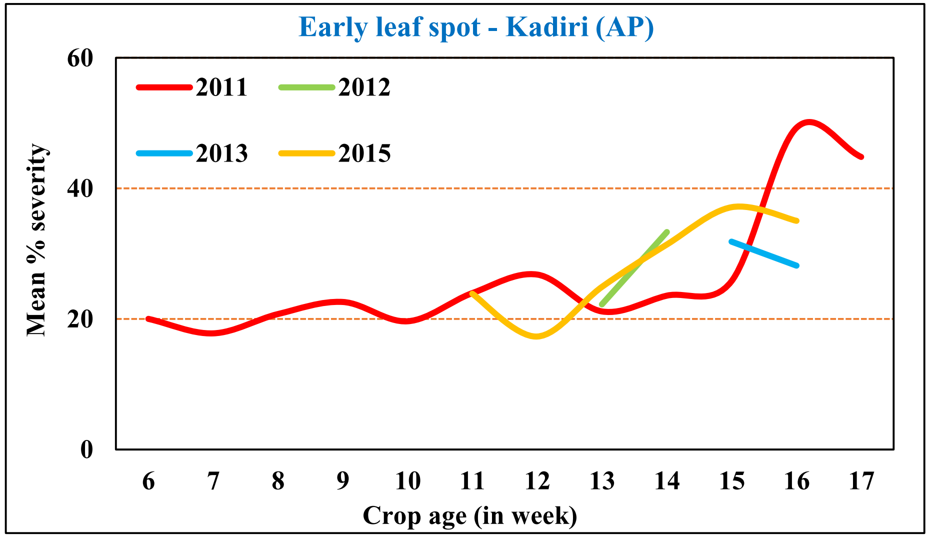
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





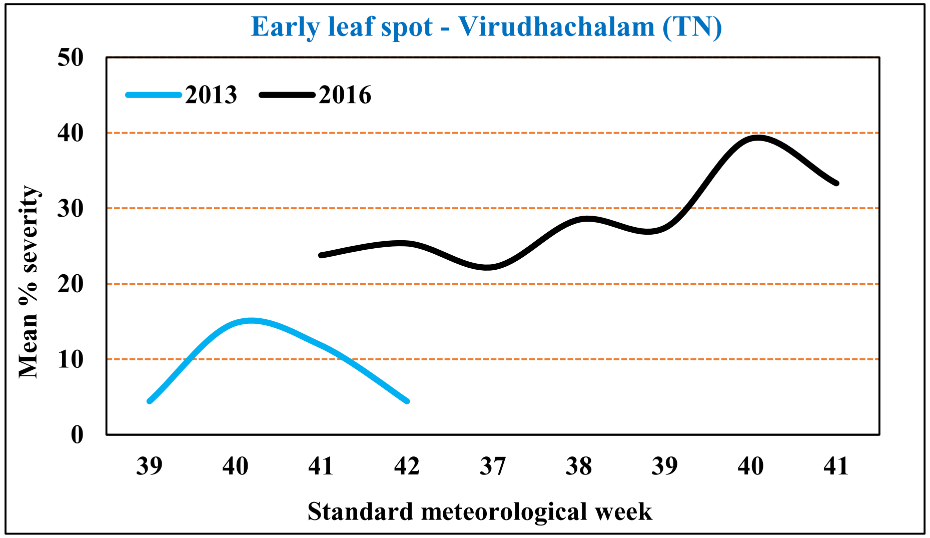


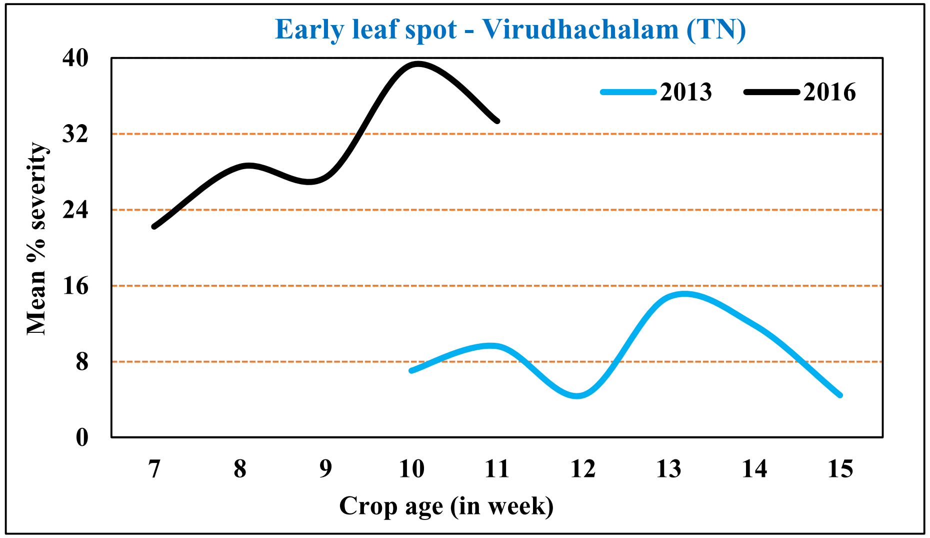


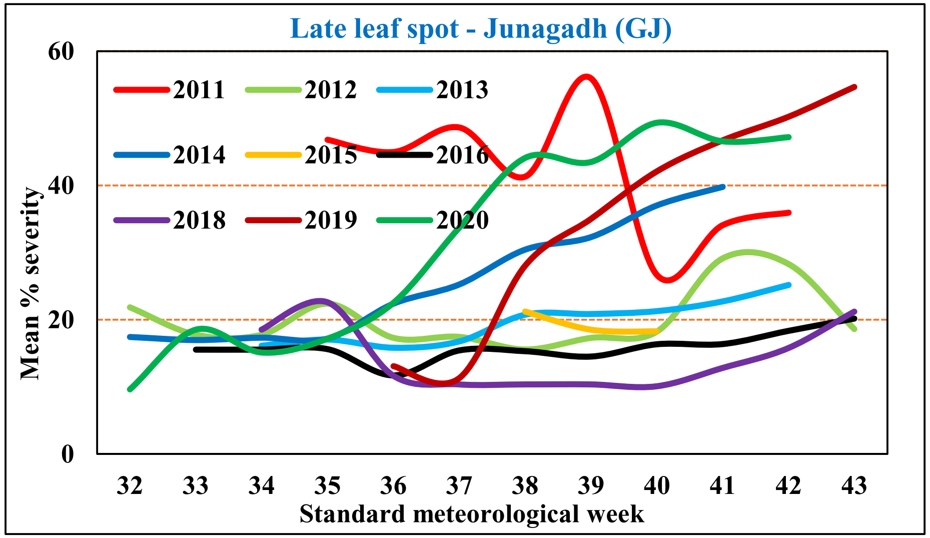
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

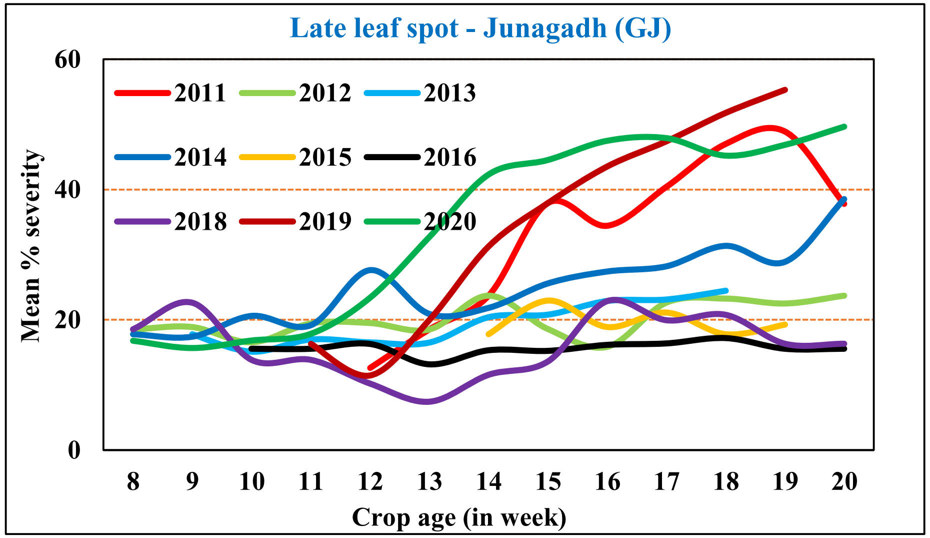
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





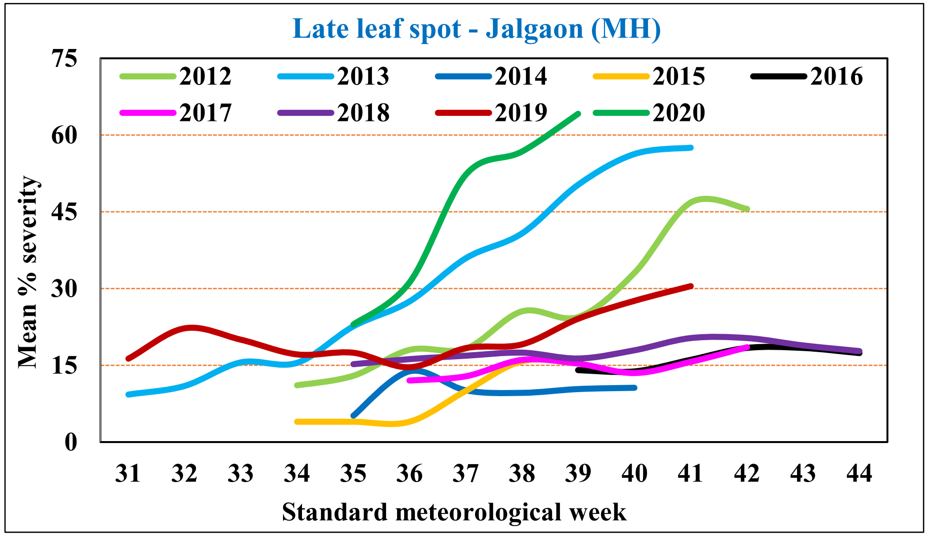


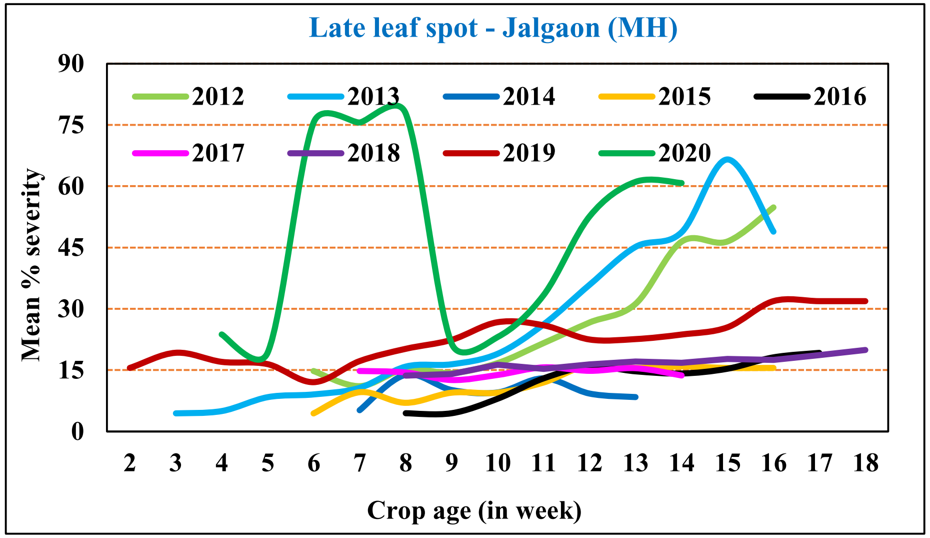


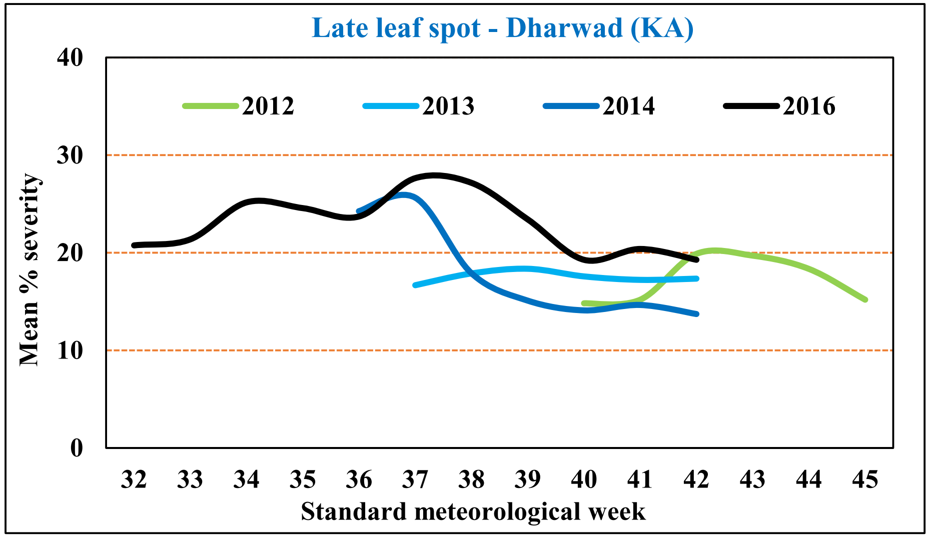
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

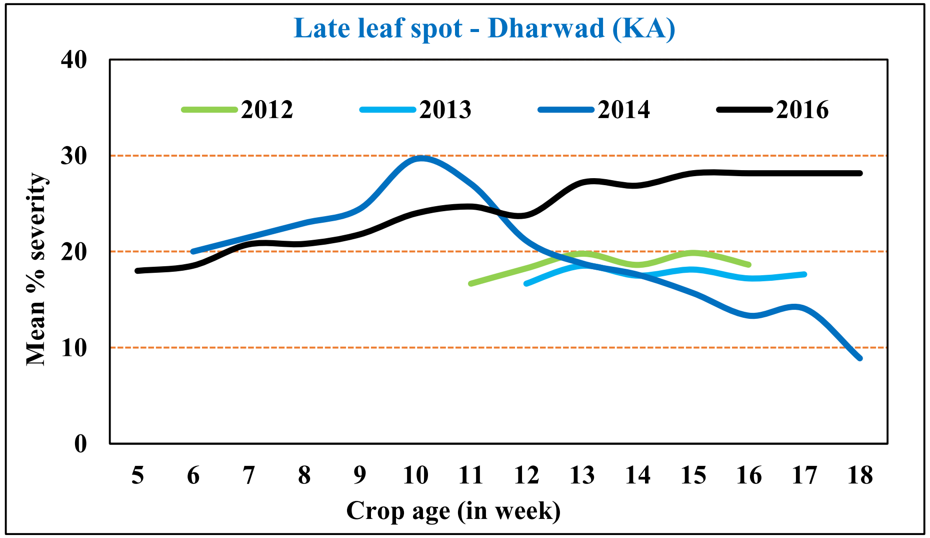
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





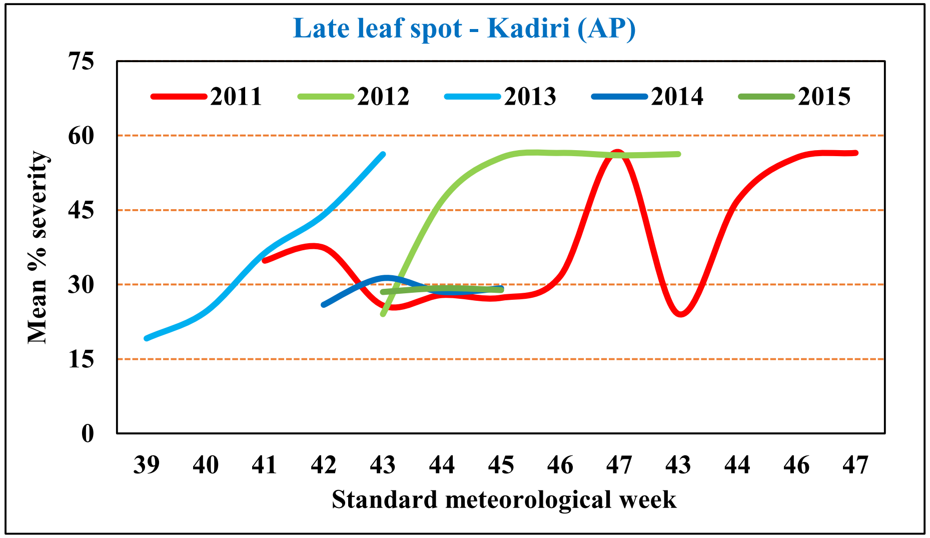


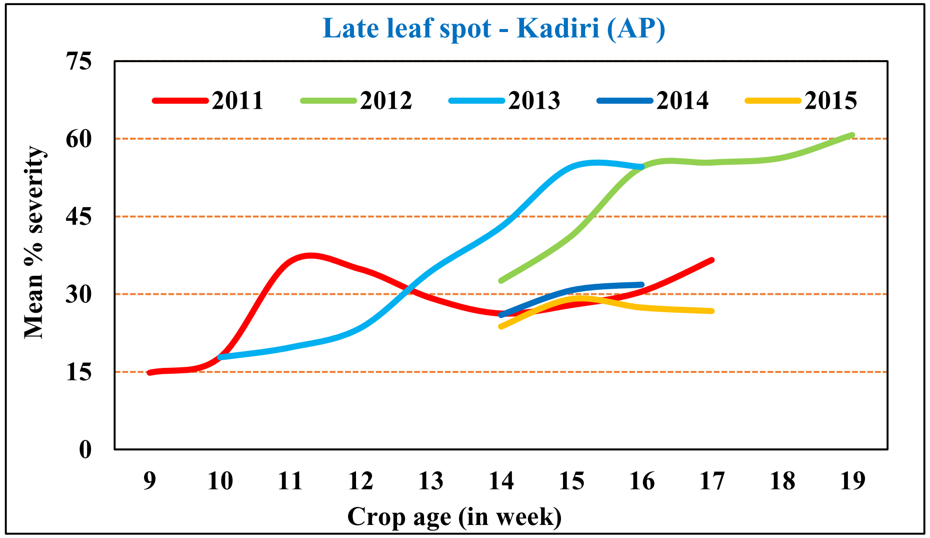


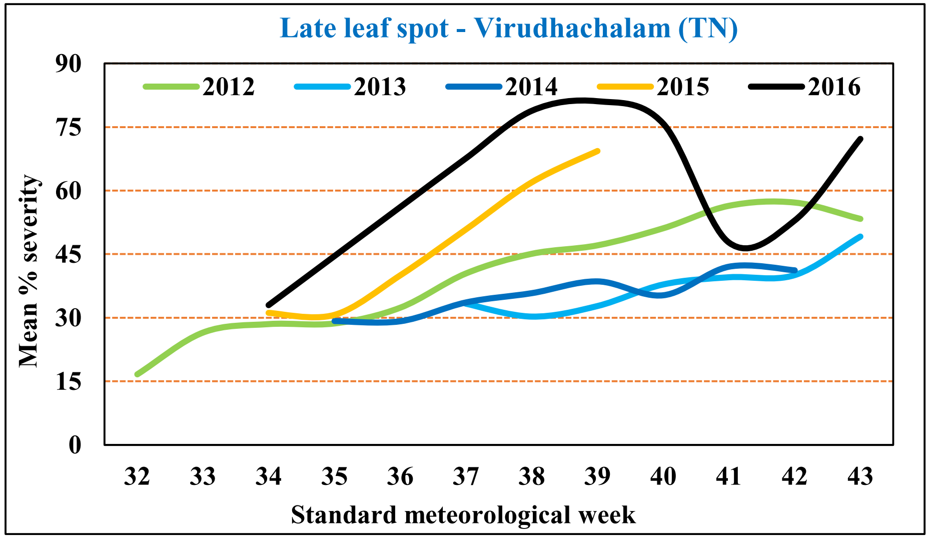
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

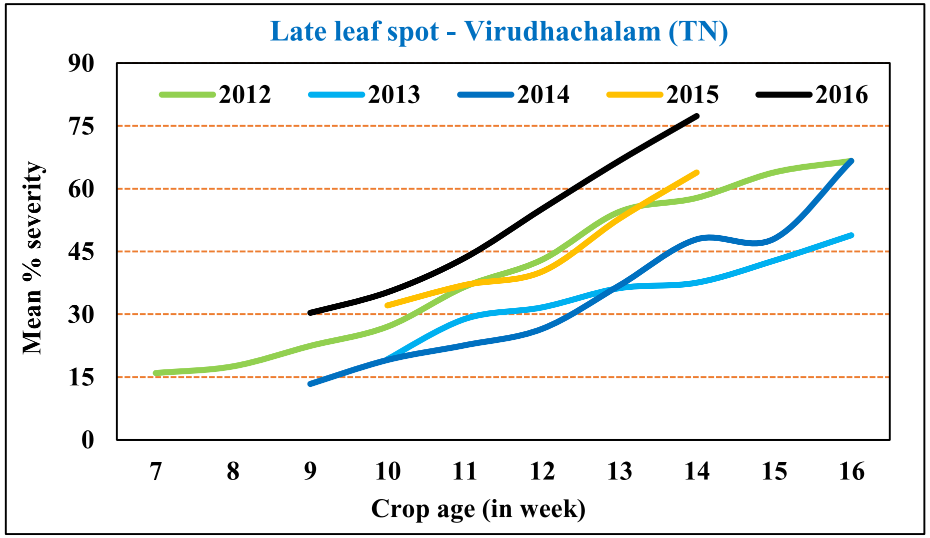
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



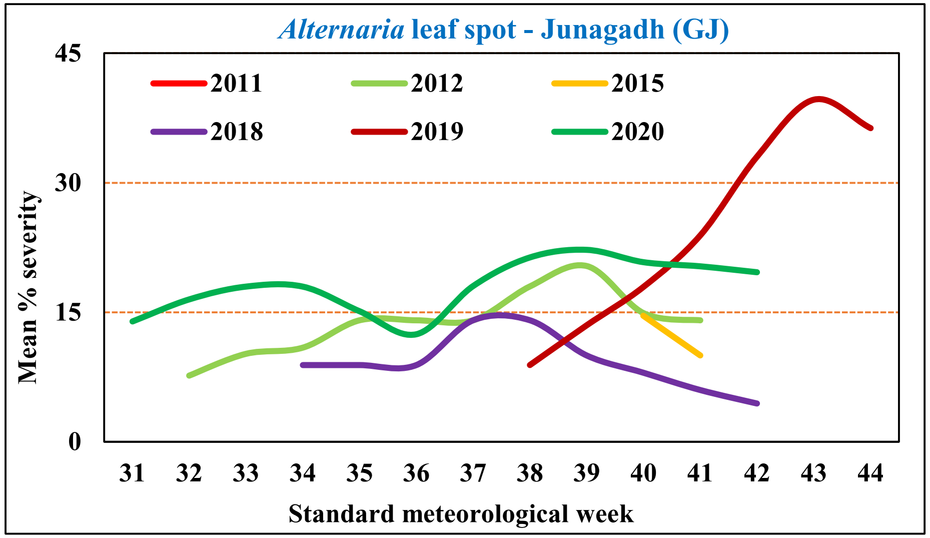


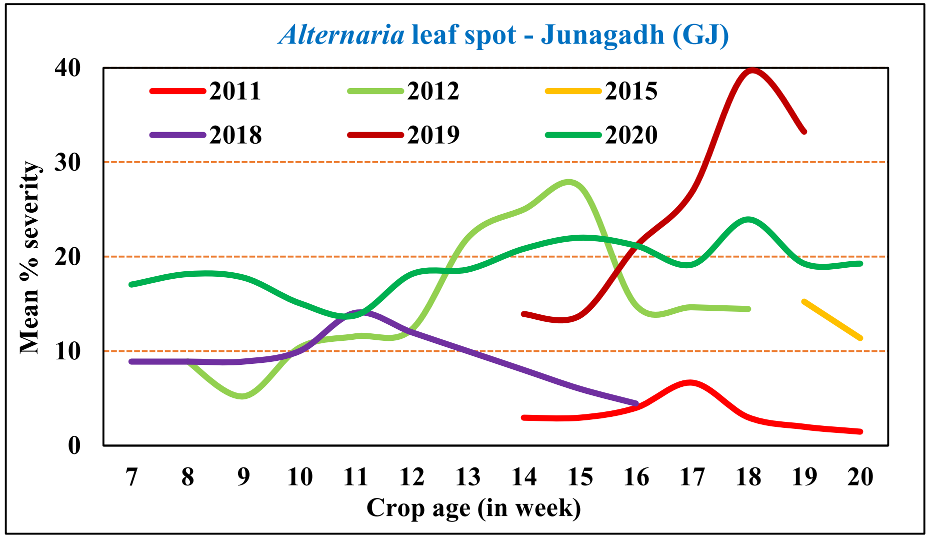


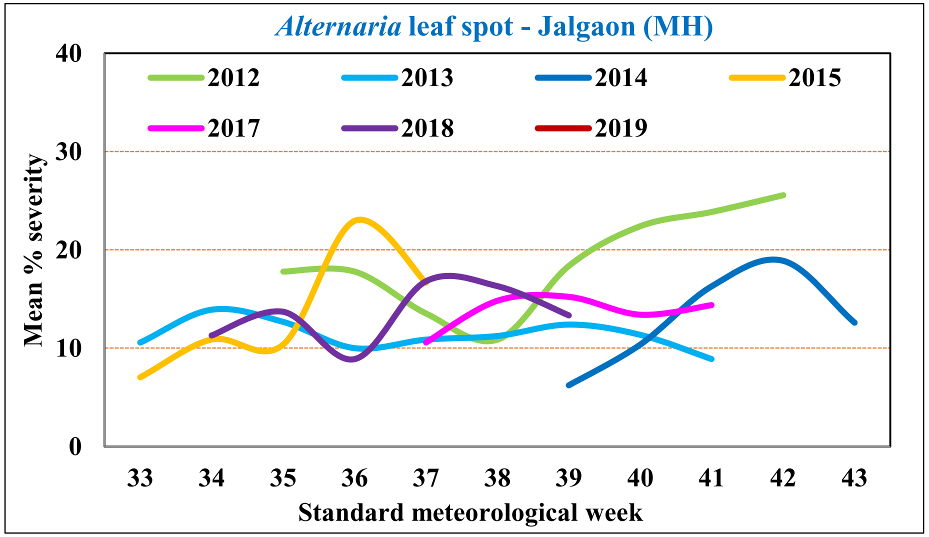


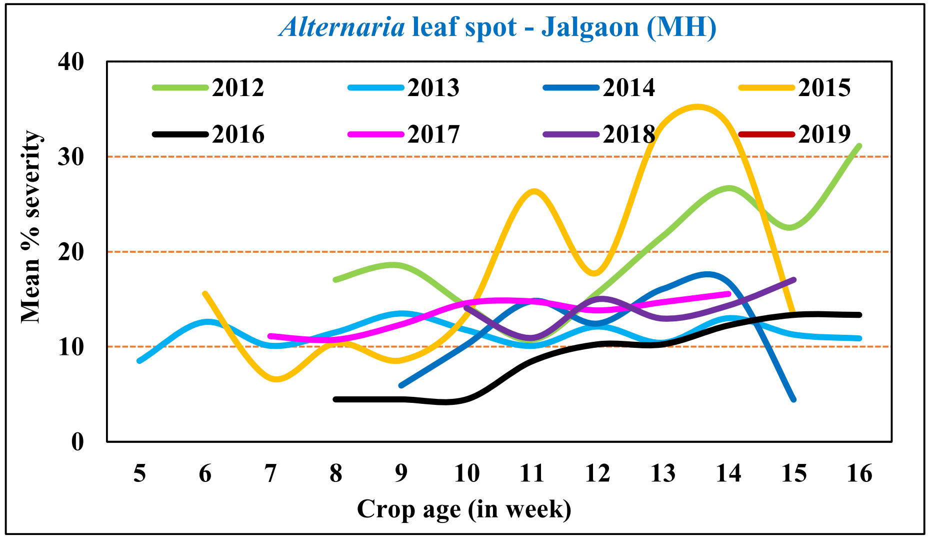
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | Seasonal dynamics based on crop age





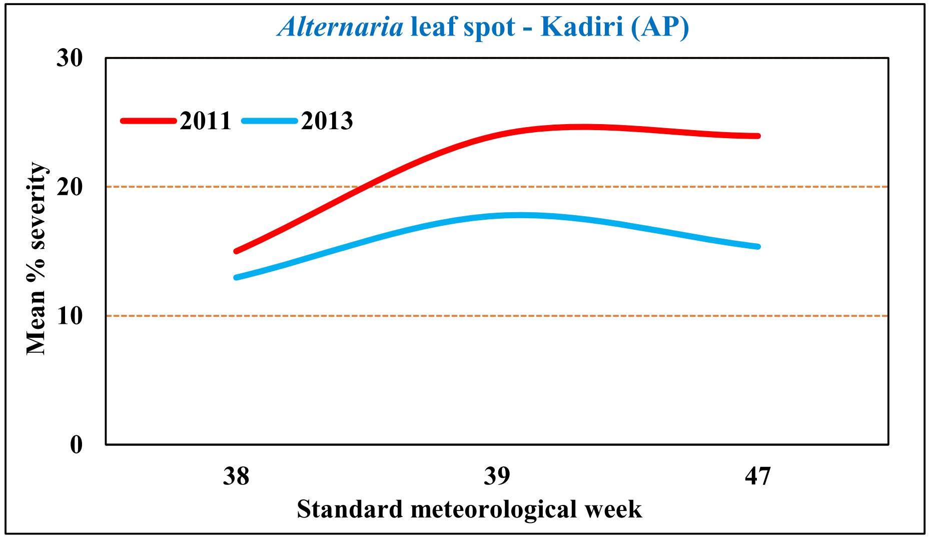


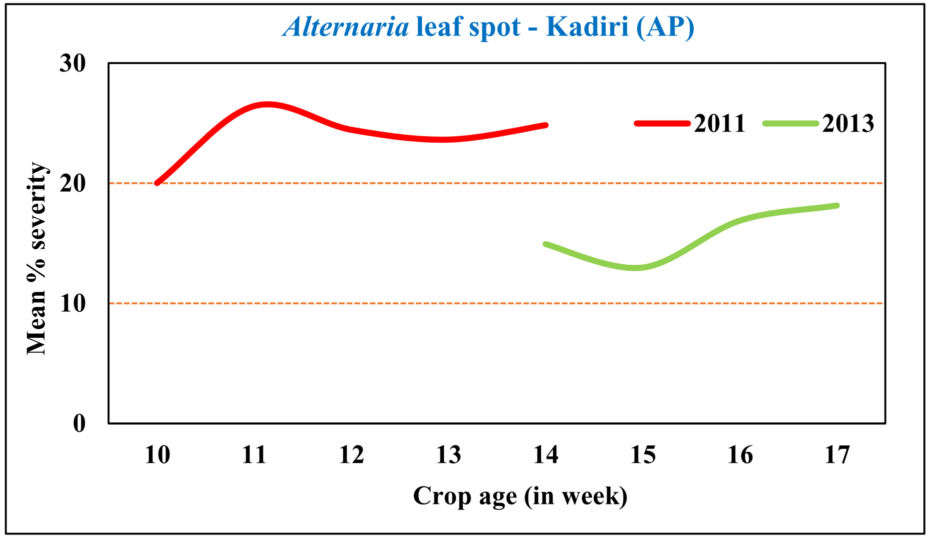


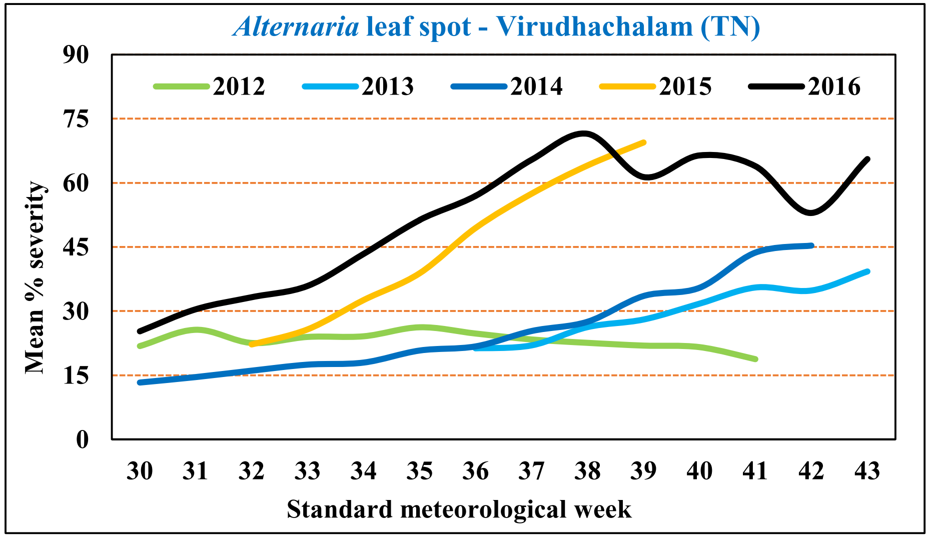
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

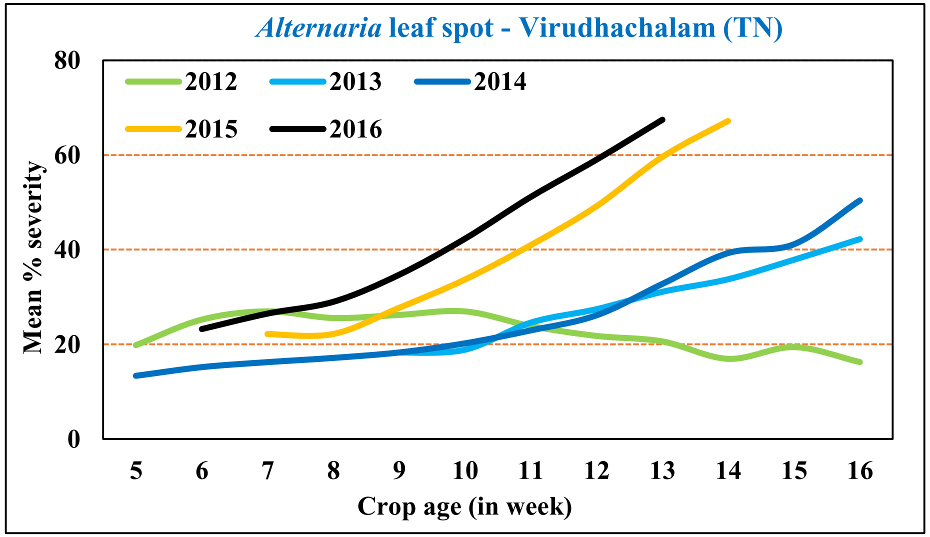
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





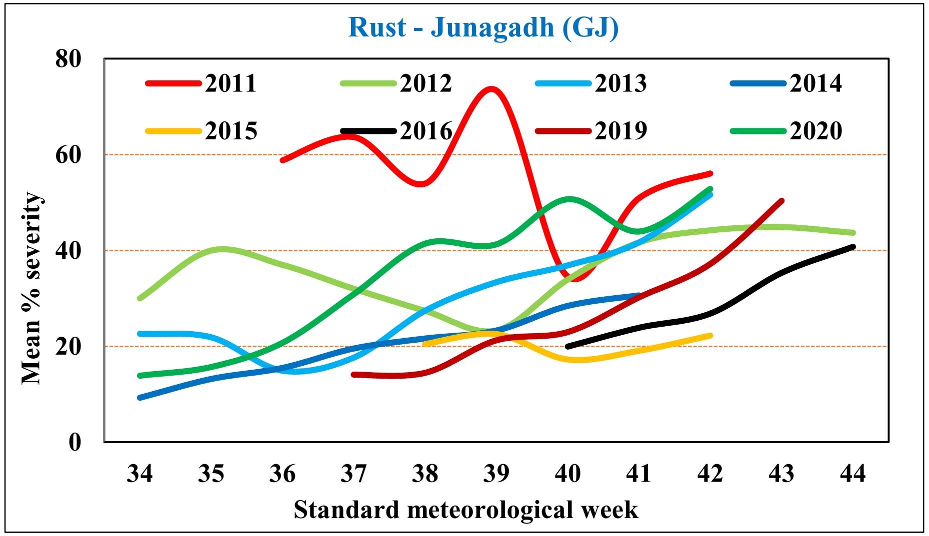


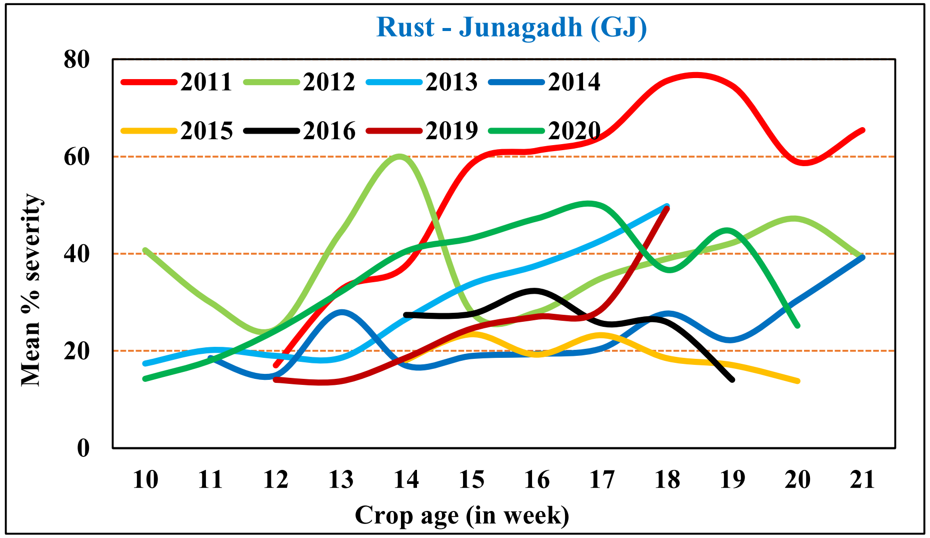


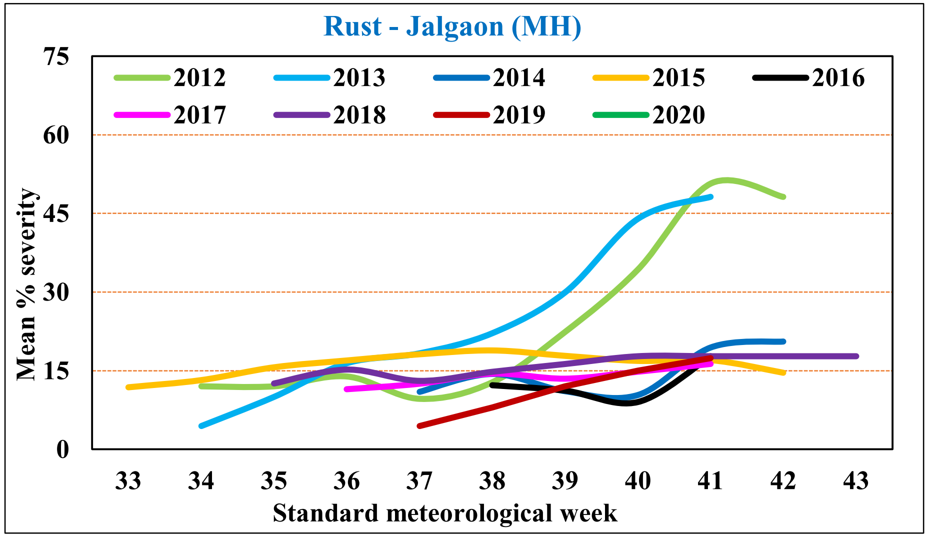
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

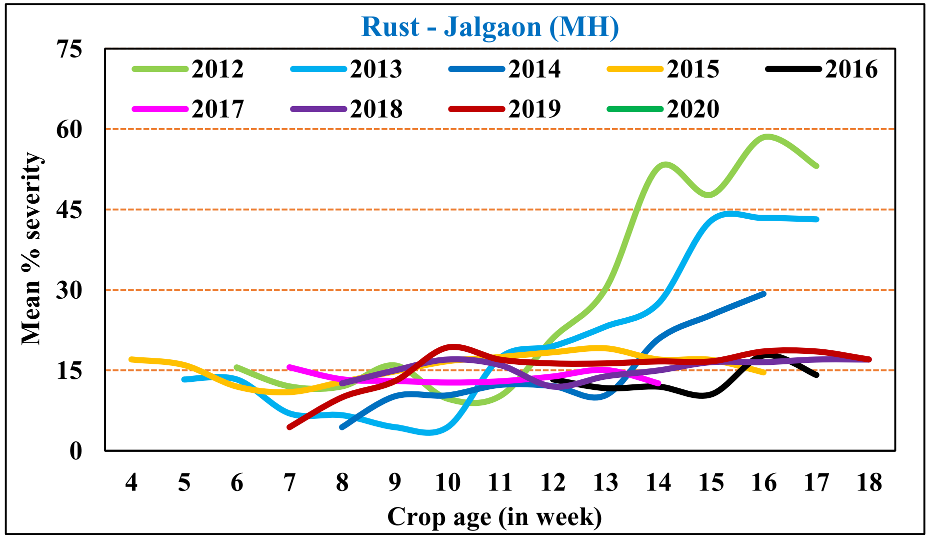
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





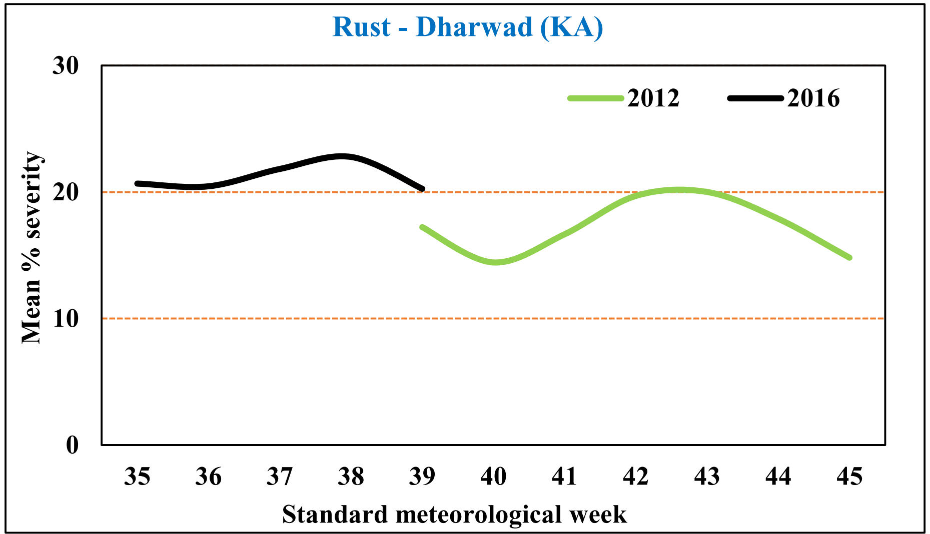


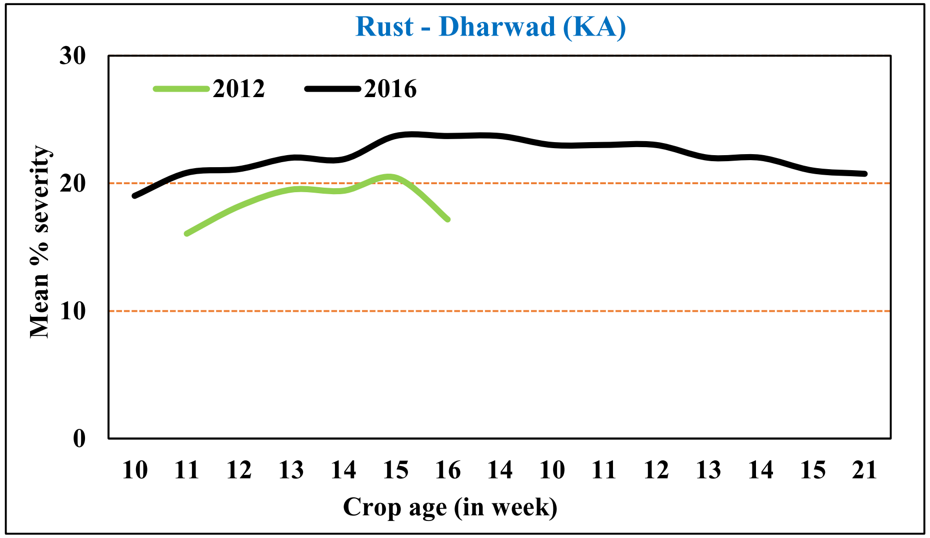


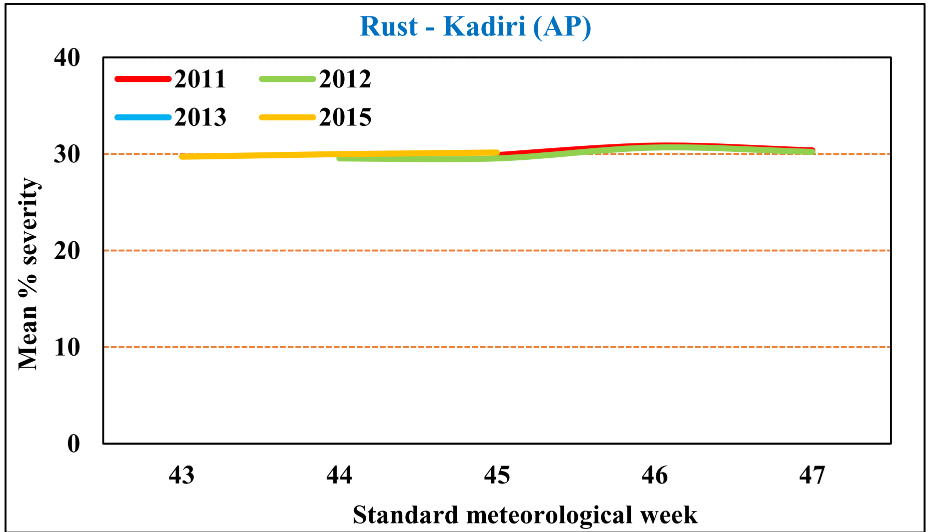
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

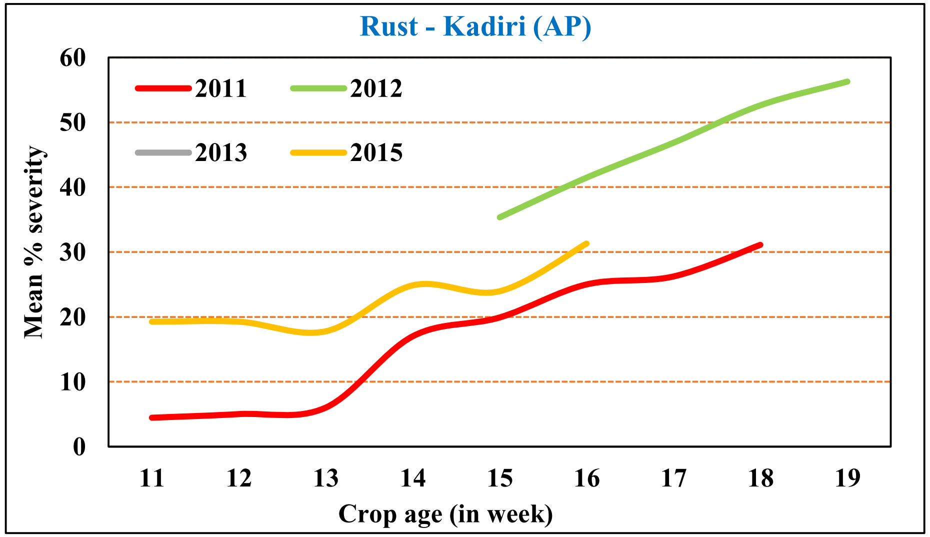
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



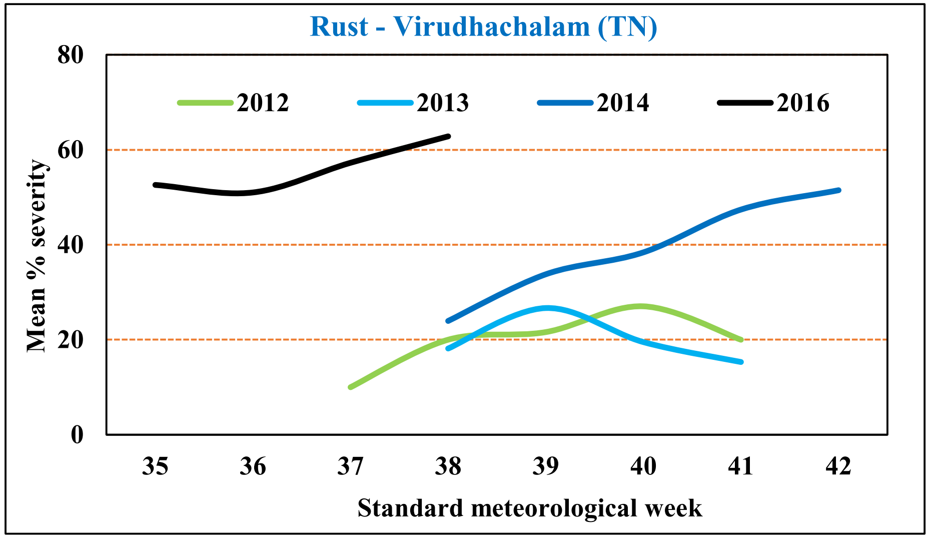


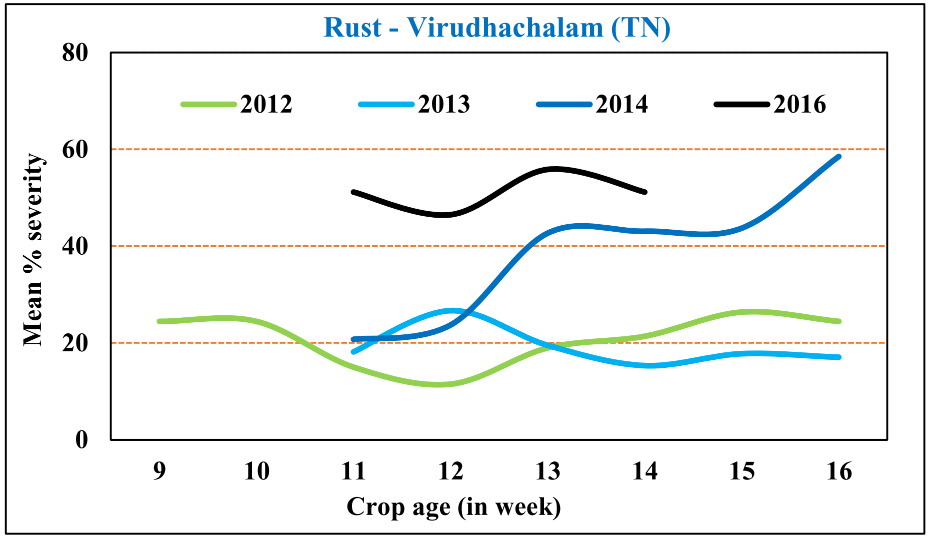


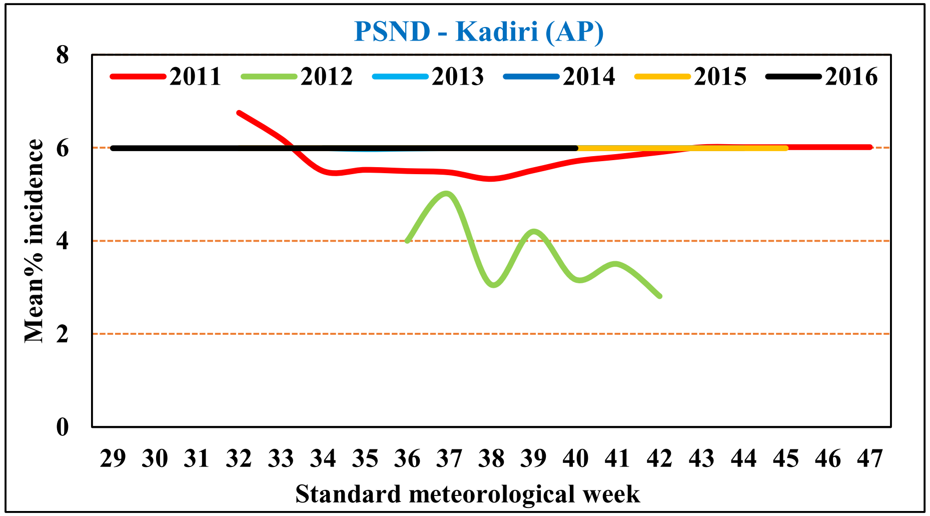


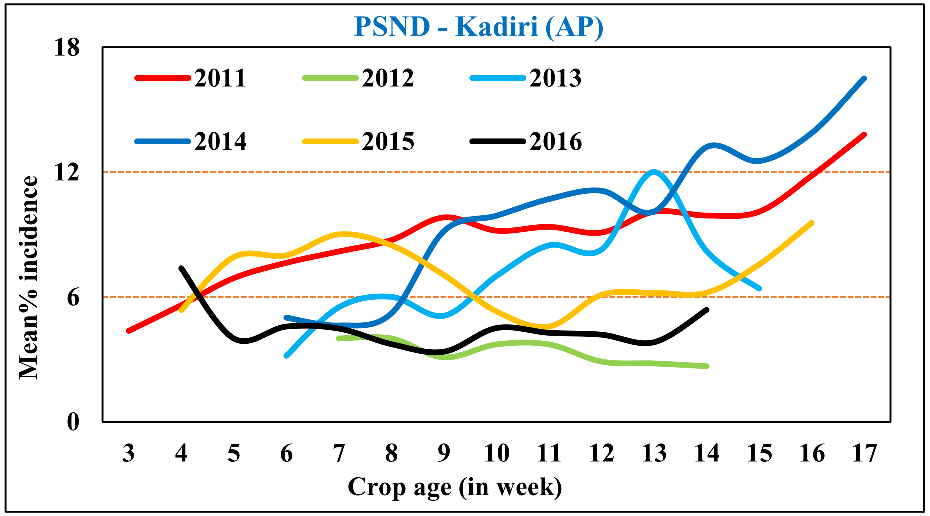
Annexure XXVII: Seasonal dynamics of insect pests and diseases of groundnut [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**









Note: Many legends and less lines shown in a graph denotes abundance/infestation (insects)/incidence/severity (diseases) very less or in traces, respectively

Annexure XXVIII

Impact of climate change on *kharif* groundnut insects and diseases - a listing

Location	Adaptive	Vulnerable
Junagadh (GJ)	1. Early leaf spot* 2. Leaf miner damage 3. Stem rot* 4. Aphid severity* 5. *Alternaria* leaf spot 6. Leaf miner abundance	1. Late leaf spot 2. Jassid infestation* 3. Collar rot* 4. *Spodoptera* damage 5. Jassid abundance* 6. Rust 7. Thrips abundance* 8. *Spodoptera* abundance 9. Aphid infestation 10. Thrips damage*
Jalgaon (MH)	1. Dry root rot 2. Leaf miner abundance 3. Rust* 4. *Alternaria* leaf spot 5. Thrips damage 6. Early leaf spot	1. Aphid infestation 2. Leaf miner damage 3. Aphid severity 4. *Spodoptera* damage 5. Stem rot* 6. Thrips abundance* 7. Late leaf spot 8. Jassid infestation 9. Jassid abundance* 10. *Spodoptera* abundance 11. Collar rot* 12. PBND*
Dharwad (KA)	1. *Alternaria* leaf spot 2. Rust 3. Late leaf spot* 4. Jassid abundance* 5. Thrips damage* 6. Leaf miner damage* 7. Jassid infestation* 8. Leaf miner abundance* 9. Thrips abundance* 10. *Spodoptera* abundance	1. *Spodoptera* damage* 2. Early leaf spot*
Kadiri (AP)	1. Thrips abundance* 2. Leaf miner abundance* 3. Thrips damage 4. PBND* 5. PSND* 6. Jassid abundance 7. Jassid infestation	1. Collar rot 2. Leaf miner damage* 3. Rust 4. Late leaf spot 5. Stem rot* 6. Early leaf spot* 7. Dry root rot*

Impact of climate change on *kharif* groundnut insects and diseases - a listing

Location	Adaptive	Vulnerable
Virudhachalam (TN)	1. Leaf miner damage* 2. Thrips abundance* 3. Thrips damage 4. Aphids infestation 5. Jassid damage* 6. *Spodoptera* abundance* 7. *Spodoptera* damage*	1. Jassid abundance 2. Aphid severity 3. Rust* 4. Leaf miner abundance* 5. Collar rot* 6. Dry root rot* 7. *Alternaria* leaf spot* 8. Stem rot
Insects and diseases have been listed along the order of importance for the cumulative impact of climate change based on species adaptation index values; Symbol * associated with the insect or disease parameter indicates the definitive influence of changing climatic variables (MaxT, MinT and/or RF) irrespective of their significance of their magnitude		

Annexure XXIX
Survey reports on diseases of *kharif* tomato

- Amount of rainfall, distribution and dry spell influenced the disease diversity and its intensity in semi-arid regions of Karnataka. High rainfall, humidity coupled with moderate temperature triggered late blight in Belgaum during 2012. Amount of rainfall and number of rainy days also affected the appearance and severity of bacterial spot, buck eye rot, powdery mildew and *Septoria* leaf spot.

- Late blight was recorded from Belgaum during 2011 with severity of 10.2 % and was absent in 2012 during the same period. Very young crop in several fields were badly hit during July-August by late blight and replanted with cereal crop. The region received about 32, 118 and 61 % more rainfall during June, July and September 2011 respectively compared to 2012. Average minimum temperature ranged from 18.2 to 18.9 ^{0} C during September and June 2011 compared to 18.4 to 20.9 ^{0} C during the same period of 2012. Humidity was also high during June (82 %) and July (93 %) of 2012 compared to 77 and 88 % of July. Conditions to late blight development and spread were favourable during 2012 compared to 2011. Sufficient rainfall and morning fog resulted in favourable conditions for late blight.

- Bacterial spot appeared in severe form in Davangere district, Karnataka with 65.3 % severity during 2011. The region had 12.5 % more number of rainy days between June and September. The region also received 32 % more pre monsoon rains which must have triggered the bacterial spot pathogen. High soil moisture with intermittent rainfall favours the bacterial spot of tomato. However, same disease was absent in 2012.

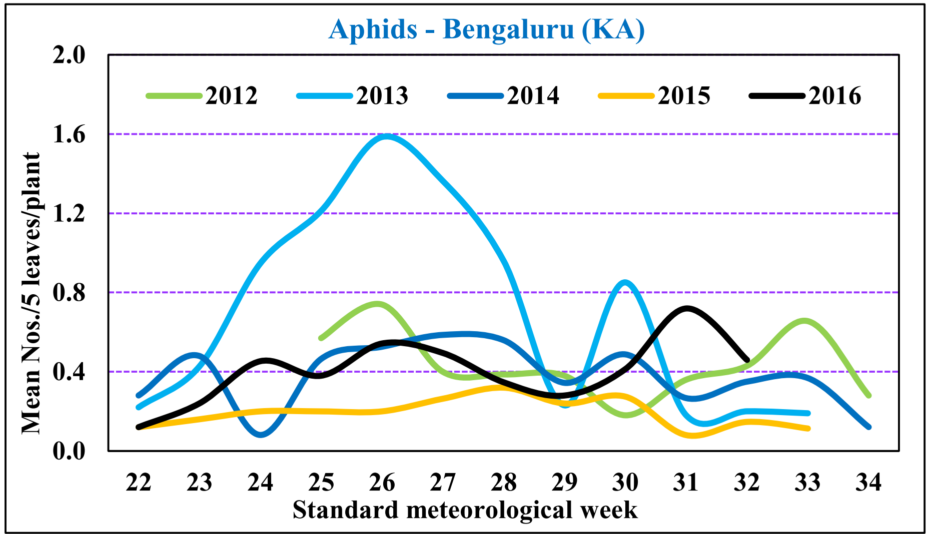
- Buck eye rot favoured by high moisture and humidity was also noticed only during 2011. Powdery mildew was noticed only during 2012 in Belgaum with severity of 27.5 %. Changed disease scenario was prevalent due to less rainfall during 2012 over 2011. Powdery mildew was found favoured by low rainfall and dry spell. In the surveyed regions, there was less rainfall to the tune of 45 %, 35 % and 9 % in Belgaum, Davangere and Havery districts, respectively. Powdery mildew was found favoured by low rainfall and moderate humidity unlike late blight which is favoured by high moisture with moderate temperature. *Septoria* leaf spot, though occurred at low level during 2011, did not appear during 2012 which could be attributable to the high humidity coinciding with monsoon.

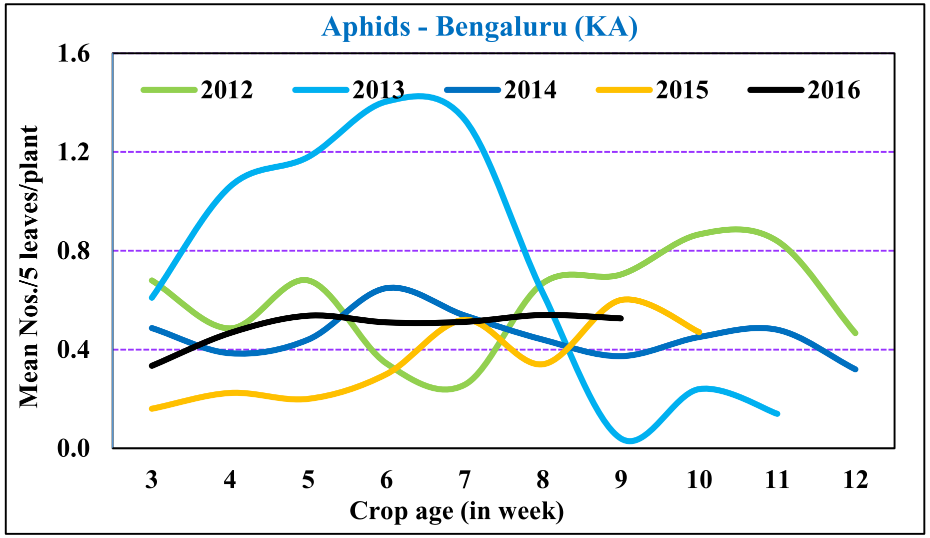
- Disease scenario of tomato in mid - hills and sub-tropical plains was carried out during August – December 2011-12. Nine disease *viz*., early blight (*Alternaria solani*), late blight (*Phytophthora infestans*), *Phoma* leaf spot (*Phoma lycopersici* (Syn. *Phyllosticta lycopersici*), *Septoria* leaf spot (*Septoria lycopersici*), bacterial spot (*Xanthomonas campestris* pv *vesicatoria*), bacterial wilt (*Ralstonia solanacearum*), powdery mildew (*Oidim* sp.), leaf curl (tomato leaf curl virus) and buck eye rot (*Phytophthora nicotianae* var. *parasitica*) were reported from Solan during both the years with varying intensities. During 2011, bacterial spot was predominant (26.4%), while *Septoria* leaf spot dominated (41.1%) during 2012. High soil moisture with intermittent rainfall favour bacterial spot of tomato. Early blight once reported to be dominant occurred at moderate levels. Scenario of late blight, bacterial wilt, leaf curl and buck eye rot remained almost similar in both the years. Powdery mildew which occurred at low level during 2011 failed to appear in 2012. *Phoma* leaf spot was found as an emerging disease, which together with bacterial spot and late blight could limit tomato production in mid hills. Moderate temperature and high rainfall (>800 mm) during the growing season may be responsible for growth, development and spread of late blight, *Septoria* leaf spot, bacterial leaf spot and buck eye rot in Solan.

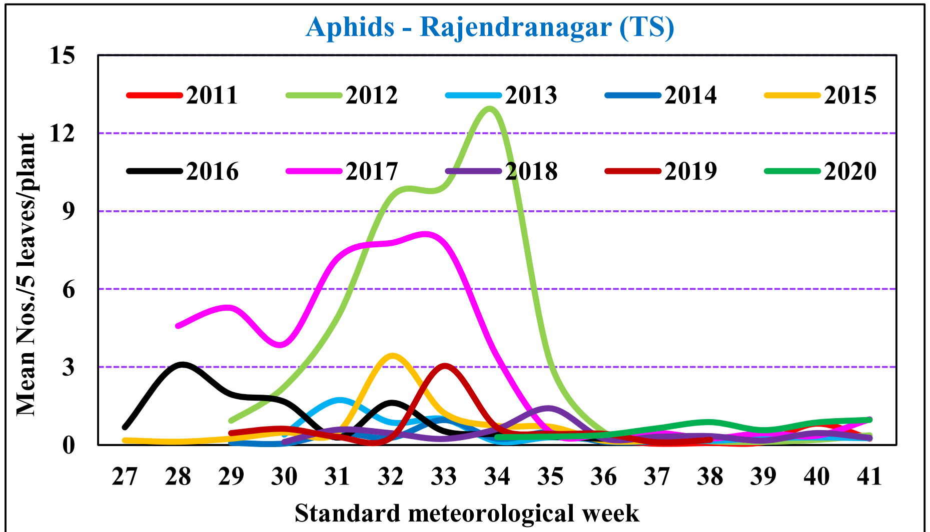
- In Chhattisgarh, diseased scenario varied wherein early blight, *Fusarium* wilt, powdery mildew and leaf curl were prominent. *Phoma* leaf spot, *Septoria* leaf spot, late blight, bacterial spot and buck eye rot which are favoured by high moisture and moderate temperature in mid hills were absent in Chhattisgarh. On the contrary, *Fusarium* wilt, which was absent in mid hills was noticed in Chhattisgarh albeit low level. *Fusarium* wilt was serious at 25 to 30 C. Early blight was recorded at moderate level in both the years (12.9 to 36.4 %). Powdery mildew was recorded at low level of 3.3 to 5.5 %. In UP, early blight was severe (80%) in Barabanki, followed by Etah and Kanpur wherein the severity was 52.4 and 47.9 %, respectively. Barabanki received 60 mm rainfall during May, 2011, which is 159 % higher than the normal (IMD, 2008-2012) that seemed to have favoured early blight development and spread. Incidence of *Sclerotium* wilt was low (2.2%) in Kanpur and incidence of leaf curl was negligible in 2012.

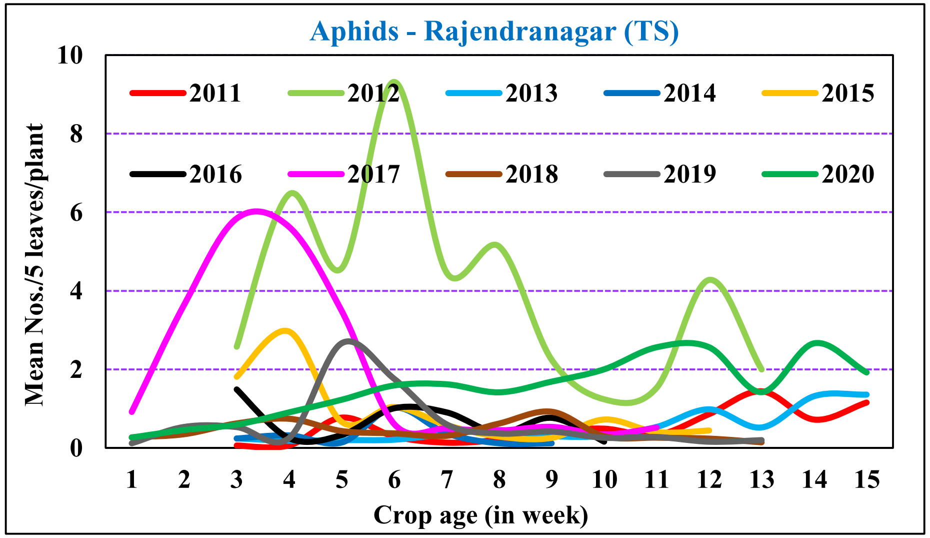
Annexure XXX: Seasonal dynamics of insect pests and diseases of *kharif* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**









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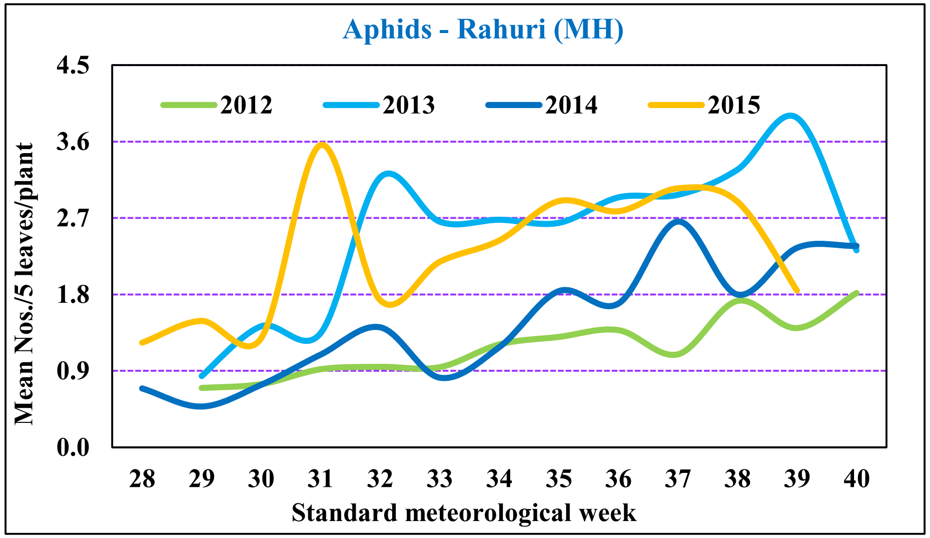

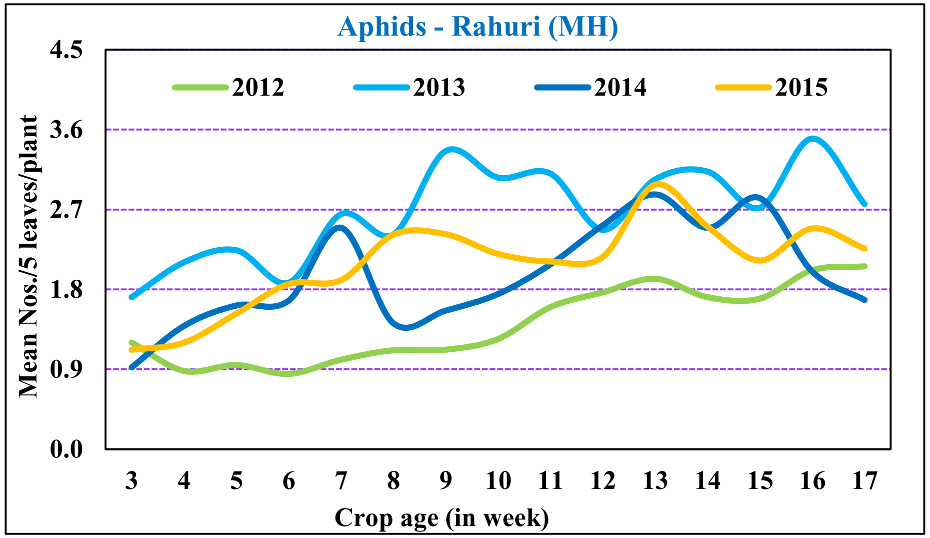

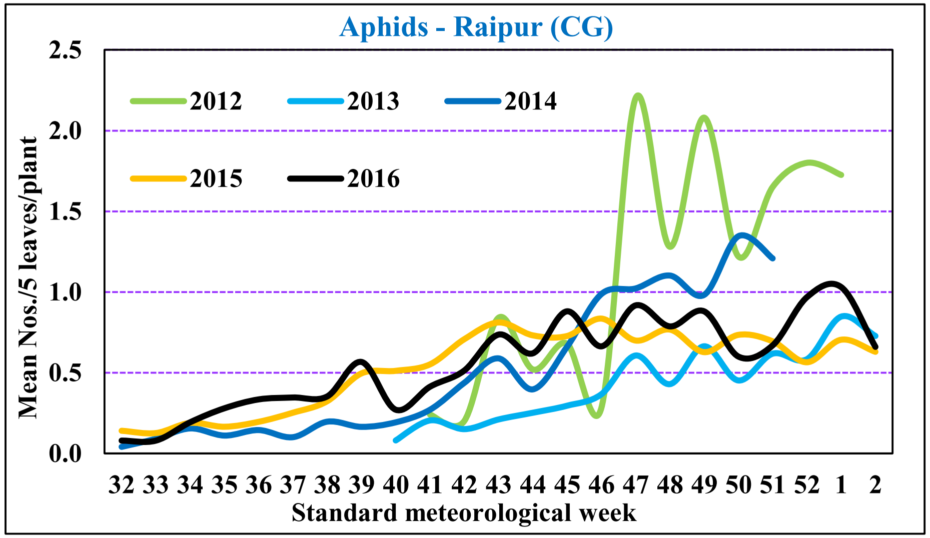

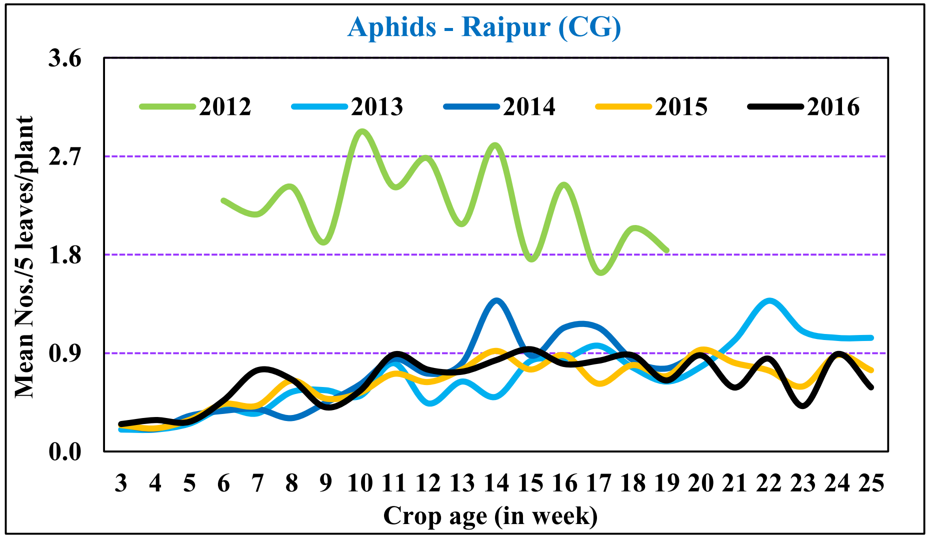

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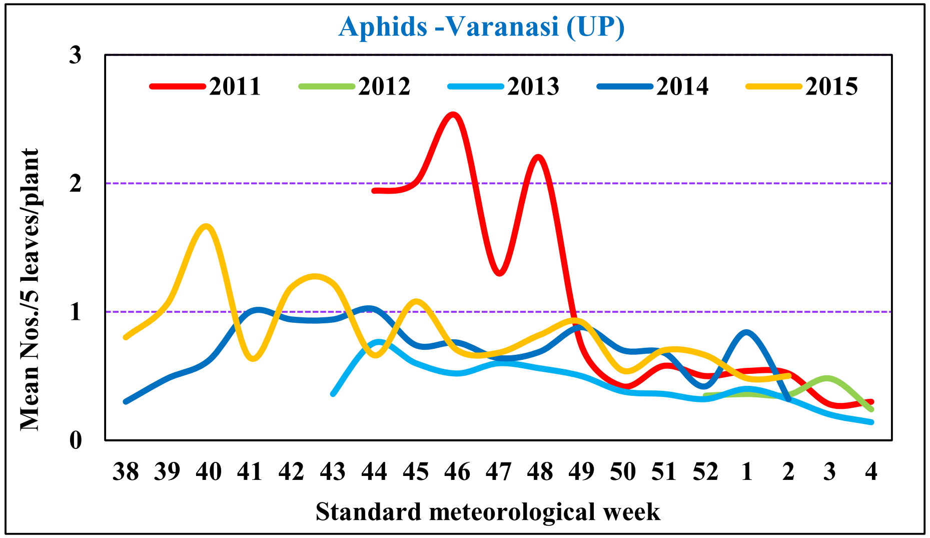

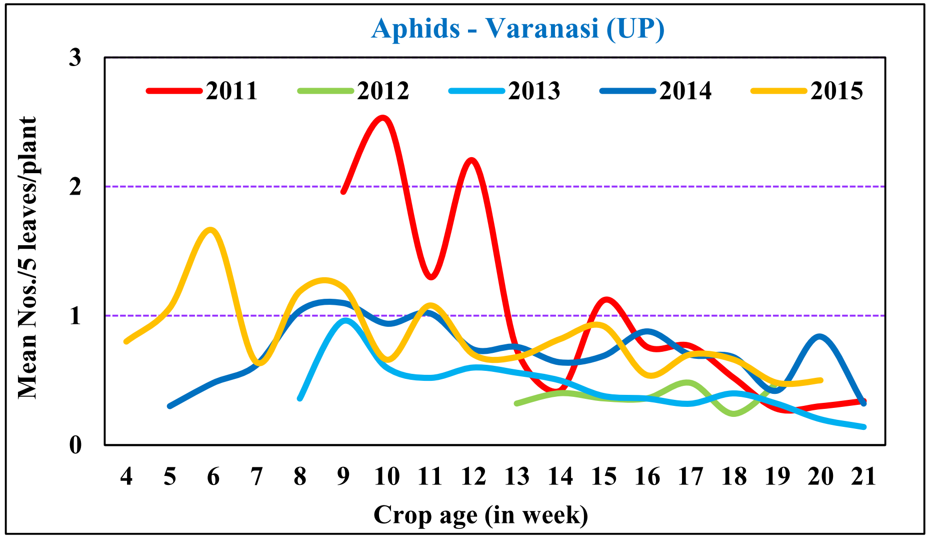

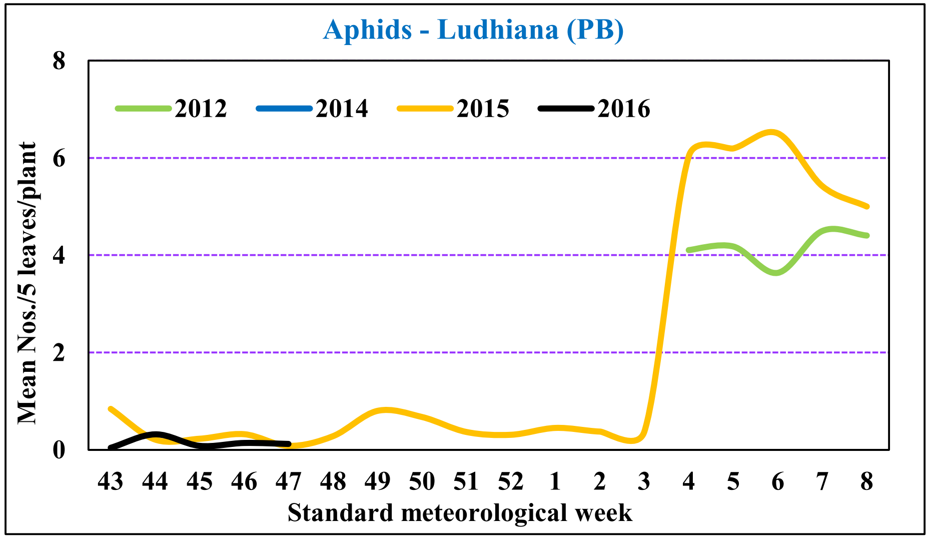

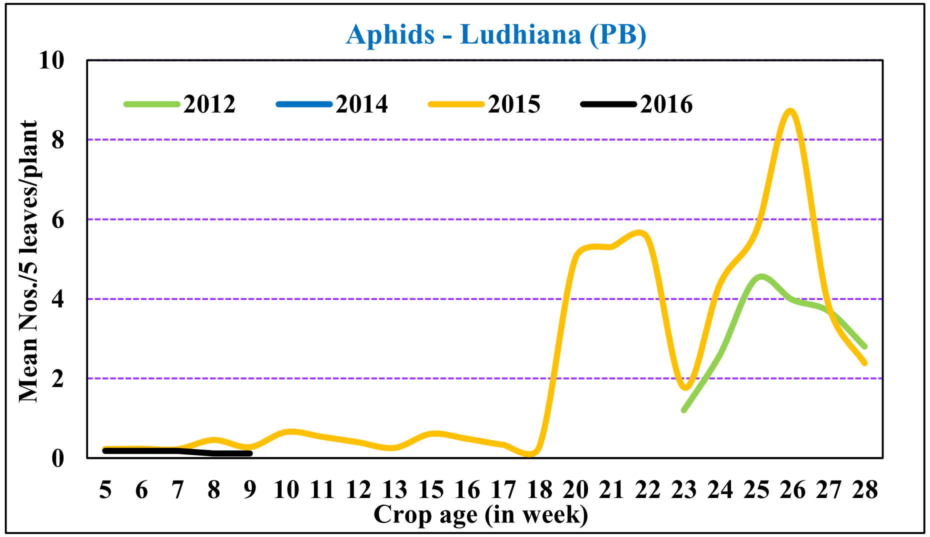

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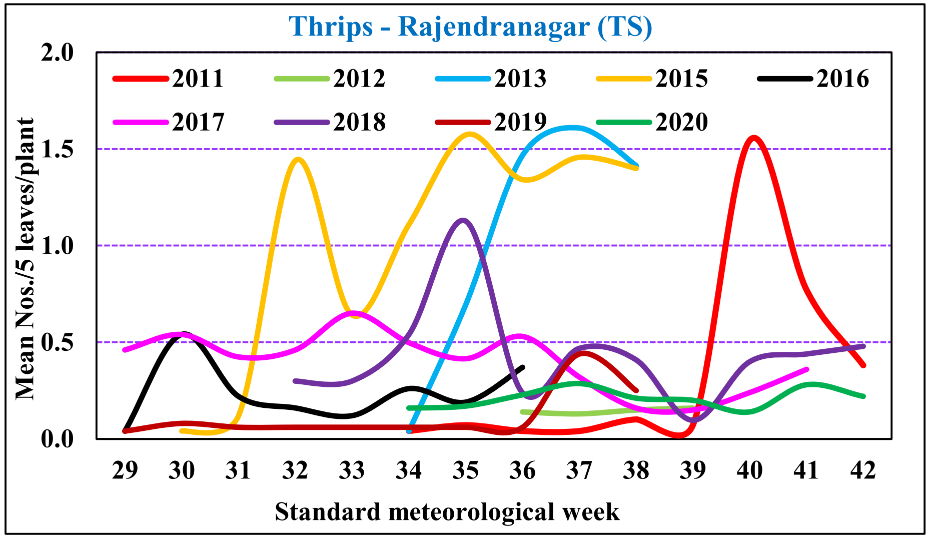

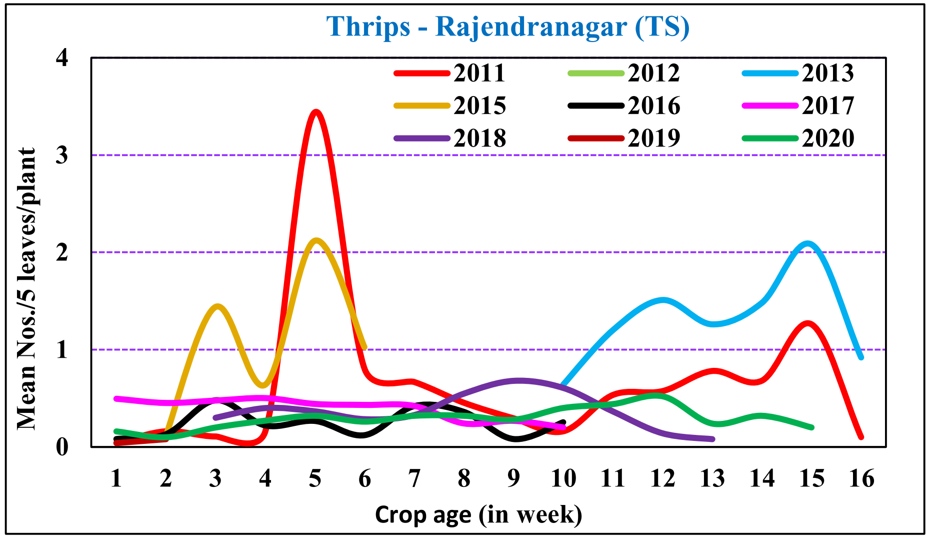

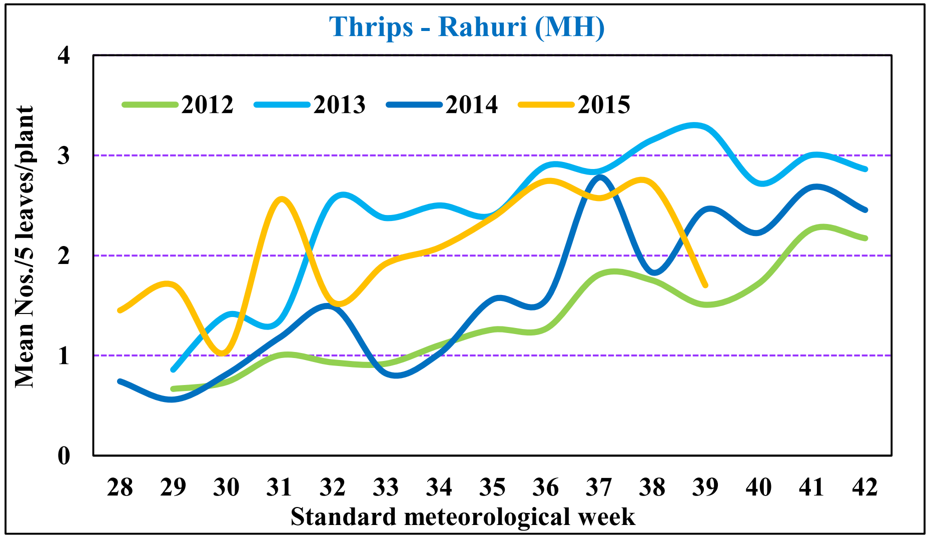

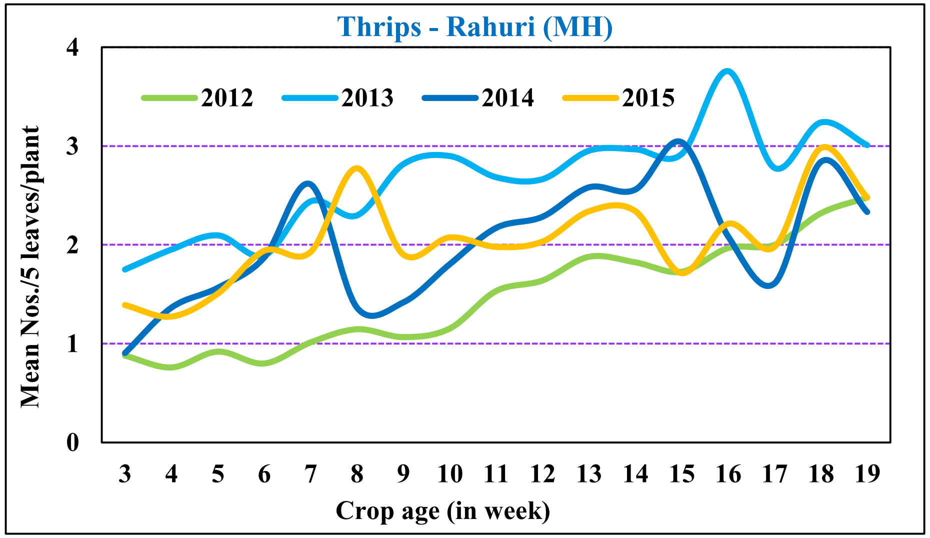

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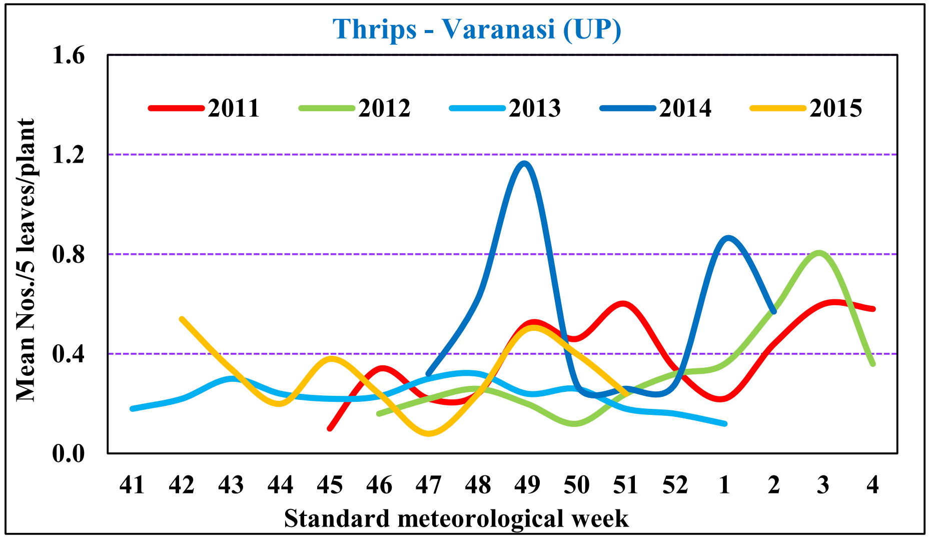

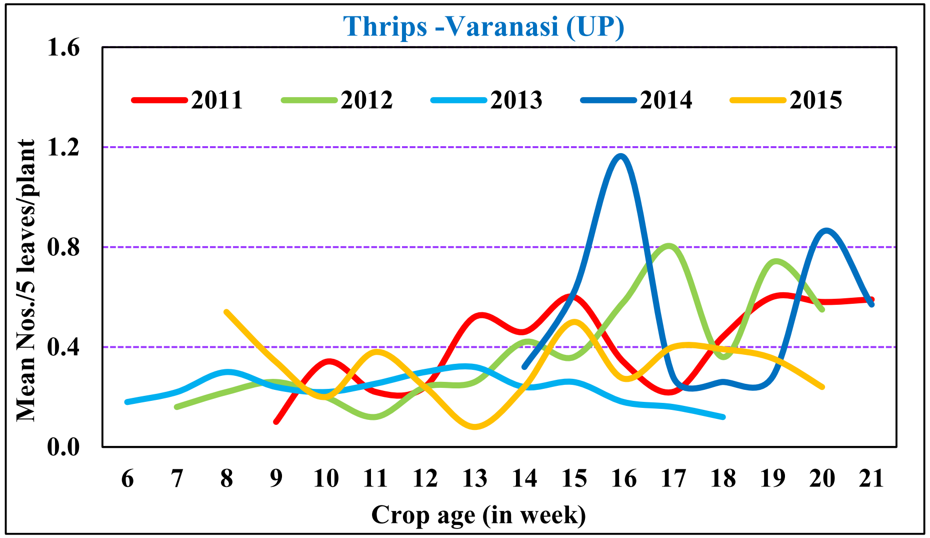

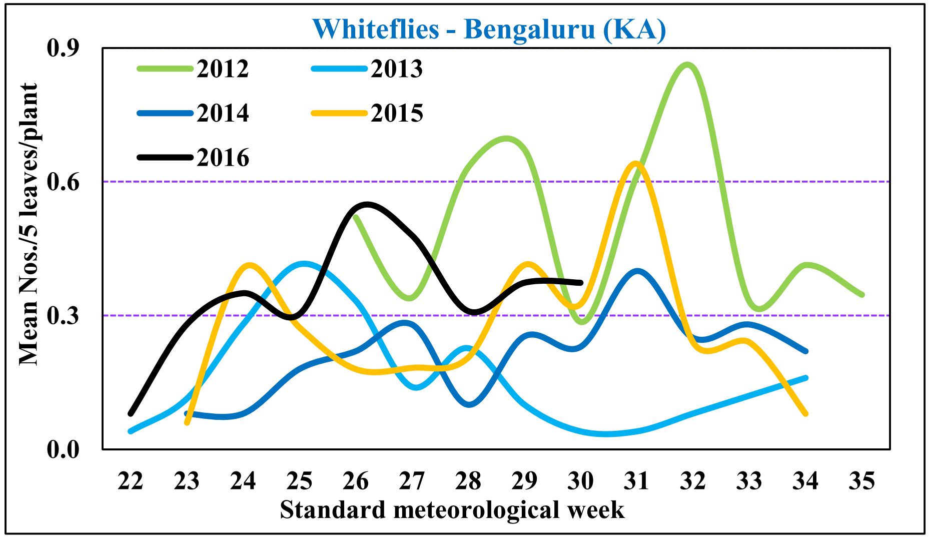

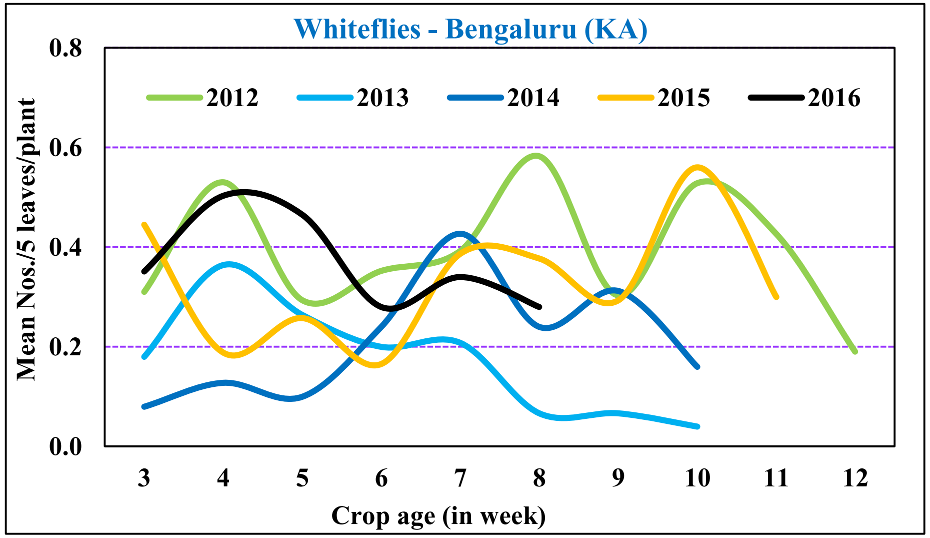

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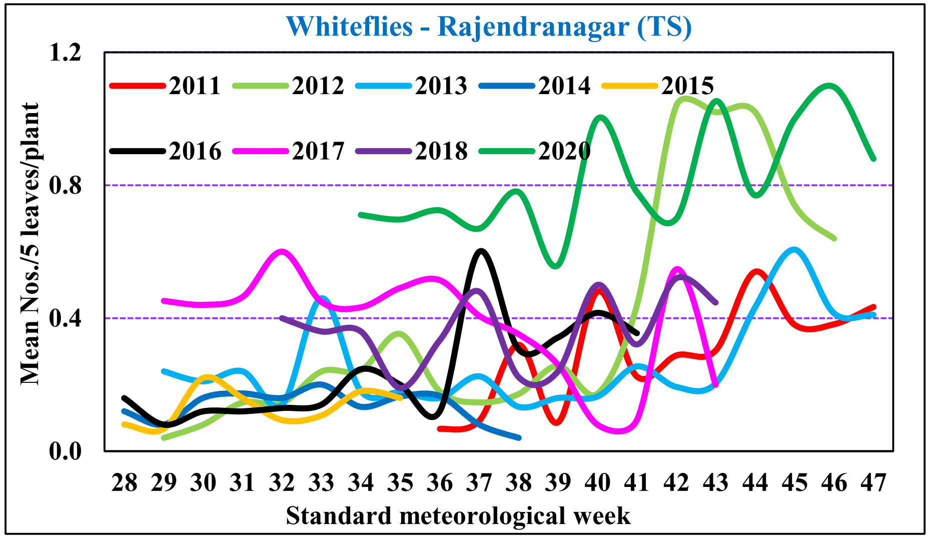

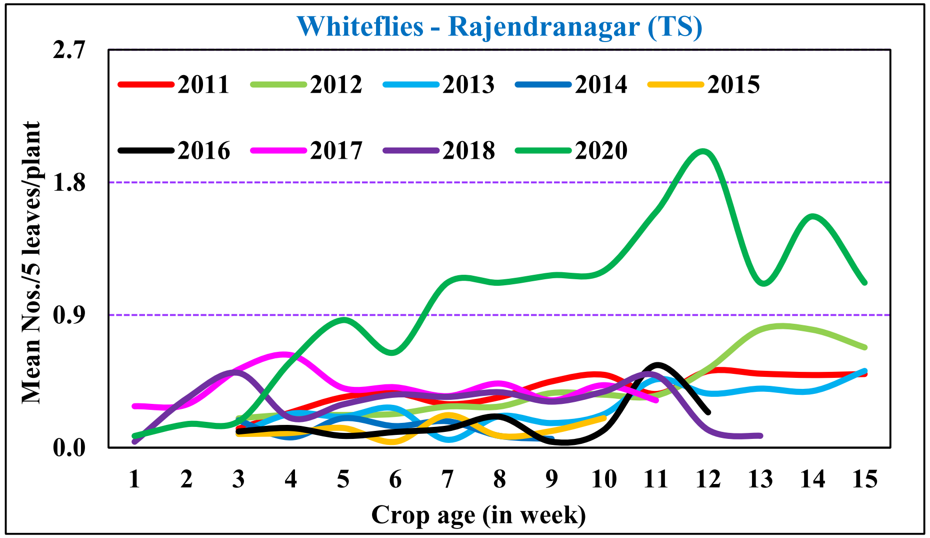

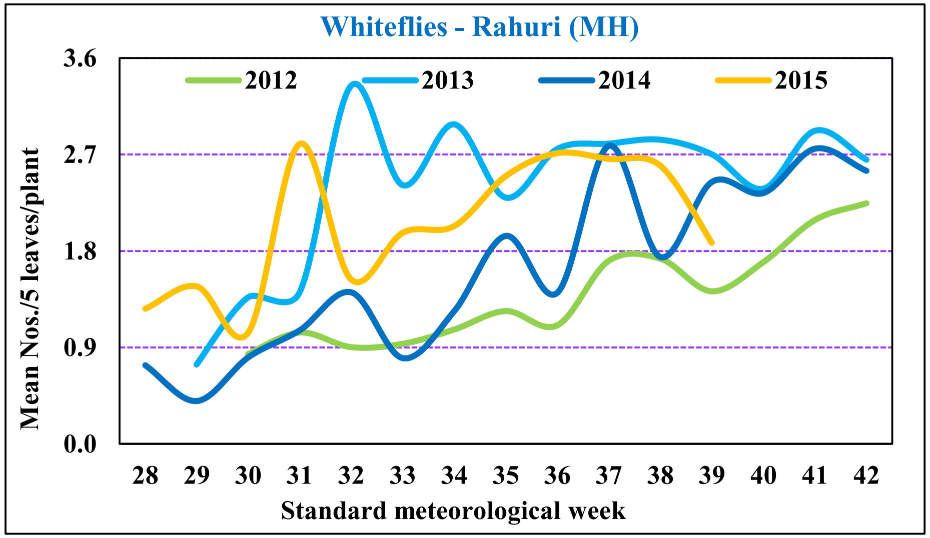

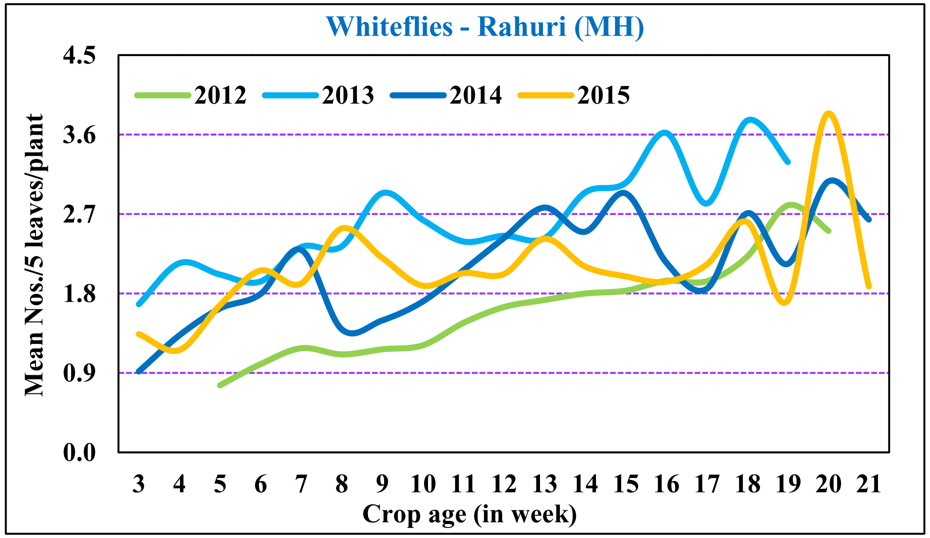

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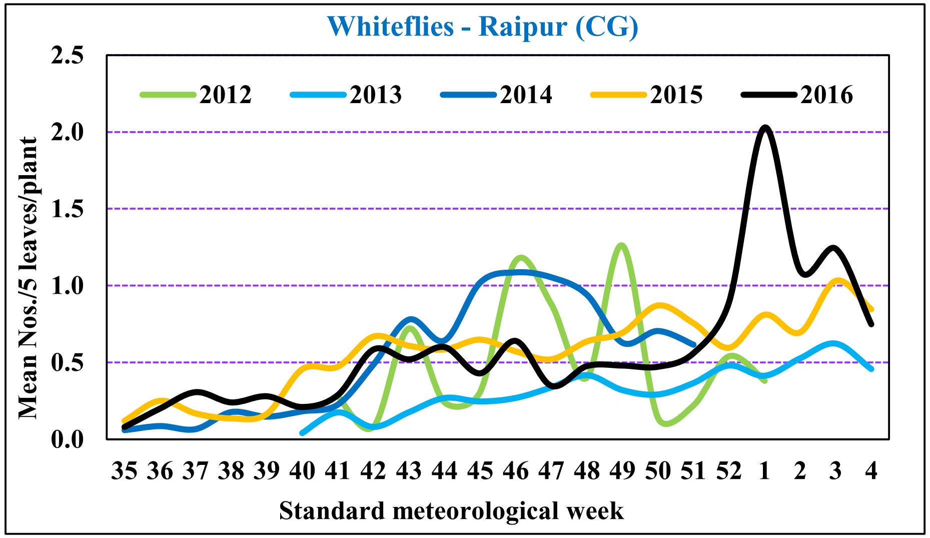

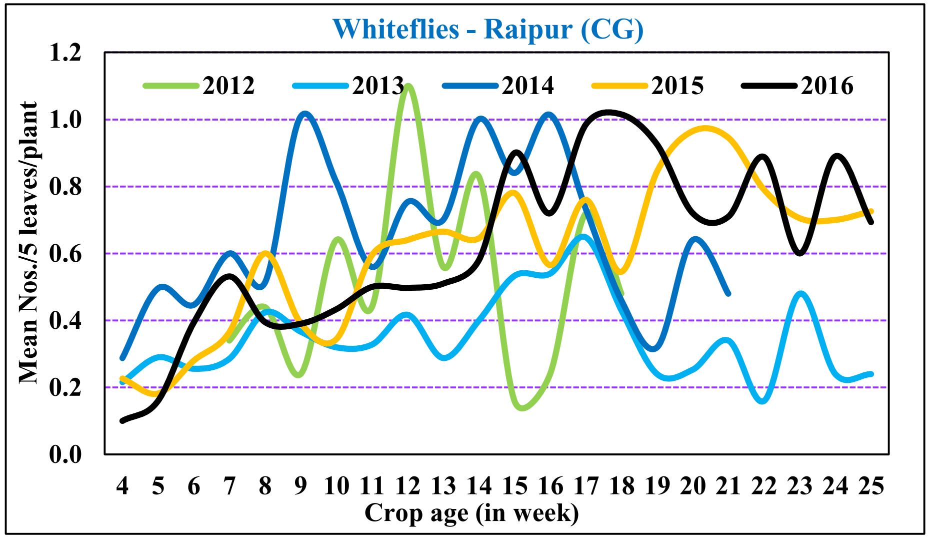

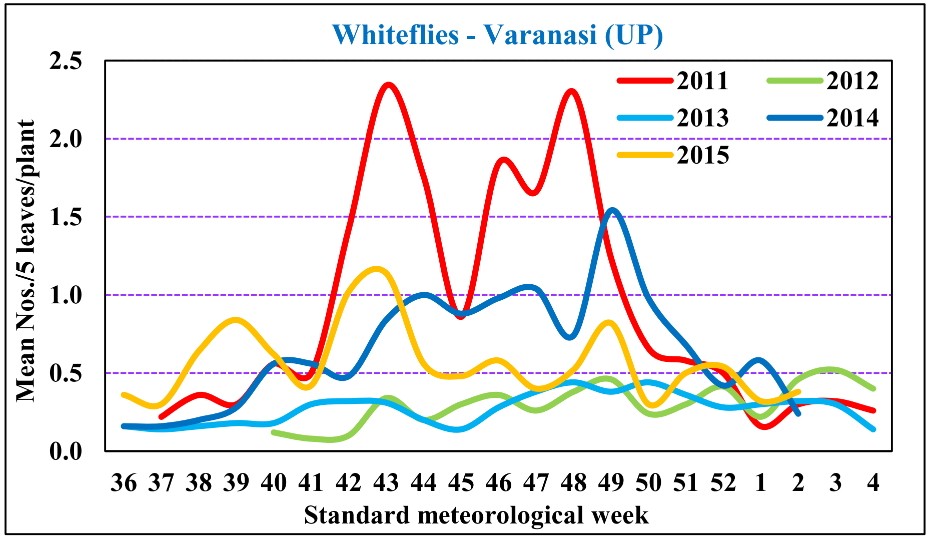

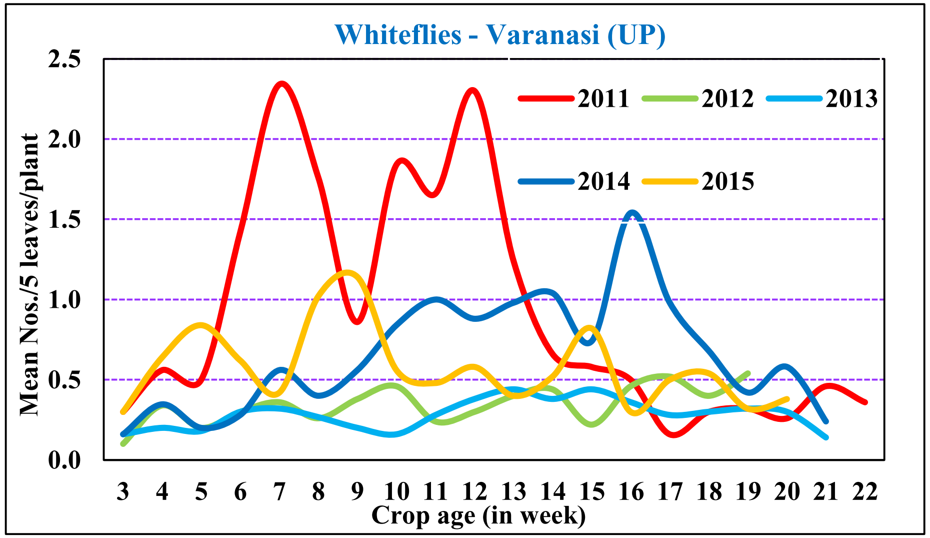

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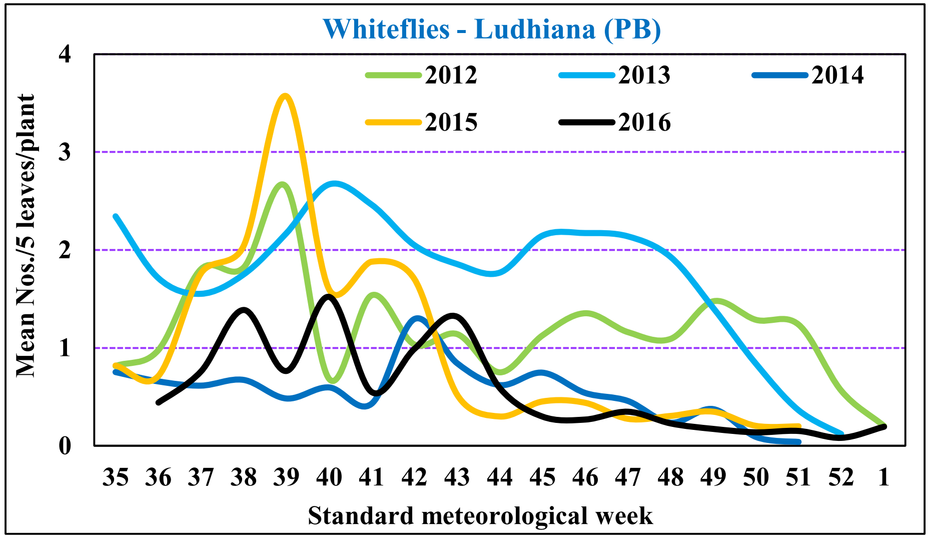

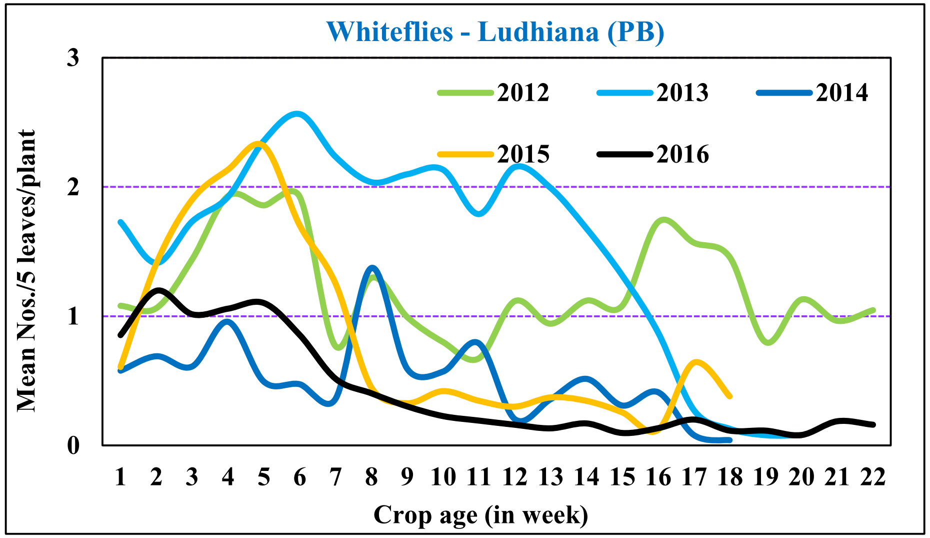

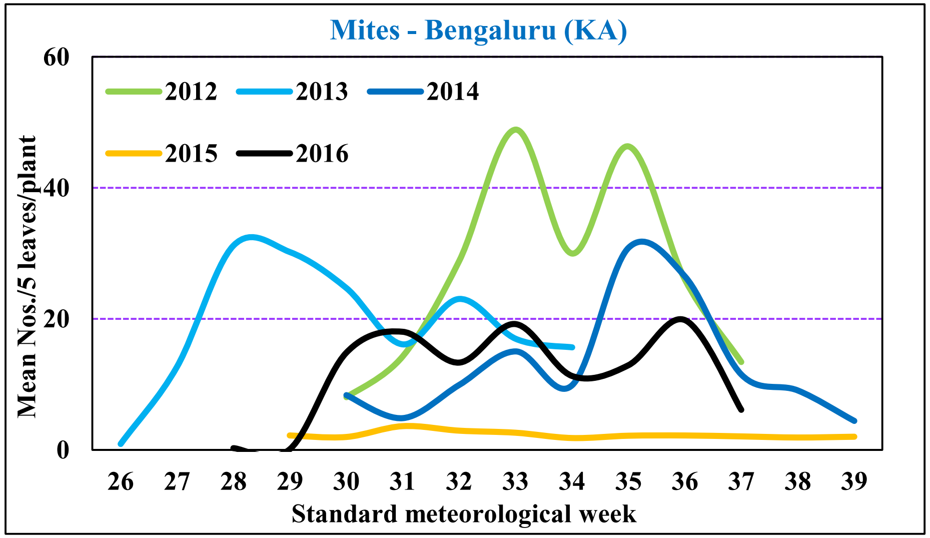

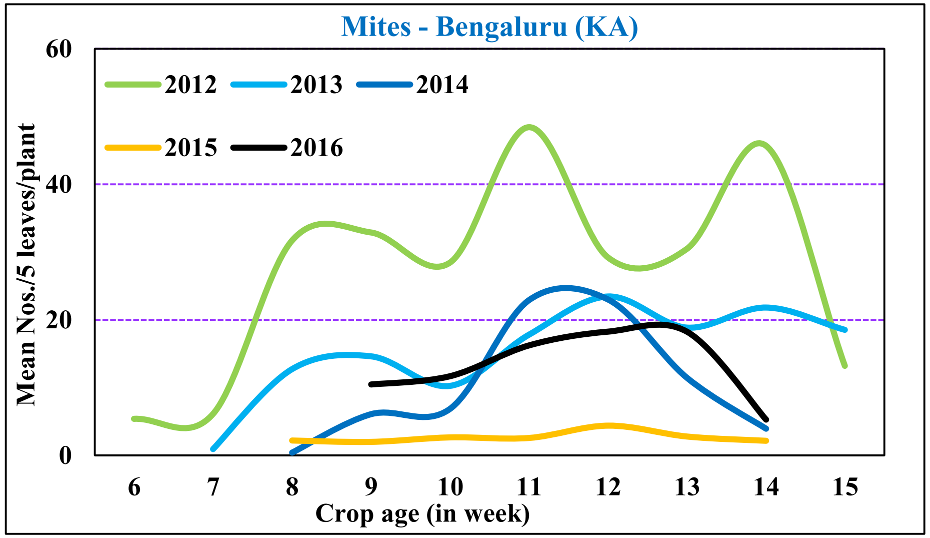

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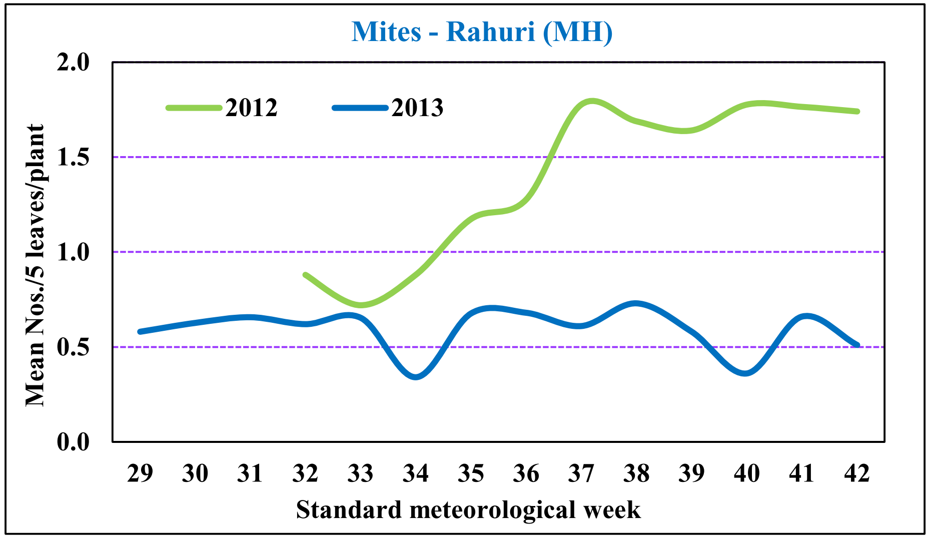

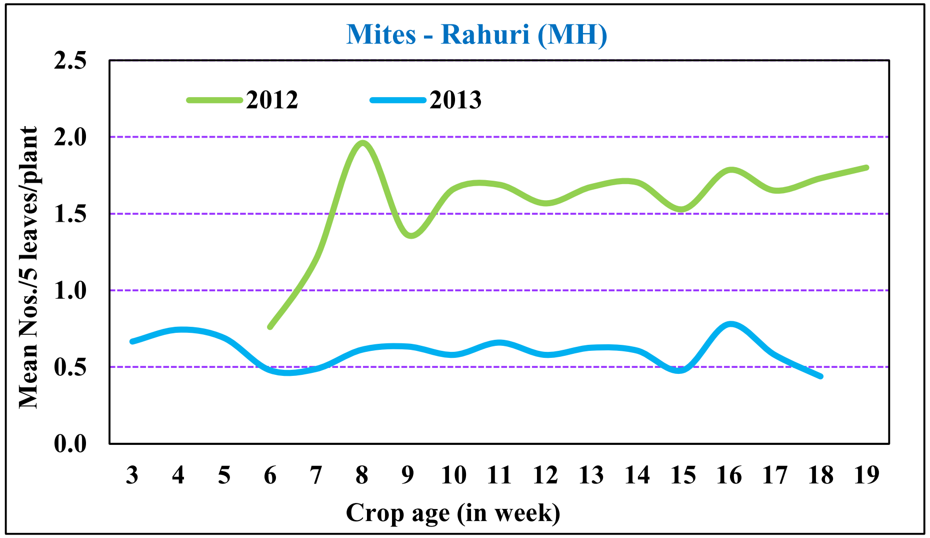

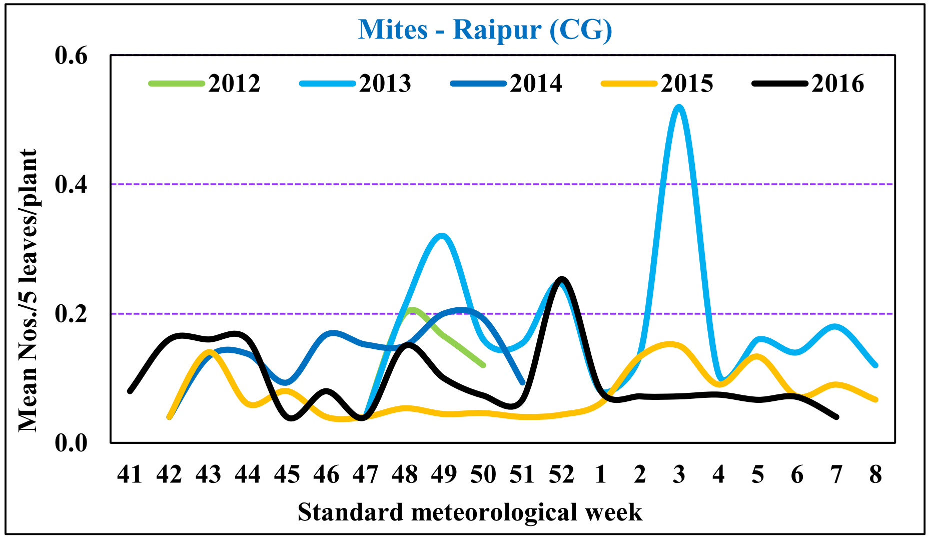

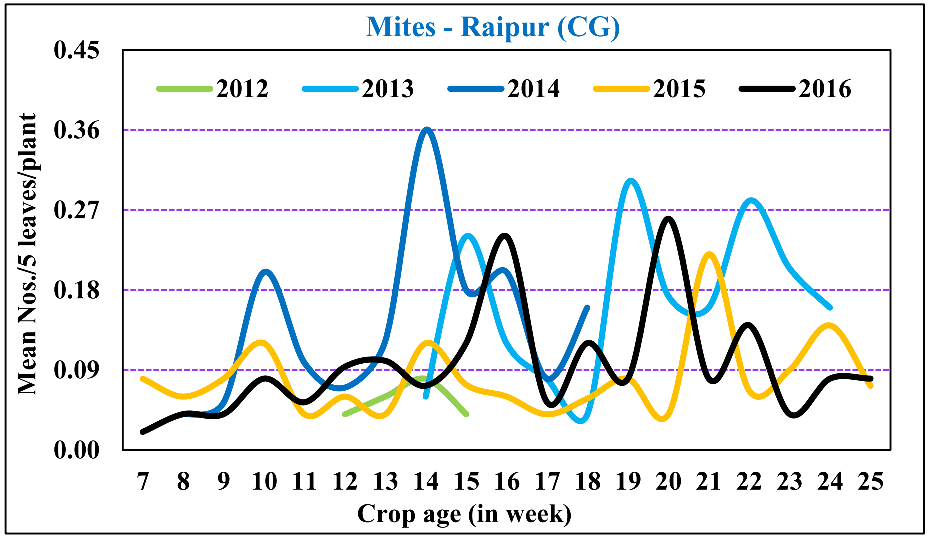

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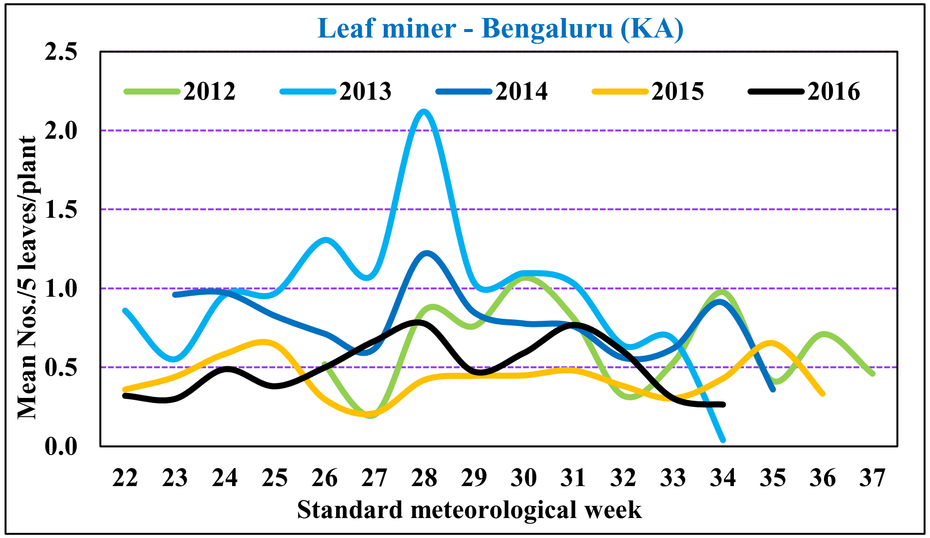

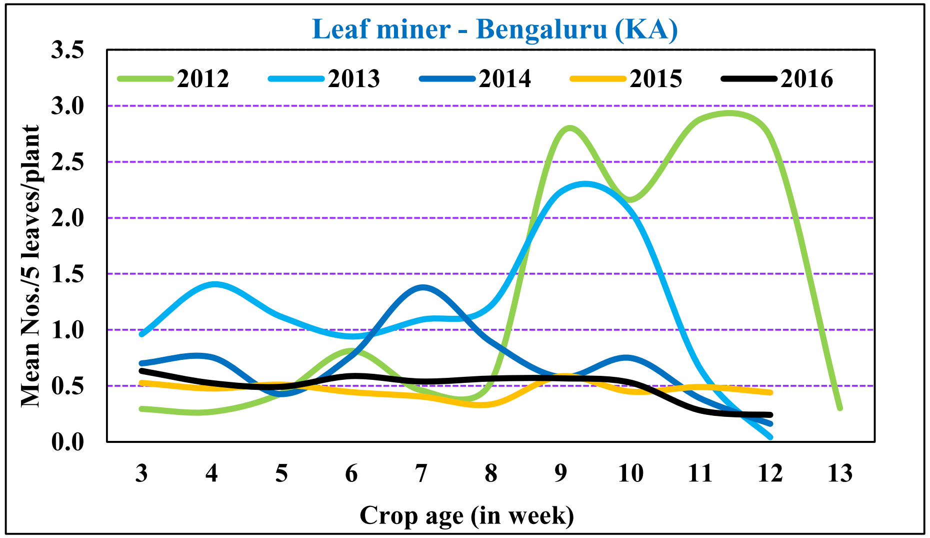

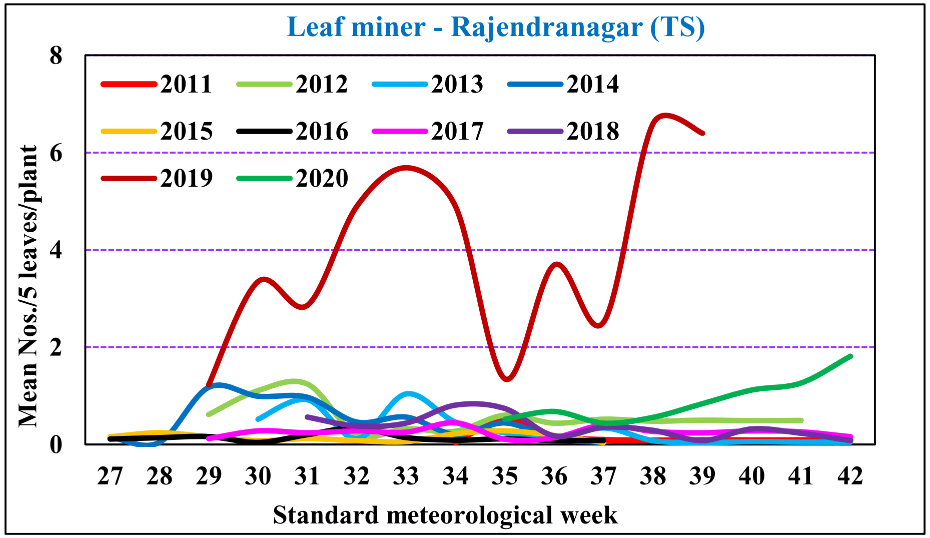

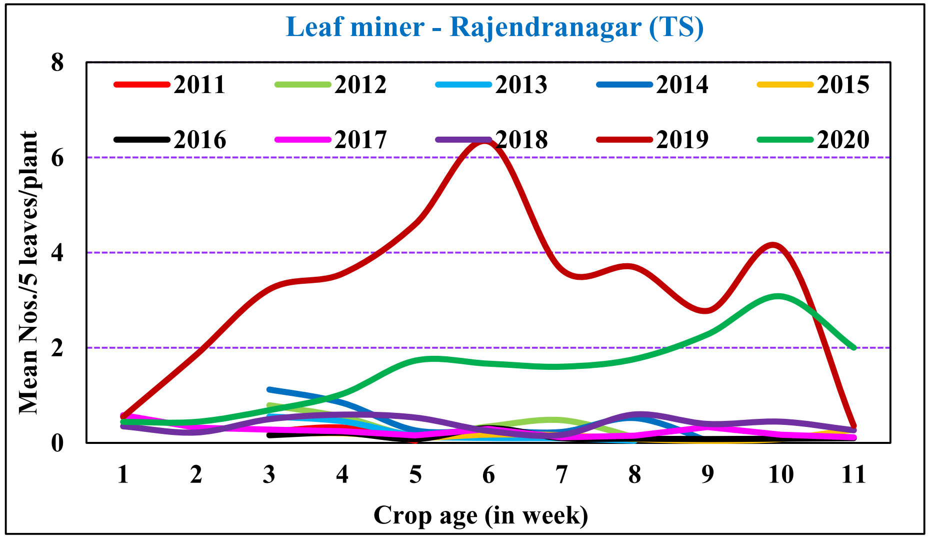

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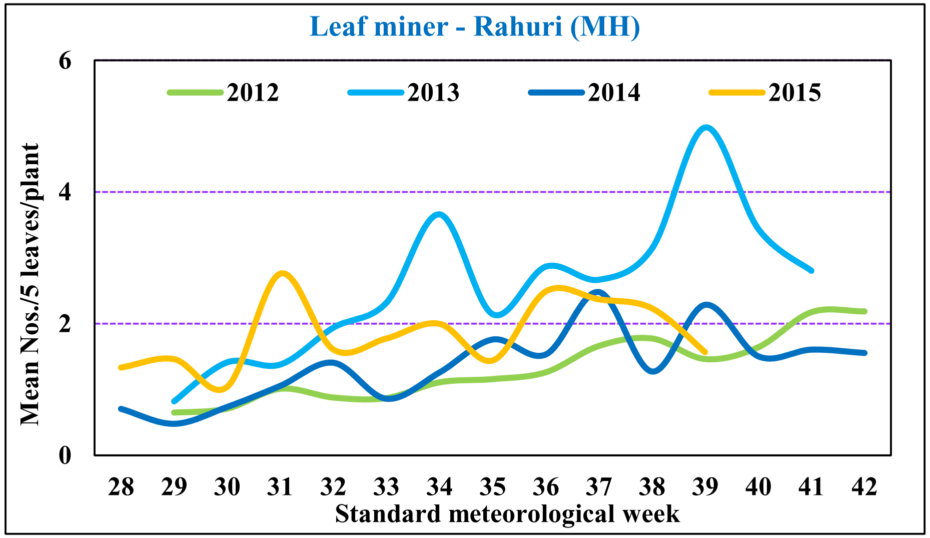

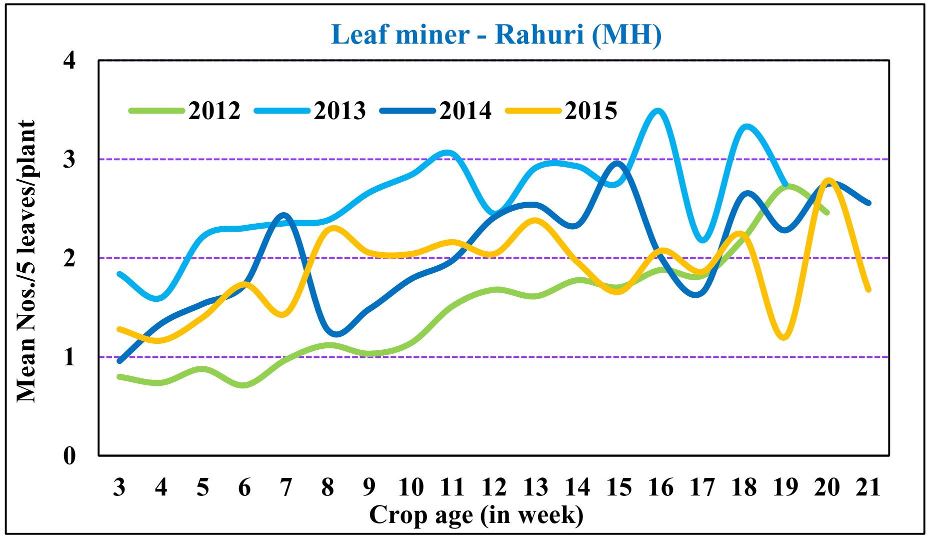

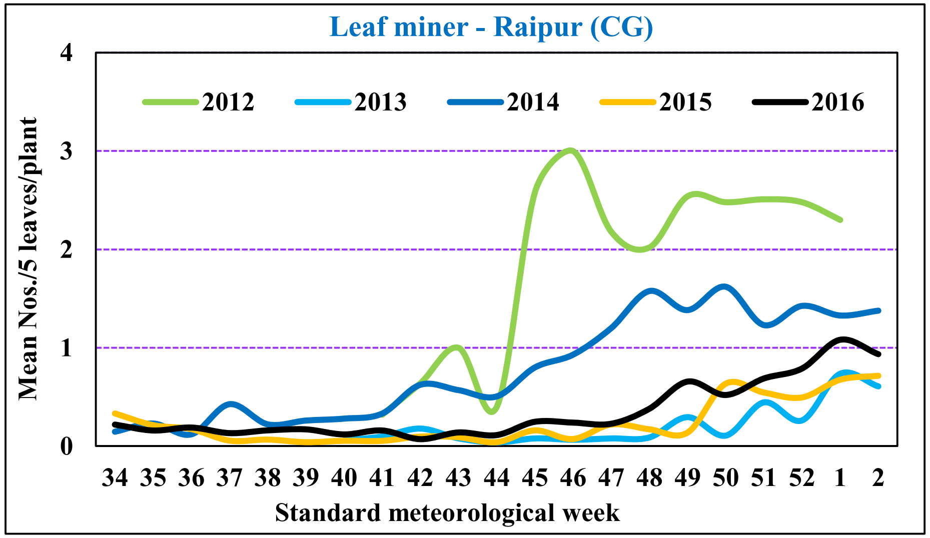

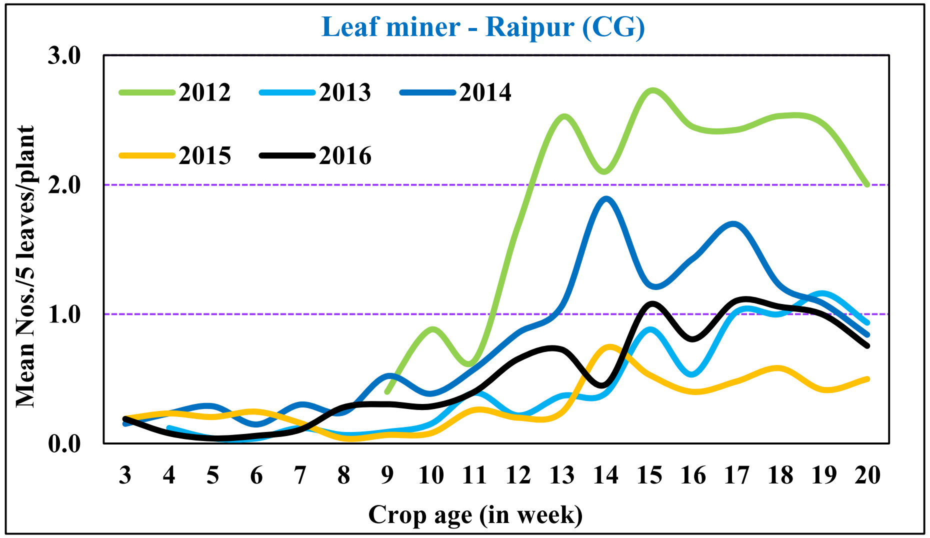

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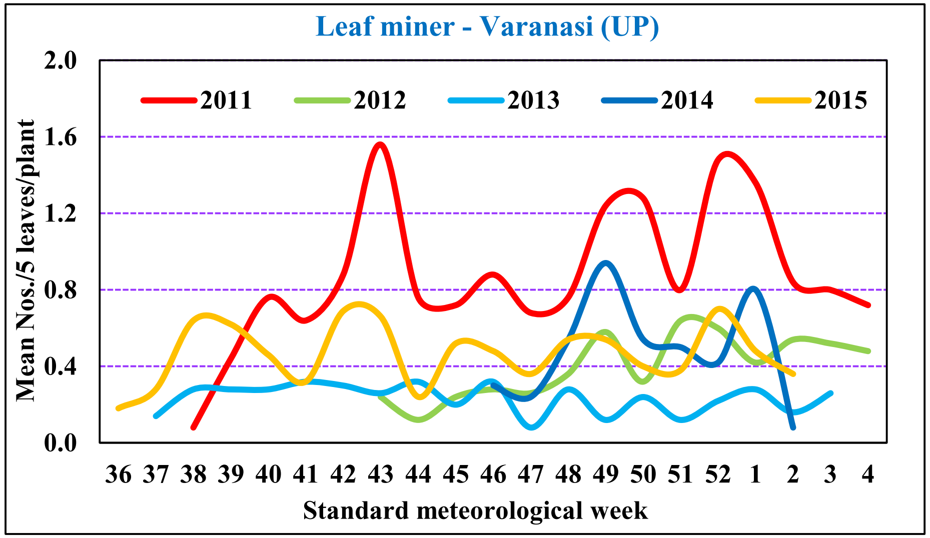

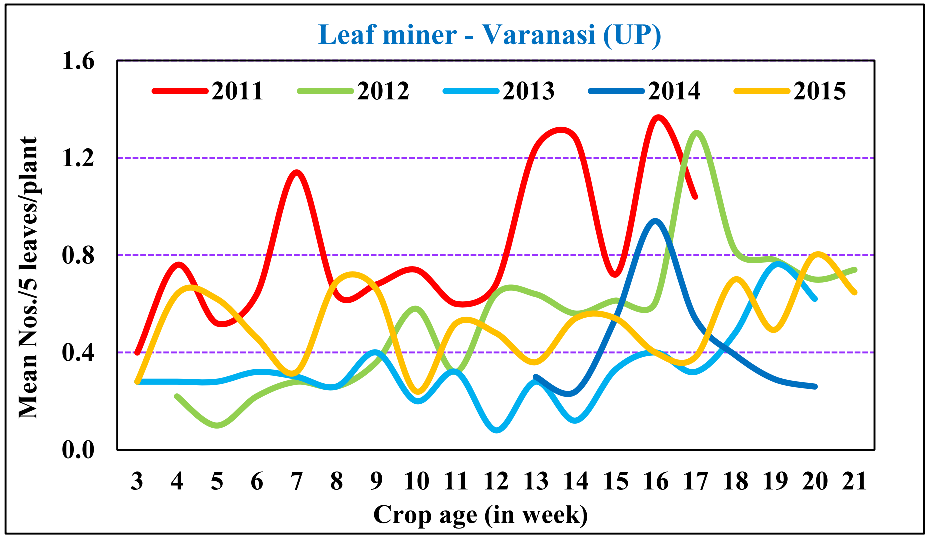

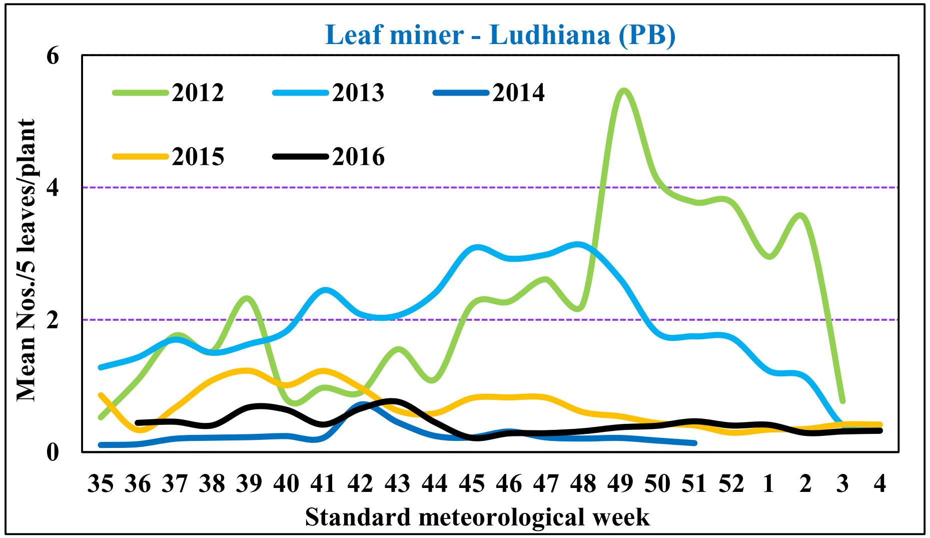

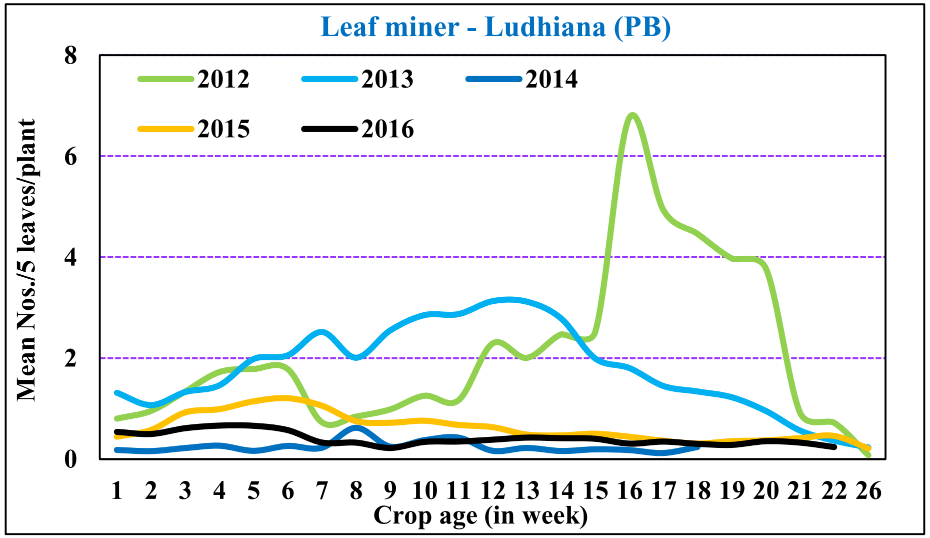

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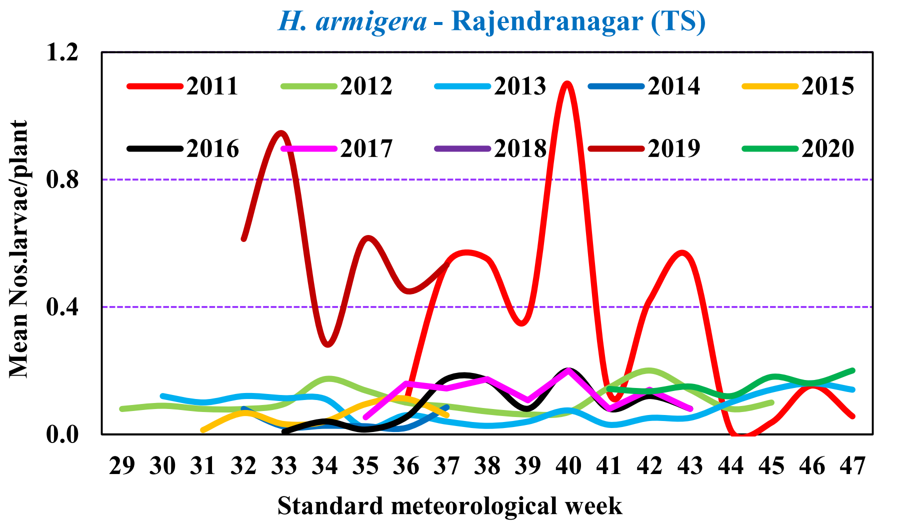

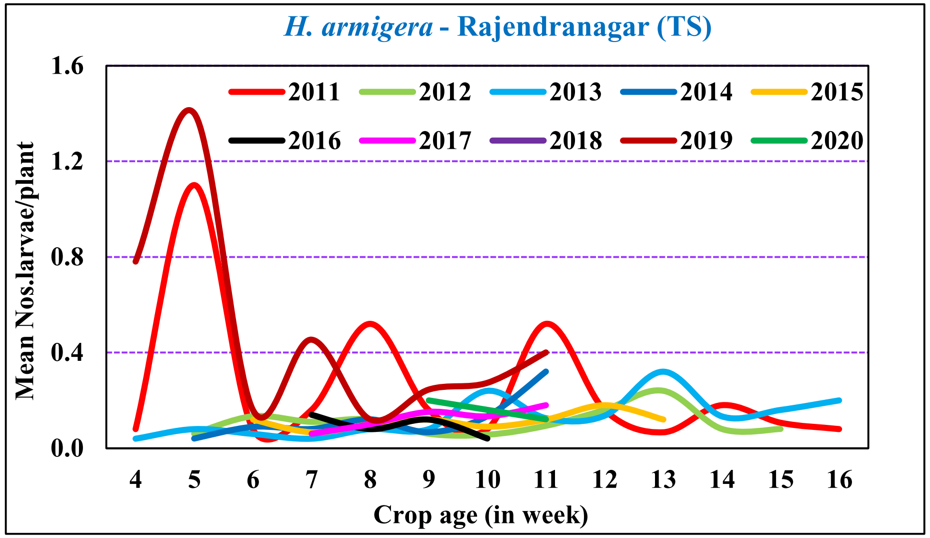

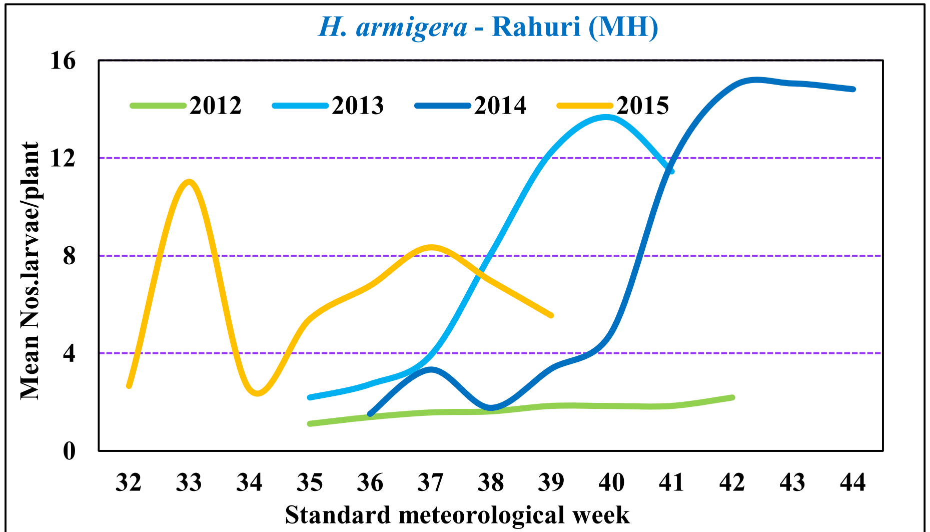

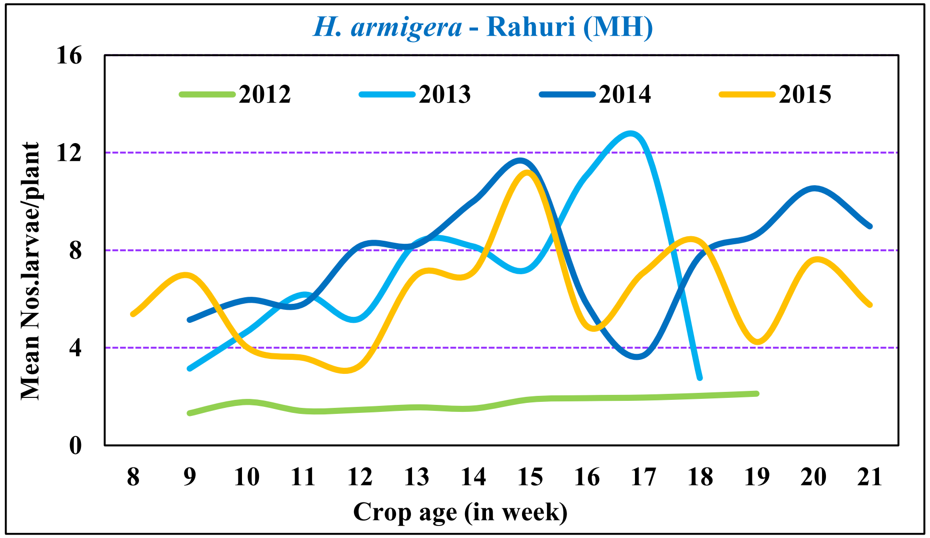

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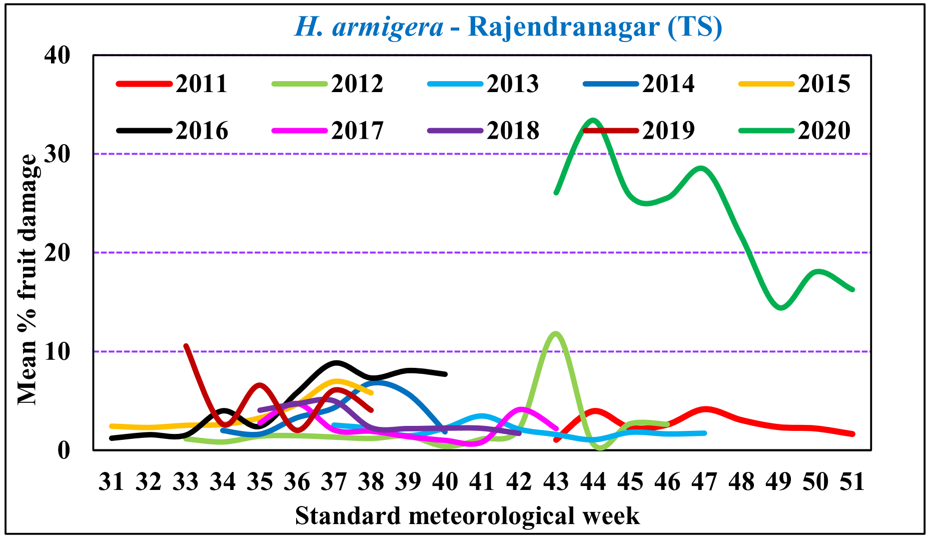

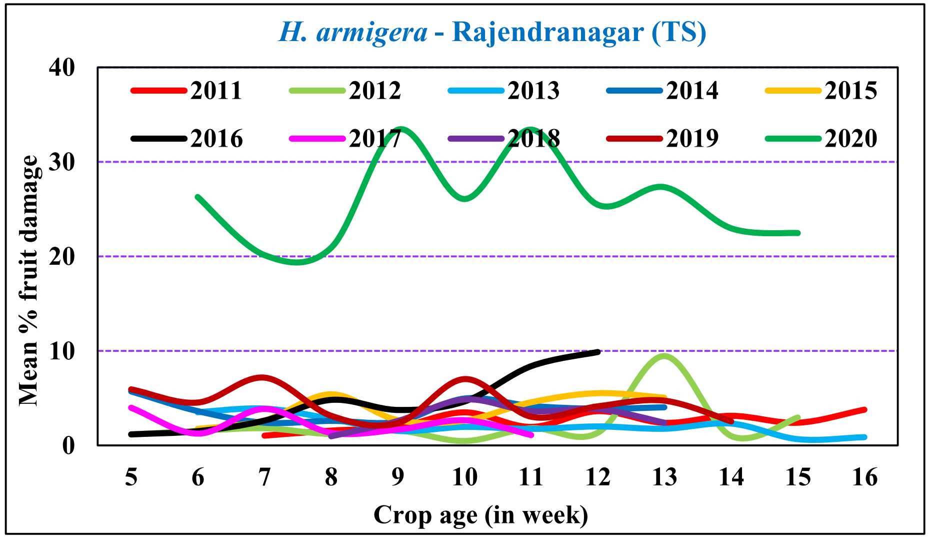

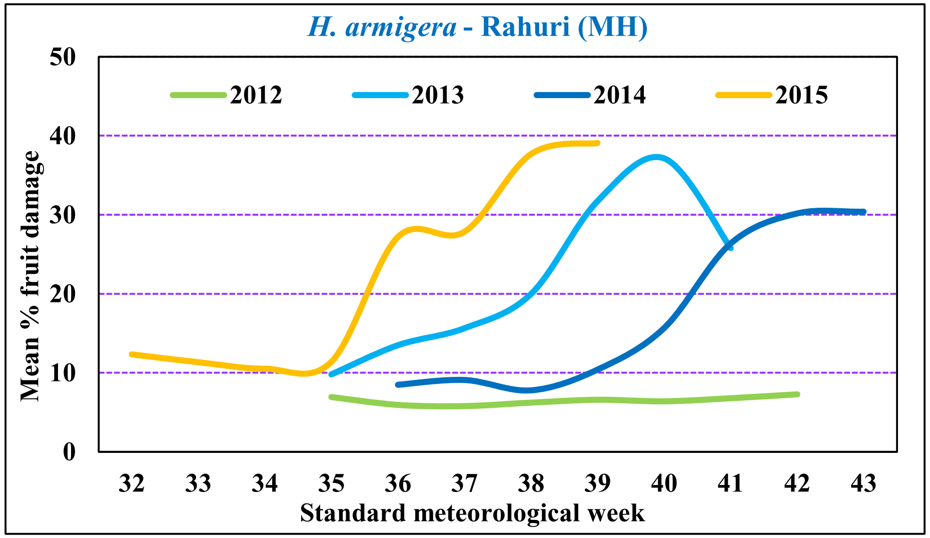

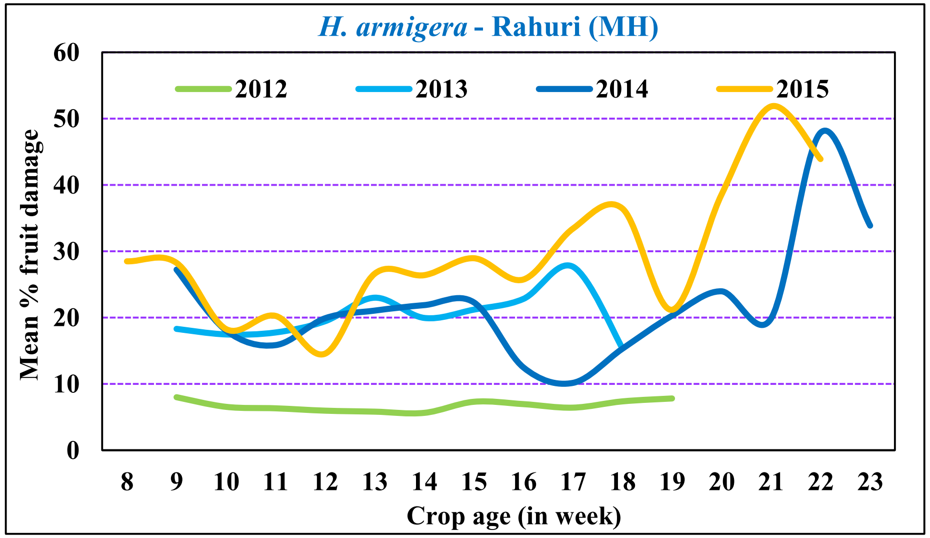

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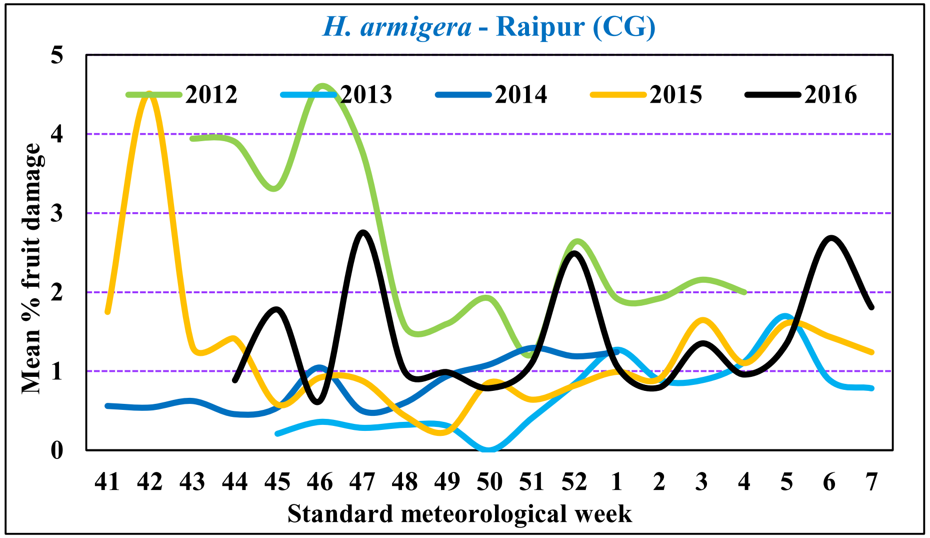
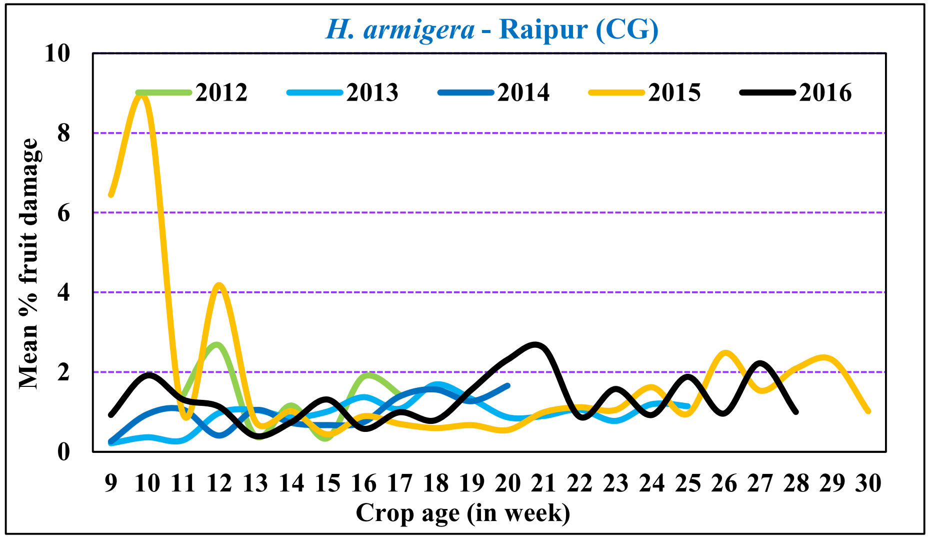
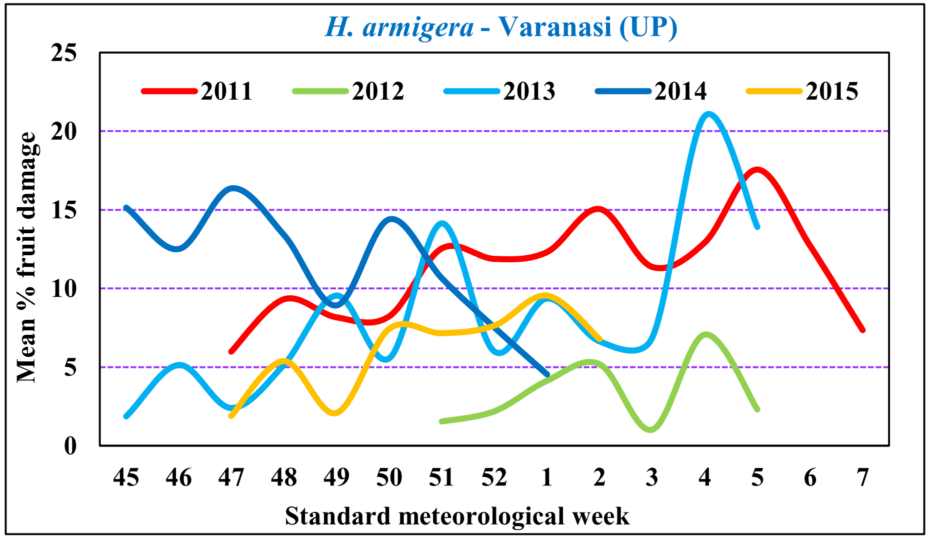
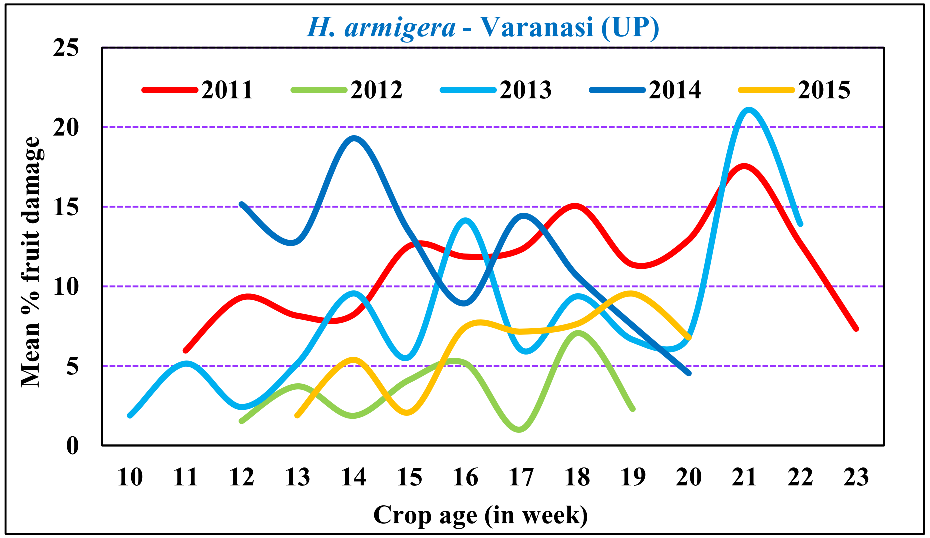




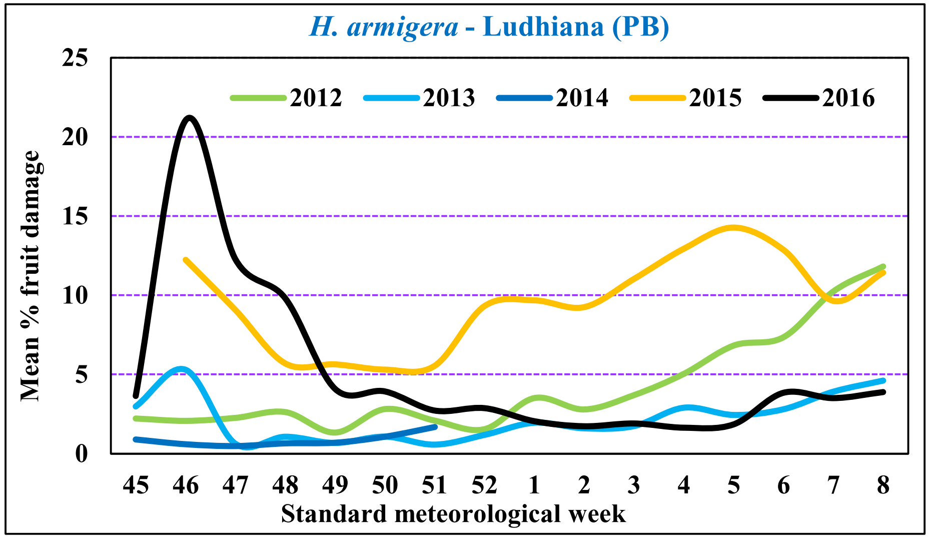


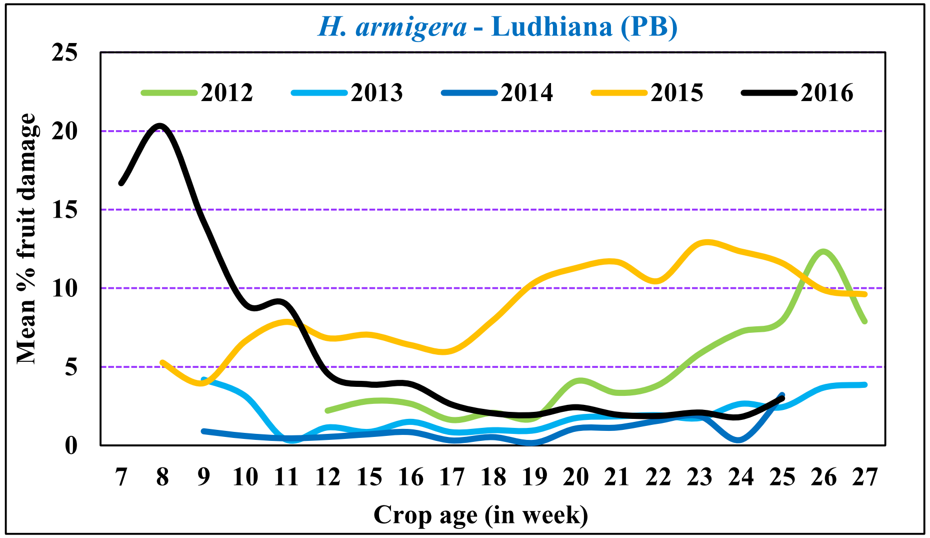


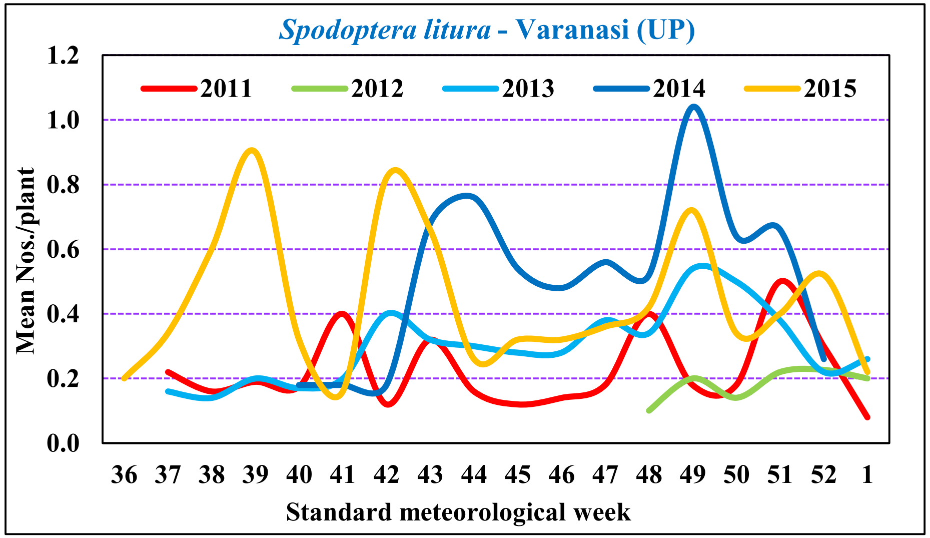
Annexure XXX: Seasonal dynamics of insect pests and diseases of *kharif* tomato [Arranged for study locations under each insect/disease]

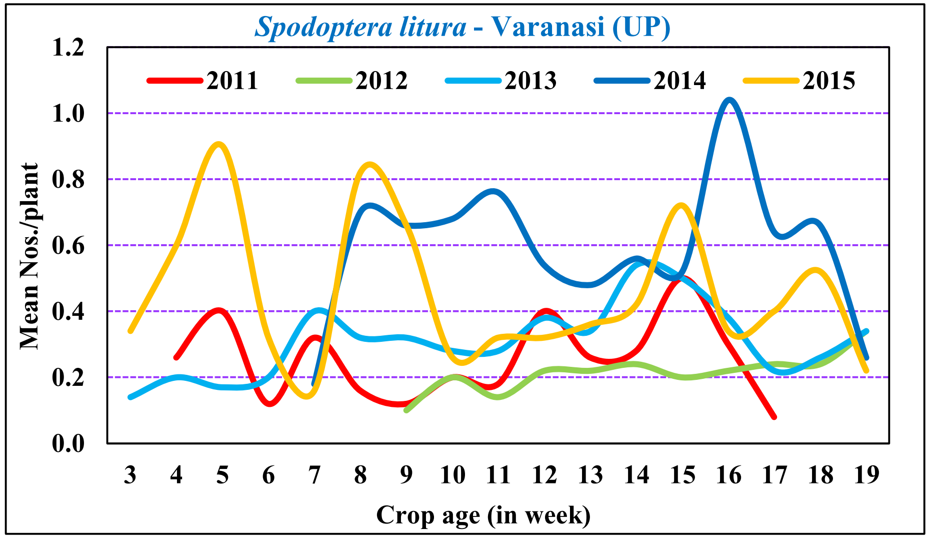
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





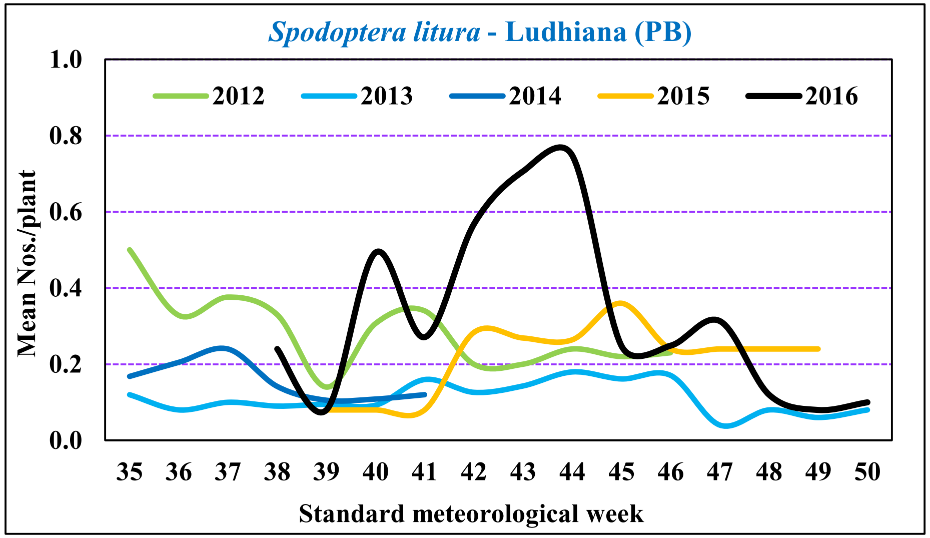


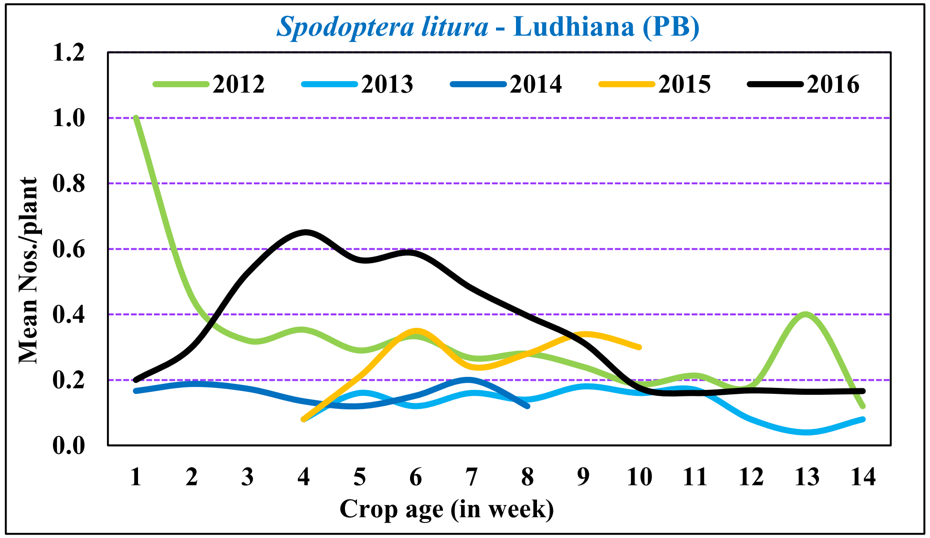


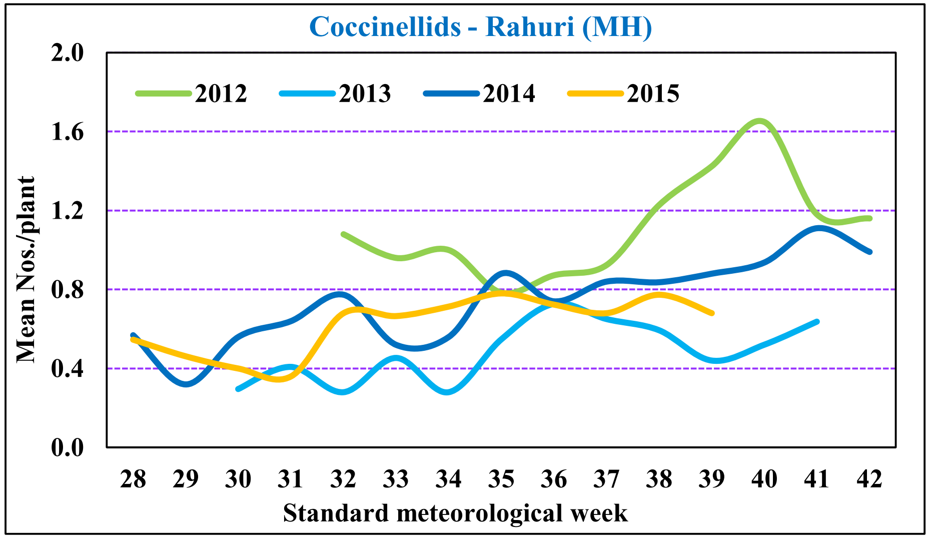
Annexure XXX: Seasonal dynamics of insect pests and diseases of *kharif* tomato [Arranged for study locations under each insect/disease]

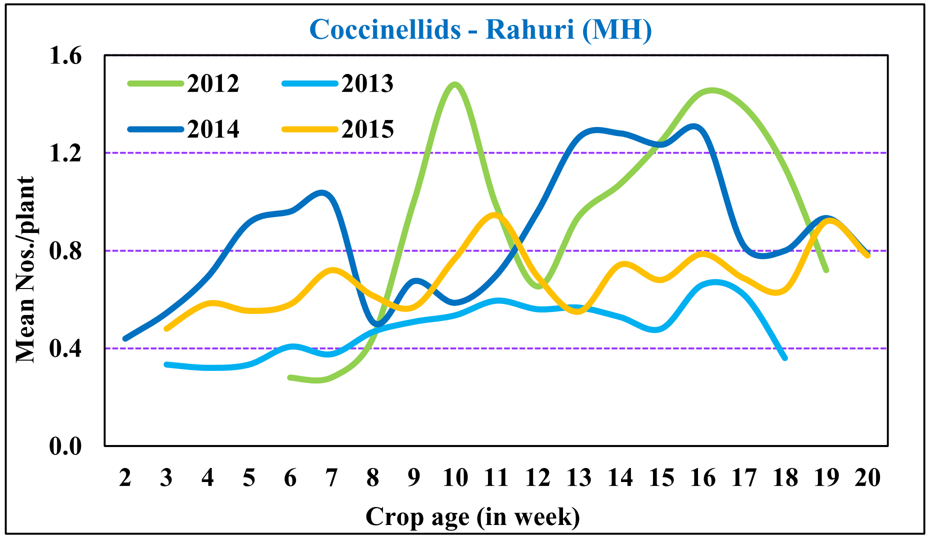
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





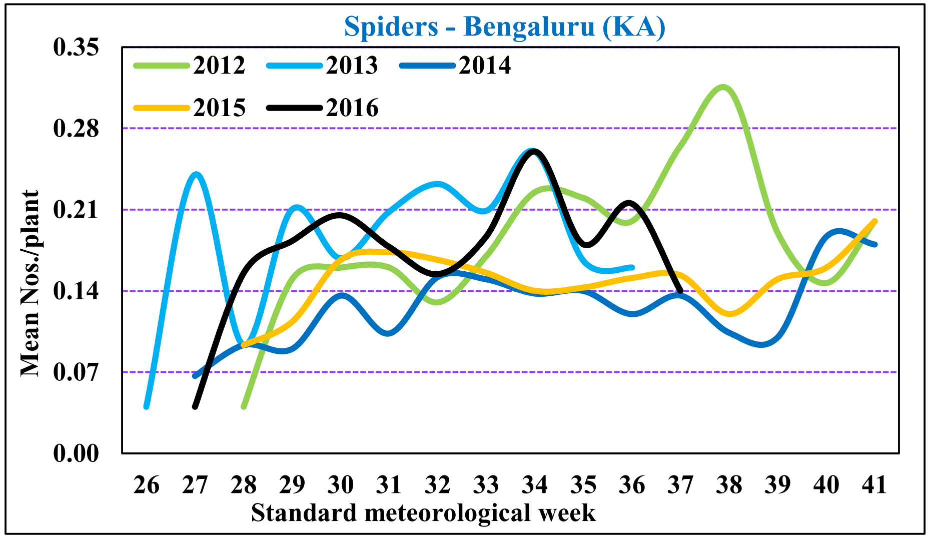


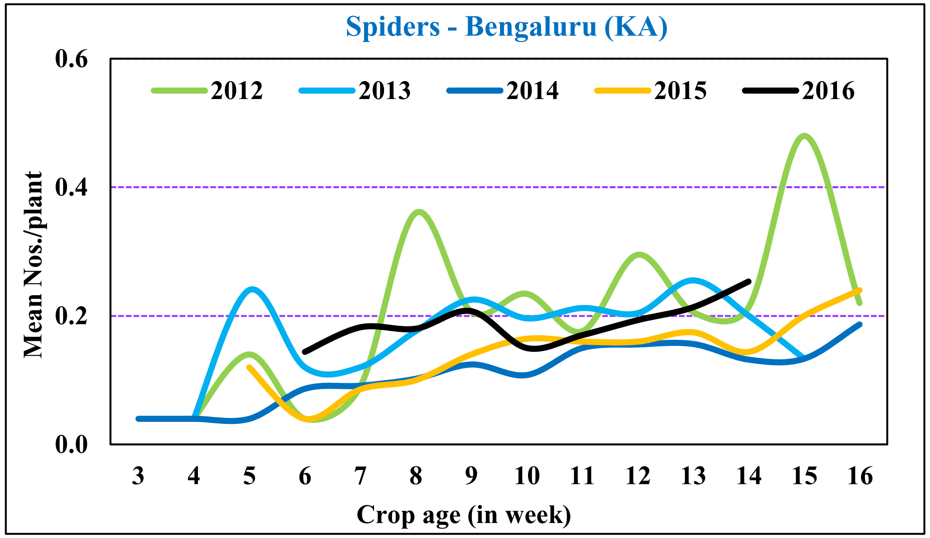


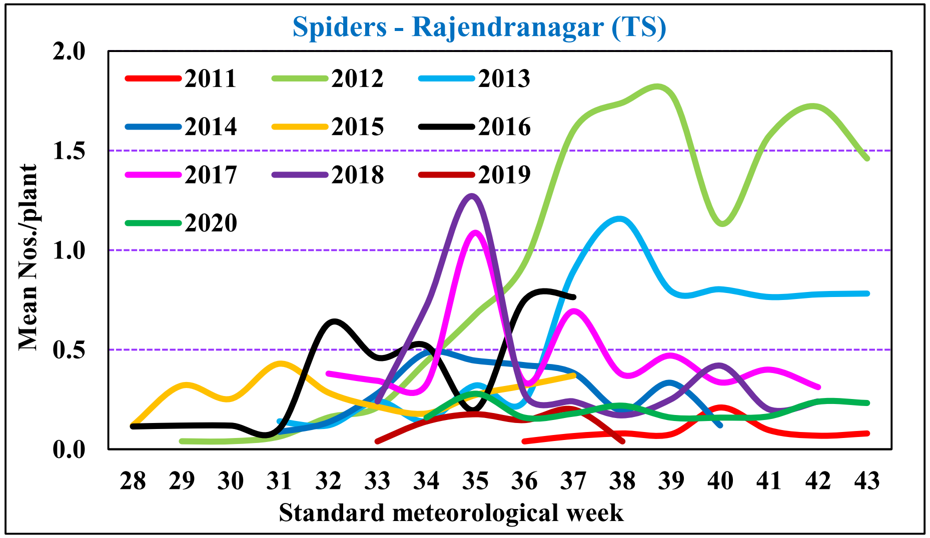
Annexure XXX: Seasonal dynamics of insect pests and diseases of *kharif* tomato [Arranged for study locations under each insect/disease]

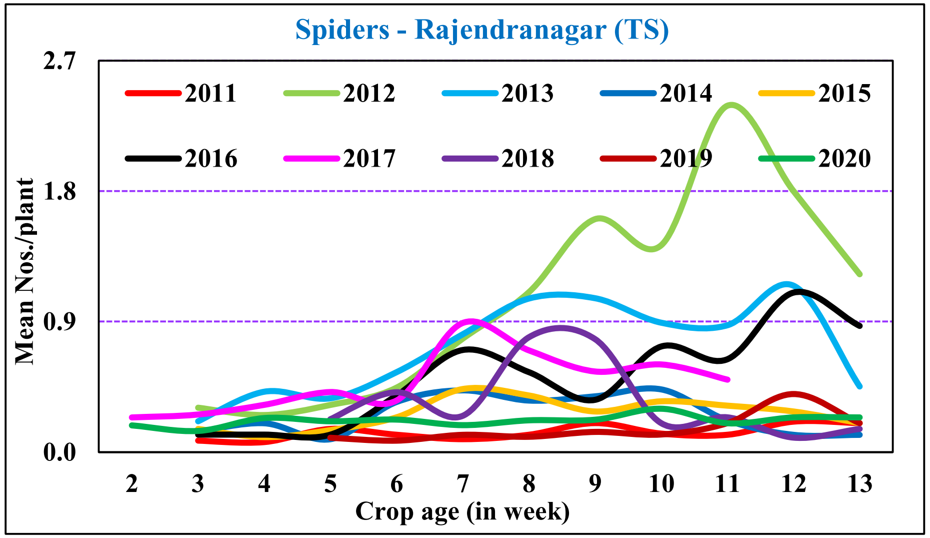
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





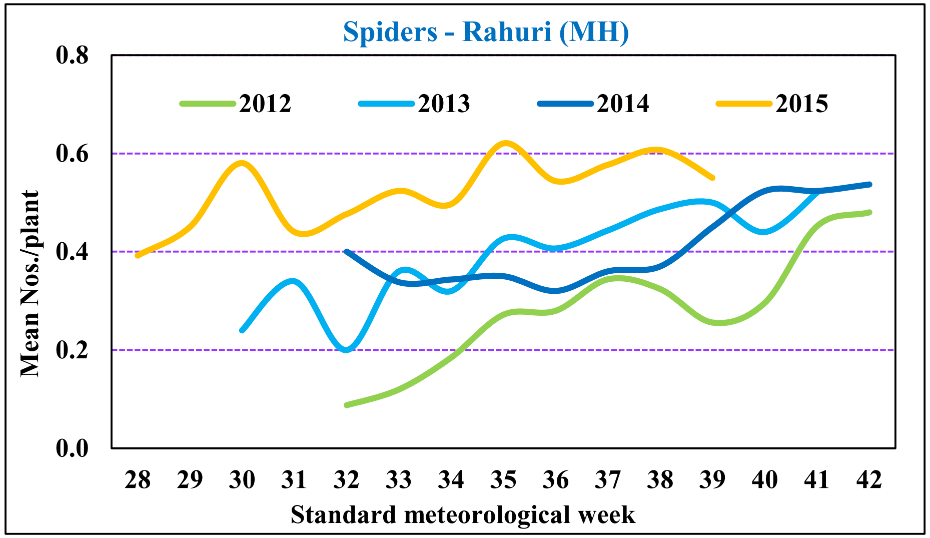


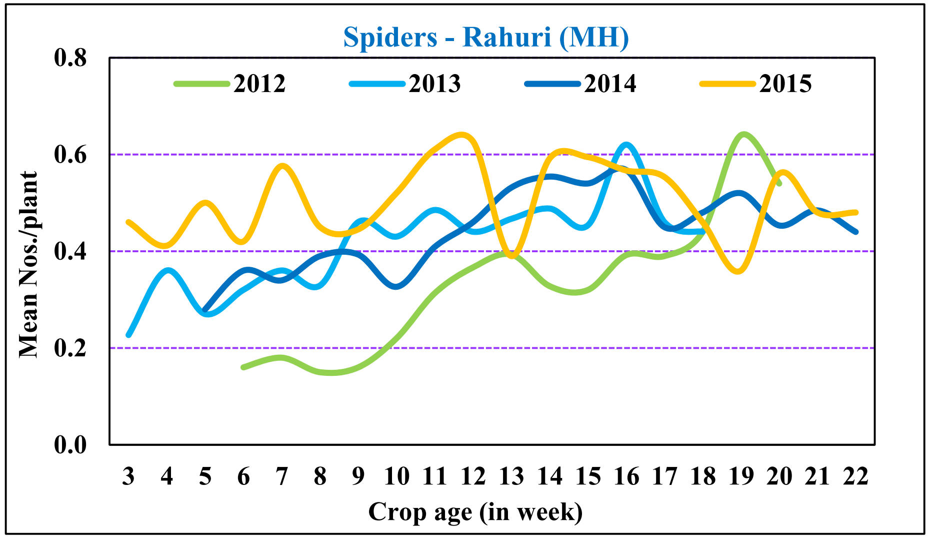


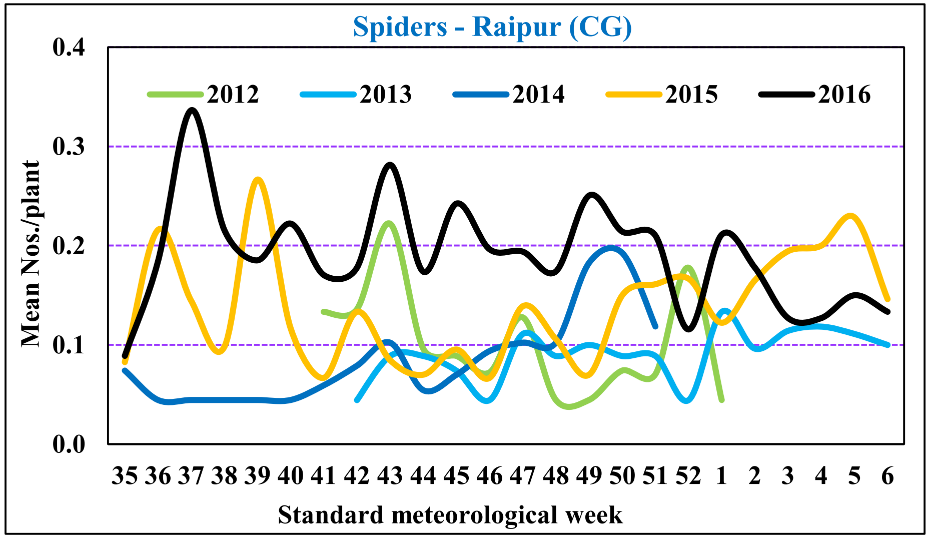
Annexure XXX: Seasonal dynamics of insect pests and diseases of *kharif* tomato [Arranged for study locations under each insect/disease]

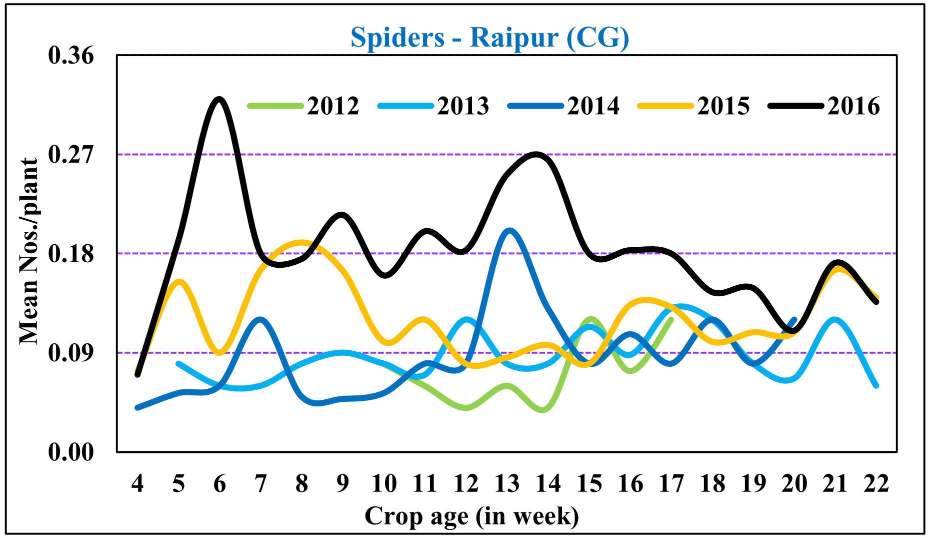
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





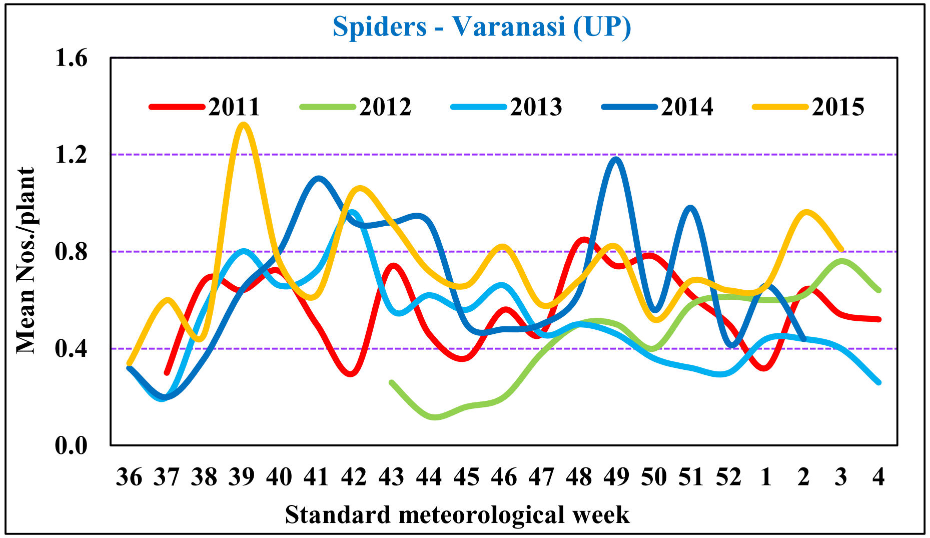


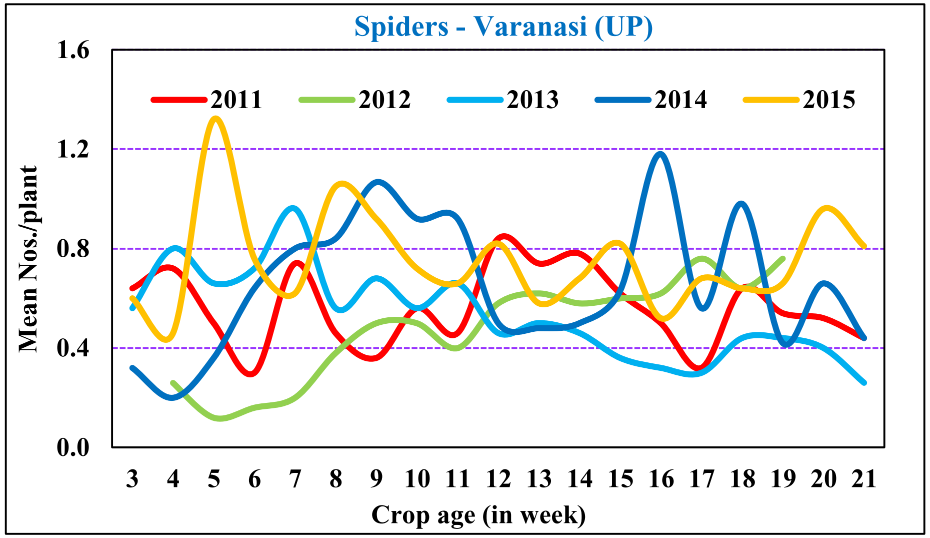


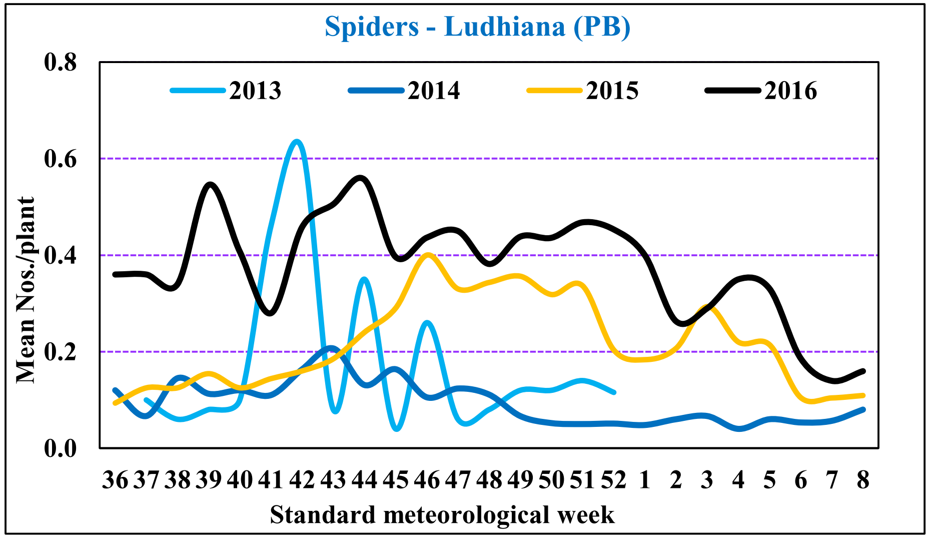
Annexure XXX: Seasonal dynamics of insect pests and diseases of *kharif* tomato [Arranged for study locations under each insect/disease]

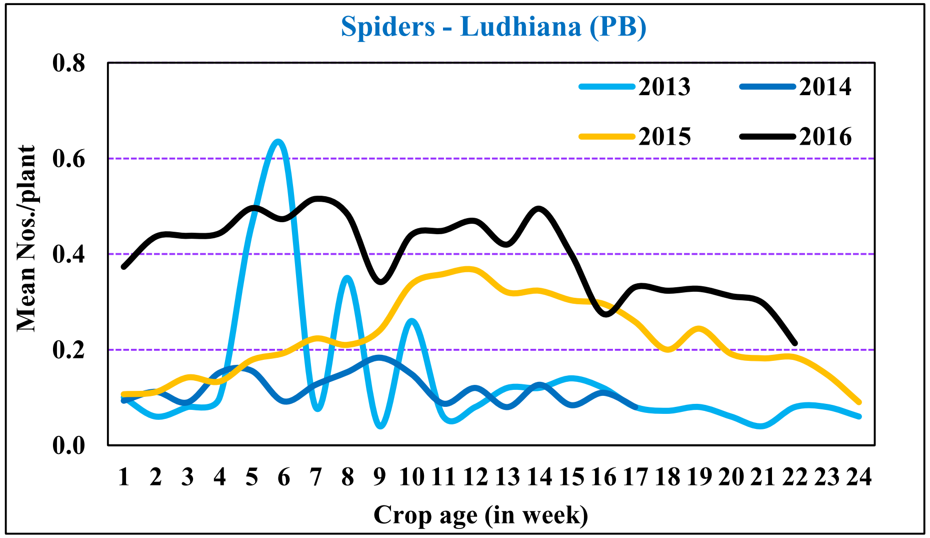
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



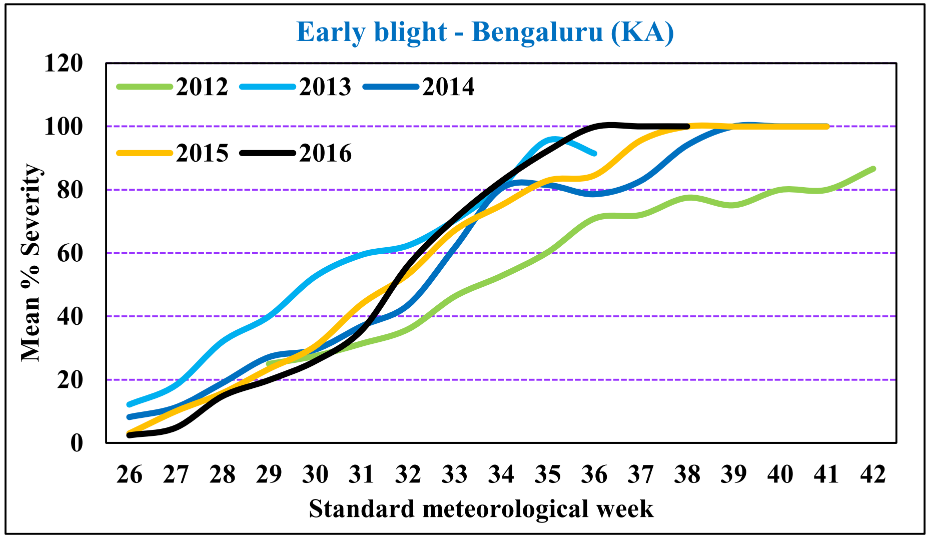


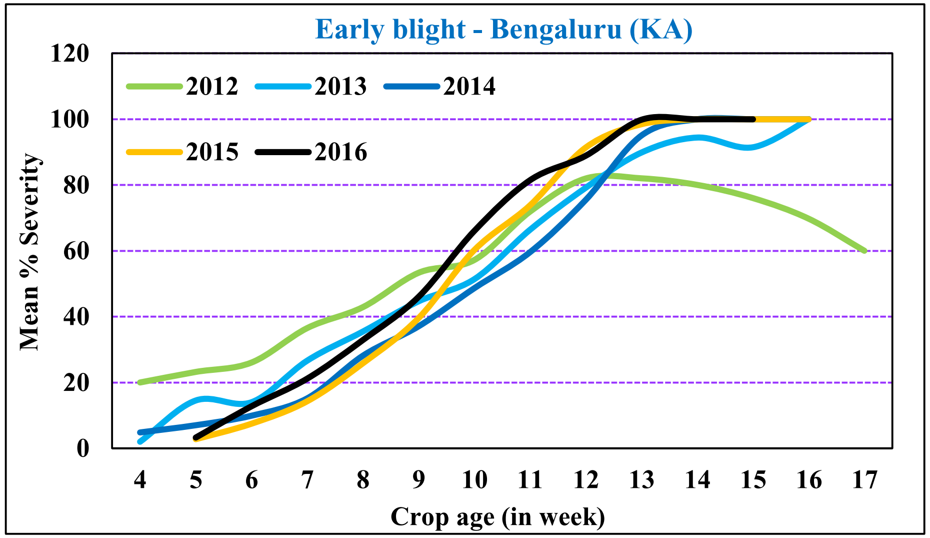


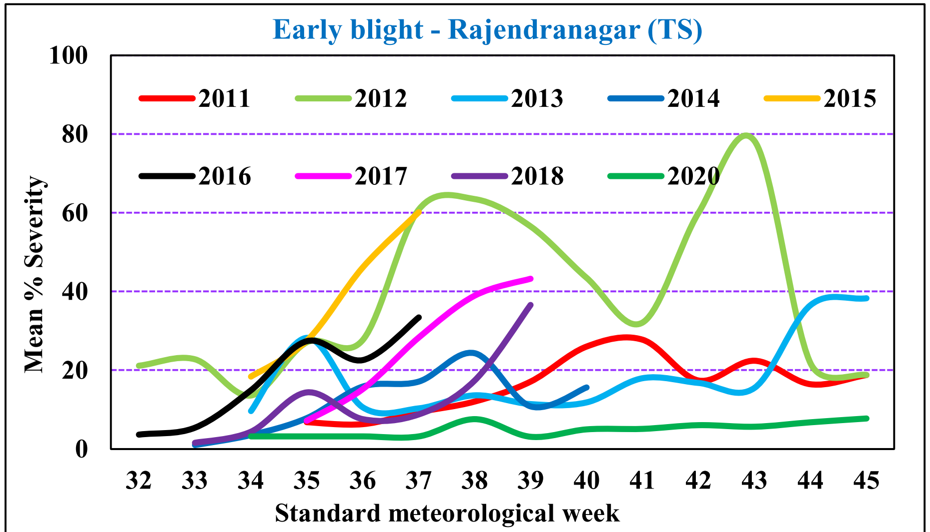


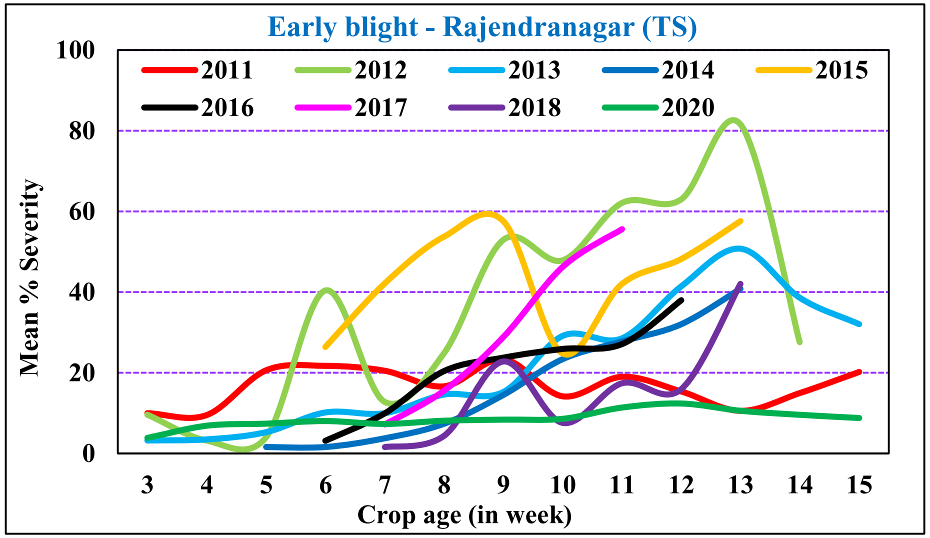
Annexure XXX: Seasonal dynamics of insect pests and diseases of *kharif* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | Seasonal dynamics based on crop age



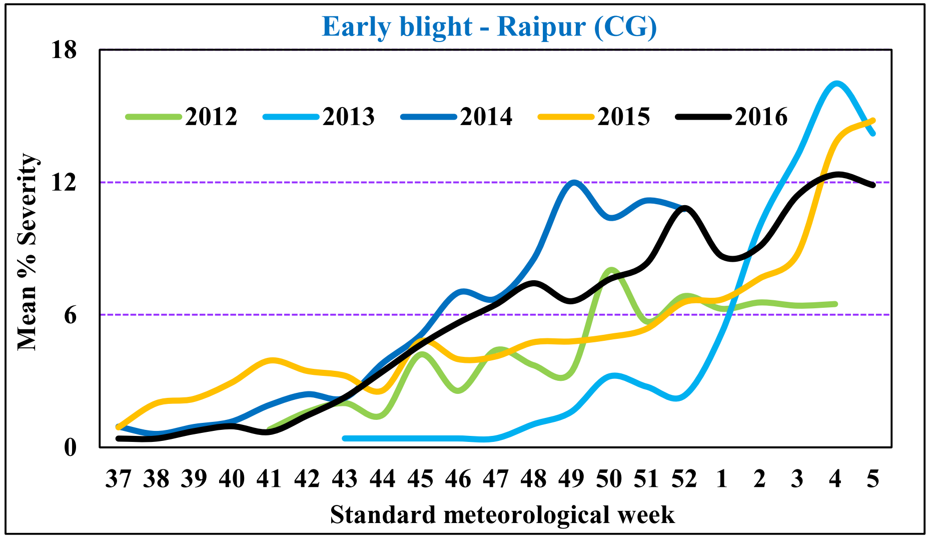


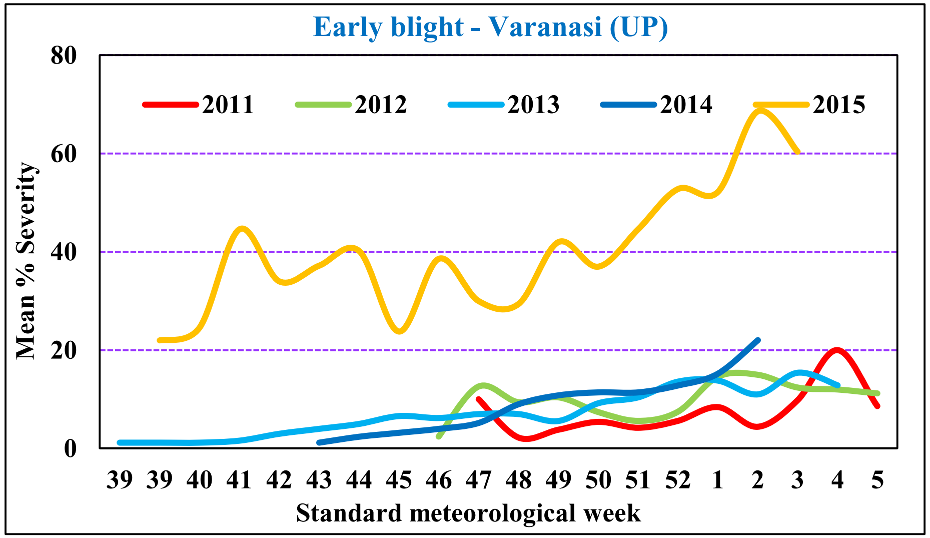




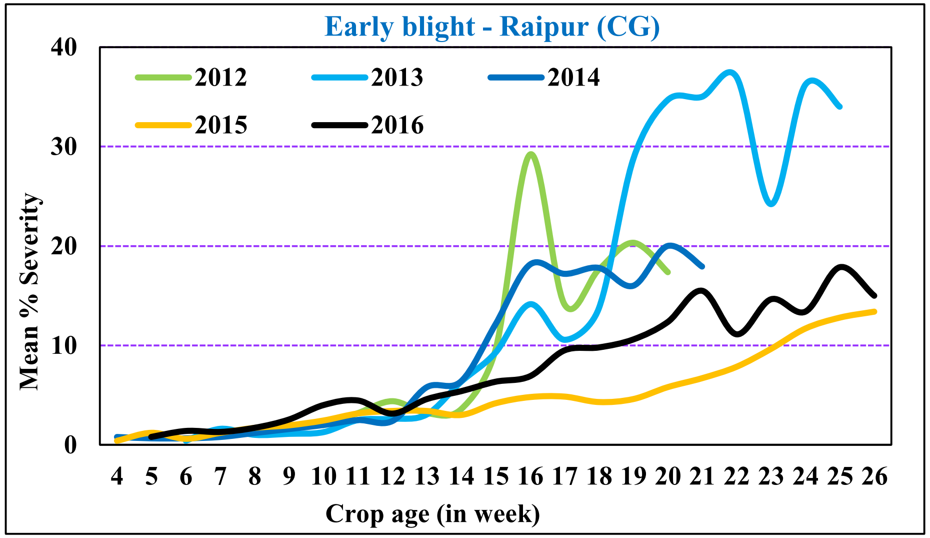
Annexure XXX: Seasonal dynamics of insect pests and diseases of *kharif* tomato [Arranged for study locations under each insect/disease]

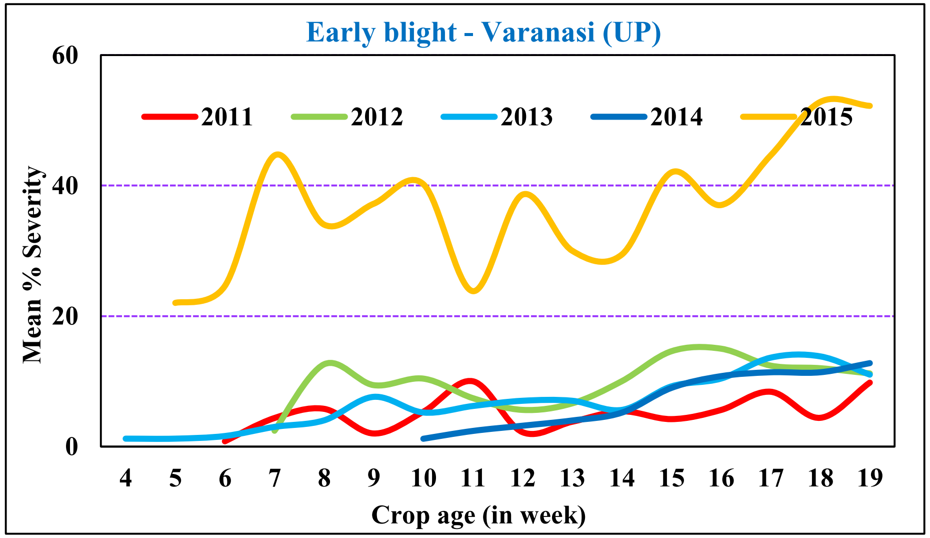
Seasonal dynamics based on standard meteorological weeks





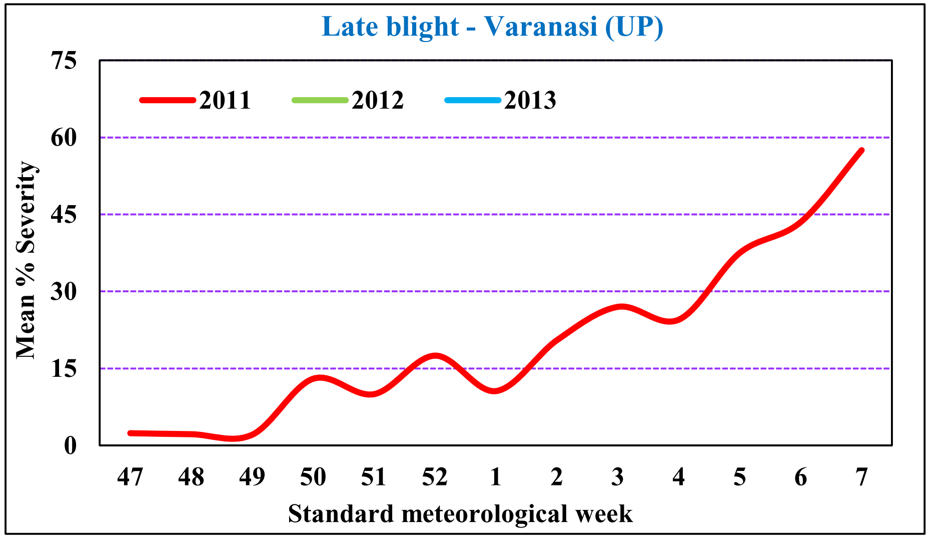
Seasonal dynamics based on crop age

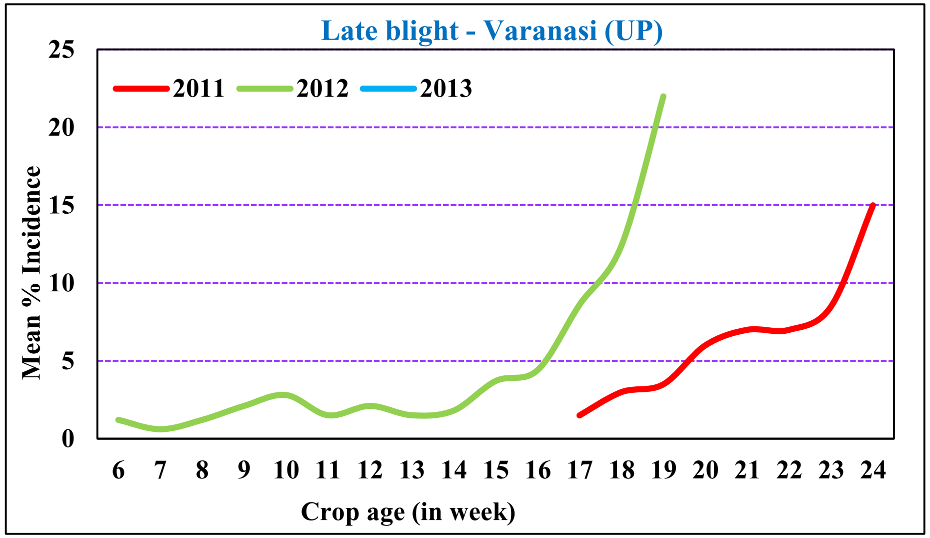


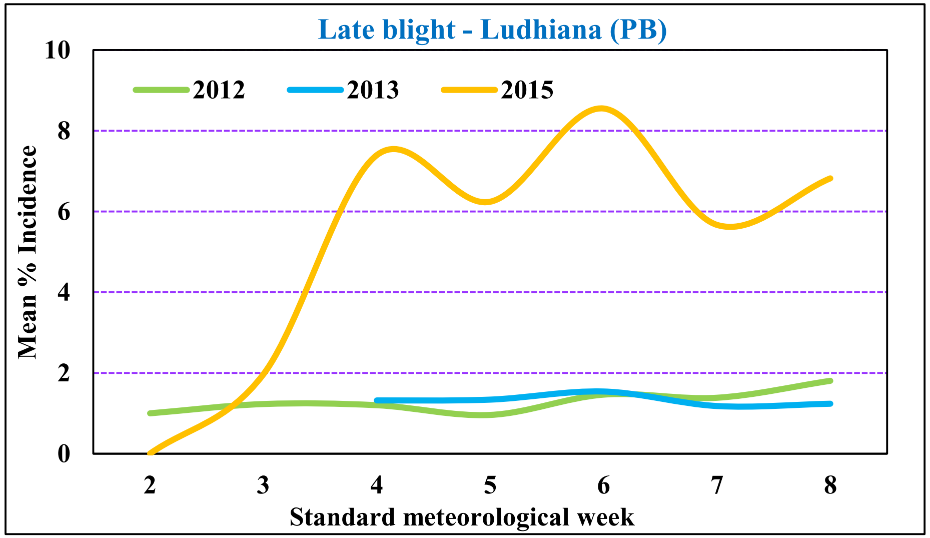


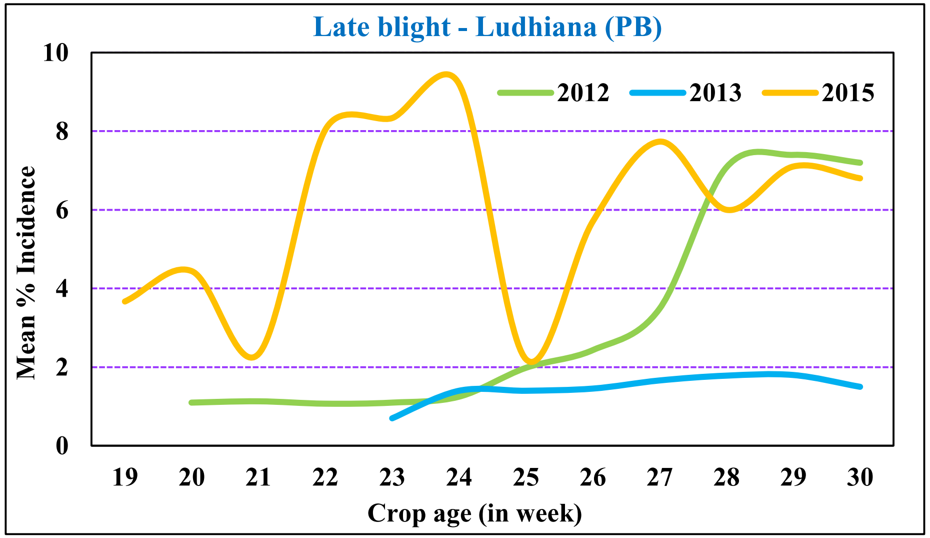
Annexure XXX: Seasonal dynamics of insect pests and diseases of *kharif* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | Seasonal dynamics based on crop age



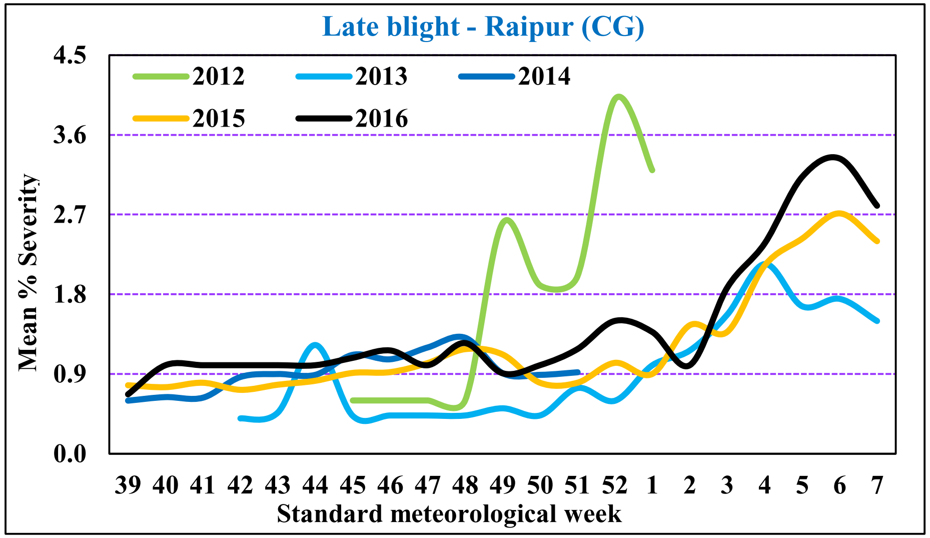


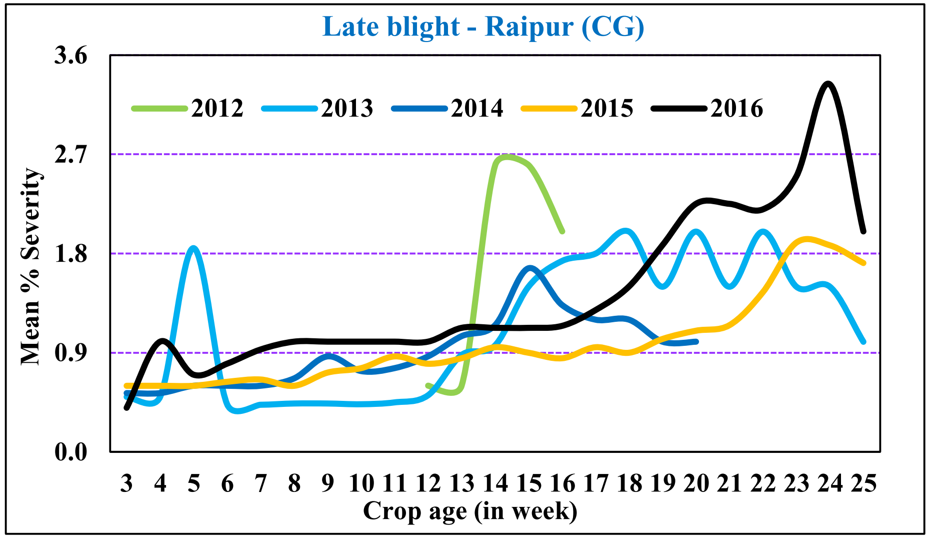


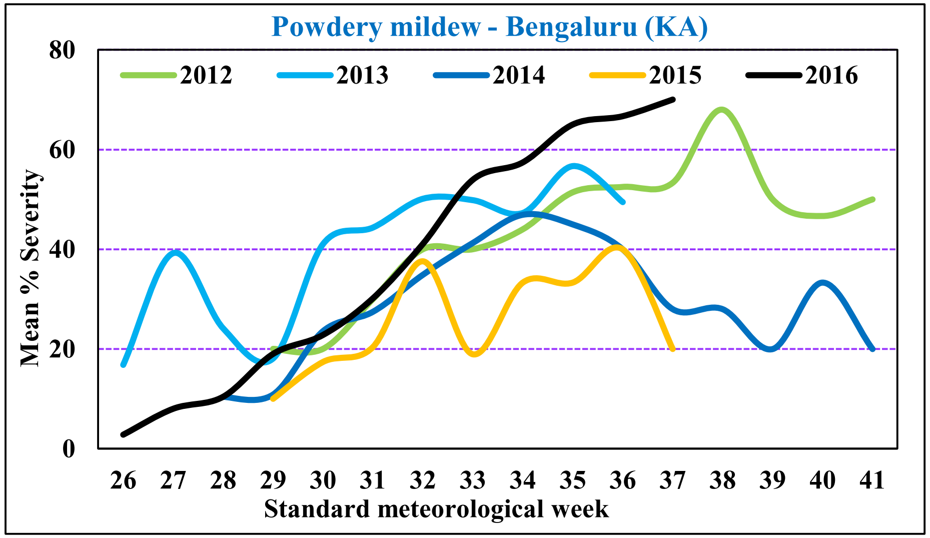


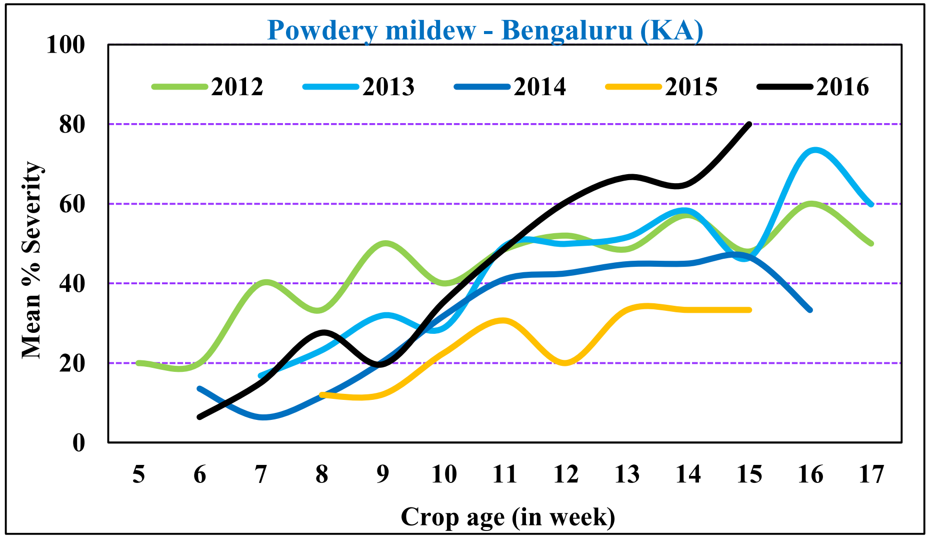
Annexure XXX: Seasonal dynamics of insect pests and diseases of *kharif* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



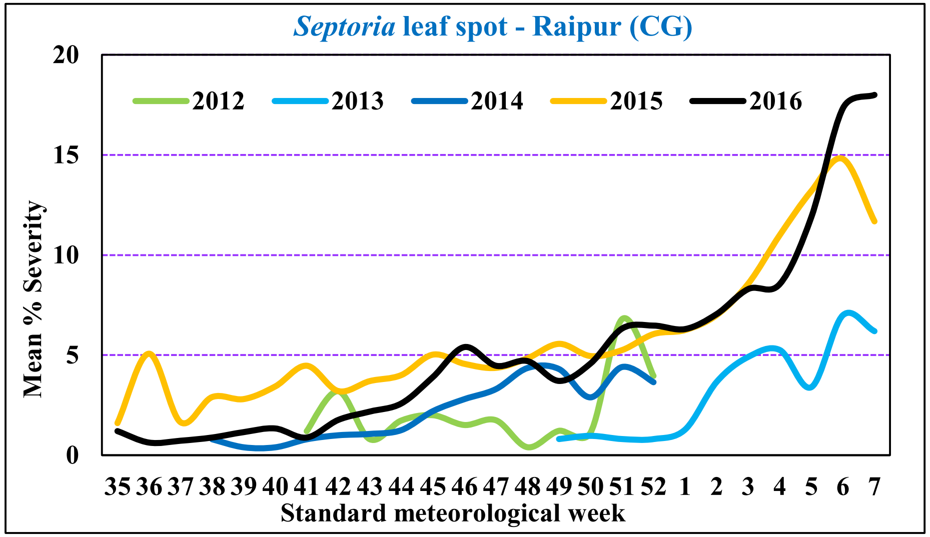


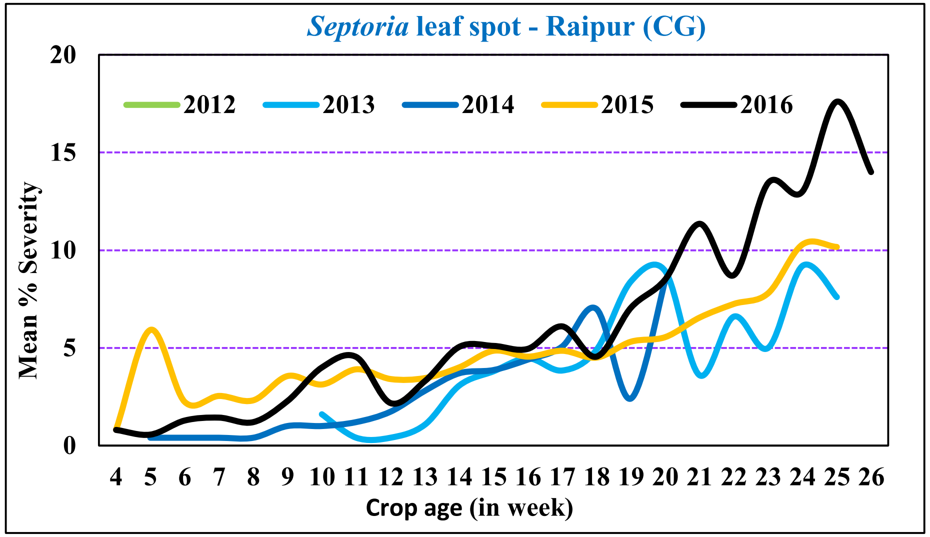


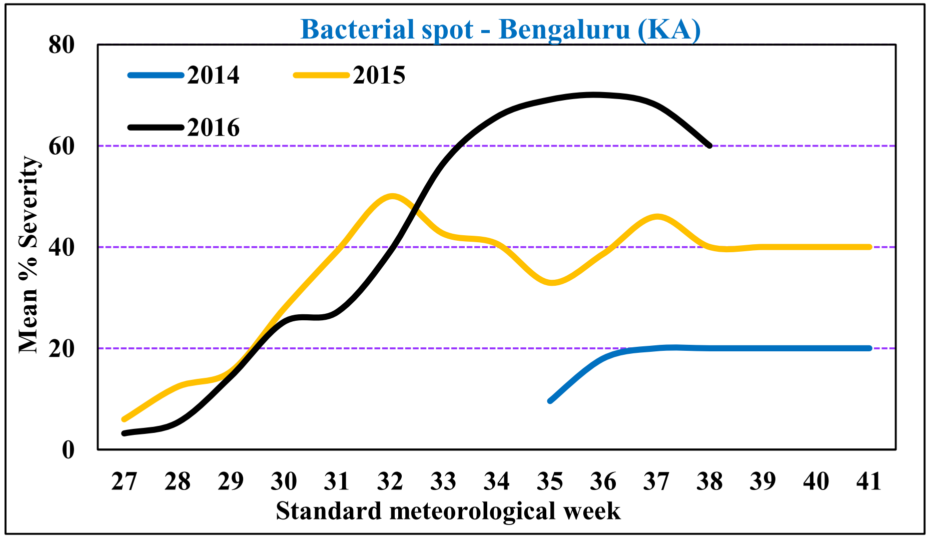


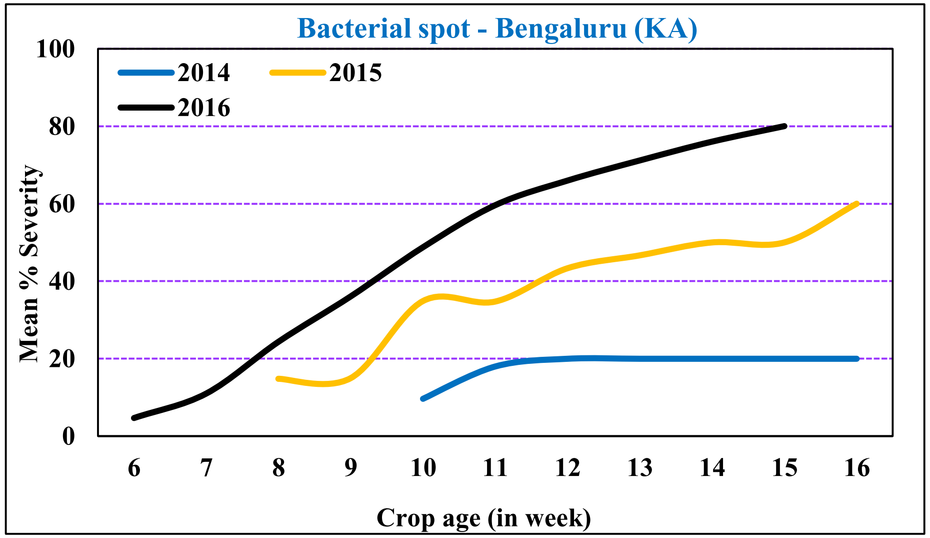
Annexure XXX: Seasonal dynamics of insect pests and diseases of *kharif* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**





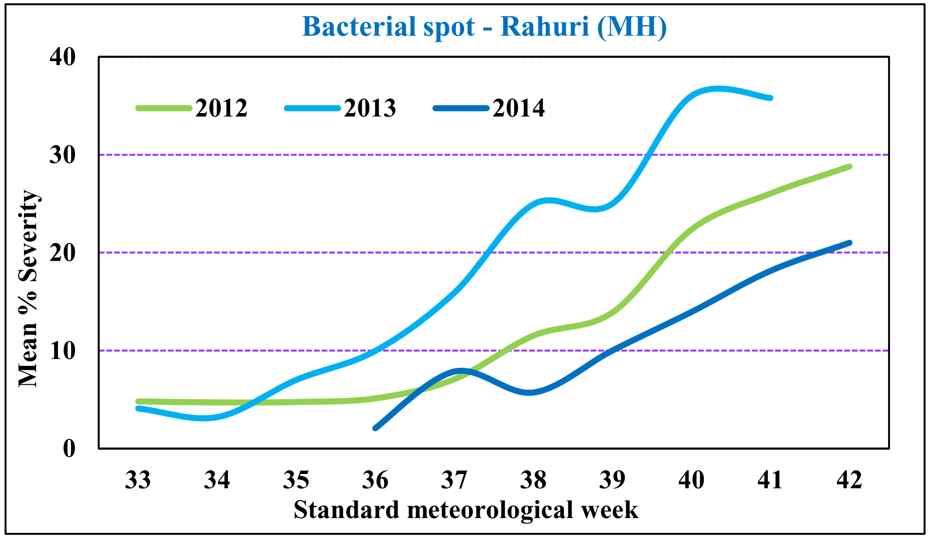


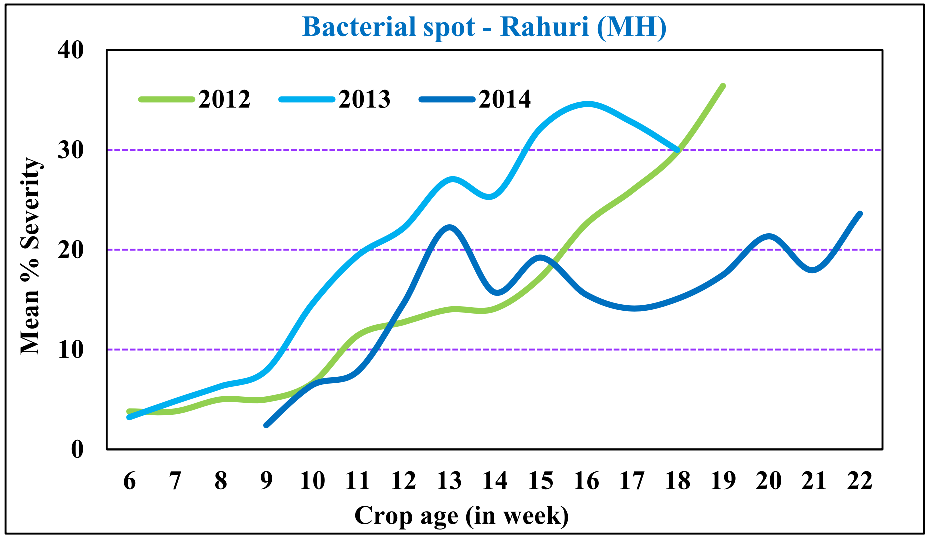


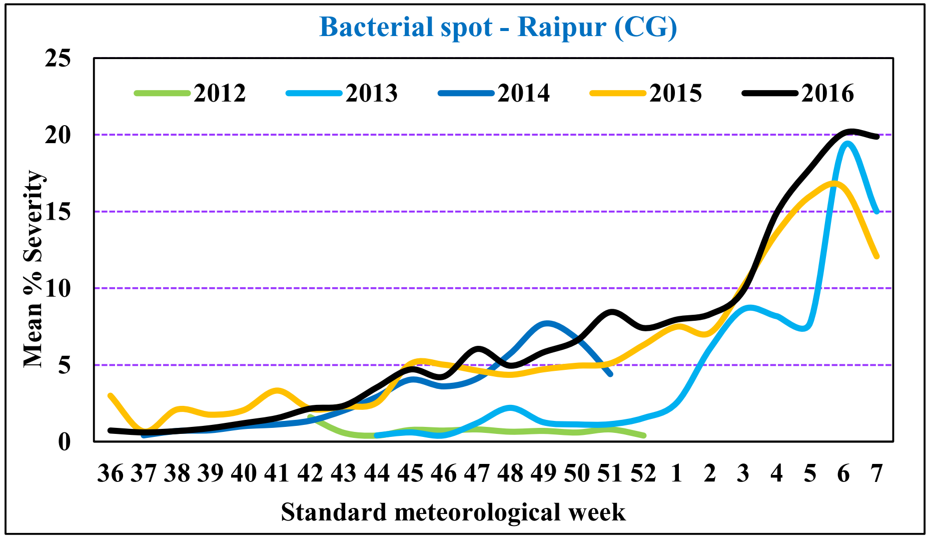
Annexure XXX: Seasonal dynamics of insect pests and diseases of *kharif* tomato [Arranged for study locations under each insect/disease]

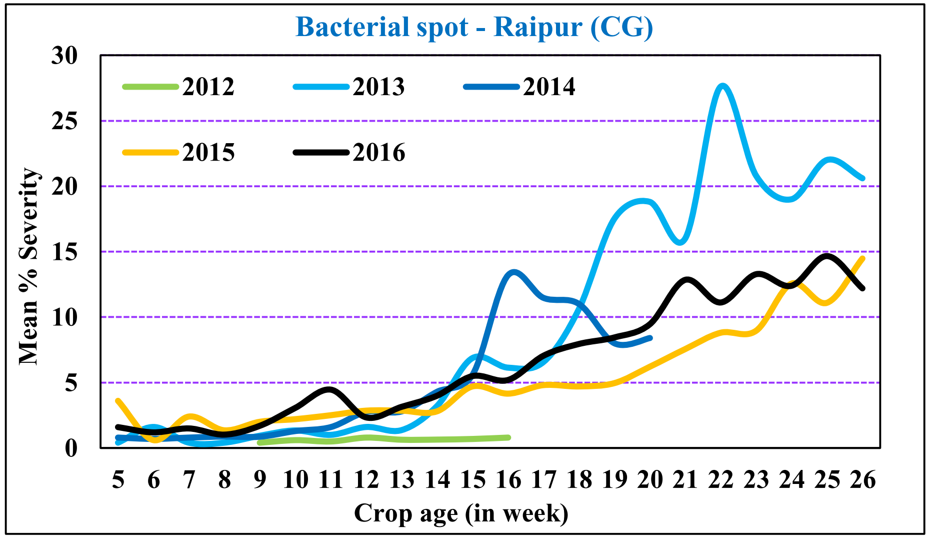
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



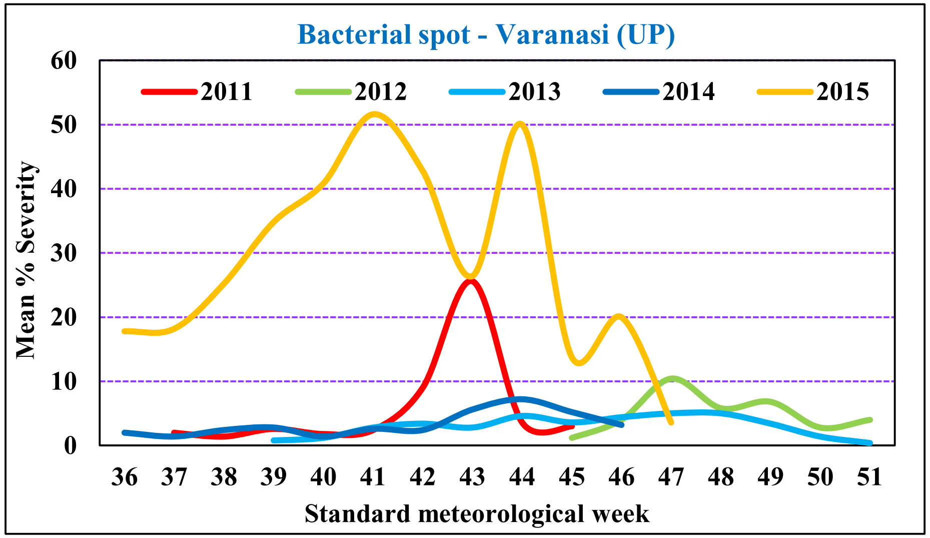


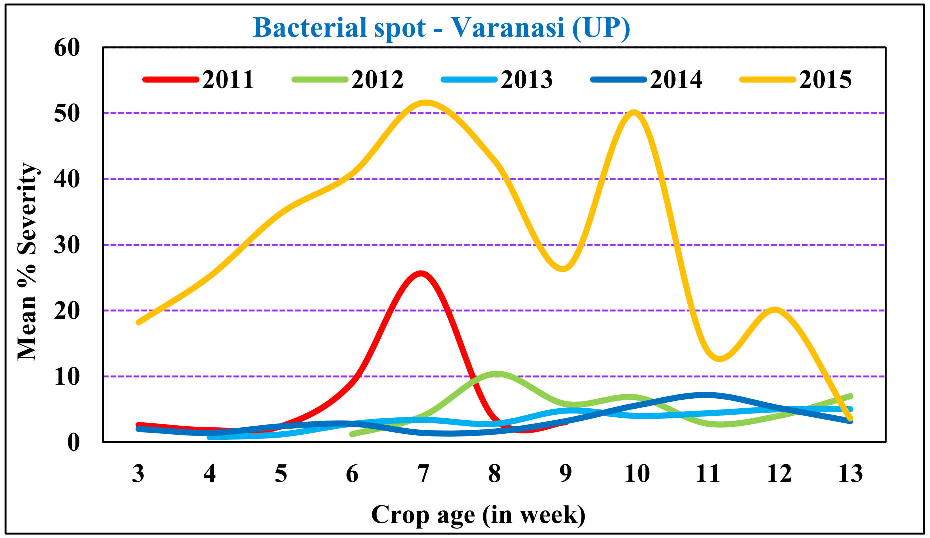


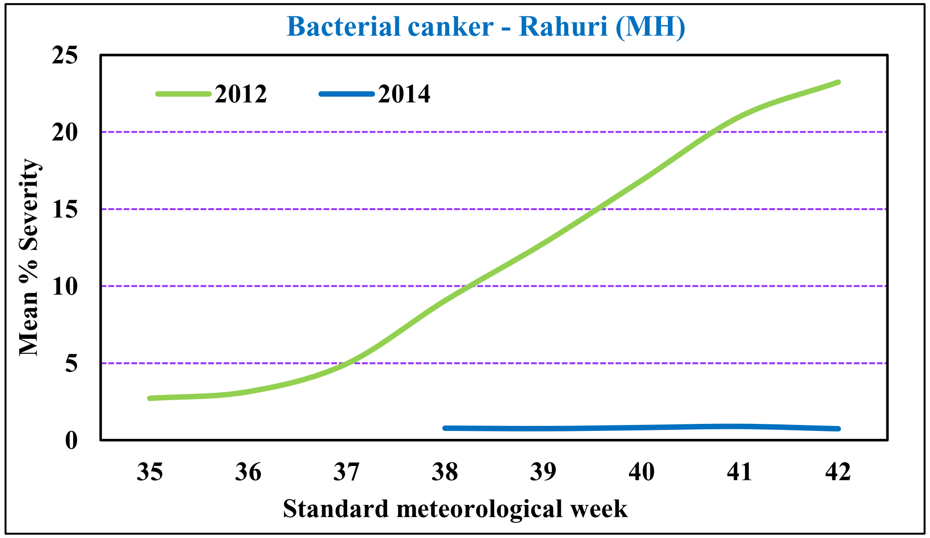


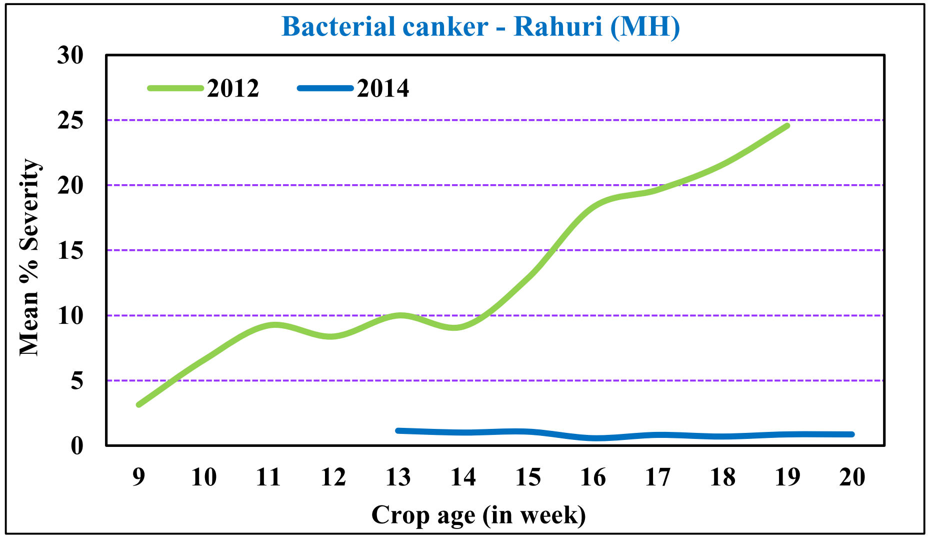
Annexure XXX: Seasonal dynamics of insect pests and diseases of *kharif* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



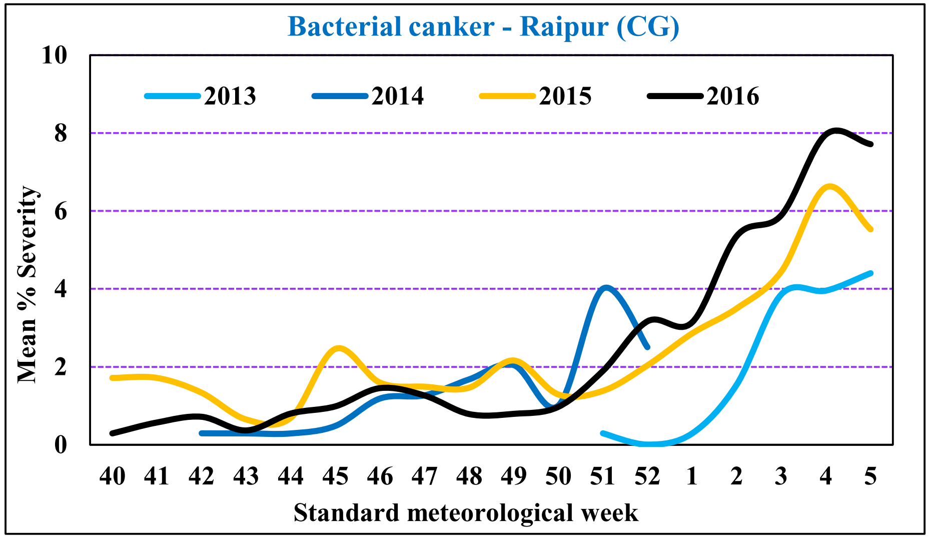


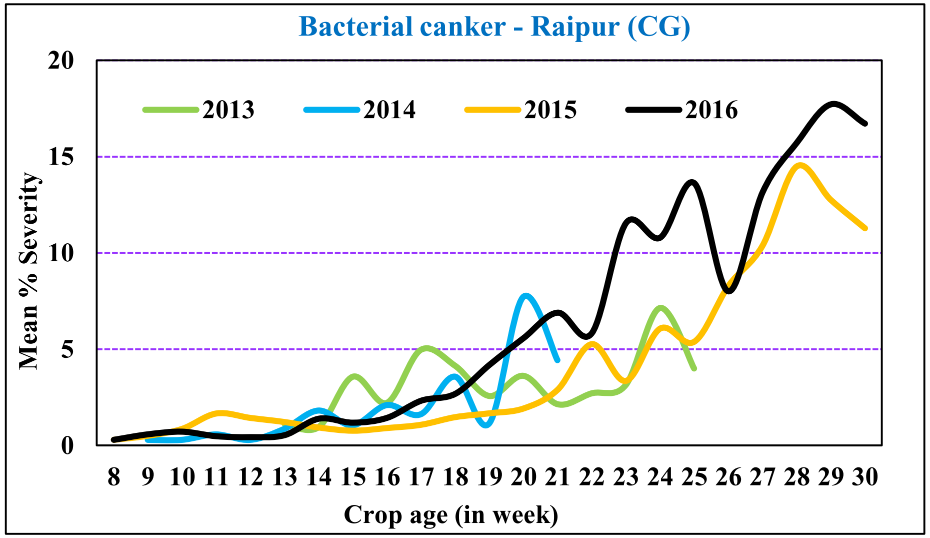


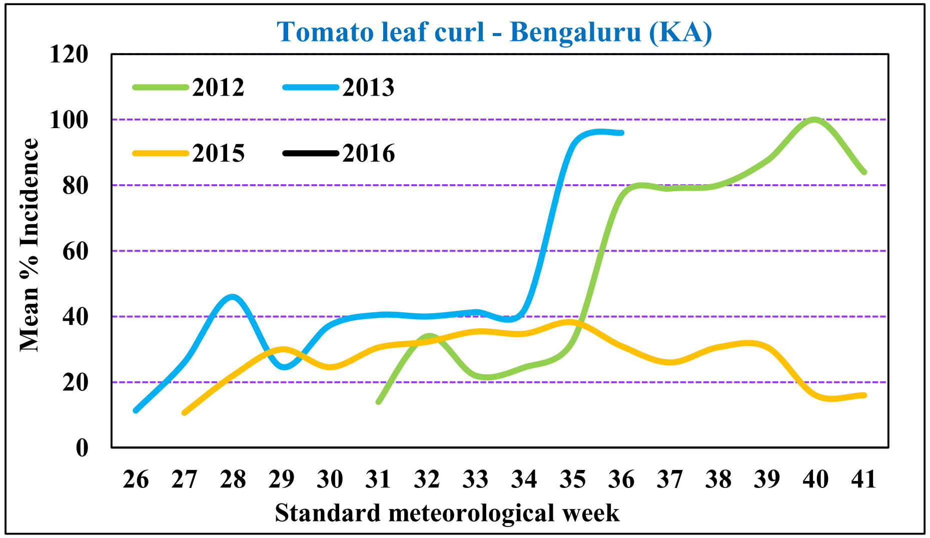


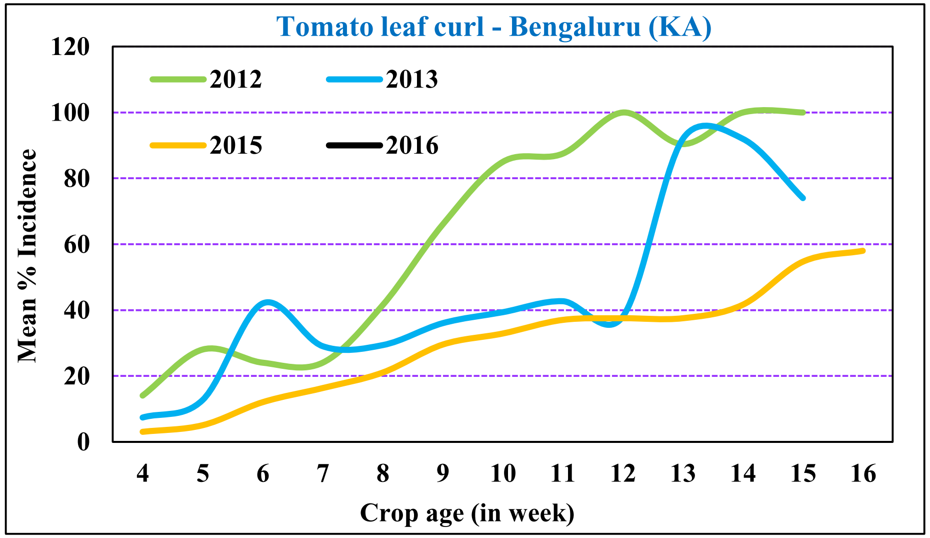
Annexure XXX: Seasonal dynamics of insect pests and diseases of *kharif* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



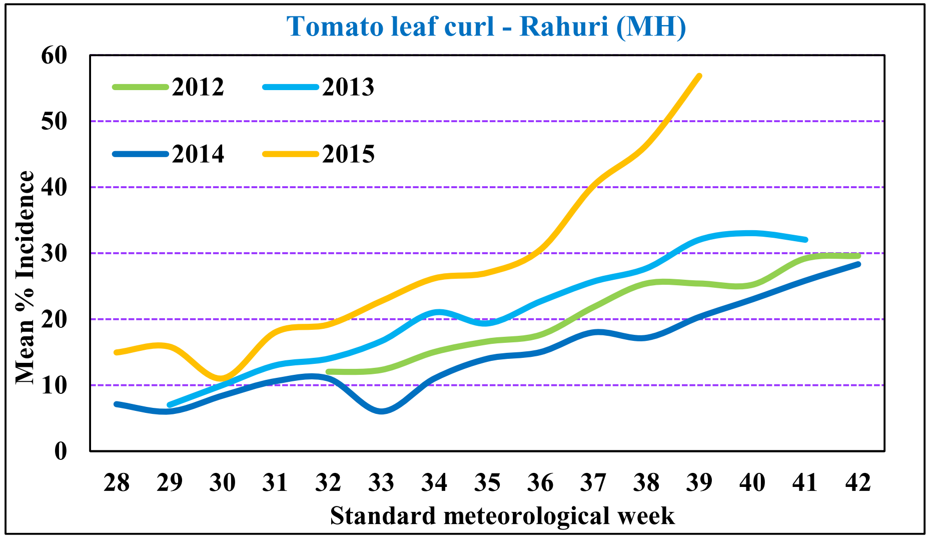


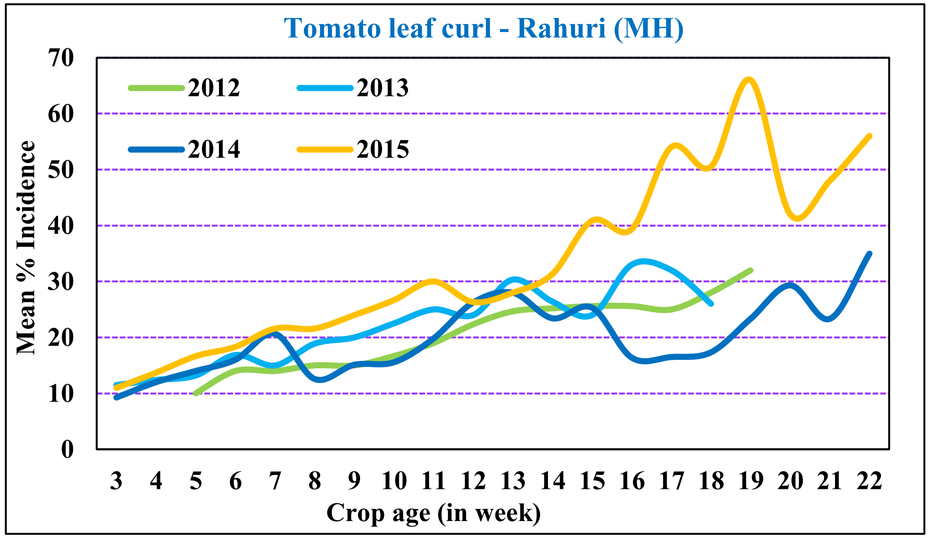


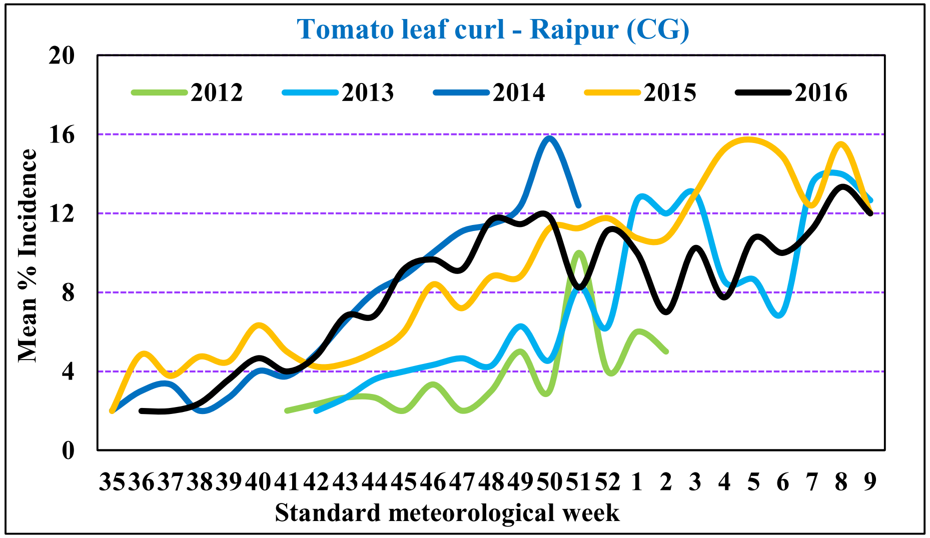


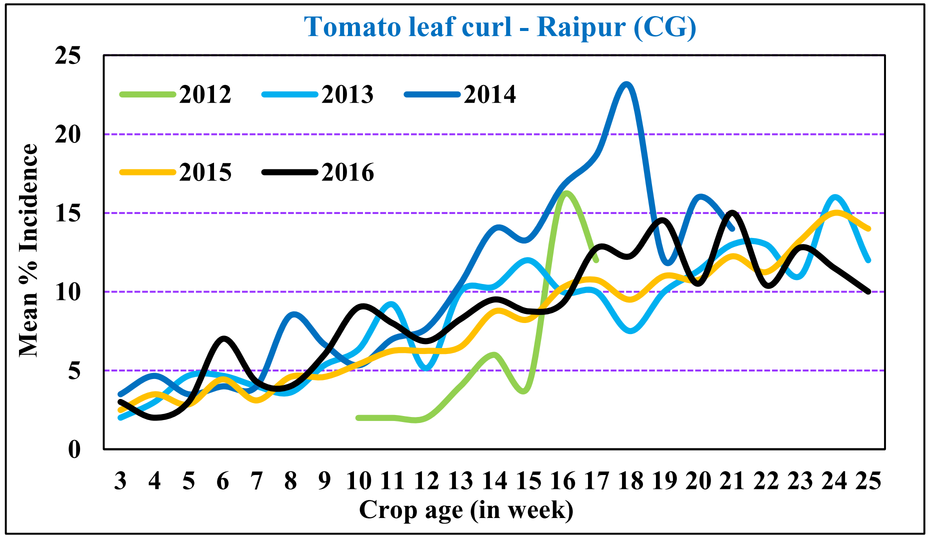
Annexure XXX: Seasonal dynamics of insect pests and diseases of *kharif* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**





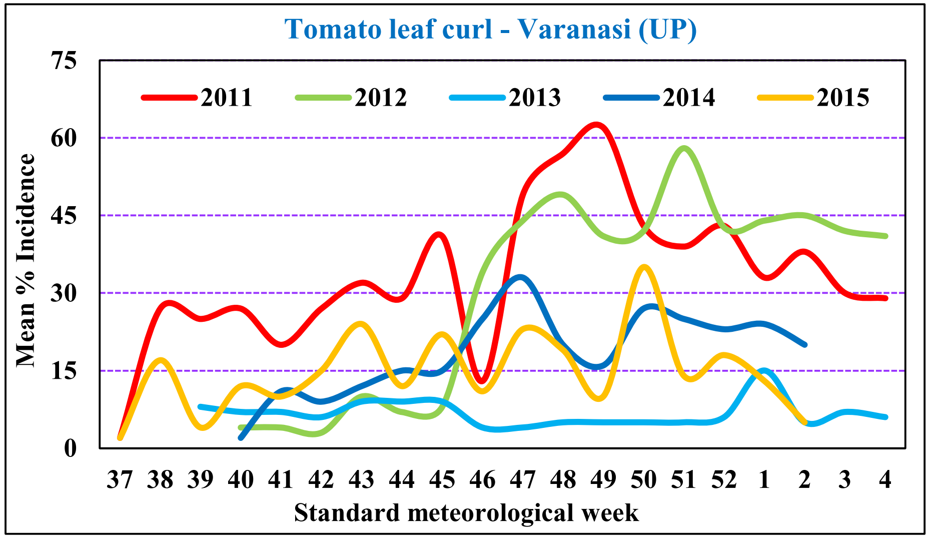


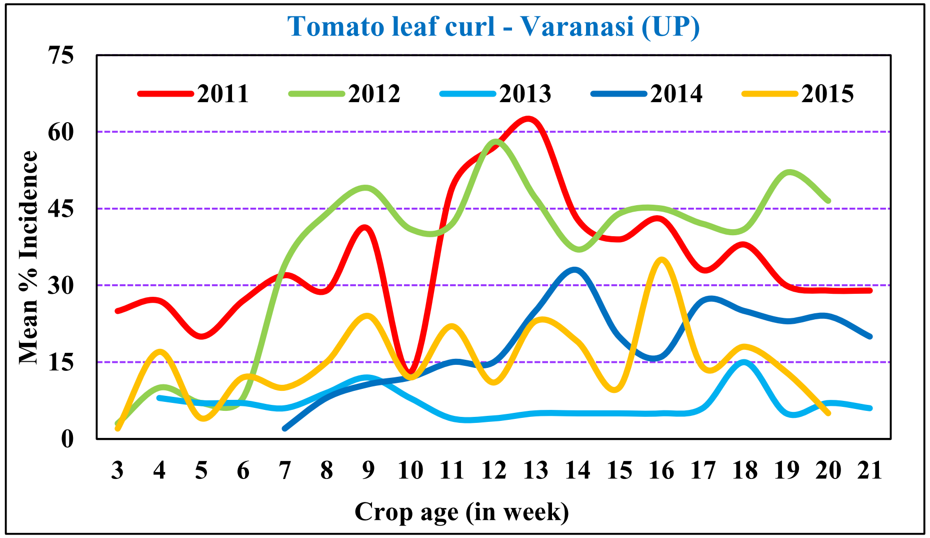


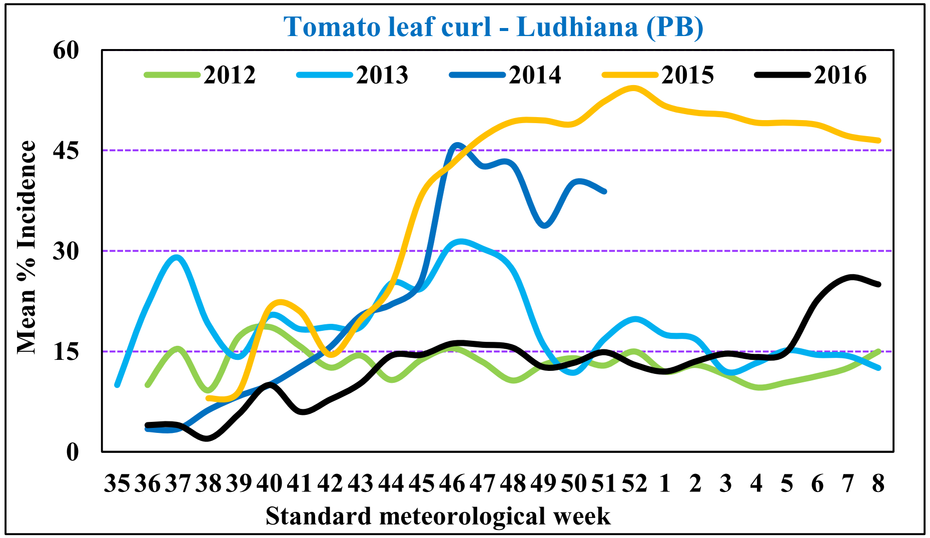
Annexure XXX: Seasonal dynamics of insect pests and diseases of *kharif* tomato [Arranged for study locations under each insect/disease]

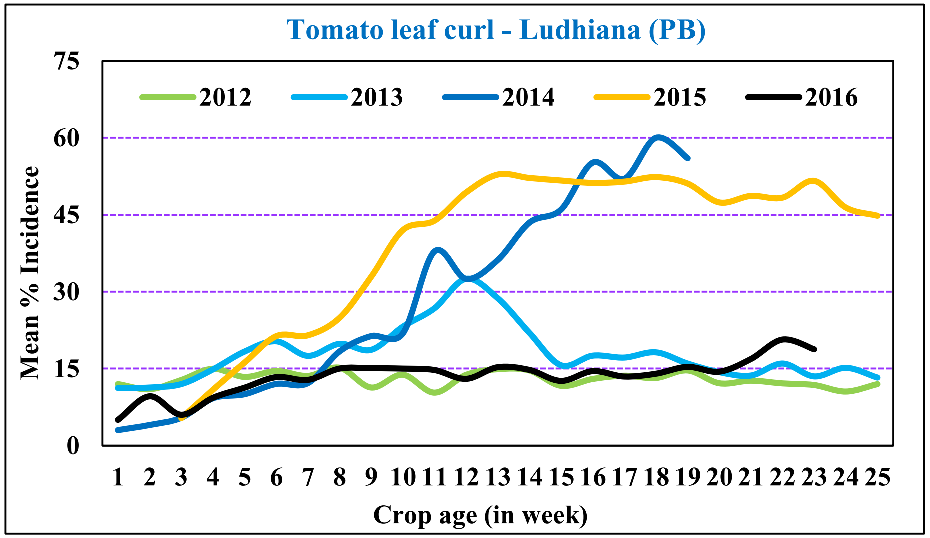
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





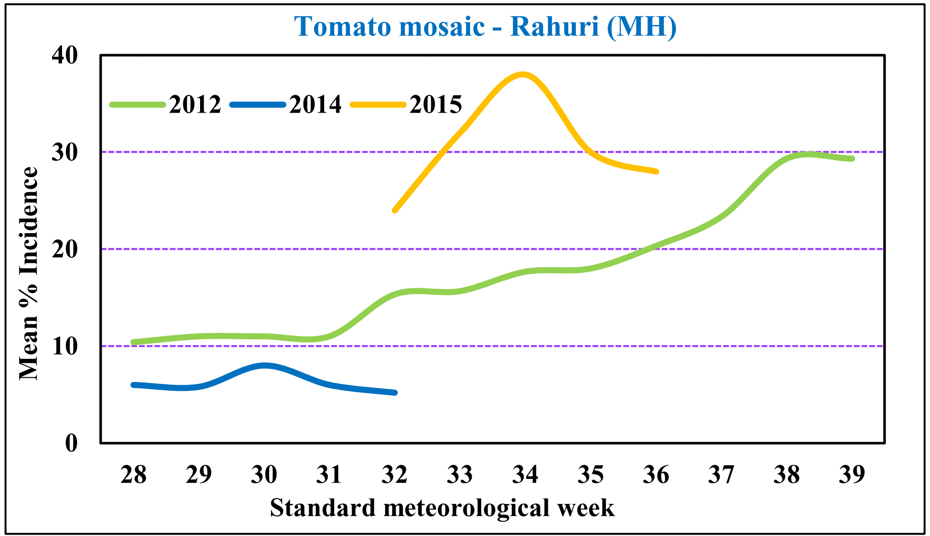


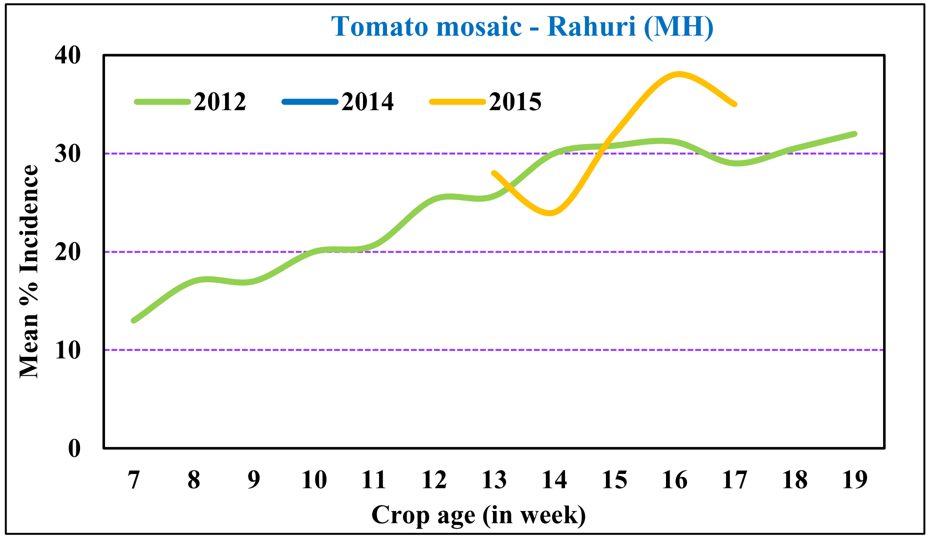


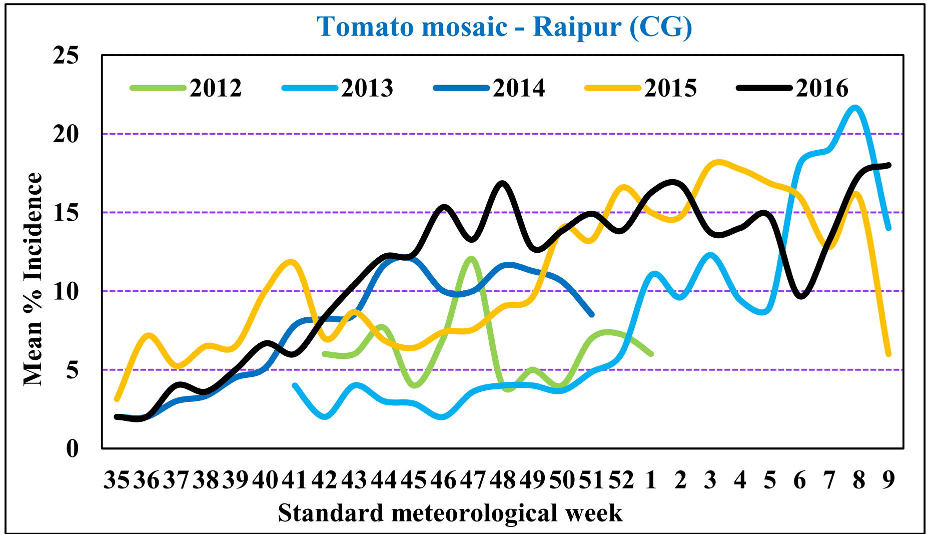
Annexure XXX: Seasonal dynamics of insect pests and diseases of *kharif* tomato [Arranged for study locations under each insect/disease]

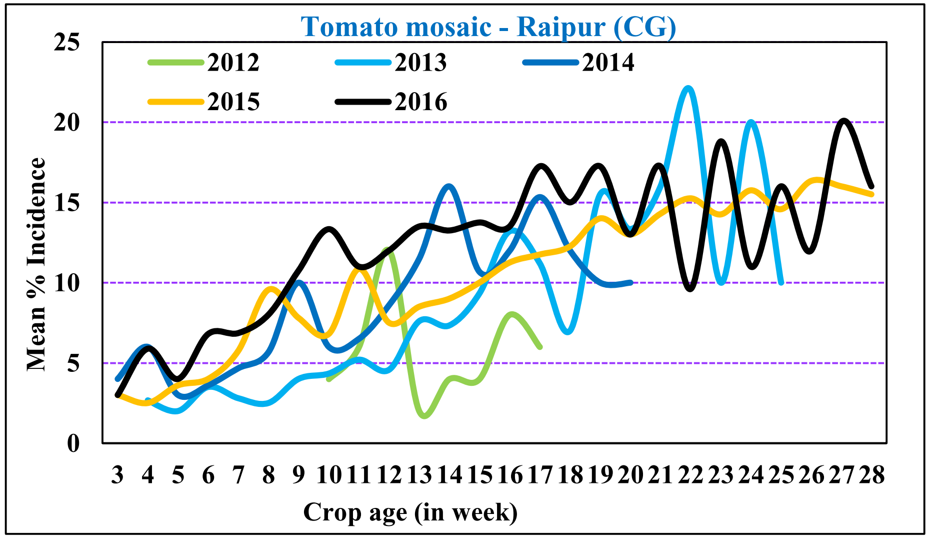
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





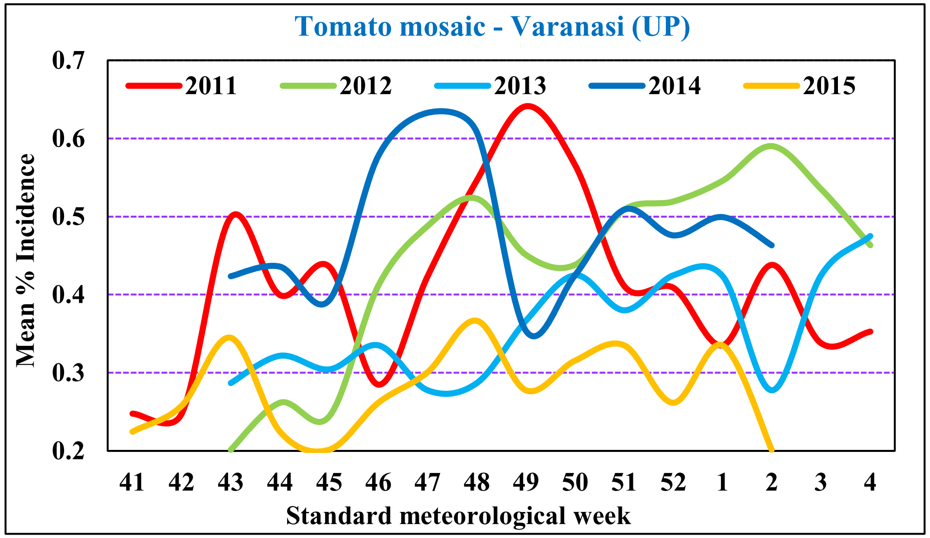


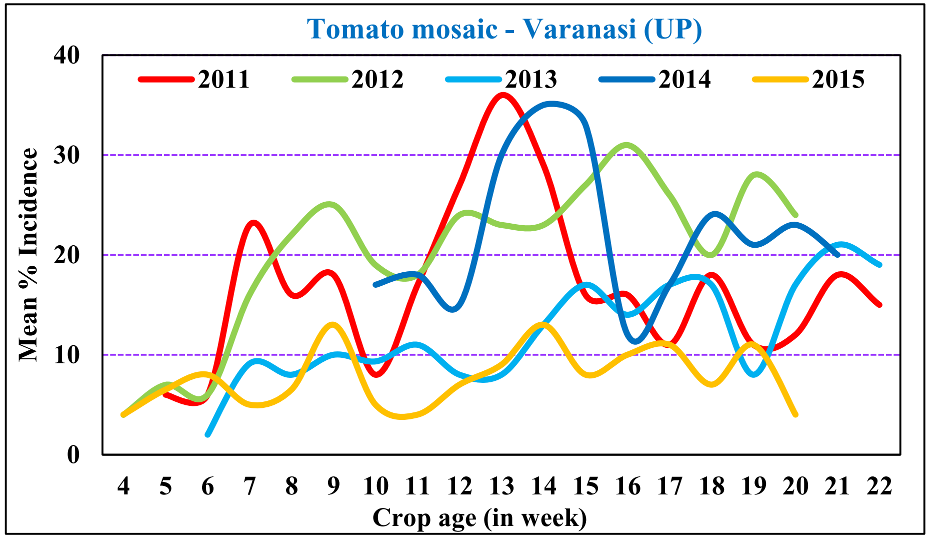


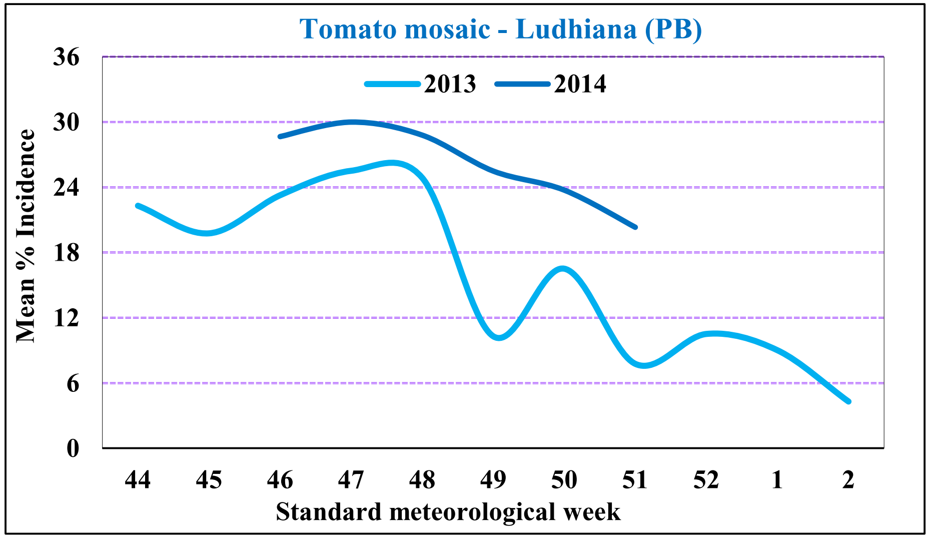
Annexure XXX: Seasonal dynamics of insect pests and diseases of *kharif* tomato [Arranged for study locations under each insect/disease]

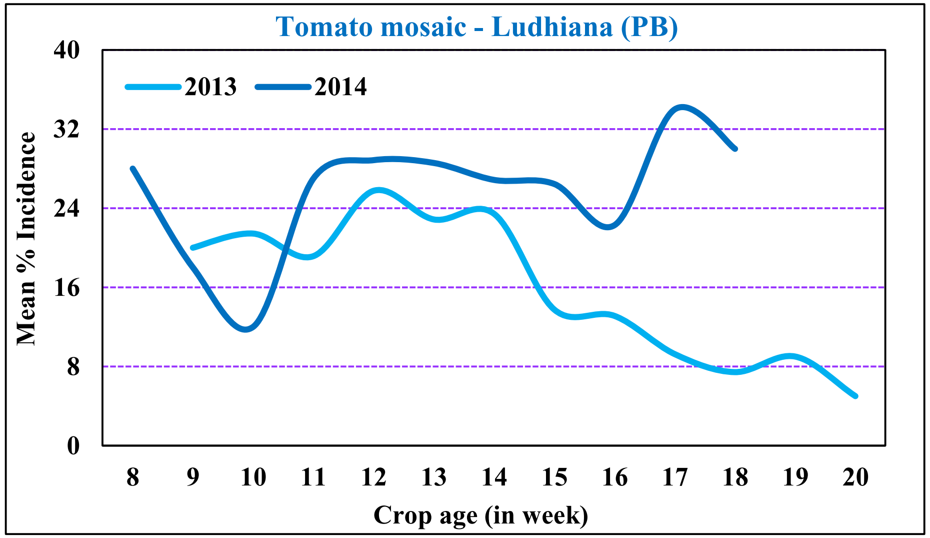
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





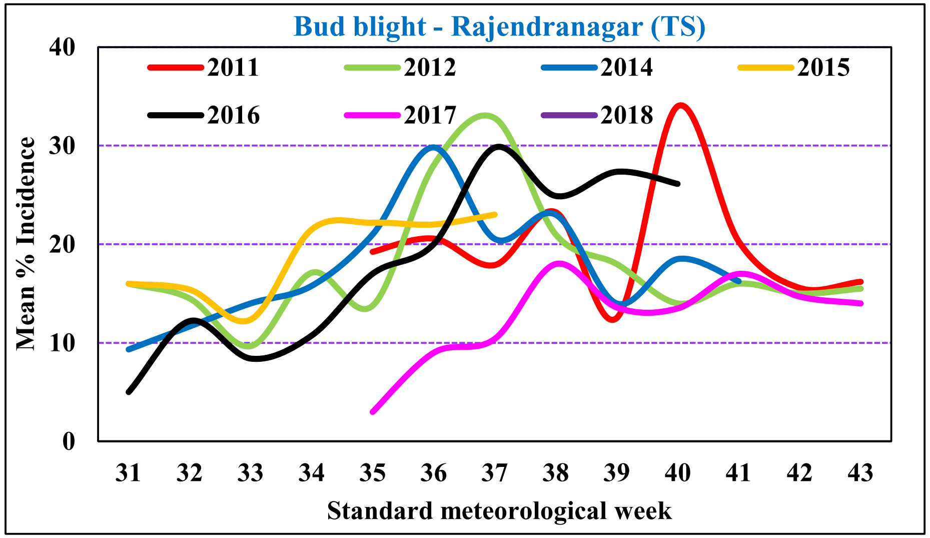


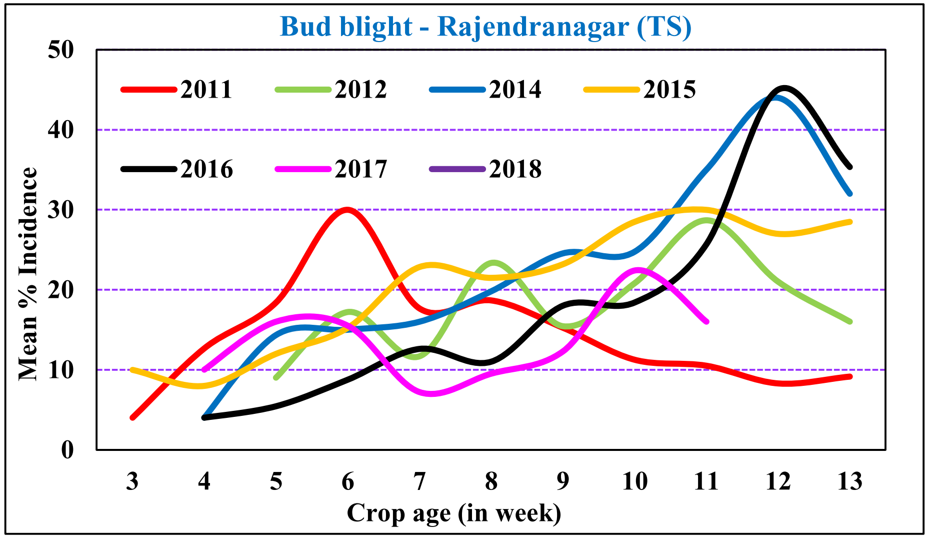


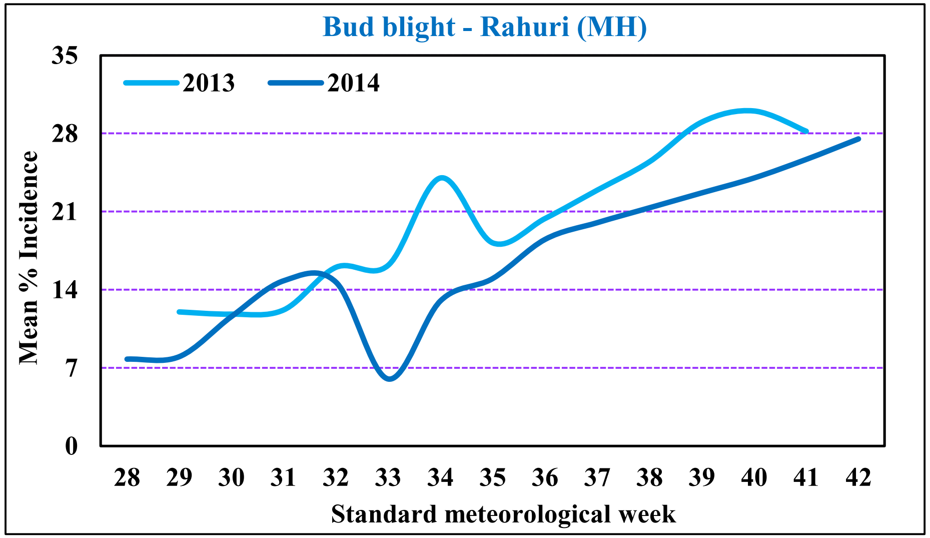
Annexure XXX: Seasonal dynamics of insect pests and diseases of *kharif* tomato [Arranged for study locations under each insect/disease]

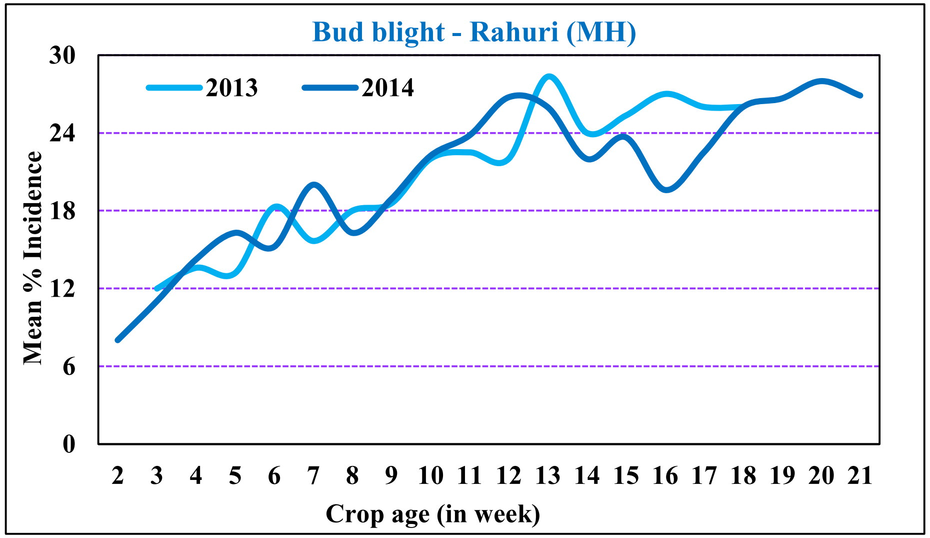
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





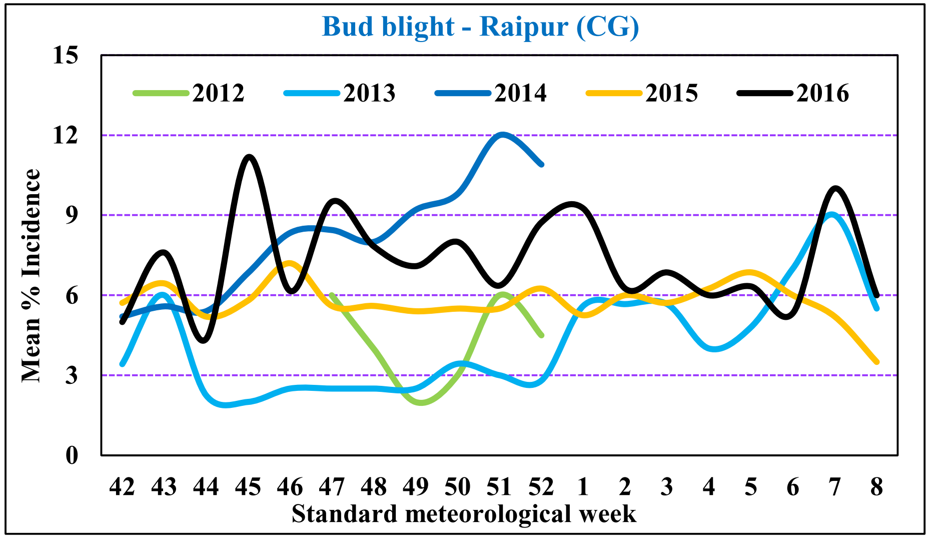


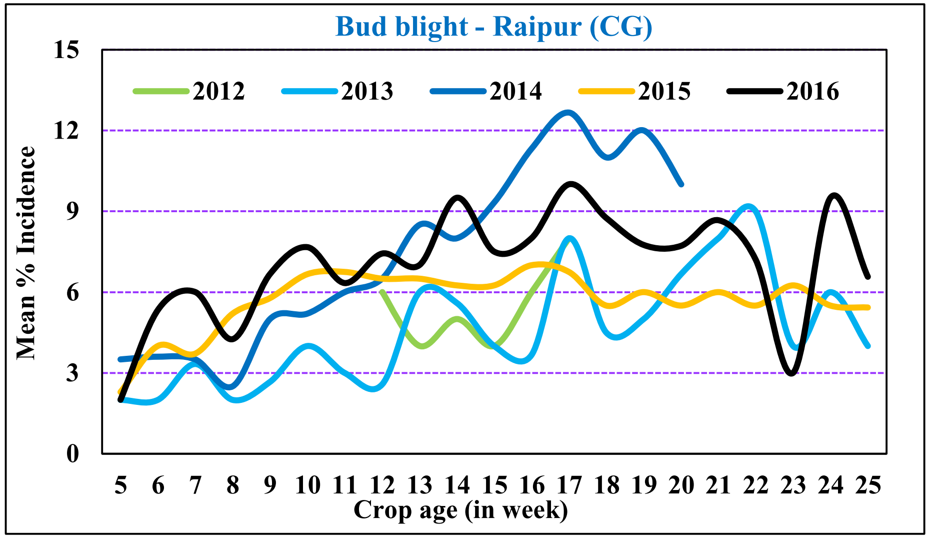


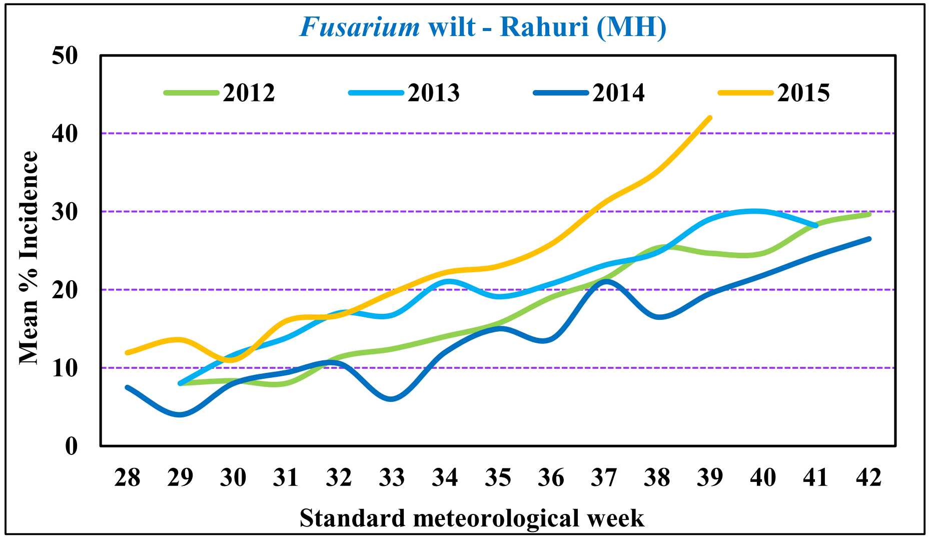
Annexure XXX: Seasonal dynamics of insect pests and diseases of *kharif* tomato [Arranged for study locations under each insect/disease]

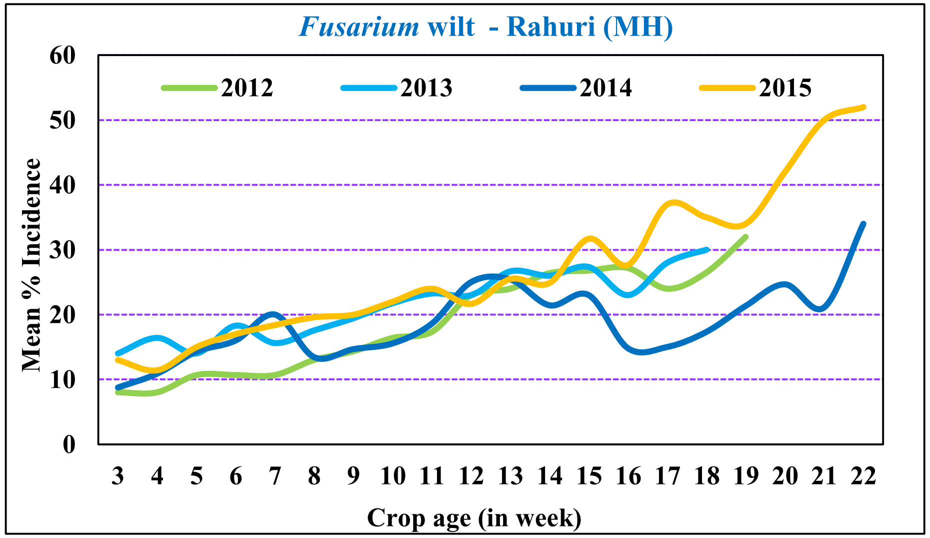
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





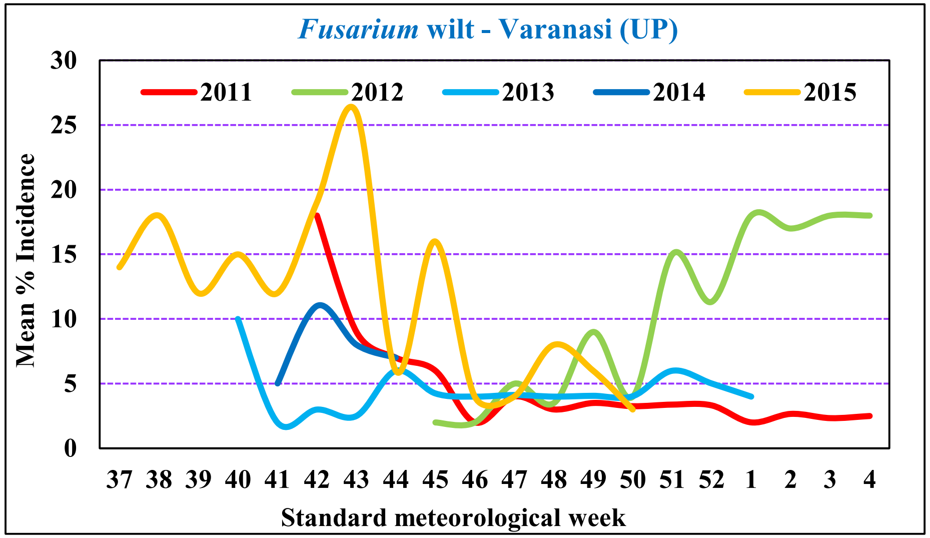


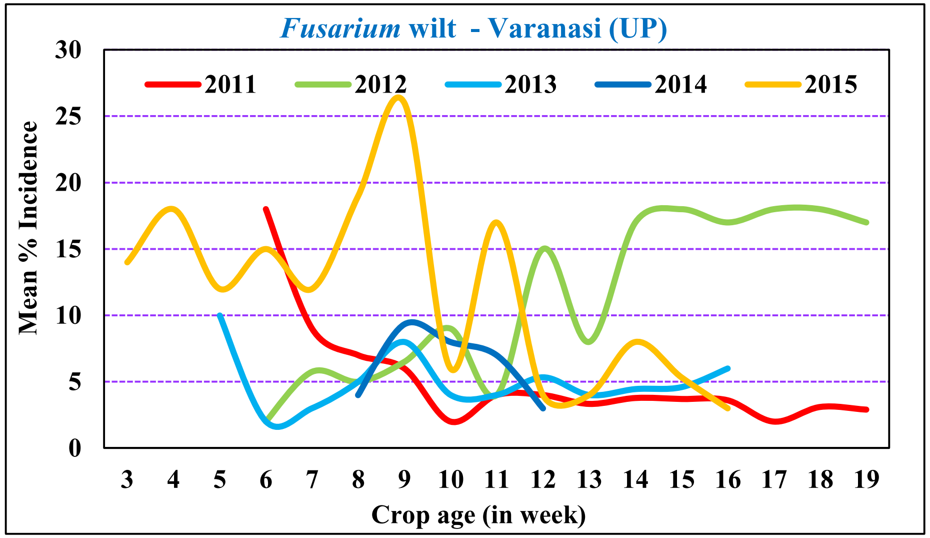


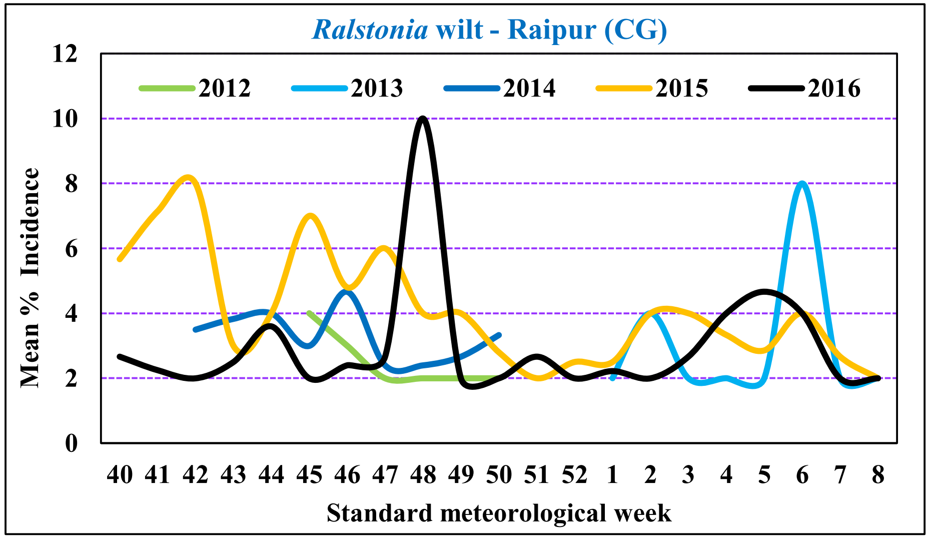
Annexure XXX: Seasonal dynamics of insect pests and diseases of *kharif* tomato [Arranged for study locations under each insect/disease]

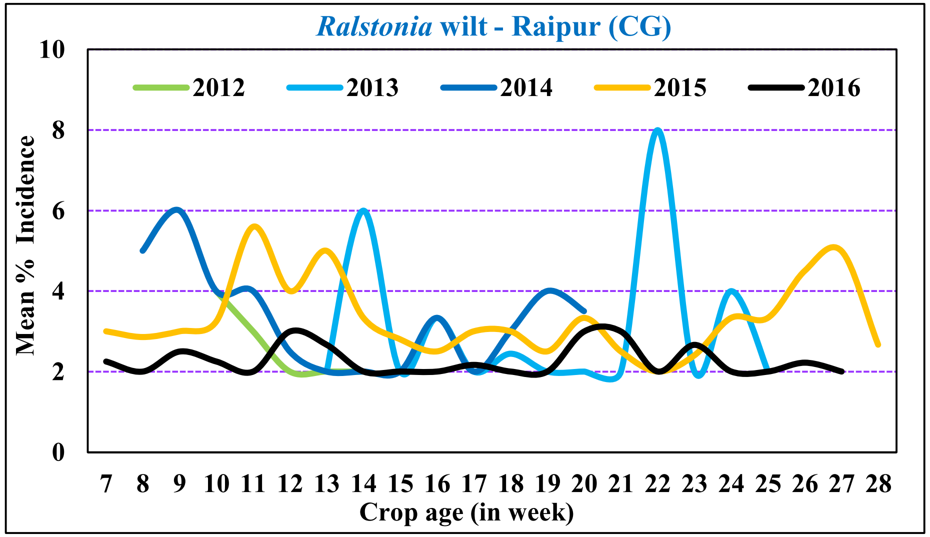
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





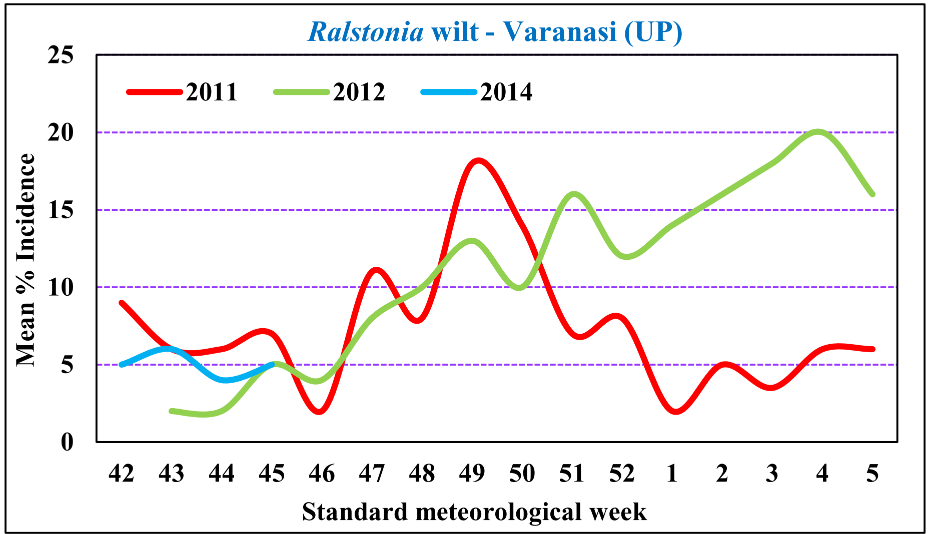


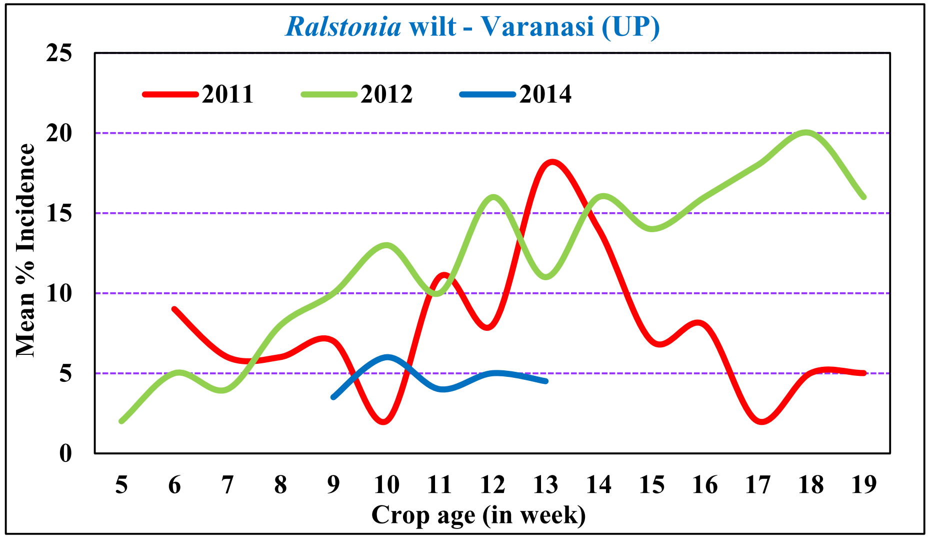


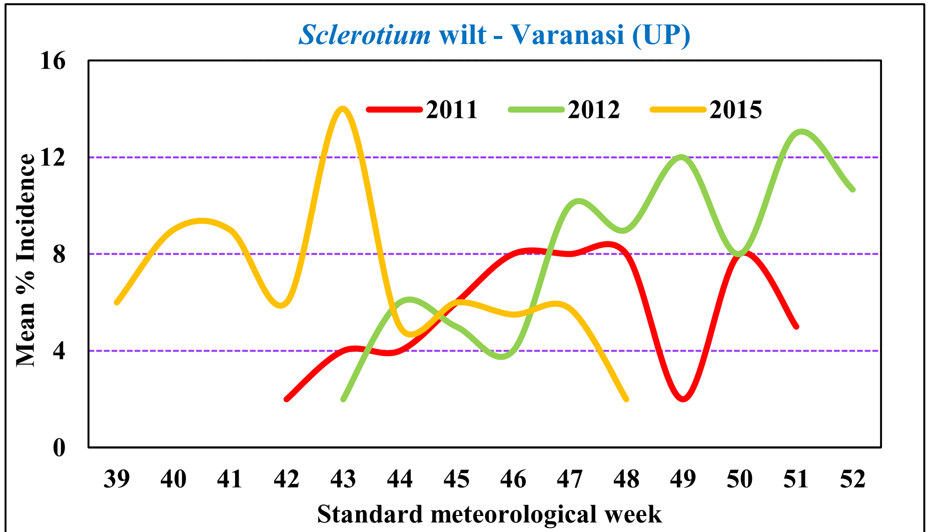
Annexure XXX: Seasonal dynamics of insect pests and diseases of *kharif* tomato [Arranged for study locations under each insect/disease]

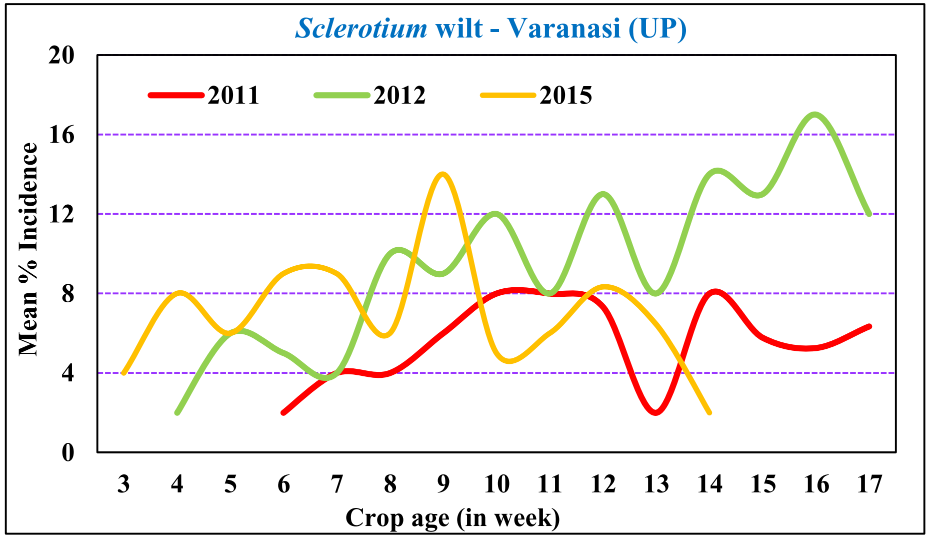
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



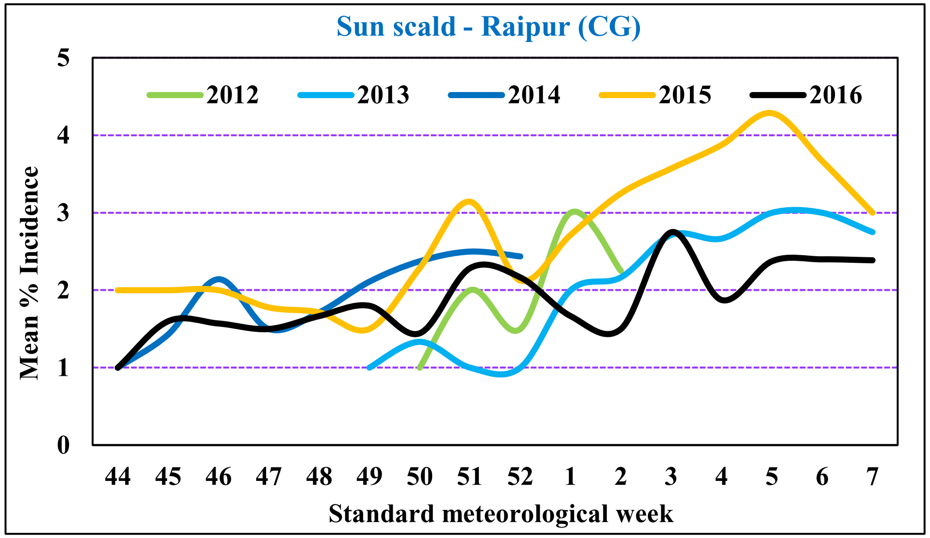




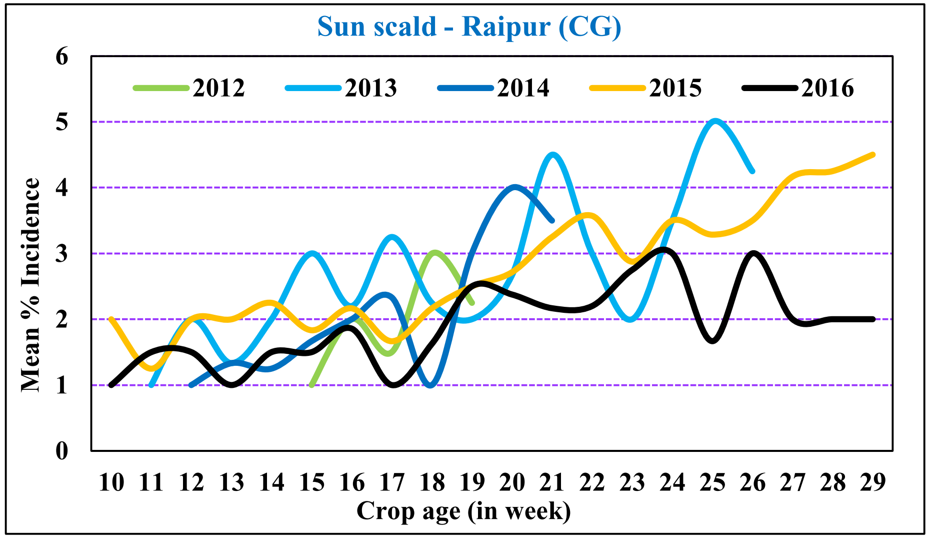


Annexure XXX: Seasonal dynamics of insect pests and diseases of *kharif* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks



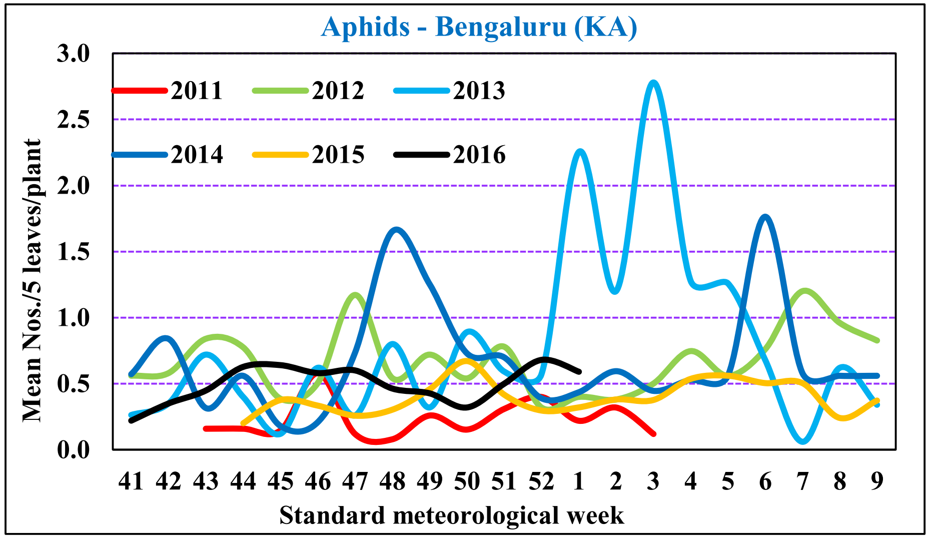
Seasonal dynamics based on crop age

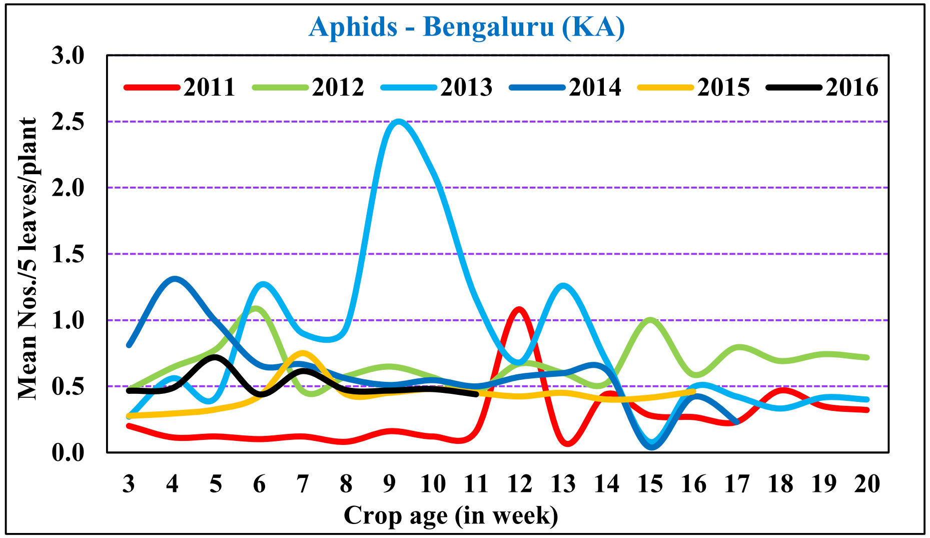


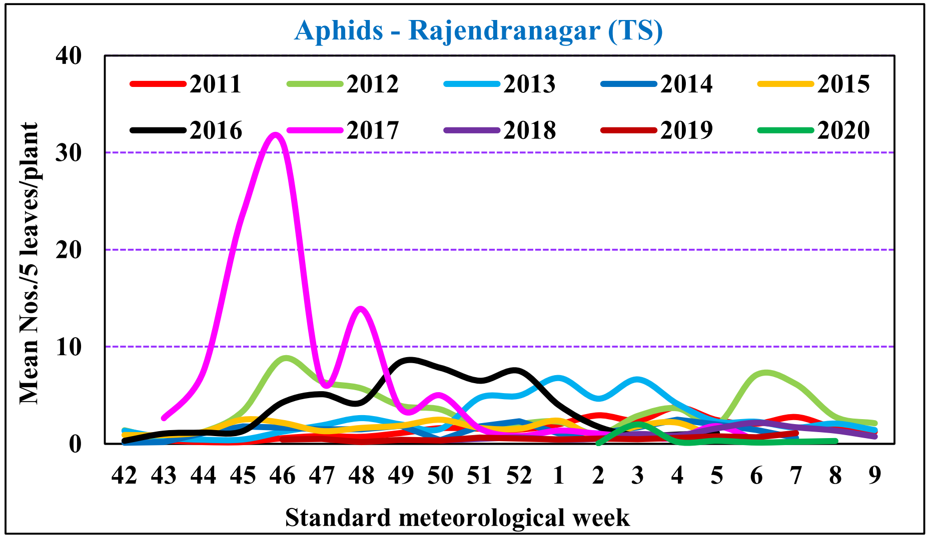
Note: Many legends and less lines shown in a graph denotes abundance/infestation (insects)/incidence/severity (diseases) very less or in traces, respectively

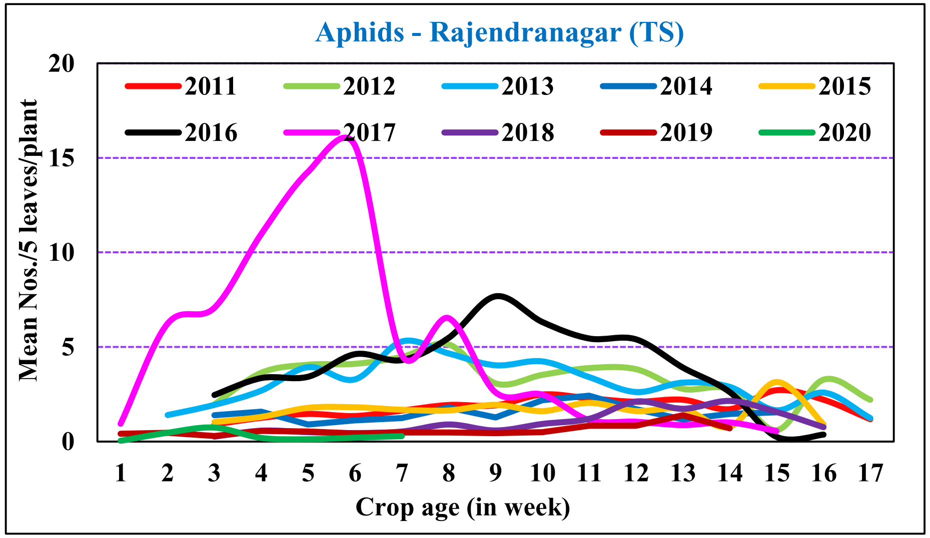
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | Seasonal dynamics based on crop age





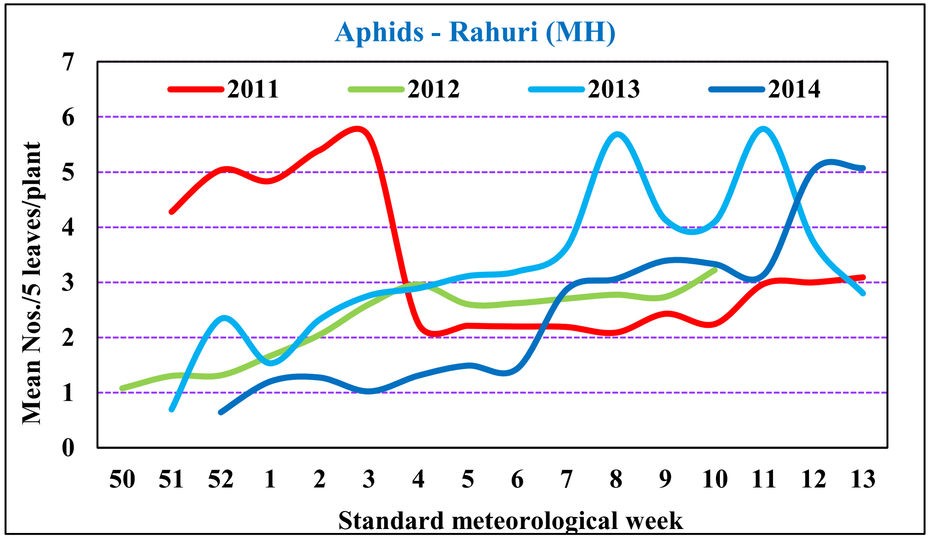


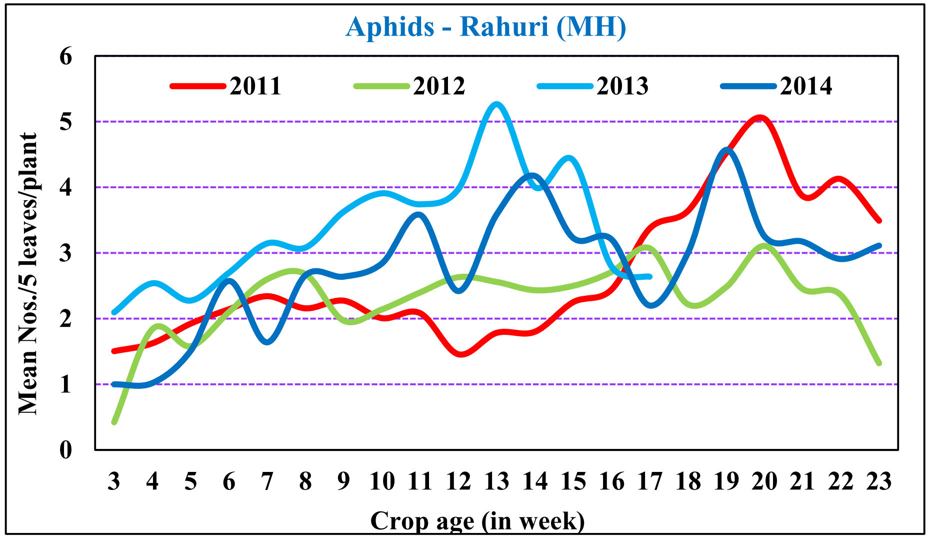


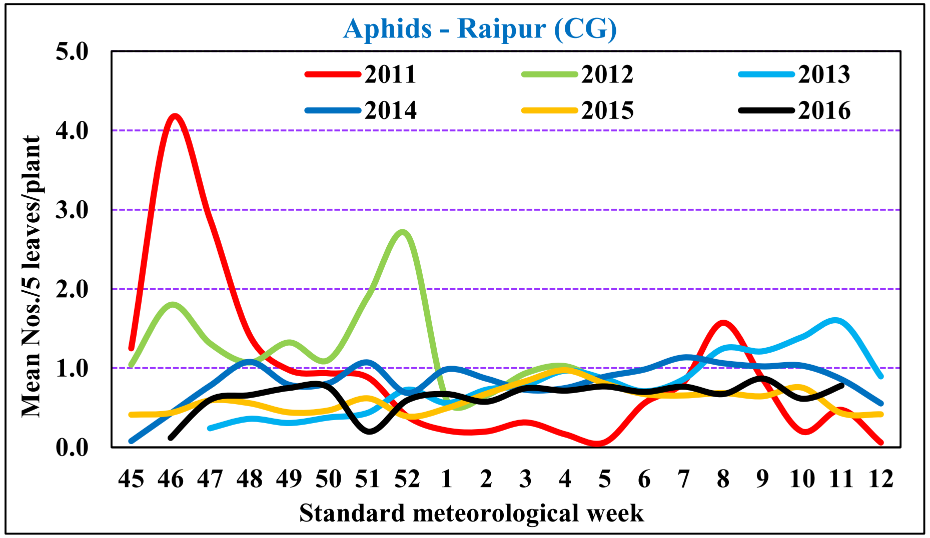
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

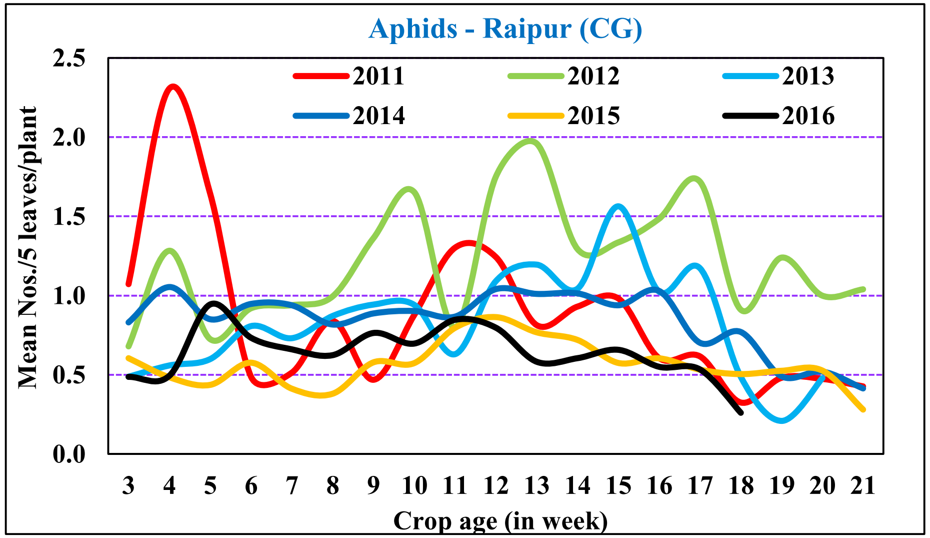
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





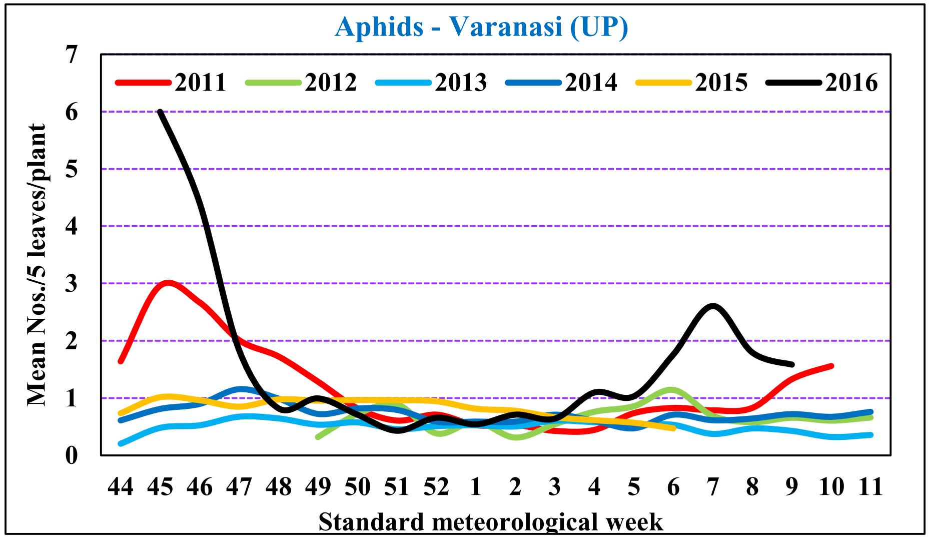


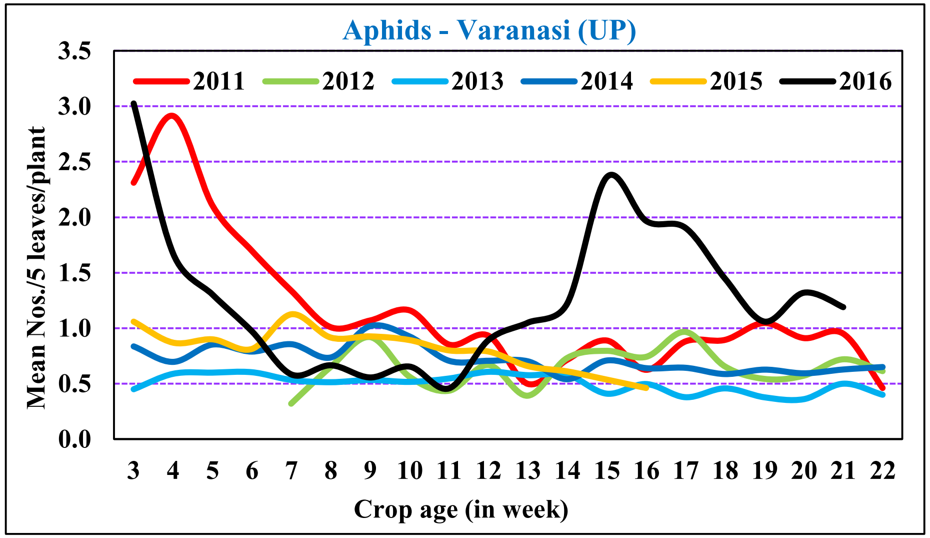


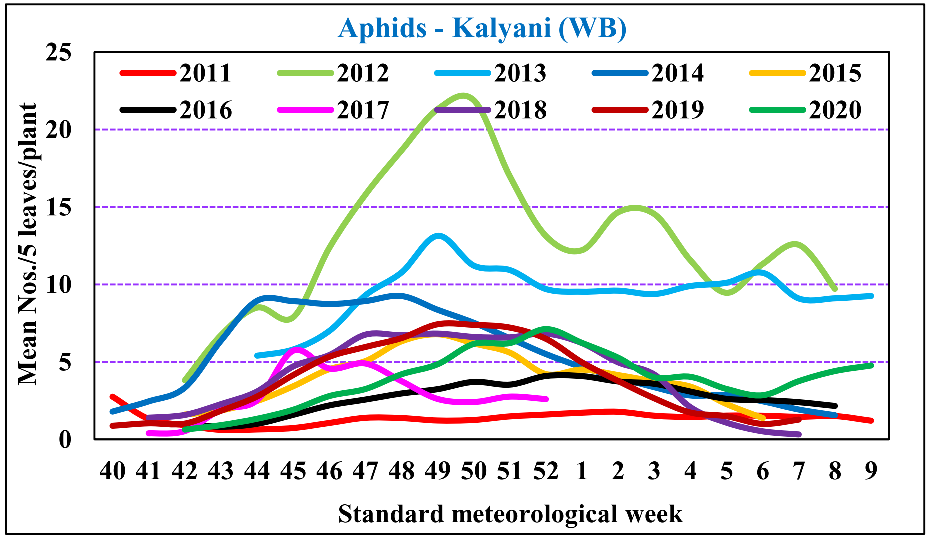
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

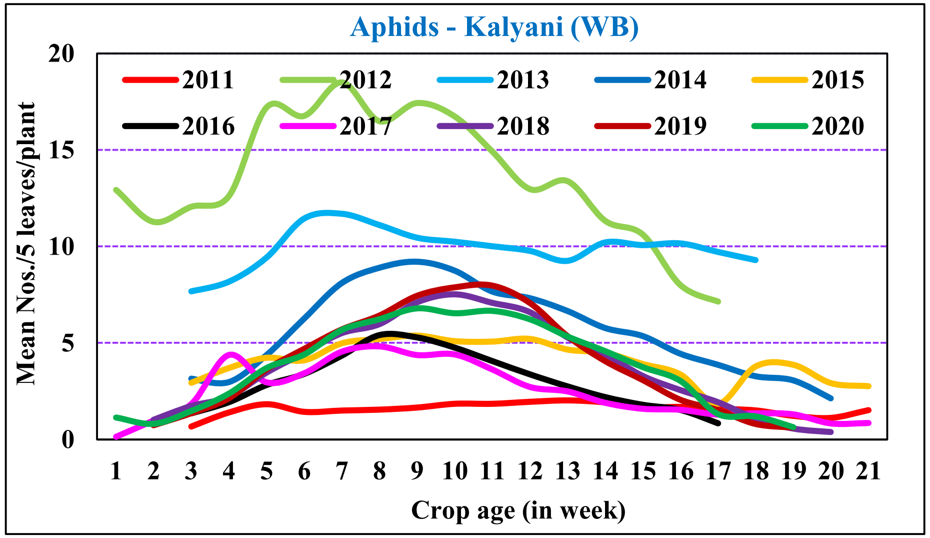
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





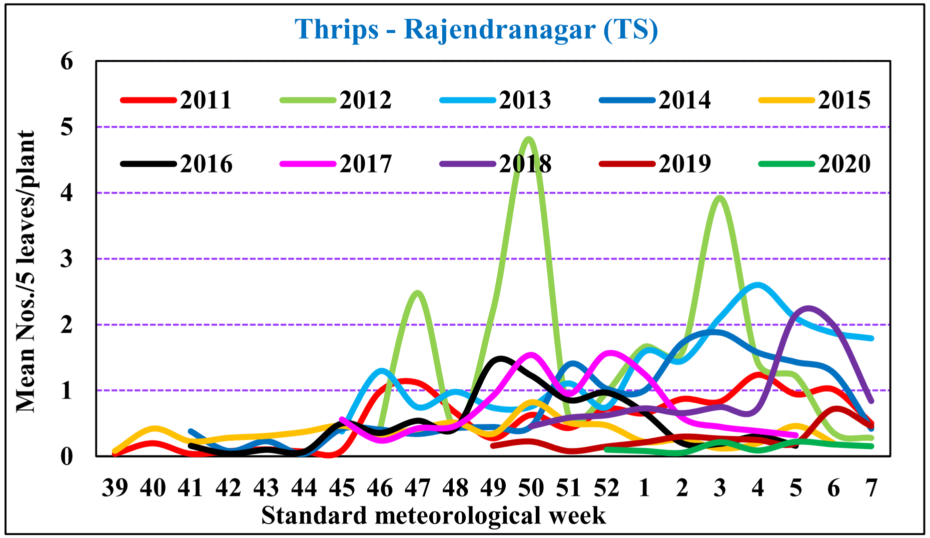


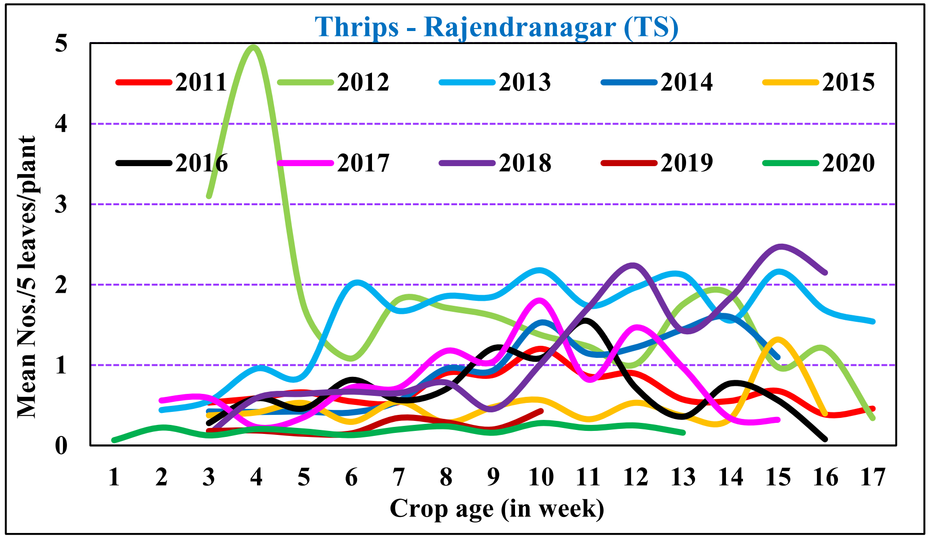


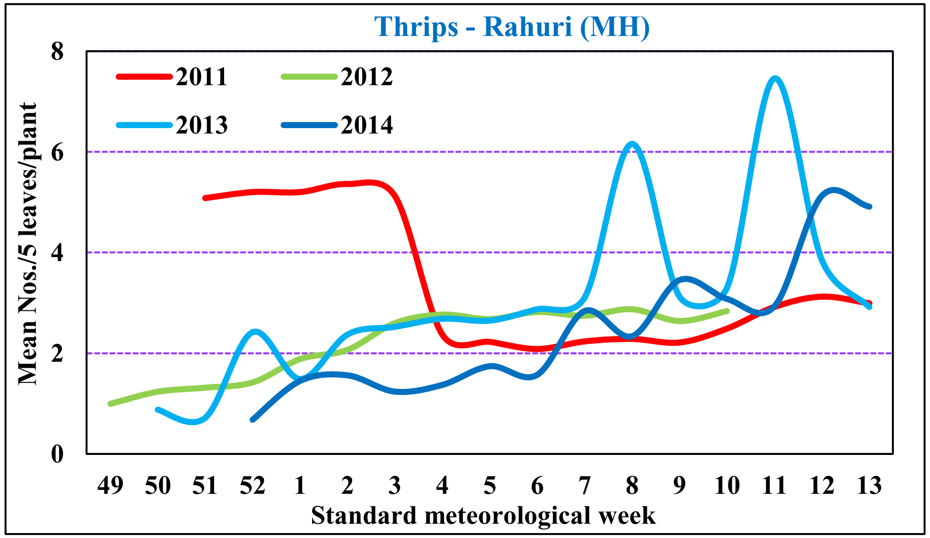
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

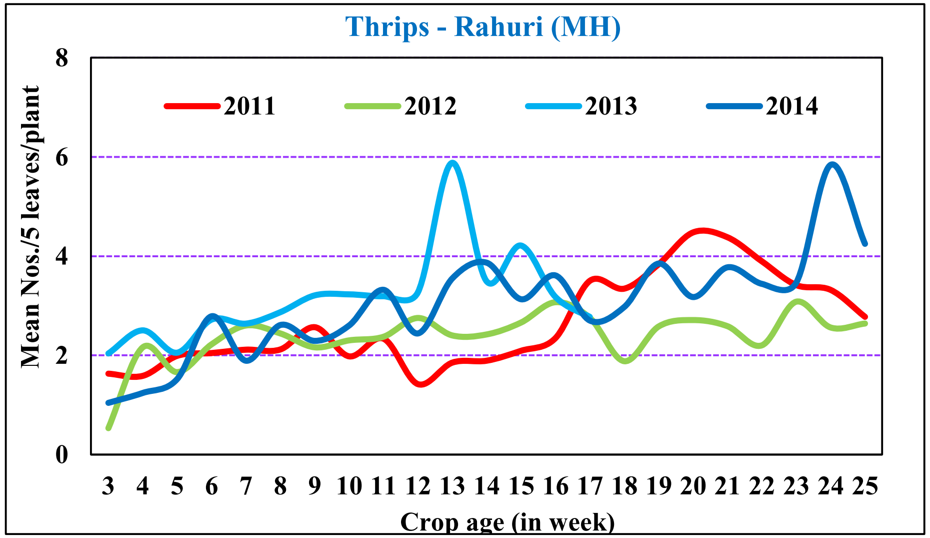
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



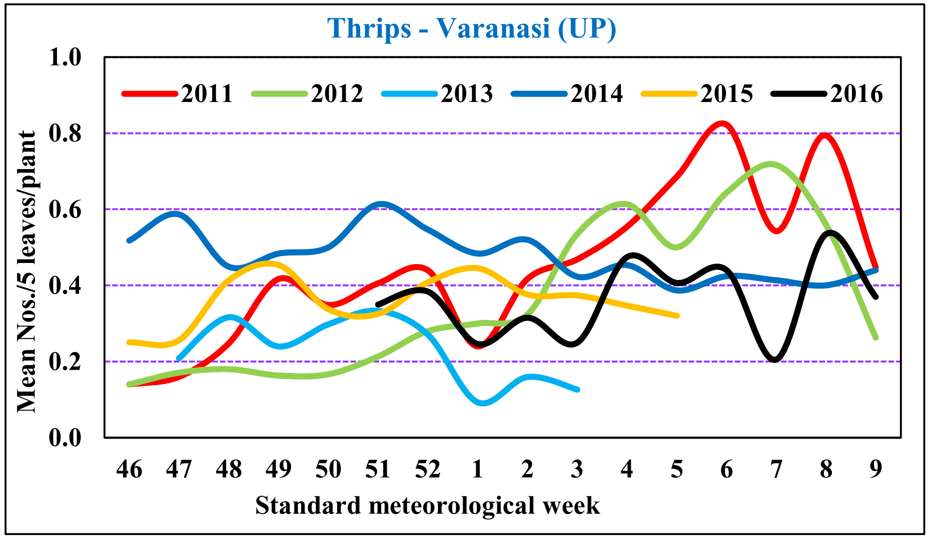


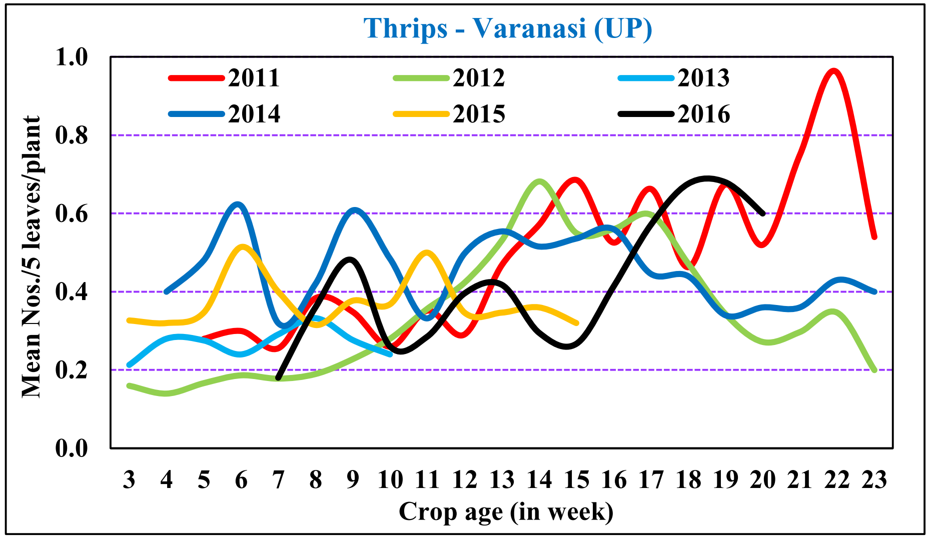


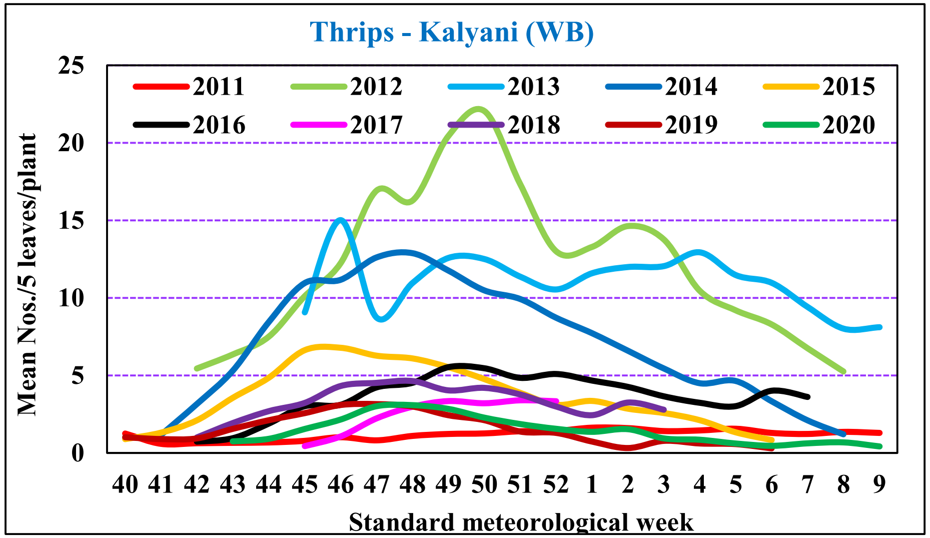


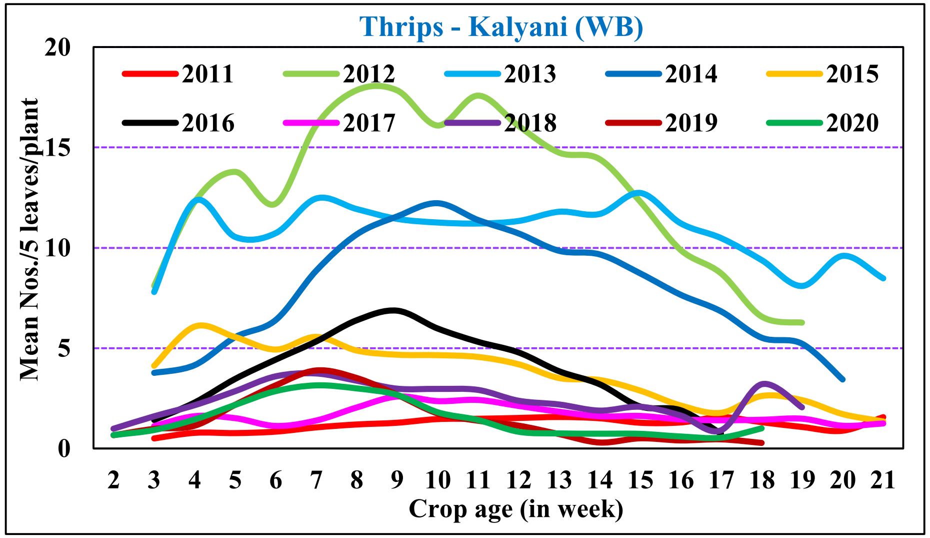
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



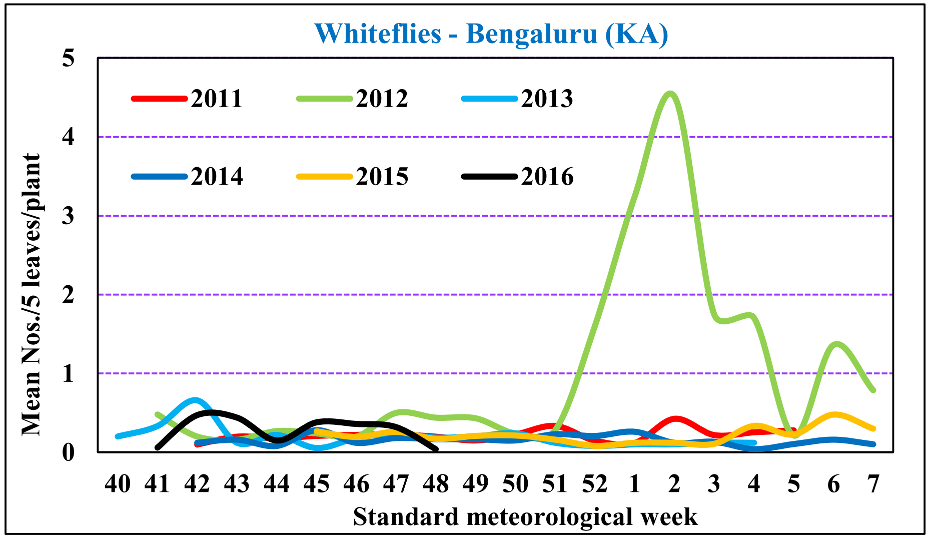


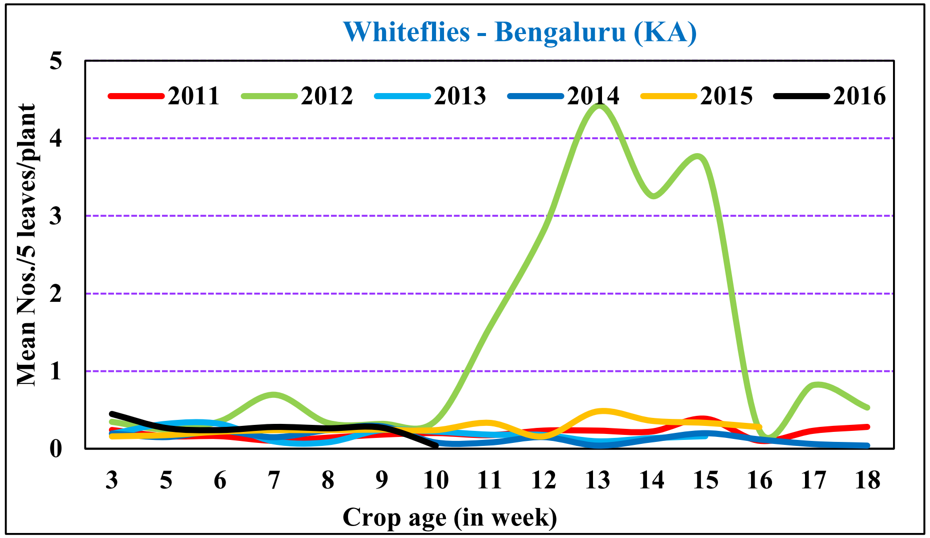


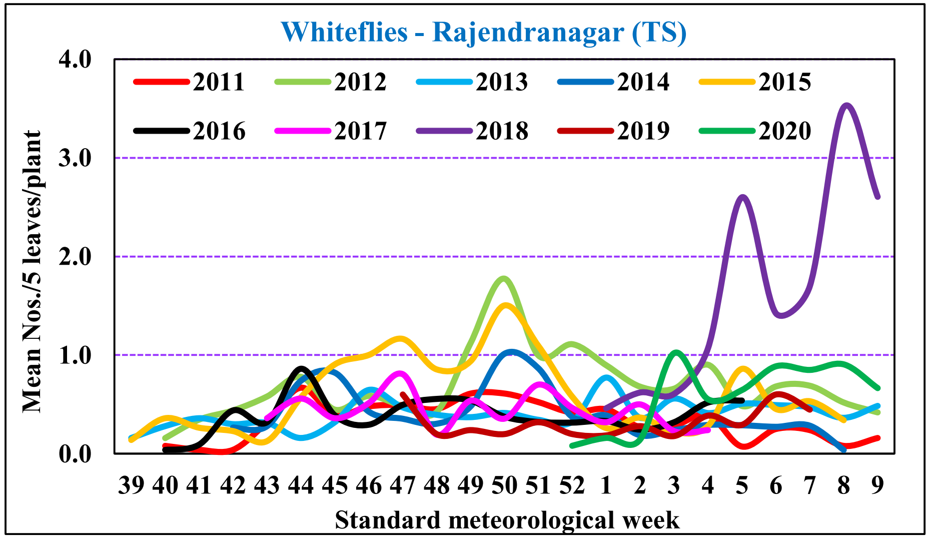


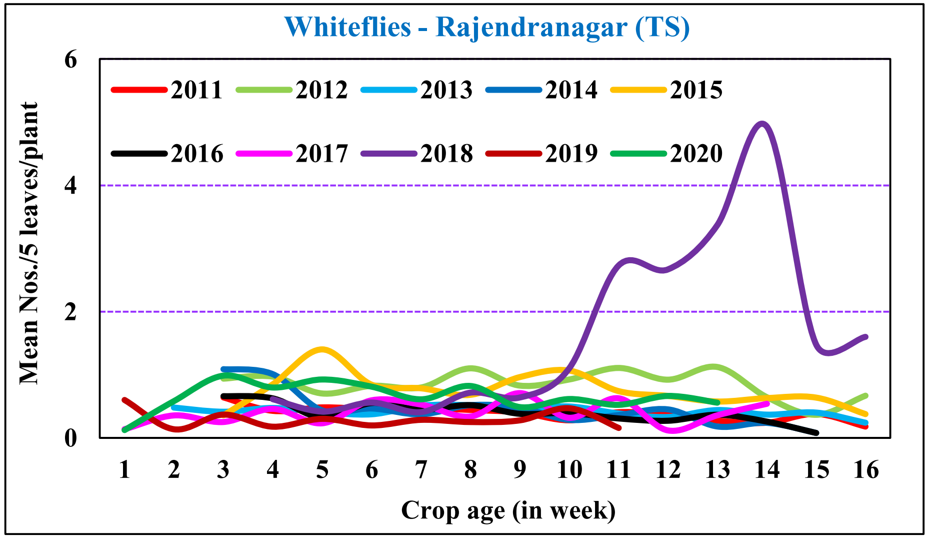
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



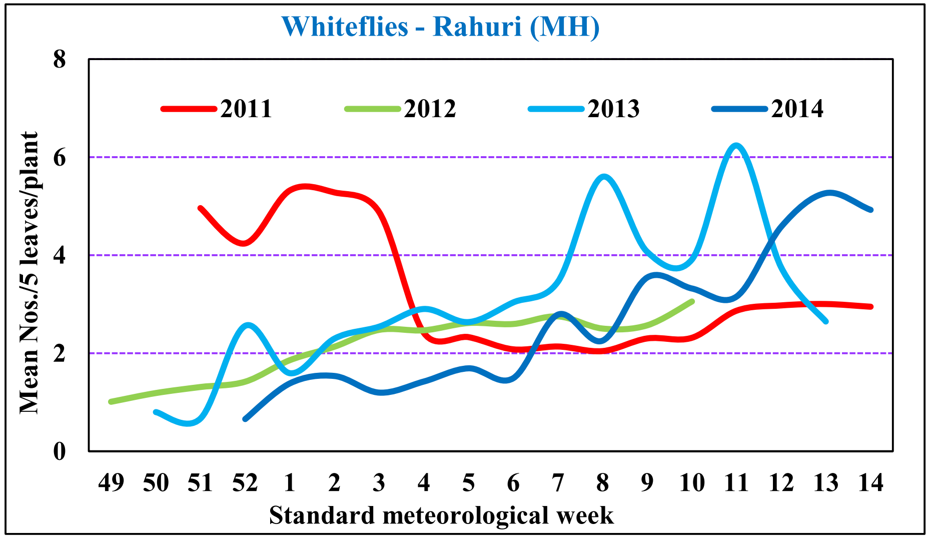


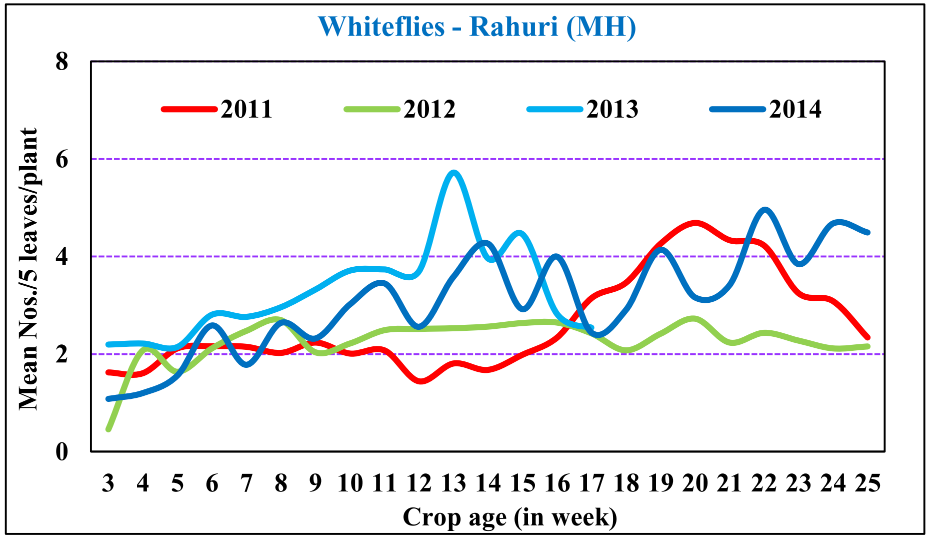


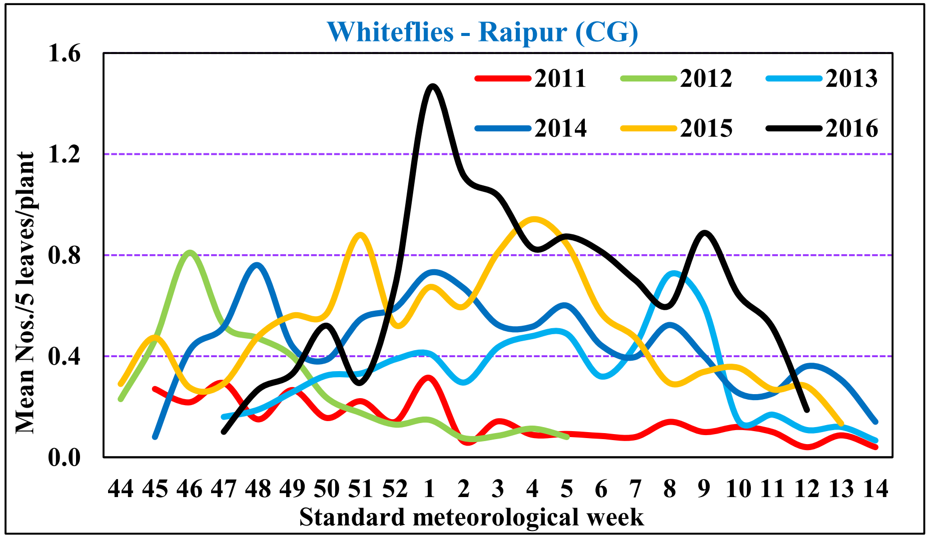


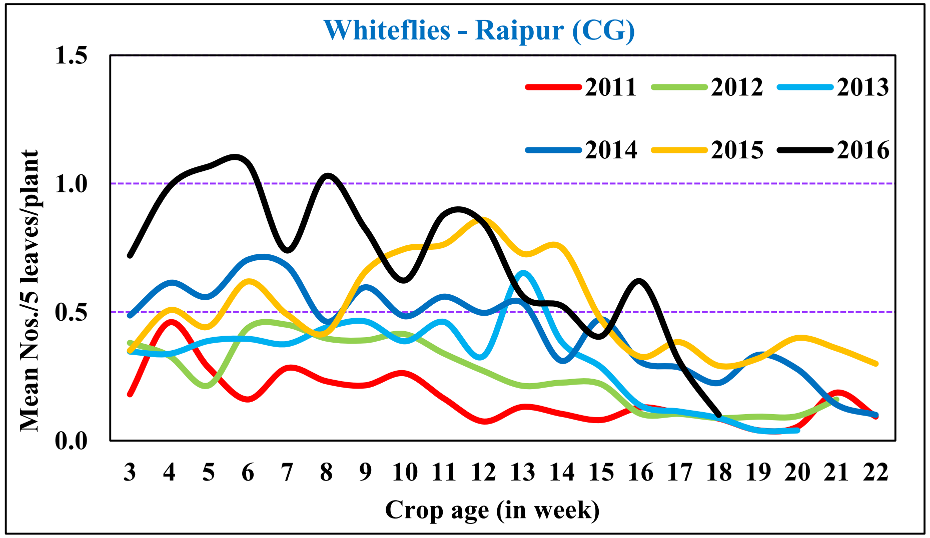
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**





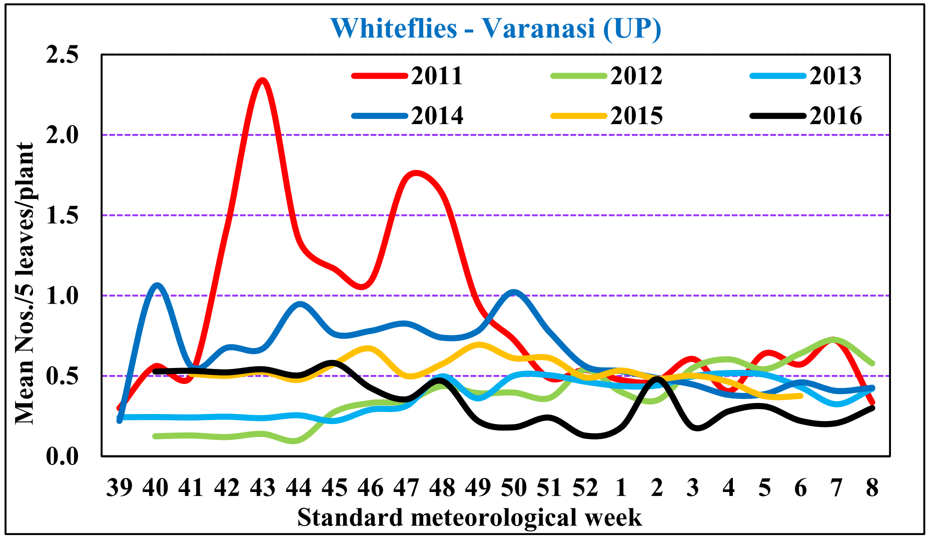


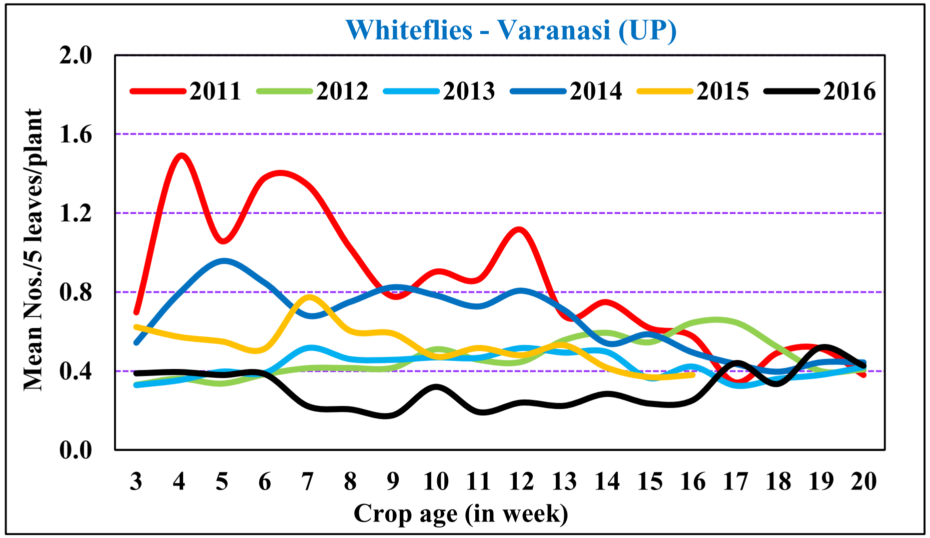


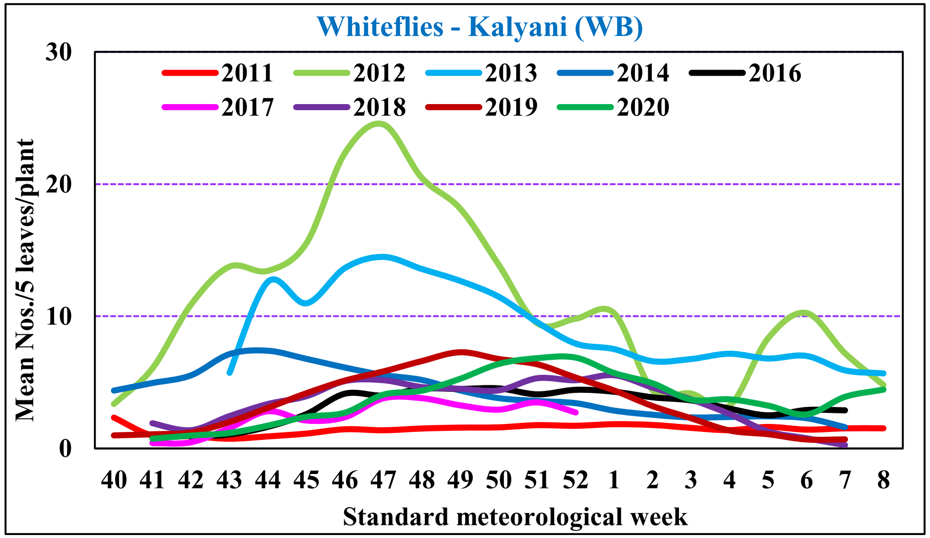
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

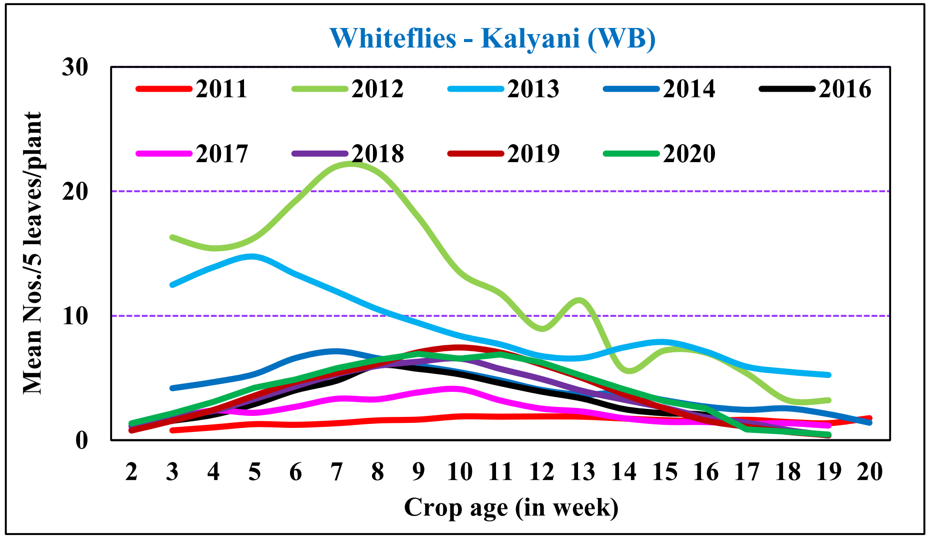
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



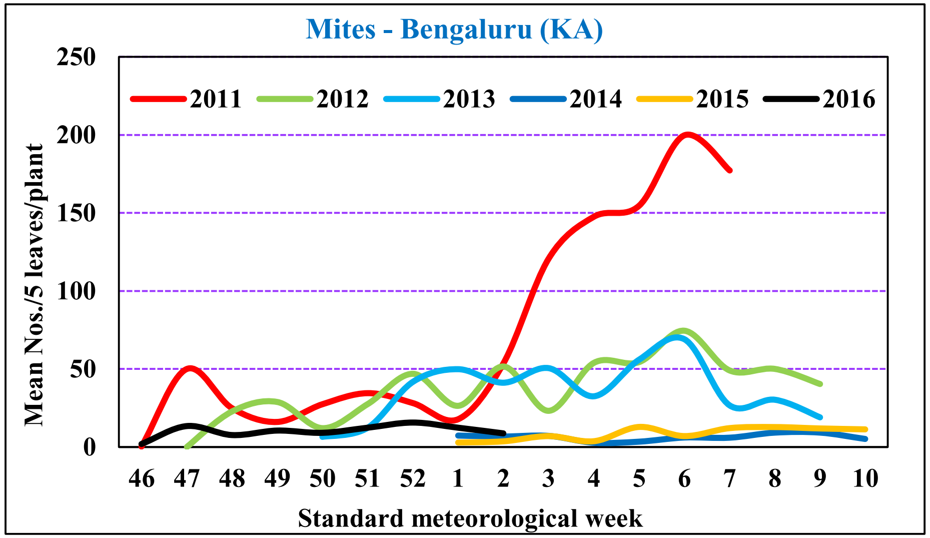


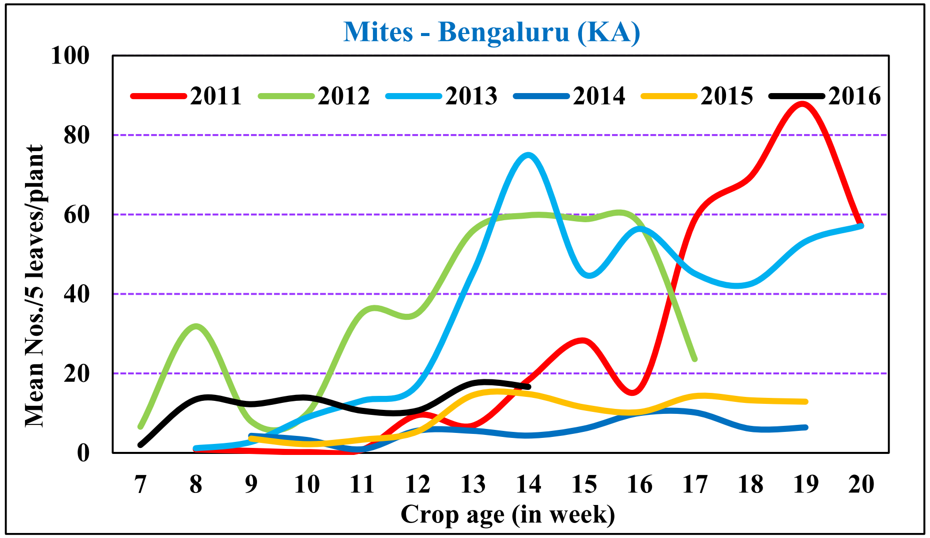


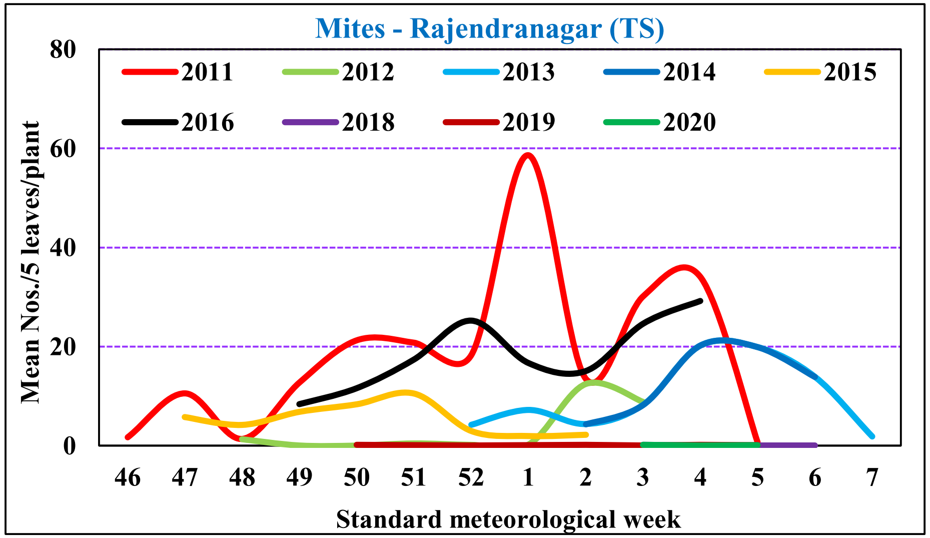


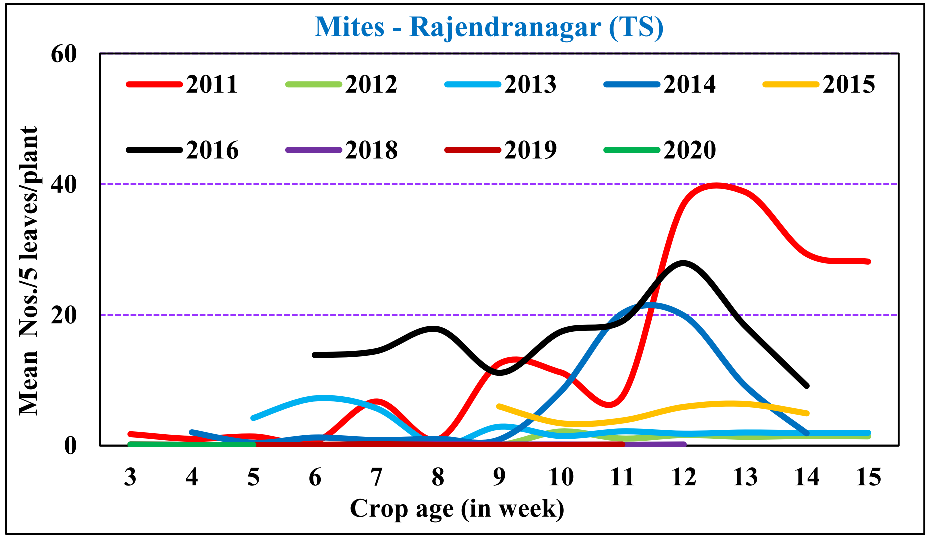
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**





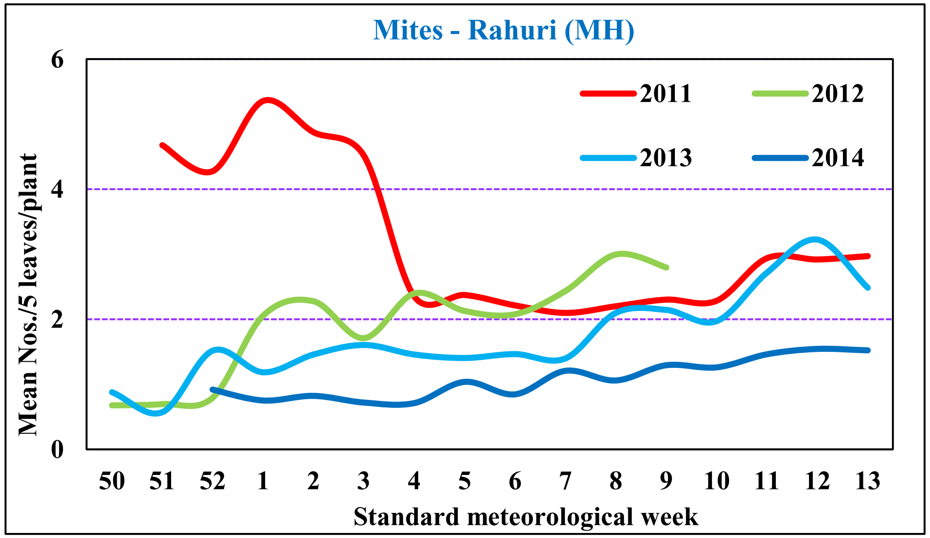


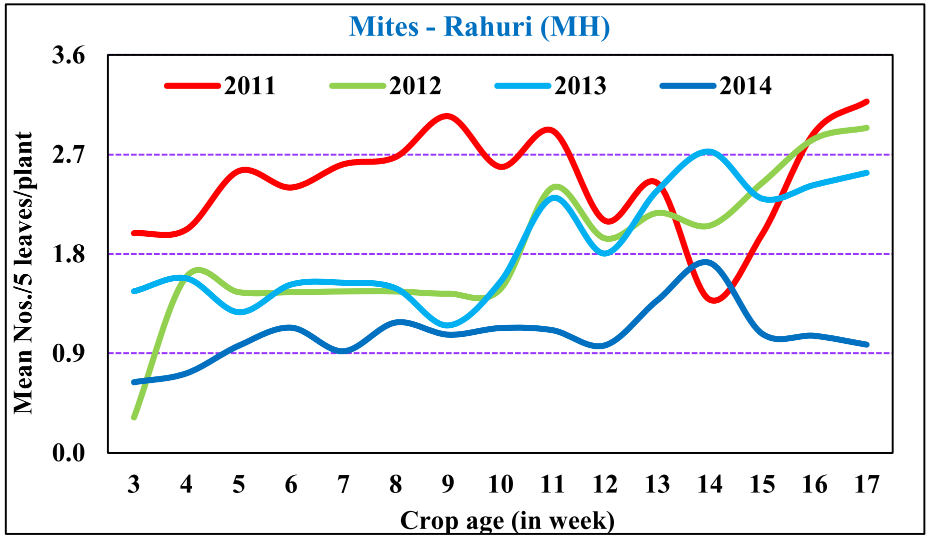


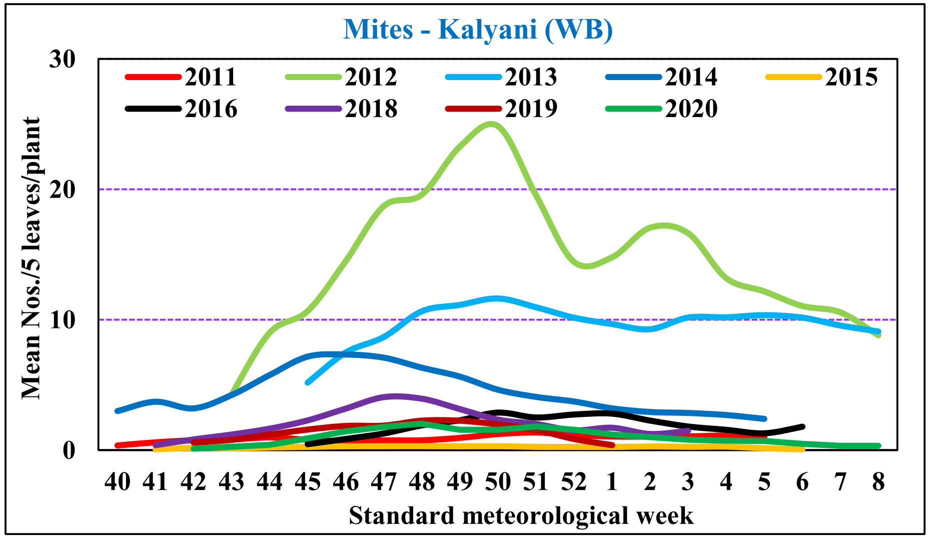
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

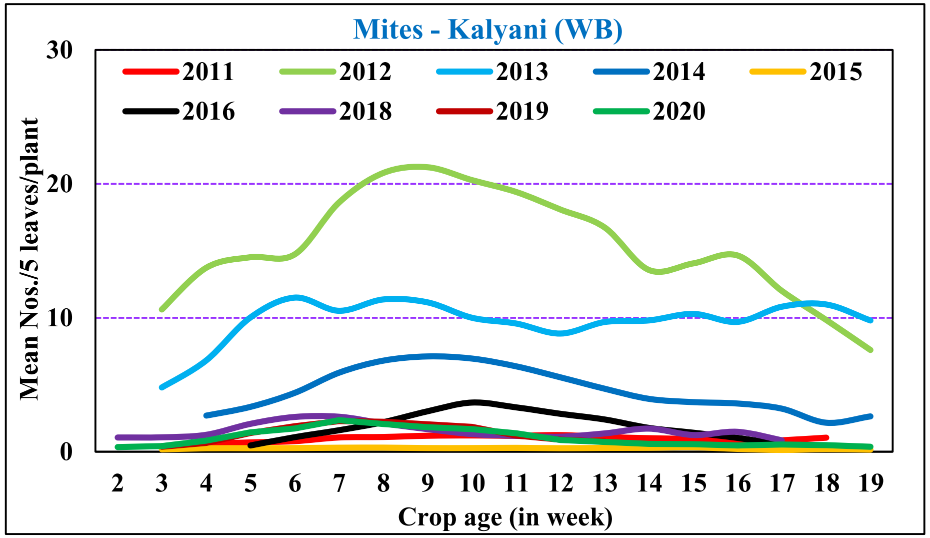
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





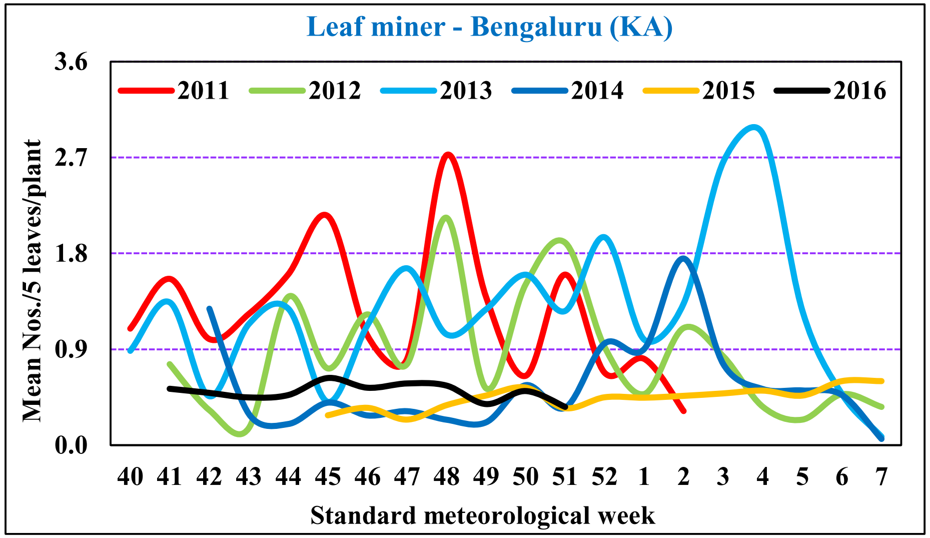


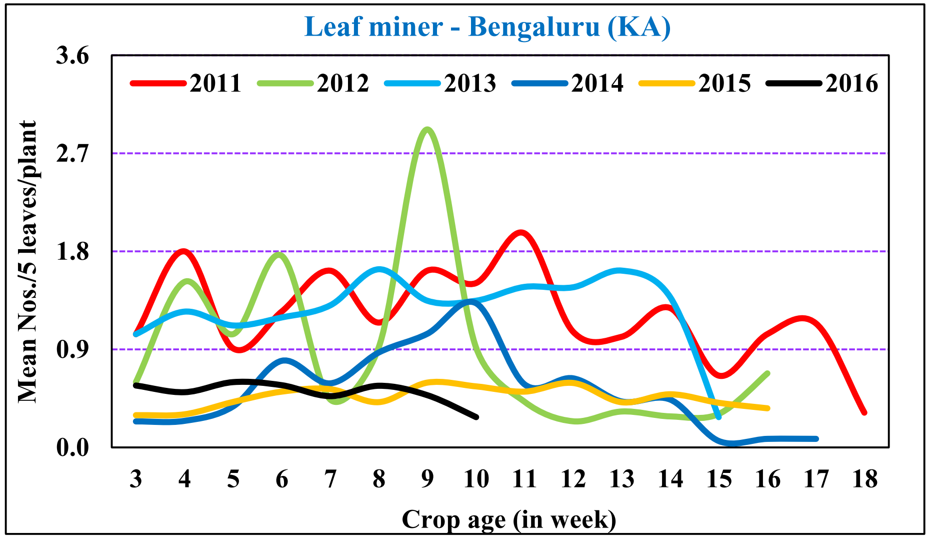


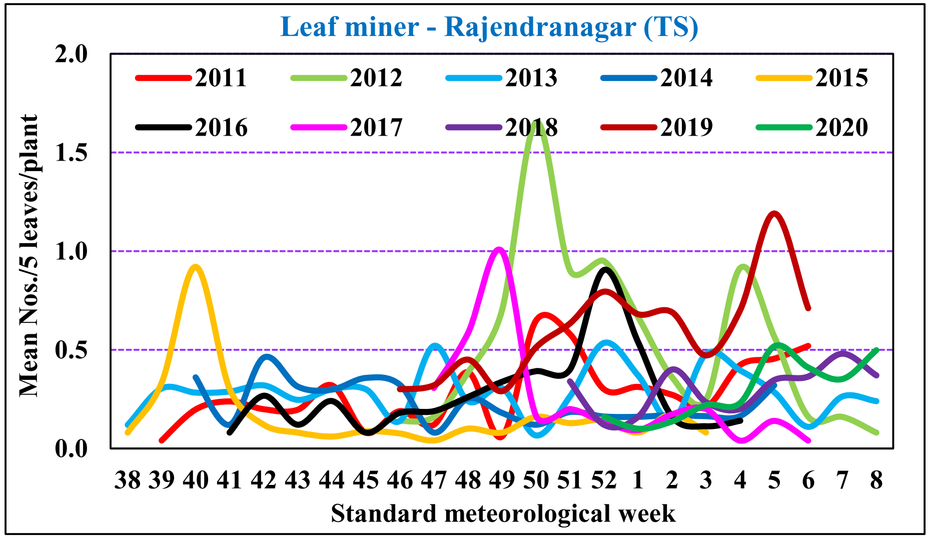
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

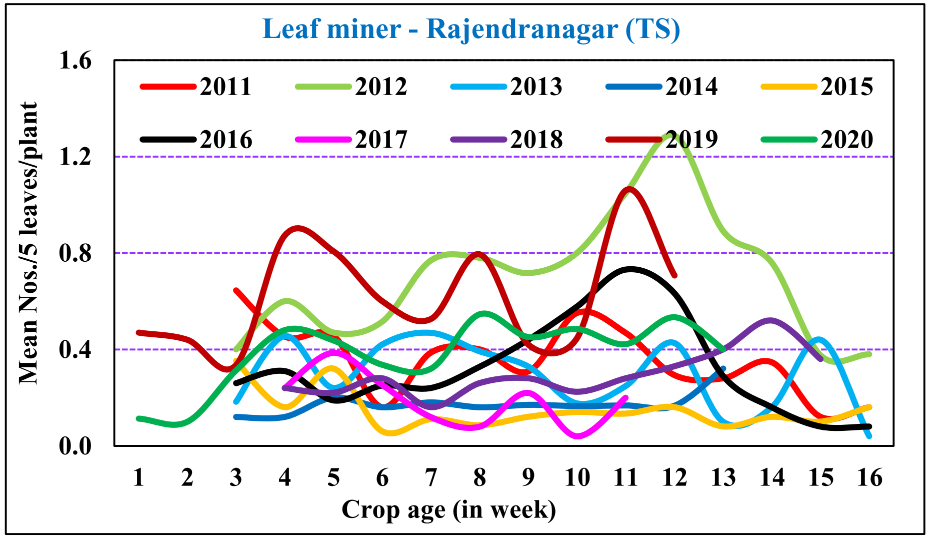
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





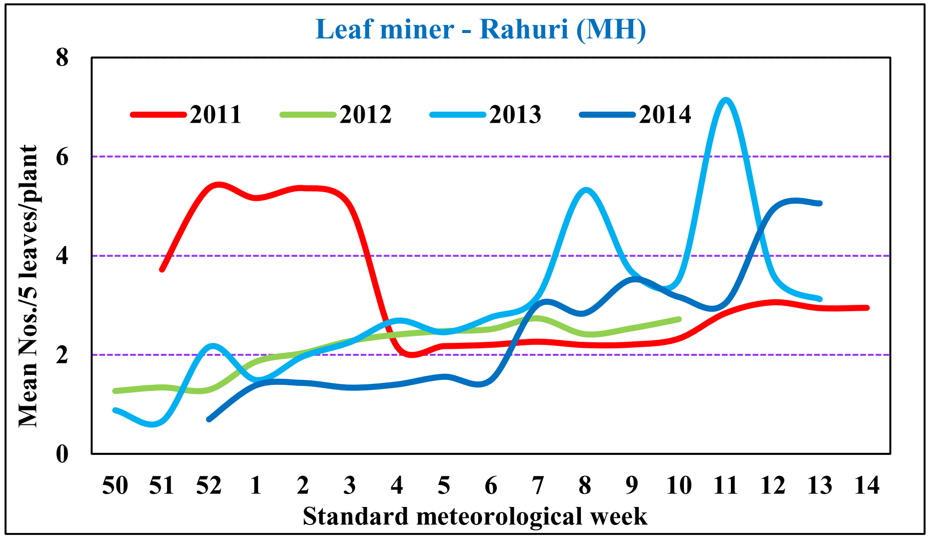


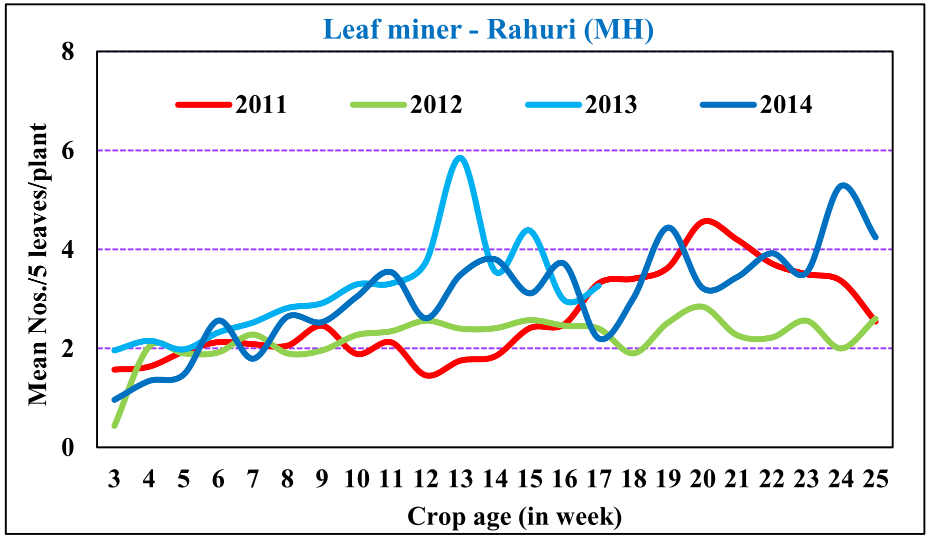


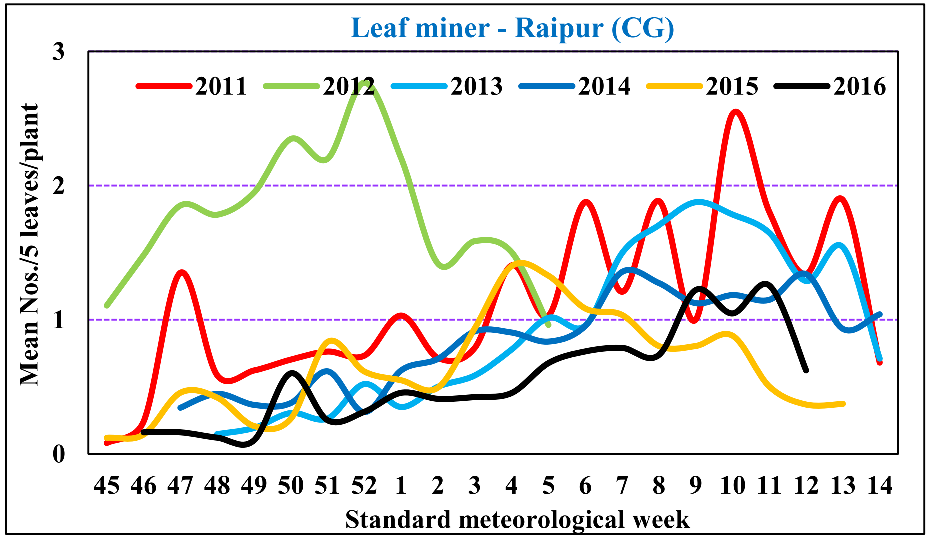
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

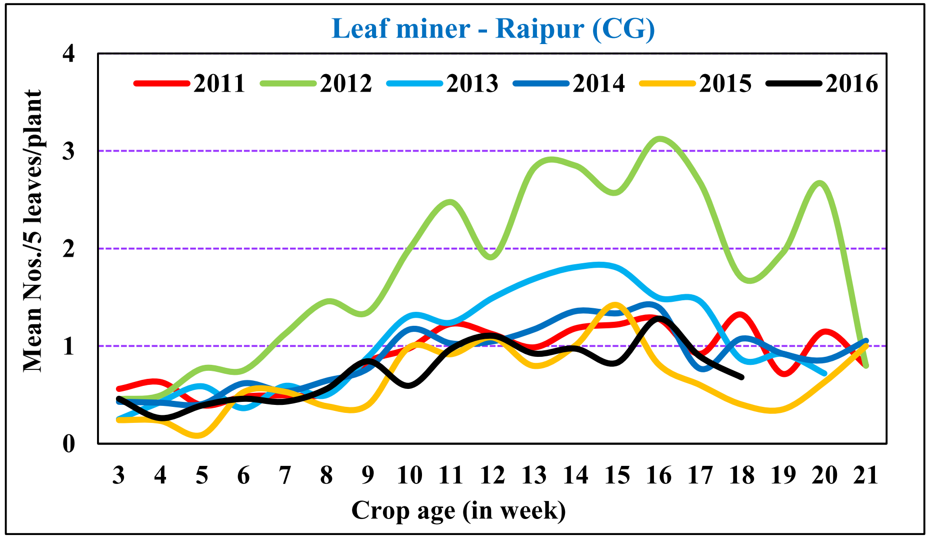
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





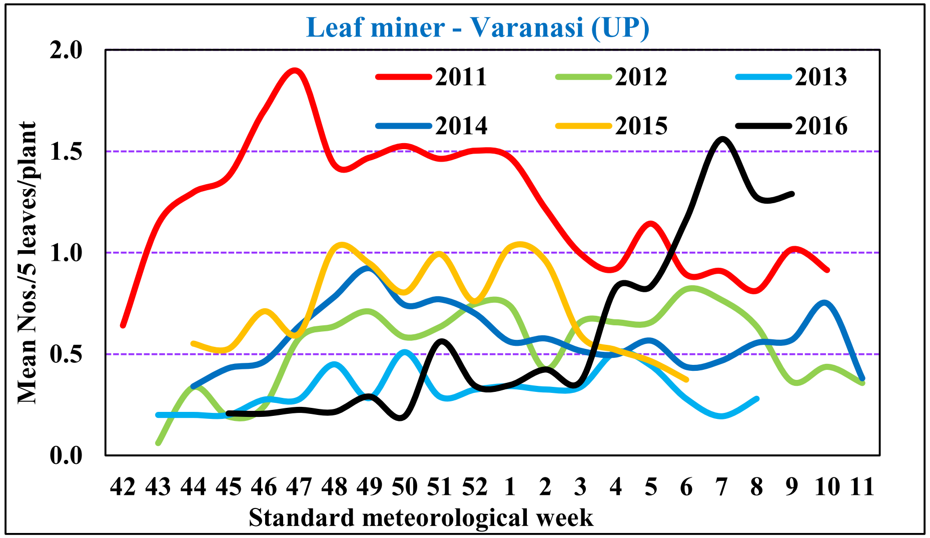


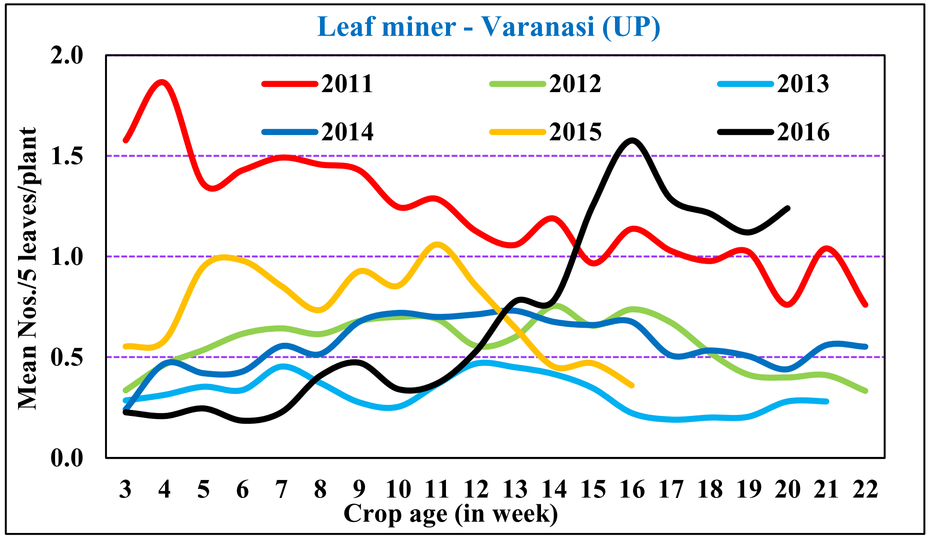


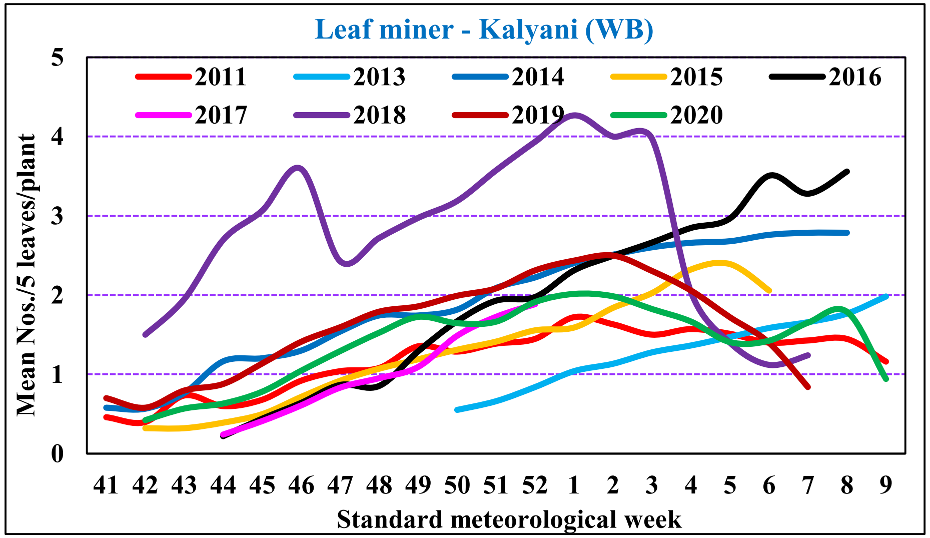
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

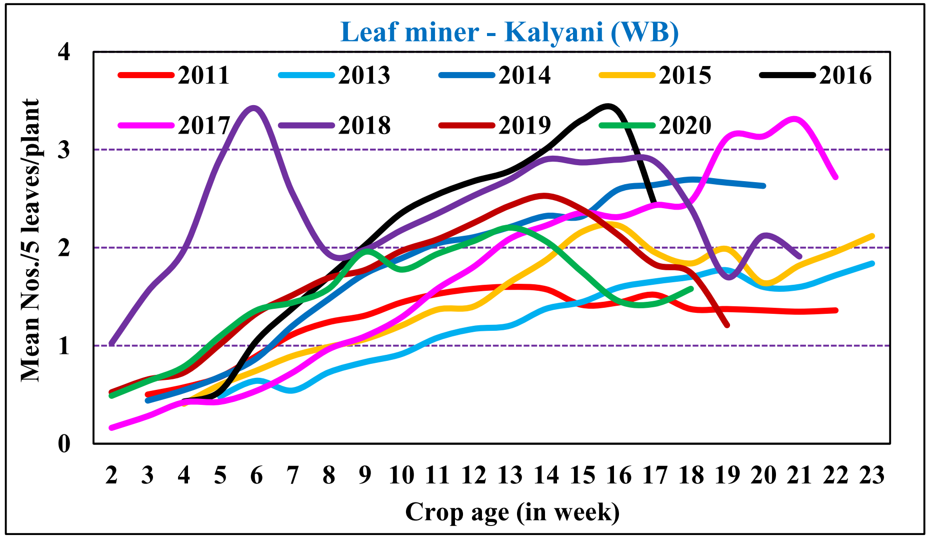
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



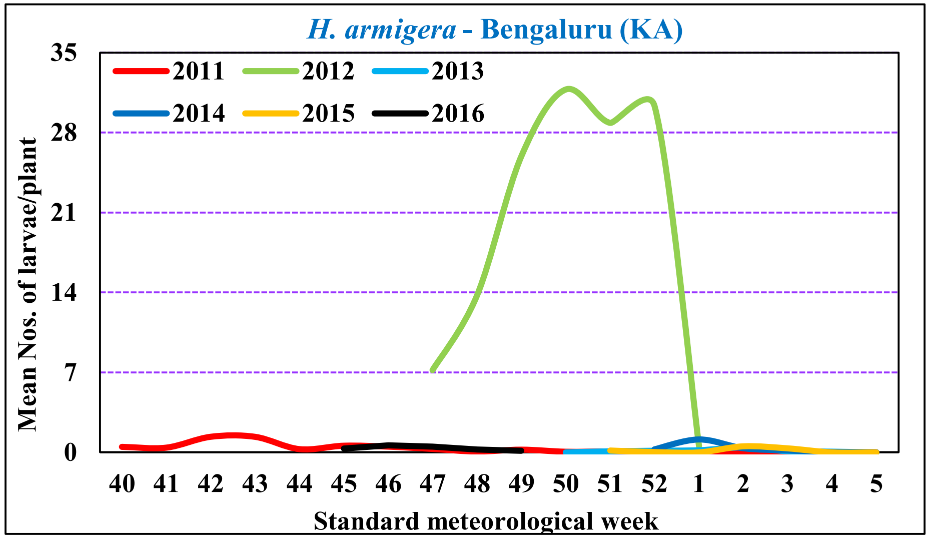


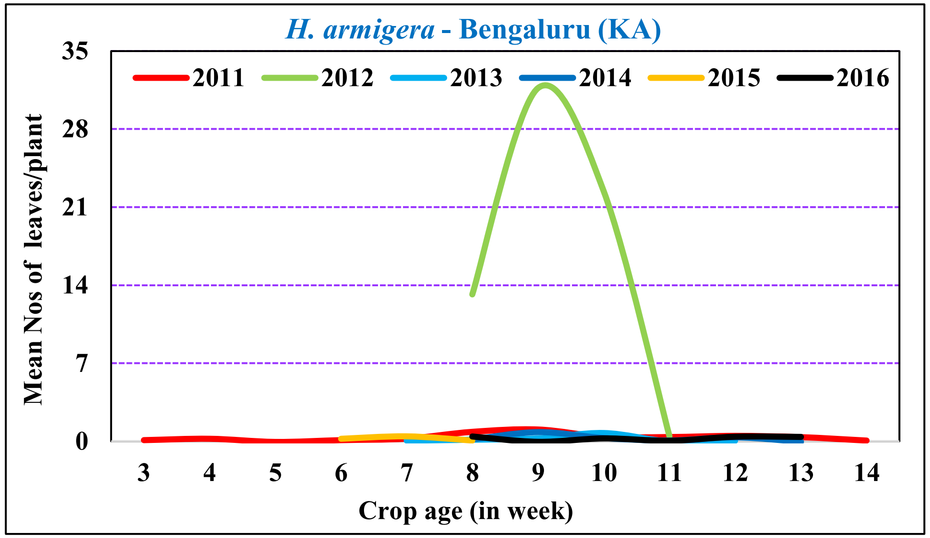


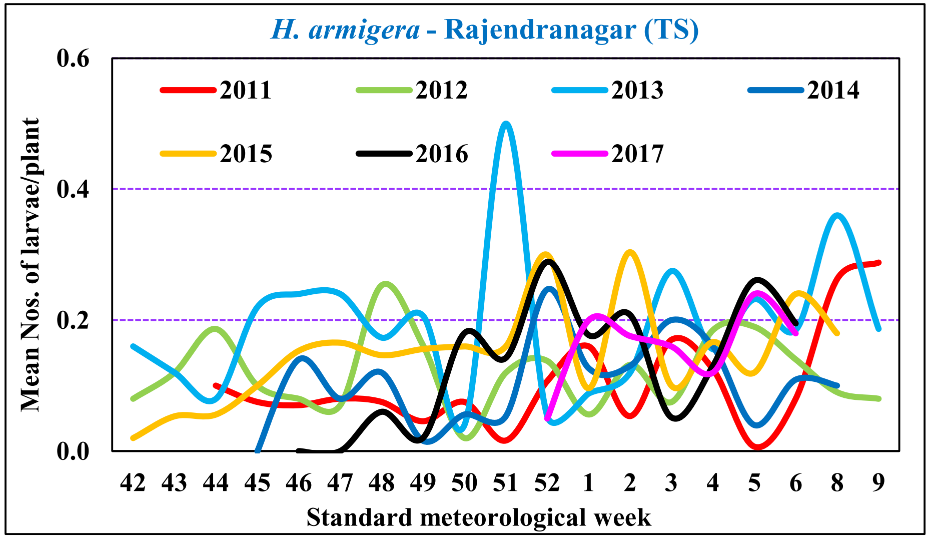


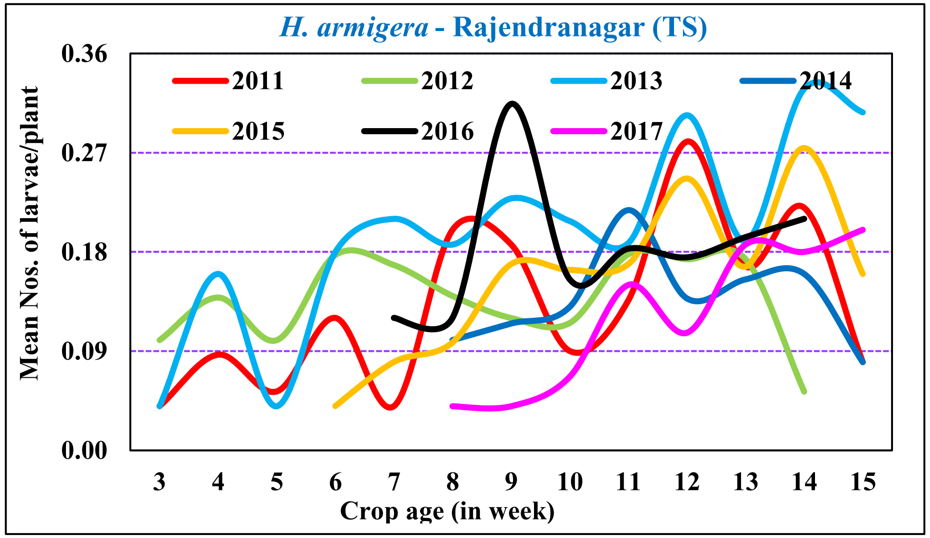
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



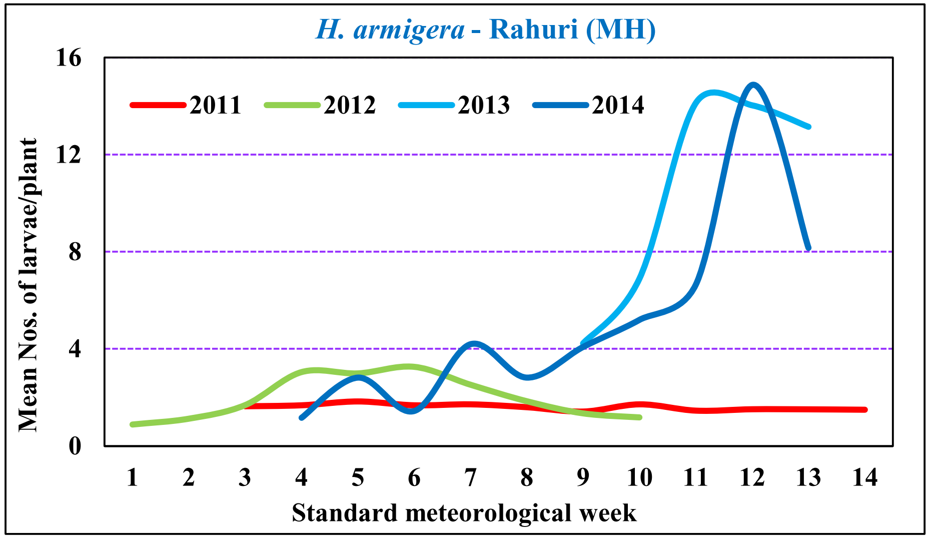


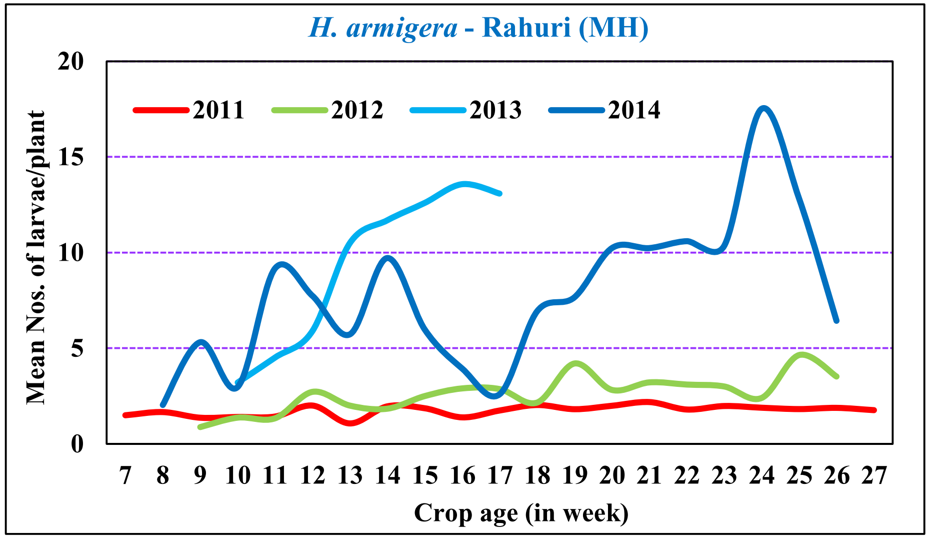


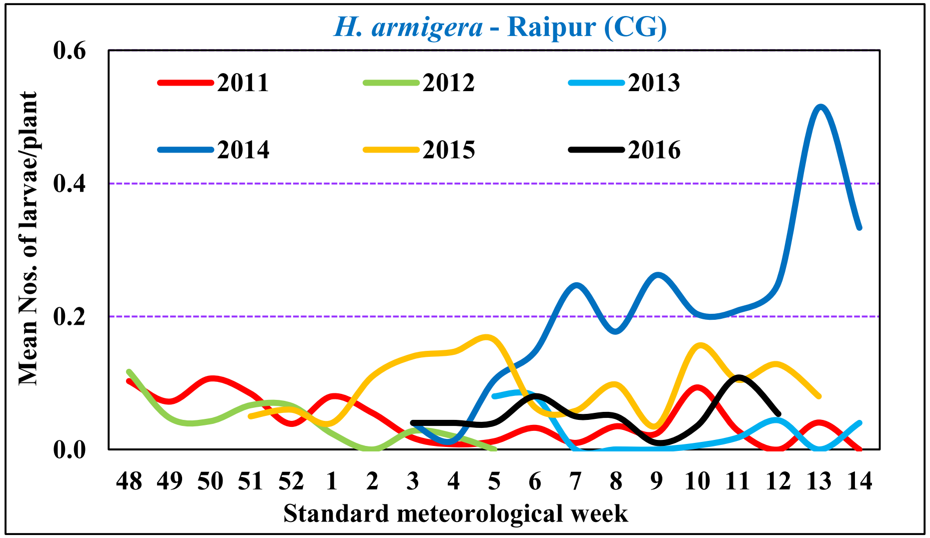


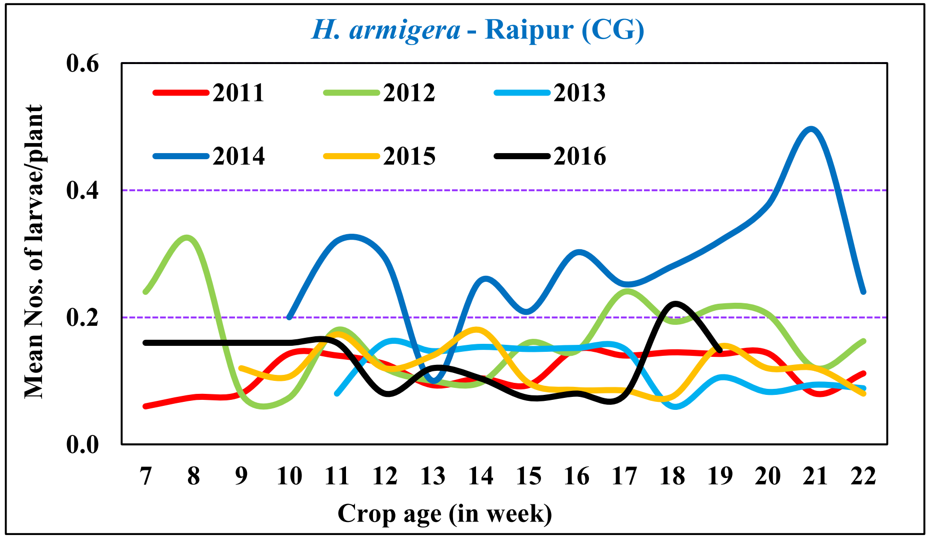
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



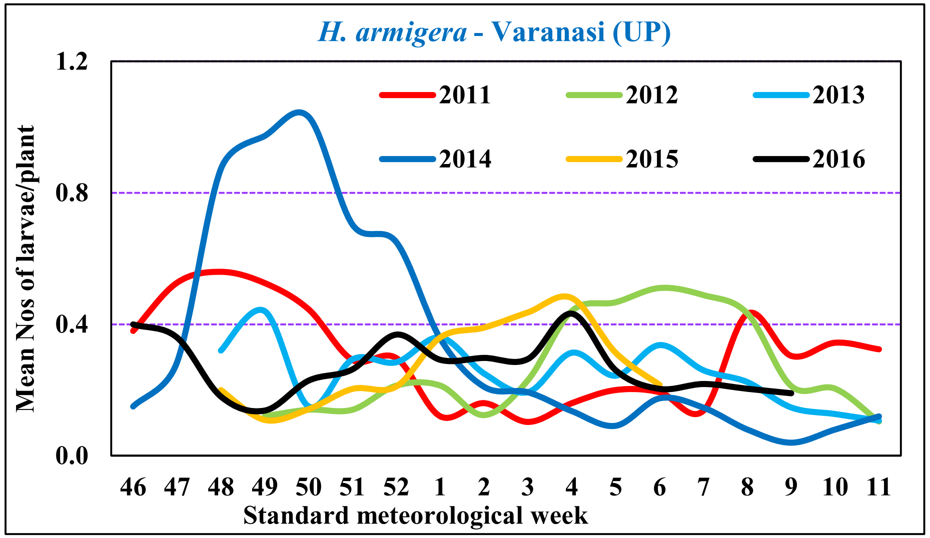


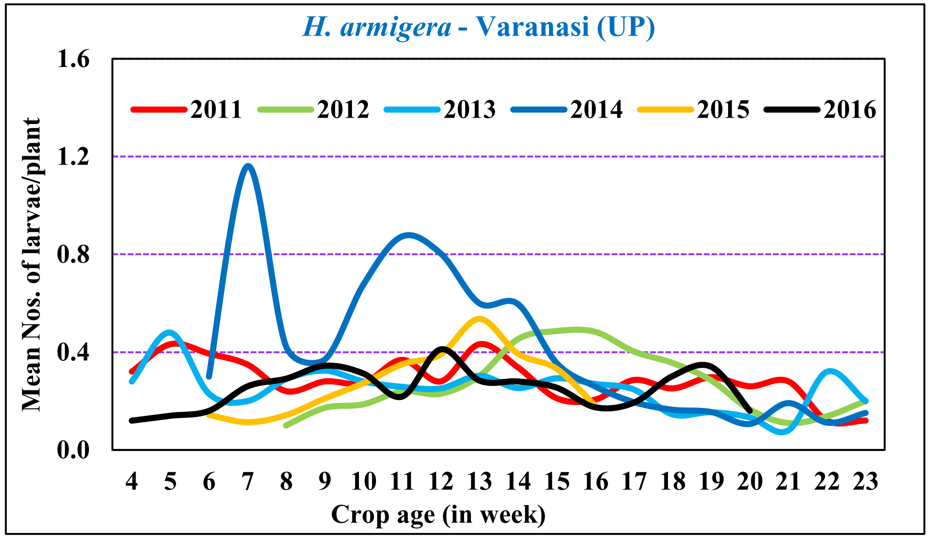


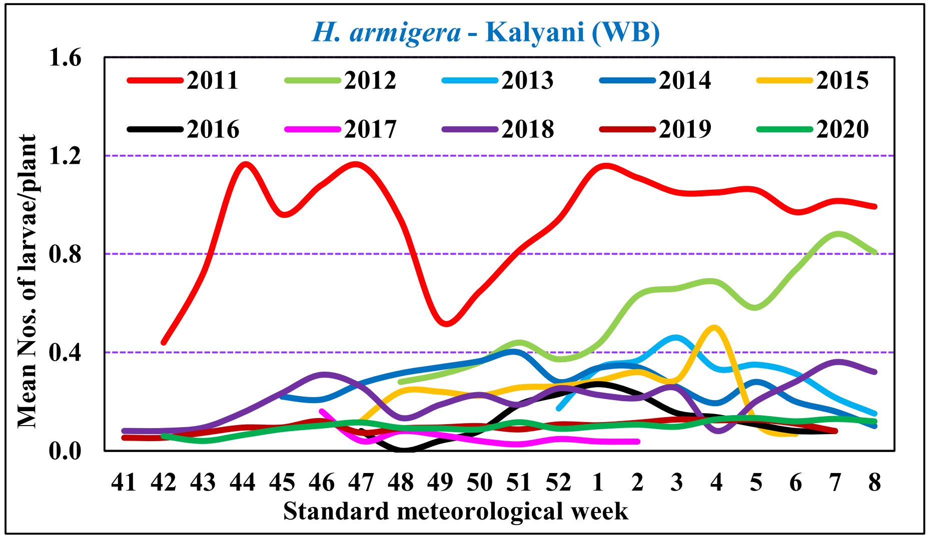


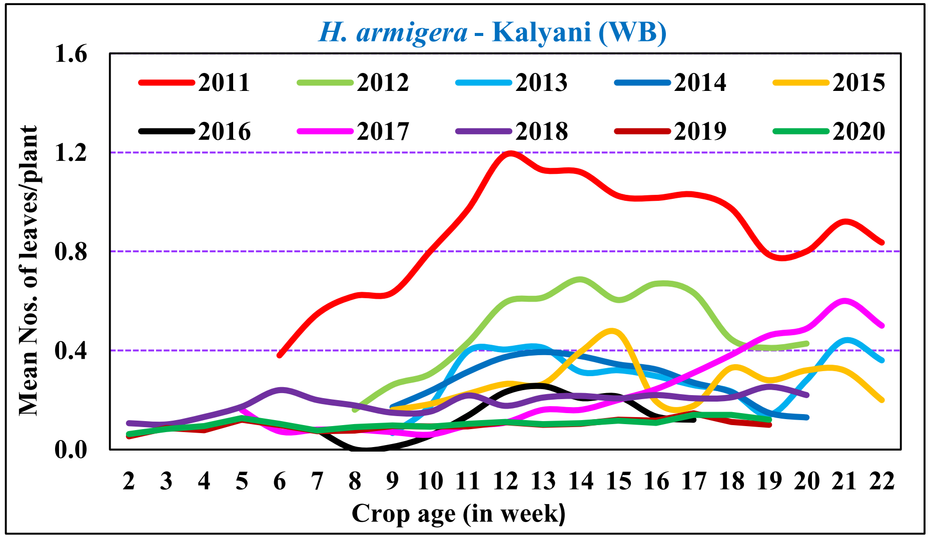
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



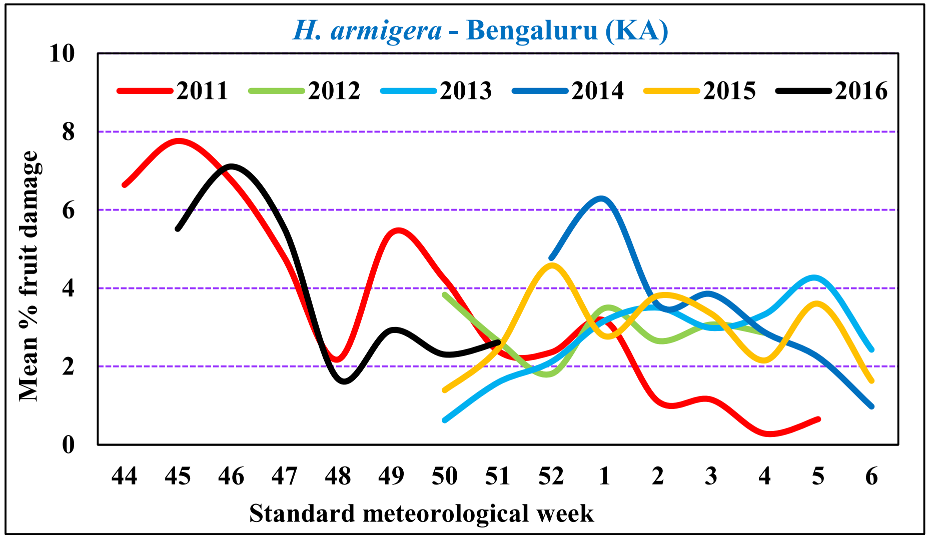


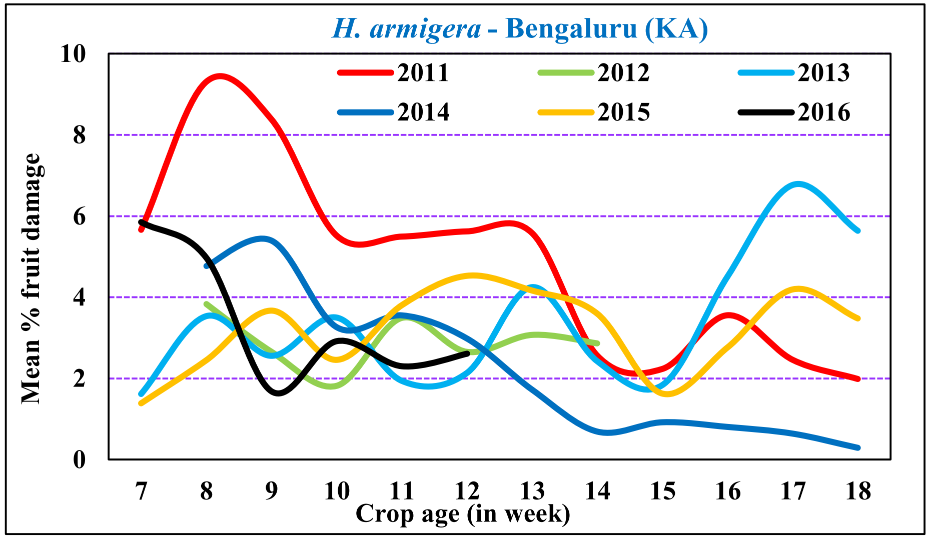


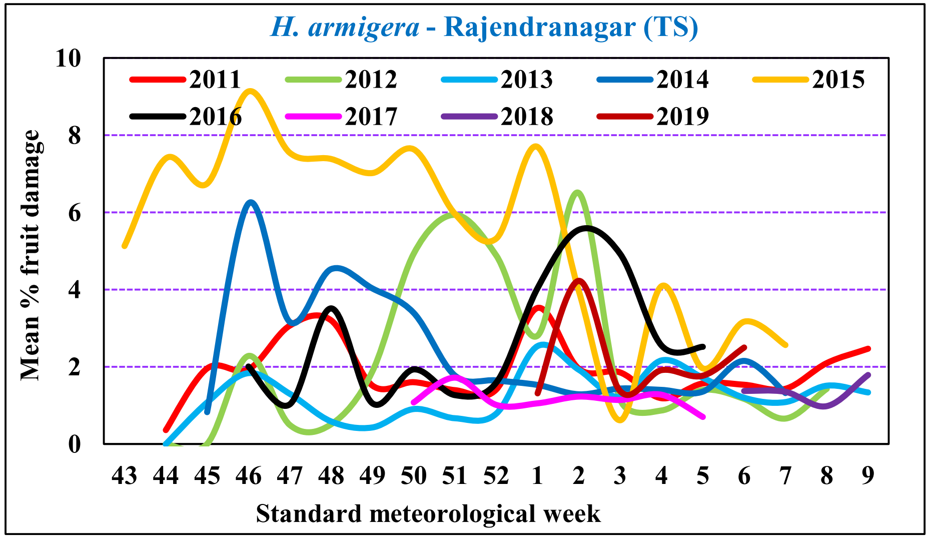


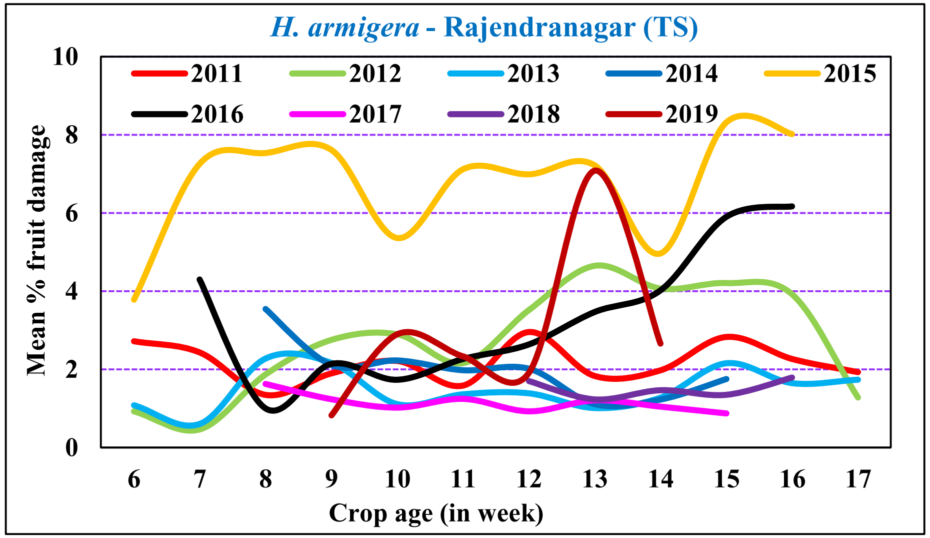
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



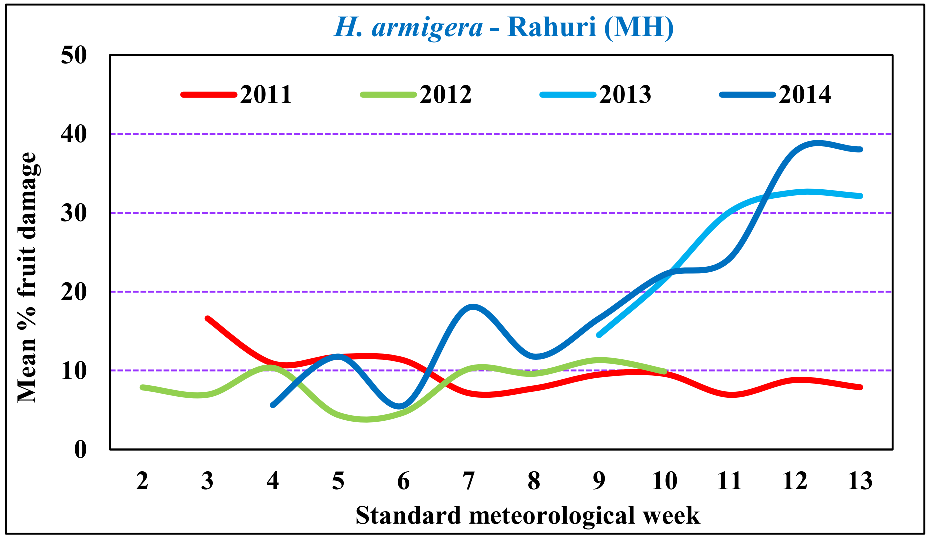


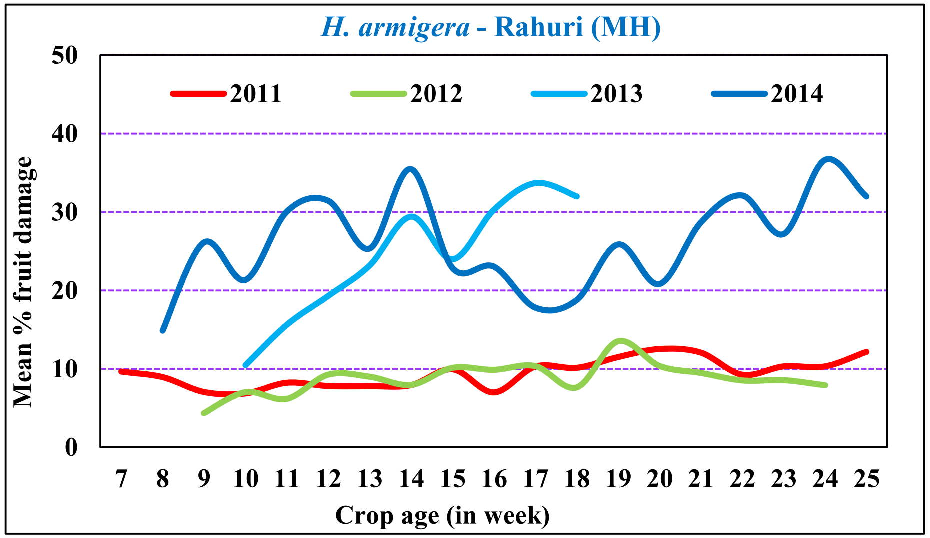


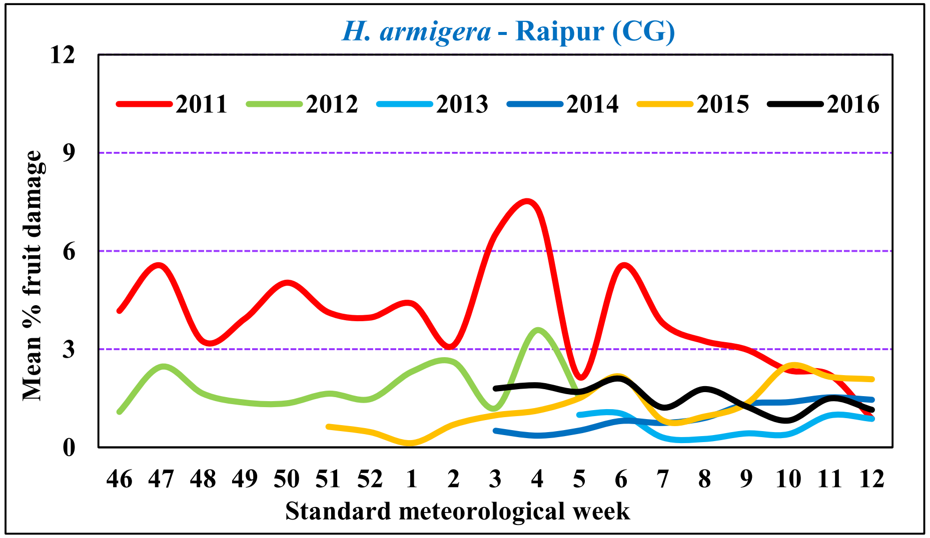


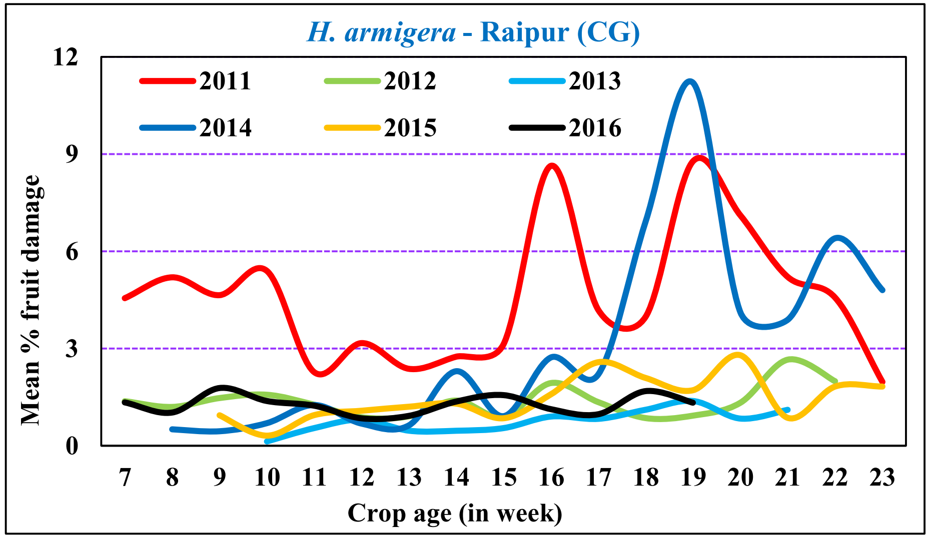
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



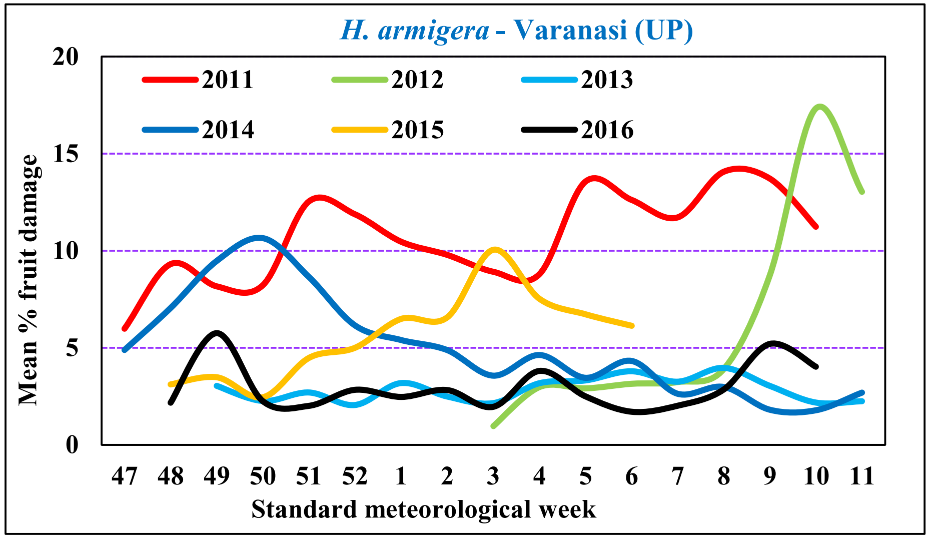


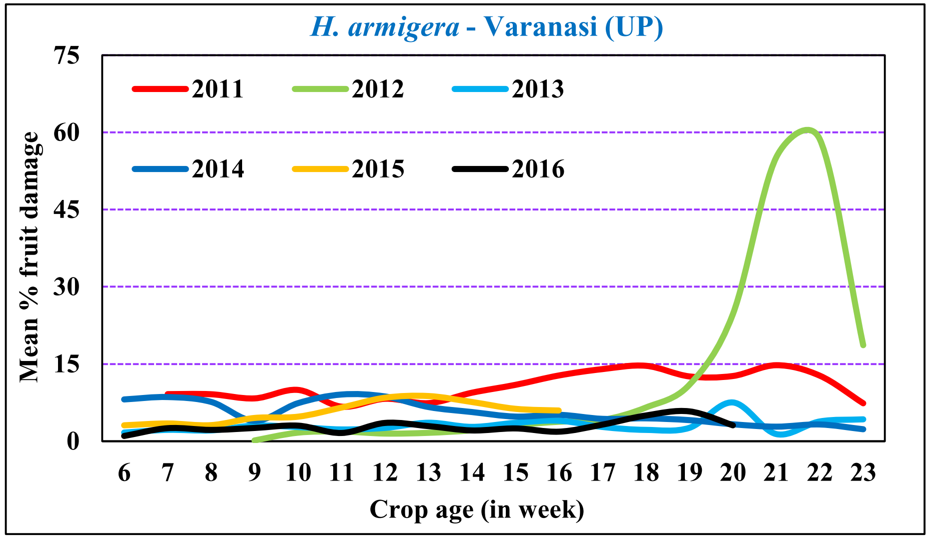


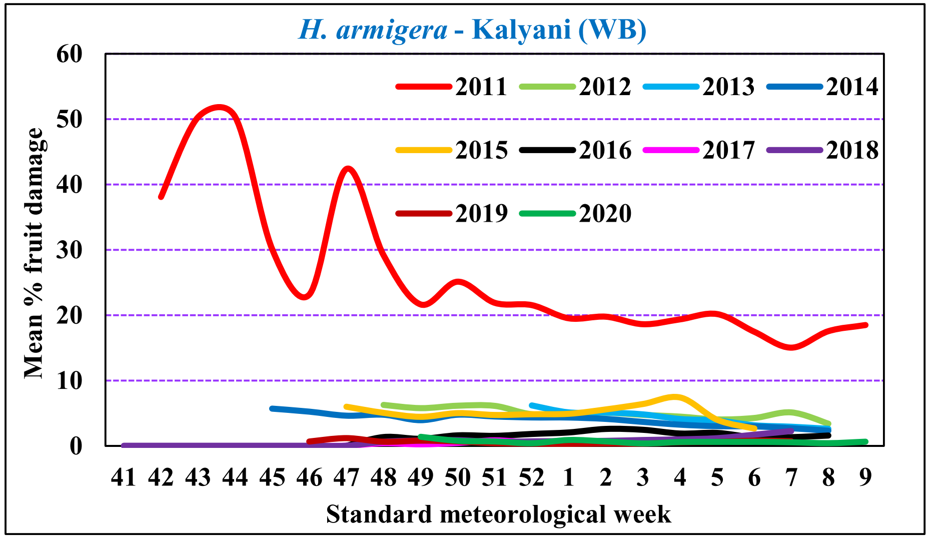


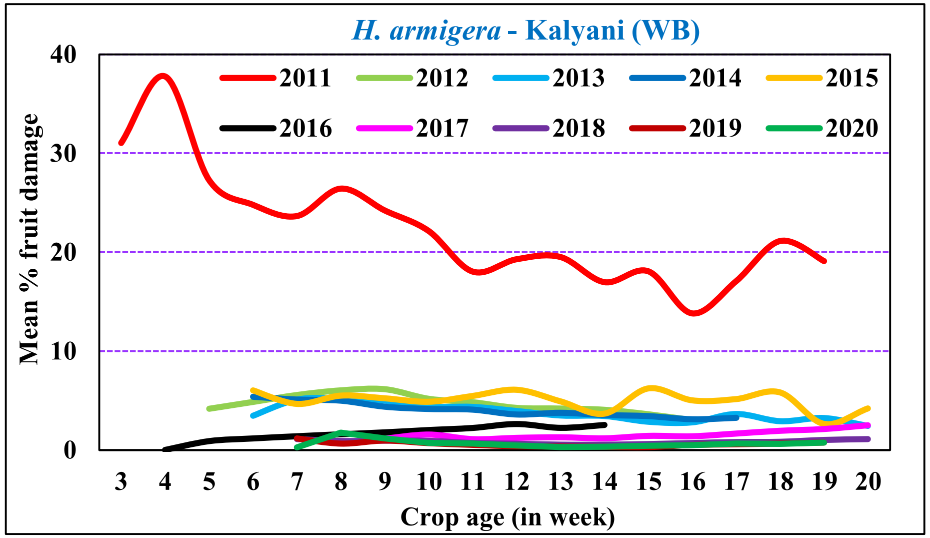
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



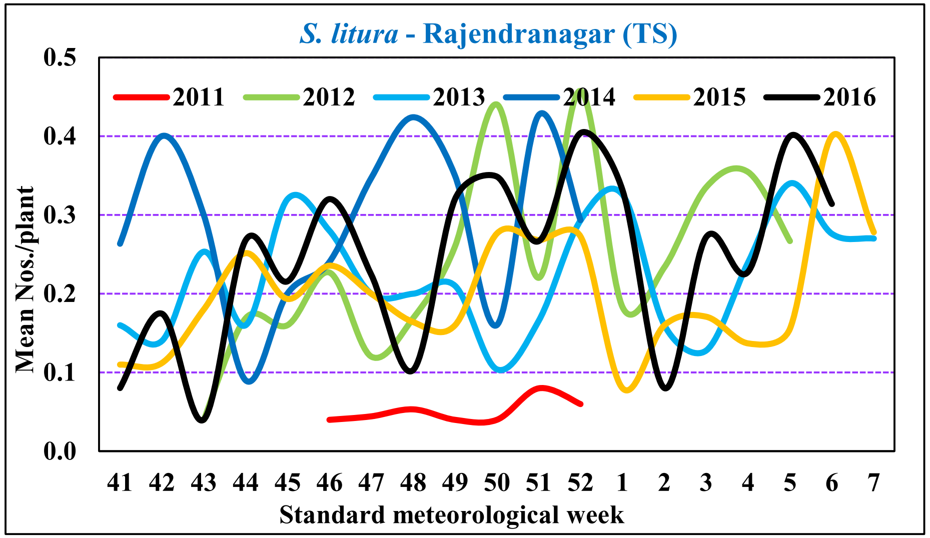


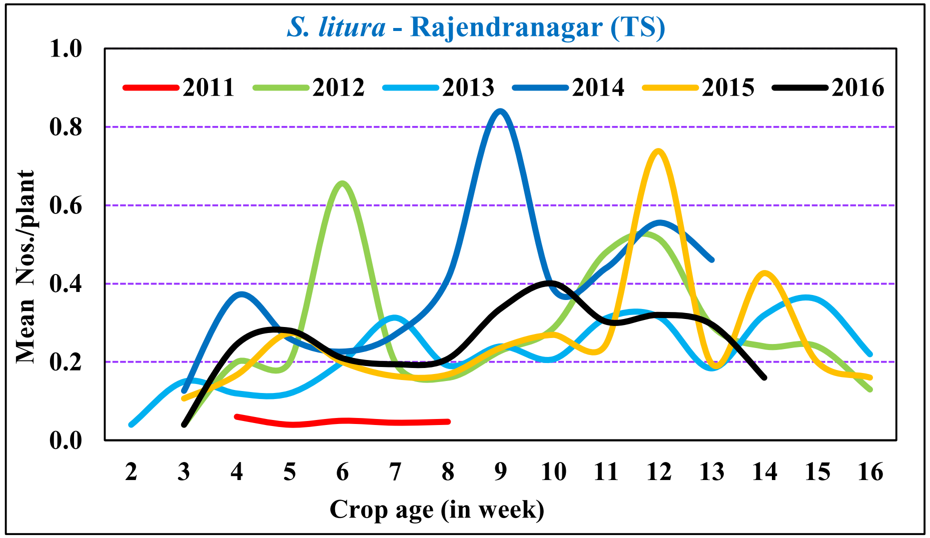


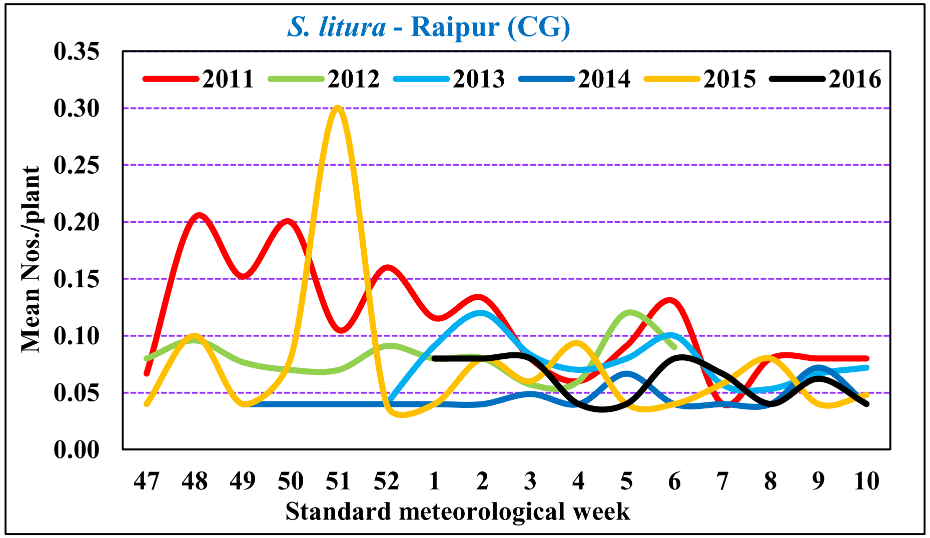


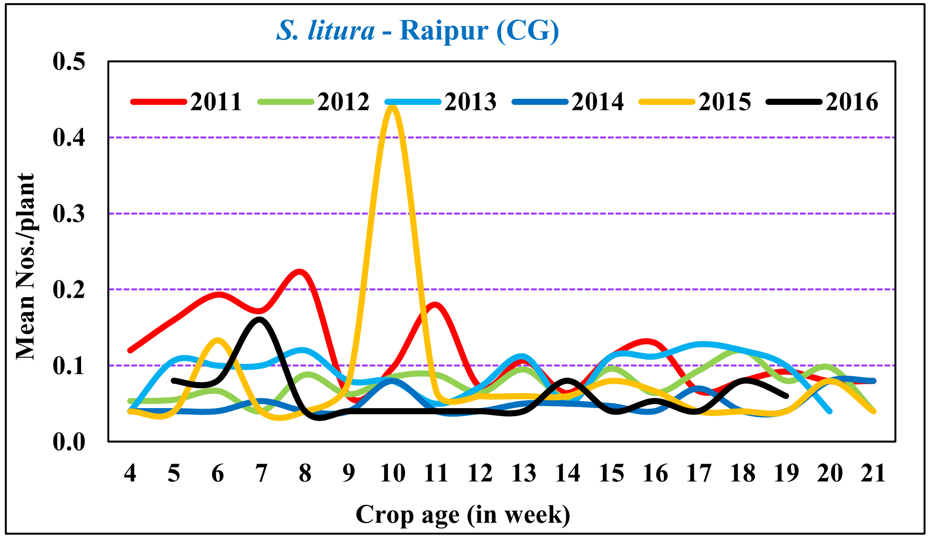
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



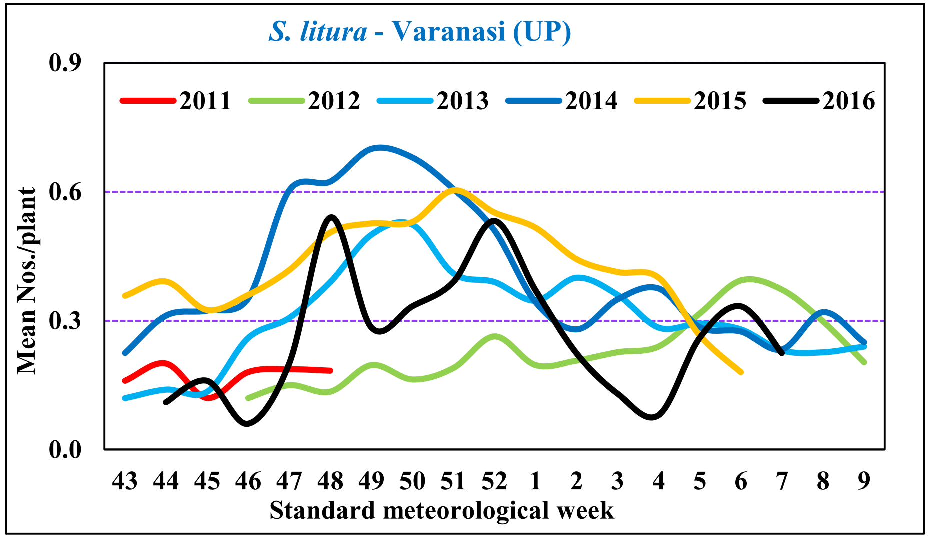


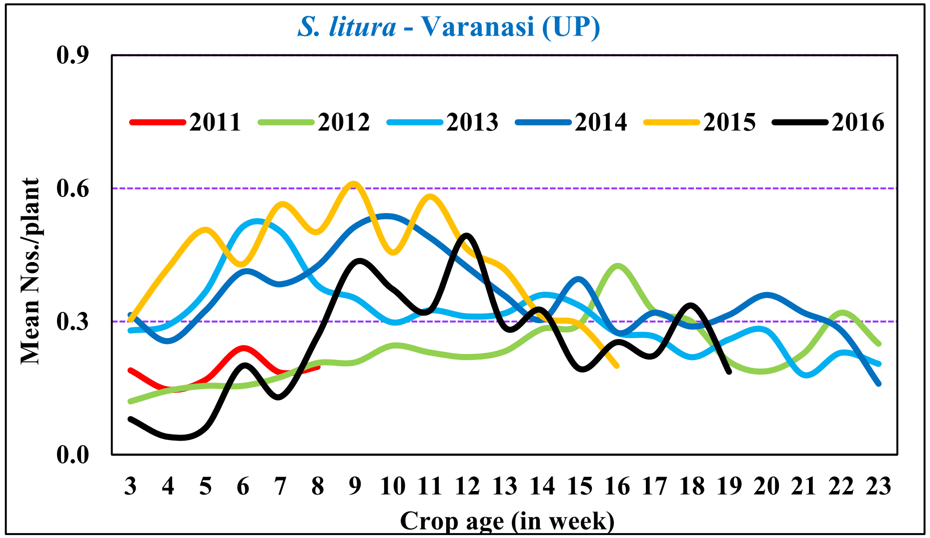


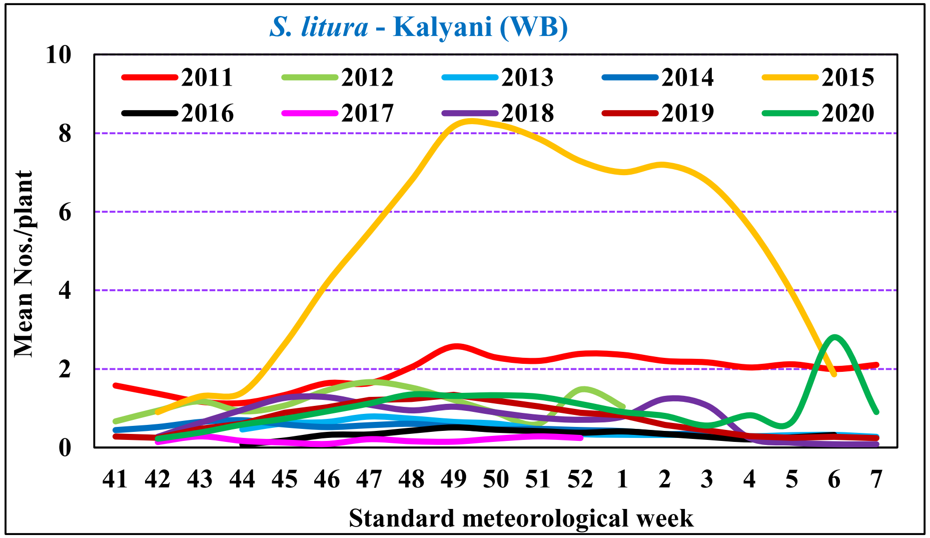


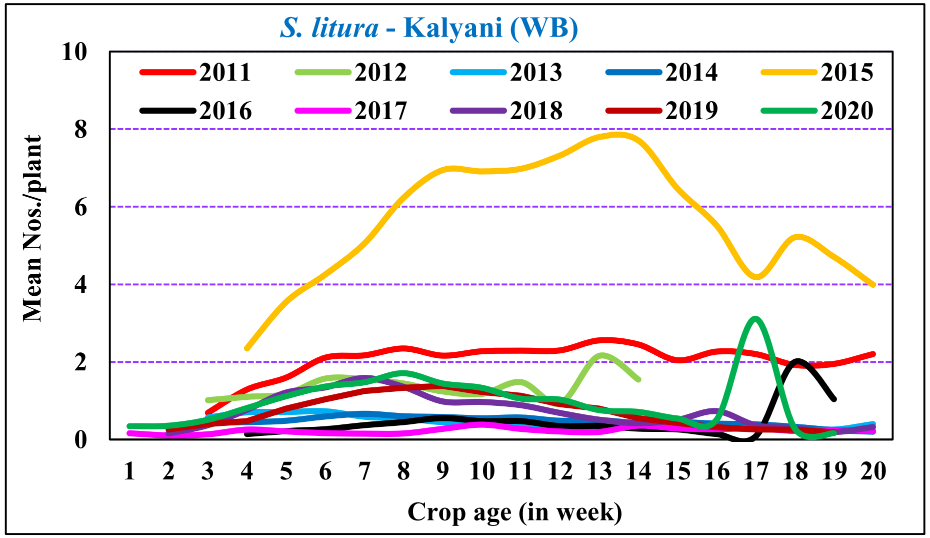
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



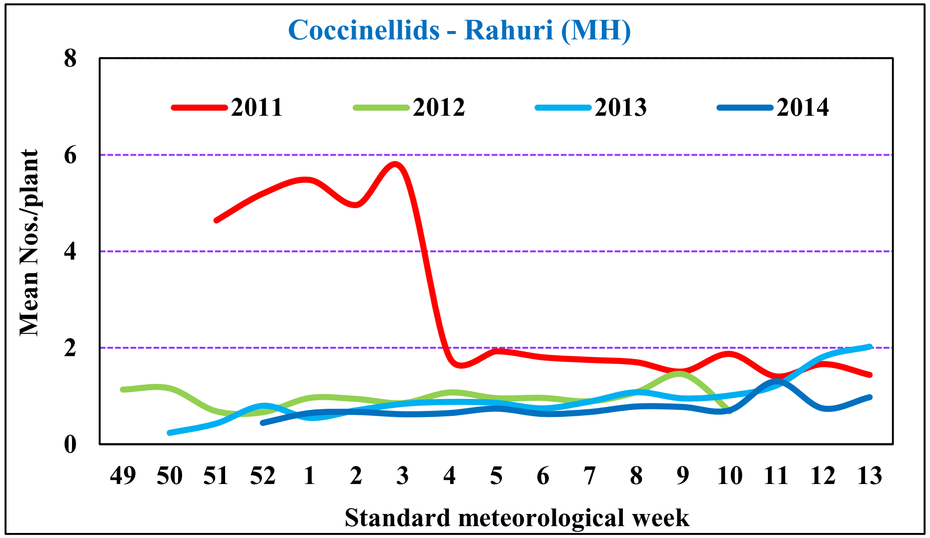


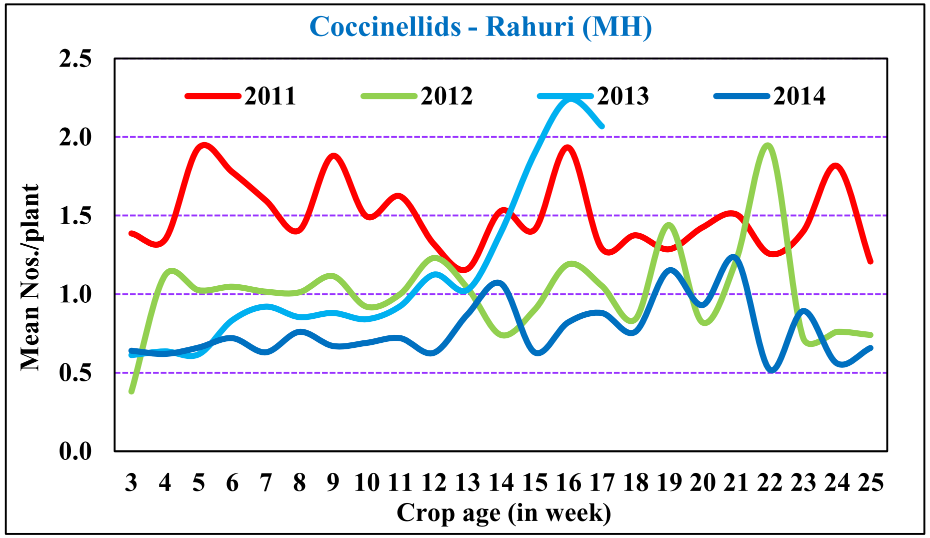


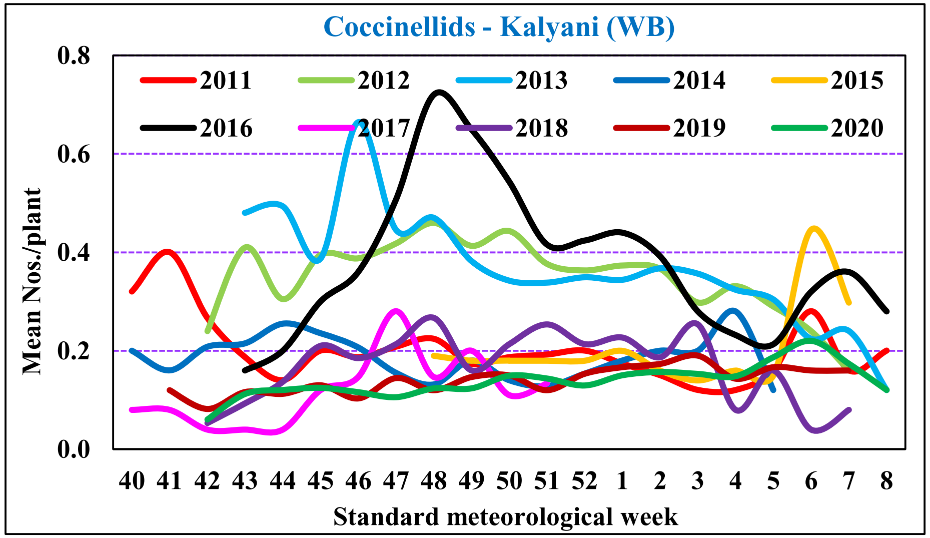


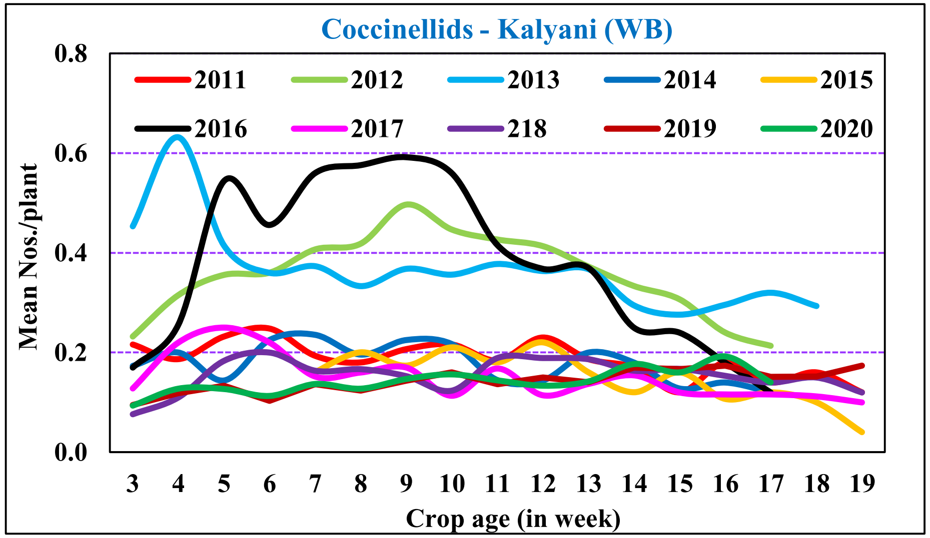
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**





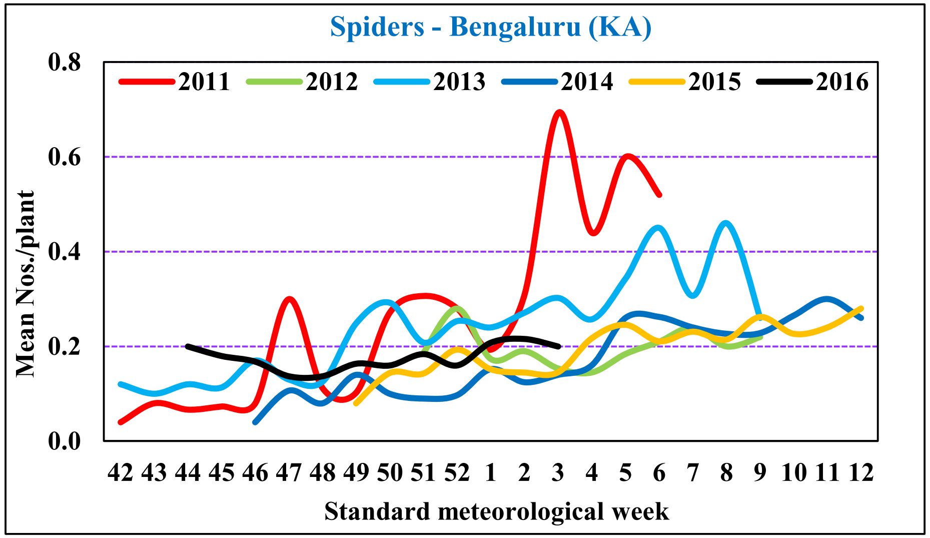


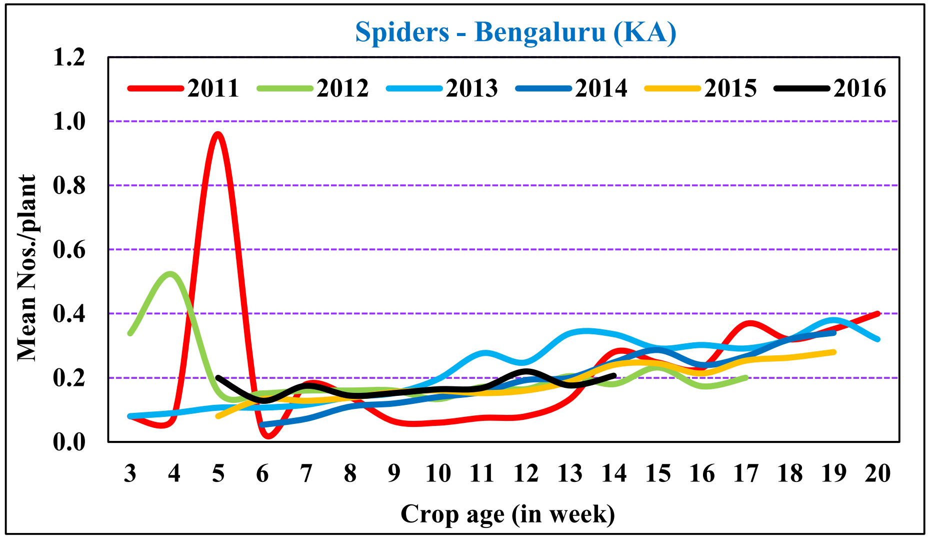


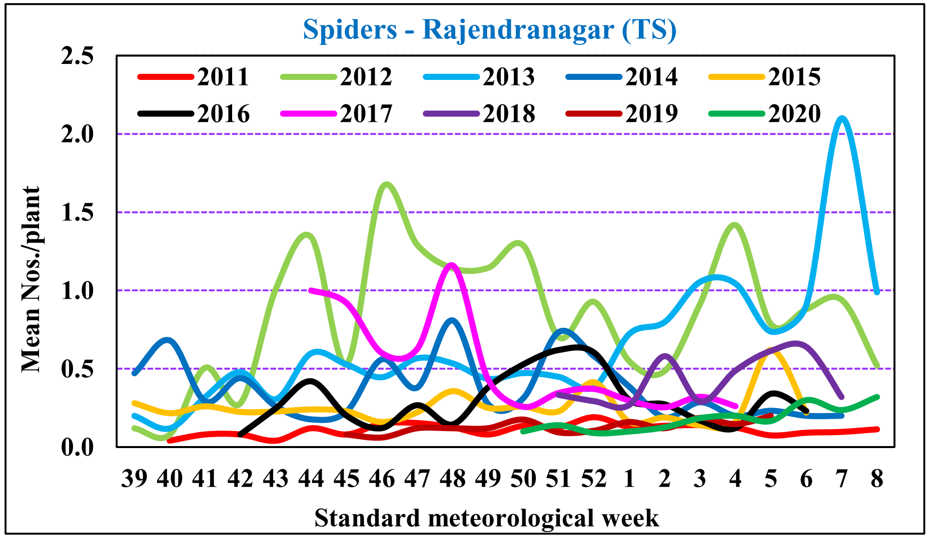
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

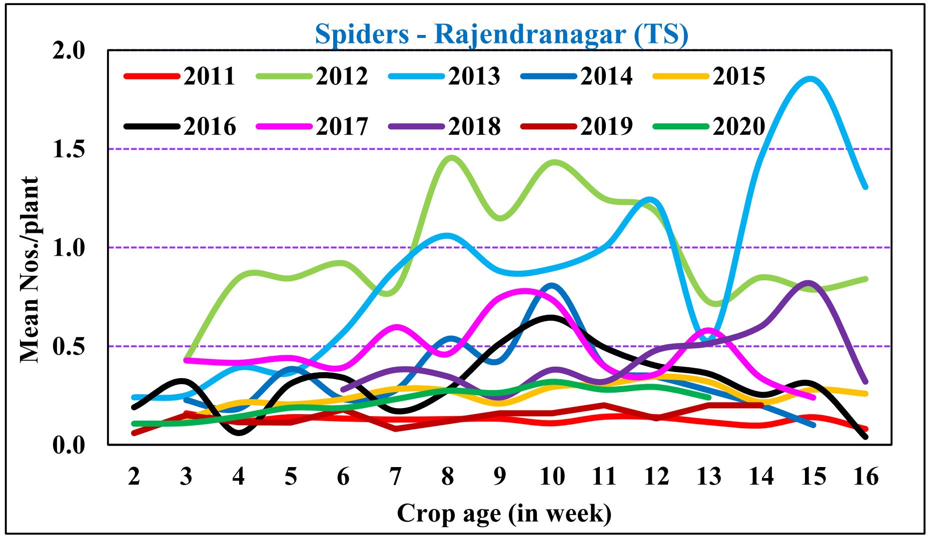
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



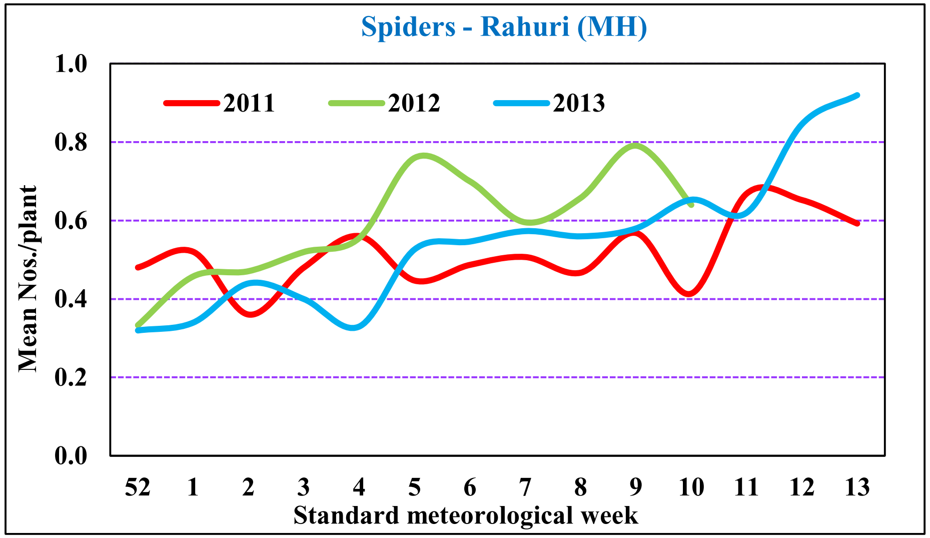


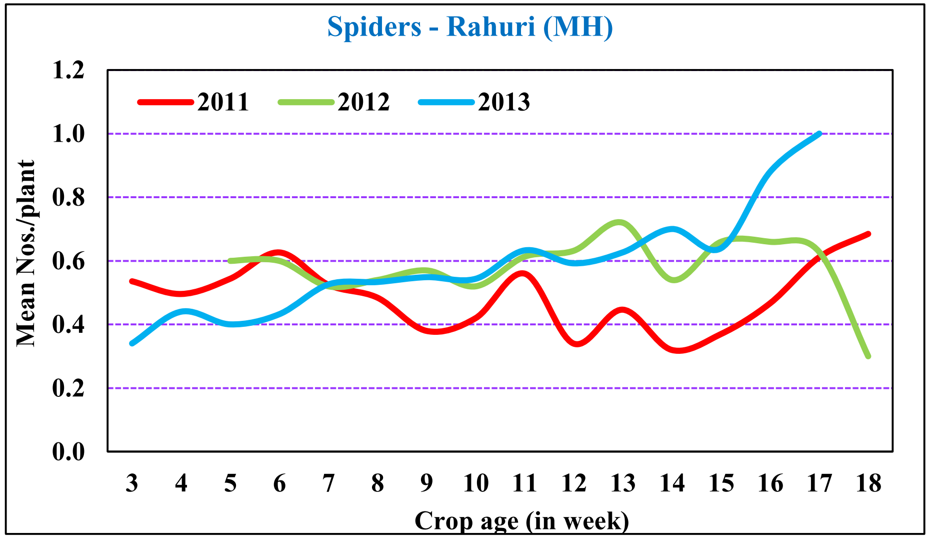


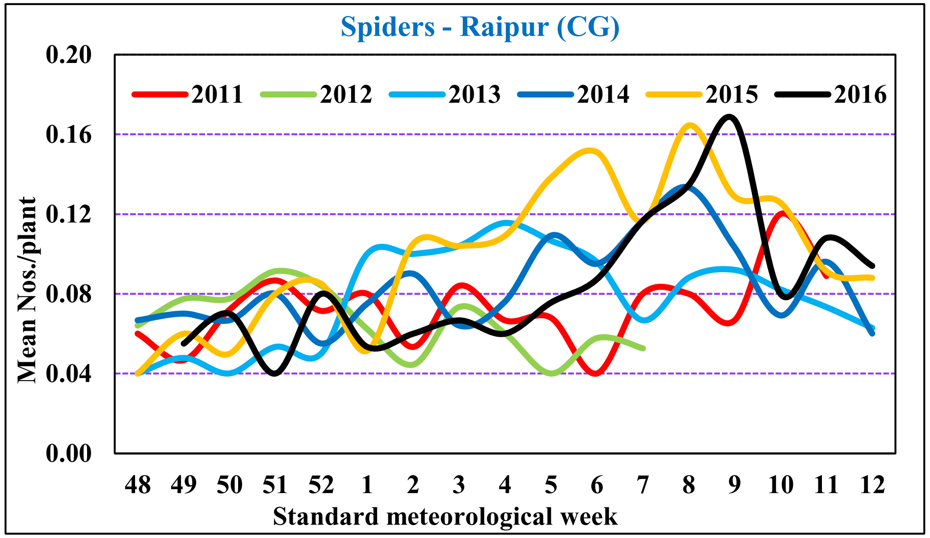


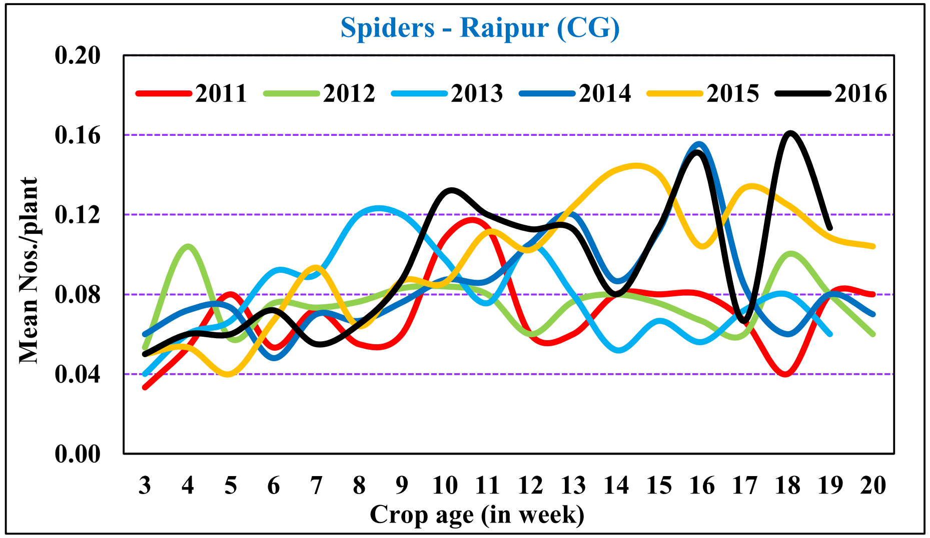
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | Seasonal dynamics based on crop age



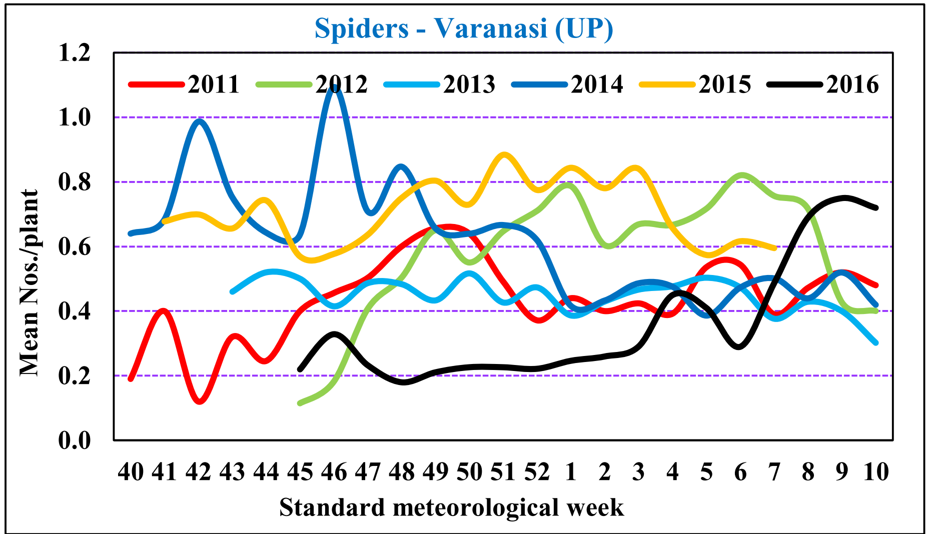


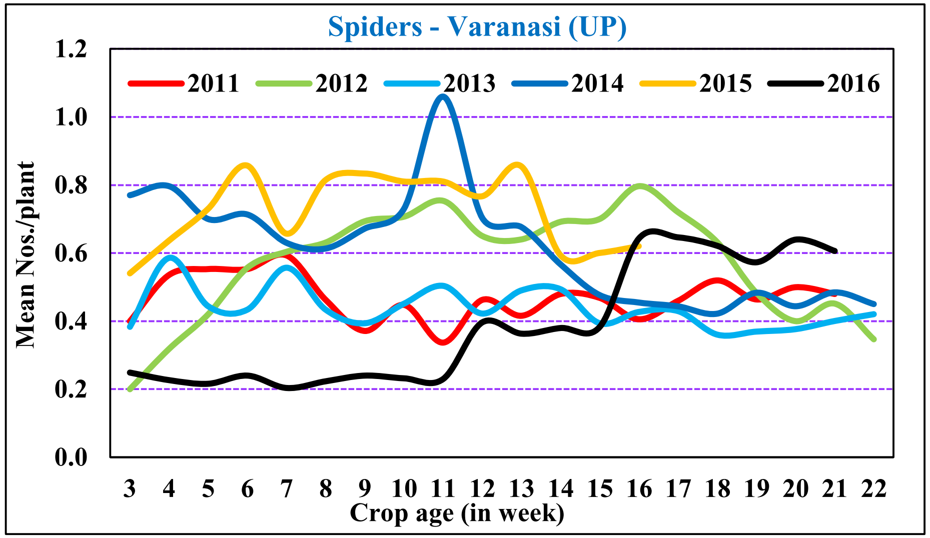


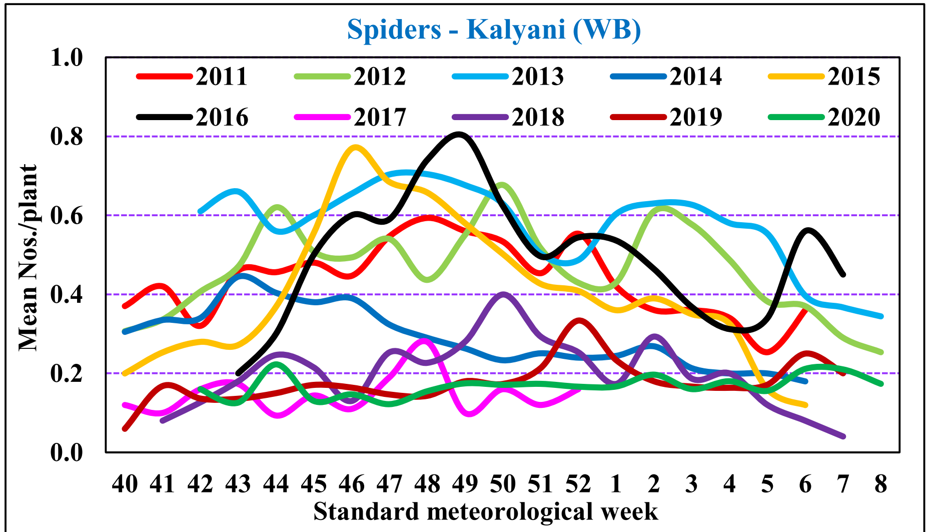


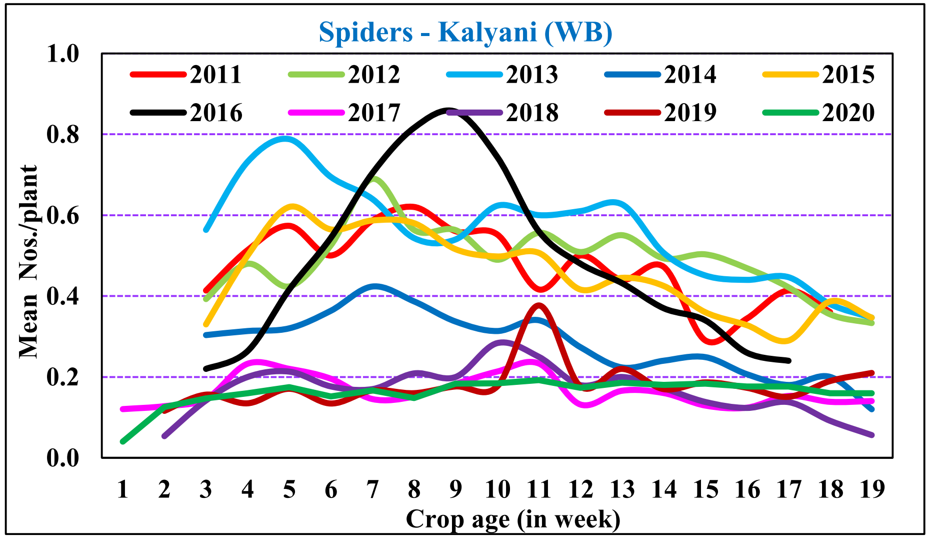
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



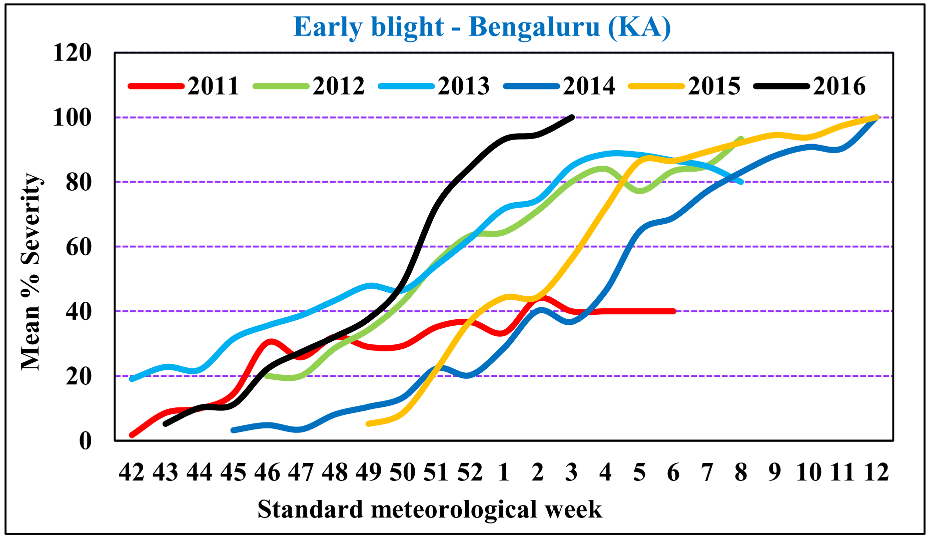


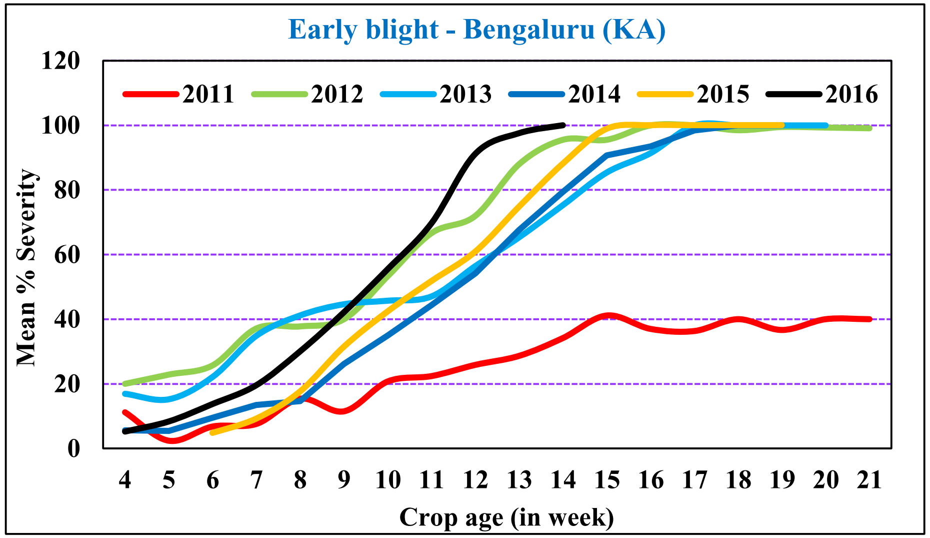


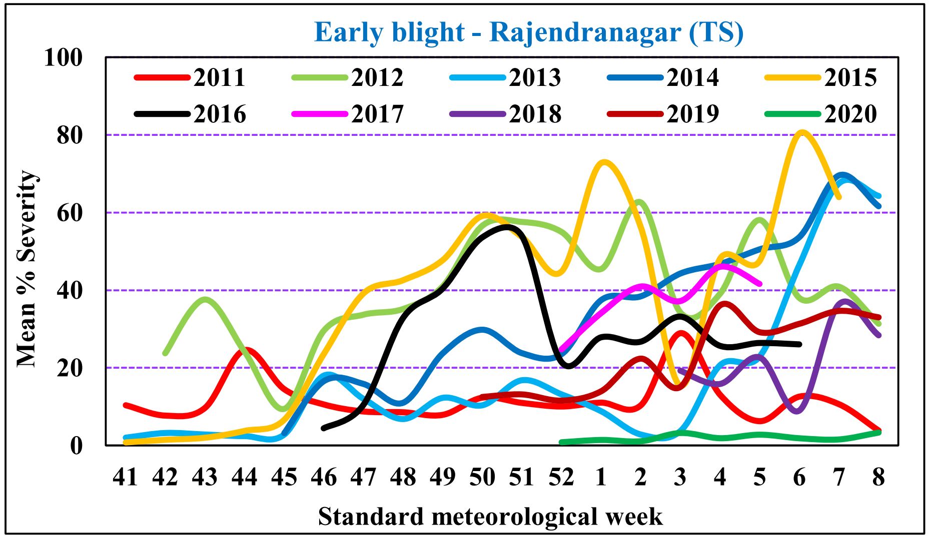


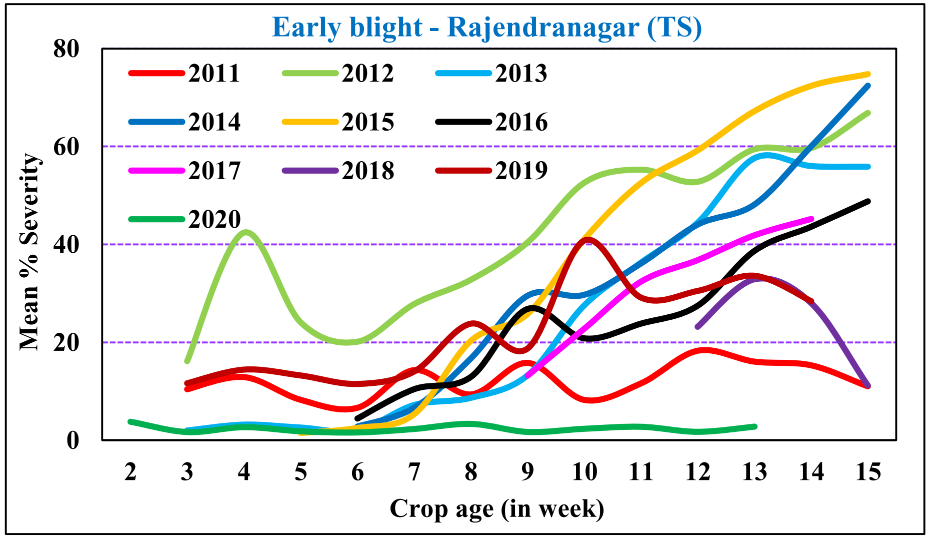
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks — **Seasonal dynamics based on crop age**



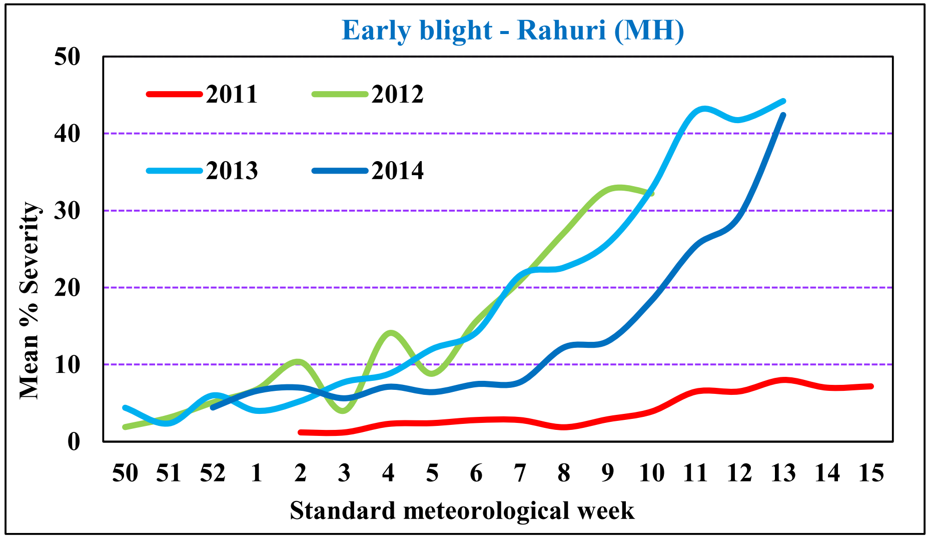


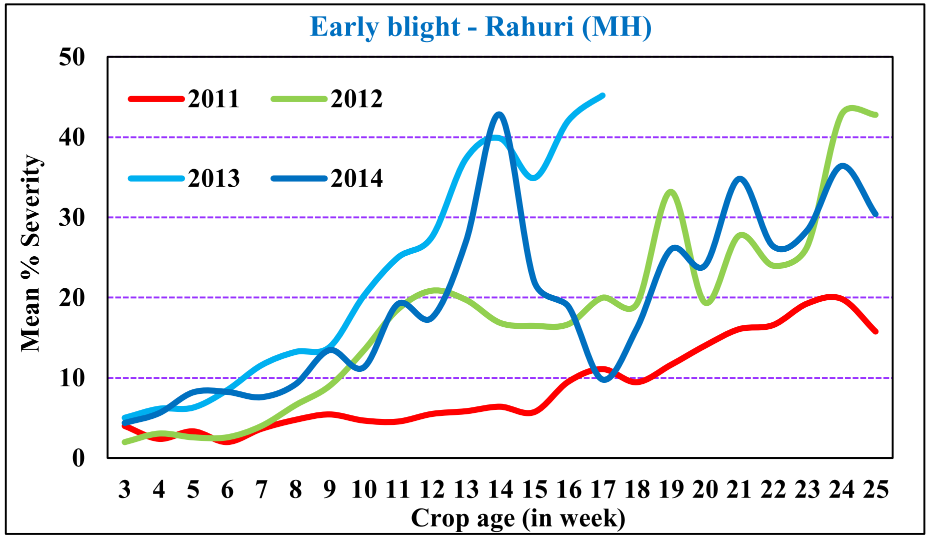


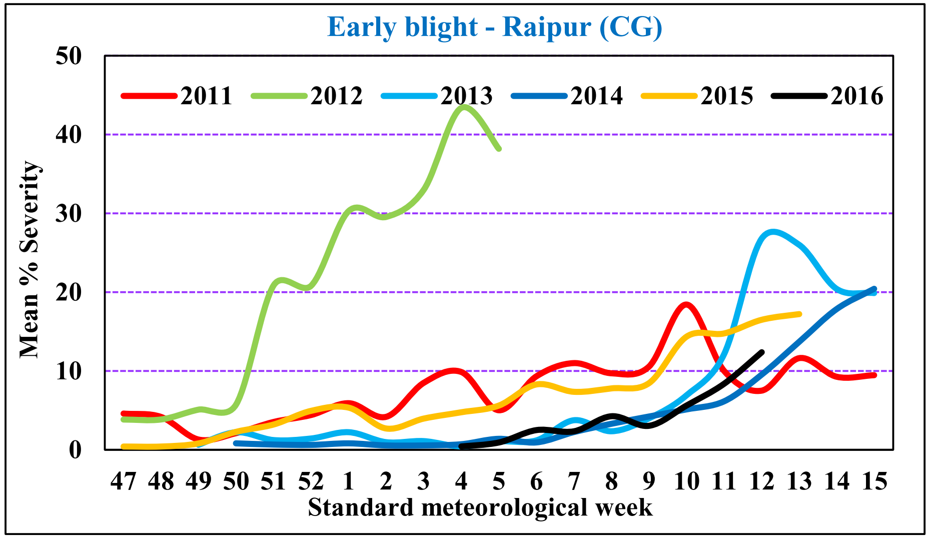


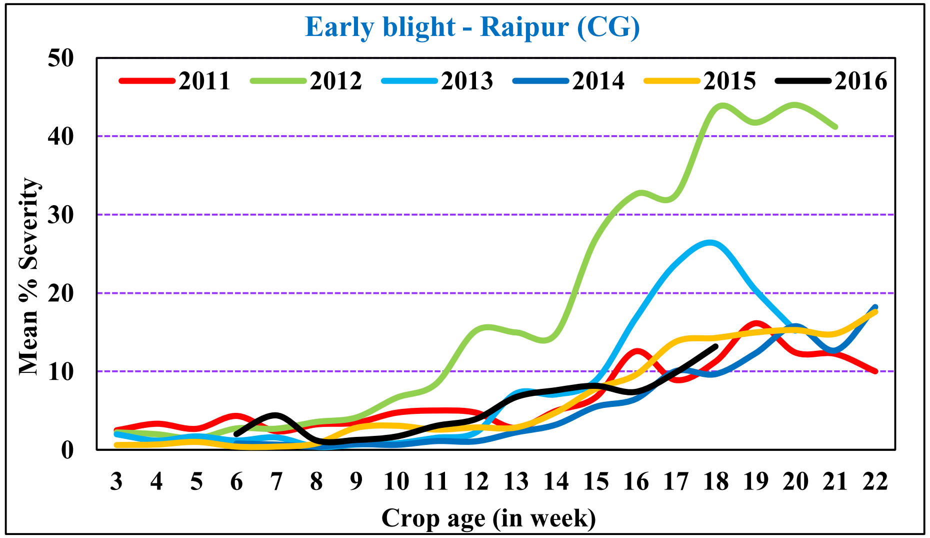
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



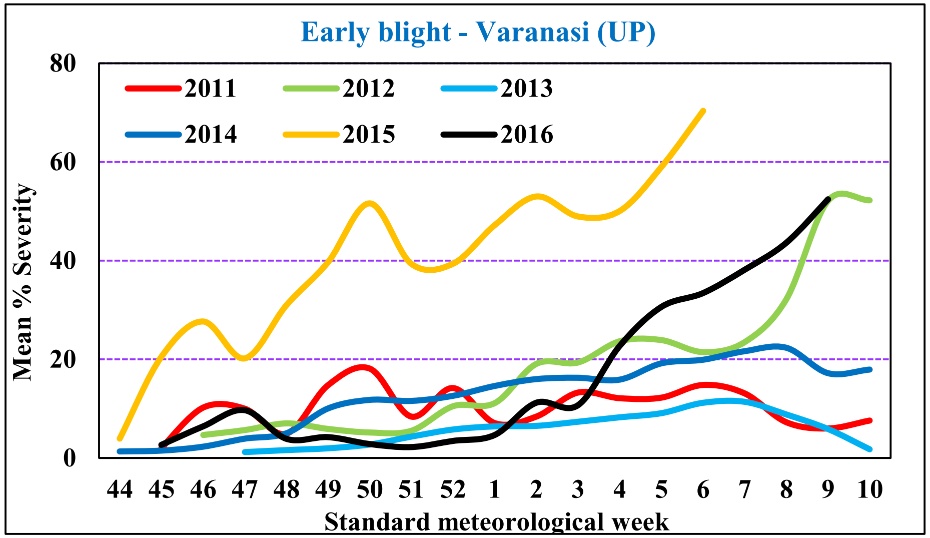


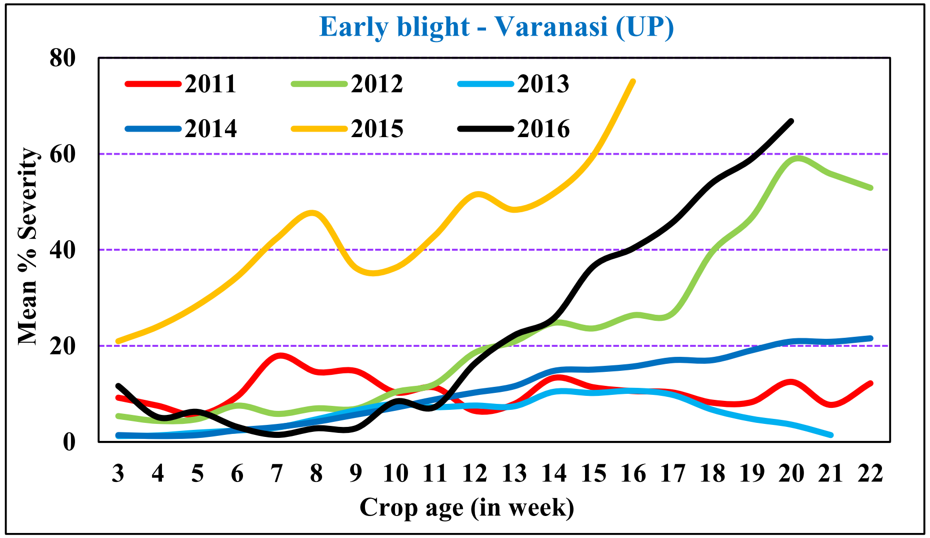


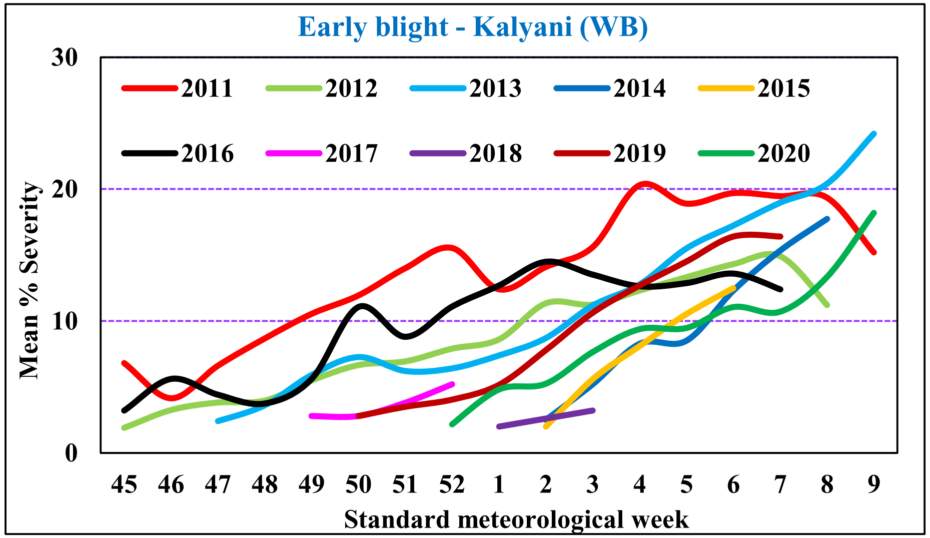


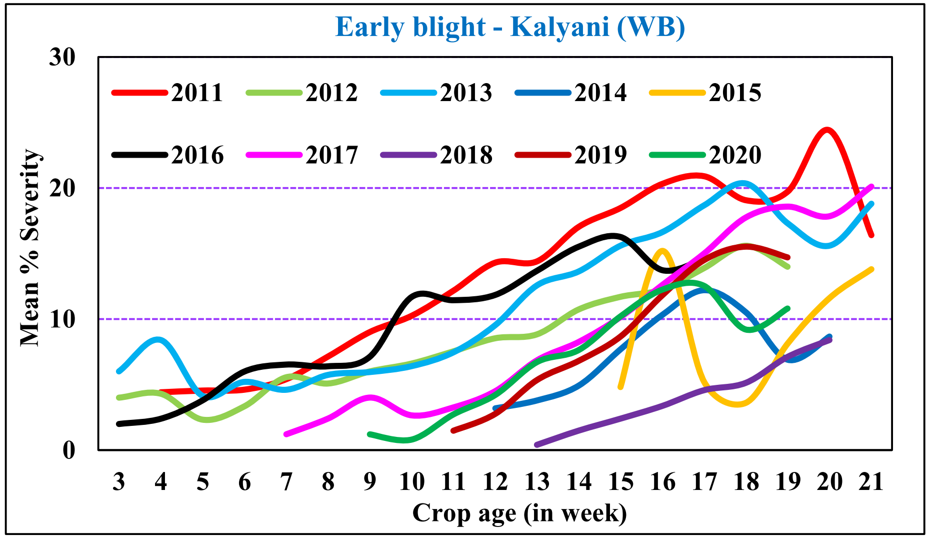
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



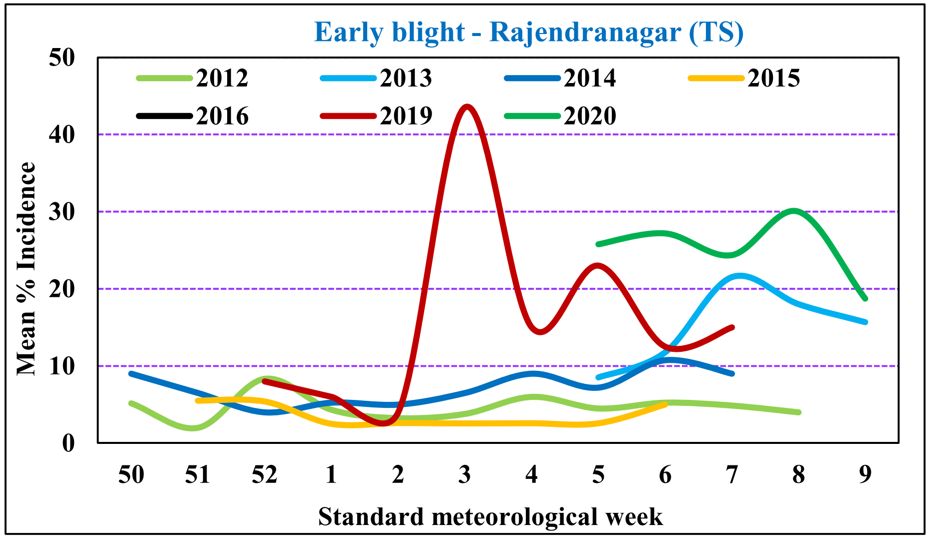


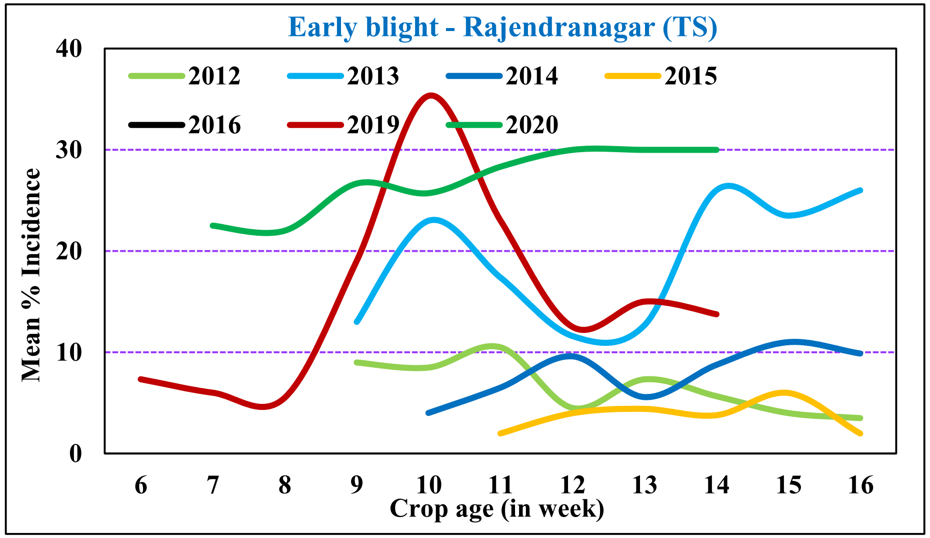


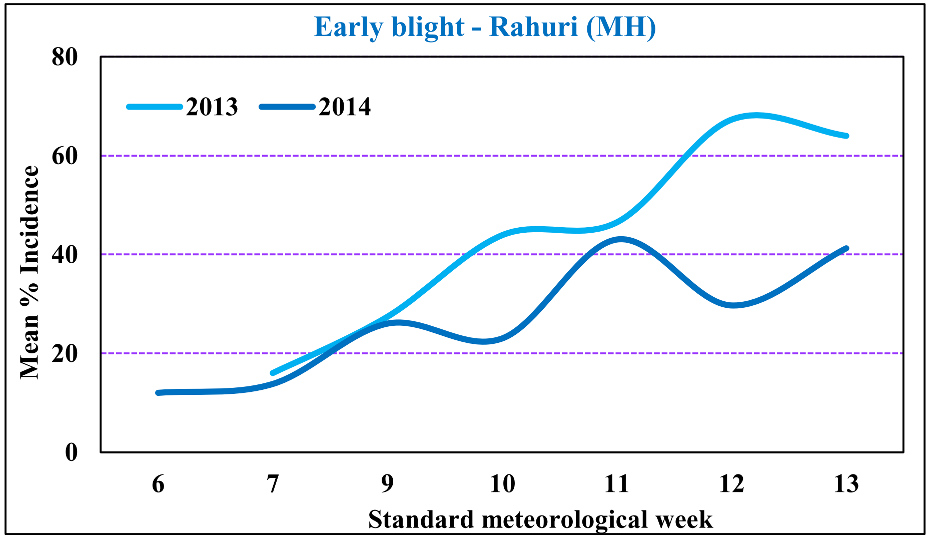


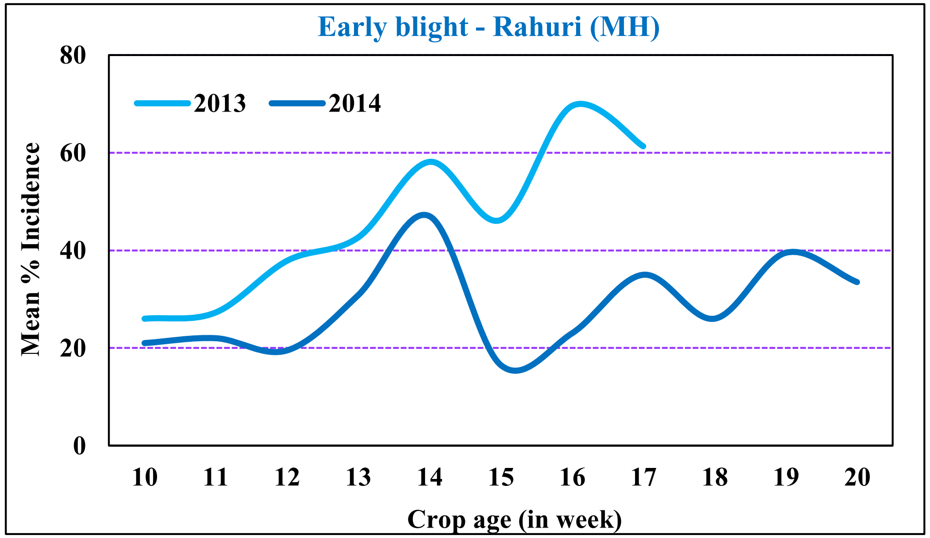
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



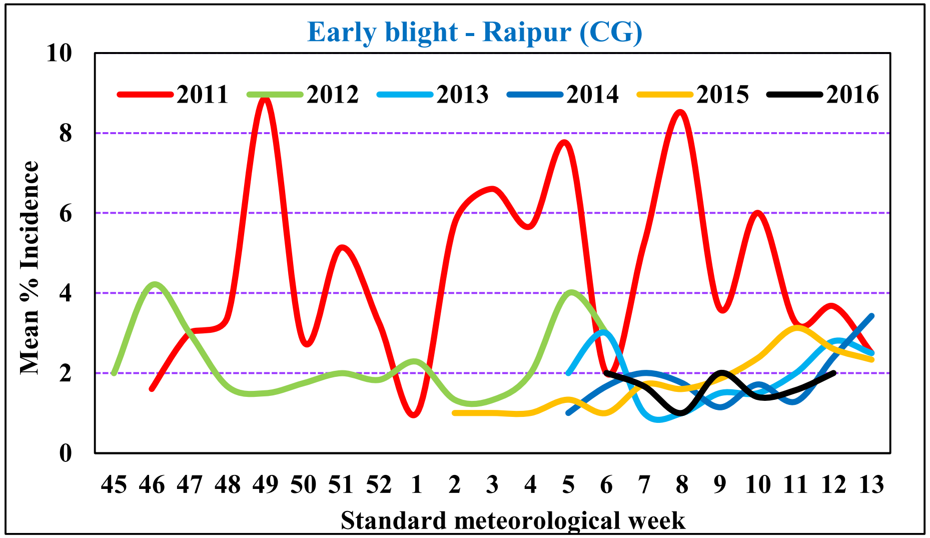


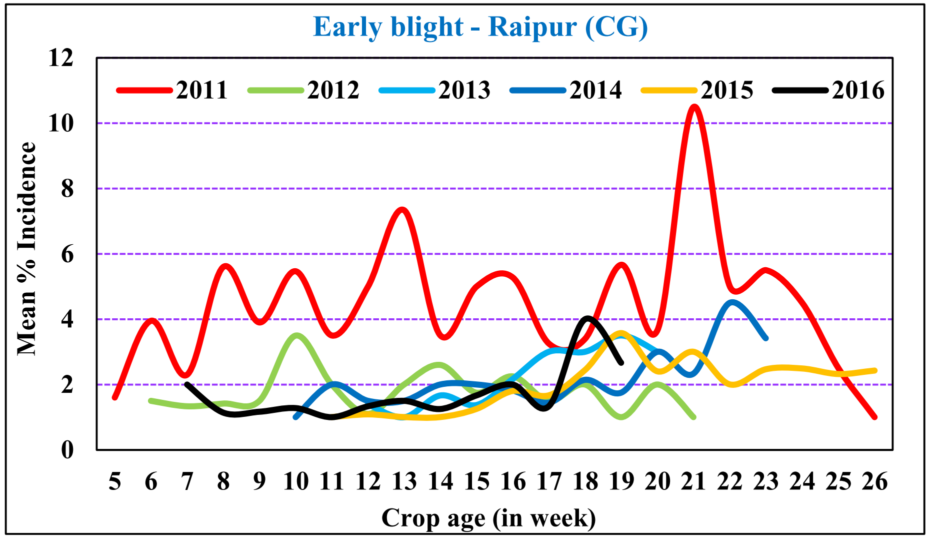


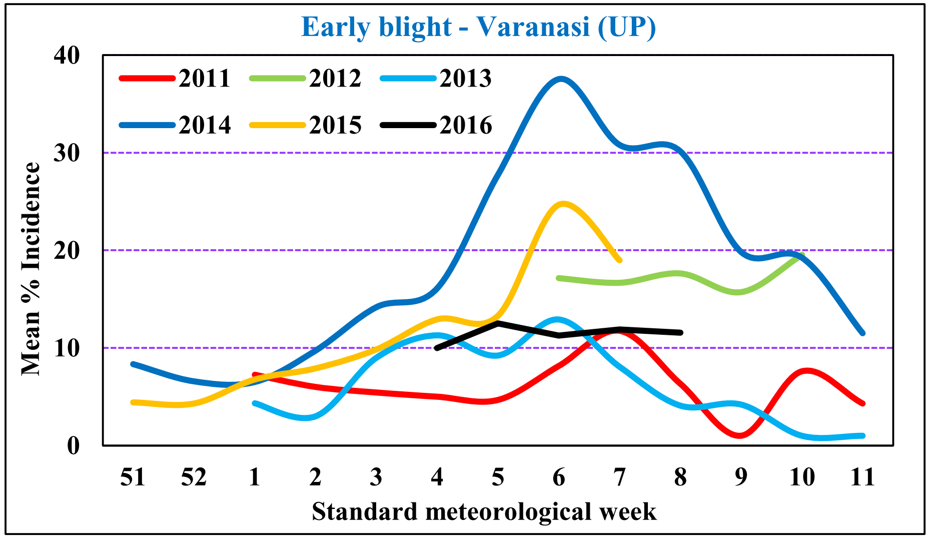


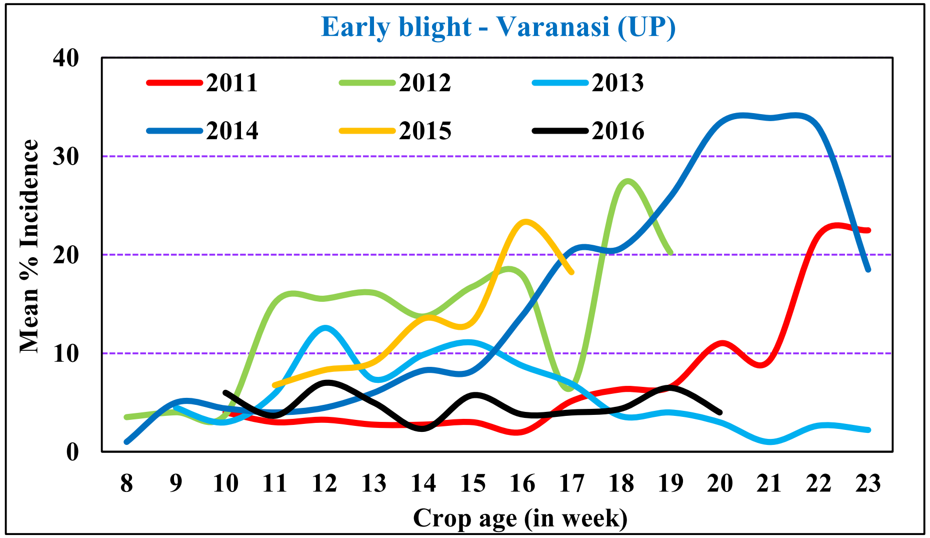
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



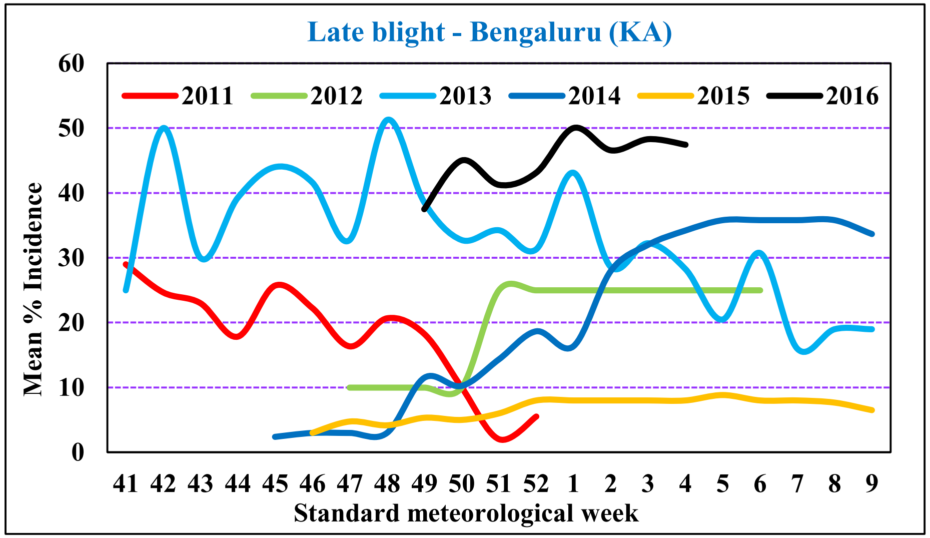


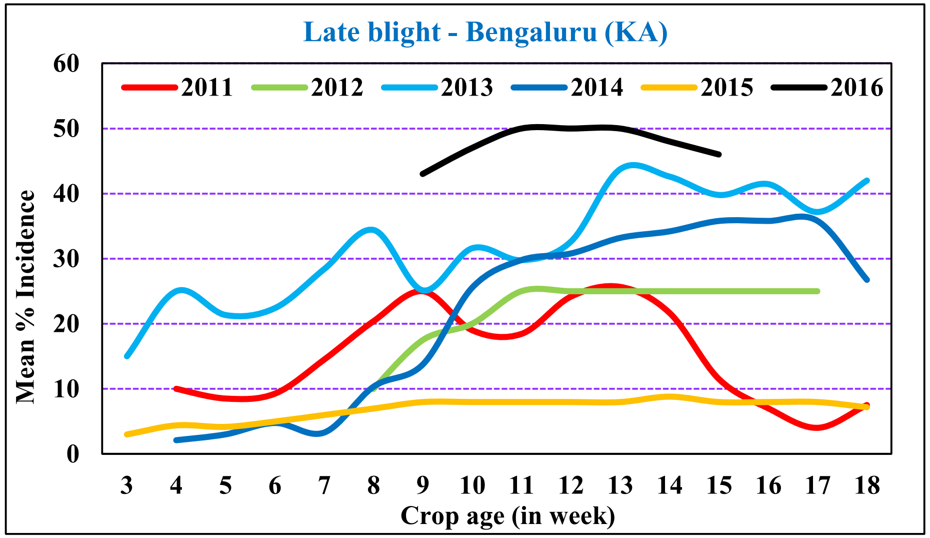


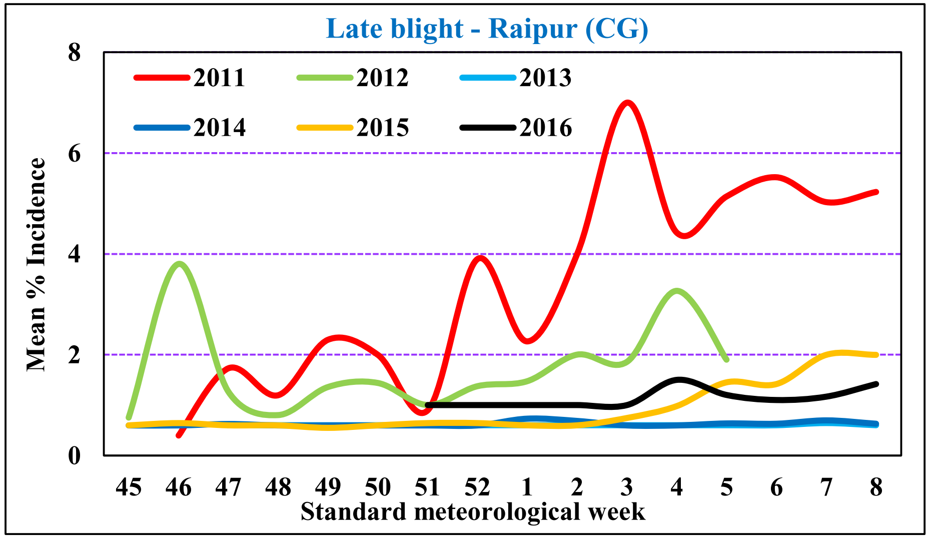


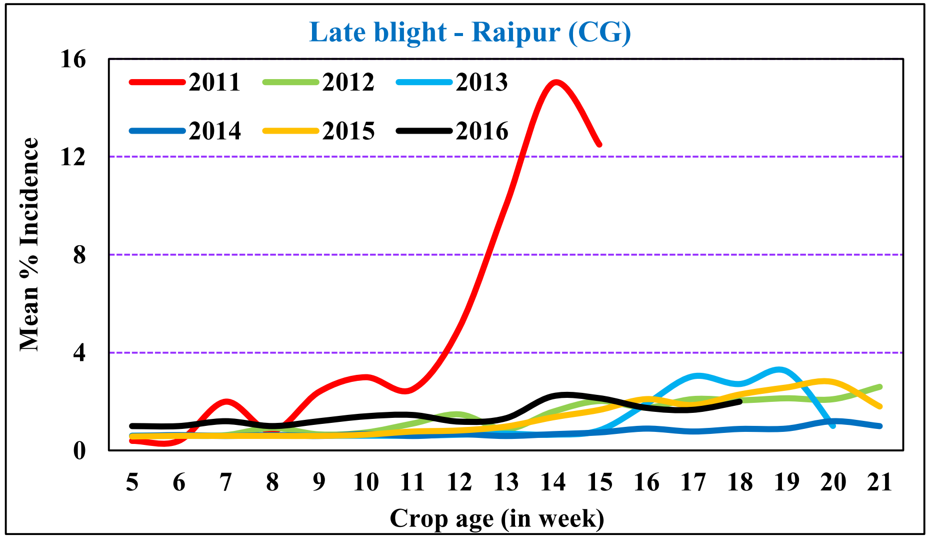
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



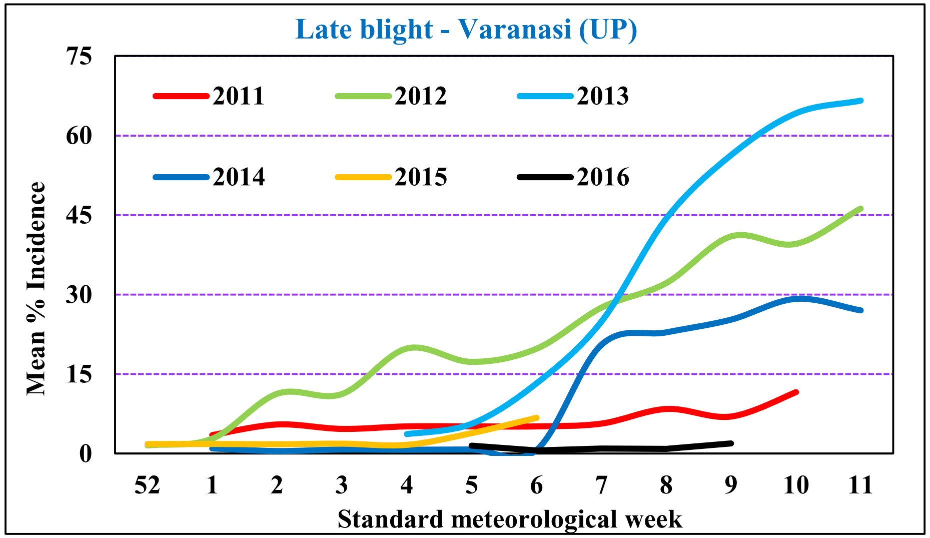


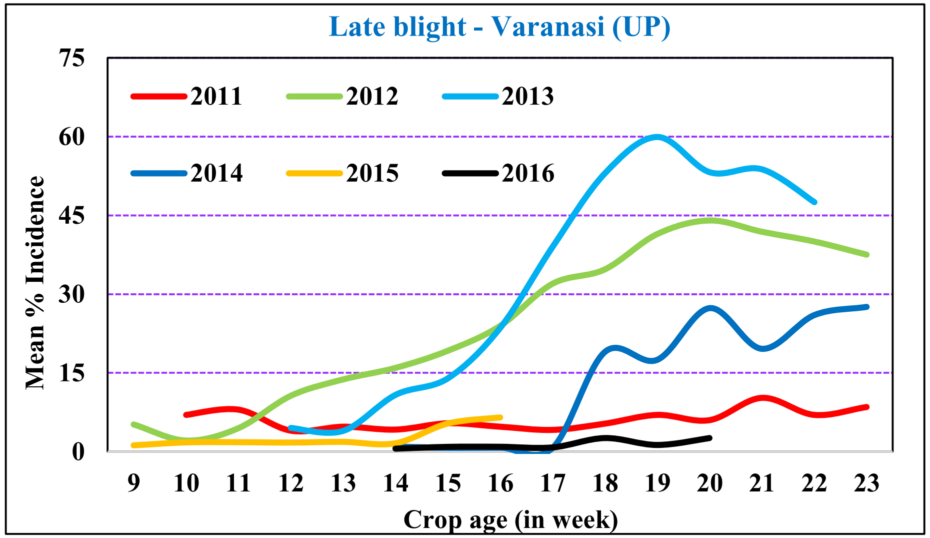


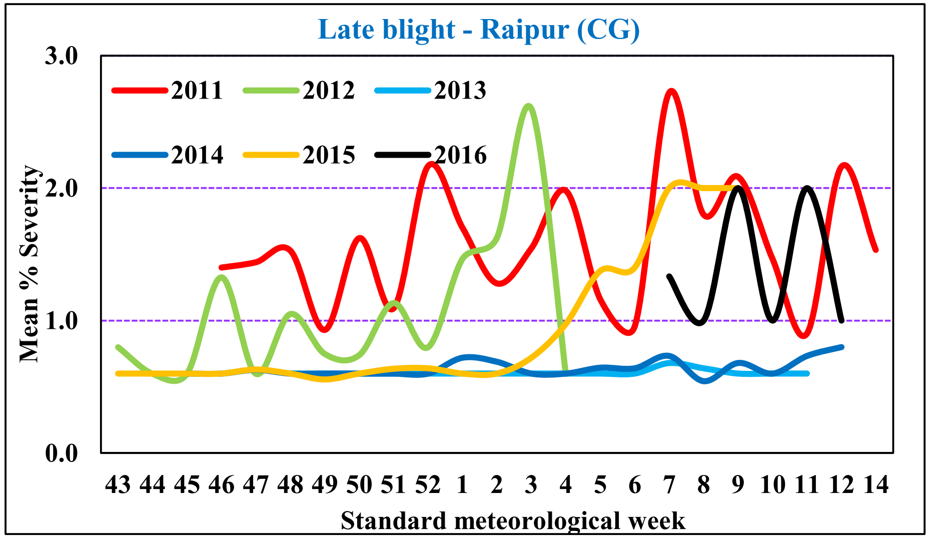


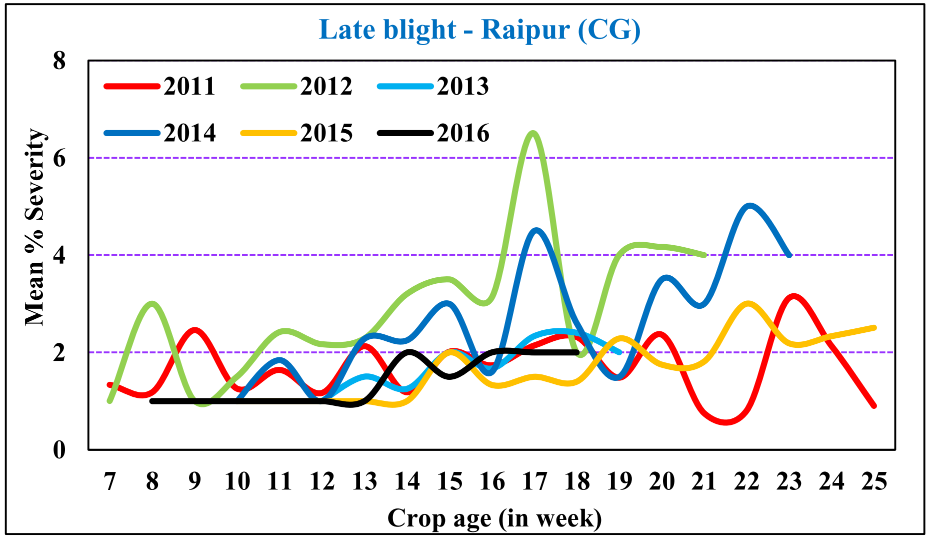
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



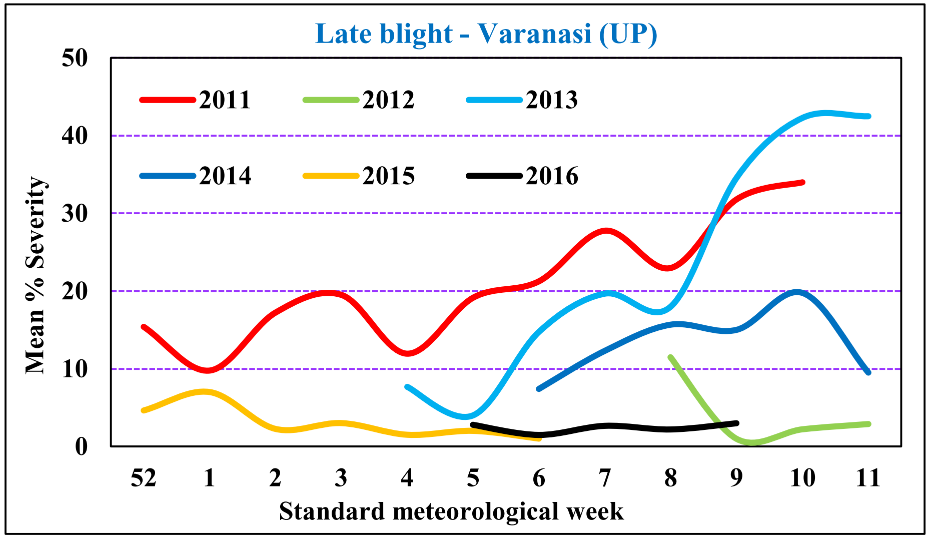


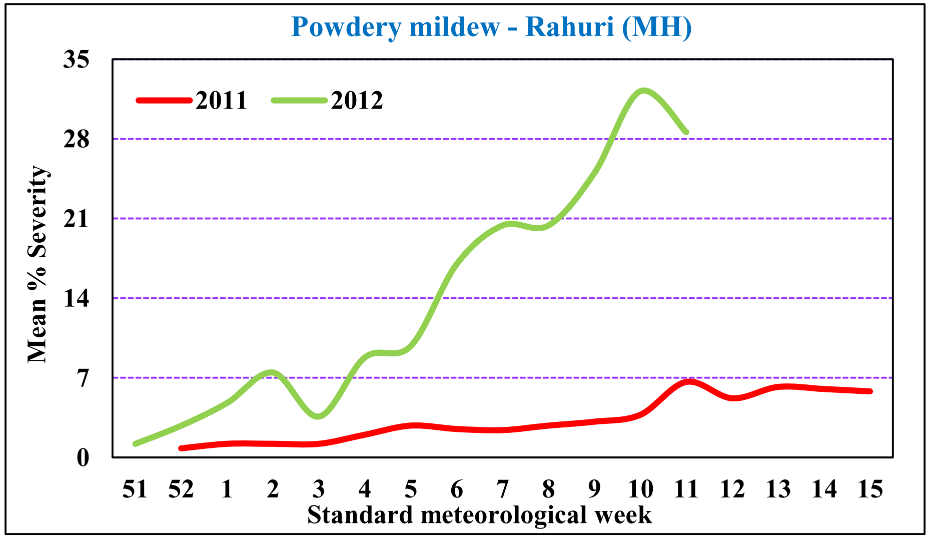




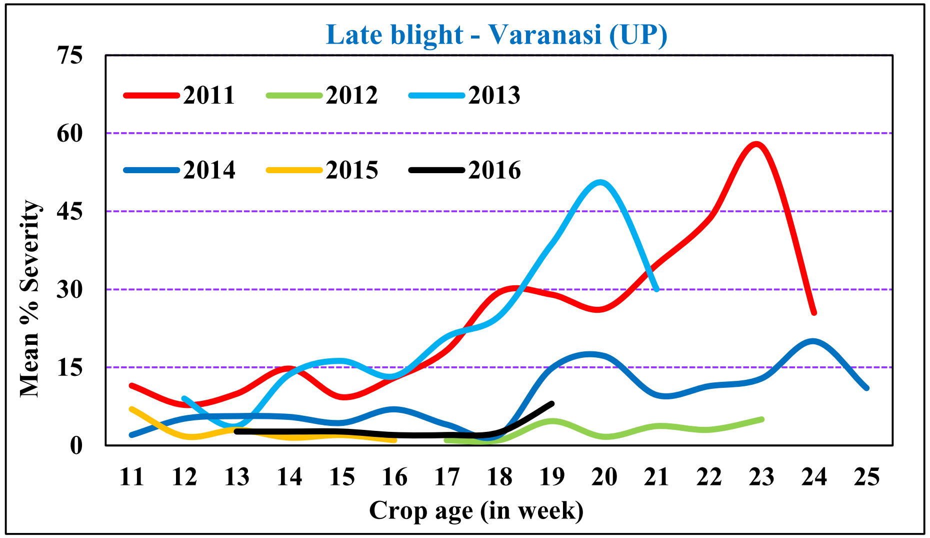
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

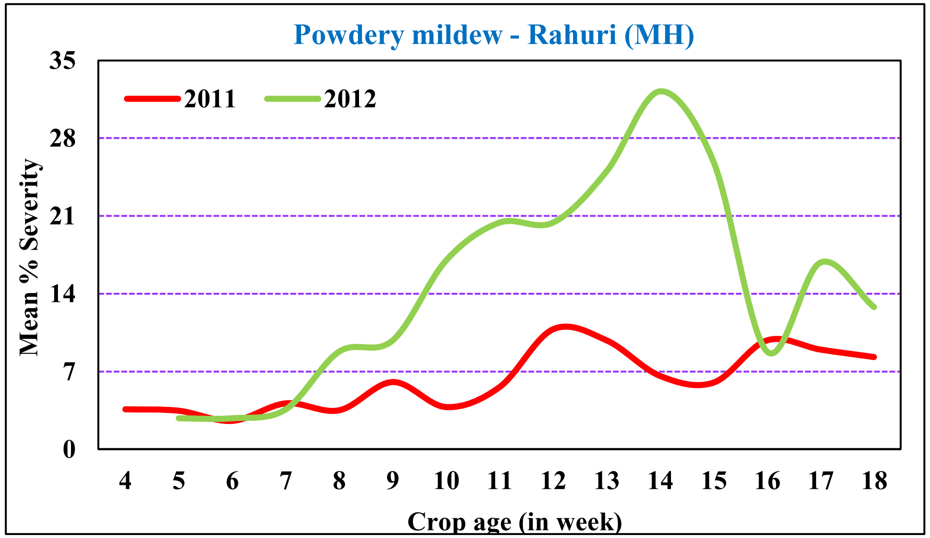
Seasonal dynamics based on standard meteorological weeks





Seasonal dynamics based on crop age





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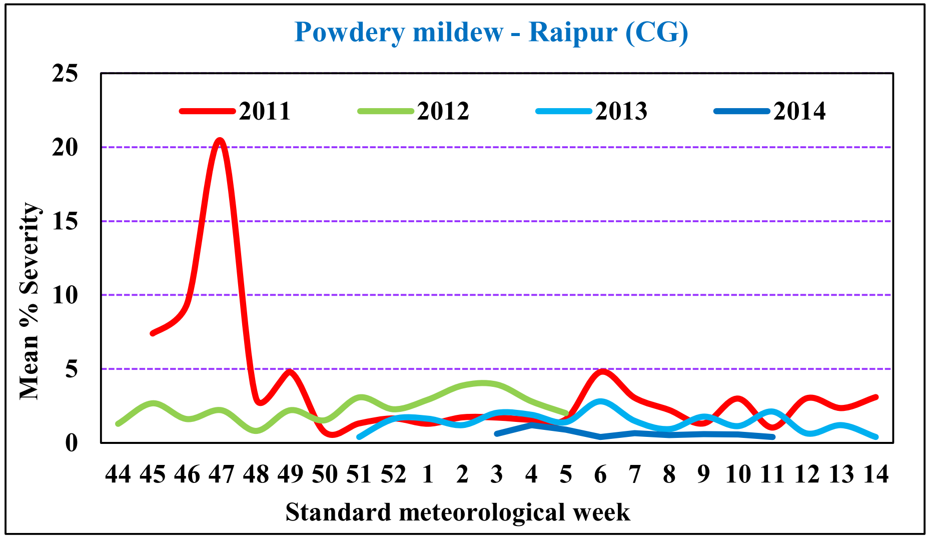
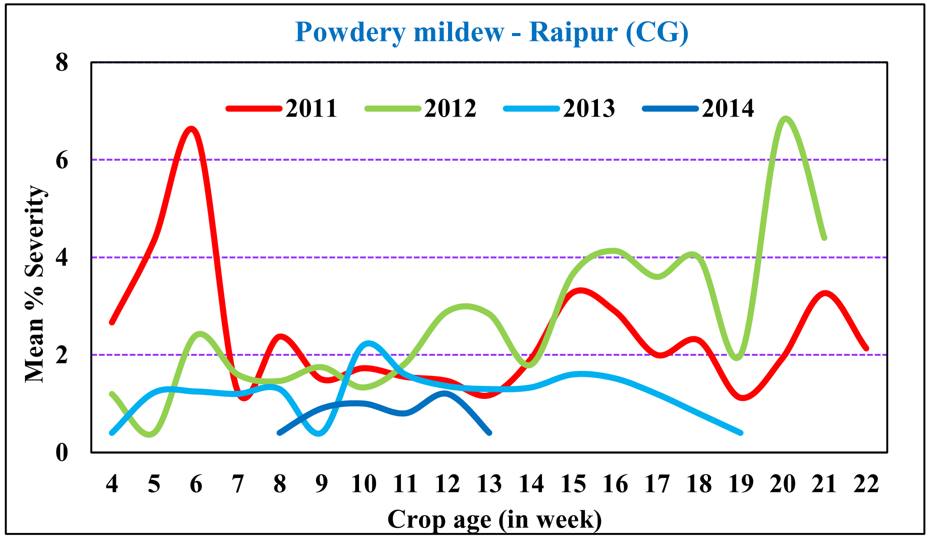
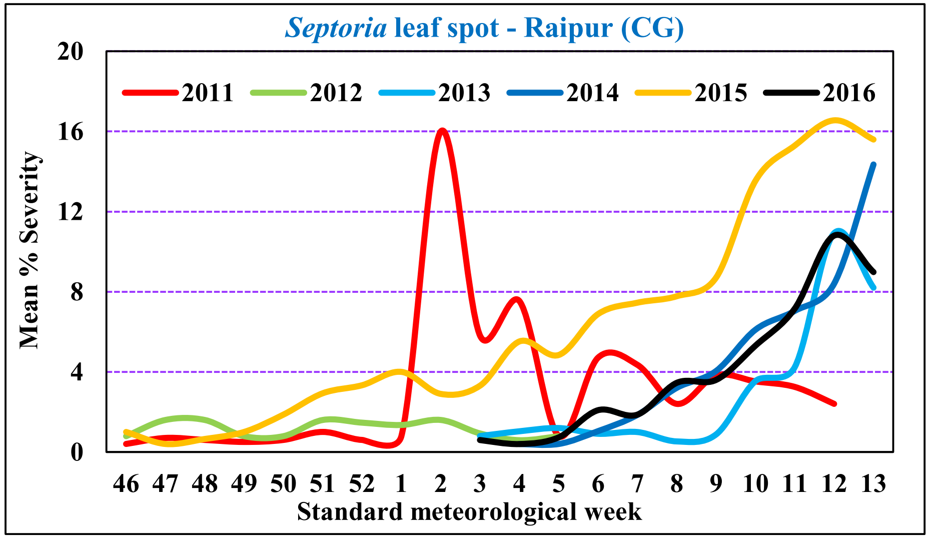
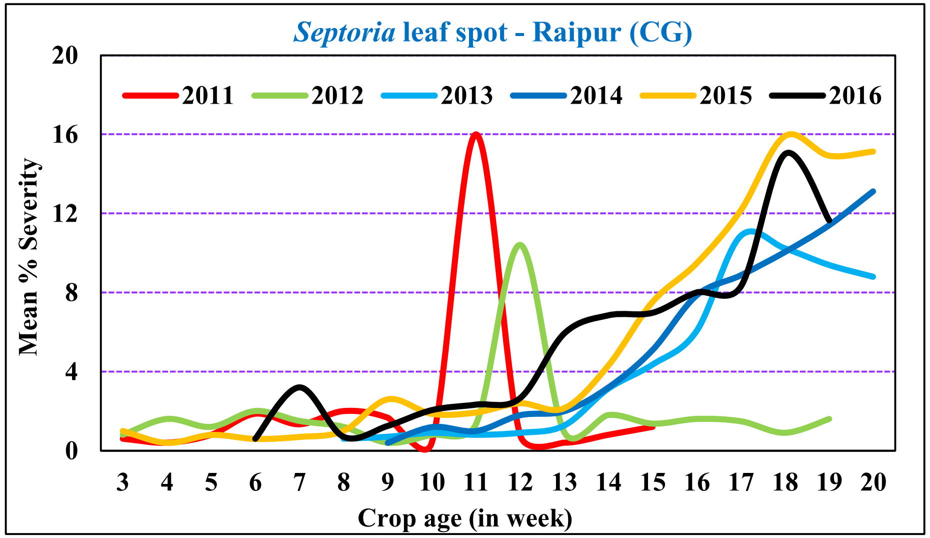
Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**





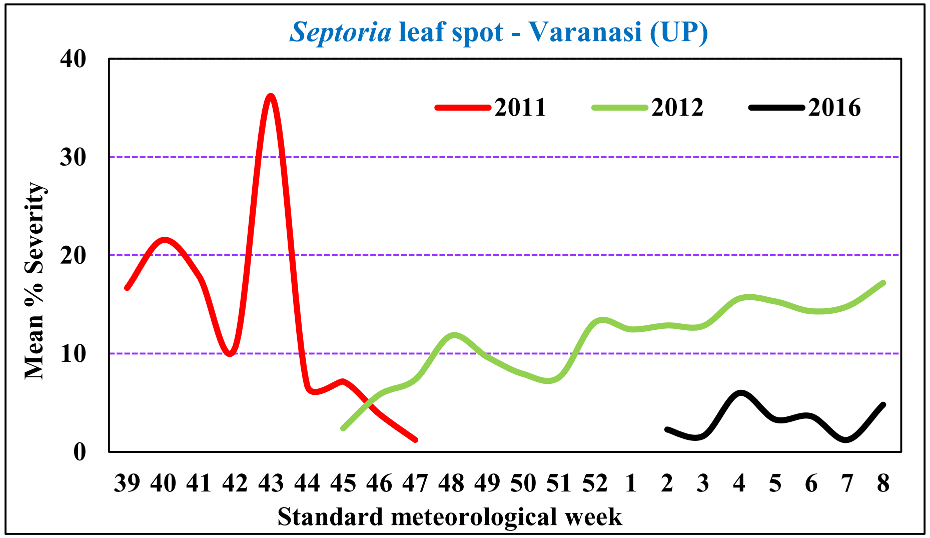


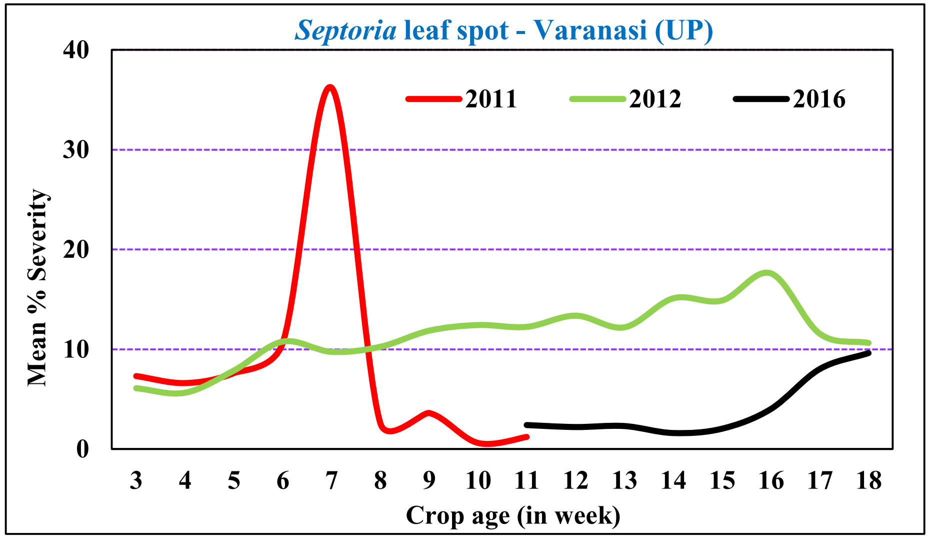


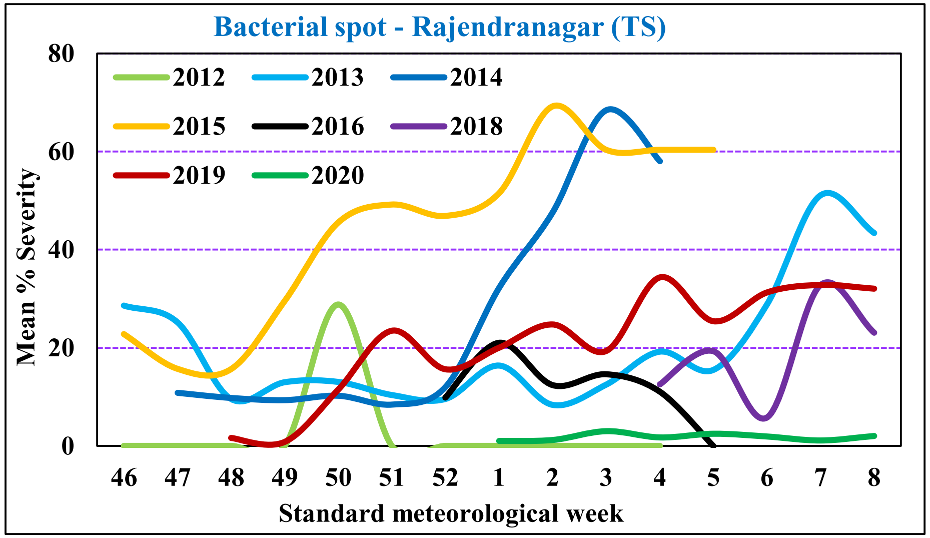
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

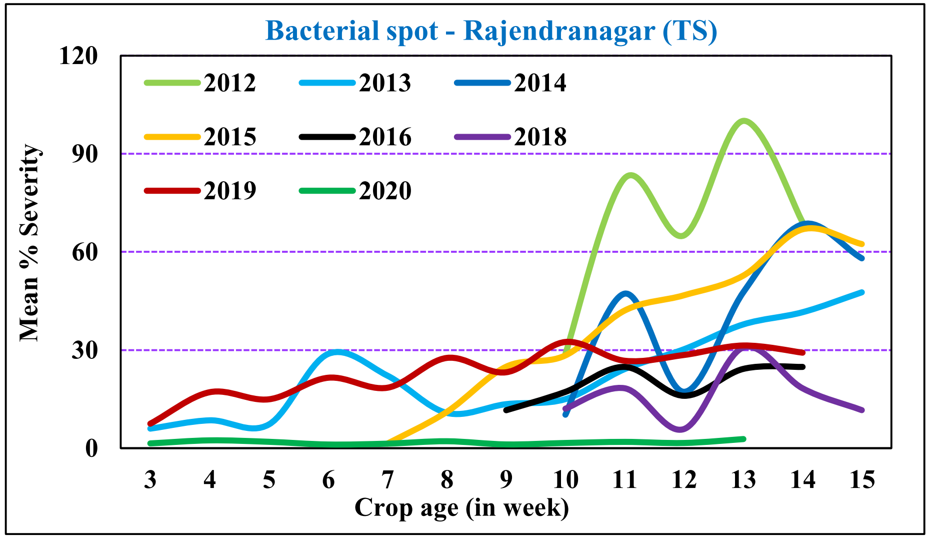
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



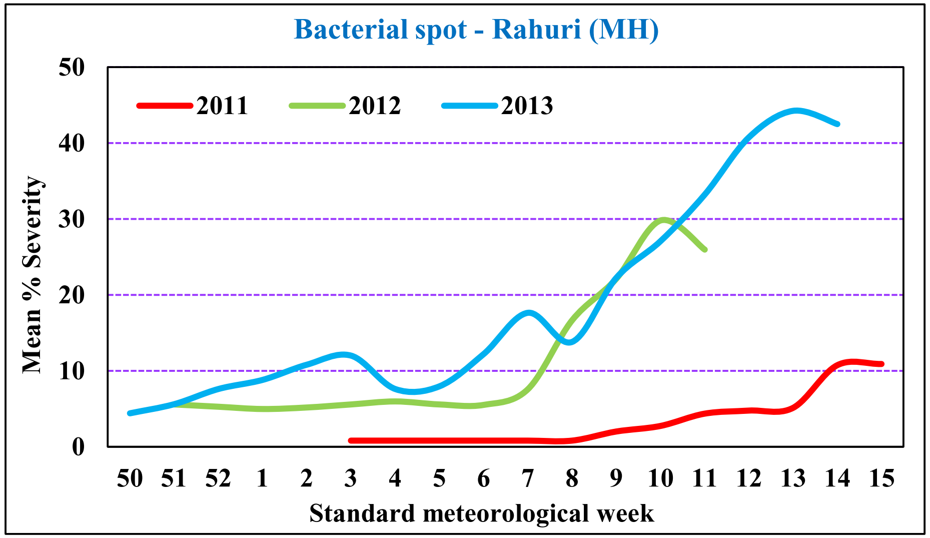


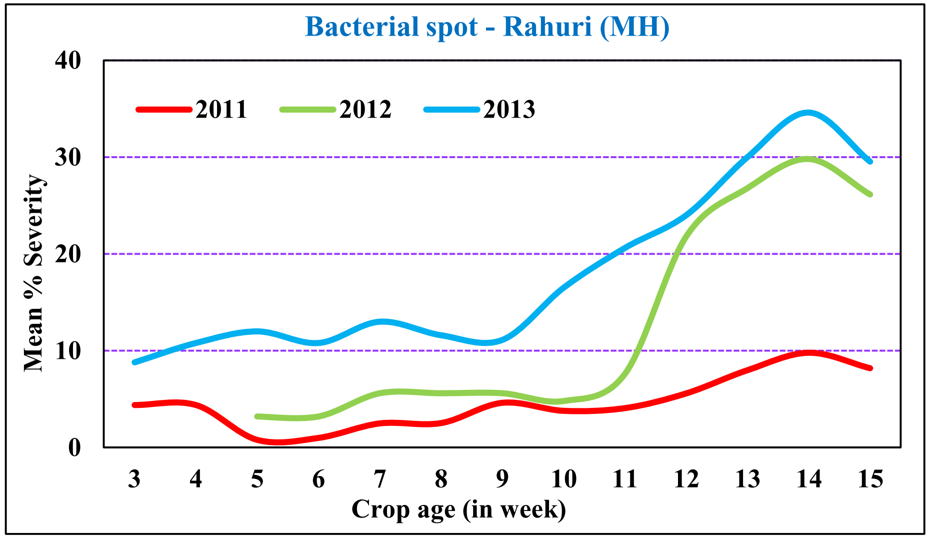


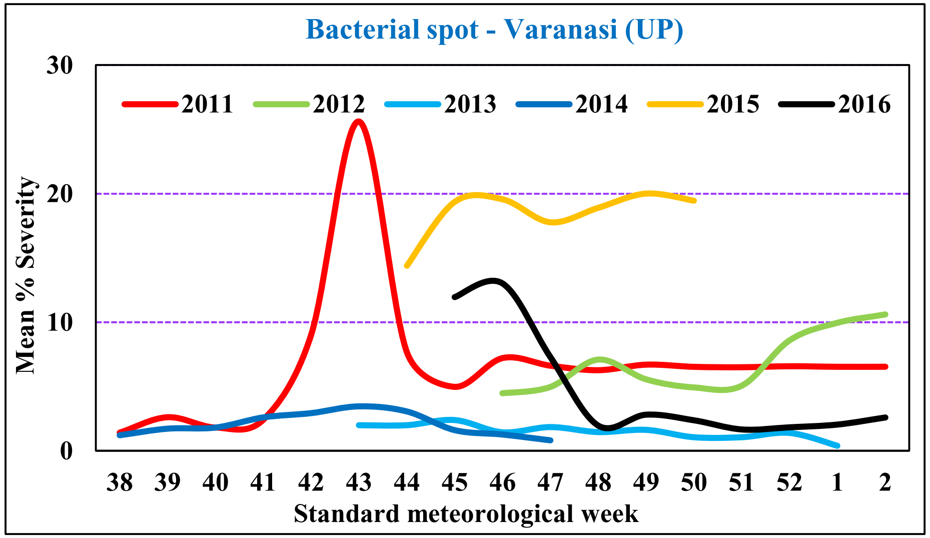


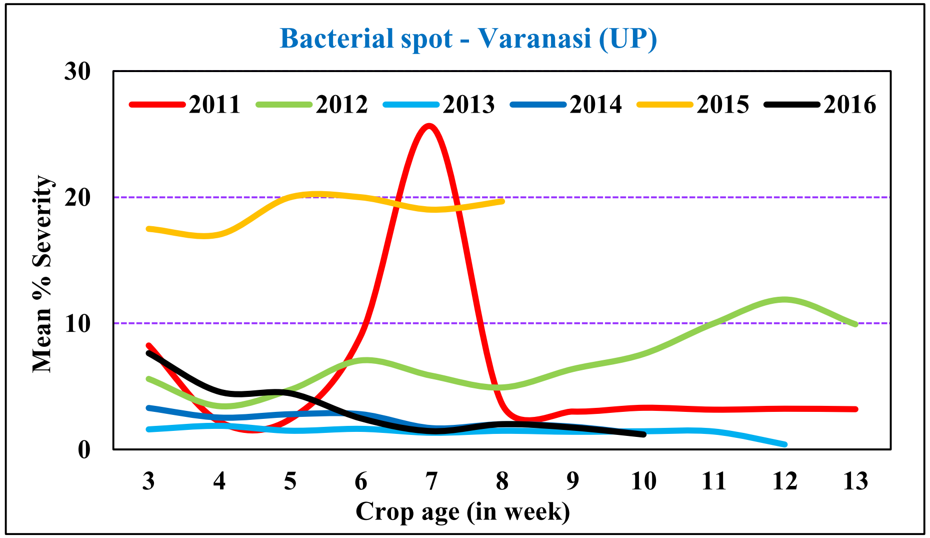
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



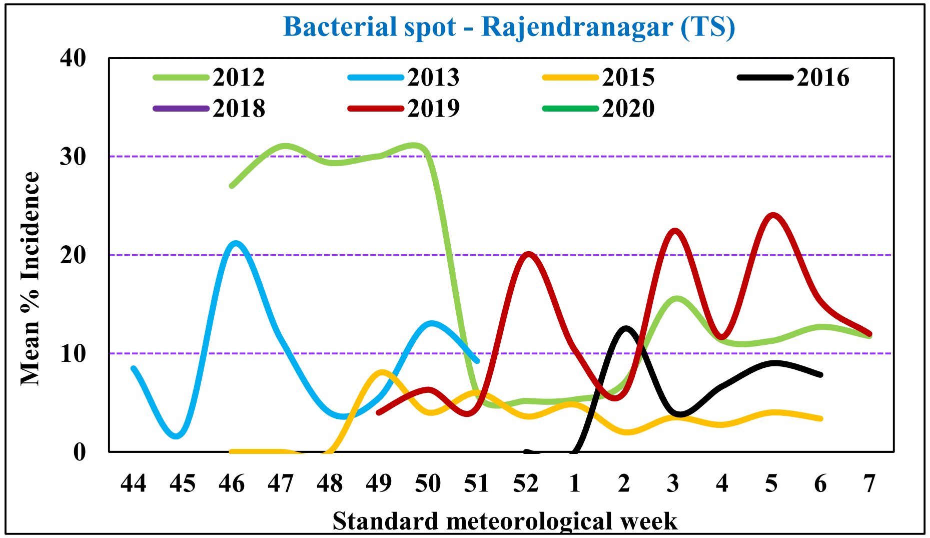


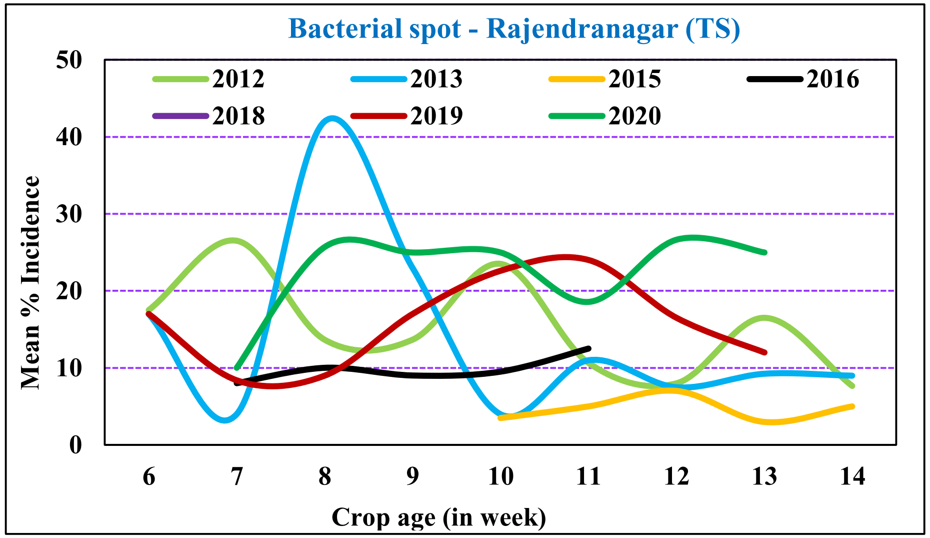


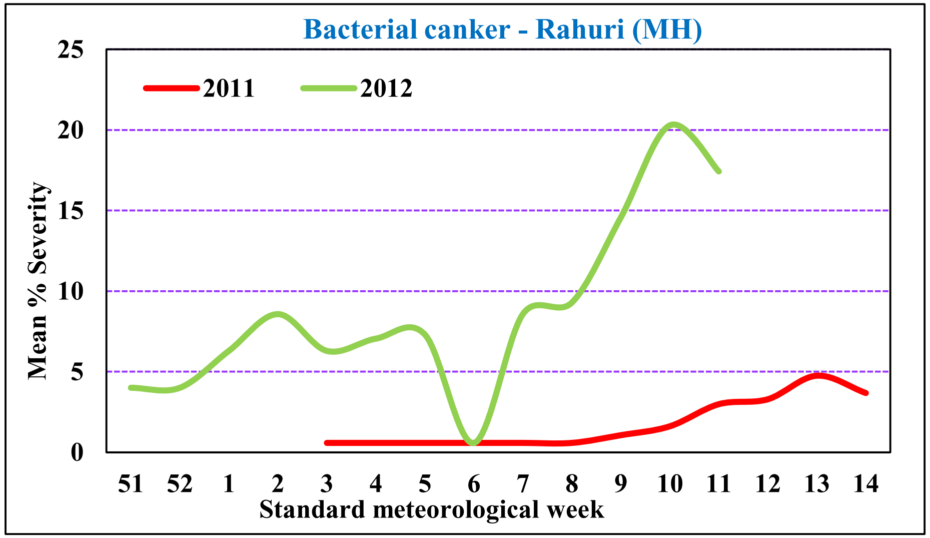


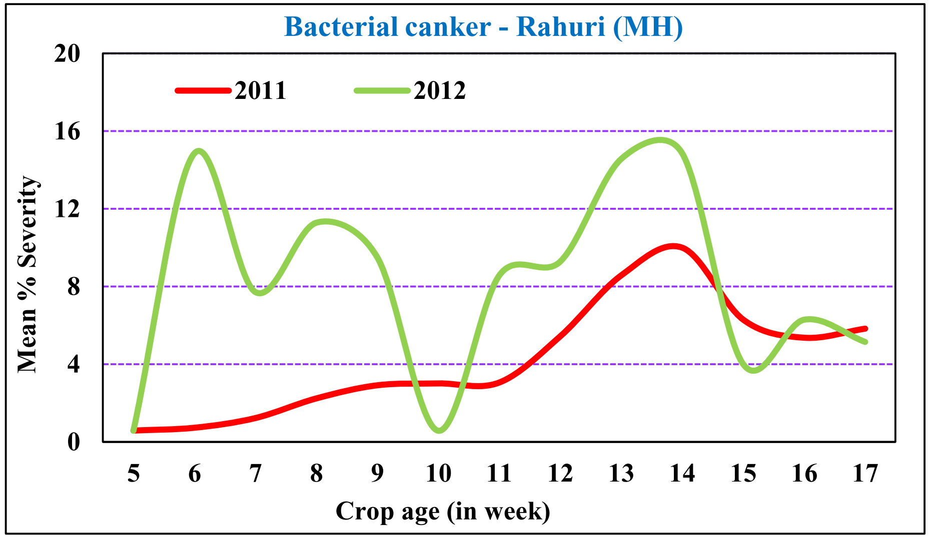
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**









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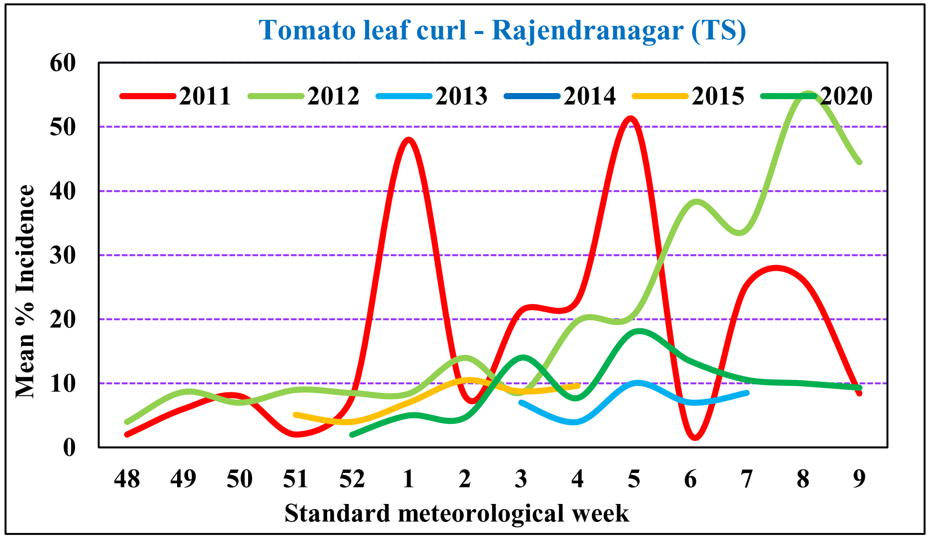
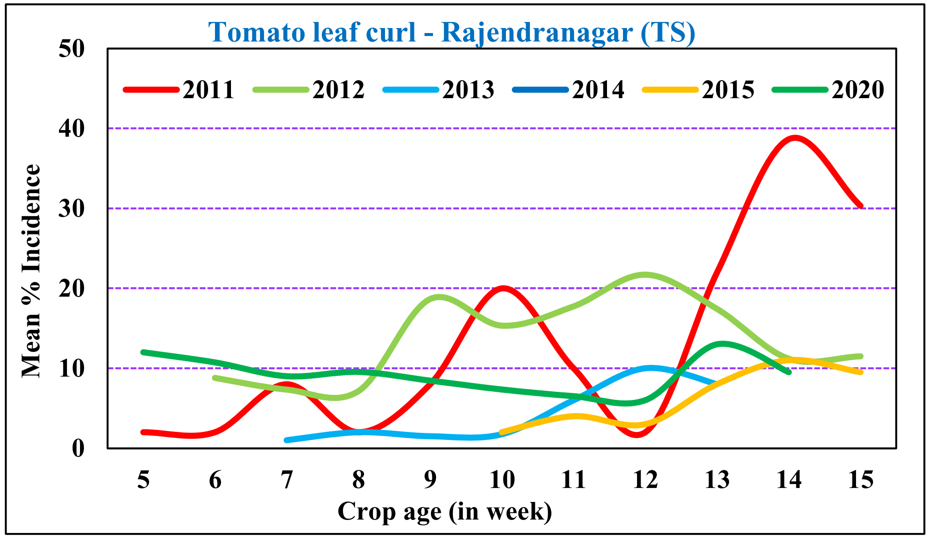
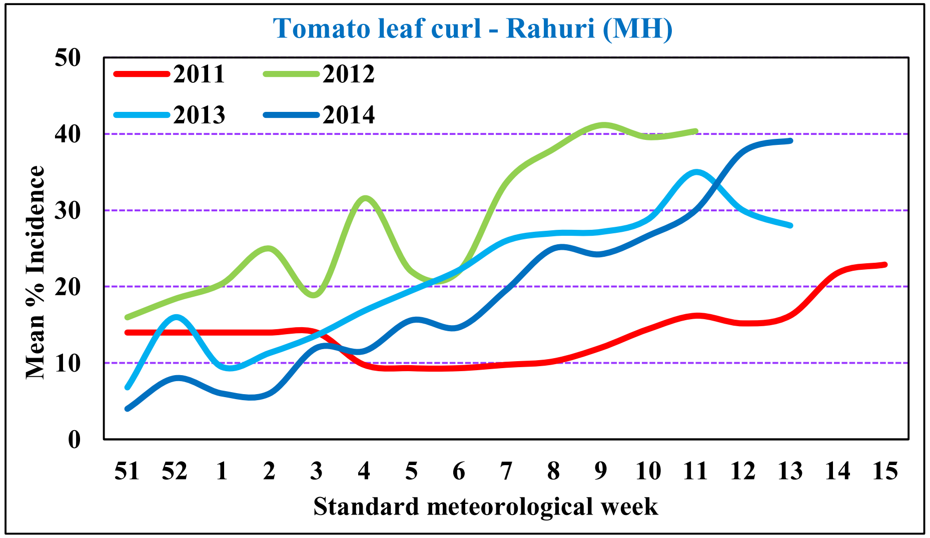
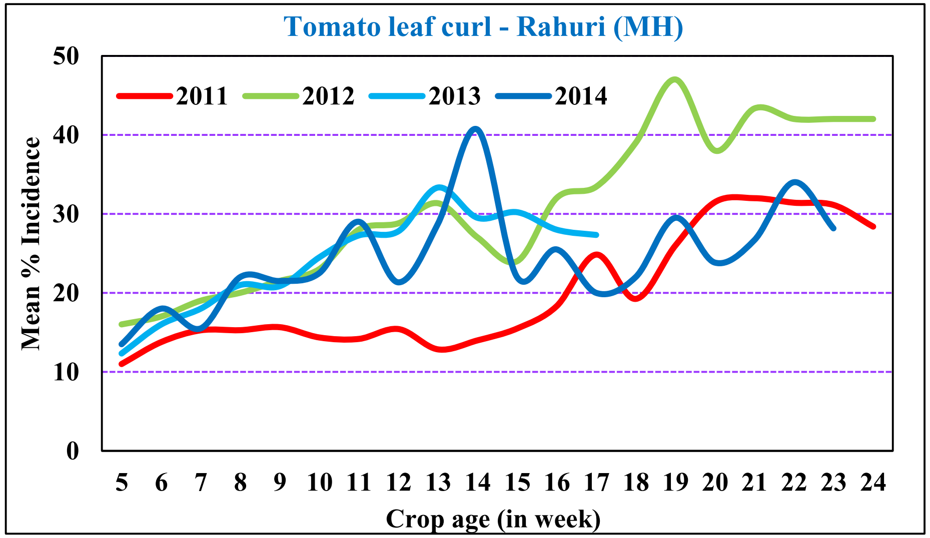
Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**



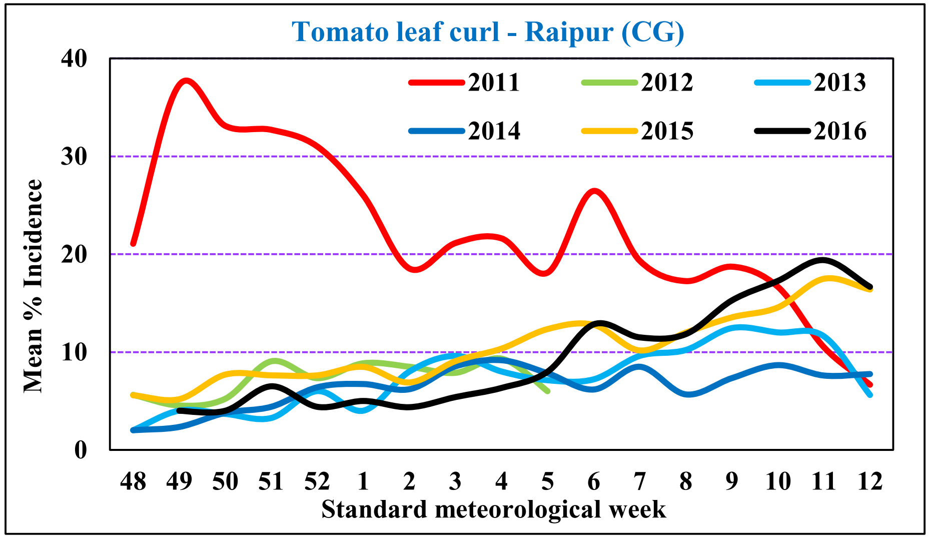


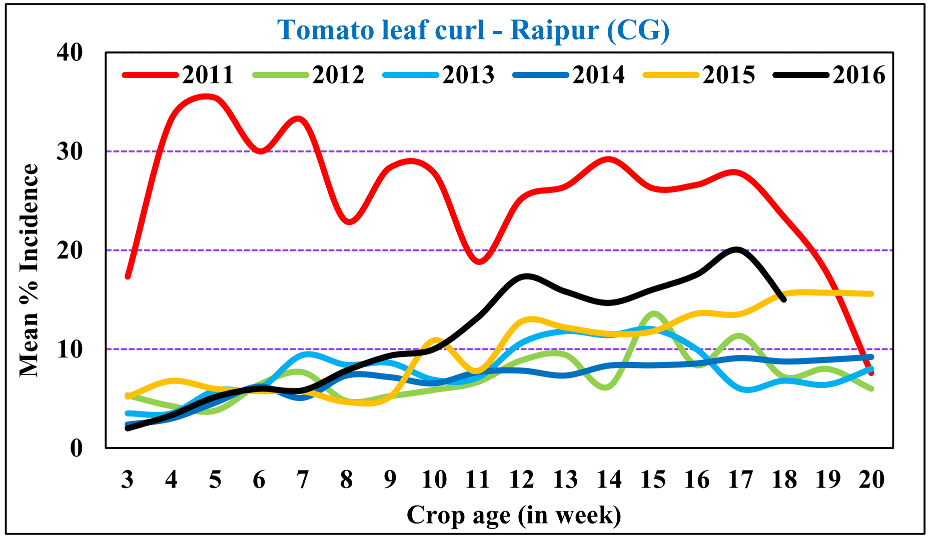


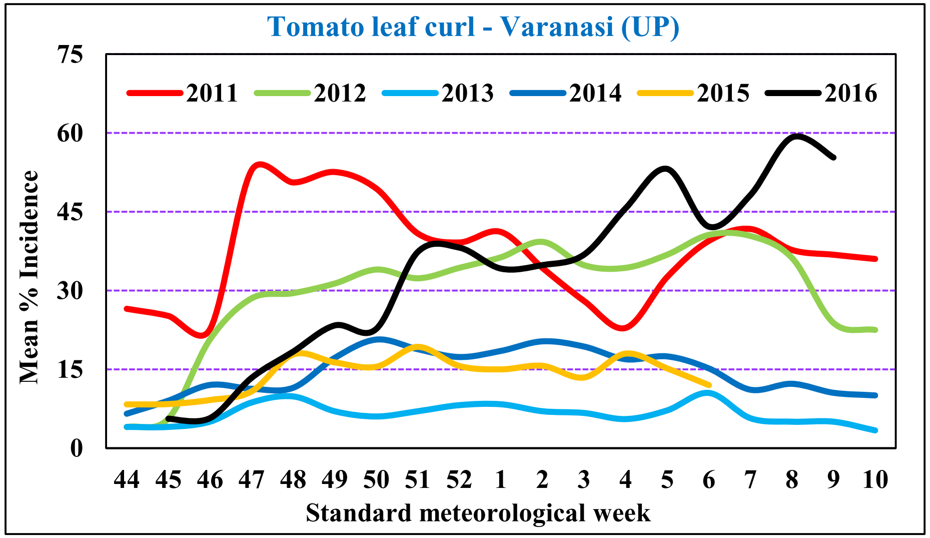


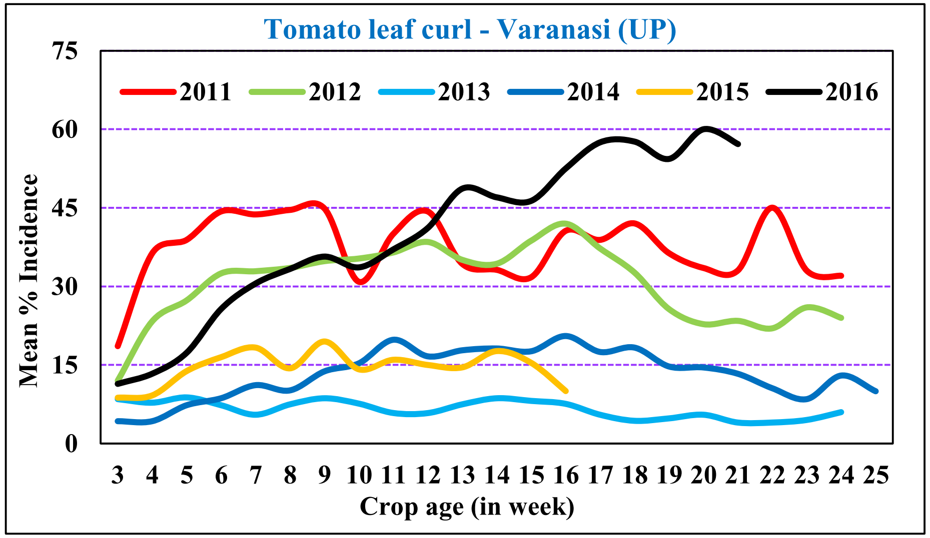
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks | **Seasonal dynamics based on crop age**





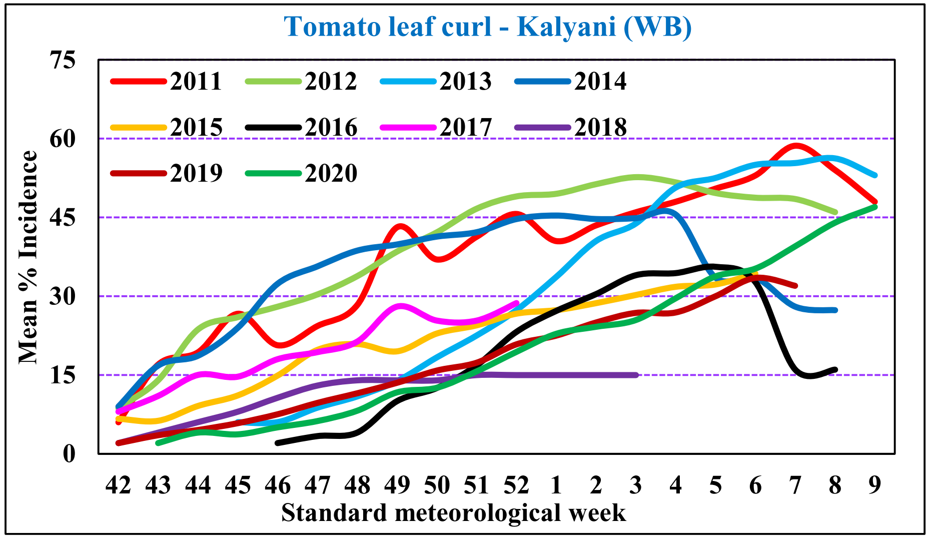


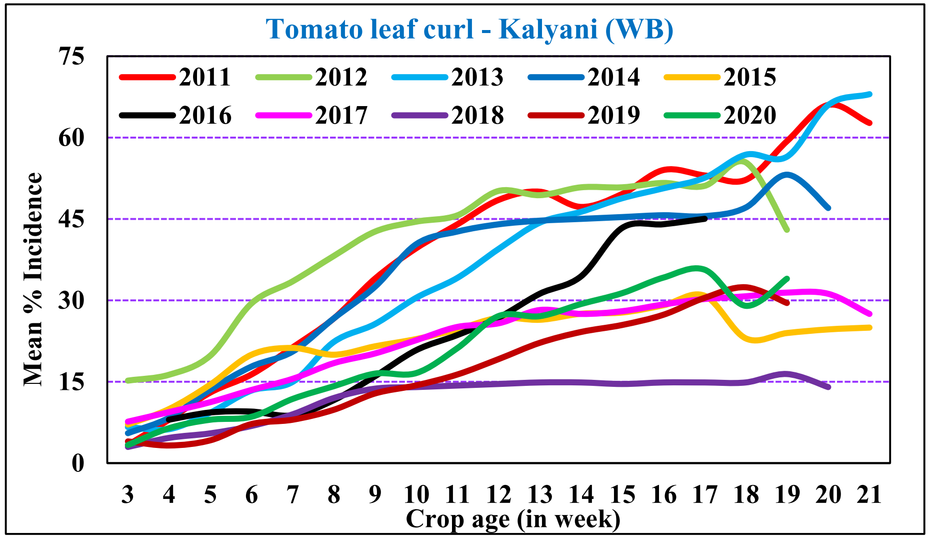


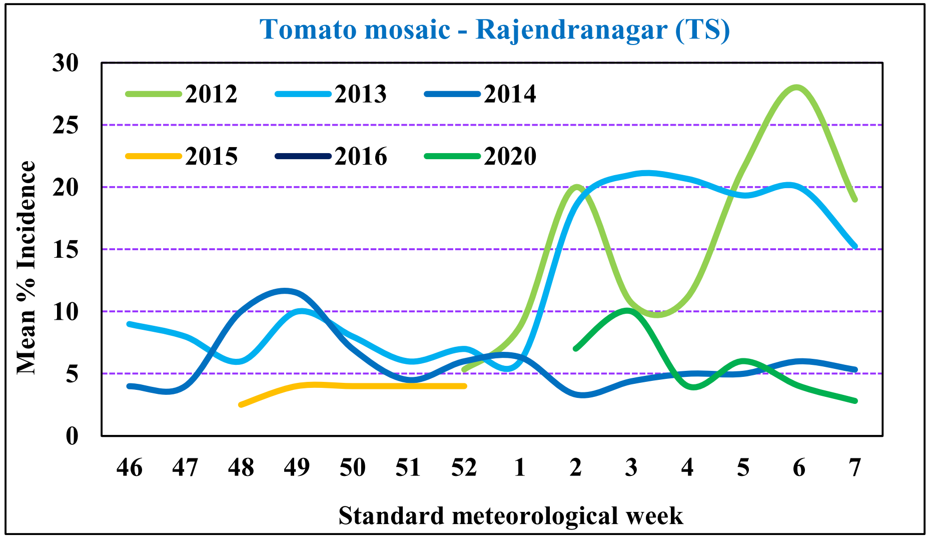
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

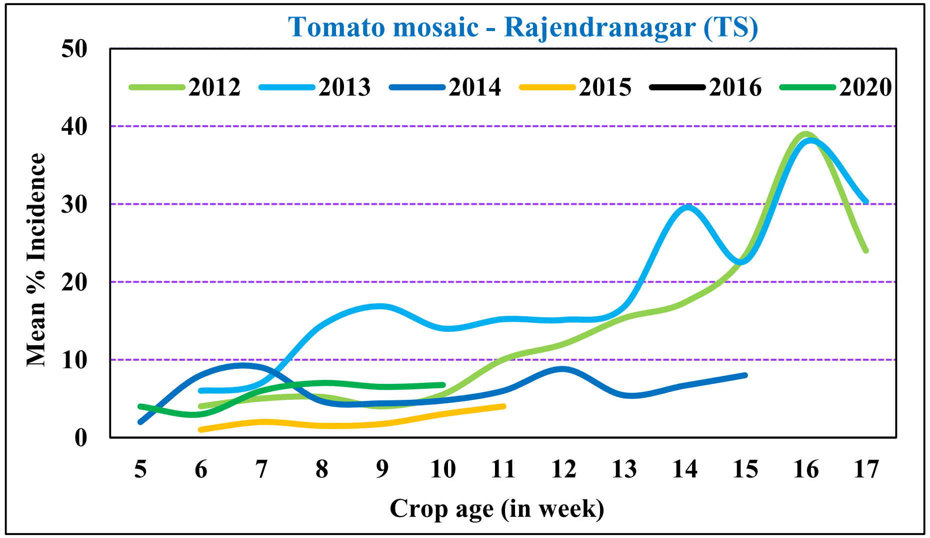
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





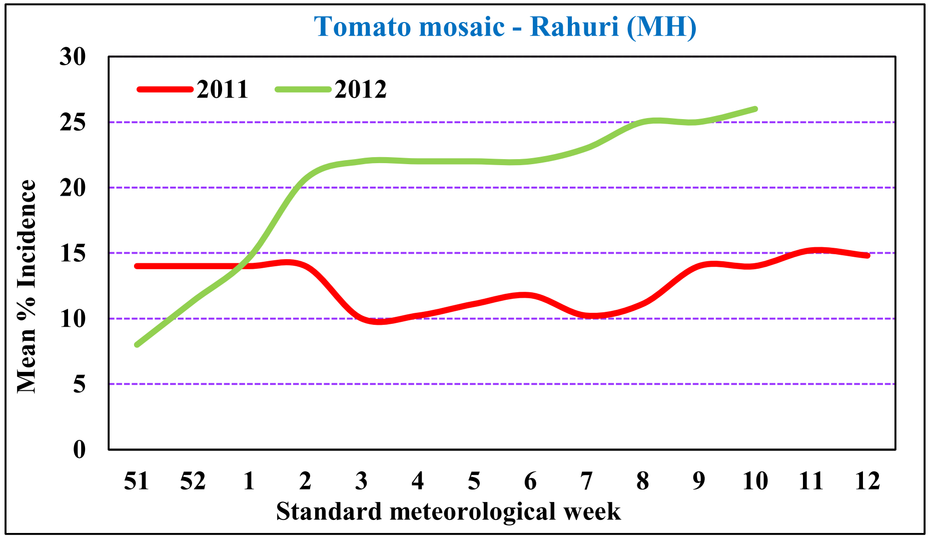


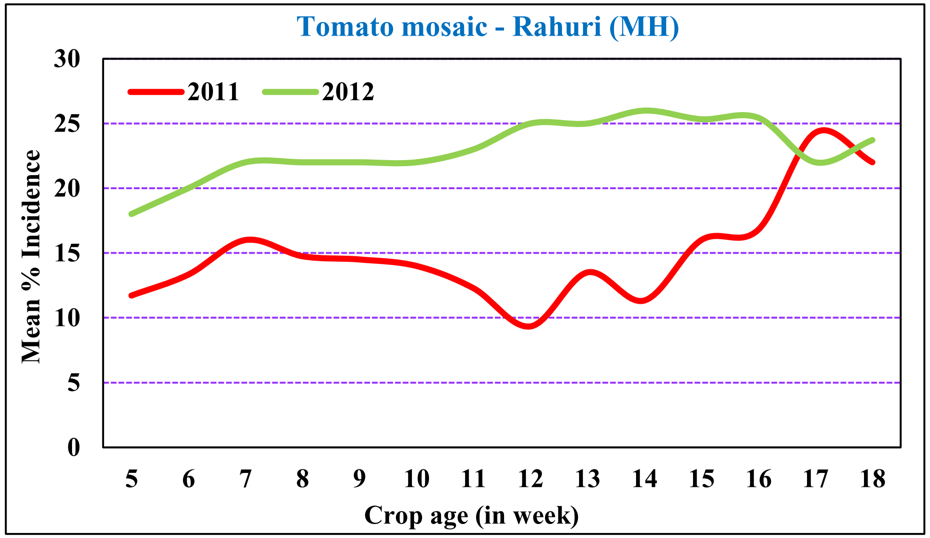


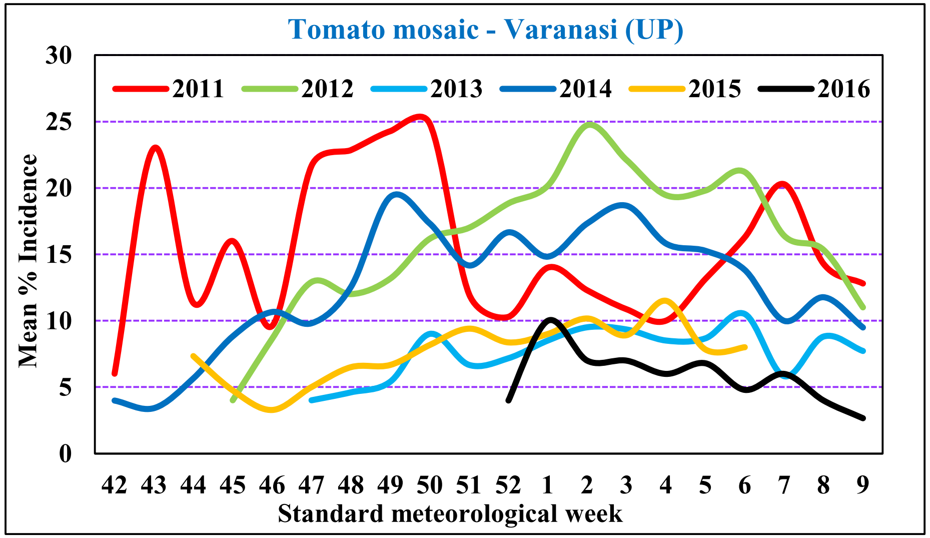
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

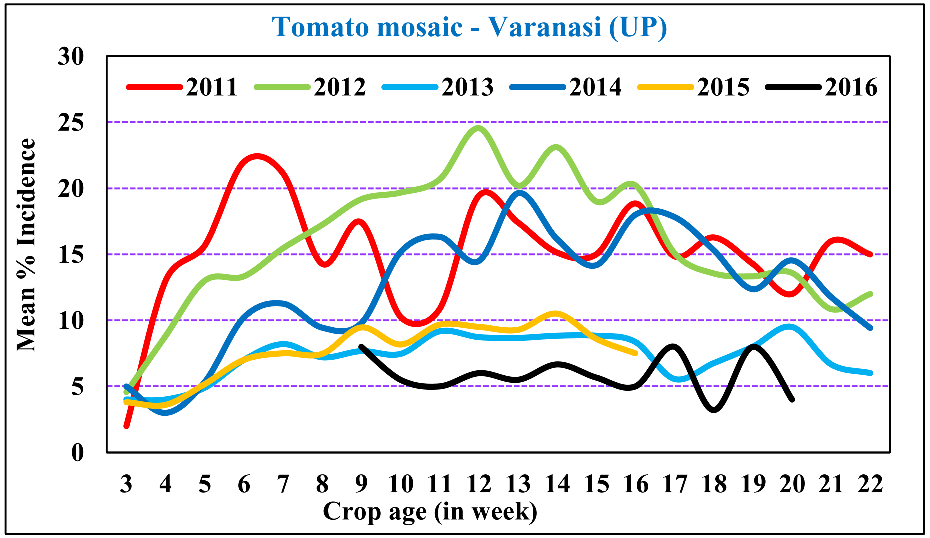
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age





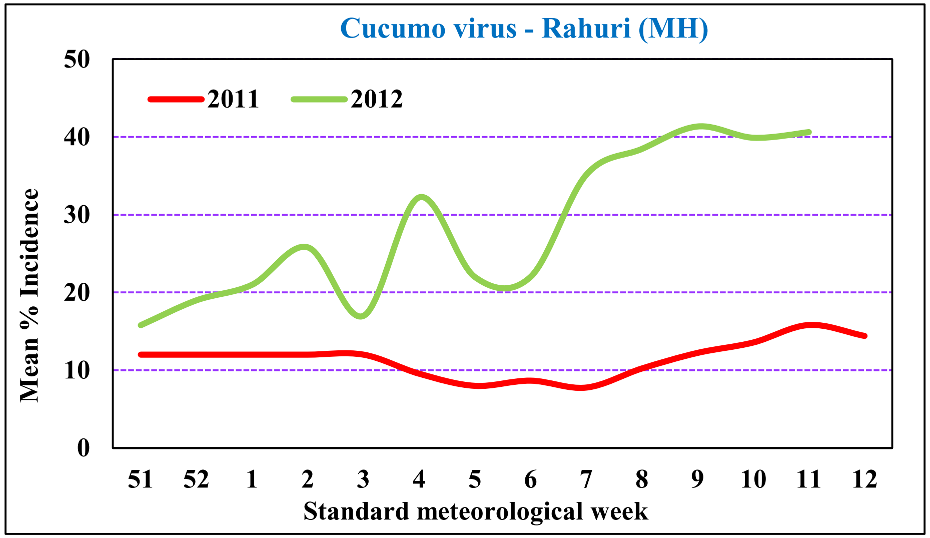


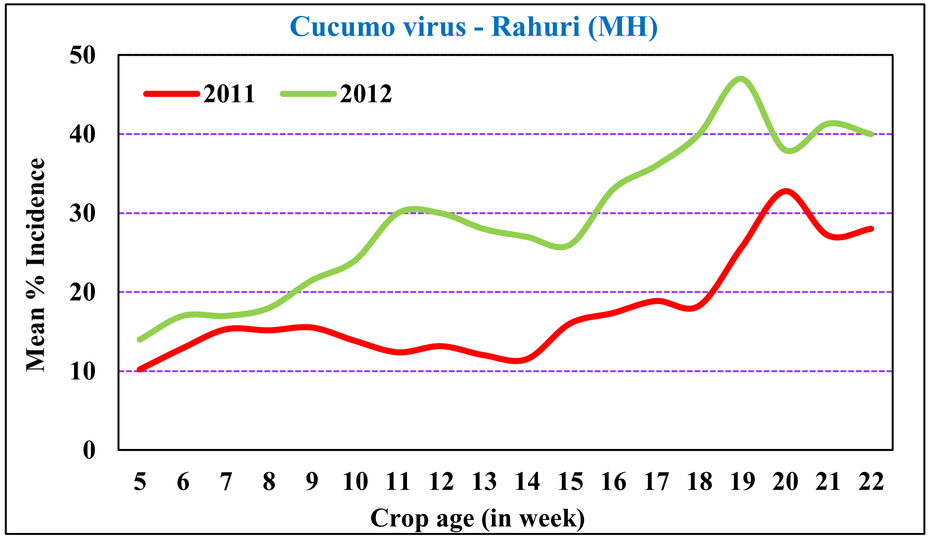


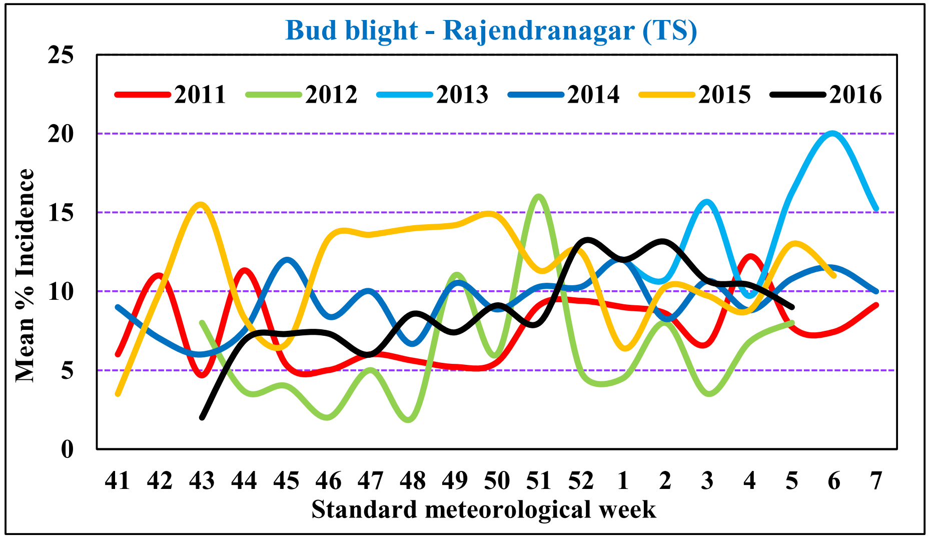
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

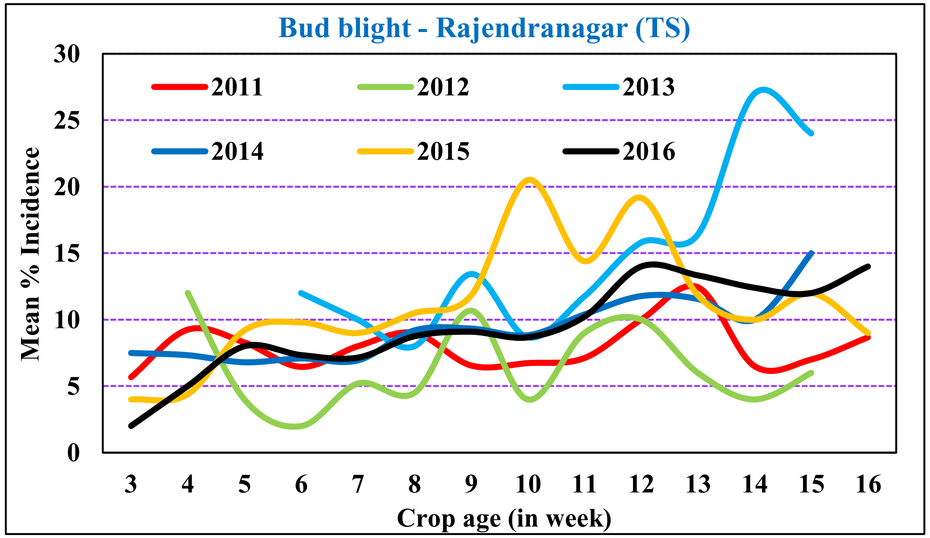
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



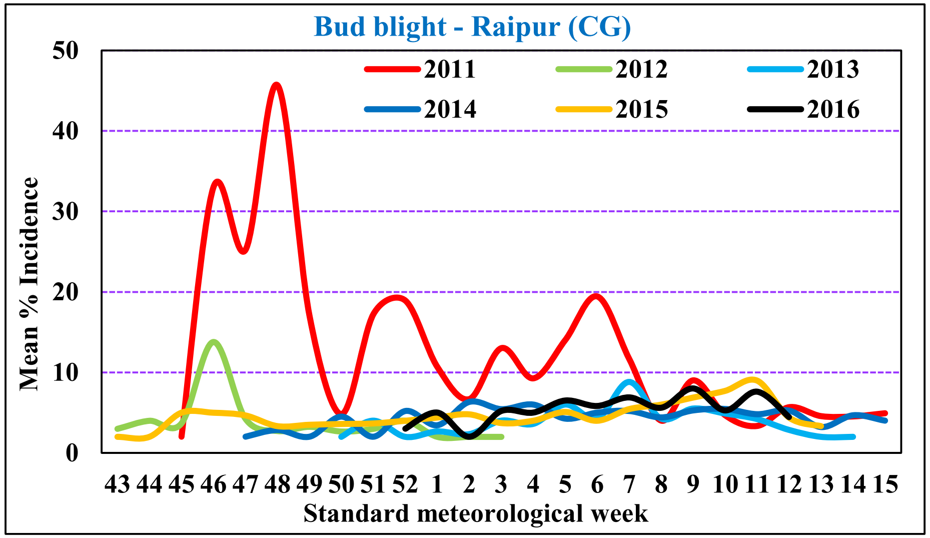


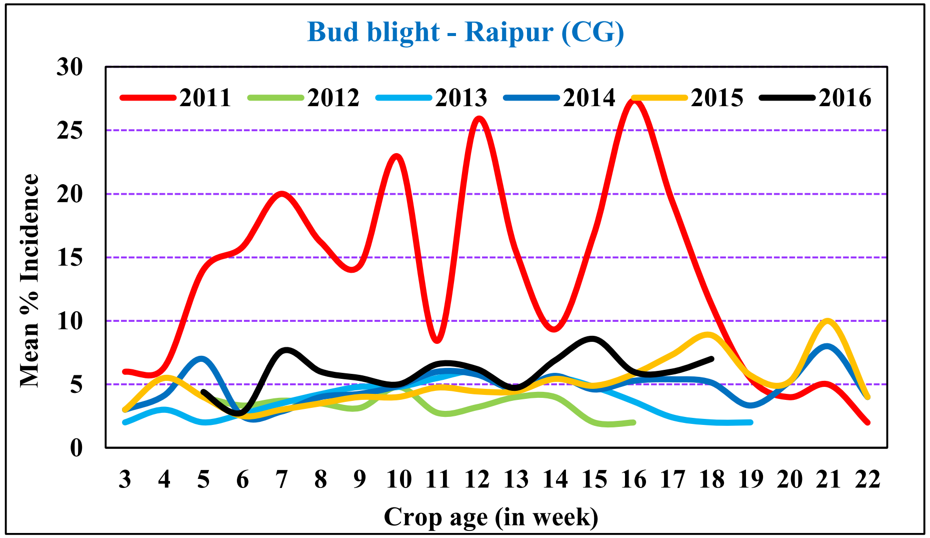


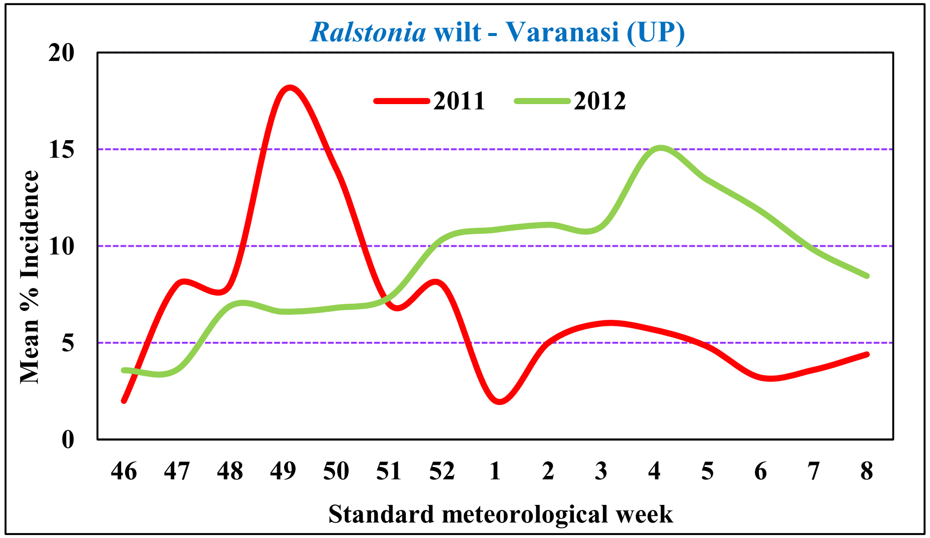


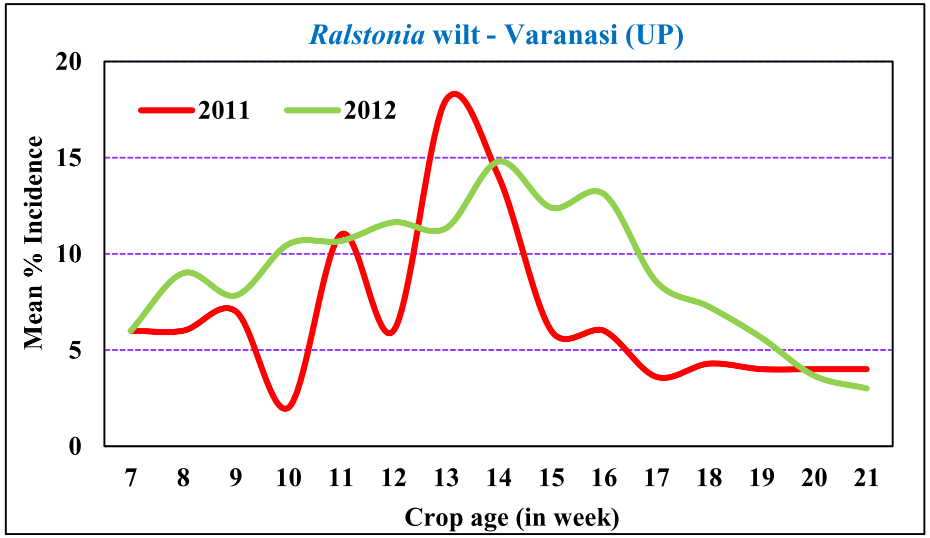
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks	Seasonal dynamics based on crop age





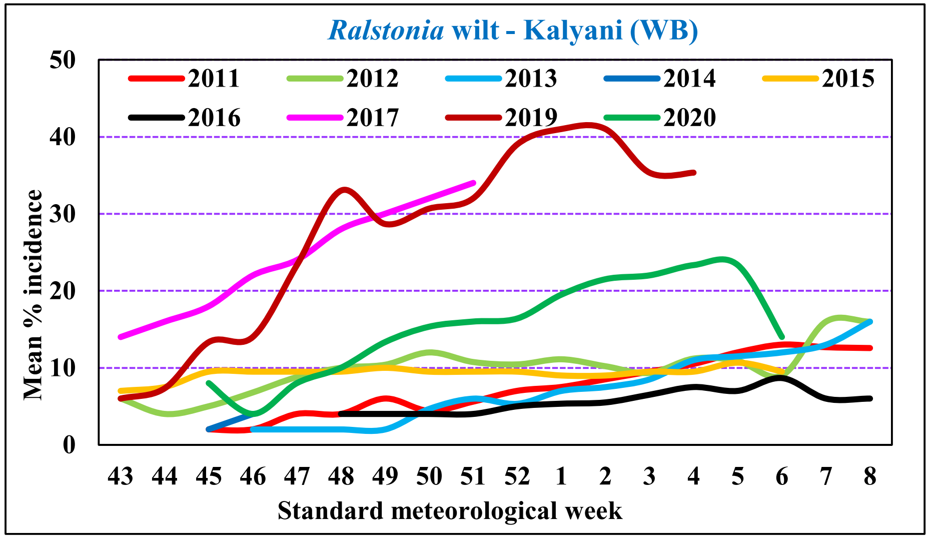


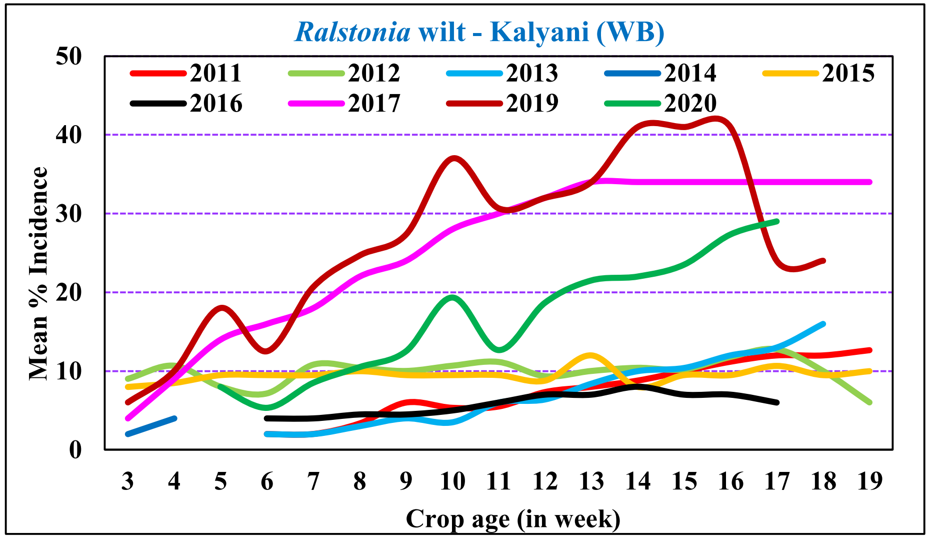


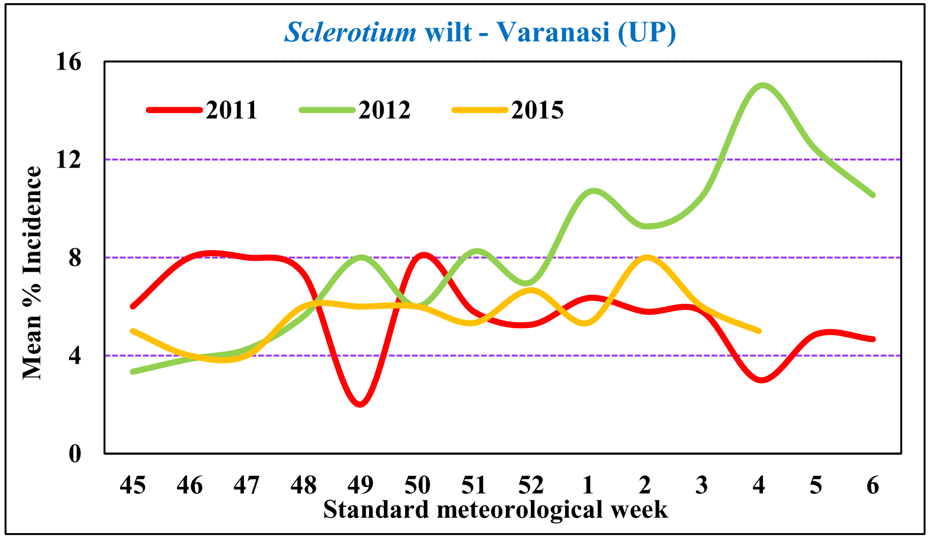
Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

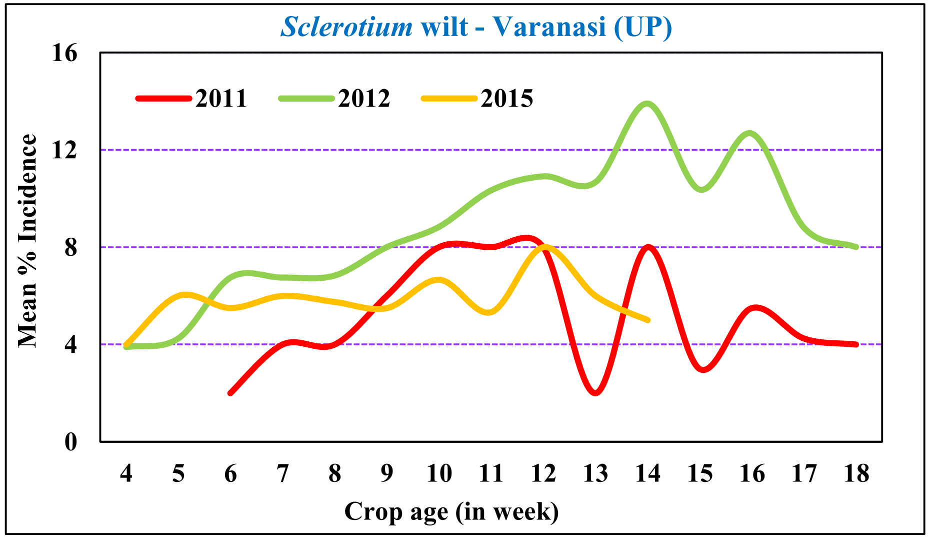
Seasonal dynamics based on standard meteorological weeks

Seasonal dynamics based on crop age



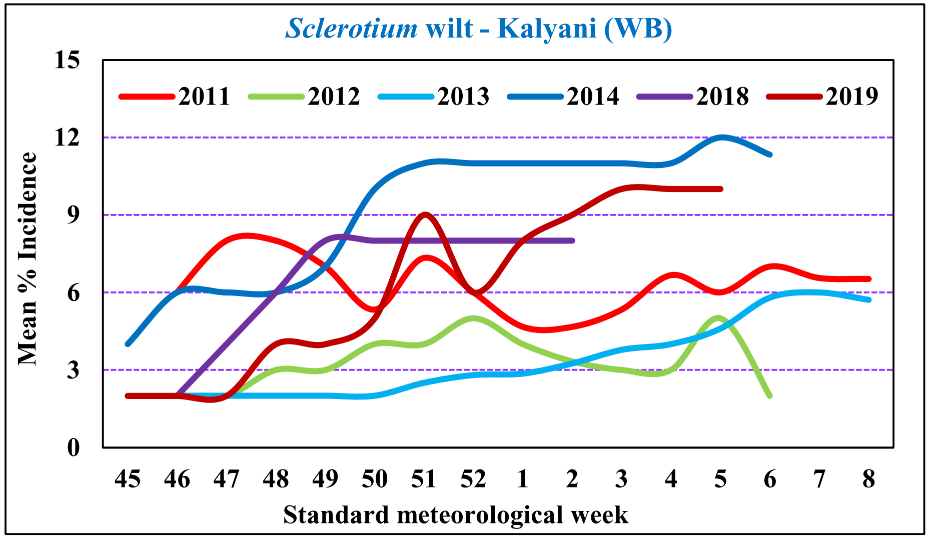




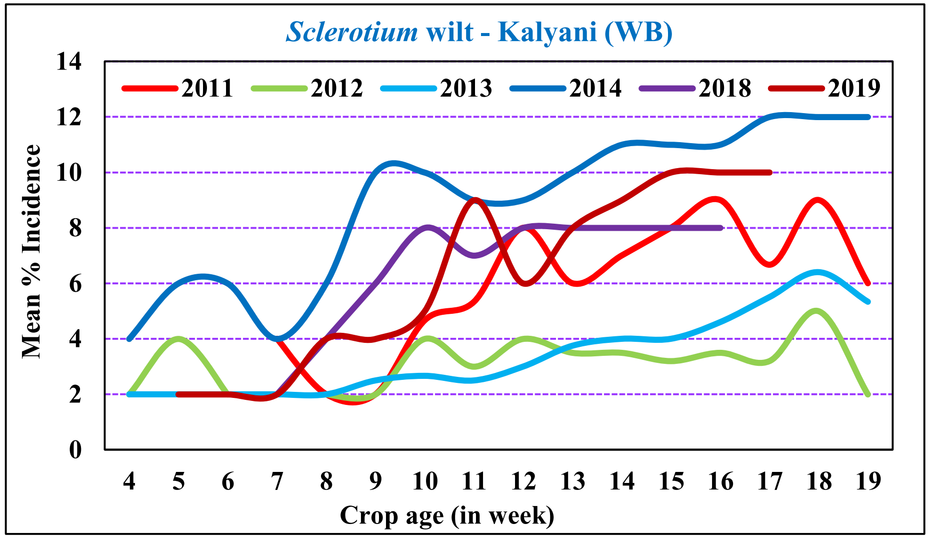


Annexure XXXI: Seasonal dynamics of insect pests and diseases of *rabi* tomato [Arranged for study locations under each insect/disease]

Seasonal dynamics based on standard meteorological weeks



Seasonal dynamics based on crop age



Note: Many legends and less lines shown in a graph denotes abundance/infestation (insects)/incidence/severity (diseases) very less or in traces, respectively

Annexure XXXII

Impact of climate change on *kharif* and *rabi* tomato insects and diseases - a listing

Location	*Kharif*		*Rabi*	
	Adaptive	Vulnerable	Adaptive	Vulnerable
Bengaluru (KA)	1. Early blight- severity 2. Whiteflies 3. Powdery mildew* 4. Spiders 5. Mites*	1. Bacterial spot - severity 2. Tomato leaf curl 3. Aphids* 4. Leaf miner*	1. *Spodoptera litura* 2. *Septoria* leaf spot* 3. Late blight – severity* 4. Leaf miner* 5. *H. armigera* - larval population* 6. Mites*	1. Whiteflies 2. Aphids 3. Spiders* 4. *H. armigera* -fruit damage 5. Tomato leaf curl 6. Early blight – severity*
Rajendranagar (TS)	1. Mites 2. Whiteflies* 3. Early blight - severity 4. Spiders 5. Aphids	1. *H. armigera* – larval population 2. Bud blight* 3. Bacterial canker – incidence*	1. Bacterial canker - incidence 2. *H. armigera* –larval population* & fruit damage* 3. Bacterial spot – incidence* 4. Tomato mosaic*	1. Whiteflies* 2. Bacterial spot severity 3. Bud blight* 4. *S. litura* – larval population 5. Leaf miner* 6. Thrips 7. Aphids* 8. Mites* 9. Spiders* 10. Early blight severity* 11. Tomato leaf curl
Rahuri (MH)	1. Mites 2. *H. armigera* - fruit damage	1. *H. armigera* – larval population 2. Spiders 3. Coccinellids 4. Tomato mosaic 5. Tomato leaf curl* 6. Whiteflies* 7. Aphids* 8. Thrips* 9. Early blight – severity* 10. Leaf miner* 11. Bacterial canker – severity* 12. Bacterial spot - severity* 13. Cucumo virus* 14. Powdery mildew*	1. Bacterial canker – severity* 2. Mites* 3. Coccinellids 4. *S. litura*	1. Tomato mosaic* 2. Powdery mildew* 3. Spiders 4. Tomato leaf curl* 5. Cucumo virus* 6. Aphids 7. Thrips 8. Leaf miner 9. Bacterial spot – severity* 10. Whiteflies 11. *H. armigera* – larval population* & fruit damage* 12. Early blight - severity*

Impact of climate change on *kharif* and *rabi* tomato insects and diseases - a listing

Location	*Kharif*		*Rabi*	
	Adaptive	**Vulnerable**	**Adaptive**	**Vulnerable**
Raipur (CG)	1. Aphids* 2. Leaf miner 3. Early blight - severity 4. Bacterial spot - severity 5. *Septoria* leaf spot 6. Tomato leaf curl 7. Mites 8. Spiders 9. Sun Scald 10. Late blight severity	1. *H. armigera*- larval population 2. Bud blight 3. Tomato mosaic 4. Bacterial canker- severity 5. Whiteflies 6. *H. armigera* - fruit damage 7. Bacterial spot- incidence 8. Bacterial canker – incidence* 9. *Ralstonia* wilt*	1. Spiders 2. Tomato mosaic	1. *Septoria* leaf spot 2. Whiteflies 3. Tomato leaf curl 4. Early blight - severity 5. *S. litura* – larval population 6. *H. armigera* – larval population & fruit damage 7. Leaf miner* 8. Bud blight 9. Aphids 10. Powdery mildew* 11. Late blight – incidence*
Varanasi (UP)	1. *Fusarium* wilt* 2. Whiteflies* 3. Leaf miner 4. Mealybug 5. Aphids* 6. Spiders	1. *S. litura* 2. Early blight – severity* 3. Thrips* 4. *H. armigera* - fruit damage 5. *Ralstonia* wilt 6. Bacterial spot – severity* 7. Late blight –severity* 8. Tomato mosaic* 9. Tomato leaf curl 10. *Sclerotium* wilt 11. *Septoria* leaf spot	1. *S. litura* – larval population 2. Late blight - severity* & incidence 3. *Ralstonia* wilt 4. Aphids* 5. *Septoria* leaf spot*	1. Spiders* 2. Tomato mosaic* 3. *H. armigera* –fruit damage * & larval population 4. *Sclerotium* wilt 5. Thrips* 6. Leaf miner* 7. Tomato leaf curl* 8. Whiteflies* 9. Early blight – severity* 10. Bacterial spot – severity*
Ludhiana (PB)	1. Aphids 2. Late blight – incidence & severity 3. *H. armigera* - fruit damage	1. Whiteflies 2. Leaf miner 3. Early blight - incidence	-	-
Kalyani (WB)	-	-	1. Thrips* 2. Mites* 3. Aphids* 4. Whiteflies* 5. Tomato leaf curl* 6. Leaf miner* 7. Coccinellids 8. Mealybug - severity 9. *Ralstonia* wilt 10. Early blight - severity 11. Tomato mosaic	1. *Sclerotium* wilt 2. Spiders* 3. *H. armigera* – larval population* & fruit damage* 4. *S. litura* – larval population*

Insects and diseases have been listed along the order of importance under each column in respect of locations to understand the cumulative impact of climate change based on species adaptation index values. The unit of pest reporting is standard as in SAI tables (Tables 89-91) and specific mention has been made wherever the reporting units have been double for a single insect/disease in a given location or the units differed between locations for a given insect/disease; Symbol * on insects and diseases indicates the significance of the relation between population dynamics/disease progression and magnitude of the climate change at least with one or two or all three climatic variables MaxT, MinT and/or RF irrespective of the significance or non-significance of magnitude of change in respect of climatic variable *per se*

Azadi Ka Amrit Mahotsav

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