Received: 22 November 2019 | Accepted: 4 February 2020 | Published online: 8 April 2020

DOI: 10.1002/agj2.20170

Agronomy Journal

ARTICLE

Pest Interactions in Agronomic Systems

Comprehensive preventive measures for leaf curl and fruit borer management in tomato

Rakesh Pandey[1] | **A. K. Chaturvedi**[2]

[1]Department of Entomology, Banda University of Agriculture & Technology, Banda, India

[2]Krishi Vigyan Kendra, Bhadohi, ICAR-Indian Institute of Vegetable Research, Varanasi, India

Correspondence
Rakesh Pandey, Department of Entomology, Banda University of Agriculture & Technology, Banda, India.
Email: pandeyent@gmail.com

Abstract

Tomato (*Solanum lycopersicum* L.) is one of the most important Solanaceous and remunerative vegetable crops. However, despite its value in fresh and processing markets, many farmers are concerned about pest resistance. Therefore, looking to the seriousness of pest menace particularly leaf curl and fruit borer, research is needed to reduce the chemical pressure and establish an ecological equilibrium in tomato fields. A combination of bio-intensive pest management (BIPM) and chemo-intensive pest management (CIPM) were followed trap crop marigold (*Tagetes erecta* L.) and yellow sticky traps to manage these pests during 2016–2017 and 2017–2018. The percent plant infestation with leaf curl (0.6–0.9) and fruit infestation with fruit borer (5.2–6.7) were observed in BIPM and CIPM. In these fields, the application of insecticides increased yields 30–38.3%. There was 47.1–56.8% higher net return in BIPM and 59.5–68.9% higher in CIPM than farmers' practices. Similarly, benefit cost ratio was analyzed 2.5:3.6 in BIPM and 2.5:3.7 in CIPM.

1 | INTRODUCTION

Tomato is one of the most economically important Solanaceous vegetable crops in the world. India is ranked second in tomato production area followed by China. In India, tomato crop covers a total area 0.79 million ha with a production of 19.76 million tons (DAC&FW, 2018). There are several biotic and abiotic factors associated to low productivity in tomato, but leaf curl and fruit borer are the two serious biotic threats in limiting the cultivation of tomato.

Tomato Leaf Curl Virus (TLCV) is a viral disease caused by whitefly, *Bemesia tabaci* (Gennadius) (Hemiptera: Aleyrodidae), that can reduce both the fruit quality and yield (Bandte, Pestemer, Büttner, & Ulrichs, 2009). Muniyappa et al. (2000) reported that summer-planted tomato yielded less (6.4–52.2%) than winter-planted tomato (52.5–100%). Butter and Rataul (1981) and Kalloo (1996) observed the leaf curl disease incidence, severity, and losses (17.6–99.7%). Sastry and Singh (1973) reported 92.3% losses when infection occurred at 30 d after transplanting. They also observed the yield reductions 94.9, 90.0, 78.0, and 10.8% when infection of TLCV occurred at 2, 4, 6, and 10 wk after planting, respectively. The estimated losses caused by *B. tabaci* transmitted geminiviruses reach about 20% of tomato production in the United States, but 30–100% damage was reported from the Dominican Republic, Cuba, Mexico, Guatemala, Honduras, Nicaragua, Costa Rica, Venezuela, and Brazil (Antignus, 2007).Tomato leaf curl disease was first time observed in Middle East during 1930–1950 and now it is distributed worldwide (Lefeuvre et al., 2010). In India, tomato leaf curl disease was first reported by Vasudeva in 1948 from Northern India and Sam Raj in 1950 from Central India. This malady is due to a complex of virus groups transmitted through *B. tabaci*. This complex of viruses found in the regions of India, Pakistan, and Australia is known as TLCV and in the regions of Israel and Europe is known as TYLCV (Tomato

Abbreviations: BIPM, bio-intensive pest management; CD, critical difference; CIPM, chemo-intensive pest management; FP, farmer's practice; TLCV, Tomato Leaf Curl Virus.

Yellow Leaf Curl Virus; Pandey, Choudhury, & Mukherjee, 2009). The TLCV infected plants show symptoms of stunted growth, wrinkling of leaves, pale yellowing to deep yellowing of leaves, yellowing of veins, leaf margins curl upward giving cup-shaped appearance, and flower drop before fruit set (Melzer et al., 2009). The virus can cause infection at any stage of growth and development of plants. The global distribution of tomato crop and the outbreak vector, whitefly, led to the severe spread of this devastating disease. Tomato leaf curl virus and some other viruses of the genus Begomovirus (Xie et al., 2013) have become a major threat in cultivation of tomato worldwide. The Begomovirus is a circular, single-stranded DNA virus which is exclusively being transmitted by whitefly in a persistent circulative manner (Rubinstein & Czosnek, 1997).

Besides leaf curl disease, a wide number of insect pests play a significant role in limiting the production and productivity of tomato. Among these insect pests, the tomato fruit borer *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) is the most destructive insect pest worldwide. *H. armigera* is polyphagous insect pest and mostly occurs year-round due to its wide range of hosts. It is one of the nastiest insect pests in agriculture, accounting for the consumption of over 55% of the total insecticides used in India (Puri, 1995), and causes yield losses ranging from 20 to 60% (Dhandapani, Umeshchandra, & Murugan, 2003; Gadhiya, Barad, & Bhut, 2014; Meena & Raju, 2014; Selvanarayanan & Narayanasamy, 2006). Early instar larvae feed on foliage and flower buds and mature instars bore in to the fruits (Rath & Nath, 1997), impair the quality of fruit (Reddy & Zehr, 2004; Singh & Chahal, 1978; Tewari & Moorthy, 1984), and make them unfit for human consumption. At present, looking to the economic significance of tomato cultivation, farmers used to apply the synthetic chemicals in injudiciously to manage the insect pests and diseases (Babar, Hasnain, Aslam, Ali, & Ahmad, 2016). Due to continuous occurrence of *H. armigera* on different host plants, tomato receives too much insecticide pressure throughout the year (Shaheen, 2008).

As *B. tabaci* and *H. armigera* are difficult to manage, it is very important to combat these maladies through different approaches. Prevention is the one of the best management strategies to check further spread of viral plant diseases. However, chemicals play a significant role in minimizing the population of viral vectors, which ultimately decreases the incidence of disease (Castle, Palumbo, & Prabhaker, 2009). Due to the seriousness of leaf curl disease and tomato fruit borer and the ill-effects of synthetic chemicals, it is imperative to study the management of these menaces through bio- and chemo-intensive pest management approaches.

2 | MATERIALS AND METHODS

2.1 | Location of the study

The study was conducted in 0.125 ha area located in Bhadohi (82°56′ east longitude and 25°40′ north latitude). The study area falls under humid subtropical climatic zones of India as per Köpen classification. The climate was hot and humid in summer and cold and dry in winter with an intervening rainy season. The temperature in the area ranged between 5 and 46 °C and an annual rainfall of 1,563 mm was reported (Singh, Singh, Singh, & Singh, 2008). However, the average observed rainfall was 700–750 mm during the growing season. The maximum and minimum temperatures were 38–40 and 5–6 °C, respectively, however, the maximum and minimum relative humidity was 80–85 and 60–65%, respectively, during growing season. The soil texture of the study area was sandy loam and loam. The organic matter of the soil ranged from 0.74 to 1.39%. The concentration of nutrients was extracted with the help of a Pusa Soil Test and Fertilizer Recommendation Kit (PUSA STFR Meter Kit, Indian Agricultural Research Institute, New Delhi, India). The available nitrogen (N), phosphorous (P), and potassium (K) varied from 217.15 to 560.00, 116.4 to 167.4, and 426.4 to 446.4 kg ha^{-1}, respectively. The concentrations of sulfur, zinc, iron, magnesium, and boron were between 51.71 and 56.99 kg ha^{-1}, 11.70 and 14.60 ppm, 26.50 and 37.10 ppm, 17.45 and 19.27 ppm, and 0.001and 0.175 ppm, respectively.

2.2 | Details of technologies assessed against leaf curl disease and fruit borer

In the study region, most farmers used commercially available insecticides to control insect problems. To reduce the risk of resistance and the amount of insecticides applied, we evaluated two management strategies, bio-intensive pest management (BIPM) and chemo-intensive pest management (CIPM) derived by ICAR-Indian Institute of Vegetable Research (Pandey, Pandey, & Chandra, 2003).

Only commercially available chemicals such as Sonata [Profenophos], Ustaad [Cypermethrin], and Imidagold [Imidacloprid] were used under FP. The BIPM included planting of 40-d-old seedling of marigold (*T. erecta*) around the field, installation of yellow sticky trap at 15 per ha, removal and destruction of infested plant or fruit, application of neem oil at 3 ml L^{-1}, and *Bacillus thuringiensis* at 2 ml L^{-1} in alternate manner. However, CIPM consisted of planting of 40-d-old seedling of marigold around the field, installation of yellow sticky trap at 15 per ha, removal and destruction of infested plant or fruit, application of chlorantraniliprole 18.5 SC at

0.35 ml L^{-1}, and flubendiamide 20 WG at 0.25 g L^{-1} in alternate manner.

2.3 | Field trials

The improved variety of tomato, Kashi Aman, was grown in the field to test the effectiveness of different treatments. The seed rate of tomato was used at 400 g ha^{-1} for raising the nursery during the first week of July 2016 and 2017. Seedlings 30–35 d old were transplanted in the second week of August 2016 and 2017 with a distance between rows and plant of 60 by 45 cm. The farmyard manure was applied in the field at 10 Mg ha^{-1} during field preparation and N, P, and potash fertilizers were applied at 120:80:60 kg ha^{-1}, respectively. The seedbed was regularly irrigated with a watering can to ensure proper growth and development of the seedlings. The weeds were removed mechanically twice at 30 and 60 d after transplanting with a small spade. All the agronomic practices were similar for the three assessed treatments. The early infested leaf curl plants (2–3% of total transplanted plants) were uprooted by hand to avoid spread of the disease. Backpack sprayers were used for insecticide application.

Field trials were conducted in two successive cropping seasons (2016–2017 and 2017–2018) at farmers' fields. The field trials were carried out in a randomized complete block design with five replications. The unit plot size was 12 by 7 m for each regime where the seedlings were transplanted.

2.4 | Data collection

The yellow sticky traps were installed 20 d after transplanting (in the month of Sept. 2016 and 2017 during vegetative stage). The traps were replaced 60 d after each installation.

Ten plants were randomly selected (after uprooting early infested plants) from each plot and tagged for the periodical observations on yield. Starting with the first picking or harvesting, fruits were weighed separately from each plot at each harvest. The infested plants were marked based on typical symptoms of the disease. The percent plant infestation was assessed by recording the number of plants showing disease symptoms and the total number of plants examined at each location throughout the cropping period by using the following formula:

$$\text{Percent plant/fruit infested} = \frac{\text{Number of infested plants/fruits}}{\text{Total number of plants/fruits}} \times 100$$

The percent plant infestation was recorded separately per plot. Similarly, percent fruits infested with fruit borer were assessed by recording the number of fruits showing bore hole and the total number of fruits examined from each plot. The plot yield of each harvesting was also recorded separately, and total yield was calculated in tons ha^{-1}. The economic parameters (cost of cultivation, gross return, net return, and benefit/cost ratio) were also assessed. To justify the economic viability of the appropriate management strategy against leaf curl disease and fruit borer, the benefit/cost ratio was calculated from the marketable yield, regarding cost of treatments incurred in the management. The market price of tomato fruits, rate of insecticides, and labor cost were undertaken as approved by the Indian government to compute the B/C ratio by using following formula (Baral et al., 2006):

$$\text{BC ratio} = \frac{\text{Value of yield over control (USD \$ Mg}^{-1})}{\text{Total cost of production(USD \$ ha}^{-1})}$$

The cost of production consisted of costs for seed, nursery raising, field preparation, transplanting, fertilizer application, irrigation, weeding and harvesting, costs for insecticides, spraying, trap, installation of yellow sticky traps, and uprooting of infested plants. The Indian rupees (INR) were converted to US dollar with the conversion rate of US $1 = 67.75 INR.

To compute the total return, the value of fruits obtained in each treatment was calculated separately as per the market rate. The market price of tomato was $440,375 Mg^{-1} (2016–2017) and $542,000 Mg^{-1} (2017–2018; Agarwal & Banerjee, 2019; Kumar, Chauhan, & Grover, 2016; Tambe, Hile, & Patare, 2018). Net return was also calculated by subtracting the total cost from total return.

2.5 | Statistical analysis

The data collected from the experiments were subjected to analysis of variance (ANOVA) for different treatments. The data on percent plant infestation and percent fruit infestation were transformed as $\sqrt{(x + 0.5)}$ and subjected to ANOVA for different tests. Fisher's protected critical difference (CD) test was used to indicate the difference between the treatments at the probability level of $p < .05$ in fixed effect model following the procedure described by Gomez and Gomez (1984).

3 | RESULTS

The percent plant infestation with leaf curl was the lowest (0.6) in CIPM, however, 0.9% of plants were infested in BIPM and 23.4–28.6% of plants were infested under farmers' practices (FP; Table 1). Similarly, Table 2 represents the percent fruit infestation, and it was the lowest (5.2–6.7) in both regimes that is, BIPM and CIPM during 2016–2017 and 2017–2018. The data revealed that the percent fruits infestation was statistically at par in BIPM and CIPM and

TABLE 1 Percent plants infested with leaf curl disease in tomato

	Percent plant infestation	
Technology assessed	2016–2017	2017–2018
FP[a]	23.4a[b]	28.6a
	(8.5)[c]	(9.4)
BIPM	0.9b	0.9b
	(1.73)	(1.73)
CIPM	0.6b	0.6b
	(1.46)	(1.51)
LSD (CD, $P = .05$)	0.75	0.85
SE	±0.32	±0.37

[a]FP, farmer's practice; BIPM, bio-intensive pest management; CIPM, chemo-intensive pest management; LSD, least significant difference; CD, critical difference; SE, standard error.
[b]Means within each row of each section followed by the same letter are not significantly differences ($p \leq .05$).
[c]Figures in parentheses are transformed values.

TABLE 2 Percent fruits infested with fruit borer in tomato

	Percent fruit infestation	
Technology assessed	2016–2017	2017–2018
FP[a]	26.7a[b]	25.7a
	(3.4)[c]	(3.3)
BIPM	6.7b	5.2b
	(1.7)	(1.5)
CIPM	6.7b	5.2b
	(1.7)	(1.6)
LSD (CD) ($P = .05$)	0.97	1.06
SE	±0.42	±0.46

[a]FP, farmer's practice; BIPM, bio-intensive pest management; CIPM, chemo-intensive pest management; LSD, least significant difference; CD, critical difference; SE, standard error.
[b]Means within each row of each section followed by the same letter are not significantly differences ($p \leq .05$).
[c]Figures in parentheses are transformed values.

significantly different than FP. However, 25.7–26.7% of fruits were infested in FP.

The highest yield (32.9 Mg ha^{-1}) was recorded in CIPM followed by BIPM (30.9 Mg ha^{-1}) and FP (25.3 Mg ha^{-1}) during 2016–2017. The CIPM and BIPM had similar yields between them and were and greater than FP (Table 3). The BIPM and CIPM treatments were statistically at par in yield data but significantly different from FP. During 2017–2018, the highest yield (39.3 Mg ha^{-1}) was observed in CIPM followed by BIPM (37.0 Mg ha-1) and FP (27.2 Mg ha^{-1}). All three treatments were statistically different from each other. Overall economic assessment for the tested treatments showed that both years followed similar trend (Table 4). The frequency of application of insecticides was 5–6 in FP, however, only three sprays were required to manage the leaf curl

TABLE 3 Total fruit yield of tomato at final harvest

	Yield Mg ha^{-1}	
Technology assessed	2016–2017	2017–2018
FP[a]	25.3b[b]	27.2c
BIPM	30.9a	37.0b
CIPM	32.9a	39.3a
LSD (CD) ($P = .05$)	2.14	0.77
SE	±0.93	±0.33

[a]FP, farmer's practice; BIPM, bio-intensive pest management; CIPM, chemo-intensive pest management; LSD, least significant difference; CD, critical difference; SE, standard error.
[b]Means within each row of each section followed by the same letter are not significantly differences ($p \leq .05$).

and fruit borer both in BIPM and CIPM. The highest net return in 2016–2017 was $8,766,172.5 ha^{-1} (CIPM), followed by $8,089,011.3 ha^{-1} (BIPM) and $5,497,573.75 ha^{-1} (FP), and $15,557,432.5 ha^{-1}, $14,441,590 ha^{-1}, and $9,209,257.5 ha^{-1} for CIPM, BIPM, and FP in 2017–2018, respectively. The benefit/cost ratio was observed to be higher in CIPM (2.52) followed by BIPM (2.46) and FP (1.97) during 2016–2017 and CIPM (3.69), BIPM (3.55), and FP (2.66) during 2017–2018. The highest additional income over FP (the difference of net return between CIPM and FP) was $3,268,598.7 ha^{-1} and $63,481,75 ha^{-1} during 2016–2017 and 2017–2018, respectively.

4 | DISCUSSION

The leaf curl disease and fruit borer in tomato are gaining serious attention because of severe yield losses. Insecticide resistance is also a problem for these insects. The injudicious use of fertilizers and pesticides along with climatic variability during the cropping period regulate the intensity of insect pests and ensures the persistence of insect pests throughout the year. Therefore, it is really hard to manage these challenging insect pests. A study has been conducted in a comprehensive manner to avoid these problems in tomato cultivation. There isn't sufficient literature pertaining to BIPM and CIPM regarding tomato, however, the results have been discussed here with help of the available literature.

Tomato leaf curl disease is caused by the begomoviruses (Xie et al., 2013) and it constitutes the largest group of plant viruses that ravages the crops by causing various diseases. The begomoviruses have a wide host range and affects many dicotyledonous plants belonging to several families. There are certain ways to check the spread of leaf curl diseases. Foliar sprays of neem and its products can kill the eggs, nymphs, and adults of whitefly. Neem oil and other plant extracts gave satisfactory results in controlling leaf curl disease (Khan et al., 2013). A number of insecticides are also used by various

TABLE 4 Overall economic assessment for per hectare area

Year	Benefit/cost assessments	FP[a]	BIPM	CIPM
2016–2017	Number of sprayings	5	3	3
	Cost of production, 1,000 × US$	5,657.13	5,531.79	5,748.59
	Total Return, 1,000 × US$[b]	11,154.70	13,620.80	14,514.76
	Net Return, 1,000 × US$	5,497.57	8,089.01	8,766.17
	Benefit/Cost ratio	1.97	2.46	2.52
2017–2018	Number of sprayings	6	3	3
	Cost of production, 1,000 × US$	5,565.66	5,650.35	5,775.69
	Total Return, 1,000 × US$[b]	14,774.92	20,091.94	21,333.12
	Net Return, 1,000 × US$	9,209.26	14,441.59	15,557.43
	Benefit/Cost ratio	2.66	3.55	3.69

[a]FP, farmer's practice; BIPM, bio-intensive pest management; CIPM, chemo-intensive pest management.
[b]Market price of tomato at US \$440,375 Mg^{-1} during 2016–2017 & US \$542,000 Mg^{-1} during 2017–2018.

workers to minimize the population of whiteflies and other insect pests (Asit, Praveen, Subrata, & Arup, 2017; Bacci et al., 2007). The spread of TLCV can be partially controlled by reducing the vector population through insecticide sprays (Cohen, Melamed-Madjar, & Hameiri, 1974; Sharaf, 1986; Zeshan, Khan, Ali, & Arshad, 2015). In addition to sprays, yellow sticky traps are very good tools to attract the whiteflies. This attribute is used in monitoring and controlling the insect pests. Installation of yellow sticky traps from the vegetative stage managed very well in field trials by showing the least leaf curl infested plants in the present study. This observation is supported by Srinivasan (2010). These traps not only controlled whiteflies but also other insect pests, even adults of *H. armigera*, by incidentally sticking to the gummy surface of traps during their field movements. Thus, the yellow sticky traps may help in lowering the overall insect pest fauna in field conditions.

However, there are several ways to monitor and control the *H. armigera* population. *H. armigera* has been effectively controlled by chemicals such as chlorantraniliprole and flubendiamide. The present finding is in partial accordance with that of Gadhiya et al. (2014) who reported chlorantraniliprole as effective insecticide against *H. armigera* in groundnut (*Arachis hypogaea* L.). In addition to chemical control, other strategies were also applied, for example, marigold (*T. erecta*) as trap crop to combat the fruit borer problem. Trap crop provides the protection by preventing the insect pests from reaching the main crop and the insect pests are diverted away from the main crop or concentrated in certain patches where they are easily controlled. Trap crops are more attractive to the insect pests and has an added advantage to attract the natural enemies fauna (Päts, Ekbom, & Shovgård, 1997). The present study also received attention in regulating the population of *H. armigera* as reported by Srinivasan, Moorthy, and Raviprasad (1994). Continuous presence of tight bud stage since the incidence of *H. armigera* facilitates feeding for tomato fruit borer throughout cropping season and reduces the tendency of larvae of *H. armigera* to migrate to tomato crop. These findings draw their support from previous works of Srinivasan and Moorthy (1991), Srinivasan et al. (1994), Virk, Brar, and Sohi (2004), and Hussain and Bilal (2007). Among the several potent microbials, *B. thuringiensis* has been reported as promising potential against lepidopterous larvae (Bravo, Gill, & Soberón, 2005; Burges, 1981; Glare & O'Callaghan, 2000; Schnepf et al., 1998). The percent fruit borer infestation is almost same in BIPM and CIPM. The present finding is also in the same line as of Mehta, Vaidya, and Kashyap (2000); Rahman, Haque, Alam, Mahmudunnabi, and Dutta (2014); Ram and Singh (2011); and Ravi, Santharam, and Sathiah (2008), who reported that *Bacillus thuringiensis* was effective against *H. armigera*. Dhaka, Singh, Ali, Yadav, and Yadav (2010) and Ram and Singh (2011) reported lower yield with the treatment of *B. thuringiensis* than with chemical insecticides. However, *B. thuringiensis* treated plots yield higher than FP. This study is also matched with the study of Chandrakar, Ganguli, Kaushik, and Dubey (1999) and Rahman et al. (2014).

The overall performance of BIPM and CIPM was judged based on economic parameters. However, the cost of production was higher in BIPM and CIPM than FP because the cost of seedlings of marigold and yellow sticky traps were added in addition to the other components. However, the reduced frequency of application of insecticides curtailed the cost of protection, reduced chemical pressure, and helped maintain the ecological equilibrium in field conditions. Sreekanth, Lakshmi, and Rao (2014) reported that the highest benefit/cost ratio was obtained in chlorantraniliprole-treated plots in comparison with other chemical insecticides. This statement also confirms the present finding that CIPM received a higher benefit/cost ratio. The present study is also corroborated with the reports of Agarwal & Banerjee, 2019; Kumar and Mahla (2016); Kumar et al., 2016; Singh, Dotasara, Kherwa, and Singh (2017); and Tambe et al., 2018.

Therefore, considering the bio-efficacy of different components, it may be concluded that CIPM should be followed in the areas with maximum leaf curl and fruit borer problems, particularly in winter season crops where the plant infestation reaches more than 80%. Besides, BIPM may also be followed in the areas receiving moderate problems of leaf curl and tomato fruit borer or to the areas explored for organic cultivation.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support and encouragement from Directors, ICAR-Indian Institute of Vegetable Research, Varanasi and ICAR-Agricultural Technology Application Research Institute, Kanpur.

ORCID

Rakesh Pandey https://orcid.org/0000-0001-9035-2816

REFERENCES

Agarwal, P. K., & Banerjee, A. (2019). Economic analysis of tomato cultivation in Kandi Block of West Bengal, India. *Economic Affairs*, *64*(3), 643–647. https://doi.org/10.30954/0424-2513.3.2019.21

Antignus, Y. (2007). The management of Tomato Yellow Leaf Curl Virus in Greenhouses and the Open Field, a Strategy of Manipulation. In H. Czosnek (Ed.), *Tomato Yellow Leaf Curl Virus Disease* (pp. 263–278). Dordrecht: Springer.

Asit, K. M., Praveen, K. M., Subrata, D., & Arup, C. (2017). Effective management of major tomato diseases in the gangetic plains of Eastern India through integrated approach. *Agriculture Research & Technology*, *10*(5).

Babar, T. K., Hasnain, M., Aslam, A., Ali, Q., & Ahmad, K. J. (2016). Comparative bioefficacy of newer insecticides against tomato fruit borer, *Helicoverpa armigera* (Hubner) on tomato crop under field conditions. *Pakistan Entomological*, *38*(2), 115–122.

Bacci, L. A. L., Crespo, T. L., Galvan, E. J., Pereira, M. C., Picanço, G. A., & Chediak, M. (2007). Toxicity of insecticides to the sweet potato whitefly (Hemiptera: Aleyrodidae) and its natural enemies. *Pest Management Science*, *63*(7), 699–706. https://doi.org/10.1002/ps.1393

Bandte, M., Pestemer, W., Büttner, C., & Ulrichs, C. (2009). Ecological aspects of plant viruses in tomato and pathogen risk assessment. *Acta Horticulturae*, *821*, 161–168. https://doi.org/10.17660/ActaHortic.2009.821.17

Baral, K., Roy, B. C., Rahim, K. M. B., Chatterjee, H., Mondal, P., Mondal, D., … Talekar, N. S. (2006). Socio-economic parameters of pesticide use and assessment of impact of an IPM strategy for the control of eggplant fruit and shoot borer in West Bengal, India (AVRDC Technical Bulletin No. 37). Shanhua, Taiwan: AVRDC-The World Vegetable Center.

Bravo, A., Gill, S. S., & Soberón, M. (2005). Bacillus thuringiensis Mechanisms and Use. In L. I. Gilbert, K. Iatrou, & S. S. Gill (Eds.) *Comprehensive Molecular Insect Science* (Vol. 6, pp. 175–206). Amsterdam, the Netherlands: Elsevier. https://doi.org/10.1016/B0-44-451924-6/00081-8

Burges, H. D. & Hussey, N.W. (Eds.) (1971). *Microbial control of insects and mites*. Cambridge, MA: Academic Press.

Butter, N. S., & Rataul, H. S. (1981). Nature and extent of losses in tomatoes due to tomato leaf curl virus (TLCV) transmitted by whitefly, *Bemisia tabaci* Gen. (Hemiptera, Aleyrodidae). *Indian Journal of Ecology*, *8*, 299–300.

Castle, S., Palumbo, J., & Prabhaker, N. (2009). Newer insecticides for plant virus disease management. *Virus Research*, *141*, 131–139. https://doi.org/10.1016/j.virusres.2008.12.006

Chandrakar, G., Ganguli, R. N., Kaushik, U. K., & Dubey, V. K. (1999). Management of tomato fruit borer, *Heliothis armigera* (Hub.) using biopesticides. *Journal of Zoological Systematics and Evolutionary Research*, *10*(2), 105–107.

Cohen, S., Melamed-Madjar, V., & Hameiri, J. (1974). Prevention of the spread of Tomato yellow leaf curl virus transmitted by *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae) in Israel. *Bulletin of Entomological Research*, *64*, 193–197. https://doi.org/10.1017/S0007485300031072

DAC & FW. (2018). *Horticultural Statistics at a Glance 2018*. New Delhi, India: Government of India, Ministry of Agriculture & Farmers' Welfare.

Dhaka, S. S., Singh, G., Ali, N., Yadav, A., & Yadav, A. (2010). Field evaluation of Insecticides and Bio-pesticides against *Helicoverpa armigera* on Tomato. *Annals Plant Protection Sciences*, *18*(1), 13–16.

Dhandapani, N., Umeshchandra, R. S., & Murugan, M. (2003). Bio-Intensive Pest Management (BIPM) in major vegetable crops: An Indian perspective. *Food Agriculture and Environment*, *1*(2), 333–339.

Gadhiya, H. A., Barad, P. K., & Bhut, J. B. (2014). Effectiveness of synthetic insecticides against *Helicoverpa armigera* (Hübner) hardwick and *Spodoptera litura* (Fabricius) infesting groundnut. *The Bioscan*, *9*(1), 23–26.

Glare, T. R., & O'Callaghan, M. (2000). Toxicity to insects. In *Bacillus thuringiensis: Biology, Ecology and Safety* (pp. 350). Chichester, UK: John Wiley and Sons.

Gomez, K. A., & Gomez, A. A. (1984). Single-Factor Experiments. In *Statistical Procedures for Agricultural Research* (2nd ed). New York, NY: John Wiley and Sons.

Hussain, B., & Sheikh, B. (2007). Efficacy of different insecticides on tomato fruit borer *Helicoverpa armigera*. *Journal of Entomology*, *4*(1), 64–67. http://doi.org/10.3923/je.2007.64.67

Kalloo, G. (1996). Leaf curl virus of tomato and chili in India. In *Proceeding of the phase I final workshop of the South Asian Vegetable Research Network* (pp. 229–234). Kathmandu, Nepal: South Asian Vegetable Research Network.

Khan, M. H., Ahmad, N., Rashdi, S., Rauf, I., Ismail, M., & Tofique, M. (2013). Management of sucking complex in bt cotton through the application of different plant products. *Pakistan Journal of Life Science*, *1*(01), 42–48.

Kumar, P., Chauhan, R. S., & Grover, R. K. (2016). Economics analysis & tomato cultivation under polyhouse and open field conditions in Haryana. *Indian Journal of Applied and Natural Science*, *8*(2), 846–848. https://doi.org/10.31018/jans.v8i2.883

Kumar, V., & Mahla, M. K. (2016). Bioecology of tomato fruit borer and its management with biopesticides (Master's thesis). Maharana Pratap University of Agriculture & Technology, Udaipur.

Lefeuvre, P., Martin, D. P., Harkins, G., Lemey, P., Gray, A. J. A., Meredith, S., … Heydarnejad, J. (2010). The Spread of Tomato yellow leaf curl virus from the Middle East to the world. *PLOS Pathogens*, *6*. https://doi.org/10.1371/journal.ppat.1001164

Meena, L. K., & Raju, S. V. S. (2014). Bio-efficacy of newer insecticides against tomato fruit borer, *Helicoverpa armigera* (Hubner) on tomato, *Lycopersicon esculentum* Mill under field conditions. *The Bioscan*, *9*(1), 347–350.

Mehta, P. K., Vaidya, D. N., & Kashyap, N. P. (2000). Management of tomato fruit borer, *Helicoverpa armigera* (Hub.) using insecticide and biopesticide. *Himachal Journal of Agricultural Research*, *26*, 50–53.

Melzer, M. J., Ogata, D. Y., Fukuda, S. K., Shimabuku, R., Borth, W. B., Sether, D. M., & Hu, J. S. (2009). Tomato yellow leaf curl. *Plant Disease*, *70*, 1–2.

Muniyappa, V., Venkatesh, H. M., Ramappa, H. K., Kulkarni, R. S., Zeidan, M., Tarba, C. Y., … Croznek, H. (2000). Tomato leaf curl virus from Bangalore (ToLCV-Ban4): Sequence comparison with Indian ToLCV isolates, detection in plants and insects and vector relationships. *Archives of Virology*, *145*, 1583–1598. https://doi.org/10.1007/s007050070078

Pandey, K. K., Pandey, P. K., & Chandra, S. (2003). IPM in vegetables (Sabjiyo me ekikrit nasheejeev prabandhan Technical Bulletin 11, pp. 13–14). Kelabela, India: Indian Institute of Vegetable Research.

Pandey, P., Choudhury, N. R., & Mukherjee, S. K. (2009). A geminiviral amplicon (VA) derived from tomato leaf curl virus (ToLCV) can replicate in a wide variety of plant species and also acts as a VIGS vector. *Journal of Virology*, *6*, 152. https://doi.org/10.1186/1743-422X-6-152

Päts, P., Ekbom, B., & Shovgård, M. (1997). Influence of intercropping on the abundance, distribution and parasitism of *Chilo* spp. (Lepidoptera: Pyralidae). *Bulletin of Entomological Research*, *87*, 507–513. https://doi.org/10.1017/S0007485300041377

Puri, S. N. (1995). Present status of IPM in India. In *Proceeding of National Seminar on Integrated Pest Management in Agriculture*, (pp. 2003–2004). Maharashtra, India.

Rahman, A. K. M. Z., Haque, M. A., Alam, S. N., Mahmudunnabi, M., & Dutta, N. K. (2014). Efficacy of microbials as insecticides for the management of tomato (*Lycopersicon esculentum*) fruitworm, *Helicoverpa armigera* (Hubner). *The Agriculturists*, *12*(1), 68–74. https://doi.org/10.3329/agric.v12i1.19583

Ram, S., & Singh, S. (2011). Evaluation of botanical, microbial and chemical insecticide on the fruit damage inflected by fruit borer in tomato. *Vegetable Science*, *38*(2), 162–164.

Rath, P. C., & Nath, P. (1997). Screening of some tomato genotypes for susceptibility to the fruit borer, *H. armigera* (Hub.) at Varanasi. *Vegetable Science*, *24*(2), 153–156.

Ravi, M., Santharam, G., & Sathiah, N. (2008). Ecofriendly management of tomato fruit borer, *Helicoverpa armigera* (Hubner). *Journal of Biopesticides*, *1*(2), 134–137.

Reddy, K. V. S., & Zehr, U. B. (2004). Novel Strategies for Overcoming Pests and Diseases in India. In *Proceedings of the 4th International Crop Science Congress on new directions for a diverse planet* (pp. 1–8). Brisbane, Australia: International Crop Science Society.

Rubinstein, G., & Czosnek, H. (1997). Long-term association of tomato yellow leaf curl virus with its whitefly vector *Bemisia tabaci*: Effect on the insect transmission capacity, longevity and fecundity. *Journal of General Virology*, *78*, 2683–2689. https://doi.org/10.1099/0022-1317-78-10-2683

Sastry, K. S. M., & Singh, S. J. (1973). Assessment of losses in tomato by tomato leaf curl virus. *Indian Journal of Mycology and Plant Pathology*, *3*, 50–54.

Schnepf, E., Crickmore, N., Van Rie, J., Lereclus, D., Baum, J., Feitelson, J., … Dean, D. H. (1998). *Bacillus thuringiensis* and its pesticidal crystal proteins. *Microbiology and Molecular Biology Reviews*, *62*, 775–806.

Selvanarayanan, V., & Narayanasamy, P. (2006). Factors of resistance in tomato accessions against the fruitworm, *Helicoverpa armigera* (Hubner). *Crop Protection*, *25*(10), 1075–1079.

Shaheen, N. (2008). Is organic forming suitable solution for Pakistan. *SDPI Research News Bulletin*, *15*, 78–81.

Sharaf, N. (1986). Chemical control of *Bemisia tabaci*. *Agriculture, Ecosystems & Environment*, *17*, 111–127. https://doi.org/10.1016/0167-8809(86)90032-0

Singh, A. K., Singh, L., Singh, A., & Singh, R. K. (Eds.) (2008). District specific technological interventions for eastern region. In *Inventory of Agricultural Technologies for Uttar Pradesh*. Kanpur, India: Indian Council of Agricultural Research.

Singh, D., & Chahal, B. S. (1978). Control of tomato fruit borer (*Heliothis armigera* Hubner) in Punjab, Haryana. *Journal Horticultural Sciences*, *7*, 182–186.

Singh, N., Dotasara, S. K., Kherwa, B., & Singh, S. (2017). Management of tomato fruit borer by incorporating newer and biorational insecticides. *Journal of Entomology and Zoology Studies*, *5*(2), 1403–1408.

Sreekanth, M., Lakshmi, M. S. M., & Rao, Y. K. (2014). Bio-efficacy and economics of certain new insecticides against gram pod borer, *Helicoverpa armigera* (Hubner) infesting pigeonpea (*Cajanus cajan* L.). *International Journal of Plant Animal and Environmental Science*, *4*(1), 11–15.

Srinivasan, K., & Moorthy, P. N. K. (1991). Indian mustard as a trap crop for management of major lepidopterous pests on cabbage. *Tropical Pest Management*, *37*, 26–32.

Srinivasan, K., Moorthy, K. P. N., & Raviprasad, T. N. (1994). African marigold as a trap crop for the management of fruit borer *Helicoverpa armigera* on tomato. *International Journal of Pest Management*, *40*, 56–63. https://doi.org/10.1080/09670879109371532

Srinivasan, R. (2010). *Safer tomato production methods: A field guide for soil fertility and pest management*. Shanhua, Taiwan: AVRDC.

Tambe, P. C., Hile, R. B., & Patare, S. D. (2018). Cost and returns of summer tomato production in Ahmednagar district of Maharashtra. *Journal of Pharmacognosy and Phytochemistry*, *7*(4), 1525–1527.

Tewari, G. C., & Moorthy, P. N. K. (1984). Yield loss in tomato caused by fruit borer. *Indian Journal of Agricultural Sciences*, *54*, 341–343.

Virk, J. S., Brar, K. S., & Sohi, A. S. (2004). Role of trap crops in increasing parasitation efficiency of *Trichogramma chilonis* Ishii in cotton. *Journal of Biological Control*, *18*, 61–64.

Xie, Y., Jiao, X., Zhou, X., Liu, H., Ni, Y., & Wu, J. (2013). Highly sensitive serological methods for detecting tomato yellow leaf curl virus in tomato plants and whiteflies. *Virology Journal*, *10*. https://doi.org/10.1186/1743-422X-10-142

Zeshan, M. A., Khan, M. A., Ali, S., & Arshad, M. (2015). Correlation of conducive environmental conditions for the development of whitefly, *Bemisia tabaci* population in different tomato genotypes. *Pakistan Journal of Zoology*, *47*, 1511–1515.

How to cite this article: Pandey R, Chaturvedi AK. Comprehensive preventive measures for leaf curl and fruit borer management in tomato. *Agronomy Journal*. 2020;112:5125–5131. https://doi.org/10.1002/agj2.20170