

B. Sc (Agriculture)
Optional Course

CRP 451- Physiological Techniques in crop production (1+1)

Lecture. No. 1.

Classification of abiotic stresses - Drought – types-Drought resistance and tolerance mechanisms- adaptations-Physiological traits associated with drought -osmotic adjustment

Stress refers to a condition that diverges from the normal range that a given plant encounters to such an extent as to prevent the plant from expressing fully its genetic potential for growth, development and reproduction.

Stress, is a highly subjective phenomenon defined as a state of threatened homeostasis. Depending on their nature, external stresses are usually divided into biotic (i.e. herbivorous insects and pathogens such as fungi, bacteria and viruses) or abiotic (i.e. including, among others, high or low temperature, submergence or drought and salinity).

During their lifetime, all living organisms inevitably and constantly face all sorts of environmental stresses that often occur suddenly and/or simultaneously. Classically, different strategies can be applied to minimize deleterious effects of stresses, such as resistance, tolerance, avoidance or escape. Being sessile, plants cannot escape and are therefore more prone to the deleterious effect of unfavorable environmental growth conditions. Because responses are critical to ensure their survival, plants have developed specific and efficient strategies that allow them to precisely perceive different environmental stresses and respond and/or adapt to them.

Drought is classified into three major categories (Dai, 2011):

- (i) agricultural drought;
- (ii) meteorological drought; and
- (iii) hydrological drought.

Meteorological drought is a period with less than average precipitation, associated often with above-normal temperatures, which precedes and causes other types of drought. Meteorological drought is caused by constant changes in large-scale atmospheric circulation patterns such as high pressure.

Agricultural drought is a period with below average precipitation, less frequent rain events, or above-normal evaporation, resulting in reduced crop production and plant growth.

Hydrological drought occurs when there is a reduced supply of water or water levels from river streams and other water storage structures such as aquifers, lakes, or reservoirs fall below long-term mean levels.

A lack of rainfall triggers agricultural and hydrological droughts; but other factors, including high temperature, poor irrigation management, and external factors such as overgrazing and erosion also cause drought.

Drought resistance

Resistance: The ability of the plant to live, grow, and yield satisfactorily with limited water supply or under periodic water deficits

Escape: Ability of a plant to mature before water stress becomes a serious limiting factor

Avoidance: Ability of a plant to maintain high water status during drought (able to exclude stress)

Tolerance: Ability of a plant to withstand water stress of low water potential (without suffering injury posses repair mechanism)

Drought Resistance Mechanisms

Understanding the concept and components of drought resistance is a key factor for improving drought tolerance of crops. Drought resistance mechanisms have been extensively reviewed and summarized from crop physiology, plant breeding and molecular perspectives for different crops

Drought resistance can be classified broadly into three categories (Taiz and Zeiger, 2002):

- (i) desiccation postponement (the ability to maintain tissue hydration or drought tolerance at high water potential);
- (ii) desiccation tolerance (the ability to function while dehydrated or drought tolerance at low water potential); and
- (iii) drought escape, where the plants avoid drought by completing life cycles before the onset of dry periods to sustain some reproduction.

These drought resistance mechanisms vary with the geographical area based on soil and climatic conditions. For example, tolerance to extreme drought conditions (air <0% relative humidity (RH)), is achieved by limiting their metabolic functions. Whereas most of the cultivated plants cannot withstand a water deficit less than 85% RH during vegetative period, these plants adapt to drought by either dehydration avoidance or dehydration tolerance to maintain biological functions.

Dehydration avoidance (plant's capacity to sustain high water status by water uptake or a reduction of water loss in dry conditions) is achieved through the development of a large and deep root system to acquire water from the soil as well as through the closure of stomata or a non-permeable leaf cuticle to reduce transpiration.

Physiological traits, such as osmotic adjustment, contents of ABA, chlorophyll, proline and soluble sugars, and toxic removal mechanisms such as peroxidase or superoxide dismutase activity etc., contribute to dehydration tolerance.

Adaptation to drought

Drought resistance

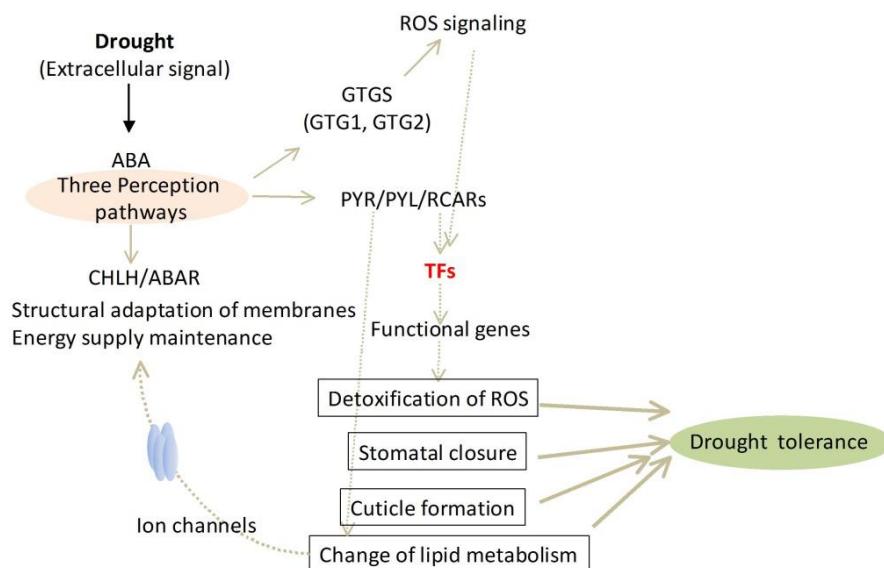
Drought resistance is defined as “the capacity of plants to survive during the period of drought with little or no injury”.

There are three important categories of plants growing in the areas facing drought.

1. Ephemerals

2. Succulents

3. Non-succulent perennials



A schematic model of the signal chain from drought stress perception to physiological responses and drought tolerance

1. Ephemerals

These are short lived plants and they complete their life cycle within a short favourable period during rainy season. They pass dry periods in the form of seeds. They are called as drought escaping plants.

2. Succulent plants

Accumulated large quantities of water and use it slowly during dry period. Thus they pass dry periods on drought without facing it. Such plants develop several morphological adaptations for reducing transpiration such as thick cuticle, reduced leaf area, sunken stomata, etc.

3. Non succulent plants

These are in fact real drought enduring (tolerant) plants. They tolerate drought without adapting any mechanism to ensure continuous supply of water. They develop many morphological adaptations which are collectively called xeromorphy. They develop, in general, grayish colour, reflecting surfaces, smaller leaves, extensive root system, leaf fall during dry season sunken stomata and thick cuticle etc. They develop an elaborated conducting system. The stomata remain closed mostly in dry periods.

The plants develop several protoplasmic peculiarities such as cell size, cell structure, increased permeability, increased imbibitional power, elasticity, small vacuoles, higher osmotic pressure etc.

Physiological Traits Affecting Crop Response to Drought

Effects of water deficit at the whole plant level are manifested by effects on plant phenology, growth and development, source–sink relations and plant reproduction processes. An understanding of the various physiological traits controlling/regulating crop responses to drought is required for identifying natural genetic variation for drought tolerance. These traits could be broadly classified as shoot- and root-related traits

1. Phenology

Plant developmental traits such as early vigour or phenology may be particularly significant in water-limiting conditions.

- i) Faster phonological development is particularly useful in drought situations where late season drought is prominent.
- ii) The early planting system
- iii) The early maturing cultivars thus completing the reproductive stage before the period of possible drought
- iv) Seed size and early seedling vigour were found to be associated with drought tolerance
- v) Early flowering is an adaptive strategy under drought conditions

2. Root architecture

The role of the plant root system is to uptake water and nutrients from the soil through its highly responsive and plastic morphology, which allows the plant to adjust and exploit the varying soil physical and chemical properties.

An increased depth and density of roots is considered a major mechanism for improving water uptake under drought conditions.

3. Leaf water potential

Leaf water potential (LWP) is recognized as an index for whole plant water status (Turner, 1982). In a normal irrigated plant, plants transpire and create a negative LWP, which results in the uptake of water. Under water deficit conditions, LWP becomes more and more negative with no water to fill the xylem resulting in cavitations leading to the loss of turgor and wilting of plants.

4. Leaf relative water content

Leaf relative water content (RWC) is closely related with cell size and it may strongly reflect the balance between water supply to the leaf and transpiration. RWC should serve as a practical and reliable indicator of drought resistance in mass selection programmes. It has been suggested that plant water status, rather than plant function, controls crop performance under drought.

Therefore, those genotypes that can maintain higher LWP and RWC are drought resistant simply because of their superior internal water status. A positive relationship was observed between grain yield and RWC measured during the reproductive stage in wheat, where the high-yield selections maintained a significantly higher RWC than the low yield selections.

The difference in RWC among cultivars is highly influenced by plant maturity, adaptation and severity of stress and hence it may be used as a secondary selection trait.

When leaf RWC falls to around 70%, photosynthesis in most species becomes irreversibly depressed.

5. Stomatal conductance

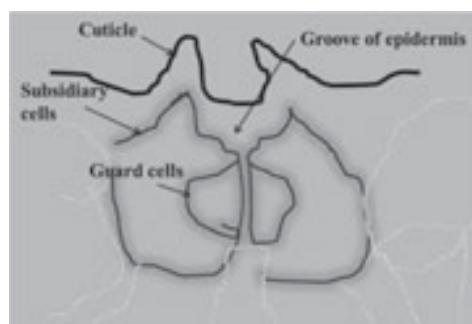
Stomata, the specialized cells performing gas exchange in plants, account for water loss through transpiration. Transpiration rate is influenced by the diffusion resistance, provided by the stomatal pores and by the humidity gradient between the leaf's internal air spaces and ambient air. The stoma closes when leaf water potential decreases. The plant hormone ABA is involved in stomatal closure and appears to trigger stomatal closure even before significant decline in water potential occurs.

Successful application of stomatal regulation using a partial root-zone drying and regulated deficit irrigation (RDI) in horticultural crops showed that reducing stomatal conductance by partial irrigation resulted in improved water use efficiency and productivity equivalent to non-stress conditions.

Through genetic engineering and mutant approaches, several genes were manipulated to regulate stomatal closure downstream of ABA production.

6 Anatomical modifications to reduce water loss (sunken stomata/ glaucousness/ epicuticular wax/ leaf pubescence)

Plants such as *Nerium oleander*, *Ficus* spp, and modified leaves of certain plants (pine needles) avoid drought by sunken stomata, which is an anatomical adaptation. In these species, stomata are sunken below the epidermal plane.



The guard cells are located in a depression, creating a more humid microclimate in the boundary layer. Air in the depression is slightly protected from wind, and any molecule of water that

escapes from the stoma may remain in the depression long enough to actually bounce back into the leaf rather than being evaporated.

Glaucousness is the waxy covering of the plant cuticle that renders a dull-white or bluish-green cast referred to as bloom in crops. Genotypes with low cuticular transpiration rates can conserve RWC in water-deficient conditions. Glossy leaf trait was found to be associated with seedling stage drought tolerance.

Leaf pubescence density is considered as an adaptive trait for drought tolerance. Pubescent hairs reflect excess radiation and reduce epidermal conductance.



7. Cell membrane stability

One of the cellular components that is intensively affected by water stress is the cell membrane. During a water deficit, membrane permeability increases, which leads to disruption of cell membrane leading to the efflux of electrolytes. The measurement of ion leakage and further estimation of membrane stability had been used as criteria for selection for drought resistance

A positive association between cell membrane stability (CMS) and high phospholipids content was observed in drought tolerant crops.

8. Oxidative damage and reactive oxygen species scavenging indicators

Reactive oxygen species (ROS) are produced as by-products of various metabolic pathways localized in different cellular compartments. In plants, ROS are continuously produced predominantly in chloroplasts, mitochondria and peroxisomes. The equilibrium between production and scavenging of ROS may be perturbed by a number of adverse abiotic stress factors, including drought. Abnormal increase in ROS leads to irreversible damage to the cellular membrane, photosynthesis, and ultimately cell death.

The ROS molecules such as hydrogen peroxide, superoxide, and singlet oxygen are detoxified by non-enzymatic antioxidants such as ascorbate and glutathione (GSH), as well as tocopherol, flavonoids, alkaloids and carotenoids. Enzymatic ROS scavenging mechanisms in plants include superoxide dismutase (SOD), ascorbate peroxidase (APX), glutathione peroxidase (GPX) and catalase (CAT).

ROS may act as positive signaling molecules to regulate the response of plant growth to water stress.

9. Osmotic adjustment

Osmotic adjustment (OA) is defined as the active intracellular accumulation of organic solutes in response to an increasing water deficit. OA is considered a useful trait because it provides a means for maintaining cellular turgor when tissue water potential declines. OA has been shown to maintain stomatal conductance and photosynthesis at lower water potentials, delayed leaf senescence and death, reduced flower abortion, improved root growth, and increased water extraction from the soil as water deficit develops.

Sugars and aminoacids are major constituents of osmoregulation in expanded leaves of many species. Changes in potassium may also contribute substantially to osmoregulation. The other solutes which may contribute to small changes in osmoregulation are organic acids (malate, citrate, nitrate and chloride ions).

10. Canopy temperature

Canopy temperature is considered as a sister/surrogate trait in relation to stomatal conductance as they are directly related. Plants with high stomatal conductance transpire more and thus maintain a cooler canopy temperature. Canopy temperature and its depression relative to ambient air temperature indicate how much transpiration cools the leaves under a hot and humid climate that typically is associated with drought stress.

11. Chlorophyll fluorescence and reflection indices

Drought affects the photosynthetic activity of leaves as a consequence of altered chlorophyll A fluorescence kinetics. The analysis of changes in chlorophyll fluorescence kinetics provides detailed information on the structure and function of the photosynthetic apparatus, especially photosystem II.

12. Effective use of water

Water use efficiency (WUE) was widely used as a breeding target in water-saving agriculture. High WUE, which is the ratio between the amounts of dry matter produced per unit of water applied, could contribute to crop productivity under drought. The positive association between WUE and total biomass yield in a drought environment suggests that improvement of the WUE of a crop plant should result in superior yield performance if a high harvest index can be maintained.

Stress proteins

Stress proteins are a large group of different proteins induced by different environmental and biotic stress in various organisms. A group of relatively small molecular weight proteins is developmentally regulated in growing seed such as that of barley. Their accumulation during embryo development has a role in protecting the embryo as the seed matures and desiccates during maturation (typically to about 10% water content). These are defined as 'late embryogenesis abundant' (LEA) proteins. LEA proteins are proteins in plants that protect other [proteins from aggregation](#) due to [desiccation](#) or [osmotic stress](#). Further research found that LEA proteins consist of a family, including several similar proteins such as dehydrins.

These are not limited to seed embryo and they can be induced by drought stress in various plant tissues. Some are ABA responsive while others are not.

Work with transgenic plants indicated that the LEA family of stress protein might have a role in drought and osmotic stress resistance. Their exact function is not clear but it may involve osmotic adjustment or protection of cellular membranes or organelles during desiccation. They may also act as molecular chaperons and in that respect they are very similar to low molecular weight heat shock proteins (HSP). In this role they may conserve protein structure during stress.

Expansins are plant cell wall proteins. They have unique "loosening" effects on plant cell walls. Local expression of expansins induces the entire process of leaf development and modifies leaf shape. They are also induced by ABA

Proteases: They help degrading irreparable denatured proteins

Carbon isotope discrimination (Δ)

Carbon isotope discrimination (Δ) has been proposed as a method for evaluating water use efficiency (WUE) in C₃ plants and as a precise technique for screening plants with higher tolerance under water deficit conditions. The isotopes are unevenly distributed among and within different compounds, and this isotopic distribution can reveal information about the physical, chemical, and metabolic processes involved in carbon transformations. When soil moisture levels are decreased, a common response is simultaneous decreases in photosynthesis, transpiration, and leaf conductance. If the "supply function" of photosynthesis (leaf conductance) decreases at a faster rate under stress than the "demand function". This effect should be measurable either an increase in δ or correspondingly as a decrease in Δ .

Mitigating Water Stress

1. Foliar spray of 2% c DAP + 1% KCl (MOP) during critical stages of flowering and grain formation
2. 3% Kaoline spray at critical stages of moisture stress
3. Foliar spray of 500 ppm Cycocel (1 ml of commercial product per litre of water)
4. Mulching with 5 tones of sorghum / sugarcane trash, which saves 19-20% of irrigation water by reducing evaporation loss of water
5. Split application of N and K fertilizers
6. Use of biofertilizers viz., Azospirillum or phosphobacteria @ 10 packets / ha along with 25 kg of soil or FYM
7. Seed hardening with 1% KH₂PO₄, 1% KCl, 100 ppm Succinic acid, 0.5% NaCl, 100 ppm ZnSO₄, 100ppm MnSO₄, 100 ppm Ascorbic acid, 250 ppm Cycocel, 0.5% MgSO₄ for 6 – 8 hours (depending upon nature of seed coat) soaked in equal volume of water
8. **Use of plant growth regulators (PGR)**

Cycocel & Mepiquat chloride

For promoting root growth (for more water absorption) and suppressing leaf area development (for reducing transpiration loss of water) and delaying onset of leaf senescence.

Cytokinins and Salicylic acid

They delay the leaf senescence processes and also favour stem reserve utilization by the developing grains especially during the water deficit situations.

Brassinolides

These PGRs increase the photosynthetic activity of the plants

Ascorbic acid

Ascorbic acid acts as an anti-oxidant agent for scavenging Reactive Oxygen Species (ROS) accumulating under stress and thus avoiding membrane damage.

9. As in cotton, nipping terminal portion f main stem beyond 15th (at 70 - 80 DAS) and at 20th node (at 90 DAS) in the case of hybrids and varieties respectively for arresting transpiratory loss of water)
10. Foliar spray of 0.5% zinc sulphate + 0.3 % boric acid + 0.5 % Ferrous sulphate + 1% urea during critical stages of moisture stress

Study questions

1. Define osmotic adjustment
2. Enumerate the adaptations of plants to drought
3. What are three types of antitranspirants and give example for each type
4. Explain in detail about mechanism of drought tolerance
5. Write anatomical modifications to reduce water loss from the plants
6. Explain the management options for drought

Lec 02. Reactive Oxygen Species and Scavenging enzymes

Reactive oxygen species (ROS) are produced as a normal product of plant cellular metabolism. Various environmental stresses lead to excessive production of ROS causing progressive oxidative damage and ultimately cell death. Despite their destructive activity, they are well-described second messengers in a variety of cellular processes, including conferment of tolerance to various environmental stresses. Whether ROS would serve as signaling molecules or could cause oxidative damage to the tissues depends on the delicate equilibrium between ROS production, and their scavenging. Efficient scavenging of ROS produced during various environmental stresses requires the action of several nonenzymatic as well as enzymatic antioxidants present in the tissues.

An unavoidable consequence of aerobic metabolism is production of reactive oxygen species (ROS). ROS include free radicals such as superoxide anion ($O_2\bullet-$), hydroxyl radical ($\cdot OH$), as well as nonradical molecules like hydrogen peroxide (H_2O_2), singlet oxygen (1O_2), and so forth. Stepwise reduction of molecular oxygen (O_2) by high-energy exposure or electron-transfer reactions leads to production of the highly reactive ROS. In plants, ROS are always formed by the inevitable leakage of electrons onto O_2 from the electron transport activities of chloroplasts, mitochondria, and plasma membranes or as a byproduct of various metabolic pathways localized in different cellular compartments. Environmental stresses such as drought, salinity, chilling, metal toxicity, and UV-B radiation as well as pathogens attack lead to enhanced generation of ROS in plants due to disruption of cellular homeostasis [6–15]. All ROS are extremely harmful to organisms at high concentrations. When the level of ROS exceeds the defense mechanisms, a cell is said to be in a state of “oxidative stress.” The enhanced production of ROS during environmental stresses can pose a threat to cells by causing peroxidation of lipids, oxidation of proteins, damage to nucleic acids, enzyme inhibition, activation of programmed cell death (PCD) pathway and ultimately leading to death of the cells.

Among the ROS, Both $O_2\bullet-$ and H_2O_2 are only moderately reactive. The cellular damage by ROS appears to be due to their conversion into more reactive species. The formation of $\cdot OH$ is dependent on both H_2O_2 and $O_2\bullet-$ and, thus, its formation is subject to inhibition by both SOD and CAT. The Haber-Weiss reaction generates $\cdot OH$ from H_2O_2 and $O_2\bullet-$. $\cdot OH$ is the most reactive among all ROS.

Enzymatic Components

The enzymatic components of the antioxidative defense system comprise of several antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), guaiacol peroxidase (GPX), enzymes of ascorbate-glutathione (AsA-GSH) cycle ascorbate peroxidase (APX), monodehydroascorbate reductase (MDHAR),

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operate in different subcellular compartments and respond in concert when cells are exposed to oxidative stress.

1. Superoxide Dismutase (SOD)

SOD activity has been reported to increase in plants exposed to various environmental stresses, including drought and metal toxicity. Increased activity of SOD is often correlated with increased tolerance of the plant against environmental stresses. It was suggested that SOD can be used as an indirect selection criterion for screening drought-resistant plant materials. Overproduction of SOD has been reported to result in enhanced oxidative stress tolerance in plants.

Superoxide dismutase (SOD, 1.15.1.1) plays central role in defense against oxidative stress in all aerobic organisms. The enzyme SOD belongs to the group of metalloenzymes and catalyzes the dismutation of $O_2\cdot^-$ to O_2 and H_2O_2 . It is present in most of the subcellular compartments that generate activated oxygen.

2. Catalase (CAT)

H_2O_2 has been implicated in many stress conditions. When cells are stressed for energy and are rapidly generating H_2O_2 through catabolic processes, H_2O_2 is degraded by CAT in an energy efficient manner. Among antioxidant enzymes, catalase (CAT, 1.11.1.6) was the first enzyme to be discovered and characterized. It is a ubiquitous tetrameric heme-containing enzyme that catalyzes the dismutation of two molecules of H_2O_2 into water and oxygen.

3. Ascorbate Peroxidase (APX)

APX is regarded as one of the most widely distributed antioxidant enzymes in plant cells and isoforms of APX have much higher affinity for H_2O_2 than CAT, making APXs efficient scavengers of H_2O_2 under stressful conditions. Many workers have reported enhanced activity of APX in response to abiotic stresses such as drought, salinity, chilling, metal toxicity, and UV irradiation. APX found in organelles scavenges H_2O_2 produced within the organelles, whereas cytosolic APX eliminates H_2O_2 produced in the cytosol, apoplast or that diffused from organelles.

Water use efficiency:

Water use efficiency (or transpiration efficiency) describes the intrinsic trade-off between carbon fixation and water loss that occurs in dryland plants because water evaporates from the interstitial tissues of leaves whenever stomata open for CO₂ acquisition.

Vast amounts of water are transpired in comparison with the small amounts of carbon that are fixed by photosynthesis. Typical crop plants transpire 200–1,000 g of water per g of assimilated carbon. One theoretical avenue for improving yields with less water is through manipulation of the relationship between carbon gain (photosynthesis) and water loss (transpiration). The ratio between these two parameters, called water use efficiency.

WUE is usually the ratio of aboveground biomass or economic yield to water use or evapotranspiration (ET).

Carbon Isotope discrimination

Carbon discrimination (A) technique, considered a possible future tool for screening and selection of crop species for high water use efficiency (WUE) and high yields.

Neutron probe measurements confirmed the earlier reports of a strong correlation of Carbon discrimination with grain yield and water use efficiency of wheat. There are two naturally occurring stable isotopes of carbon, ¹²C and ¹³C.

Identifying genotypes with high water use efficiency and high yield has become an important issue as environmentally friendly and sustainable agricultural practices receive high priority in all countries. For the initial screening process, rapid but reliable greenhouse or field methods for assessing the yield potential, particularly under water limited environments, would be invaluable. Water stress is the most important limitation to crop productivity in water scarce arid and semi-arid regions of the world. Although agronomic practices are important under water deficit agricultural areas, cultivar improvement is usually seen as the most promising approach to increase yields. Plant breeders and plant physiologists believe that better adapted and high yielding varieties could be bred more efficiently and effectively if plant attributes which are indicative of high yields under water limited conditions could be identified and used as selection criteria. Therefore identification of plant attributes contributing to superior performance of crop plants under drought conditions has been a long-term goal of plant scientists. Water use efficiency is a trait which can contribute to crop productivity in the areas where water resources are scarce because it is considered an important component of adaptation to drought. Water use efficiency, in general terms, is the ratio of productivity to water loss by a plant. It is defined as the molar ratio of photosynthesis to transpiration (short-term measurements) or as the ratio of biomass produced to water consumed (long-term measurements). One of the difficulties in using plant water use efficiency as a trait for

identifying genotypes superior in performance under drought conditions is the difficulty of accurately assessing water use efficiency in large scale field experiments. Faquhar et al. have shown that genotypic variability in intrinsic water use efficiency (mole of C fixed per mole of water transpired) is closely associated with **13C discrimination** in C3 plants. Subsequent studies demonstrated that the extent of I₃C isotope discrimination is a reliable indicator of water use efficiency.

Study questions

1. Write various ROS and its place of synthesis
2. Write the impact of ROS on plant metabolism
3. What is Water Use Efficiency?
4. How carbon isotope discrimination can be used to identify high WUE plants?
5. List out Enzymatic and Non-enzymatic antioxidants?

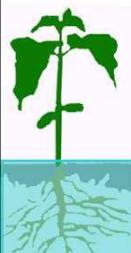
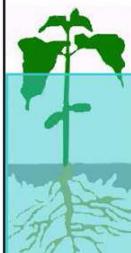
Lecture. 3.

Flooding - Physiological mechanism of adaptation- physiological traits associated with flooding- Role of ethylene

Many ecosystems worldwide are vulnerable to flooding, either progressive or rapid, such as areas close to watercourses or exposed to monsoons. Man-made flooding can also occur, as in paddy fields where rice, which is well adapted to flooded environments, is cultivated. Global warming is associated with an increase in flooding events characterized by their unexpected occurrence, regimes and localization. Unusual water submersion resulting in excessively wet or flooded soils can severely affect crop production coupled with a modification in plant distribution in natural ecosystems

The term flooding is often used to depict different situations in which the water excess can range from water saturated soil (*i.e.* waterlogging) to deep water columns causing complete submergence of plants. Waterlogging corresponds to the full saturation of the soil pores with water, and with a very thin – or even without – a layer of water above the soil surface. Hence, under waterlogged conditions, only the root system of plant is under the anaerobic conditions imposed by the lack of oxygen, while the shoot is under atmospheric normal conditions.

Flooding is the situation in which there is a water layer above the soil surface. This water layer can be shallow or deep, so that it can provoke partial or complete submergence of plants. It should be noted that, at the same water depth, the degree of plant submergence will depend on the developmental stage (*eg.* seedlings *vs.* adult plants) and plant growth habit (*eg.* creeping plant growth *vs.* erect plant growth), among other traits influencing plant height. Under partial submergence conditions, plants have a portion of their shoots underwater, besides having their roots completely immersed in water-saturated soil. Under complete submergence, plants confront the most stressful scenario because both, shoot and root plant compartments, are underwater, and in this case the chances to capture atmospheric oxygen and to continue with carbon fixation are restricted.

	Waterlogging	Flooding			
		Partial submergence		Complete submergence	
	Only the root system is under anaerobic conditions		All roots are immersed in water while just a portion of the shoot (which depends on the water depth) is covered by water		All plant is under the water level. Water depth and turbidity are important factors defining this scenario

Plants are aerobic organisms and need oxygen (O_2) to survive, and thus suffer severely from O_2 deprivation. Water submersion drastically reduces O_2 availability since it diffuses slowly in water, dropping to concentrations that can restrict aerobic respiration. In addition to the slow diffusion, the solubility of O_2 in water is poor. One litre of air contains approximately 33-fold more O_2 than one litre of water at 20 °C. Water is a remarkable barrier to general gas diffusion, leading to concomitant phenomena such as ethylene entrapment in submerged organs and, depending on the light conditions, increased CO_2 levels. A flooded environment can also suffer from low light, thus reducing photosynthesis, and from high concentrations of toxic soil compounds.

A major constraint resulting from excess water, at least for poorly adapted species, is an inadequate supply of oxygen to submerged tissues; diffusion of oxygen through water is 10⁴-fold slower than in air. In addition to the threat of oxygen deficiency, excess water also leads to other changes in the soil that influence plants; levels of the plant hormone ethylene. Moreover, when flooding results in complete submergence, and in normally submersed aquatic plants, availability to the shoots of carbon dioxide, light and oxygen typically diminish.

Growth and development of the vast majority of vascular plant species is impeded by soil flooding, and particularly by complete submergence, both of which can result in death. However, numerous wetland species are highly productive in flood-prone areas. This is achieved by means of a combination of life-history traits and certain key physiological adaptations and acclimations such as physical ‘escape’ from a submerged environment, avoidance of oxygen-deficiency through effective internal aeration, anoxia tolerance, and a capacity to prevent, or repair, oxidative damage during re-aeration.

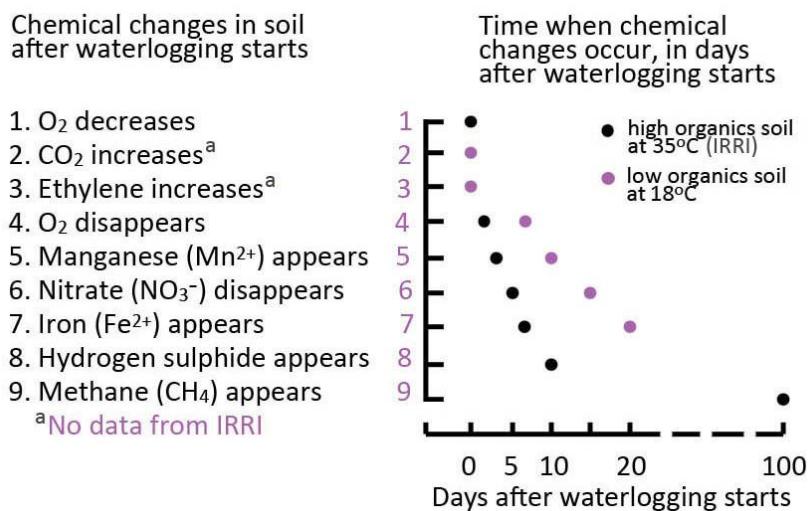
When flooding extends to submergence of the shoot, photosynthesis becomes severely restricted by a deficiency of external carbon dioxide and by shading. Furthermore, total submergence can interfere with flowering and pollination essential for completion of the reproductive cycle. In many aquatic and amphibious species, these debilitating effects are overcome by an oxygen-dependant, ethylene-mediated stimulation of underwater shoot elongation that encourages renewed contact with the aerial environment.

In drained soils, diffusion in the gas phase of the bulk soil sustains the O_2 supply needed for roots to respire at optimal rates. Soil flooding impedes O_2 movement into soils, and so roots experience hypoxia (sub-optimal O_2) and anoxia (absence of O_2). O_2 is the terminal electron

acceptor of mitochondrial electron transport, so anoxia inhibits respiration and the resulting energy deficit has major implications for roots. In addition, decreases in soil redox potential result in significant changes to the soil elemental profile.

As soon as O_2 is depleted, NO_3^- is used by some soil microorganisms as an alternative electron acceptor in their respiration; NO_3^- is reduced to NH_4^+ , so it becomes the main form of mineral nitrogen in waterlogged soils. In the rhizosphere of roots with radial O_2 loss (ROL), however, NH_4^+ can be converted back to NO_3^- , with both these forms of mineral nitrogen absorbed by roots. Manganese oxides are the next electron acceptors used by anaerobic microorganisms, followed by iron oxides resulting, respectively, in elevated concentrations of Mn^{2+} and Fe^{2+} in the soil solution; these soluble forms often increase to levels that are toxic to plants. Further decrease in the redox potential results in the reduction of SO_4^{2-} to H_2S , which is also potentially toxic. In addition to these inorganic phytotoxins (Fe^{2+} , Mn^{2+} , or H_2S), various short-chain fatty acids can also accumulate in waterlogged soils. In addition to phytotoxins, some nutrients change in availability in flooded soils; e.g., P becomes more available, whereas Zn becomes less available.

Also detrimental to plants is the accumulation of metabolites (e.g. acetic acid, butyric acid, propionic acid) produced as a result of anaerobic metabolism by microorganisms in waterlogged soils. These compounds can have adverse effects on root growth (e.g. cell division and viability) and nutrient acquisition (e.g. activity of various membrane transporters, membrane permeability) and, ultimately, shoot growth.



Plants develop a suite of anatomical, morphological and physiological responses in order to deal with partial submergence imposed by flooding. The most common anatomical response is the generation of aerenchyma in tissues which facilitates the transport of oxygen from shoots to roots. This aerenchymatic tissue provides a continuous system of interconnected aerial spaces (aerenchyma lacunae) of lower resistance for oxygen transport from aerial shoots to submerged roots, allowing root growth and soil exploration under anaerobic conditions.

At morphological level, usual responses to flooding include adventitious rooting and increases in plant height and consequently, in the proportion of biomass above water level. These adventitious roots, which have high porosity, help plants to continue with water and nutrient uptake under flooding conditions, replacing in some way the functions of older root system. This also helps to facilitate the oxygenation of submerged tissues through the aerenchyma tissue.

There are three mechanisms for generating these ‘replacement’ root systems:

- (i) Stimulation of the outgrowth of pre-existing root primordia in the shoot base
- (ii) Induction of a new root system that involves initiation of root primordia and their subsequent outgrowth and

- (iii) Placing roots at the soil surface involving the re-orientation of the root extension

The two first mechanisms appear to be triggered by ethylene, which is thought to increase the sensitivity of plant tissues to auxin. The application of exogenous ethylene stimulated the production of adventitious roots without changing the root levels of indole acetic acid (IAA, an auxin). These results indicate that adventitious rooting is due to an increased sensitivity of tissues to auxin and not due to an increase in its concentration.

Table 18.3

Comparison of leaf traits influencing gas exchange and photosynthesis by terrestrial wetland plants when under water and submerged aquatic plants

Leaf traits for:	Terrestrial wetland plants	Submerged aquatic plants
Morphology		
Leaf size	Medium-large	Small-medium
Dissected/lobed	Rare	Common
Strap-shaped	Rare	Common
Leaf thickness	Moderate-thick	Thin
Hairs/trichomes	Rare	Absent
Surface hydrophobicity resulting in leaf gas films	Common	Absent
Anatomy		
Stomata	Always present	Absent/non-functional
Cuticle	Always present	Absent/highly reduced
Chloroplasts in epidermal cells	Only in guard cells	Common
Aerenchyma	Variable	Variable
Supporting fibres	Always present	Rare
Porosity of lamina	High in thick, low in thin lamina	High in thick, low in thin lamina
Photosynthetic pathway		
C3	Common	Common
C4	Rare	Rare (but uncertain)
CAM	Absent	Rare
*Ability to utilise HCO_3^-	Absent	Common

*Use of HCO_3^- can involve external conversion to CO_2 owing to low pH within the diffusive boundary layer and/or the enzyme carbonic anhydrase (CA) at the cell/tissue surfaces, or via the uptake of HCO_3^- and its intracellular conversion to CO_2 by CA. The ability to utilize HCO_3^- is common in algae, macroalgae and aquatic angiosperms (summarised by Pedersen et al. 2013).

At physiological level, flooding modifies water relations and plants carbon fixation. Closing of stomata, with or without leaf dehydration, reduction of transpiration and inhibition of photosynthesis, are responses that can occur in hours or days, depending on the tolerance to

flooding of each plant species. The faster response is the increase in the petiole angle, called hyponastic growth, where maximum angle (70-80°, an almost vertical position) is reached just in four hours, an increase in petiole length follows and maximize the leaf area above the water level. It was proved that both the increase in petiole angle and lengthening, are well mimicked by treating plants with ethylene,

Another specific change at shoot level implies stem hypertrophy, which is a white spongy tissue with large volumes of intercellular gas spaces. This tissue is secondary aerenchyma that forms externally from a phellogen and is homologous to cork. Its role seems to be increasing air space which allows for increased movement of gases between water and plant tissues. In woody plants, an important morphological trait developed by tolerant species is lenticels hypertrophy at the stem base. These special structures, allow oxygen entrance into shallow roots through aerenchyma and intercellular spaces.

Flood tolerant plants exposed to complete submergence exploit two contrasting suites of traits, escape or quiescence, to survive this stress. In brief, plants with the escape strategy:

- (i) increase the growth rate of shoot organs, such as petioles and stems, so as to emerge above floodwaters, and
 - (ii) initiate the development of aerenchyma to facilitate internal gas diffusion.
- Quiescent plants,

on the other hand, “wait out the submergence event” and are characterized by:

- (i) conservation of energy and carbohydrates via, for example, a reduction of the underwater growth rate, and
- (ii) an increase of molecular components that prepare shoot and root organs for future conditions with low O₂ and production of protective molecules that counteract harmful cellular changes associated with flooding, such as production of ROS.

An important trait for plants that survive flooding by means of the quiescence strategy is reduction of underwater growth to conserve carbohydrates and retention of chlorophyll to enable continued, albeit reduced, photosynthesis.

Plant water relations

In flood sensitive species like *Solanum lycopersicum*, *Pisum sativum*, *Helianthus annuus* and *Nicotiana tabacum*, a few hours after the soil becomes flooded, the water uptake by roots is reduced. The reduction of water absorption under flooding is a consequence of a reduction of the root hydraulic conductivity. The reduction of water uptake under water excess of the soil in flooding sensitive species shows the paradoxical response of wilting of leaves.

Photosynthesis responses

A common response to flooding is the reduction of plant carbon fixation. In the short term, photosynthesis can drop as a result of a restriction of CO₂ uptake due to stomata closing.

- lower leaf chlorophyll content
- a reduced activity of carboxylation enzymes, and
- an oxidative damage on photosystem II by reactive oxygen species

both the content of Rubisco protein as well as its activation can be significantly reduced by flooding.

ROS

The main ROS are superoxide, single oxygen, hydrogen peroxide and hydroxyl radical, which are very reactive and provoke damage to lipid membranes and proteins. To manage the level of ROS for protecting cells, plants have antioxidants like ascorbate, glutathione and tocopherols, and enzymes (*i.e.* peroxidases, superoxide dismutase, glutathione reductase, catalase) with ability to scavenge ROS and regenerate the antioxidants. The scavenging capacity can be over passed due to the higher production of ROS, thus generating oxidative damage on the proteins of the photosynthetic apparatus

Effect of flooding stress on the endogenous levels of PGRs and their effect on plants

Endogenous levels of PGRs such as GA and cytokinins (CK) are reduced in the roots. This has enhanced levels of ABA and ethylene in the shoots causing stomatal closure and early onset of senescence respectively. It is also reported that levels of auxins are reduced and that of Aminocyclopropane -1-Carboxylic Acid (ACC), precursor for the ethylene biosynthesis are increased under flooding stress. Important roles played by these endogenous PGRs during high moisture (flooding) stress are summarized in the following table.

Sl. No.	Level of PGR in plants	Effects on plants under water logging
1.	Reduced Auxins	Causes “Hypertrophy” (Swelling of stem base by collapse or enlargement of cells in cortex)
2.	Decreased GA	Causes reduction in cell enlargement and stem elongation
3.	Decreased CK	Results in early on-set of senescence and reduced rate of assimilate partitioning to the sinks
4.	Increased ABA	Cause stomatal closure with consequential decrease in the rate of gas exchanges during photosynthesis, respiration and transpiration; results in efflux of K ⁺ from the guard cells; decreases ion transport due to lower rate of transpiration; decrease the starch formation in the guard cells resulting in stomatal closure
5.	Increased Ethylene	Causes “Epinasty” of leaves (uneven growth of leaves due to more cell elongation on upper side than the lower side of the leaf); induces senescence and Hypertrophy in plants.

Thus, the O₂ stress in the roots under flooding produces signals, via transpiration stream, to the leaves affecting stomatal behaviour ultimately.

Mitigation of water logging

1. Providing adequate drainage for draining excessive stagnating water around the root system.
2. Spray of growth retardant of 500 ppm cycocel for arresting apical dominance and thereby promoting growth of laterals
3. Foliar spray of 2% DAP + 1% KCl (MOP)

4. Nipping terminal buds for arresting apical dominance and thus promoting growth of sympodial branches (as in cotton) for increasing productivity
5. Spray of 40 ppm NAA for controlling excessive pre-mature fall of flowering/buds/young developing fruits and pods
6. Spray of 0.5 ppm brassinolide for increasing photosynthetic activity
7. Foliar spray of 100 ppm salicylic acid for increasing stem reserve utilization under high moisture stress.
8. Foliar spray of 0.3 % Boric acid + 0.5 % ZnSO₄ + 0.5 % FeSO₄ + 1.0 % urea during critical stages of the stress

Study Questions

1. Write the adaptation of plants to flooding stress
2. Enumerate the role of hormones in flooding tolerance
3. How to mitigate the flooding stress?
4. What changes occur in soil after flooding?
5. Write the physiological responses of plants to flooding

Lec. 4

Temperature stress

Relatively hot temperatures can impair plant function or development through either direct effects of high tissue temperature or indirect effects of the high evaporative demand and water stress that accompany hot weather. The magnitude of heat stress depends on intensity (temperature), duration of exposure and rate of increase because plants have some ability to acclimate and more rapid increases in temperature can be more damaging. High temperatures shorten the duration of growth of both the leaves and the grains, accelerating their development and thus limiting the ability of the plant to accumulate the carbohydrate necessary for grain growth. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3676804/>

Plant Response to Heat Stress

Plant responses to HT vary with the degree of temperature, duration and plant type. At extreme HT, cellular damage or cell death may occur within minutes, which may lead to a catastrophic collapse of cellular organization. Heat stress affects all aspects of plant processes like germination, growth, development, reproduction and yield. Heat stress differentially affects the stability of various proteins, membranes, RNA and cytoskeleton structures, and alters the efficiency of enzymatic reactions in the cell for which the major physiological processes obstacle and creates metabolic imbalance.

Growth

Among the growth stages of plant the germination is affected first of all like reduced germination percentage, plant emergence, abnormal seedlings, poor seedling vigor, reduced

radicle and plumule growth of germinated seedlings. Inhibition of seed germination is also well documented in HT which often occurs through induction of ABA. Reduction in net assimilation rate (NAR) is also another reason for reduced relative growth rate (RGR).

The morphological symptoms of heat stress include scorching and sunburns of leaves and twigs, branches and stems, leaf senescence and abscission, shoot and root growth inhibition, fruit discoloration and damage and damage to leaf-tip and margins, rolling and drying of leaves, and necrosis. High temperatures may alter the total phenological duration by reducing the life period. Increases in temperatures 1–2 °C than the optimum result in shorter grain filling periods and negatively affect yield components.

Photosynthesis

High temperature has a greater influence on the photosynthetic capacity of plants especially of C₃ plants than C₄ plants. In chloroplast, carbon metabolism of the stroma and photochemical reactions in thylakoid lamellae are considered as the primary sites of injury. Thylakoid membrane is highly susceptible to HT. Major alterations occur in chloroplasts like altered structural organization of thylakoids, loss of grana stacking and swelling of grana. Again, the photosystem II (PSII) activity is greatly reduced or even stops. Heat shock reduces the amount of photosynthetic pigments.

HT causes loss of cell water content. It markedly affects the leaf water status, leaf stomatal conductance (gs) and intercellular CO₂ concentration. Heat imposes negative impacts on leaf of plant like reduced leaf water potential, reduced leaf area and pre-mature leaf senescence which have negative impacts on total photosynthesis performance of plant.

Reproductive Development

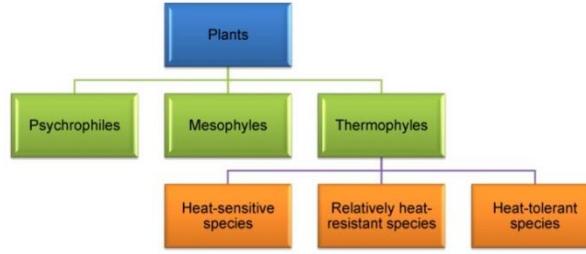
Although all plant tissues are susceptible to heat stress at almost all the growth and developmental stages, the reproductive tissues are the most sensitive, and a few degrees elevation in temperature during flowering time can result in the loss of entire grain crop cycles. During reproduction, a short period of heat stress can cause significant decrease in floral buds and flowers abortion.

The reasons for increasing sterility under abiotic stress conditions including the HT are impaired meiosis in both male and female organs, impaired pollen germination and pollen tube growth, reduced ovule viability, anomaly in stigmatic and style positions, reduced number of pollen grains retained by the stigma, disturbed fertilization processes, obstacle in growth of the endosperm, proembryo and unfertilized embryo. It was demonstrated that increase of the seasonal average temperature 1 °C decreased the grain yield of cereals by 4.1% to 10.0%.

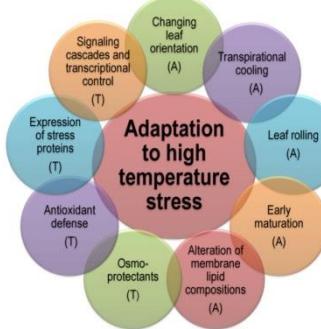
Plant Adaptation to Heat Stress

Living organisms can be classified into three groups, subject to the preferred temperature of growth. There are

- (a) Psychrophiles: which grow optimally at low temperature ranges between 0 and 10 °C;
- (b) Mesophytes: which favor moderate temperature and grow well between 10 and 30 °C; and
- (c) Thermophytes: which grow well between 30 and 65 °C or even higher.



Under HT conditions, plants exhibit various mechanisms for surviving which include long-term evolutionary phenological and morphological adaptations and short-term avoidance or acclimation mechanisms such as changing leaf orientation, transpirational cooling, or alteration of membrane lipid compositions. Closure of stomata and reduced water loss, increased stomatal and trichomatous densities, and larger xylem vessels are common heat induced features in plant. Plants growing in a hot climate avoid heat stress by reducing the absorption of solar radiation. This ability is supported by the presence of small hairs (tomentose) that form a thick coat on the surface of the leaf as well as cuticles, protective waxy covering. In such plants, leaf blades often turn away from light and orient themselves parallel to sun rays (paraheliotropism). Solar radiation may also be reduced by rolling leaf blades. High temperature stress can also be avoided by crop management practices such as selecting proper sowing methods, choice of sowing date, cultivars, irrigation methods, *etc.*



Different adaptation mechanisms of plants to high temperature. A: Avoidance, T: Tolerance.

Tolerance Mechanisms

Heat tolerance is generally defined as the ability of the plant to grow and produce economic yield under HT. Plants have evolved various mechanisms for thriving under higher prevailing temperatures. They include short term avoidance/acclimation mechanism or long term evolutionary adaptations. Some major tolerance mechanisms, including ion transporters, late embryogenesis abundant (LEA) proteins, osmoprotectants, antioxidant defense. In case of sudden heat stress, short term response, *i.e.*, leaf orientation, transpiration cooling and changes in membrane lipid composition are more important for survival

(a) Membrane state, structure and composition

In order to tolerate high temperatures, plants must maintain membrane fluidity within a biologically functional range (membrane thermostability). The degree to which membrane fluidity increases with temperature is dependent on membrane composition. Lipids that have unsaturated fatty acid chains, short fatty acid chains or a low sterol content generally form membranes that are more fluid and less stable at high temperatures. The sensitivity of membranes to heat stress can be reduced by increasing the proportion of saturated lipids or by altering the composition of specific lipids.

(b) Heat shock proteins

Within minutes of temperature rising above the optimum, the expression of most genes used for general metabolism is inhibited, however, a sub-set of specialized stress response genes are actively up-regulated. The best characterized of these genes are a multi-family group known as **heat shock proteins** (HSP). HSP utilize a novel transcription factor to respond directly to heat, and their levels have been shown to rise along with temperature until the lethal threshold temperature is reached. On exposure to high temperature HSP expression typically peaks after 1-2 hours and diminishes after 6-8 hours, after which the cell environment is modified enough for the transcription and translation of other genes to resume

Many HSP are thought to act as **chaperone proteins**, protecting other proteins from denaturation by reducing misfolding, unfolding, and aggregation. Chaperone activity also helps maintain the translocation of proteins across cell membranes. Larkindale *et al.* (2005), describe five classes of HSP the names indicating the molecular weight:

- HSP60 and HSP70 have been shown to act as chaperone proteins in plants and other organisms, and some also function to stabilise membranes preventing the loss of permeability.
- HSP90 are less well characterised in plants, they are thought to interact with signal transduction proteins that form part to the overall heat stress response.
- HSP100 act as chaperone proteins in conjunction with HSP60 and HSP70 and may perform other roles. Plants lacking HSP 100 can grow normal at optimum temperatures but are unable to acclimate during heat stress.
- Small HSP are particularly important in plants but are less well characterized than HSP60 and HSP70. Small HSP are a diverse group including several gene families that are targeted to different cellular compartments, including the cytosol, chloroplast and mitochondria. The function of many of the Small HSP is still unknown. Some may be involved in chaperone protein activity and some are involved in maintaining membrane stability including the protection of membranes essential for the functioning of PSII.

Certain HSP also act to clean up the cell, removing denatured proteins by increasing the proteolysis activity of ubiquitin. The removal of potentially toxic protein aggregations is thought to be a key part of acclimation to heat stress.

(c) Reactive Oxygen Species (ROS)

Like other abiotic stress, heat stress might uncouple enzymes and metabolic pathways which cause the accumulation of unwanted and harmful ROS most commonly singlet oxygen (${}^1\text{O}_2$), superoxide radical (O_2^-), hydrogen peroxide (H_2O_2) and hydroxyl radical (OH^\cdot) which are responsible for oxidative stress. The impairment of metabolic function during heat stress results

in increased production of ROS, which in turn causes secondary damage to proteins and membranes. Accumulation of ROS during heat stress has been associated with both the light reactions and the Calvin cycle reactions. The reaction centre of PSII is particularly vulnerable, producing superoxide radicals, hydroxyl radicals and hydrogen peroxide under heat stress. Antioxidant enzymes and non-enzyme systems serve to limit the formation of the most damaging ROS, such as singlet oxygen, and to detoxify the cells through ROS-scavenging.

(d) Heat stress response: other mechanisms

Among the metabolites associated with heat acclimation perhaps the best characterised are the compatible solutes. In the case of heat stress, their primary role is thought to be similar to that of the chaperone proteins, i.e. the protection of protein and membrane function. There is also increasing interest in the role of isoprene in heat tolerance. Isoprene is a small hydrocarbon sometimes released from plants in large quantities. In particular, the production of isoprene has been shown to reduce the inhibition of photosynthesis during moderate heat stress, perhaps by associating with the thylakoid membrane to increase hydrophobic interactions and protect membrane function.

Use of Exogenous Protectants

One of the ways to deal with adverse effects of heat stress may involve exploring some molecules that have the potential to protect the plants from the harmful effects of HT. In recent, exogenous application of protectant such as osmoprotectants, phytohormones, signaling molecules, trace elements, *etc.*, have shown beneficial effect on plants grown under HT as these protectants has growth promoting and antioxidant capacity. Accumulation of osmolytes such as Pro, GB and Tre is a well-known adaptive mechanism in plants.

Low Temperature Stress

Effects of Chilling Stress

Chilling stress affects several functions in plants including membrane structure and function, changes in nucleic and protein synthesis, water and nutrient balances, cellular cytoskeletal structure, photosynthetic and respiratory metabolisms. Chilling injury can be divided into a single primary event and several secondary events.

A single primary event has been proposed in which the chilling temperature can cause membrane phase transition from a liquid crystalline phase to the solid gel phase. Such changes can decrease membrane permeability, i.e., fluidity and can affect any of the above-mentioned secondary events, which ultimately lead to the expression of symptoms.

Physiological and Biochemical Effects of Chilling Stress

Generally enzymes are more labile to high temperatures than they are to low temperatures. However, enzymes having subunits such as pyruvate P_i dikinase and phosphofructokinase, which are involved in carbon fixation reactions in C₄ plants and glycolysis respectively, are inactivated by chilling temperature as a result of converting them from tetramers to dimers.

Another enzyme affected by chilling stress is K-mediated ATPase, the reduced activity of which leads to K ion leakage from cells. The levels of three adenine nucleotides, viz., ATP, ADP and AMP are reduced by chilling. Chilling may inhibit photosynthesis by affecting both the light and dark reactions. When a plant is exposed to chilling stress during the day, the injury is probably due to photo-inhibition at the oxidative side of PS II involving D1 protein. Under this condition, normal electron carrier may be disrupted leading to electrons being used to form free-radical species, which may cause degradation of membranes. Respiration rates can either increase or decrease depending on the severity and duration of chilling stress. Increased rates may be due to the diversion of the normal electron transport to the cyanide-resistant pathway, which is usually not linked with ATP generation.

(b) Acclimation to Cold Temperature

Chilling-sensitive plants can be acclimated or hardened to low temperature by gradually reducing the temperature. Plants accumulate sugar alcohol, proline and glycinebetaine that may serve to stabilize membranes.

Common Symptoms

- Reduced plant growth and death
- Surface lesions on leaves and fruits
- Abnormal curling, lobbing and crinkling of leaves
- Water soaking of tissues
- Cracking, splitting and dieback of stems
- Internal discolouration (vascular browning)
- Increased susceptibility to decay
- Failure to ripen normally
- Loss of vigour (potato lose the ability to sprout if chilled)

Freezing Stress

Two types of freezing occur in plant cells and tissues

- Vitrification : Solidification of the cellular content into non-crystalline state (amorphous state) .It occurs by rapid freezing of cells (decrease in temperature by more than 30C/min) to a very low temp.
- Crystallisation / ice formation : Crystallisation of ice occur either extracellularly or intracellularly (gradual cooling /drop in temperature)

Freezing damage occurs primarily due to the formation of ice crystals, which damage cell structure when the temperature falls below 00C.

- Ice usually forms first in the cell walls and intercellular spaces
- Damage occurs when ice crystals grow and puncture into the cytoplasm

Effects of Freezing Stress

Plants generally withstand freezing temperatures either by avoidance or by tolerance. One avoidance mechanism involves the process of super-cooling by means of which solutes

accumulate in cells and lower the freezing temperature of the cytoplasm too much below the freezing point of pure water. This is achieved either by synthesis of solutes, such as sugars, polyols and other osmotic solutes, or by the movement of water from one tissue to another that is less sensitive to freezing.

The physiological processes that are affected by freezing stress are in many ways similar to those affected by chilling stress, but these are more pronounced. One of the primary differences is related to the development of intracellular ice in case of freezing stress and cavitation of cells that lead to the death of cells and tissues. Plants in these environments grow slowly but have photosynthetic rates that are comparable to plants growing in warmer environment.

Higher photosynthetic rates in cold climate are the result of elevated levels of Rubisco, and this may be regarded as metabolic compensation. Most of these plants show C₃ pathway, but as a result of the cold climate in which they grow, photorespiration is kept to a minimum. Plants growing in cold climate tend to store large portion of their carbohydrate reserves in underground organs and allocate large portions of photosynthetic to the maintenance and replenishment of roots and underground organs.

Study questions

1. Define vitrification
2. List out physiological traits associated with high and low temperature
3. List out functions of HSPs and CSPs
4. Write the plants adaptations to high temperature
5. Enumerate plants responses to high temperature

Lec 05. Salinity

The salts that give rise to salinity come mainly from weathering of rocks, or from aerial deposition of ocean aerosols via wind or rain (Soil with an ECe of 4 dS m⁻¹ will have a salt concentration of 80–100 mM NaCl) most of the time, and substantially reduce the yield of most crop species. The main salt of saline soils is NaCl, but sometimes there are also significant concentrations of Ca₂₊, Mg₂₊, SO₄²⁻ and CO₃²⁻. Seawater intrusion on to low-lying coastal land can also deposit large amounts of salt.

Salinity can occur naturally (primary salinity), or as a result of human activities (secondary salinity).

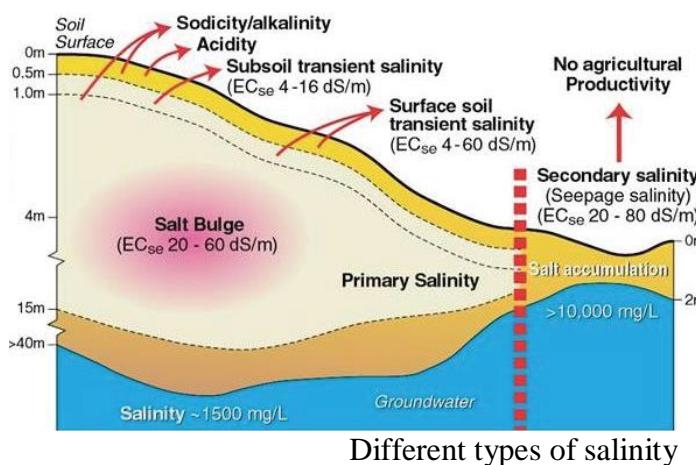
Natural salinity occurs where the rainfall is low and the salt remains in the subsoil. Salt can move in and out of the root zone with seasonal rainfall, giving rise to the term ‘transient salinity’.

Sodicity occurs in soils in which Na⁺ makes up a high percentage of the cations bound to clay particles. This causes loss of soil structure, and the soil becomes waterlogged when wet and

hard as it dries. Sodic soils affect plant growth because roots cannot penetrate layers that are hypoxic or hard. A soil is defined as sodic if the exchangeable sodium percentage (ESP) is greater than 15. Most sodic soils have a pH above 7, the pH depending on whether they were formed from carbonate, bicarbonate, chloride or sulfate salts

The two main causes of secondary salinity are irrigation, and the clearing of land. Irrigation systems are prone to salinization and waterlogging, due to brackish irrigation water, or to excessive leaching and subsequent rising water tables. The amount of salt removed from the soil by crops is negligible, so salt accumulates in the root zone. This accumulation can be managed by leaching and drainage.

Salinity can also be caused by dryland agriculture. The cause of this ‘dry land salinity’ is the clearing of land for dry land agriculture, and replacement of native perennial vegetation by annual crops. This ‘dryland salinity’ can be managed by crop rotations.



These soils have a low fertility potential and the salt excess has many negative effects, including:

- increases the osmotic pressure of the soil solution making water absorption more difficult;
- inhibits imbibition and germination of the seeds;
- inhibits the growth of the root system;
- has a toxic influence on the protoplasm;
- inhibits anabolic processes—photosynthesis and protein synthesis;
- prevents starch formation in somatic cells;
- causes oversaturation of the root system cells with salts, which leads to loss of selectivity in the process of ion absorption, the later entering passively into the cell in order to be accumulated in abundance in the vacuole.

Morpho-physiological changes resulting from excess salinity are:

- disruption of chloroplast submicroscopic structure, leading to etiolated leaves
- reduction of the leaf area
- thickening of the cuticle and palisade tissue in leaves under the action of chlorides and sulphates
- increased succulence of the tissues
- an reduction in the diameter and height of the stem and its lignification

According to their reaction to salts, plants are classified into:

- glycophytes, plants that can't withstand saline soils;
- halophytes plants that during phylogenesis have developed various adaptations that allow them to withstand high concentrations of salts.

Depending on the mechanisms of detoxification and elimination of salts by plants, halophytes are divided into three groups:

(1) Euhalophytes (*Suaeda*, *Salsola*, *Salicornia*). Succulent plants with increased resistance to salinity. The cells of these plants have the ability to withstand high salt concentrations due to the fact that the cells have a high osmotic pressure (about 100 atm), allowing them to absorb water from the saline soil.

(2) Crinohalophytes (*Statice gmelini*, *Tamarix gallica*). These plants absorb salts from the soil, but do not accumulate them in the cell sap but eliminate them through the pores. An increased intensity of photosynthesis characteristic for these plants leads to an increased salt concentration in the cell sap and enables water absorption in soils with a high water retention capacity.

(3) Glycohalophytes (*Artemisia maritima*, *Artemisia salina*). The cytoplasm of the root cells is impermeable to salts and they do not penetrate the cell. The high osmotic pressure in cells allows water absorption due to the accumulation of soluble sugars and organic acids.

According to the degree of salinity resistance crop species are classified as follows:

- salt-sensitive plants: peas, beans, rice, corn, flax, potato, buckwheat, oats, cucumber, radish, carrot, garlic, clover, alfalfa, timothy, fruit trees
- plants with average resistance: rye, wheat, barley, millet, cotton, sunflower, cabbage, soybean, tomato plant, couch grass, grass-of-Sudan
- salt resistant plants: some varieties of barley, sorghum, sugar beet, fodder beet, pumpkin, eggplant, kale.

Physiological Constraints Imposed by Salinity

Osmotic stress

A salt concentration in the soil of 4 dS m^{-1} or 40 mM NaCl has an osmotic pressure of about 0.2 MPa, which affects the ability of plants to take up water. This osmotic effect has a flow-on effect, via internal signals, to reduce the rate of cell expansion in growing tissues, and the degree of stomatal aperture in leaves. The reduction in stomatal conductance of CO_2 limits the rate of photosynthesis, which together with the slower formation of photosynthetic leaf area reduces the flow of assimilates to the meristematic and growing tissues of the plant, both leaves and roots, although leaves are often more affected than roots. For a moderate salinity stress, an inhibition of lateral shoot development becomes apparent over weeks, and over months there are effects on reproductive development, such as early flowering or a reduced number of florets.

Ionic imbalance

The second major constraint imposed by salinity is Na^+ toxicity and ionic imbalance in the cell cytosol. Due to the similarity in physicochemical properties between Na^+ and K^+ (i.e. ionic radius and ion hydration energy), the former competes with K^+ for major binding sites in

key metabolic processes in the cytoplasm, such as enzymatic reactions, protein synthesis and ribosome functions.

1. High concentrations of Na^+ in the soil substantially reduce the activity of many essential nutrients, making them less available for plants. As an example, the presence of 100 mM NaCl in the soil solution results in nearly three-fold drop in Ca^{2+} activity.

2. Na^+ may directly compete at uptake sites with many essential cations such as K^+ (Fig. 3.1), Mg^{2+} or NH_4^+ .

Oxidative stress

Oxidative stress is defined as the toxic effect of chemically reactive oxygen species (ROS) on biological structures. Both osmotically induced stomatal closure and accumulation of high levels of toxic Na^+ species in the cytosol under saline conditions impair photosynthetic machinery and reduce plants capacity to fully utilize light that was absorbed by photosynthetic pigments. This leads to formation of ROS in green tissues. Importantly, ROS production under saline conditions occurs not only in leaf but also in root tissues. The detrimental effects of ROS are a result of their ability to cause lipid peroxidation in cellular membranes, DNA damage, protein denaturation, carbohydrate oxidation, pigment breakdown and an impairment of enzymatic activity.

Impact on plant growth

Salts in the soil water inhibit plant growth for two reasons.

First, the presence of salt in the soil solution reduces the ability of the plant to take up water, this is referred to as the osmotic or water-deficit effect of salinity.

Second, if excessive amounts of salt enter the plant in the transpiration stream there will be injury to cells in the transpiring leaves and this may cause further reductions in growth. This is called the salt-specific or ion-excess effect of salinity.

Disturbance to photosynthesis

The most dramatic and readily measurable whole plant response to salinity is a decrease in stomatal aperture. Salinity affects stomatal conductance immediately, firstly and transiently owing to perturbed water relations and shortly afterward owing to the local synthesis of ABA. Rates of photosynthesis per unit leaf area in salt-treated plants are often unchanged, even though stomatal conductance is reduced. It is explained by the changes in cell anatomy described above that give rise to smaller, thicker leaves and result in a higher chloroplast density per unit leaf area.

Physiological Mechanisms Conferring Salinity Tolerance in Plants

Osmotic adjustment

To maintain the normal growth, plants must therefore readjust to increased external osmolality. This can be done by accumulating a variety of molecules in cytoplasm to counteract the external osmotic pressure.

Three major avenues are available for organisms

- (i) plants can accumulate a range of organic osmolytes by increasing their uptake from external media
- (ii) osmotic adjustment can be achieved by *de novo* synthesis of compatible solutes; and

- (iii) plants can rely on inorganic rather than organic osmolytes and increase accumulation of Na^+ , Cl^- and K^+ for osmotic adjustment purposes.

Four major classes of osmolytes are usually distinguished sugars, polyols, amino acids and quaternary ammonium compounds.

Sodium exclusion from uptake by roots

Na^+ extrusion from the cytosol to the external medium under saline conditions is an active, energy consuming process.

Intracellular sodium sequestration

Efficient Na^+ sequestration in the vacuole is energetically the most favourable and efficient way to achieve osmotic adjustment under saline conditions. The compartmentation of Na^+ into the vacuoles provides an efficient mechanism to achieve this aim.

Potassium retention in the cytosol

With Na^+ toxicity occurring as a result of its competition with K^+ for enzyme activation and protein biosynthesis. plant salinity tolerance may be achieved not only by cytosolic Na^+ exclusion but also by efficient cytosolic K^+ retention. Potassium uptake and retention in plant cells is mediated by a large number of various transporters.

Anatomical Adaptation

several anatomical features are considered to be essential in plant adaptation to a highly saline environment. While most of them are related to efficient Na^+ sequestration or secretion.

Leaf succulence

Leaf succulence is a term used to describe thickening of leaf tissues and the resultant increase in the volume of leaf sap. The physiological rationale beyond this phenomenon is a significant increase in the cell (and, hence, vacuole) size leading to the possibility of more efficient intracellular Na^+ sequestration in this organelle.

Salt glands and bladders

Salt bladders and glands are arguably the most remarkable anatomical feature related to salinity. Three major types of gland or bladder structures are known

- (i) two celled excretory structures found in most of the graminoids
- (ii) multicellular structures found in some graminoids and several dicotyledonous families and
- (iii) The main function of salt glands and bladders is the elimination or sequestration of excess salt from metabolically active tissues.

Changes in the root anatomy

Root growth is usually less affected than leaf growth, and root elongation rate recovers remarkably well after exposure to NaCl or other osmotic. The adaptive advantage of increased branch root growth when the seminal or axile tip is slowed could be the maintenance to total root length for access to water and nutrients.

In order to improve crop plant resistance to high concentrations of salts in the soil various methods may be used which improve both the chemical and colloidal characteristics of the cell protoplasm and the physicochemical properties of the soil.

Depending on the type and amount of salt the following are used:

- gypsum and phosphogypsum on saline and alkaline soils with strong alkaline reaction;
- finely ground limestone (calcium carbonate) and quicklime (calcium oxide) in pulverized state on saline soils;
- organic fertilizers—vegetal remains, manure and other to improve the physicochemical, mechanical, chemical and biological properties of the soils;
- physiologically acidic fertilizers: $(\text{NH}_4)_2\text{SO}_4$, ammonia water (NH_4OH), urea
- the administration of microelements (Al, Mn, Cu, B, Zn) in order to modify the permeability of the plasma membrane of absorbent cells;
- treatment of the seeds with salt solutions of increasing concentration

Salt resistance can be increased by using of specific hardening methods: germinated seeds are kept for an hour in 3 % NaCl solution and then washed. Such seeds have a lower exchange of substances, but possess a higher resistance to salt.

Study questions

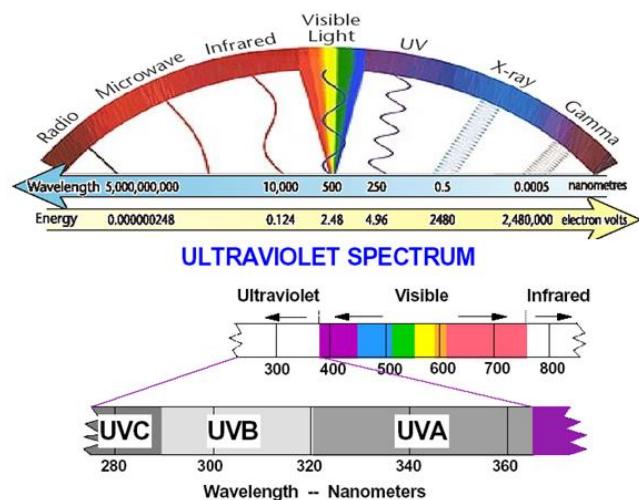
1. Differentiate osmotic and ionic stress
2. Enumerate the mechanism of salinity tolerance
3. Define oxidative stress? And write the effect of ROS on plant metabolism
4. What is osmotic adjustment and how it help in salinity tolerance
5. Write any four salinity tolerant plants

Lec 6. Light and UV Radiation Stress in Plants

Rapidly changing light conditions can reduce carbon gain and productivity in field crops because photosynthetic responses to light fluctuations are not instantaneous. Plant responses to fluctuating light occur across levels of organizational complexity from entire canopies to the biochemistry of a single reaction and across orders of magnitude of time. Although light availability and variation at the top of the canopy are largely dependent on the solar angle and degree of cloudiness, lower crop canopies rely more heavily on light in the form of sunflecks, the quantity of which depends mostly on canopy structure but also may be affected by wind. The ability of leaf photosynthesis to respond rapidly to these variations in light intensity is restricted by the relatively slow opening/closing of stomata, activation/deactivation of C₃ cycle enzymes, and up-regulation/down-regulation of photoprotective processes. The metabolic complexity of C₄ photosynthesis creates the apparently contradictory possibilities that C₄ photosynthesis may be both more and less resilient than C₃ to dynamic light regimes, depending on the frequency at which these light fluctuations occur.

Our nearest star, the sun, emits short wavelength radiation that is incident on the earth's atmosphere. Most of the radiation in the atmosphere is infrared radiation (700-3000 nm, 67% of the photons) and visible light (400-700 nm, 28%; Nobel, 1983). Ultraviolet radiation (UV, 200-400 nm), on the other hand, reaches the atmosphere in smaller amounts (5% of the photons). The biologically most hazardous part of UV radiation, i.e. UV-C (200-280 nm) and

UV-B (280-320 nm) below 290 nm, are completely absorbed by the stratospheric ozone (O_3) layer and by other oxygen molecules in the atmosphere. In addition, the ozone layer absorbs some longer-wave UV-B and UV-A radiation (320-400 nm) (Fig. 1). However, of the total solar energy reaching the earth's surface, UV-B radiation comprises about 1.5% and UV-A radiation about 6.4%. The intensity of UV-B radiation, in particular, is affected by the thickness of the ozone layer, which in turn varies periodically as a consequence of natural processes such as seasons, winds and solar cycles. In addition, latitude, time of year and time of day determine the length of the path of a UV-B photon through the absorptive ozone layer.

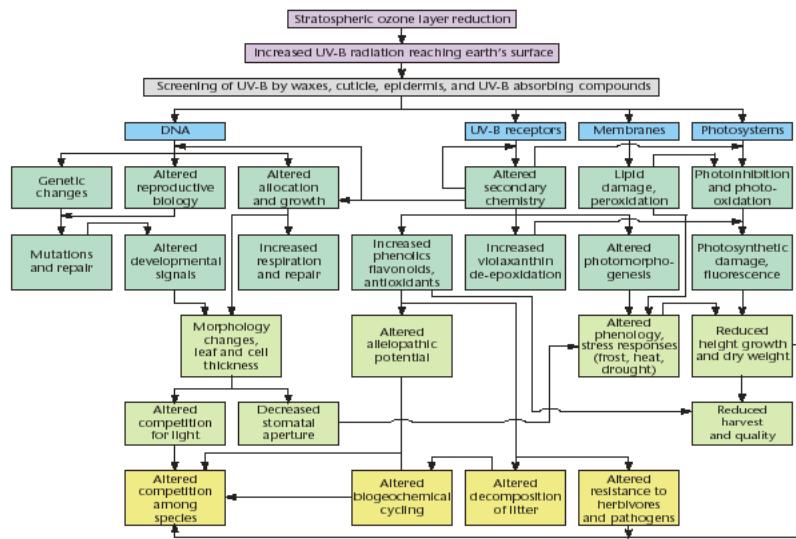


On average, the ozone concentration in the stratosphere is low, i.e. about ten ozone molecules per million molecules of air; and it is highly dynamic because the ozone molecules are created and destroyed continuously. Depletion of the ozone layer has repeatedly been reported to occur over Antarctica, but in the 1990's there were also frequent occurrences of major spring-time ozone depletion over the Arctic. It has been found that the main man-made compounds responsible for enhancing ozone breakdown are the chlorofluorocarbons (CFC) and nitrogen oxides. Recently, it was also found that the increasing concentrations of greenhouse gases result in stratospheric cooling, thus creating suitable conditions for breakdown of ozone molecules. Therefore, the most recent predictions based on stratospheric chemistry and climate-change models estimate that in the northern areas ($60\text{--}90^\circ N$), compared with the long-term means, the maximum springtime UV-B radiation will increase up to 50-60% in 2010-2020.

Effect of UV-B radiation in plants

Elevated levels of UV-B radiation will have many direct and indirect effects on plants. Even present-day levels of UV-B radiation affect the growth and development of plants. The direct effects of UV-B radiation on plant cells are mostly damaging, because UV-B photons have enough energy to create lesions in important UV-B-absorbing biomolecules such as nucleic acids and proteins. It is known that the photoproducts of DNA formed by UV-B radiation, cyclobutane pyrimidine dimers and pyrimidine (6-4) pyrimidone and (6-4) photoproducts, are all toxic and mutagenic. In addition, the altered DNA and RNA structures may interfere with transcription and replication; and therefore protein synthesis may be slowed down during UV-B stress. In order to avoid the effects of DNA damage, plants have efficient systems for DNA repair, including

photoreactivation and excision repair, which are involved in restoring the structure of genetic material during exposure to UV-B radiation. However, the indirect effects of UV-B on plant cells can also be damaging: UV-B radiation may cause oxidative damage in chlorophylls and polyunsaturated lipids by increasing the formation of free radicals and peroxides. To prevent oxidative damage, cells contain antioxidants, e.g., phenolic compounds, that scavenge the free radicals. Phenolic compounds have variable antioxidant properties; and several studies have shown that during UV-B exposure, the production of compounds with efficient antioxidant structures, such as additional hydroxyl groups on ring B of the flavonoid skeleton, is favoured. Plant cells also contain enzymes, e.g., superoxide dismutase (SOD) and catalase, which scavenge superoxide radicals and protect the cells against H₂O₂, respectively.



Signal transduction and gene expression

In addition to damaging plant cell components, UV-B radiation often exerts its effects through altered patterns of gene activity; e.g., the effects of UV-B radiation on photosynthesis, UV-B-screening phenolics, growth, reproductive processes, plant form and timing of life phases, are all caused by altered gene action. The mechanisms by which plants perceive UV-B radiation are not fully understood, but it has been suggested that direct absorption of UV-B by DNA could result in the formation of a “signal” that regulates the transcription of genes.

In addition, it has been hypothesized that in plant cells, specific UV-B photoreceptor-mediated signalling processes regulate gene expression. However, the characteristics of a UV-B photoreceptor and how the signals are transduced after UV-B perception, are not yet known.

In addition to the increase in ROS other known signal transduction intermediates increase their levels. These include salicylic acid (SA), jasmonic acid (JA) and ethylene. Using *Arabidopsis* mutants that are insensitive to SA, JA and ethylene, clear differences in gene activity response have been demonstrated. Furthermore, although ROS is

involved in down-regulation of RNA for photosynthetic proteins, the chloroplast signal may not be involved. There are at least three separate signal transduction pathways involved in UV-B gene regulation and substantial “cross-talk” must take place.

A unique response of plants to UV-B radiation relates to the property of high photosynthetically active radiation (PAR) to ameliorate its damaging impact. This ‘protection’ against UV-B damage did not involve synthesis of protective pigments, but was related to the function of the photosynthetic apparatus itself. The photosynthetic system can act as a photoreceptor and specific wavelengths can change chloroplast gene expression. Research conducted by Jordan *et al.*, (1994) on etiolated tissue is also indicative of a strong link between the development of the photosynthetic apparatus and UV-B-induced gene expression. The connections between UV-B radiation and photosynthesis, and the signal transduction pathways that lead to modification of gene expression are yet to be comprehended.

Study questions

1. Write wavelength for three types of UV radiation
2. Write the effect of UV-B radiation in plants
3. Short notes photoreceptors
4. How UV radiation helps in ROS production
5. Write the role of phenolics in UV stress tolerance

Lecture. 07. Impact of heavy metals on physiology and productivity of crops –

Phytoremediation

Introduction

Heavy metals are among the contaminants in the environment. Beside the natural activities, almost all human activities also have potential contribution to produce heavy metals as side effects. Migration of these contaminants into noncontaminated areas as dust or leachates through the soil. Several methods are already being used to clean up the environment from these kinds of contaminants. The chemical technologies generate large volumetric sludge and increase the costs; chemical and thermal methods are both technically difficult and expensive that all of these methods can also degrade the valuable component of soils.

Phytoremediation has become an effective and affordable technological solution used to extract or remove inactive metals and metal pollutants from contaminated soil. Phytoremediation is the use of plants to clean up a contamination from soils, sediments, and water. This technology is environmental friendly and potentially costeffective. Plants with exceptional metal-accumulating capacity are known as hyperaccumulator plants. Phytoremediation takes the advantage of the unique and selective uptake capabilities of plant root systems, together with the translocation, bioaccumulation, and contaminant degradation abilities of the entire plant body.

Many species of plants have been successful in absorbing contaminants such as lead, cadmium, chromium, arsenic, and various radionuclides from soils. One of phytoremediation categories, phytoextraction, can be used to remove heavy metals from soil using its ability to uptake metals which are essential for plant growth (Fe, Mn, Zn, Cu, Mg, Mo, and Ni). Some metals with unknown biological function (Cd, Cr, Pb, Co, Ag, Se, Hg) can also be accumulated.

Heavy metals

Heavy metals are conventionally defined as elements with metallic properties and an atomic number >20. The most common heavy metal contaminants are Cd, Cr, Cu, Hg, Pb, and Zn. Metals are natural components in soil. Some of these metals are micronutrients necessary for plant growth, such as Zn, Cu, Mn, Ni, and Co, while others have unknown biological function, such as Cd, Pb, and Hg.

Metal pollution has harmful effect on biological systems and does not undergo biodegradation. Toxic heavy metals such as Pb, Co, Cd can be differentiated from other pollutants, since they cannot be biodegraded but can be accumulated in living organisms, thus causing various diseases and disorders even in relatively lower concentrations. Heavy metals, with soil residence times of thousands of years, pose numerous health dangers to higher organisms. They are also known to have effect on plant growth, ground cover and have a negative impact on soil microflora. It is well known that heavy metals cannot be chemically degraded and need to be physically removed or be transformed into nontoxic compounds.

Arsenic (AS)

Arsenic (atomic number 33) is a silver-grey brittle crystalline solid with atomic weight of 74.9, specific gravity 5.73, melting point 817°C (at 28 atm), boiling point 613°C, and vapor pressure 1mm Hg at 372°C. Inorganic arsenic compounds are mainly used to preserve wood. Organic arsenic compounds are used as pesticides, primarily on cotton plants. Arsenic exists in the -3, 0, +3, and +5 valence oxidation states, and in a variety of chemical forms in natural waters and sediments. Two most common forms in natural waters arsenite and inorganic arsenate, referred as As^{3+} and As^{5+} .

Arsenic is one of the contaminants found in the environment which is notoriously toxic to man and other living organisms. It is a highly toxic element that exists in various species. It is generally accepted that the inorganic species, arsenite [As^{3+}] and arsenate [As^{5+}], are the predominant species in most environments. The trivalent compounds (arsenites) are more toxic than the pentavalent compounds (arsenates). It has been reported that As^{3+} is 4 to 10 times more soluble in water than As^{5+} . Although As^{5+} tends to be less toxic compared to As^{3+} , it is thermodynamically more stable due to it predominates under normal conditions and becomes the cause of major contaminant in ground water.

Lead (Pb)

Lead (Pb), with atomic number 82, atomic weight 207.19, and a specific gravity of 11.34, is a bluish or silvery-grey metal with a melting point of 327.5°C and a boiling point at atmospheric pressure of 1740°C. It has four naturally occurring isotopes with atomic weights 208, 206, 207 and 204 (in decreasing order of abundance). Soil and plants can be contaminated by lead from car exhaust, dust, and gases from various industrial sources. Since Pb²⁺ is not biodegradable, once soil has become contaminated, it remains a long-term source of Pb²⁺ exposure. Metal pollution has a harmful effect on biological systems and does not undergo biodegradation.

Soil can be contaminated with Pb from several other sources such as industrial sites, from leaded fuels, old lead plumbing pipes, or even old orchard sites in production where lead arsenate is used. Lead accumulates in the upper 8 inches of the soil and is highly immobile. Contamination is long-term. Without remedial action, high soil lead levels will never return to normal. In the environment, lead is known to be toxic to plants, animals, and microorganisms. Effects are generally limited to especially contaminated areas.

Mercury (Hg)

Mercury is a naturally occurring metal that is present in several forms. Metallic mercury is shiny, silver-white, odorless liquid. Mercury combines with other elements, such as chlorine, sulfur, or oxygen, to form inorganic mercury compounds or salts, which are usually white powders or crystals. Mercury, which has the lowest melting point (-39°C) of all the pure metals, is the only pure metal that is liquid at room temperature. As any other metal, mercury could occur in the soil in various forms. It dissolves as free ion or soluble complex and is nonspecifically adsorbed by binding mainly due to the electrostatic forces, chelated, and precipitated as sulphide, carbonate, hydroxide, and phosphate. There are three soluble forms of Hg in the soil environment. The most reduced is Hg⁰ metal with the other two forms being ionic of mercurous ion and mercuric ion Hg²⁺, in oxidizing conditions especially at low pH. Hg⁺ ion is not stable under environmental conditions since it dismutates into Hg⁰ and Hg²⁺.

Mercury is a persistent environmental pollutant with bioaccumulation ability in fish, animals, and human beings. Mercury salts and organomercury compounds are among the most poisonous substances in our environment. Environmental contamination due to mercury is caused by several industries, petrochemicals, minings, painting, and also by agricultural sources such as fertilizer and fungicidal sprays. Some of the more common sources of mercury found throughout the environment include but may not be limited to the household bleach, acid, and caustic chemicals (e.g., battery acid, household lye, muriatic acid (hydrochloric acid), sodium hydroxide, and sulfuric acid), instrumentation containing mercury (e.g., medical instruments, thermometers, barometers, and manometers), dental amalgam (fillings), latex paint (manufactured prior to 1990), batteries, electric lighting (fluorescent lamps, incandescent wire filaments, mercury vapor lamps, ultraviolet lamps), pesticides, pharmaceuticals (e.g., nasal sprays, cosmetics, contact lens

products), household detergents and cleaners, laboratory chemicals, inks and paper coatings, lubrication oils, wiring devices and switches, and textiles. Though mercury use in many of the above items being produced now is restricted or banned, there are still some existing, older products in use.

Terrestrial plants are generally insensitive to the harmful effects of mercury compounds; however, mercury is known to affect photosynthesis and oxidative metabolism by interfering with electron transport in chloroplasts and mitochondria. Mercury also inhibits the activity of aquaporins and reduces plant water uptake.

Mercury and its compounds are cumulative toxins and in small quantities are hazardous to human health.

Phytoremediation

Phytoremediation techniques have been briefly depicted in many literatures or articles. Phytoremediation is defined as an emerging technology using selected plants to clean up the contaminated environment from hazardous contaminant to improve the environment quality. For organics, it involves phytostabilization, rhizodegradation, rhizofiltration, phytodegradation, and phytovolatilization. These mechanisms related to organic contaminant property are not able to be absorbed into the plant tissue. For inorganics, mechanisms which can be involved are phytostabilization, rhizofiltration, phytoaccumulation and phytovolatilization.

The root plants exudates to stabilize, demobilize and bind the contaminants in the soil matrix, thereby reducing their bioavailability. These all are called as **phytostabilization** process. Certain plant species have used to immobilize contaminants in the soil and ground water through absorption and accumulation by roots, adsorption onto roots, or precipitation within the root zone. This process is for organics and metals contaminants in soils, sediments, and sludges medium.

Specific plant species can absorb and hyperaccumulate metal contaminants and/or excess nutrients in harvestable root and shoot tissue, from the growth substrate through phytoextraction process. This is for metals, metalloids, radionuclides, nonmetals, and organics contaminants in soils, sediments, and sludges medium.

Phytovolatilization process is the plants ability to absorb and subsequently volatilize the contaminant into the atmosphere. This process is for metal contaminants in groundwater, soils, sediments, and sludges medium. Since phytotransformation/phytodegradation process is the breakdown of contaminants taken up by plants through metabolic processes within the plant or the breakdown of contaminants externally to the plant through the effect of compounds produced by the plants. This process is for complex organic molecules that are degraded into simpler molecule contaminants in soils, sediments, sludges, and groundwater medium.

Plant roots take up metal contaminants and/or excess nutrients from growth substrates through

Rhizofiltration the process, adsorption, or, precipitation onto plant roots or absorption into the roots of contaminants that are in solution surrounding the root zone. This process is for metals, excess nutrients, and radionuclide contaminants in groundwater, surface water, and wastewater medium.

The breakdown of contaminants in the soil through microbial activity that is enhanced by the presence of the root zone is called rhizodegradation. This process uses microorganisms to consume and digest organic substances for nutrition and energy. Natural substances released by the plant roots, sugars, alcohols, and acids, contain organic carbon that provides food for soil microorganisms and establish a dense root mass that takes up large quantities of water. This process is for organic substance contaminants in soil medium.

Mechanisms of Heavy Metal Uptake by Plant

The plants act both as “accumulators” and “excluders”. Accumulators survive despite concentrating contaminants in their aerial tissues. They biodegrade or biotransform the contaminants into inert forms in their tissues. The excluders restrict contaminant uptake into their biomass.

Plants have evolved highly specific and very efficient mechanisms to obtain essential micronutrients from the environment, even when present at low ppm levels. Plant roots, aided by plant-produced chelating agents and plant-induced pH changes and redox reactions, are able to solubilize and take up micronutrients from very low levels in the soil, even from nearly insoluble precipitates. Plants have also evolved highly specific mechanisms to translocate and store micronutrients. These same mechanisms are also involved in the uptake, translocation, and storage of toxic elements, whose chemical properties simulate those of essential elements. Thus, micronutrient uptake mechanisms are of great interest to phytoremediation.

The range of known transport mechanisms or specialized proteins embedded in the plant cell plasma membrane involved in ion uptake and translocation include (1) proton pumps (" H^+ -ATPases that consume energy and generate electrochemical gradients), (2) co and antitransporters and (3) channels. Each transport mechanism is likely to take up a range of ions. After uptake by roots, translocation into shoots is desirable because the harvest of root biomass is generally not feasible.

Plant uptake-translocation mechanisms are likely to be closely regulated. Plants generally do not accumulate trace elements beyond near-term metabolic needs. And these requirements are small ranging from 10 to 15ppm of most trace elements suffice for most needs. The exceptions are “hyperaccumulator” plants, which can take up toxic metal ions at levels in the thousands of ppm.

Since contamination is translocated from roots to the shoots, which are harvested, contamination is removed while leaving the original soil undisturbed. Some plants that are used in phytoextraction strategies are termed “hyperaccumulators.” They are plants that achieve a shoot-to-root metal-concentration ratio greater than one. Nonaccumulating plants typically have a shoot-to-root ratio considerably less than one. Ideally, hyperaccumulators should thrive in toxic environments, require little maintenance and produce high biomass, although few plants perfectly fulfill these requirements.

Metal accumulating plant species can concentrate heavy metals like Cd, Zn, Co, Mn, Ni, and Pb up to 100 or 1000 times those taken up by nonaccumulator (excluder) plants. In most cases, microorganisms bacteria and fungi, living in the rhizosphere closely associated with plants, may contribute to mobilize metal ions, increasing the bioavailable fraction. Their role in eliminating organic contaminants is even more significant than that in case of inorganic compounds. Heavy metal uptake by plant through phytoremediation technologies is using these mechanisms of phytoextraction, phytostabilisation, rhizofiltration, and phytovolatilization

Phytoextraction

Phytoextraction is the uptake/absorption and translocation of contaminants by plant roots into the above ground portions of the plants (shoots) that can be harvested and burned gaining energy and recycling the metal from the ash.

Phytostabilisation

Phytostabilisation is the use of certain plant species to immobilize the contaminants in the soil and groundwater through absorption and accumulation in plant tissues, adsorption onto roots, or precipitation within the root zone preventing their migration in soil, as well as their movement by erosion and deflation.

Rhizofiltration

Rhizofiltration is the adsorption or precipitation onto plant roots or absorption into and sequesterization in the roots of contaminants that are in solution surrounding the root zone by constructed wetland for cleaning up communal wastewater.

Phytovolatilization

Phytovolatilization is the uptake and transpiration of a contaminant by a plant, with release of the contaminant or a modified form of the contaminant to the atmosphere from the plant. Phytovolatilization occurs as growing trees and other plants take up water along with the

contaminants. Some of these contaminants can pass through the plants to the leaves and volatilize into the atmosphere at comparatively low concentrations.

Plants also perform an important secondary role in physically stabilizing the soil with their root system, preventing erosion, protecting the soil surface, and reducing the impact of rain. At the same time, plant roots release nutrients that sustain a rich microbial community in the rhizosphere. Bacterial community composition in the rhizosphere is affected by complex interactions between soil type, plant species, and root zone location. Microbial populations are generally higher in the rhizosphere than in the root-free soil. This is due to a symbiotic relationship between soil microorganisms and plants. This symbiotic relationship can enhance some bioremediation processes. Plant roots also may provide surfaces for sorption or precipitation of metal contaminants.

In phytoremediation, the root zone is of special interest. The contaminants can be absorbed by the root to be subsequently stored or metabolised by the plant. Degradation of contaminants in the soil by plant enzymes exuded from the roots is another phytoremediation mechanism.

Advantages of Phytoremediation

Phytoremediation techniques may also be more publicly acceptable, aesthetically pleasing, and less disruptive than the current techniques of physical and chemical process. Advantages of this technology are its effectiveness in contaminant reduction, low-cost, being applicable for wide range of contaminants, and in overall it is an environmental friendly method.

The major advantages of the heavy metal adsorption technology by biomass are its effectiveness in reducing the concentration of heavy metal ions to very low levels and the use of inexpensive biosorbent materials.

Phytoremediation as possibly the cleanest and cheapest technology can be employed in the remediation of selected hazardous sites. Phytoremediation encompasses a number of different methods that can lead to contaminant degradation. Phytoremediation is a low-cost option and inexpensive approach for remediating environmental media, particularly suited to large sites that have relatively low levels of contamination.

Phytoremediation can be an alternative to the much harsher remediation technologies of incineration, thermal vaporization, solvent washing, or other soil washing techniques, which essentially destroy the biological component of the soil and can drastically alter its chemical and physical characteristics as well as creating a relatively nonviable solid waste. Another advantage of phytoremediation is the generation of a recyclable metal-rich plant residue.

Phytoremediation could be a viable option to decontaminate heavy-metal-polluted soils, particularly when the biomass produced during the phytoremediation process could be

economically valorized in the form of bioenergy. The use of metal-accumulating bioenergy crops might be suitable for this purpose. If soils, contaminated with heavy metals, are phytoremediated with oil crops, biodiesel production from the resulting plant oil could be a viable option to generate bioenergy.

Defense Mechanisms Employed by Plants against heavy metal Stress

As mentioned earlier, plants possess a sophisticated and interrelated network of defense strategies to avoid or tolerate HM intoxication. Physical barriers are the first line of defense in plants against metals. Some morphological structures like thick cuticle, biologically active tissues like trichomes, and cell walls as well as mycorrhizal symbiosis can act as barriers when plants are faced with HM stress. Trichomes, for instance, can either serve as HM storage site for detoxification purposes or secrete various secondary metabolites to negate hazardous effects of metals. On the other hand, once HMs overcome biophysical barriers and metal ions enter tissues and cells, plants initiate several cellular defense mechanisms to nullify and attenuate the adverse effects of HMs. Biosynthesis of diverse cellular biomolecules is the primary way to tolerate or neutralize metal toxicity. This includes the induction of a myriad of low-molecular weight protein metallochaperones or chelators such as nicotianamine, putrescine, spermine, mugineic acids, organic acids, glutathione, phytochelatins, and metallothioneins or cellular exudates such as flavonoid and phenolic compounds, protons, heat shock proteins, and specific amino acids, such as proline and histidine, and hormones such as salicylic acid, jasmonic acid, and ethylene. When the above-mentioned strategies are not able to restrain metal poisoning, equilibrium of cellular redox systems in plants is upset, leading to the increased induction of ROS. To mitigate the harmful effects of free radicals, plant cells have developed antioxidant defense mechanism which is composed of enzymatic antioxidants like superoxide dismutase (SOD), catalase, (CAT), ascorbate peroxidase (APX), guaiacol peroxidase (GPX), and glutathione reductase (GR) and nonenzymatic antioxidants like ascorbate (AsA), glutathione (GSH), carotenoids, alkaloids, tocopherols, proline, and phenolic compounds (flavonoids, tannins, and lignin) that act as the scavengers of free radicals. As previously indicated some of the biological molecules involved in cellular metal detoxification can be multifunctional and have antiradical, chelating, or antioxidant activities. Exploitation and upregulation of any of these mechanisms and biomolecules may depend on plant species, the level of their metal tolerance, plant growth stage, and metal type. Some of the defense mechanisms used by plants against HMs will be discussed below.

Phytochelatins (PCs)

One of the mechanisms adopted by plants to detoxify HMs is the production of short-chain thiol-rich repetitions of peptides of low-molecular weight synthesized from sulfur-rich glutathione (GSH) by the enzyme phytochelatin synthase (PCS) with the general structure of (γ -glutamyl-cysteinyl)-glycine (to 11) that have a high affinity to bind to HMs when they are at toxic levels.

In plants, PCs are found to be part of the defensive act not only against metal-related stresses but also in response to other stressors such as excess heat, salt, UV-B, and herbicide. PCs are reported to be used as biomarkers for the early detection of HM stress in plants.

Metallothioneins (MTs)

MTs, which were first extracted from equine kidney in 1957, are another family of small cysteine-rich, low-molecular-weight cytoplasmic metal-binding proteins or polypeptides that are found in a wide variety of eukaryotic organisms including fungi, invertebrates, mammals, and plants as well as some prokaryotes. Contrary to PCs that are the product of enzymatically synthesized peptides, MTs are synthesized as a result of mRNA translation. Whereas PCs in plants may mainly deal with Cd detoxification, MTs appear to be capable of showing affinity with a greater range of metals such as Cu, Zn, Cd, and As. In plants, these ligands are involved in nullifying toxicity of HMs through cellular sequestration, homeostasis of intracellular metal ions, and metal transport adjustment. In addition to their role in HM detoxification, MTs are known to be active agents in a number of cellular-related events including ROS scavenger, maintenance of the redox level, repair of plasma membrane, cell proliferation, and its growth and repair of damaged DNA.

Proline

Proline is a proteinogenic five-carbon α -amino acid that acts as a compatible and metabolic osmolyte, a constituent of cell wall, free radical scavenger, antioxidant, and macromolecules stabilizer. Some other functions of Pro include promoting embryo/seed evolvement, extending stem length as well as moving plants from vegetative growth to reproductive stage. The production of elevated levels of Pro by higher plants is a typical nonenzymatic response to tensions caused by a wide range of biotic and abiotic stressors such as excessive salinity, drought, increased solar ultraviolet (UV) radiation, HMs, and oxidative stress

ArbuscularMycorrhizal (AM)

Symbiotic mycorrhizal fungi such as AM form a mutualistic symbiosis with roots of most vascular plant species under different climatic conditions in which they are beneficiary of photosynthetic assimilations provided by plants and in return they improve the mineral nutrition status of plants and can also enhance their tolerance towards some stresses and pollutants. Plant-fungal mutualism may act as a precursor in which it signals the herald of stress to symbiotic plants so that they can make their protective mechanisms active to ameliorate deleterious effects of stress earlier than nonsymbiotic plants. Principal mechanisms adopted by mycorrhizal fungi to cancel out impacts of HM stress on plants include acting as a barrier by depositing metals within

cortical cells, binding metals to cell wall or mycelium as well as sequestering them in their vacuole or other organelles releasing heat-shock protein and glutathione, precipitating or chelating metals in the soil matrix via producing glycoprotein or making phosphate-metal complexes inside the hyphae, and reducing the strength of metals by heightened root and shoot growth. The varied strategies employed by AM when facing toxicity of HMs suggest that different species of mycorrhizal fungi might act specifically or adopt the remedial function which suits the prevailing condition in either rhizosphere or plant.

Study questions

1. What are all the heavy metals?
2. Advantages of Phytoremediation
3. Explain Mechanisms adopted by Plants against heavy metal Stress
4. List out functions of Metallothioneins in heavy metal tolerance
5. Short notes on Phytochelatins (PCs)

Lecture No: 9: Diagnosis and correction measures for nutritional disorders in Cereals, Pulses, Oilseeds, Fibre and Sugar crops.

Plants need the right combination of nutrients to live, grow and reproduce. When plants suffer from malnutrition, they show symptoms of being unhealthy. Too little or too much of any one nutrient can cause problems. Plant nutrients fall into two categories: macronutrients and micronutrients. Macronutrients are those elements that are needed in relatively large amounts. They include nitrogen, potassium, sulfur, calcium, magnesium and phosphorus. Micronutrients are those elements that plants need in small amounts (sometimes trace amounts), like iron, boron, manganese, zinc, copper, chlorine and molybdenum. Both macro- and micronutrients are naturally obtained by the roots from the soil. Plant roots require certain conditions to obtain these nutrients from the soil. First, the soil must be sufficiently moist to allow the roots to take up and transport the nutrients. Sometimes correcting improper watering strategies will eliminate nutrient deficiency symptoms. Second, the pH of the soil must be within a certain range for nutrients to be release-able from the soil particles. Third, the temperature of the soil must fall within a certain range for nutrient uptake to occur. The optimum range of temperature, pH and moisture is different for different species of plants. Thus, nutrients may be physically present in the soil, but not available to plants. A knowledge of soil pH, texture, and history can be very useful for predicting what nutrients may become deficient. Nitrogen, phosphorous, and iron are the only nutrients that are commonly lacking in Arizona soils. Most of the others can be lacking under certain conditions, but deficiencies are quite rare. The following table lists nutrients that may be lacking in Arizona soils, and what deficiency symptoms often look like. Keep in mind that each plant variety is different and may display different symptoms.

Nutrient disorders and corrective measures in cereals Rice (*Oryzae sativa*)

Nitrogen

Deficiency Symptoms

Deficient plants appear stunted, thin and spindly with pale green to yellowish green leaves. The number of tillers and grain yields are reduced severely. Nitrogen is mobile in plants and under short supply conditions it is easily mobilized from older to younger leaves. The deficiency symptoms appear first and become more severe on older leaves. If deficiency occurs during the young stage of the crop, the whole plant appears uniformly pale green to yellowish green. The deficient rice field gives a clear impression of nitrogen deficiency by providing a yellowish green look to the entire crop. In later stages of the crop, older leaves become pale yellow while younger leaves remain green



Correction Measure

Use slow-release nitrogenous fertilizers such as sulphur-coated urea or urea supergranules in a basal dressing before planting. Top-dress soluble nitrogenous fertilizers such as urea in two or three split doses. For quick recovery, apply urea (2% w/v solution) as a foliar spray in standing crops. Foliar sprays are required to be repeated every 10–15 days.

Phosphorus

Deficiency Symptoms

Phosphorus-deficient rice plants appear dark green with narrow, short and erect leaves. Plants are stunted with reduced tillering. Stems are thin and spindly with retarded growth. The number of panicles and grains per panicle are drastically reduced. Phosphorus deficiency delays crop maturity. Nitrogen application gives no response, if phosphorus is deficient. Phosphorus is mobile in plants and under short supply conditions it is easily mobilized from older to younger leaves. The deficiency symptoms appear first and become more severe on older leaves. Symptoms begin with a dark green to bluish green coloration on older leaves. Younger leaves remain green and healthy. In some rice varieties having the tendency to produce rich amounts of anthocyanin pigment, red and purple colours may develop on affected older leaves.

Correction Measure

Application of phosphobacteria as a seed coating, or as a seedling dip. Application of P fertilizer 15-30 kg P ha⁻¹ to the soil, Rock phosphate broadcast before flooding when soil pH is low.

Potassium

Deficiency Symptoms

Rice crop has strong hidden hunger to potassium deficiency. Visual deficiency symptoms appear only in severe deficiency conditions and mostly during later stages of crop growth. Hybrid rice varieties are more sensitive to potassium deficiency than modern inbred improved varieties. Potassium moves readily from old to young leaves, therefore deficiency symptoms

appear first on old leaves. Yellowish brown marginal necrosis begins from the tip of the leaf and advances down the margins towards the base. Dark rust brown spots appear on the leaf surface in some rice varieties. Bronzing of older leaves is also a characteristic symptom of potassium deficiency



Correction Measure

Foliar spray of KCl @ 5gram/lit at 15 days interval up to the disappearance of symptoms

Calcium

Deficiency Symptoms

Chlorotic – necrotic split or rolled tips of younger leaves. Tips of youngest leaves become white rolled and curled. Necrotic tissue along the lateral margins.

Correction Measure

Apply CaCl₂ or Ca containing foliar sprays for rapid treatment of severe Ca deficiency. Apply gypsum in Ca-deficient high pH soils, e.g., on sodic & high K soils.

Magnesium

Deficiency Symptoms

Leaf chlorotic with white tips. Orange-yellow interveinal chlorosis on older leaves. Plant are pale colored with interveinal chlorosis first appearing on older leafs. Leaf number and leaf length are greater. The leaves are wavy and droopy.

Correction Measure

Foliar application of liquid fertilizers containing Mg (e.g., MgCl₂ 2%)

Sulphur

Deficiency Symptoms

Deficient plants appear stunted, thin and spindly with pale yellow leaves. The numbers of tillers and grains per plant are reduced. Sulphur deficiency also delays crop maturity. 2. At initial stages of growth sulphur deficiency symptoms resemble nitrogen deficiency symptoms, as in both cases the whole plant appears pale green. In contrast to nitrogen deficiency where older leaves are more pale yellow than the younger leaves, sulphur deficiency produces more pronounced chlorosis on the young leaves with comparatively darker old leaves. Sulphur is less mobile in the plant than nitrogen, so under short supply conditions deficiency symptoms tend to appear first on younger leaves .



Correction Measure

For moderate S deficiency apply 10 kg S ha⁻¹ application of 20-40 kg S ha⁻¹. Use slow acting S forms (gypsum, elemental S) if leaching is likely to be a problem. Soil application of calcium silicate: 120-200 kg ha⁻¹ or Potassium silicate: 40-60 kg ha⁻¹.

Boron

Deficiency Symptoms

White rolled leaf tips of young leaves. Reduced height with leaf tips white in colour and rolled. Death of the growing point.



Correction Measure

Soil application of borax at 0.5-3 kg ha⁻¹ or as foliar spray during vegetative growth

Copper

Deficiency Symptoms

Chlorotic streaks, bluish green leaves. Leaf tips become chlorotic with streaks on either side of the midrib, followed by appearance of dark brown necrotic lesions on the leaf tips. Leaves bluish green and leaf tip needle-like, while the leaf base appears normal. Tillering reduced.

Correction Measure

Soil application CuSO₄ at 1-5 kg Cu ha⁻¹ or apply cupric sulfate solution as foliar spray.

Manganese

Deficiency Symptoms

Interveinal chlorosis starting at the tip of younger leaves. Pale greyish green interveinal chlorosis spreading from the tip of the leaf to the base. Necrotic brown spots develop and leaf becomes dark brown. New leaves short narrow and light green.

Correction Measure

Apply MnSO₄ (5-20 kg Mn ha⁻¹) in bands along rice row. Apply foliar MnSO₄ (1-5 kg Mn ha⁻¹ in about 200 L water ha⁻¹)

Manganese

Deficiency Symptoms

Interveinal chlorosis starting at the tip of younger leaves. Pale greyish green interveinal chlorosis spreading from the tip of the leaf to the base. Necrotic brown spots develop and leaf becomes dark brown. New leaves short narrow and light green.

Correction Measure

Apply MnSO₄ (5-20 kg Mn ha⁻¹) in bands along rice row. Apply foliar MnSO₄ (1-5 kg Mn ha⁻¹ in about 200 L water ha⁻¹)

Silicon

Deficiency Symptoms

Soft, droopy leaves and culms. Leaves become chlorotic which later become necrotic brown spots. Entire leaf becomes brown or pink. Reduced panicles per m². Susceptible to lodging.

Correction Measure

Apply Calcium silicate @ 120- 200 kg/ ha (or) Potassium silicate @ 40- 60 kg/ ha for disappearance of symptoms

Zinc

Deficiency Symptoms

Dusty brown spots on upper leaves. Stunted plants. Tillering decreases. Increase spikelet. Sterility leaf base of younger leaves, become chlorotic brown and blotches streaks on lower leaves. Lower leaves are chlorotic particularly at the base.

Correction Measure

Broadcast ZnSO₄ in nursery seedbed. Dip seedlings or presoak seeds in a 2-4% ZnO suspension. Apply 5-10 kg Zn ha⁻¹ as Zn sulfate, apply 10-25 kg ha⁻¹ ZnSO₄ 7 H₂O. Apply 0.5-1.5 % ZnSO₄ ha⁻¹ as a foliar spray. At tillering (25-30 DAT), 2-3 repeated applications at intervals of 10-14 days. Zn chelates (e.g., Zn – EDTA) can be used for foliar application.

MAIZE (*Zea mays* Linn.)

Nitrogen Deficiency

Deficiency Symptoms

Maize is highly sensitive to nitrogen deficiency. Deficiency symptoms appear even in mild deficiency conditions. Nitrogen-deficient plants are stunted with thin, spindly stems and pale green to yellow leaves. Deficient plants produce hardly one small ear per plant and the ears have hardly any grains with reduced kernel size, resulting in a drastic reduction in crop yield. Nitrogen is mobile in plants and under short supply conditions it is easily mobilized from older to younger leaves. The deficiency symptoms appear first and become more severe on older leaves. If deficiency occurs during the young stage of the crop, the whole plant appears uniformly pale green to yellow. In later stages of the crop, older leaves become pale yellow while young leaves remain green.

Corrective Measures

Top-dress soluble nitrogenous fertilizers such as urea in two split doses. For quick recovery, apply urea (2% w/v solution) as a foliar spray in the standing crop. Foliar sprays are required to be repeated every 10–15 days.

Phosphorus

Deficiency Symptoms

Deficient plants appear stunted, thin and spindly with dark green leaves. The number and size of stomata in leaves are decreased. Root growth is drastically reduced. Phosphorus-deficient plants bear hardly one small ear with few grains, resulting in very poor crop yields.

In acute deficiency conditions or in favouring winter season, the purpling may cover the entire plant. 7. In the most advanced stage, affected leaves burn and die.

Corrective Measures:

Phosphate-solubilizing microbial cultures; Phosphatic fertilizers - In deficient standing crops apply soluble phosphatic fertilizers such as ammonium phosphate with irrigation water.

Potassium

Deficiency Symptoms

Potassium deficiency causes shortening of the internodes and dwarfing of plants with a general loss of the dark green colour of foliage. Affected plants produce small ears that are often very pointed and underdeveloped at the tip. Marginal chlorosis and necrosis of older leaves are the specific symptom of potassium deficiency. In severe deficiency conditions prominent red strips develop on the lower stem and leaf sheaths.

Corrective Measure

If potassium deficiency appears on a standing crop, apply soluble potassium salts such as potassium nitrate, potassium sulphate or potassium chloride with irrigation water. Foliar sprays of these salts are usually not recommended because a number of such sprays are needed to fulfil crop requirements.

Calcium

Deficiency Symptoms

Calcium deficiency in maize can destroy the entire crop. Calcium-deficient maize plants are very stunted with distorted, torn and ragged foliage. Mildly calcium-deficient plants develop small ears and distorted tassels, but if deficiency is severe, maize plants fail to grow and die before maturity. The deficiency symptoms appear first and more severely on younger leaves. Calcium deficiency symptoms begin with yellow to white inter-veinal lesions on young leaves. If the deficiency persists and becomes more severe, the new emerging leaves fail to unroll and make a ‘bull-whip-like’ structure. As symptoms advance, the new leaves develop holes in the lamina. The torn and malformed leaves give the plant a ragged appearance.



Corrective Measure

Apply analysis-based recommended quantity of calcium- containing fertilizers well before sowing. Suitable calcium containing fertilizers may be gypsum (calcium sulphate), calcium nitrate or calcium chloride. In acid soils, lime or limestone (calcium carbonate) and dolomite (a mixture of calcium carbonate and magnesium carbonate) are more suitable calcium supplements. The foliar application of 2% w/v calcium sulphate (twice) is recommended in standing crops.

Zinc

Deficiency Symptoms

Emerging leaves uniformly pale green. Chlorosis staring at the base progressive toward the tip. Margins with distinct red line. Bleached white patches on the leaves. Older leaves have yellow streaks or chlorotic striping between veins.



Correction Measure

Soil application of ZnSO₄ 20-25 Kg/ha or foliar spray of ZnSO₄ 0.5%.

Iron

Deficiency Symptoms

Deficiency appears first in newly emerging leaves. Interveinal tissue turns pale yellow with green veins chlorotic pattern uniformly leaves turn yellow or white. Newly formed leaves exhibit chlorotic symptoms and the entire crop show bleached appearance.

Correction Measure

Soil application of 20-25 Kg FeSO₄ or foliar spray of 1% FeSO₄ at weekly interval

CUMBU (PENNISETUM GLAUCUM)

Nitrogen

Deficiency Symptoms

Stunted plant growth, spindly pale yellow or deep yellow color near the tips and margins progresses toward the base.



Correction Measure

Foliar spray of Urea 1% or DAP 2%.

Phosphorus

Deficiency Symptoms

Grain filling inhibited. Stunted growth, spindly, dark green leaves with dark red coloration. Leaves appear to be erect and leathery.



Correction Measure

Foliar spray of DAP 2% 2-3 sprays

Potassium

Deficiency Symptoms

Symptoms first seen in older leaves. Irregular necrotic patterns intermingled with red pigmentation. Streaked patterns on the interveinal tissue symptoms at tips and margins move towards the base.

Correction Measure

Foliar spray of KCl 1%

Calcium

Deficiency Symptoms

Plants stunted. Young leaf tips stick together form sword-like projections. Serrated leaf edges, leaves brittle, brown, sticky near margins and turn brown.

Correction Measure

Foliar application of CaSO₄ 2% twice.

Sulphur

Deficiency Symptoms

Deficiency appears in upper leaves. Emerging leaves pale yellow in color.



Correction Measure
Foliar spray of CaSO₄ 2%

Boron

Deficiency Symptoms
Apical growing points stop developing leaves thick brittle and irregular chlorosis.



Correction Measure
Foliar spray of Borax 0.5 % at fortnightly intervals

Iron

Deficiency Symptoms
Deficiency appears first in newly emerging leaves. Interveinal tissue turns pale yellow with green veins chlorotic pattern uniformly leaves turn yellow or white. Newly formed leaves exhibit chlorotic symptoms.

Correction Measure
Soil application of 20-25 Kg FeSO₄ or foliar spray of 1% FeSO₄ at weekly interval.

Copper

Deficiency Symptoms
Younger leaf tips turn brown roll up and break.
Correction Measure
Foliar spray of CuSO₄ 0.2%

Zinc

Deficiency Symptoms
Deficiencies first in the younger leaves. Emerging leaves uniformly pale green. Chlorosis starting at the base progressive toward the tip. Bleached white patches on the leaves. Older leaves have yellow streaks or chlorotic striping between veins.



Correction Measure

Soil application of ZnSO₄ 20-25 Kg/ha or foliar spray of ZnSO₄ 0.5%

Sorghum (Sorghum bicolor)

Nitrogen

Deficiency Symptoms

Plants stunted, spindly pale yellow or deep yellow color near the tips and margins progresses toward the base heads small seed numbers reduced.



Correction Measure

Foliar spray of Urea 1% or DAP 2%.

Phosphorus

Deficiency Symptoms

Small root systems; grain filling inhibited. Growth stunted, spindly, dark green leaves with dark red coloration. Leaf sheaths bend upward with red coloration leaf. Leaves appear to be erect and leathery. Roots turn dark brown purple or black.



Correction Measure

Foliar spray of DAP 2% 2-3 sprays

Potassium

Deficiency Symptoms

Deficiency first seen on older leaves. Irregular necrotic patterns intermingled with red pigmentation. Streaked patterns on the interveinal tissue symptoms at tips and margins move towards the base.



Correction Measure

Foliar spray of KCl 1%

Calcium

Deficiency Symptoms

Plants stunted. Young leaf tips stick together form sword-like projections. Serrated leaf edges, leaves brittle, brown, sticky near margins and turn brown.

Correction Measure

Foliar application of CaSO₄ 2% twice

Magnesium

Deficiency Symptoms

Deficiency appear first on older leaves irregular necrotic spots on tips and margins deep red color on leaves become brittle, turn brown



Correction Measure

Foliar spray of MgSO₄ 2%

Sulphur

Deficiency Symptoms

Deficiency appears in upper leaves. Emerging leaves pale yellow.

Correction Measure

Foliar spray of CaSO₄ 2%

Boron

Deficiency Symptoms

Apical growing points stop developing leaves thick brittle and irregular chlorosis.

Correction Measure

Foliar spray of Borax 0.5 % at fortnightly intervals

Copper

Deficiency Symptoms

Younger leaf tips turn brown roll up and break.



Correction Measure

Foliar spray of CuSO₄ 0.2%

Iron

Deficiency Symptoms

Deficiency appears first in newly emerging leaves. Interveinal tissue turns pale yellow with green veins chlorotic pattern uniformly leaves turn yellow or white. Newly formed leaves exhibit chlorotic symptoms the entire crop show bleached appearance and dry.



Correction Measure

Soil application of 20-25 Kg FeSO₄ or foliar spray of 1% FeSO₄ at weekly interval.

Manganese

Deficiency Symptoms

Deficiency appears first in younger leaves. Leaves pale color in a streaked pattern and long narrow lesions on leaves.

Correction Measure

Foliar spray of MnSO₄ 0.2%

Zinc

Deficiency Symptoms

Deficiencies first in the younger leaves. Emerging leaves uniformly pale green. Chlorosis starting at the base progressive toward the tip. Margins with distinct red line. Bleached white patches on the leaves. Older leaves have yellow streaks or chlorotic striping between veins.

Correction Measure

Soil application of ZnSO₄ 20-25 Kg/ha or foliar spray of ZnSO₄ 0.5%

Nutritional disorders and corrective measures in Pulses

Greengram (*Vigna radiata*)

Nitrogen

Deficiency Symptoms :

Nitrogen deficiency causes retarded growth of plants. Stems become thin and elongated. Branching and flowering are reduced drastically. Reduced pod formation and poor seed set result in poor yields. Nitrogen is fairly mobile within plants and under restricted supply conditions it is rapidly redistributed from older to younger leaves. The deficiency symptoms typically appear in lower leaves first. If deficiency persists, the symptoms move up the plant to the younger leaves. The old leaves become uniformly pale green and then turn pale yellow to yellow, while the young leaves remain light green. Later, the yellow older leaves turn white and drop early.



Correction Measure :

Top-dress soluble nitrogenous fertilizers such as urea. For quick recovery, apply urea with irrigation water or as a foliar spray in the standing crop. Foliar sprays require to be repeated every 10–15 days.

Potassium

Deficiency Symptoms

Deficiency in early growth stages shows up as irregular mottling around the edges of leaves. These chlorotic areas increase as deficiency becomes more severe, then they merge so that chlorosis occurs around the edges of the leaf. As deficiency becomes more severe, chlorosis progresses toward the center of the leaf. In early growth, necrosis may be on lower leaves but later in the season it may be on leaves in the upper parts of the plant.



Correction Measure

Foliar spray of KCl 1% at fortnightly interval

Magnesium

Deficiency Symptoms

In early stages of deficiency the areas between the veins become yellow. These areas later turn deep yellow and rusty specks and necrotic blotches may appear between the veins and around the edges of the leaves. In later stages, Mg deficiency gives the appearance of early maturity.

Correction Measure

Foliar spray of MgSO₄ @ 2% at fortnightly interval

Sulphur

Deficiency Symptoms

The deficiency symptoms are first observed in younger leaves and then progress to lower leaves if the deficiency continues. The younger leaves turn chlorotic, initially becoming pale green and then pale yellow. The pattern of chlorosis appears uniform on the entire leaf lamina including the veins. In acute deficiency conditions the entire plant appears chlorotic.



Correction Measure

Foliar spraying of Calcium Sulphate 0.5-1.0 % can control the deficiency.

Boron

Deficiency Symptoms :

Upper internodes of the stem are shortened, giving the plants a rosette appearance. Upper leaves near the growing points turn yellow and sometimes red. Symptoms are most severe at the leaf tips while the leaf bases remain green.



Correction Measure :

Foliar spray of Borax 0.2% at fortnightly intervals.

Iron

Deficiency Symptoms

Iron is immobile within plants and hence it is not readily redistributed from older to younger plant tissues under reduced supply conditions. Therefore, the deficiency symptoms become evident first on younger leaves. Young leaves become yellow (chlorotic) with contrasting narrow, dark green main veins, while older leaves remain green. Chlorotic young leaves then turn yellow to white and symptoms spread down the plant to lower leaves. Dead tissues in the form of spots appear particularly at leaf margins.



Correction Measure

Apply basal dose of soluble iron fertilizers such as FeSO₄ (commonly at 25 kg/ha) or Fe chelates (10 kg/ha). Use of organic chelates proves to be more promising as they maintain iron in soil solution. In standing crops, apply FeSO₄ or Fe chelates (0.5% w/v solution) and 0.1% w/v citric acid as foliar sprays. Foliar sprays are required to be repeated every 10–15 days.

Manganese

Deficiency Symptoms

Leaves become chlorotic in interveinal areas while the veins remain green. Symptoms differ from Fe where the veins also become chlorotic. Whole leaves, veins excepted, become pale green and pale yellow. Brown spots and necrotic areas develop on lower leaves as the deficiency becomes more severe. Deficiency occurs on the new leaves, however, when later growth is normal the chlorotic leaves are no longer at top of the plant.



Correction Measure

Foliar spray of MnSO₄ @ 0.5% at fortnightly intervals or soil application of MnSO₄ @ 20 to 25 kg/ha

Zinc

Deficiency Symptoms

Green gram is very sensitive to zinc deficiency. Deficiency symptoms appear more prominently during the initial stages of crop growth, usually within 2–3 weeks after sowing.

Symptoms begin as a faint, pale green interveinal chlorosis of older leaves. Interveinal chlorosis starts from the tip of the leaf and proceeds towards the base. The loss of green colour of interveinal tissues looks like a bleaching effect on affected leaves. The main veins remain green and prominent. If deficiency persists and becomes more severe, the affected leaves develop chocolate brown necrotic spots and lesions on interveinal areas. As symptoms advance, tissues of the necrotic spot areas drop from the leaf lamina, making small holes in the affected leaf.



Correction Measure

Application of basal dose ZnSO₄ at the rate of 25 kg per ha. Spraying of 0.5% ZnSO₄ during 20, 30, 40th day after sowing.

Redgram (Cajanus cajan)

Nitrogen

Deficiency Symptoms

Nitrogen deficiency in pigeon pea is usually found during the initial stages of crop growth when root symbiotic nitrogen fixation nodules are yet to develop. In mild deficiency, the entire plant appears uniformly light green. If deficiency persists and become more severe, the older leaves show chlorosis. Interveinal chlorosis appears on the oldest leaves in the beginning of the deficiency symptom, which soon converts to a uniform pale green, greenish yellow or pale yellow colour. The midrib remains green and turns yellow at last. Interveinal chlorosis stage is mostly missing in severe deficiency conditions. Affected older leaves soon abscise.

Correction Measure :

The crop needs nitrogen during the initial stage of growth, when symbiotic nitrogen fixation by the plant is yet to start. Thus, a basal starter application of nitrogen at 20–25 kg/ha is important in nitrogen-deficient soils. Nitrogen deficiency in existing crops can be managed by applying urea with irrigation water or as a foliar spray

Phosphorus

Deficiency Symptoms :

The deficient plant develops a dark green to bluish dark green colour of the foliage. The older leaves become darker than the younger. The change in leaf colour is the only recognizable symptom of phosphorus deficiency in pigeon pea. In the most advanced stage, affected older leaves turn orange– yellow in colour and shed.



Correction Measure :

Foliar spray of DAP 2% at fortnightly interval.

Potassium

Deficiency Symptoms:

Leaf tip yellow or brown. Yellowing spreads from the tip onward along the leaf margin and may coalesce with similar areas at extremities of the lateral veins. Leaf tip becomes scorched as symptoms become more severe. The scorching may spread around the leaf margin but typically there is a yellow band between the scorched area and the healthy green tissue in the early stages. The affected leaves not showing symptoms are generally dark green. Plants stunted.



Correction Measure :

Foliar spray of KCl 1% at weekly intervals.

Magnesium

Deficiency Symptoms :

Magnesium is mobile in the plant and under short supply conditions it is transferred from older to younger leaves. The deficiency symptoms appear first and more severely on the older leaves. The youngest leaves remain green and apparently healthy. Mild interveinal chlorosis, veins remain dark green. Interveinal areas become rusty brown or bronzed and may become necrotic so that narrow elongated streaks of dying tissue appear between the veins. The margins of the young leaves frequently roll.

Correction Measure :

Foliar spray of MgSO₄ 2% and 1% Urea

Sulphur

Deficiency Symptoms :

Deficient plants become chlorotic. New leaves are first affected, but gradually the entire plant becomes uniformly chlorotic (Yellowish). If deficiency persists and becomes more severe, symptoms eventually move downwards, covering more leaves. Plant vigour, flowering and fruiting reduce drastically, resulting in poor crop yields.



Correction Measure :

Foliar spraying of Calcium Sulphate 0.5 % can control sulphur deficiency.

Boron

Deficiency Symptoms :

Upper internodes of the stem are shortened, giving the plants a rosette appearance. Upper leaves near the growing points turn yellow and sometimes red. Symptoms are most severe at the leaf tips while the leaf bases remain green.



Correction Measure :

Spraying of Boron 0.2 % at two week interval by foliar spray.

Iron

Deficiency Symptoms :

In mild deficiency conditions or at the initial stage of deficiency, the topmost younger leaves develop temporary fading of interveinal tissues to a pale green to pale yellow colour. If the deficiency persists and becomes more severe, a bright pale yellow chlorosis develops in interveinal tissues (tissues between the veins), leaving the veins green and prominent. Interveinal chlorosis of top leaves is the specific symptom of iron deficiency. As the symptoms advance, prominent green veins also fade and become light green to pale yellow. In acute deficiency conditions, the entire leaf bleaches to papery white



Correction Measure :

Foliar spray of FeSO₄ 0.5% at weekly intervals.

Manganese

Deficiency Symptoms :

Deficiency symptoms appear in older leaves of young plants. Leaves are yellow in colour. But veins are remain in green colour Young leaves turn completely yellow dark brownish black spots appear on the leaf.

Correction Measure :

Spraying of manganese sulphate (5g / Litre) at 10 days interval.

Zinc

Deficiency Symptoms :

Stunted growth narrowing of leaves with pale green or yellow. Inter-veinal chlorosis starting from tip of leaflets and spreading to the remaining area leaving only the midrib green.

Correction Measure :

Foliar spray of ZnSO₄ at 0.5% at fortnightly interval or soil application of ZnSO₄ 10-15 kg/ha.

BLACKGRAM

Nitrogen

Deficiency Symptoms

Insufficient nitrogen supply restricts plant height. The leaf size and number of branches are reduced. Nitrogen deficiency reduces flowering, decreases the number of pods and pod

length and reduces the number of seeds and seed size, ultimately resulting in low yields. In short supply conditions, nitrogen is readily transferred from older to younger tissues because it is fairly mobile within plants. Therefore, the deficiency symptoms tend to occur first and become more severe on the lower leaves, then working up the plant to the younger leaves.

Correction Measure

Top-dress soluble nitrogenous fertilizers such as urea. For quick recovery, apply urea (2% w/v solution) as a foliar spray in the standing crop. Foliar sprays must be repeated every 10–15 days.

Phosphorus

Deficiency Symptoms

Crop maturity is delayed. The number and size of pods are decreased which leads to poor yields. Phosphorus is mobile within plants and is readily translocated from older to younger tissues of the plant under restricted supply conditions. Therefore, older leaves display deficiency symptoms first. Deficient plants become dark green in appearance and the lower stems turn purplish. If deficiency persists for long, the dark green leaves turn bluish green. Phosphorus-deficient plants often develop purple pigmentation on older leaves.

Correction Measure

If standing crops show the deficiency, apply soluble phosphatic fertilizers such as ammonium phosphate with irrigation water.

Magnesium

Deficiency Symptoms

Leaves along with veins appear in green colour then it turns to yellowish colour. Basal leaves are green in colour. Later leaves spot are appear in between the veins. Leaves are curled downward direction. Lowest, leaves become white to yellow with the base of the leaf remaining green. Pale brown necrotic spots develop with dark brow margin. Brown spots appear on the pods.

Correction Measure

Foliar spray of MgSO₄ 1% at fortnightly intervals.

Sulphur

Deficiency Symptoms

Deficient plants become chlorotic. New leaves are first affected, but gradually the entire plant becomes uniformly chlorotic.

Correction Measure

Folia spray of CaSO₄@0.5-1.0%

Boron

Deficiency Symptoms

Upper internodes of the stem are shortened, giving the plants a rosette appearance. Upper leaves near the growing points turn yellow and sometimes red. Symptoms are most severe at the leaf tips while the leaf bases remain green.

Correction Measure

Foliar spray of Borax 0.2% at fortnightly intervals.

Manganese

Deficiency Symptoms :

Deficiency symptoms appear in older leaves of young plants. Leaves are yellow in colour. But veins are remain in green colour. Later, reddish pale yellow colour leaves are produced. Young leaves turn completely yellow dark brownish black spots appear on the leaf.

Correction Measure :

Spraying of 1% MnSO₄ during 20, 30, 40 DAS or application 10 kg of MnSO₄ as a basal dose.

Zinc

Deficiency Symptoms :

Deficiency will appear one month after germination. Interveinal areas of leaves become yellow and die prematurely. Reduction of growth in plants. Yellowish smaller leaves, veins remain green in colour.

Correction Measure :

Application of basal dose ZnSO₄ at the rate of 25 kg per ha. Spraying of 0.5% ZnSO₄ during 20, 30, 40th day after sowing.

Soyabean

Nitrogen

Deficiency Symptoms :

Growth will be stunted and leaves a very pale green. Nitrogen deficiency occurs because the soybean roots are not nodulated or nodules are not effective because of poor soil fertility or low levels of Mo.

Correction Measure :

Foliar spray Urea 1% at fortnightly interval

Potassium

Deficiency Symptoms

Deficiency in early growth stages shows up as irregular mottling around the edges of leaves. These chlorotic areas increase as deficiency becomes more severe, then they merge so that chlorosis occurs around the edges of the leaf. As deficiency becomes more severe, chlorosis

progresses toward the center of the leaf. In early growth, necrosis may be on lower leaves but later in the season it may be on leaves in the upper parts of the plant.

Correction Measure

Foliar spray of KCl 1% at fortnightly interval

Magnesium

Deficiency Symptoms

In early stages of deficiency the areas between the veins become yellow. These areas later turn deep yellow and rusty specks and necrotic blotches may appear between the veins and around the edges of the leaves. In later stages, Mg deficiency gives the appearance of early maturity.

Correction Measure

Foliar spray of MgSO₄ @ 2% at fortnightly interval

Sulphur

Deficiency Symptoms

Deficient plants become chlorotic. New leaves are first affected, but gradually the entire plant becomes uniformly chlorotic.

Correction Measure

Foliar spraying of Calcium Sulphate 0.5-1.0 % can control the deficiency.

Iron

Deficiency Symptoms

Iron deficiency of soybeans occurs on some soils when the pH is high. Frequently it is on soils which contain considerable quantities of free lime. With Fe deficiency, the whole leaf including the veins turns yellow. Interveinal areas turn chlorotic first then the veins become chlorotic and finally, under severe Fe deficiency, the leaves turn almost white.

Correction Measure

Foliar spray of FeSO₄ 1% at fortnightly intervals or soil application of FeSO₄ 5 to 10 kg/ha

Manganese

Deficiency Symptoms

Leaves become chlorotic in interveinal areas while the veins remain green. Symptoms differ from Fe where the veins also become chlorotic. Whole leaves, veins excepted, become pale green and pale yellow. Brown spots and necrotic areas develop on lower leaves as the deficiency becomes more severe. Deficiency occurs on the new leaves, however, when later growth is normal the chlorotic leaves are no longer at top of the plant.

Correction Measure

Foliar spray of MnSO₄ @ 0.5% at fortnightly intervals or soil application of MnSO₄ @ 20 to 25 kg/ha

Zinc

Deficiency Symptoms

Zinc deficiency of soybeans is not common. The leaves become chlorotic, then rusty brown in color. The veins remain green. The chlorosis is uniform over the leaf and not concentrated initially on the edges as occurs with deficiencies such as K.

Correction Measure

Foliar spray of ZnSO₄ 1% at fortnightly intervals or soil application of ZnSO₄ 20 to 25 kg/ha

Nutritional disorders and corrective measures in Oilseeds

Groundnut

Nitrogen

Deficiency Symptoms

The entire plant may become light green in appearance. Since nitrogen is a mobile nutrient within plants, it is rapidly translocated from older to younger leaves (if the plant is not supplied with sufficient nitrogen). The deficiency symptoms appear primarily on older leaves. In prolonged deficiency, the symptoms also become more severe on lower leaves. Older leaves become uniformly yellow while young leaves may remain light green



Correction Measure

Foliar spray of Urea 1 to 2% at fortnightly intervals.

Potassium

Deficiency Symptoms

Symptoms begin as chlorosis at the tip and along the leaf margins of old leaves; some chlorosis may also occur in interveinal areas. Old leaves turn brown and become scorched from the tips and along the margins. Eventually, the old leaves dry and fall off early.



Correction Measure

Foliar spray of KCl 1 to 2% at fortnightly intervals

Calcium

Deficiency Symptoms

Very rare in leaves and stems, small distorted leaves near branch tips, and terminal buds blacken and fail to continue to develop. Most common symptom in developing fruit is lack of kernel formation, darkened plumule if kernel develops, and reduced seed germination.



Correction Measure

Soil application of Gypsum 200 kg/ha

Sulphur

Deficiency Symptoms

Initially, the whole plant appears light green. The younger leaves become pale green or pale yellow. The uniform chlorosis develops over the entire leaf, covering both the veins and the interveinal tissues. In acute deficiency conditions, the entire plant turns yellow



Correction Measure

Soil application of Gypsum 200 kg/ha.

Boron

Deficiency Symptoms

Growth of young leaves restricted giving a rosette effect. The pod development is affected resulting in the production of 'pop' pods. Leaves small, branches stubby and stems may split pots show hollow heart and discoloration.



Correction Measure

Apply Borax 10 Kg + Gypsum 200 Kg/Ha At 45 Days After Sowing.

Copper

Deficiency Symptoms

Chlorosis in younger leaves, distorted leaf lets and scattering of yellowish white spots on leaves.

Correction Measure

Foliar spray of CuSO₄ 0.2% at fortnightly intervals.

Manganese

Deficiency Symptoms

Interveinal chlorosis and stunted growth.

Correction Measure

Foliar spray of MnSO₄ 0.5% at fortnightly intervals / soil appln. Of MnSO₄ 5-10 kg/ha.

Iron

Deficiency Symptoms

A pale yellow chlorosis develops in interveinal tissues while the veins remain green and prominent; this chlorosis extends the full length of the leaves. As the chlorosis advances, veins also become chlorotic and the entire leaf may appear pale yellow. In the later stage, leaves turn almost white and may become necrotic.



Correction Measure

Foliar spray of 1% FeSO₄ on 30,40 and 50 days after sowing.

Zinc

Deficiency Symptoms

Light yellow stripes along with veins of leaf blade under acute condition-veinally chlorosis and cessation of growth of terminal bud. Older leaves may show slight chlorosis.

Correction Measure

Apply 25 kg ZnSO₄/ha (basal) or foliar spray of ZnSO₄ 1% at fortnightly intervals.

Sesame

Nitrogen

Deficiency Symptoms

The nitrogen-deficient plant shows poor growth. The stem becomes short and thin. The plant has poor branching. The number and size of capsules are drastically reduced and fewer seeds are produced per capsule. Crop yield declines sharply. Paling of the entire plant occurs due to lack of chlorophyll content in the leaves.

Corrective Measures

Urea (2% w/v solution) as a foliar spray in the standing crop. Foliar sprays must be repeated every 10–15 days.

Phosphorus

Deficiency Symptoms

Branching suppressed, stalks slender, lower leaves dull dark, grayish green. Necrosis of lower of majority of leaves is followed by defoliation.

Correction Measure

Soil application of single super phosphate 2% DAP foliar spray at fortnightly intervals.

Potassium

Deficiency Symptoms

Symptoms develop initially as marginal chlorosis on lower leaves. The marginal chlorosis then rapidly proceeds inwards. The chlorotic tissues progressively become necrotic. The leaves eventually die and fall off prematurely.

Correction Measure

Apply potassic fertilizers to the soil at or before planting as per soil testing recommendations.

In standing crops, apply soluble potassium salts with irrigation water.

Calcium

Deficiency Symptoms

Terminal bud dies out following distortion of the tips and bases of young leaves. Hooking downward of the young leaf tips followed by twisting and puckering.



Correction Measure

Soil application of gypsum @ 50 kg/ha.

Magnesium

Deficiency Symptoms

Lower leaves develop interveinal chlorosis, light yellow in color becoming orange later. Green color persists in midrib and veins giving a characteristic pattern.



Correction Measure

Foliar spray of 2% MgSO₄ at fortnightly intervals.

Sulphur

Deficiency Symptoms

Sulphur deficiency produce smaller new leaflets with yellow and erect petioles than the normal. Plants are smaller in size and modulation is poor.

Correction Measure

Foliar spray 0.5 - 1% of calcium sulphate

Boron

Deficiency Symptoms

Yellowing of plant tops and of the youngest leaves. Upper leaves became dark green, coriaceous, with edges curved down. inhibits root elongation leading to the death of root tips.



Correction Measure

Foliar spray Borax 0.2% at fortnightly intervals.

Iron

Deficiency Symptoms

Decrease the dry weight of leaves, stem root decrease in taproot length and its dry mass. The leaves show deficiency symptoms mild chlorosis.

Correction Measure

Foliar application of ferrous sulfate 0.5% at weekly interval.

Manganese

Deficiency Symptoms

Deficiency symptoms appear in the form of interveinal chlorotic mottling of apical part of the second set of leaves. The entire laminae become severely mottled and the interveinal chlorotic areas develop light brown irregular necrotic patches. These patches, which are initially more conspicuous near the leaf apices, later spread to the entire laminae, which eventually turn severely necrotic. Symptoms gradually spread from the middle to the young and old leaves.



Correction Measure

Foliar spray of 0.2 – 0.3% MnSO₄ solution 2-3 times at weekly intervals or soil application of MnSO₄ 10 kg/ha.

Zinc

Deficiency Symptoms

Prevents seed formation thus reducing yield.

Correction Measure

Foliar application of ZnSO₄ 0.5% or soil application of ZnSO₄ 10 kg/ha.

Sunflower

Nitrogen

Deficiency Symptoms :

Chlorosis of young leaves & old leaves (early stages), Marginal Chlorosis, Whole leaf Chlorosis Yellow-Pale green Death of whole leaf, Chlorosis followed by death. Thin stems, spindly stems pale green stems are seen fewer or smaller mature heads. Sunflower responds to 30-80 kg N/ha depending upon soil moisture status.



Correction Measure

Foliar spray of 1% Urea at weekly intervals.

Phosphorus

Deficiency Symptoms:

Interveinal Cholorsis Yellow – Pale green leaves, Interveinal necrosis stems: Short & Thin Stems. Bent petioles (resulting in leaves pointing downwards), Reproductive stage symptoms expressed: Delayed maturity, Fewer or smaller mature heads which set few grains/seed. Lower grain yield, Dark Brown necrotic lesions, Grey-dark brown necrotic lesions.



Correction Measure

Soil application of SPP or Foliar application of DAP 2%.

Potassium

Deficiency Symptoms :

Deficiency symptoms appear on old leaves whilst young leaves remain green and healthy, Chlorosis of old leaves (early stages). Marginal chlorosis with Yellow-Pale green leaves & puckering of the leaves Necrosis on older leaves & interveinal necrosis. The stem show stout & Stunted stem growth. Leaf tips & or margins curl up or down giving a wavy appearance. Fewer or smaller mature heads which set few grains / seed Bronze / Pale brown necrotic lesions.



Correction Measure :

Soil application of Murate of potash 20 kg/ha at foliar spray of KCl 1%.

Magnesium

Deficiency Symptoms :

Yellowing of older leaves; interveinal chlorosis

Correction Measure :

Foliar spray of MgSO₄@1-2%

Sulphur

Deficiency Symptoms

Plants showing paling/yellowing of leaves. Yellowing spreads from the base to the apex. Growth of plants is reduced. The size of capitulum is severely restricted. Inflorescence may remain covered within the bracts. Maturity of flowers is delayed.

Correction Measure

Application of 25 kg S/ha or 80 kg N+25 kg S.

Boron

Deficiency Symptoms :

Young and middle leaves of plants develop small chlorotic patches. Chlorotic patches become more pronounced and develop orange coloured necrotic areas in young leaves. Shoot apex of plants may turn necrotic and cease to grow. Young leaves show severe curling and distortion. This leads to appearance of side branches bearing small leaves. Eventually all the young leaves turn necrotic.



Correction Measure :

Spray of Borax (0.2%) on capitulum at ray floret opening stage for increasing seed filling, Yield and oil content.

Copper

Deficiency Symptoms :

Deficiency symptoms appear as interveinal chlorosis of the upper half of the old leaves starting from the tip of the leaf. Chlorosis is generally restricted to the apical half of the lamina. Chlorotic areas later develop dark brown necrotic scorching, which spreads along the margins towards the base of the leaf. Laminae becomes shriveled and withered. Marginal scorching of the leaves becomes more pronounced and brown necrotic spots develop near the midrib.



Correction Measure :

2 to 3 sprays of 0.2% copper sulphate solution at weekly intervals.

Iron

Deficiency Symptoms:

Yellowing of young leaves; interveinal chlorosis

Correction Measure :

Foliar spray of FeSO₄@0.5%

Manganese

Deficiency Symptoms :

Deficiency symptoms appear in the form of interveinal chlorotic mottling of apical part of the second set of leaves. The entire laminae become severely mottled and the interveinal chlorotic areas develop light brown irregular necrotic patches. These patches, which are initially more conspicuous near the leaf apices, later spread to the entire laminae, which eventually turn severely necrotic. Symptoms gradually spread from the middle to the young and old leaves.



Correction Measure :

Foliar Spray Of 0.2 – 0.3% Mnso₄ Solution 2-3 Times At Weekly Intervals Or Soil Application Of MnSO₄ 10 kg/ha.

Zinc

Deficiency Symptoms :

Light yellow stripes along with veins of leaf blade under acute condition-veinally chlorosis and cessation of growth of terminal bud. Older leaves may show slight chlorosis.

Correction Measure :

Foliar spray of ZnSO₄@0.5%

Fiber crops

Cotton

Nitrogen

Deficiency Symptoms

General yellowing of the older leaves. Stunted growth with few vegetative fruiting branches.

Correction Measure

Urea 1% foliar spray or DAP 2% can control this deficiency

Phosphorus

Deficiency Symptoms

Dark green stunted plants. Small leaves and the symptoms first appear on the lower or older leaves and progress upward on the stalk. Delay in blooming and fruiting.

Correction Measure

Foliar application of 2% DAP.

Potassium

Deficiency Symptoms

Older leaves are chlorotic, droopy and have yellow spots between the veins the edges turn yellow then brown curl downward and die. Brown spots appear between vein dry the margins and tip of leaves. The tips curl and breakdown. The leaves brown-reddish brown of dry. The maturity and quality of both offered.

Correction Measure

Foliar spray of 1 % KCl

Calcium

Deficiency Symptoms

Large plants and few fruiting forms. Crinkle leaf and poor root growth.

Correction Measure

Soil application of gypsum @ 50 kg/ha.

Magnesium

Deficiency Symptoms

Leaf cupping and interveinal chlorosis, veins remain green; starts in young leaves.

Correction Measure

Foliar spray of MgSO₄ @ 1 %

Sulphur

Deficiency Symptoms

Pale green to yellow colour of young leaves at the top leave green colour which is similar to N deficiency, but N deficiency begin near the bottom and not at the top. The plants are small and spindly with short, slender stalks.

Correction Measure

Foliar spray of MgSO₄ @ 1 %

Iron

Deficiency Symptoms

Yellowing of cotton leaves at top of plant following irrigation.

Correction Measure

Soil application of FeSO₄ @ 5 kg/ha or foliar spray of 0.5% FeSO₄.

Boron

Deficiency Symptoms

Short leaf petioles with dark green rings. Excessive shedding of buds and young bolls. Ruptured nectarines, small bolls, and delayed maturity. Terminal bud dies, more lateral branches with short internodes. Black discolouration at the base of bolls. Bolls dry and fall young leaves become thick, brittle with water spots.

Correction Measure

Soil application of borax 0.5 kg/ha or foliar spray of borax 0.2

Manganese

Deficiency Symptoms

Yellowing of cotton leaves at top of plant following irrigation.

Correction Measure

Soil application of FeSO₄ @ 5 kg/ha or foliar spray of 0.5% FeSO₄.

Zinc

Deficiency Symptoms

Pronounced interveinal chlorosis differs from manganese in that leaves are more misshapen, tips of leaves elongated and parallel. Both old and young leaves show red pigmentation; leaves lose normal green colour of interveinal portions turn golden yellow colour. Brown spots extend from leaf tips to base and later dry. Plants show shorter appearance.

Correction Measure

Soil application of ZnSO₄ 5 kg/ha or foliar application of ZnSO₄ 1%.

Sugar crops Sugarcane

Nitrogen

Deficiency Symptoms:

All leaves of sugarcane exhibit a yellow – green colour. Die back occur in older leaves. Retardation of growth. Cane stalks are smaller in diameter. Premature drying of older leaves. Roots attain a greater length but are smaller in diameter.

Correction Measure :

Soil application of N fertilizer or Foliar spray of Urea 1-2% twice at weekly interval.

Phosphorus

Deficiency Symptoms :

Colour of the leaves in greenish blue or red - purple discolouration on tips and margins, narrow and somewhat reduce in length. Reduction in length of sugarcane stalks, diameters of which taper rapidly at growing points. Poor or no tillering. Decreased shoot / root ratio with restricted root development.

Corrective Measure:

Foliar spray of DAP 2% twice at fortnight interval. Applying large amounts upto 1 tonne/ha of rock phosphate. Application of triple super phosphate @ 0.5 to 0.75 kg /ha

Potassium

Deficiency Symptoms :

The plants will have depressed growth. Yellowing and marginal drying of older leaves and Development of slender stalks. Orange, yellow colour appears in the older lower leaves which develop numerous chlorotic spots that later become brown with dead centre result in ‘firing’ appearance. Reddish discoloration which is confined to the epidermal cells of the upper surfaces and midribs of the leaves. Bunchy top appearance. Poor root growth with less member of root hairs.

Correction Measure :

Foliar spray of KCl 1% twice at fortnightly interval

Calcium

Deficiency Symptoms :

Minute chlorotic spots with dead centers which later become dark reddish-brown. Plants weak with thin stalks and soft rid. Growth is retarded.

Correction Measure :

Soil application of 100kg/ha of Gypsum.

Magnesium

Deficiency Symptoms :

Young leaves are light green or yellowish-green with smaller chlorotic spots that become dark brown. Rusty or freckled appearance spotting pronounced on the older leaves. Stalks show internal browning.

Correction Measure :

Soil application of MgSO₄ 25kg/ha or Foliar spray of MgSO₄ 2% twice at fortnight interval.

Sulphur

Deficiency Symptoms :

Plants have an off-color or yellowish-green appearance like N deficiency the youngest leaves are more chlorotic. Stalks short thin and leaf area reduced.

Correction Measure :

Foliar spray of K₂SO₄ 1% twice at fortnight interval.

Boron

Deficiency Symptoms

Leaves become smaller; malformed leaves

Correction Measure

Foliar spray of borax@0.2-0.5%

Copper

Deficiency Symptoms

Symptoms occur in young leaves; leaves become yellow in color with smaller in size

Correction Measure

Foliar spray of CuSO₄@2%

Iron

Deficiency Symptoms :

Young leaves where pale stripes with scanty chlorophyll content occur between parallel lines. Leaves turn completely white, even in the veins and midribs. Restricted Root growth. Stunted appearance with constricted internodes

Corrective Measure :

Foliar spraying of 250-500g of ferrous sulphate dissolved in 100 lit of water or Soil application of 25kg/ha of ferrous sulphate or Application of 100 kg of ferrous sulphate mixed with 12.5 tonnes of farmyard manure for one hectare (or) Alternatively foliar spraying of 5 kg of ferrous sulphate with 2.5 kg of urea in 500 litres of water for one hectare should be done.

The foliar spraying may be repeated at an interval of 7-10 days depending upon on the severity of the disorder.

Manganese

Deficiency Symptoms :

A chlorosis in young leaves increases to a uniform yellow a gray metallic purplish luster develops on the appear surface. Upward curving of blade margins.

Correction Measure :

Foliar spray of MnSO₄@1-2%

Molybedenum

Deficiency Symptoms :

Resembles S deficiency. Pitting develops along the veins.

Correction Measure :

Foliar spray of sodium molybdate@2mg/litre

Zinc

Deficiency Symptoms :

Light greening or yellowing first appears in younger leaves followed by pitting, collapse and drying of interveinal tissue, leaving the veins green

Correction Measure :

Foliar spray of ZnSO₄@0.5%

SUGARBEET

Nitrogen

Deficiency Symptoms :

Yellowing of leaves. Premature senescence of older leaves. Seedlings yellow, center leaves green in colour.

Correction Measure :

Foliar spray Urea 1% twice at weekly interval.

Phosphorus

Deficiency Symptoms :

Plants smaller in size and have a deep green color ranging from a dull grey green to almost bluish-green.

Correction Measure :

Foliar spray of DAP 2% twice at fortnight interval.

Potassium

Deficiency Symptoms :

Marginal tanning and scorching of mature leaves. Center leaves remain normal. Intreveinal scorching. Crinkled leaf surface of mature leaves.

Correction Measure :

Foliar spray of KCl 1% twice at weekly interval

Calcium

Deficiency Symptoms :

Leaves crinkling downward and cupping or young leaf blades with chlorotic margins. Young blades become tip burn. The growing-point damaged.

Correction Measure :

Foliar spray of CaCl₂ 0.5% twice at fortnight interval

Magnesium

Deficiency Symptoms :

Easily confused with K deficiency. Mature leaves become chlorotic, interspersed with interveinal necrosis. Base of the blade remains green, after forming a green triangle at the base.

Correction Measure :

Foliar spray of MgSO₄ 1% twice at Fortnight interval.

Boron

Deficiency Symptoms :

Symptoms first appear in young leaves; crinkled appearance of leaves.

Correction Measure :

Foliar spray of borax @0.5%

Copper

Deficiency Symptoms :

Green netted veining followed by a "bleaching" of the leaf blade tissues. Symptoms differ from the spotted necrosis of Fe deficiency.

Correction Measure :

Foliar spray of CuSO₄ 0.25%

Iron

Deficiency Symptoms :

Yellowing of young leaves; leaves size become small

Correction Measure :

Foliar spray of FeSO₄ 0.5% twice at fortnight interval

Manganese

Deficiency Symptoms :

Marginal chlorosis of young leaves, which later turn brown. Fruits with raised spots which are dark brown on black in colour. Leaves give striated appearance from the edges.

Correction Measure :

Foliar spray of MnSO₄ @1%

Study questions

1. Write the symptoms of major nutrients
2. Define hidden hunger
3. Write physiological disorders in cereals and pulses
4. What are all the immobile and mobile elements

Lecture No: 10: Diagnosis and Correction Measures for Nutritional Disorders in Fruits and vegetable crops

BANANA

Nitrogen

Deficiency Symptoms :

Nitrogen deficiency causes slow growth and paler leaves with reduced leaf area and rate of leaf production. Leaf petioles short, thin and compressed, thin profuse roots and lesser number of suckers are produced due to lack of N.



Corrective Measure :

Foliar spray of urea 2% at weekly intervals till disappearance of the deficiency symptom.

Phosphorus

Deficiency Symptoms :

The deficiency of P causes complete cessation of elongation, at a height of about two feet resetting of leaves with older leaves becoming increasingly irregularly necrotic, leaf production is reduced, and marginal chlorosis and premature death are caused. P deficiency causes a blue or dark green coloration of leaves.



Corrective Measure :

40-60 g SSP / plant. Entire quantity of phosphorus fertilizer should be applied at the time of last ploughing or applied at the time of filling the pits.

Potassium

Deficiency Symptoms

Deficiency of potassium causes marked reduction in growth, interval profusely smaller, premature yellowing of plant. Purplish brown patches appear at the base of the petioles and in severe cases the centre of the corm may show area of brown, water soaked disintegrated cell structures. Fruits are badly shaped, poorly filled and unsuitable for marketing. Splits develop parallel to the secondary veins and the lamina folds downwards, while the midrib bends and fractures, leaving the distal half of the leaf hanging.



Corrective Measure

Foliar spray of KCl 2% at weekly interval till the symptom disappear.

Calcium

Deficiency Symptoms

Characterized narrow band of marginal chlorosis of leaves turning into necrotic fallow. Leaves become small, growth shunted. Youngest leaves with thickened secondary veins. Splitting and curling of leaf edges. Distal end of midrib interveinal and marginal chlorosis.

Corrective Measure

Application of gypsum @ 250Kg/ha.

Magnesium

Deficiency Symptoms

Magnesium deficiency symptoms show green banding around the margin and next to the midrib. Leaves turn yellowish with brown spots on the leaf margin. Plant height reduced marginal yellowing of leaf margin extends towards the midrib. Purplish mottling of leaf petiole and malformation of leaves. Fruits do not ripen well and become tasteless.



Corrective Measure

Spraying MgSO₄ 5% or application of dolomite lime stone 3t/ha effectively corrects the deficiency.

Sulphur

Deficiency Symptoms

Deficiency causes chlorosis and delaying of green colour in newly emerging leaves, thickening and leaf puckering, reduced plant growth and growth and reduced leaf size. The heart leaf becomes white and leaf blades become very soft and tear easily.



Corrective Measure

Application of ammonium sulphate @ 100g/plant.

Boron

Deficiency Symptoms

Newly emerging leaves are malformed. Plants show stunted growth. Chlorotic streaks appear perpendicular to the veins. Incomplete leaf formation and inhibition of fruit and flower. Deficiency of boron may result in reduction in weight and size of the bunch and it will affect the proper filling of the bunch.



Corrective Measure

Soil application of 20 g Borax per tree. Borax acid 0.2% foliar sprays on 4th and 5th month after planting.

Copper

Deficiency Symptoms :

Plants show overall droopy appearance with shortened intervals between petioles. Size of leaves reduced.

Corrective Measure

Application of 20 Kg CuSO₄/ha into the soil or foliar spray of 2% CuSO₄ is recommended.

Iron

Deficiency Symptoms :

Iron deficiency has been recorded in alkaline soils and is identified by interveinal chlorosis of young leaves.



Corrective Measure

Soil application of FeSO₄ 5/g/ha or foliar spray of 0.5% FeSO₄ at weekly intervals is recommended.

Manganese

Deficiency Symptoms :

Marginal chlorosis of young leaves, which later turn brown. Fruits with raised spots which are dark brown on black in colour. Leaves give striated appearance from the edges.

Corrective Measure

Weekly foliar spray of 2% MnSO₄ up to the symptoms disappear.

Zinc

Deficiency Symptoms :

Deficiency appears in the young plants. Interveinal chlorosis of leaves with chlorotic stripes. Leaves appear papery whole in colour. Finger twisted, short, thinner and light green colour.



Corrective Measure

Application of 50 g/plant ZnSO₄ at time of planting is recommended or foliar application of ZnSO₄ at 3 g/litre + urea (5g per litre) + 10 ml non ionic sticker in 20 litres of water. The above prepared solution is sprayed at 45 and 60 DAP.

Nitrogen

Deficiency Symptoms :

Yellow undersized leaves, severe retardation of growth, twigs become yellow in color. Fruits smaller and mature early. Leaves small with general yellowing



Correction Measure :

Application of recommended nitrogenous fertilizers (80 kg N/ha) or foliar application of Urea 2-4% at fortnightly intervals.

Phosphorus

Deficiency Symptoms :

Retarded growth premature dropping of older leaves partial die-back from the tip small green younger leaves are borne at the tips of the branches. Some branches show die back. Leaf tip necrosis and premature abscission of leaves.



Correction Measure :

Soil application of single super phosphate or foliar application of ortho phosphoric acid 0.5% thrice is highly recommended.

Potassium

Deficiency Symptoms :

Darkening of leaves, reduced growth and vigour. Appearance of white, yellow or orange chlorotic spots in older leaves and distributed irregularly over both under and upper leaf surfaces. Necrotic areas develop along the leaf margins. Poor growth of roots. Die back with tip burn with small leaves.



Correction Measure :

Foliar spray of KCl 2% at fortnightly intervals will give the best results.

Calcium

Deficiency Symptoms :

Abnormal growth of young leaves and growing points resembling boron deficiency severe deficiency leads to death of the bud.

Correction Measure :

Soil application of gypsum at 50 kg/ha is recommended as the remedy.

Magnesium

Deficiency Symptoms :

Reduction in growth premature defoliation yellowish brown chlorosis featured by a green wedge down the central part of the leaf bronzing starting from the edge of the leaf rounded margin between each pair of lateral veins.

Correction Measure :

Soil application of MgSO₄ 5-10 kg/ha a foliar spray of MgSO₄ 2% at fortnightly intervals.

Sulphur

Deficiency Symptoms :

Symptoms first appear on young leaves with fading of green colour. Growth is stunted. Leaf tip remains green and with severe deficiency the whole leaf turns yellow.



Correction Measure :

Soil application of sulphur fertilizer

Boron

Deficiency Symptoms :

Deficiency is common in high rainfall areas, high temperature, soil acidity and calcareous soils. Fruits become brown in colour. Flesh may become soft and watery which cracks down to the centre.

Correction Measure :

Application of 5-10 kg Borax / ha a foliar spray of 0.25% Borax at 10 days interval

Copper

Deficiency Symptoms :

Shoots produced on long drooping S-shaped branches of previous growth are weak lose foliage and die back.

Correction Measure :

Foliar spray of Copper oxy chloride 0.2% at fortnightly intervals will give the best results.

Copper

Deficiency Symptoms :

Shoots produced on long drooping S-shaped branches of previous growth are weak lose foliage and die back.

Correction Measure :

Foliar spray of Copper oxy chloride 0.2% at fortnightly intervals.

Manganese

Deficiency Symptoms :

Deficiency appears on the middle of the plant. Interveinal chlorosis of leaves. Reduced growth leaf symptoms appear very late leaves show a yellowish green background with a fine network of green veins on the upper surface and disappearing after a few weeks mature leaves thicker and blunted. Specks of light grey to grayish brown colour appear under mid deficiency.

Correction Measure :

Foliar application of MnSO₄ 0.2% at fortnightly intervals.

Zinc

Deficiency Symptoms :

Leaf blade thickens leaf shape is distorted leaf margin up or down the tip may curve back interveinal areas leaves are usually smaller thickened leaf blade brittle spaced leaves show a rosette appearance. Some twigs die back flower panicles of trees showing little leaf symptoms are usually small irregular in shape drooping spikes.



Correction Measure :

Soil application of ZnSO₄ 10 kg/ha or foliar spray of ZnSO₄ 0.5% or nitrozinc at 150 ml /100litres of water.

Grapes

Phosphorus

Deficiency Symptoms

Pigmentation seen in old leaves; the rate of leaf growth is affected.

Correction Measure

Soil application of super phosphate or foliar spray of DAP@1-2%

Potassium

Deficiency Symptoms

A dull, dark green color will appear on the leaves. In mid-to late summer, leaves may have a bronze color, especially on the west-facing side of the trellis. Some leaves may have dark spots or blotches. This symptom often has been characterized as black leaf of grapes Marginal chlorosis, browning, and drying may occur as the deficiency becomes more severe. Other possible symptoms include brown dead spots or areas throughout the leaf. In sever cases, more than half of the leaves on a vine may show these symptoms. Severe potassium deficiency greatly reduces vine vigor, berry size, and crop yield. Symptoms of potassium deficiency generally develop in mid-shoot leaves followed by older basal leaves.

Correction Measure

Foliar sprays of K₂SO₄or KNO₃ can be effective to temporarily reduce a severe K deficiency. Soil application in general 40-160 kg per acre have been adequate. Foliar spray KNO₃ 1% is recommended.

Calcium

Deficiency Symptoms

Growth of the plant is reduced. symptoms are first seen at the growing points of the plant, which may become necrotic and die. Marginal leaf chlorosis followed by necrosis will be evident on the youngest leaves. Flower buds will fail to develop. The youngest leaves will remain small and deformed and will tend to curl upward at the margins.

Correction Measure

Foliar spray of CaSO₄ 1% or soil application of gypsum @ 50 kg/ha.

Magnesium

Deficiency Symptoms

Symptoms of Mg deficiency develop on the older leaves first. Chlorosis (yellowing) appears between the veins of the leaves while the veins remain green. As a vine becomes more severely affected, interveinal chlorosis intensifies in older leaves and spreads to younger leaves toward the terminals of canes. The younger terminal leaves may not exhibit symptoms until the entire vine is extremely deficient. Early symptoms: green leaf margins with yellow between the veins. Deficiency of magnesium appears first on basal leaves of shoots as a yellowing between veins. Symptoms progress to dead blotches on the leaves, which may be a rusty-red. Advanced stage yellow between veins interspersed with brown or often rust-colored areas. First chlorosis of

basal leaf margins, than between and secondary veins, leaf margin burn may develop, interveinal areas become white yellow or red depending on variety.

Correction Measure

Mix magnesium sulfate at the rate of 6 kg per 200 litres of water. Two applications usually are adequate. Apply the first shortly after bloom and the second two weeks later. Each spray application requires about 400 to 500 litres of the mixture per acre to adequately cover the vines.

Sulphur

Deficiency Symptoms

Whole orchard or spot-wise stunted growth of pale-green plants.



Correction Measure

Foliar spray of MgSO₄@1%

Boron

Deficiency Symptoms

Poor fruit set clusters will tend to be small, and berries will not fully develop on the rachis. Terminal buds may not break in the spring, and ends of shoots sometimes are distorted. Borax or borate, B carriers, can be sprayed on in the spring when needed. Pre-bloom sprays seem to be an effective way to get B into flower parts. Use foliar applications at an annual rate of one pound of actual boron per acre.



Correction Measure

Foliar spray of Borax 0.2% at soil application of Borax 25-50 g/plant.

Iron

Deficiency Symptoms

Leaf veins remain green interveinal portion turns yellow young leaves small but not deformed.



Correction Measure
Foliar spray of 0.5% FeSO₄

Manganese

Deficiency Symptoms

Symptoms first appear as interveinal chlorosis, or yellowing of the younger terminal leaves. Applying fertilizer-grade manganese sulfate at 20 to 40 gm per vine, or 100 to 200 kg per acre, depending on vine size and severity of the deficiency.



Correction Measure
Foliar application of Mn can be sprayed for immediate effect mix manganese sulfate at the rate of 160 gram plus 80 gram of hydrate lime per 200 litres of water. Two application usually will provide season-long control of manganese symptoms. First appln.just after bloom or when symptoms first appear and second two weeks later.

Zinc

Deficiency Symptoms

Poor fruit set and stunted shoots with small, misshapen leaves foliar application of zinc is the most effective method for treating Zn deficiency.



Correction Measure

Neutral zinc products containing 50-52% Zn, or zinc oxide (75-80% Zn) are both effective as foliar sprays. Zinc spray applications are most effective in improving fruit set when applied during the period of two weeks prior to bloom up to full bloom. If foliar deficiency symptoms persist or reappear, a second application may be necessary.

ACID LIME

Nitrogen

Deficiency Symptoms

Dull green, yellowish, smaller leaves. Die back of twigs, thin and bushy appearance of tops with sparse bloom. Vein chlorosis. New leaves are greater than older.

Correction Measure

Foliar spray urea 2% at 15 days interval.

Potassium

Deficiency Symptoms

Slower growth, shedding of leaves at blossom time. New shoots poorly attached to twig. Smaller leaves, twigs die back, scorching of leaf tips, small brown resinous spots on leaf. Small wrinkled spotted leaves. Small fruits, thin peel. In mandarin – yellowing and bronzing of leaves become twisted, wrinkled and spindly twigs.

Correction Measure

Foliar spray of KNO₃ 2% at fortnightly interval. Application of 200g N, 100g P₂O₅ and 200g K₂O / tree/year.

Boron

Deficiency Symptoms

Premature wilting, water soaked spots on leaves. Premature shedding of leaves, bushy appearance curling of leaves, splitting and curling of veins. Fruits with gum spots and lumps, hand abnormal shape and small.

Correction Measure

Foliar spray of [borax@0.5%](#)

Copper

Deficiency Symptoms

Reduced growth and dark green colour of leaves, twin led malformed leaves. New leaves shriveled, bushy growth.

Correction Measure

Foliar spray of CuSO₄ each 0.5% at fortnightly interval.

Manganese

Deficiency Symptoms

Fine network of green veins as a light green background on young leaves. Leaf remains fairly green. Dark green irregular bands on mature leaves, along the midrib. White spots develop in interveinal area with die back symptom.

Correction Measure

Foliar spray of 0.5% MnSO₄ at fortnightly interval.

Zinc

Deficiency Symptoms

Irregular and chlorite leaf spots, mottled leaf, small leaves, severe dieback of twigs. The area near midrib and lateral veins remain green. Terminal twigs with narrow small erect leaves. Small, thin skinned fruits.

Correction Measure

Foliar spray 2% ZnSO₄ with 1% lime at fortnightly interval.

SAPOTA

Nitrogen

Deficiency Symptoms

Stunted growth. The bark of the shoots turned reddish-brown in colour. On elongating shoots the immature leaves were amber to bright red in colour while the mature leaves remained small and yellow-green in colour. Early abscission of leaves, smaller and fewer fruits.

Correction Measure

Foliar sprays of urea 2% were more effective treatment with 250 g N per tree from both sources increases the fruit weight and yield.

Phosphorus

Deficiency Symptoms

Pigmentation seen in older leaves; leaf size become small

Correction Measure

Foliar spray of DAP 2% at fortnightly intervals.

Potassium

Deficiency Symptoms

Light brown specks scattered all over the leaves which appeared later merged forming necrotic patches between the large veins. Browning on the under side of the leaves and chlorotic areas between veins due to K deficiency.

Correction Measure

Application of KCl at 80 kg per hectare. Application of K₂SO₄ instead of potassium chloride to the sapota plants.

Magnesium

Deficiency Symptoms

Leaves become lighter green which gradually turned greenish yellow, remaining deeper green along the mid rib and larger veins. Leaves turned yellow with scattered brown lesion on the leaf blade. Intervenial chlorosis on older leaves followed by necrosis of distal leaf edge.

Correction Measure

Application of dolomite or spraying magnesium nitrate 1% can avoid the deficiency.

Sulphur

Deficiency Symptoms

Yellowing of young leaves; growth of the leaf will be affected

Correction Measure

Foliar spray of CaSO₄@1%

Boron

Deficiency Symptoms

Leaves were yellowish-green in colour the older leaves showed signs of burning at the tips and along the margins which abscissed prematurely. The tip burning of young leaves and splits or crack on the midrib and large veins on the underside of the leaf.

Correction Measure

Soil application of borax at 5 kg/ha.

Copper

Deficiency Symptoms

The leaf veins developed a reddish-brown colour, premature defoliation and die back of twigs also occurred. The tip of the twigs developed multiple buds which died soon.

Correction Measure

Application CuSO₄ 5 to 10 Kg/ha. Cu-fungicide sprays will be helpful in correcting the deficiency

Iron

Deficiency Symptoms

yellowing of young leaves; occurrence of interveinal chlorosis



Correction Measure

Foliar spray of FeSO₄@0.5 % at fortnightly intervals

Zinc

Deficiency Symptoms

Symptoms seen in young leaves; size of the leaf become small



Correction Measure

Foliar spray of ZnSO₄@0.5%

AMLA

Boron

Deficiency Symptoms

Fruit necrosis which begins with the browning of inner most part of the mesocarpic tissues at the time of endocarp hardening. This is extended towards the epicarp resulting into brownish black areas on the fruit surfaces depending of the severity of the disorder, mesocarp of affected fruits turns black from brown which later turns into corky and gummy pockets.



Correction Measure

Spray of Borax 0.6% thrice at monthly intervals

VEGETABLE CROPS TOMATO

Nitrogen :

Deficiency Symptoms :

Restricted shoot growth and spindly appearance of plants. Older leaves at first turn yellowish green; under severe deficiency, the whole plant becomes pale green. The leaflets are small, erect and with pink veins which are more clearly noticeable on the underside. Leaves die prematurely. Flowers buds turn yellow and fall off. Fruits when formed, remain small.



Corrective Measure :

Foliar spray of urea 1% twice at weekly interval.

Phosphorus

Deficiency Symptoms :

Plants look lush blue-green or purplish in colour. The stems very thin and stunted while the roots were brown with restricted development of lateral branches. Mature leaves to be small with down curled leaflets. The oldest leaves, having initially purplish tints and scorched areas, later became yellow with purple veins and died prematurely.

Corrective Measure :

Foliar spray DAP 1% twice at fortnightly interval.

Potassium

Deficiency Symptoms :

Yellowish spots in the margins of new leaves which later spread over the leaf surface and subsequently turned brown, starting with the older leaves. Plants were stunted, hard and chlorotic. Leaves first become grey at the margin and later interveinally. The tips and margins underwent scorching and turned upwards K deficiency symptoms appeared first in the oldest leaves. Leaves remained small and plant growth restricted. Chlorosis and necrosis then spread to younger leaves with defoliation of yellowed and curled older leaves.



Corrective Measure :

Foliar spray of K₂SO₄ 1% thrice at weekly interval.

Calcium

Deficiency Symptoms :

The plants became flaccid; dead spots appeared on the upper stems and the growing apex died. Upper leaf colouration initially was darker green, but, later turning yellow at the edges and died. Scorching and die back of the main stem, strong curing of the leaves inwards and downwards. Fruits showing blossom end rot were found to ripen less rapidly. Blossom end rot is closely associated with Ca deficiency of the fruit. Sunken region of few millimeters in width, near distal end of youngest fruit.



Corrective Measure :

Soil application of CaSO₄ 1 to 2 kg/acre or Foliar spray of CaCl₂ 0.5% thrice at fortnightly interval.

Magnesium

Deficiency Symptoms :

Chlorosis of foliage. Interveinal areas became yellow or greenish yellow while leaf margins remained green. Mg deficiency starts as interveinal yellowing at the leaf margins on older leaves, which later become brown and withered interveinal yellowing and necrosis. Sunken necrotic spots which appeared shiny from back of leaf appear the first symptoms of Mg deficiency as discoloration of the margins. Yellowing progressed from base to the top of the plant.

Corrective Measure :

Foliar spraying of 2% MgSO₄ twice at fortnightly interval or soil application of dolomite at 2 ton/ha or magnesium sulphate at 20 kg/ha.

Sulphur**Deficiency Symptoms :**

Symptoms are somewhat similar to nitrogen deficiency. Younger leaves are affected. Lower leaves yellowish green while stems were hard and woody. Older leaves developed necrosis at tips and margins with development of small purple spots between the veins. Young leaves stiff and curled downward.

Corrective Measure :

Foliar spray of CaSO₄ 1% twice at fortnightly interval or gypsum @ 50 kg/ha.

Boron**Deficiency Symptoms:**

Yellowish of the tips of the leaflets oldest leaves with prominent pink veins. Yellow spots then enlarged. Yellowing of the tips of lower leaves and brittleness of the leaflets and petiolues. Yellow leaflet tips became dry and brown. Leaf margins remained free from such browning. Severe deficiency led to stiff, thick and shortened stems, death of the growing points and development of yellow, brown and purple areas on leaf. Uneven ripening and development of corky pits in fruits.

Corrective Measure :

Foliar spray Borax 0.3% twice at fortnightly interval or soil application Borax 20 kg/ha.

Copper**Deficiency Symptoms :**

Reduction in growth, curling of leaf upwards and inwards with severe scorching. Poor root development. Overall grey-green colour followed by chlorosis of lower leaves. Chlorotic leaves subsequently became bronzed and later brown with development of necrosis at the margins and blackening of veins. Margin and tips of leaves witled while in the case of older leaves, there was a stiff rolling up of margins. Leaves were found to be blue-green in colour. Leaf number, leaf size reduced.

Corrective Measure :

Foliar spray of 0.5% CuSO₄ twice at fortnightly interval.

Iron**Deficiency Symptoms :**

Leaf veins remain green interveinal portion turns yellow young leaves small but not deformed.

Corrective Measure :

Foliar spray of 0.5% FeSO₄

Manganese**Deficiency Symptoms:**

Reduction in leaf size and development of interveinal orange-yellow mottling over the tip. Mottling spreads over the whole leaflet turn yellow while the veins remain green. Numerous

small, dark brown, necrotic spots with chlorosis in leaflets of very young leaves. Lamina becoming narrower and longer. Root system reduced than normal plants.

Corrective Measure :

Foliar spray of MnSO₄ 0.5% twice at fortnightly interval.

Molybelenom

Deficiency Symptoms :

Mottling in lower leaves followed by scorching of margins and inrolling. Extensive flower drop older leaves senesced and dropped off prematurely with death of the growing point.

Corrective Measure:

Foliar spray of NaMO₄ 0.05% twice at weekly interval.

Zinc

Deficiency Symptoms :

Deficiency appears first on older leaves in the form of interveinal chlorosis. Inhibit both vegetative growth and fruit production. Shortened internodes, diminutive leaves with undercurling of leaflets, epinastic curvature of leaves and chlorosis. Oozing out of cell contents as a brown fluid from the leaves.

Corrective Measure :

Foliar spray of ZnSO₄ 1% twice at fortnightly interval.

BRINJAL

Nitrogen

Deficiency Symptoms

Light green to a yellowing symptom first occurs in older leaves progressing to the newer leaves. Firing of the older leaves. Leaves plants stunted with hard, fibrous and slender stems. Older leaves become stiff.



Correction Measure

Foliar spray of Urea 2% twice at weekly interval.

Potassium

Deficiency Symptoms

Older leaves affected first. Leaf tips and margins turn yellow and then become scorched continuing inward to the leaf center. Leaf margin cup downward interveinal leaf necrosis restricted growth. Poorly developed roots and fruit.



Correction Measure

Foliar application of K₂SO₄ @1%.

Magnesium

Deficiency Symptoms

Interveinal chlorosis of older larger leaves veins remain green necrotic areas with time and die.

Leaf margins curl upward purple tinting on older leaves smaller fruit.

Correction Measure

Foliar spray of MgSO₄ @2%.

Calcium

Deficiency Symptoms

Necrosis at tip and margins of newer immature leaves nearest the terminal growth with a distorted appearance stems thick fibrous retarded growth terminal buds die. Brown to Black leathery spots on the underside of fruits.



Correction Measure

Foliar spray of 2% Calcium sulphate twice at weekly intervals.

Sulphur

Deficiency Symptoms

Newer leaves light green to yellowish leaf veins appear lighter in color leaf tips cupping downward stems hard fibrous and spindly.

Correction Measure

Foliar spray of K₂SO₄ 1%.

Boron**Deficiency Symptoms**

Leaves chlorotic small thick brittle and misshapened the base of the new leaves wrinkled or deformed internodes short with a resetting appearance terminal bud dies.

Correction Measure

Soil application of borax 5Kg/ha or foliar spray of borax 0.2%.

Iron**Deficiency Symptoms**

Leaf veins remain green interveinal portion turns yellow young leaves small but not deformed.

Correction Measure

Foliar spray of 0.5% FeSO₄

Manganese**Deficiency Symptoms**

Upper newer leaves affected first interveinal chlorosis veins remaining green chlorotic spots become necrotic and brown plants stunted.

Correction Measure

Foliar spray of 0.5% MnSO₄

Zinc**Deficiency Symptoms**

Young leaves small and narrow with interveinal yellow to white coloration, Necrotic spotting of older leaves.

Correction Measure

Soil application of 20-25 Kg ZnSO₄/ha or foliar spray of ZnSO₄ @ 0.5%.

BHENDI**Potassium****Deficiency Symptoms**

Stunted plant growth; old leaves become turn yellow in color and occurrence of marginal chlorosis

Correction Measure

Foliar spray of KCl@1%

Boron**Deficiency Symptoms**

Leaves become brittle; stunted plant growth



Correction Measure

Foliar spray of [borax @0.5%](#)

Boron

Deficiency Symptoms

young leaves become smaller in size; malformed fruits

Correction Measure

Foliar spray of [borax @0.5%](#)

Iron

Deficiency Symptoms

Stunted plant growth; chlorosis occur in young leaves



Correction Measure

Foliar spray of FeSO₄ @ 05.%

Zinc

Deficiency Symptoms

Marked depression in leaf production and leaf size occurred within about 3 weeks and leaf mottling developed about 2 weeks later. The stem diameter was reduced.



Correction Measure

Foliar spray of ZnSO₄ 0.5% or Soil application of 10kg ZnSO₄/ha

CHILLI

Nitrogen

Deficiency Symptoms

Branches are short, thin small distorted leaves colour changes from light green to yellowish green fruits small and chlorotic



Correction Measure

Foliar spray of Urea 1% at fortnightly intervals

Phosphorus

Deficiency Symptoms

Plants stunted leaves small narrow inwardly curved. Older leaves yellowish with pink margin fruits small distorted in shape.

Correction Measure

Foliar spray of DAP 2% at fortnightly intervals

Potassium

Deficiency Symptoms

Growth suppressed leaf number reduced size small colour yellowish necrotic lesions along the veins crinkling leaves and marginal scorch.

Correction Measure

Foliar spray of K₂SO₄ 1% at fortnightly intervals

Calcium

Deficiency Symptoms

Growth of the plant is reduced symptoms are first seen at the growing points of the plant, which may become necrotic and die. Marginal leaf chlorosis followed by necrosis will be evident on the youngest leaves. Pale brown sunken areas will also develop around the blossom end of the pepper fruits (blossom – end rot or BER). Flower buds will fail to develop. The youngest leaves will remain small and deformed and will tend to curl upward at the margins.



Correction Measure

Foliar spray of CaSO₄ 1% or soil application of gypsum @ 25 kg/ha.

Sulphur

Deficiency Symptoms

Chlorosis occur in young leaves; leaves become small

Correction Measure

Foliar spray of CaSO₄@0.5 -1.0%

Boron

Deficiency Symptoms

Newly emerging leaves are malformed. Plants show shunted growth. Chlorotic streaks appear perpendicular to the veins. Incomplete leaf formation and inhibition of fruit and flower. Deficiency of boron may results in reduction in weight and size of the fruit.



Correction Measure

Foliar spray of [borax@0.2%](#)

Copper

Deficiency Symptoms

Plants show overall droopy appearance with shortened intervals between petiole. Size of leaves reduced.

Correction Measure

Foliar spray of CuSO₄@2%

Iron

Deficiency Symptoms

Symptoms are first seen in the youngest leaves. Initially the smallest veins remain green, which produces a reticulate pattern of green veins on yellow leaves. The leaves eventually turn completely chlorotic but there is no associated necrosis.



Correction Measure

Foliar spray of FeSO₄ 0.5% at fortnightly intervals.

Manganese

Deficiency Symptoms

Marginal chlorosis of young leaves, which later turn brown. Fruits with raised spots which are dark brown on black in colour.

Correction Measure

Foliar spray of MnSO₄@1-2%

Boron

Deficiency Symptoms

Newly emerging leaves are malformed. Plants show shunted growth. Chlorotic streaks appear perpendicular to the veins. Incomplete leaf formation and inhibition of fruit and flower. Deficiency of boron may results in reduction in weight and size of the fruit.

Correction Measure

Foliar spray of [borax@0.2%](#)

ONION

Nitrogen

Deficiency Symptoms

Leaves become yellowish green erect and upright curled, wilted and dwarf. At maturity tissue above bulbs become soft.

Correction Measure

Foliar spray of Urea 1% or DAP 2% twice at weekly intervals.

Phosphorus

Deficiency Symptoms

Slow growth, maturity blazed. Leaf colour becomes light green and bulbs have few dried outer peals. Tip burn in older leaves.

Correction Measure

Foliar spray of DAP 2% twice at fortnightly intervals

Potassium

Deficiency Symptoms

Tip burn symptoms, leaves become dark green and erect. Bolting promoted. Older leaves become yellow and necrotic.

Correction Measure

Foliar spray of K₂SO₄ 1% twice at weekly intervals.

Calcium

Deficiency Symptoms

Occurrence of chlorosis;

Correction Measure

Foliar spray of CaCl₂@1%

Sulphur

Deficiency Symptoms

Yellowing of young leaves

Correction Measure

Foliar spray of MgSO₄

Copper

Deficiency Symptoms

Scales become thin and pale yellow colour. The bulbs lack firmness and solidity and early maturation leaves show tip burn with Chlorate mottling.

Correction Measure

Foliar spray of CuSO₄ 0.3% twice at weekly interval.

Iron

Deficiency Symptoms

Complete yellowing of young leaves

Correction Measure

Foliar spray of FeSO₄@0.5%

Manganese

Deficiency Symptoms

Leaves show tip burn, light coloured and curling. Growth restricted. Bulking delayed with thick necks.

Correction Measure

Foliar spray of MnSO₄@ 0.3% twice at fortnightly interval.

Molybdenum

Deficiency Symptoms

Terminal leaf become curling; yellowing of leaves

Correction Measure

Foliar spray of sodium molybdate@0.2%

Zinc

Deficiency Symptoms

Growth restricted. Leaves yellow colour strips and bend.

Correction Measure

Foliar spray of ZnSO₄ 0.5% twice at for nightly interval.

BOTTLRGOURD

Potassium

Deficiency Symptoms

Lower (old) leaves show puckering and yellowing in interveinal areas and marginal scorching.



Correction Measure

Foliar spray of KCl@1%

Calcium

Deficiency Symptoms

Leaf growth will be affected; terminal flower bud and growth of the fruit will be severely affected



Correction Measure

Foliar spray of [CaCl₂@0.5%](#)

Magnesium

Deficiency Symptoms

Symptoms seen in old leaves; occurrence of interveinal chlorosis



Correction Measure
Foliar spray of MgSO₄@0.5%

Boron

Deficiency Symptoms
Buckering of leaves; leaves become brittle when symptoms seem severe
Correction Measure
Foliar spray of borax@0.5%

Iron

Deficiency Symptoms
Chlorosis occur in young leaves; leaves turn into yellow
Correction Measure
Foliar spray of FeSO₄@0.5%

BITTERGOURD

Nitrogen
Deficiency Symptoms
Stunted plant growth;Old leaves turn yellow in color



Correction Measure
Foliar spray of urea @ 1%

Potassium

Deficiency Symptoms
Interveinal necrosis of old leaves, puckering, distortion and outward rolling of middle leave.



Correction Measure

Foliar spray of 0.2-0.5% K₂SO₄

Sulphur

Deficiency Symptoms

Stunted plant growth; Chlorosis occur in young leaves

Correction Measure

Foliar spray of CaSO₄ @ 0.5%

Boron

Deficiency Symptoms

Young leaves become brownish and brittle; crinkling of leaves; small and malformed fruits

Correction Measure

Foliar spray of sodium molybdate @ 0.5%

Iron

Deficiency Symptoms

Chlorosis occur in young leaves; leaves turn into yellow



Correction Measure

Foliar spray of [FeSO₄@0.5%](#)

Manganese

Deficiency Symptoms

Symptoms seen in young leaves; leaves become pale yellow

Correction Measure

Foliar spray of [MnSO₄@0.5%](#)

Zinc

Deficiency Symptoms

Symptoms will be seen in young leaves; leaves become small

Correction Measure

Foliar spray of ZnSO₄ @ 0.5%

SNAKEGOURD

Nitrogen

Deficiency Symptoms

Apical growing points stop developing leaves thick brittle and irregular chlorosis.

Correction Measure

Foliar spray of Borax 0.5 % at fortnightly intervals

Potassium

Deficiency Symptoms

Older leaves affected first. Leaf tips and margins turn yellow and then become scorched continuing inward to the leaf center.

Leaf margin cup downward interveinal leaf necrosis restricted growth.

Correction Measure

Foliar spray of K₂SO₄ @1 % at fortnightly intervals

Magnesium

Deficiency Symptoms

Apical growing points stop developing leaves thick brittle and irregular chlorosis.

Correction Measure

Foliar spray of Borax 0.5 % at fortnightly intervals

Manganese

Deficiency Symptoms

Symptoms seen in young leaves; leaves become pale yellow

Correction Measure

Foliar spray of MnSO₄ @0.5 % at fortnightly intervals

CUCUMBER

Nitrogen

Deficiency Symptoms

Both vegetative growth and fruit production are severely restricted plants appear pale and spindly. New leaves are small but remain green, whereas the oldest leaves turn yellow and die. The yellowing spreads up the shoot to younger leaves. Yield is reduced and fruit are pale, short and thick.

Correction Measure

Side-dress deficient in-ground crops with 20-50 kg N/ha, or apply fortnightly foliar sprays of 2% urea at high volume.

Potassium

Deficiency Symptoms

Potassium deficiency causes yellowing and scorching or older leaves. These symptoms begin at the margins of the leaf and spread between the veins towards its centre. Large areas of tissue around the major veins remain green until the disorder is well advanced. A brown scorch develops in the yellow areas and spreads until the leaf is dry and papery. Potassium from a fertilizer side-dressing will move from the soil surface to the roots only if the soil is very sandy. Potassium fertilizers are therefore best incorporated in the soil before planting. Fertigation or drip feeding can also be used to treat a deficient crop.

Correction Measure

Foliar spray of KCl 1% at weekly interval.

Calcium

Deficiency Symptoms

Emerging leaves appear scorched and distorted and may cup downwards because the leaf margins have failed to expand fully. Mature and older leaves are generally unaffected. With a severe deficiency, flowers can abort, and the growing point may die. Fruits from calcium-deficient plants are smaller and tasteless, and may fail to develop normally at the blossom end. Injury from calcium deficiency can be reduced by regular foliar sprays of calcium nitrate (800 g/100 L).

Correction Measure

Application of gypsum / foliar spray of CaSO₄ 2%.

Magnesium

Deficiency Symptoms

Magnesium deficiency causes yellowing of older leaves. The symptom begins between the major veins, which retain a narrow green border. A light tan burn will develop in the yellow regions if the deficiency is severe. Fruit yields are reduced.

Correction Measure

Incorporate magnetite (300 kg/ha) or dolomite (800 kg/ha) into deficient soils before planting. Fortnightly foliar sprays of MgSO₄ (2 kg/100 L) at high volume (500-1000 L/ha).

Boron

Deficiency Symptoms

Distortion of newer leaves (in severe cases the growing point dies) and the appearance of a broad yellow border at the margins of the oldest leaves. Young fruit can die or abort; abortion rates are high. Stunted development and mottled yellow longitudinal streaks, which develop into corky marking (scurfing) along the skin.

Correction Measure

Foliar spray of 0.2% Borax at forthrightly interval. Application of 10 kg borax per hectare to deficient soil before will prevent boron deficiency.

Boron

Deficiency Symptoms

Distortion of newer leaves (in severe cases the growing point dies) and the appearance of a broad yellow border at the margins of the oldest leaves. Young fruit can die or abort; abortion rates are

high. Stunted development and mottled yellow longitudinal streaks, which develop into corky marking (scurfing) along the skin.

Correction Measure

Foliar spray of 0.2% Borax at forthrightly interval. Application of 10 kg borax per hectare to deficient soil before will prevent boron deficiency.

Iron

Deficiency Symptoms

Iron deficiency causes a uniform pale green chlorosis of the newest leaves; all other leaves remain dark green. Initially, the veins remain green, which gives a net-like pattern. If the deficiency is severe, the minor veins also fade, and the leaves may eventually burn, especially if exposed to strong sunlight. Good drainage and soil aeration favour iron availability. Foliar sprays of iron sulphate (150 g/100 L) can be used to treat symptoms

Correction Measure

Foliar spray of 0.5% FeSO₄

Manganese

Deficiency Symptoms

The veins of middle to upper leaves of manganese-deficient plants appear green against the mottled pale green to yellow of the blade.

Correction Measure

Spray the foliage with MnSO₄ (100 g/100 L).

Zinc

Deficiency Symptoms

Reduction in leaf size, shorting of internodes. Leaves pale green in colour and with green veins.

Correction Measure

Foliar application of 0.5% ZnSO₄ a soil application of 5-10 kg ZnSO₄ / ha.

CARROT

Nitrogen

Deficiency Symptoms

The Number and size of leaves were reduced and pale green colour of leaves change to yellow roots because thin, stiff and fibrous.

Correction Measure

Foliar spray of urea @1%

Phosphorus

Deficiency Symptoms

Plants were shorter, smaller leaves, distorted in shape and pink tinge appear along margin and veins. Formation of shortage root delayed.

Correction Measure

Soil application of recommended dose of Phosphorous fertilizer

Potassium

Deficiency Symptoms

Leaf colour change to pale yellow and brown scorches appear at later stages. Violet streaks appear on roots. Growth is retarded.

Correction Measure

Foliar spray of KCl@1%

Calcium

Deficiency Symptoms

Symptoms are marked on younger plant parts. Leaves become chlorotic fever and roots are smaller.

Correction Measure

Foliar spray of CaCl₂@0.5-1.0%

Magnesium

Deficiency Symptoms

Chlorotic on mature leaves. Which later abscise and fall off. The roots are smaller in size, stiff and pale in colour.

Correction Measure

Foliar spray of MgSO₄@0.5-1.0%

Sulphur

Deficiency Symptoms

Chlorosis occur in young leaves

Correction Measure

Foliar spray of CaSO₄@0.5%

Boron

Deficiency Symptoms

Crinkling of leaves; carrot size become smaller

Correction Measure

Foliar spray of borax@0.5%

Iron

Deficiency Symptoms

Chlorosis on younger leaves. Storage roots were reduced in size and become pale in colour.

Correction Measure

Foliar spray of FeSO₄@0.5%

Zinc

Deficiency Symptoms

Young leaves become smaller i.e. little leaf symptoms. and become yellow in color

Correction Measure

Foliar spray of ZnSO₄@0.5%

CAULIFLOWER

Nitrogen

Deficiency Symptoms

Plants have a uniform yellowish color, with leaves closest to the roots the root system very large oldest leaves will show purpling on underside first and margins of leaves tips will then turn purple followed by whole leaf taking on this color growth is retarded and plants have a poor root system.



Correction Measure

Foliar spray of Urea 1% at fortnightly intervals

Phosphorus

Deficiency Symptoms

Pink color pigmentation seen in old leaves; stunted plant growth

Correction Measure

Foliar spray of DAP 2% twice at fortnightly interval

Potassium

Deficiency Symptoms

Appears first on oldest cabbage leaves as spots shiny green leaves turn dull green, leaf margins turn a yellowish green followed by withering mature heads are loose and smaller. In K-deficient cauliflower, leaf tips turn brown, leaves turn inward and can have a crinkled surface.



Correction Measure

Foliar spray of K₂SO₄ 1% twice at weekly intervals.

CABBAGE

Nitrogen

Deficiency Symptoms

Yellowing of old leaves; stunted plant growth



Correction Measure

Foliar spray of urea@1%

Phosphorus

Deficiency Symptoms

Pigmentation in old leaves; curd size and quality will be affected



Correction Measure

Soil application of recommended dose phosphorus and foliar spray of

Potassium

Deficiency Symptoms

Appears first on oldest cabbage leaves as spots shiny green leaves turn dull green, leaf margins turn a yellowish green followed by withering mature heads are loose and smaller. In K-deficient cauliflower, leaf tips turn brown, leaves turn inward and can have a crinkled surface.

Correction Measure

Foliar spray of K₂SO₄ 1% twice at weekly intervals.

Calcium

Deficiency Symptoms

Leaf growth will be inhibited; scorching symptoms occur in new leaves

Correction Measure

Foliar spray of CaCl₂@1%

Magnesium

Deficiency Symptoms

Stunted plant growth; leaves become small; yellowing symptoms occur in old leaves

Correction Measure

Foliar spray of [MgSO₄@0.5-1.0%](#)

Sulphur

Deficiency Symptoms

Youngest leaves turned purplish, cupped upward leaf edges rolled in.

Correction Measure

Soil application of Gypsum 50 kg/ha.

Boron

Deficiency Symptoms

Apical growing points stop developing leaves thick brittle and irregular chlorosis.

Correction Measure

Foliar spray of Borax 0.5 % at fortnightly intervals

Copper

Deficiency Symptoms

Symptoms occur in young leaves; leaf growth will be affected; curd size also affected



Correction Measure

Foliar spray of [CuSO₄@0.5%](#)

Iron

Deficiency Symptoms

Chlorosis occur in young leaves; leaves become smaller in size; stunted plant growth

Correction Measure

Foliar spray of [FeSO₄@0.5%](#)

Molybdenum

Deficiency Symptoms

Stunted plant growth with malformed leaves

Correction Measure

Foliar spray of sodium molybdate @ 10mg/litre

Manganese

Deficiency Symptoms

Symptoms seen in young leaves; occurrence of chlorosis; leaves become pale yellow in color

Correction Measure

Foliar spray of [MnSO₄@0.4%](#)

Zinc

Deficiency Symptoms

Occurrence of little leaf symptoms; curd size will be small; chlorosis occur in young leaves

Correction Measure

Foliar spray of [ZnSO₄@0.5%](#)

RADISH

Nitrogen

Deficiency Symptoms

The Number and size of leaves were reduced and pale green colour of leaves change to yellow roots because thin, stiff and fibrous.



Correction Measure

Foliar spray of urea @1%

Potassium

Deficiency Symptoms

Leaf colour change to pale yellow and brown scorches appear at later stages. Violet streaks appear on roots. Growth is retarded.

Correction Measure

Foliar spray of KCl@1%

Magnesium

Deficiency Symptoms

Chlorotic on mature leaves. Which later abscise and fall off. The roots are smaller in size, stiff and pale in colour.

Correction Measure

Foliar spray of [MgSO₄@0.5-1.0%](#)

Iron

Deficiency Symptoms

Chlorosis on younger leaves. Storage roots were reduced in size and become pale in colour.



Correction Measure

Foliar spray of [FeSO₄@0.5-1%](#)

Manganese

Deficiency Symptoms

Symptoms seen in young leaves; leaves become pale yellow



Correction Measure

Foliar spray of [MnSO₄@0.5%](#)

BEETROOT

Nitrogen

Deficiency Symptoms

Slow growth stems thin spindly and hard and fewer lateral shoots. Leaves fade to yellowish green, even yellow, any may turn brown and die in severe cases; lower leaves first affected; leaves are smaller and thinner than normal. Some purpling may develop under low temperature conditions.



Correction Measure

Foliar spray of Urea 1% at fortnightly intervals.

Phosphorus

Deficiency Symptoms

Maturity is delayed stems are thin and woody with shorter than normal growth. Leaves smaller and darker green; undersides have a reddish-purple coloration, on leaf veins, fibrous root development.



Correction Measure

Foliar application of DAP 2% at fortnightly intervals.

Potassium

Deficiency Symptoms

Stems slender become woody. Basal leaves first affected, grayish yellow or brown colour especially at margins, which develop scorched appearance; specks develop along veins of leaf with chlorotic areas in leaf. Root are poorly developed and discoloured.



Correction Measure

Foliar spray of 1 to 2 % KCl at fortnightly intervals.

Magnesium

Deficiency Symptoms

Loss of healthy green colour between the veins of the older leaves, later spreading to younger leaves. This inter-veinal chlorosis may turn brown, leaves become brittle and older leaves may drop.

Correction Measure

Foliar spray of MgSO₄ 1% at fortnightly intervals.

Boron

Deficiency Symptoms

Plants dwarf and stunted. Leaves are small. The young leaves fail to develop, turn brown or black and dies. Leaves assume variegated with yellow and purplish red blotches stalks with longitudinal splits. Leaves twisted rough and gresh appearance. Roots become hard and way.



Correction Measure

Borax 10kg/ha or Foliar spray of solution (20% B)

Iron

Deficiency Symptoms

Interveinal chlorosis which may develop to a more uniform yellow, almost white, in the younger leaves.



Correction Measure

Foliar spray of FeSO₄ 0.5% at fortnightly intervals.

POTATO

Nitrogen

Deficiency Symptoms

Apical growing points stop developing leaves thick brittle and irregular chlorosis.

Correction Measure

Foliar spray of Borax 0.5 % at fortnightly intervals

Potassium

Deficiency Symptoms

Apical growing points stop developing leaves thick brittle and irregular chlorosis.

Correction Measure

Foliar spray of Borax 0.5 % at fortnightly intervals

Calcium

Deficiency Symptoms

Apical growing points stop developing leaves thick brittle and irregular chlorosis.



Correction Measure

Foliar spray of Borax 0.5 % at fortnightly intervals

Sulphur

Deficiency Symptoms

Apical growing points stop developing leaves thick brittle and irregular chlorosis.



Correction Measure

Foliar spray of Borax 0.5 % at fortnightly intervals

Boron

Deficiency Symptoms

Apical growing points stop developing leaves thick brittle and irregular chlorosis.

Correction Measure

Foliar spray of Borax 0.5 % at fortnightly intervals

Iron

Deficiency Symptoms

Apical growing points stop developing leaves thick brittle and irregular chlorosis.



Correction Measure

Foliar spray of Borax 0.5 % at fortnightly intervals

Study questions

1. Write the symptoms of macro nutrients
2. What are all the correction measures of micro and macro elements
3. Write physiological disorders in horticultural crops
4. What are all the immobile and mobile elements

IMPORTANCE OF BENEFICIAL ELEMENTS

INTRODUCTION TO BENEFICIAL ELEMENTS

- ❖ The beneficial elements are **not deemed essential for all crops** but may be vital for particular plant taxa.
- ❖ Elements such as cobalt (**Co**)
 - sodium (**Na**)
 - selenium (**Se**)
 - silicon (**Si**)are considered beneficial for plants.

- ❖ These elements are not critical for all plants but may improve plant growth and yield.

ESSENTIALITY OF MINERALS

Essentiality of minerals came from **Arnon and Stout** (1939), who identified three criteria to consider an **element as essential**:

1. A plant cannot complete its life cycle in the absence of the mineral element.
2. The function of the element is not replaceable by another mineral element.
3. The element is directly involved in plant metabolism.

UPTAKE MECHANISMS OF BENEFICIAL ELEMENTS

COBALT

- ❖ Soil pH is the most important factor for cobalt uptake in roots, which increases with decreasing pH.
- ❖ IRT1 is an *Arabidopsis thaliana* iron transporter, assisted in the uptake of cobalt into plant cells. Cobalt transport occurs in the form of the **cobalt ion (Co^{2+})** through cortical cells via passive diffusion and active transport.

SELENIUM

- ❖ Se is present in different forms (elemental selenium, selenite, selenate, thioselenate, and selenide) in the soil. However, plants can absorb and sequester Se in the form of **selenite** and **selenate**.

SILICON

- ❖ Plants take up silicon in the form of monosilicic acid, **Si(OH)_4** , through roots via silicon transporters Lsi1 and Lsi2 discovered from rice plants

SODIUM

- ❖ Sodium (Na^+) at its low levels is beneficial in the presence of low potassium (K^+) levels.
- ❖ High Na⁺ levels stimulate ABA production

FUNCTIONAL RELEVANCE AGAINST ABIOTIC STRESSES AND IMPORTANCE IN PLANTS

COBALT

- ❖ Cobalt (Co^{2+}) is a micronutrient in plants, and a constituent of vitamin B12.
- ❖ In higher plants, Co^{2+} plays a major physiological role, nitrogen fixation by leguminous crops.
- ❖ Cobalt is an essential component of **cobalamine**
- ❖ In **pea** (*Pisum sativum* L.), doses of 8 mg/L of cobalt to the soil increased growth, plant nutrient levels, nodule numbers and weight, and seed pod yield and quality.
- ❖ In **sweet potato** (*Ipomea batatas* L.), 10 mg/L cobalt had a collegial effect on root growth, yield quality as starch, sugars, L-ascorbic acid, and contents of N^+ , P^{3+}
- ❖ Supplementation of 8 mg/L cobalt to **groundnut** (*Arachishypogaea*L.) plants significantly enhanced growth and yield, improved quality of pods and oil yield.
- ❖ A high concentration of cobalt might be attributed to catalase and peroxidase activities that increase catabolism rather than anabolism in **tomatoes**.
- ❖ Cobalt helps to **delay senescence** in **apples** and keeps the fruit fresh.
- ❖ Co^{2+} delays ageing in **marigold** (*Tagetespatula*L.) and chrysanthemum (*Chrysanthemum* spp.).

SELENIUM

- ❖ Se is essential for growth of some algae (*Chlamydomonas reinhardtii*) and bacteria but not for higher plants.
- ❖ Se may be an essential micronutrient for plants endemic to seleniferous soils.
- ❖ *Astragalus* and *Stanleya* are major hyperaccumulators of Se.
- ❖ Se may exert beneficial effects at their low concentration, including **increased growth in ryegrass, lettuce, potato and buckweed**.

- ❖ Se has diverse biological roles at different concentrations.
- ❖ Trace amounts are needed for normal growth and development.
- ❖ Moderate concentrations maintain homeostatic functions.
- ❖ While elevated concentrations have toxic effects on plants.

Protective effects of selenium in counteracting various abiotic stresses

- ❖ Selenium helps to ameliorate various abiotic stress injuries induced in plants by cold, drought, high temperature, water, salinity, heavy metals, UV-B stress, senescence, and desiccation stress.
- **Selenium protects plants against abiotic stresses by**
 - 1) Helping to maintain ion balance and structural integrity of cells, hence regulating the uptake and redistribution of elements essential in the antioxidative system and
 - 2) Interfering with the electron transport complex (ETC) of the photosynthetic system
- **Se affects plants by**
 - 1) Stimulating plant growth and protecting plants against abiotic stresses and heavy metal stresses at low dosage
 - 2) Acting as a pro-oxidant, which is toxic to plants at high doses.

SILICON

- ❖ Silicon is available to plants as monosilicic (Si(OH)_4) acid with 0.1–0.6 mM in soil and water and is supplied to agricultural crops in the form of potassium silicate (K_2SiO_4) or sodium silicate (Na_2SiO_4).
- ❖ In plants, silicon is deposited in cell walls in the form of amorphous silica ($\text{SiO}_2 \cdot n\text{H}_2\text{O}$) and **enhances cell wall rigidity** and strength interacting with pectins and polyphenols.
- ❖ As Si^{4+} deficiency affects plant growth, development, and reproduction, it may be classified as a '**quasi essential**' element.

- ❖ Si^{4+} is deposited in epidermal cells of leaves, hence improving leaf exposure to light by **keeping leaves more erect**; in roots, it increases cell elongation .
- ❖ Si^{4+} helps to alleviate various abiotic stresses such as metal toxicity, drought, high temperature, salt, radiation damage, freezing, and chilling.
- ❖ Silicon (Si^{4+}) acts as a signal and renders the **natural defence from herbivores** by instigating enzyme activity such as peroxidases, chitinases and polyphenoloxidases or by enhancing the release of phenolic compounds.
- ❖ Si^{4+} is polymerized in cell walls providing sturdiness, which obstructs fungal germ tubes from penetrating the epidermis .
- ❖ Si^{4+} bioactivity has been correlated with the secondary messengers of **systemic acquired resistance (SAR)**, i.e. analogous to a plant's immune system, reported in cucumber.
- ❖ Si^{4+} has an equivalent saturable effect and can modulate the activity of the post-elicitation intracellular signalling system comprising **mitogen-activated protein (MAP) kinases**.
- ❖ Si^{4+} invariably accumulates in plants, it is only the soluble forms of Si^{4+} within plants that can **provide the SAR defence response**, while the polymerized form of Si^{4+} is almost inert.
- ❖ Si^{4+} is an **obstacle for insect pests** like stem borer, brown plant hopper, rice green leaf hopper and white-backed plant hopper and non-insect pests such as leaf spider and mites.

SODIUM

- ❖ Na^+ is a beneficial element at low concentrations
- ❖ In **C4/CAM plants**, Na^+ acts as an essential element for regeneration of **PEP** (phosphoenolpyruvate) from pyruvate to fix carbon for photosynthesis.
- ❖ Also acts as an osmoregulator in stomatal movement and cell expansion.
- ❖ Na^+ application to plants of family poaceae, brassicaceae, apiaceae, asteraceae, malvaceae, fabaceae, and solanaceae enhanced growth in potassium-deficient soils.
- ❖ Some aquatic halophytes use Na^+ to facilitate nitrate uptake via Na/NO_3 co-transporters.

- ❖ Sodium assists in maintaining osmotic balance in plants by synthesizing large amounts of nitrogen

FUNCTIONAL RELEVANCE AGAINST BIOTIC STRESSES AND IMPORTANCE IN PLANTS

Beneficial metal ions are capable of protecting plants from biotic stresses in various ways:

- 1) ‘metal defence’ in metal ion-hyperaccumulators by acting either as antifeedants or as plant-systemic pesticides,
 - 2) ‘trade-off’ of organic defences,
 - 3) ‘metal therapy’ by switching a defective signalling system, or
 - 4) ‘metal-induced fortification’ of plants against pathogen attack.
- ❖ In biotic stress resistance, pathogen elicitor-induced ion fluxes and **reactive oxygen species** (ROS) are essential for triggering activation of genes responsible for the synthesis of compounds such as phytoalexins
 - ❖ ROS species can result in **cell wall lignification** that serves as a barrier for pathogen invasion.
 - ❖ ROS may also **trigger defence signals and defence**-related secondary metabolites
 - ❖ Beneficial elements at their low concentrations trigger the antioxidants, metal chelators, antifeedants, antibiotics, phytoalexins

Study questions

1. List out the beneficial elements
2. Enumerate the functions of beneficial elements
3. Write the criteria of essentiality
4. Role of beneficial elements in abiotic stress tolerance

Lecture No. 12

Role of hormones in plant growth and yield enhancement, stress management and quality improvement – Auxins, Gibberellins and Cytokinins.

Plant Growth Hormones

Most of the physiological activities and growth in plants are regulated by the **action and interaction** of some chemical substances in them called as **hormones** and by certain naturally occurring **inhibitors** e.g., phenols, flavonols and abscisic acid. To distinguish the plant hormones from the animal hormones they are termed as **phytohormones**. According to Pincus and Thimann (1948), a plant hormone is defined as “**organic substance produced naturally in the higher plants, controlling growth or other physiological functions at a site remote from its place of production and active in minute amounts.**”

These phytohormones have also been termed as growth hormones, growth promoting substances, growth substances, growth factors, growth regulators etc., by various workers and defined accordingly. The auxins were the first hormones to be discovered in plants and at one time considered to be the only naturally occurring plant growth hormones. Since then besides other less important hormones, two important groups of chemical substances having profound influence on the regulation of growth and development in plants have been discovered which are also considered as **natural plant growth hormones**. They are **gibberellins** and **cytokinins**. Beside these, **ethylene** and **abscisic acid (ABA)** and more recently **brassinosteroids** have also acquired status of natural plant growth hormones.

THE AUXINS

Discovery and Chemical Nature

The discovery of auxins dates back to last quarter of the 19th century when Charles Darwin was studying tropisms in plants. Went (1926) was successful in isolating this growth substance from Avena coleoptile tips which still retained the growth promoting activity. He cut off the tips of the Avena coleoptiles and placed them on small agar-blocks for certain period of time and then placed the agar-blocks asymmetrically on cut coleoptile stumps. All the coleoptiles

showed typical curvature even in dark. He also developed a method for determining the amount of this growth substance (i.e.auxin) which is active in very small amounts in the *Avena* coleoptile tips. This method or the bioassay is famous by the name of ***Avena* Curvature Test.**

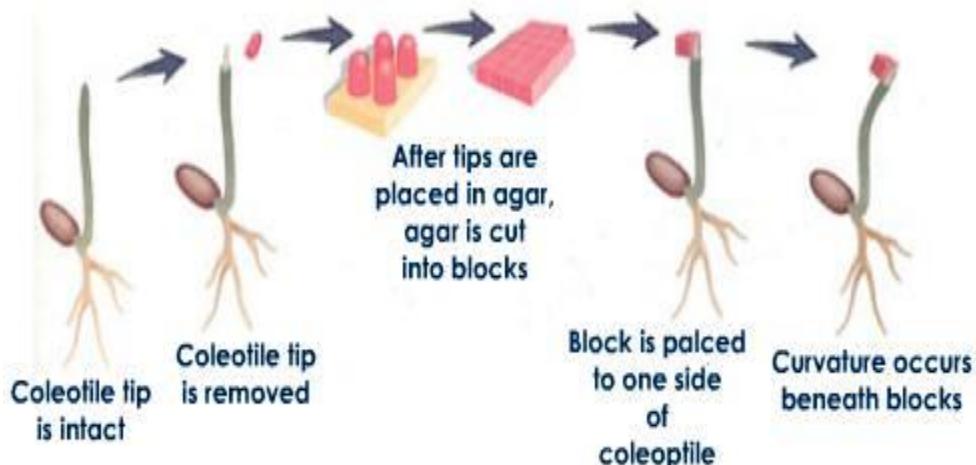


Fig.2 *Avena* Curvature Test.

<http://image.wistatutor.com/content/plant-growth-movements/oat-coleoptile-experiment.jpeg>



<http://image.wistatutor.com/content/plant-growth-movements/gibberellins-avena-test.jpeg>

Avena test (a) A piece of mica inserted on the shaded side prevented curvature of the coleoptile, (b) but not when it was inserted on the illuminated side, (c) when the tip was removed (d) but was put back with a block of gelatine, (e) normal phototropic curvature occurred.

Synthetic Auxins

Auxin is a general term used to denote substances that promote the elongation of coleoptiles tissues, particularly when treated in the *Avena* coleoptiles test or in several other bioassay techniques. Indoleacetic acid is an auxin that occurs naturally in plants.

Soon after the recognition of the importance of IAA as a plant hormone, compounds similar in structure were synthesized and tested for biological activity. Among the first compounds studied were substituted indoles, such as **indole-3-propionic acid** and **indole-3-butryic acid**. Both compounds are biologically active and commonly used as rooting hormones in horticultural work. Both have the same indole rings as IAA and a terminal carboxyl group but differ in their side chains. If longer side chains are added to the indole ring, the compounds generally lack biological activity. Certain species of plants, however, possess enzymes capable of shortening the side chains and will convert the compounds to a biologically active molecule.

Compounds lacking the indole ring but retaining the acetic acid side chain present in IAA are also biologically active. **Naphthaleneacetic acid** is such a compound and it is used as a rooting hormone for certain plants. Another biologically active synthetic auxin lacking the indole ring is 2,4-dichlorophenoxyacetic acid. This compound, known as 2,4-D, is a potent auxin and is used as a weed killer. It is probably the most widely used of the synthetic auxins in commercial crop production. The carbamate compound was developed for use as a fungicide but was also found to have auxin activity. It lacks a ring structure but does possess an acetic acid side chain.

PHYSIOLOGICAL EFFECTS OF AUXIN

(1) Cell Elongation

The primary physiological effect of auxin in plants is to stimulate the **elongation of cells in shoot**. A very common example of this can be observed in phototropic curvatures where the unilateral light unequally distributes the auxin in the stem tip (i.e. more auxin on shaded side than on illuminated side). The higher concentration of auxin on the shaded side causes the cells

on that side to elongate more rapidly resulting in bending of the stem tip towards the unilateral light.

(2) Apical Dominance

It has been a common observation in many vascular plants especially the tall and sparsely branched ones that if the terminal bud is intact and growing, the growth of the lateral buds just below it remained suppressed. Removal of the apical bud results in the rapid growth of the lateral buds. This phenomenon in which the apical bud dominates over the lateral buds and does not allow the latter to grow is called as **apical dominance**.

Skoog and Thimann (1934) first pointed out that the apical dominance might be under the control of auxin produced at the terminal bud and which is transported downward through the stem to the lateral buds and hinders their growth. They removed the apical bud of broad bean plant and replaced it with agar block. This resulted in rapid growth of lateral buds. But, when they replaced the apical bud with agar block containing auxin, the lateral buds remained suppressed and did not grow.

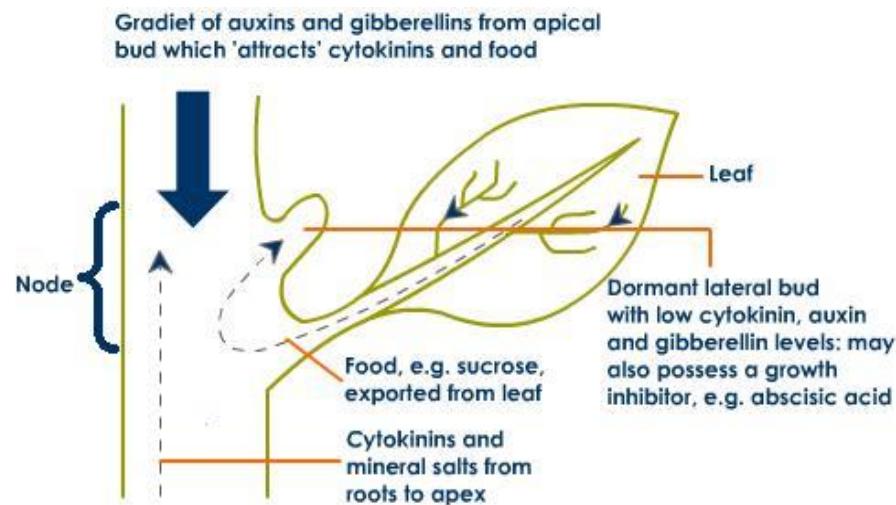


Fig.3 Possible Involvement of Plant Growth Substances in Apical Dominance in Presence of Apical Bud

<http://image.wistatutor.com/content/plant-growth-movements/auxin-apical-dominance.jpeg>

(3) Root Initiation

In contrast to the stem, the higher concentration of auxin inhibits the elongation of root but the number of lateral branch roots is considerably increased i.e., the higher conc. of auxin initiates more lateral branch roots.

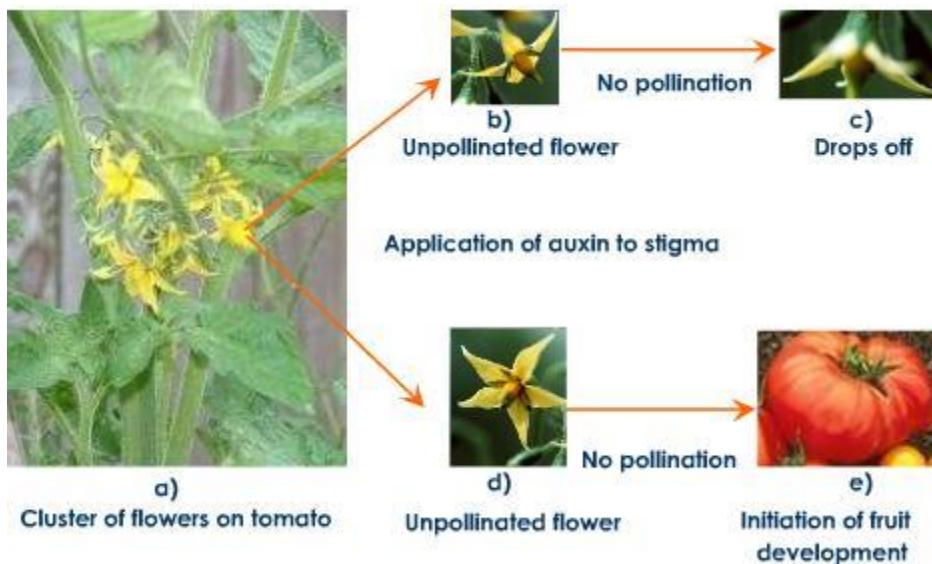
Application of **IAA** in lanolin paste to the cut end of a young stem resulted in an early and extensive rooting. This fact is of great practical importance and has been widely utilized to promote root formation in economically useful plants which are propagated by cuttings.

(4) Prevention of Abscission

Natural auxins have controlling influence on the abscission of leaves, fruits etc.

(5) Parthenocarpy

Auxin can induce the formation of parthenocarpic fruits. In nature also, this phenomenon is common and in such cases the concentration of auxins in the ovaries has been found to be higher than in the ovaries of plants which produce fruits only after fertilization. In the latter cases, the concentration of the auxin in ovaries increases after pollination and fertilization.



<http://image.wistatutor.com/content/plant-growth-movements/parthenocarpy-illustration.jpeg>

(6) Respiration

It has been established that the auxin stimulates respiration and there is a correlation between auxin induced growth and an increased respiration rate. According to **French and Beevers** (1953), the auxin may increase the rate of respiration indirectly through increased supply of **ADP** (Adenosine diphosphate) by rapidly utilizing the **ATP** in the expanding cells.

(7) Callus Formation

Besides cell elongation the auxin may also be active in cell division. In fact, in many tissue cultures where the callus growth is quite normal, the continued growth of such callus takes place only after the addition of auxin.

(8) Vascular Differentiation

Auxin induces **vascular differentiation** in plants. This has been confirmed in tissue culture experiments and from studies with transgenic plants. Cytokinins are also known to participate in differentiation of vascular tissues and it is believed that vascular differentiation in plants is probably under the control of both auxin and cytokinins.

DISTRIBUTION OF AUXIN (IAA) IN PLANT

Auxin (IAA) is widely distributed in plant but relative concentrations differ in different parts of the plant. Since auxin is synthesized in growing tips or meristematic regions of the plant from where it is transported to other plant parts, the highest concentrations of the auxin are found in these parts such as growing shoot and root tips, young leaves and developing axillary shoots.

Distribution of auxin in monocot and dicot seedlings:

In monocot seedling, the highest concentration of auxin is found in the coleoptiles tip which decreases progressively toward its base. From the base of the coleoptiles, the auxin concentration increases progressively up to the root tip. However, the concentration of auxin at the tip of root is much lower than at the coleoptiles tip.

In dicot seedling, although the pattern of auxin distribution appears to be complex, but obviously highest auxin concentrations are found in growing regions of shoot, root, young leaves and developing axillary shoots.

Within the plant, the auxins may be present in two forms-free auxins and bound auxins. Free auxins are those which can be easily extracted by various organic solvents such as diethyl ether or those which are easily diffusible such as that obtained in agar block from cut coleoptiles tip. Bound auxins on the other hand, need more drastic methods for their extraction from plants such as hydrolysis, autolysis, enzymolysis etc., and are not easily diffusible. Bound auxins occur in plant as complexes (conjugated auxins) usually with carbohydrates such as glucose, arabinose or sugar alcohols, or proteins or amino acids such as aspartate, glutamate or with inositol.

- The **free form** of auxin is **biologically active** form of the hormone. In **bound** or **conjugated form** (which predominates in plants), the auxin is considered to be biologically inactive.
- The metabolism of bound or conjugated auxin might be a major contributing factor in controlling level of free auxin in plants.

BIOSYNTHESIS OF AUXIN (IAA) IN PLANTS

TRYPTOPHAN DEPENDENT PATHWAYS

In 1935, Thimann demonstrated that a fungus *Rhizopus suinus* could convert an amino acid tryptophan (trp) into indole-3 acetic acid (IAA). Since then, it is generally held that tryptophan is primary precursor of IAA in plants.

The indole-3-acetic acid (IAA) can be formed from tryptophan by 3 different pathways.

(a) TAM (Tryptamine) pathway

Tryptophan is decarboxylated to form tryptamine (TAM) followed by **deamination** of the latter resulting in the formation of **indole-3-acetaldehyde (IAId)**. The enzymes involved are **tryptophan decarboxylase** and **tryptamine oxidase** respectively. IAId is readily **oxidised** to **indole-3-acetic acid (IAA)** by the enzyme **IAId dehydrogenase**.

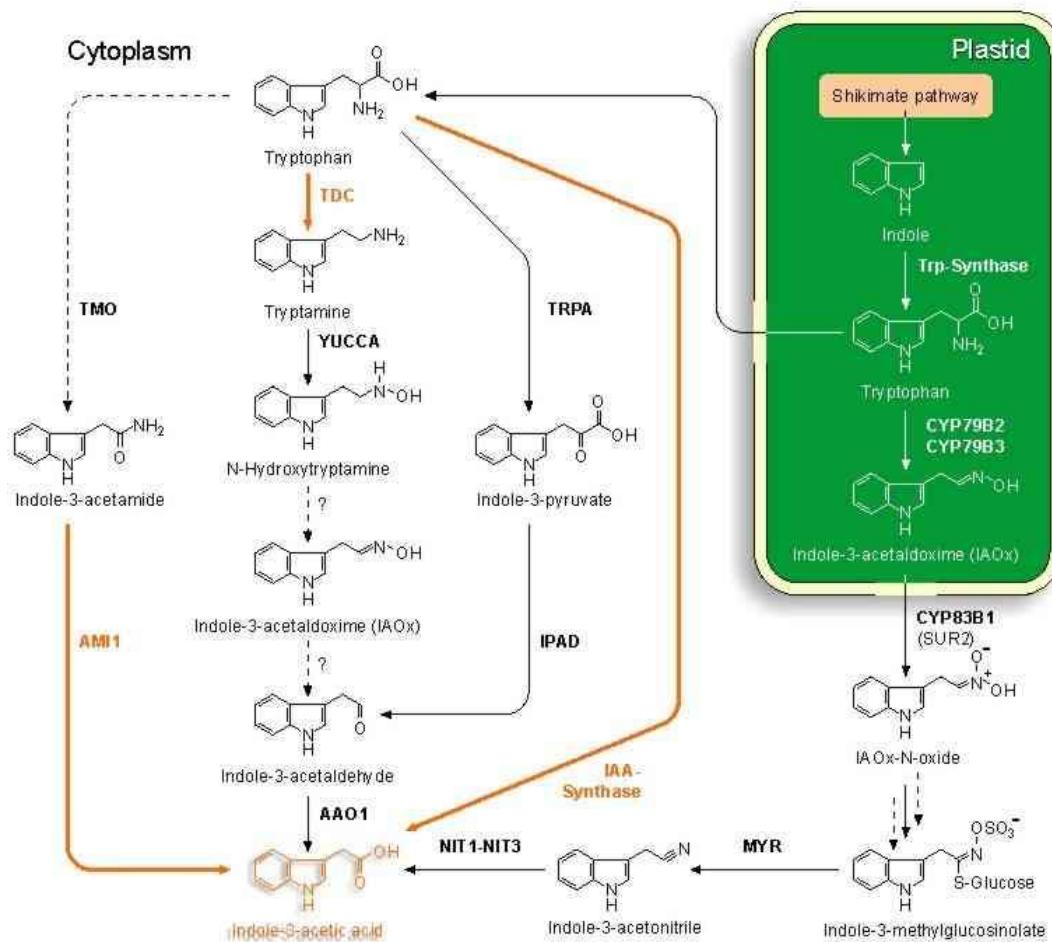
(b) IPA (Indole-3-pyruvic acid) pathway

Tryptophan is deaminated to form indole-3-pyruvic acid (IPA) followed by decarboxylation of the latter resulting in the formation of indole-3-acetaldehyde (IAId). The enzymes involved are tryptophan transminase and indole pyruvate decarboxylase.

- One of the above two methods (sometimes both) is most common pathway of formation of IAA in plants.

(c) IAN (Indole-3-acetonitrile) pathway

It occurs in some plants especially those belonging to families Brassicaceae, Poaceae and Musaceae. Tryptophan is converted into IAA in the presence of the enzyme nitrilase. Indole-3-acetaldoxime and indole-3-acetaonitrile (IAN) are the intermediates



Pathways of tryptophan-dependent indole-3-acetic acid biosynthesis.

The abbreviations are: AAO1: indole-3-acetaldehyde oxidase; AMI1: amidase 1 (indole-3-acetamide hydrolase); IAox-N-oxide: indole-3-acetaldoxime-N-oxide; IPAD: indole-3-pyruvic acid decarboxylase; MYR: myrosinase; NIT1-3: nitrilases isogenes 1 – 3; TDC: tryptophan decarboxylase; TMO: tryptophan-2-monooxygenase; TRPA: tryptophan aminotransferase; YUCCA: flavin monooxygenase-like protein.

<http://www.ruhr-uni-bochum.de/sfb480/Bilder%20Teilprojekte/A%202010/Figure%201.jpg>

TRANSPORT OF AUXIN IN PLANT

The transport of auxin in plant is predominantly polar. In stems, polar transport of auxin is basipetal i.e., it takes place from apex towards base. In roots also, the auxin transport is polar

but is primarily acropetal. Jacobs (1961) found polar transport of auxin in coleus stem sections to be both basipetal and acropetal in the ratio of 3:1. According to Audus (1959) some of the auxin synthesized by leaves may be transported to other plant parts through phloem in a rather non-polar manner. Phototropic and geotropic movements indicate towards lateral transport of auxins in stem tip and root tip respectively.

DESTRUCTION / INACTIVATION OF AUXIN IN PLANT

Sufficient levels of auxin in plant required for regulation of plant growth are maintained not only by the synthesis of auxin, but also by its destruction or inactivation.

Chief method for the destruction (degradation) of auxin in plant is its oxidation by O₂ in the presence of the enzyme **IAA-oxidase or peroxidase**. This oxidation involves removal of CO₂ from the carboxylic group of auxin (IAA) and results in the formation of a variety of compounds, but **3-methyl-oxindole** is the major end product.

Auxin may be temporarily inactivated in plants by its conversion into its bound form (bound auxin or conjugated auxin) in which auxin is conjugated to a variety of substances such as carbohydrates, amino acids, proteins or inositol etc.

Rapid inactivation of auxin may occur by irradiation with X-rays and gamma rays, Ultra violet light is also known to reduce auxin levels in plants, Inactivation or decomposition of IAA by light has been called as **Photo-oxidation/ oxidation by O₂**.

THE GIBBERELLINS

The discovery of gibberellins is quite fascinating and dates back to about the same period when auxins were discovered, but it was only after 1950s they came into prominence. A young Japanese scientist **Kurosawa** had been trying to find out why the rice seedlings infected by the fungus **Gibberella fujikuroi** (asexual stage *Fusarium moniliforme*) grew taller and turned very thin and pale. These are the symptoms of '**Backanae disease**' (meaning foolish) which is known to Japanese for over a century. In 1926, he succeeded in obtaining a filtered extract of this fungus

which could cause symptoms of the Backanae disease in healthy rice seedlings. In 1935, **Yabuta** isolated the active substance which was quite heat stable and gave it the name **gibberellin**.

PHYSIOLOGICAL EFFECTS OF GIBBERELLINS

1. Seed Germination

Certain light sensitive seeds e.g. lettuce and tobacco show poor germination in dark. Germination starts vigorously if these seeds are exposed to light or red light. This requirement of light is overcome if the seeds are treated with gibberellic acid in dark.

2. Dormancy of Buds

In temperate regions the buds formed in autumn remain dormant until next spring due to severe colds. This dormancy of buds can be broken by gibberellin treatment.

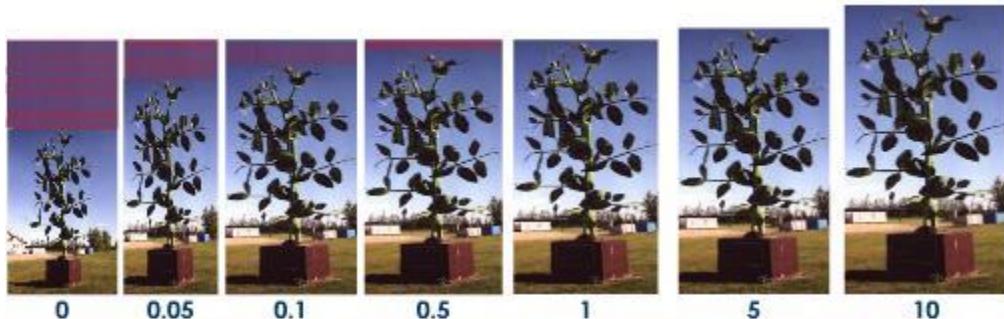
In potatoes also, there is a dormant period after harvest, but the application of gibberellin sprouts the eyes vigorously.

3. Root Growth

Gibberellins have little or no effect on root growth. At higher concentration in some plants, however, some inhibition of root growth may occur. The initiation of roots is markedly inhibited by gibberellins in isolated cuttings.

4. Elongation of the Internodes

Most pronounced effect of gibberellins on the plant growth is the elongation of the internodes, so in plants such as dwarf pea, dwarf maize etc., they overcome the **genetic dwarfism**. For instance, the light grown dwarf pea plants have short internodes and expanded leaves. But, when treated with gibberellin the internodes elongate markedly and they look like tall plants.



The influence of gibberellic acid(GA) on the growth of variety Meteor dwarf pea.

The plant on the left received no GA and shows the typical dwarf habit.

The remaining plants were treated with GA; the dose per plant in micrograms is shown.

With doses up to 5 micrograms there is increased growth of the stems with increase in GA dosage. This is the principle of the dwarf pea assay of gibberellins.

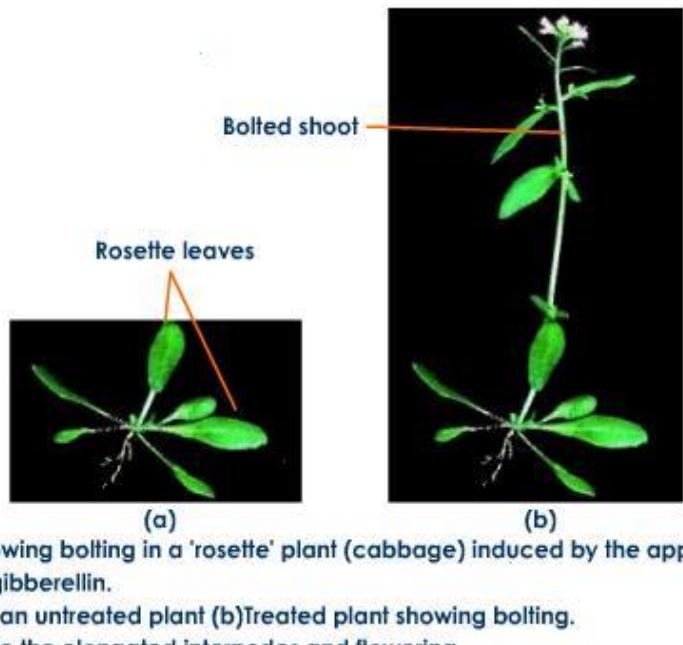
<http://image.wistatutor.com/content/plant-growth-movements/gibberellins-dwarf-pea-assay-principle.jpeg>

It is considered that in such dwarf plants (i) the gene for producing gibberellins is missing, or (ii) the concentration of the natural inhibitors is higher. When external gibberellins are applied, the deficiency of the endogenous gibberellins is made good or the external gibberellins overcome the effect of natural inhibitors which fall short.

5. Bolting and Flowering

In many herbaceous plants the early period of growth show rosette-habit with short stem and cauline leaves. Under short days the rosette habit is retained while under long days bolting occurs i.e., the stem elongates rapidly and is converted into floral axis bearing flower primordia. This bolting can also be induced in such plant e.g. *Rudbeckia speciosa* (It is a Long Day Plant*) by the application of gibberellins even under non-inductive short days.

In *Hyoscyamus niger* (also a Long Day Plant) gibberellins treatment causes bolting and flowering under non-inductive short days. While in Long Day Plants the gibberellins treatment usually results in early flowering, its effects are quite variable in Short Day Plants. It may either have no effect, or inhibit, or may activate flowering.



Showing bolting in a 'rosette' plant (cabbage) induced by the application of gibberellin.

a() an untreated plant (b)Treated plant showing bolting.

Note the elongated internodes and flowering.

<http://image.wistatutor.com/content/plant-growth-movements/bolting-rosette.jpeg>

6. Parthenocarpy

Germination of the pollen grains is stimulated by gibberellins, likewise the growth of the fruit and the formation of parthenocarpic fruits can be induced by gibberellins treatment. In many cases e.g. pome and stone fruits where auxins have failed to induce parthenocarpy the gibberellins have proven to be successful. Seedless and fleshy tomatoes and large sized grapes are produced by gibberellins treatment on commercial scale.

7. Light Inhibited Stem Growth

It is common observation that the dark grown plants become etiolated and have taller, thinner and pale stems while the light grown plants have shorter, thicker and green stems, and it may be concluded that light has inhibitory effect on stem elongation. Treatment of light grown plants with gibberellins also stimulates the stem growth and they appear to be dark grown. In such cases the protein content of the stem falls while soluble nitrogen content increases probably due to more breakdowns of proteins than their synthesis.

8. De nova Synthesis of the Enzyme- α -Amylase

One of the important functions of gibberellins is to cause *de novo* synthesis of the enzyme α -**amylase** in the **aleurone layer** surrounding the endosperm of cereal grains during germination. This enzyme brings about hydrolysis of starch to form simple sugars which are then translocated to growing embryo to provide energy source.

DISTRIBUTION OF GIBBERELLINS IN PLANTS

Gibberellins are found in all parts of higher including shoots, roots, leaves, flower, petals, anthers and seeds. Gibberellins activity has also been shown in plastids. In general, reproductive parts contain much higher concentrations of gibberellins than the vegetative parts. In growing embryos after fertilization, cell division takes place vigorously, aided by auxin followed by cell expansion. Gibberellins are responsible for cell wall loosening and cell enlargement. These enlarged cells import assimilates from the source for storage in the reproductive organs. Hence, gibberellins play major role in increasing yields of seeds and fruits. Immature seeds are especially rich in gibberellins (10-100 mg per g fresh weight) and are most favorite plant parts for isolation of gibberellins and their study. In mature seeds, the gibberellins tend to form their derivatives.

In plant, the gibberellins may occur in two different forms- free gibberellins and bound gibberellins. Bound gibberellins usually occur as gibberellins-glycosides.

BIOSYNTHESIS OF GIBBERELLINS IN PLANTS

The gibberellins which are chemically related to terpenoids (natural rubber, carotenoids & steroids) are thought to be formed by the condensation of a 5-C precursor-an isoprenoid unit called as ispentenyl pyrophosphate (IPP) through a number of intermediates to give rise to gibberellins. The primary precursor for the formation of this isoprenoid unit and synthesis of gibberellins is however, acetate. Besides gibberellins, carotenoids, rubber, steroids, abscisic acid (ABA) and part of cytokinins are also derived from 5-C isoprenoid unit.

In plants GAs are biosynthesized in apical tissues and there are three main sites of their biosynthesis,

- (i) Developing seeds and fruits,

- (ii) Young leaves of developing apical buds and elongating shoots and
- (iii) The apical regions of roots.

The pathway of GA biosynthesis can be divided into three stages each of which is accomplished in a different cellular compartment.

Stage I. Formation of terpenoid precursors and ent-kaurene in plastids.

GA is biosynthesized from a 5-C precursor IPP. The IPP may be synthesized either in plastids or cytosol. From IPP, 10-C (GPP), 15-C (FPP) and 20-C (GGPP) precursors of terpenoids are formed by condensation of 5-C units (IPP). After the formation of GGPP, the pathway becomes specific for GAs.

GGPP is converted by two cyclization reactions through copalyl pyrophosphate into entkaurene. These reactions are catalysed by the enzymes cyclases which are located in proplastids and not in mature chloroplasts and in fact constitute the first step that is specific for GAs. This step of GA biosynthesis is inhibited by compounds such as Amo-1618, Phosphon D and CCC.

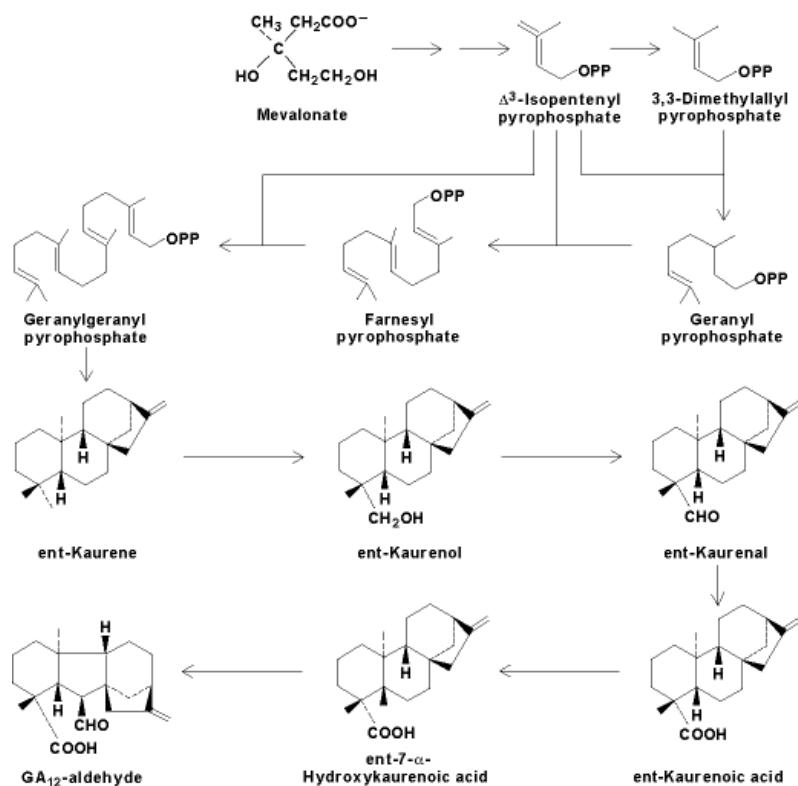
Stage II. Oxidations to form GA_{12} and GA_{53} on ER through GA_{12} aldehyde.

The **ent -kaurene** is transported from plastids to **ER (endoplasmic reticulum)**. Now a methyl group on ent-kaurene at 19th-carbon position is oxidized to carboxylic group which is followed by contraction of ring B from 6-C to 5-C ring structure to form **GA_{12} aldehyde**. GA_{12} aldehyde is subsequently oxidized to give **GA_{12} which is precursor to all other GAs in plants**. Hydroxylation of GA_{12} at C-13 results in the formation of GA_{53} .

The enzymes catalyzing the above oxidation reactions are mono-oxygenases which are located on ER and utilize cytochrome P450 in these reactions. Activity of these enzymes is inhibited by paclitaxel and other inhibitors before GA_{12} -aldehyde.

Stage III. Formation of all other GAs from GA₁₂ or GA₅₃ in cytosol.

All other steps in the biosynthesis of GAs from GA₁₂ or GA₅₃ are carried out in cytosol by soluble enzymes called dioxygenases. These enzymes require molecular O₂ and 2-oxoglutarate as cosubstrates and use ferrous iron (Fe⁺⁺) and ascorbic acid as cofactors. Environment factors such as temperature and photoperiod are known to affect biosynthesis of gibberellins.



Biosynthetic pathway of GA

<http://www.accessscience.com/loadBinary.aspx?filename=289000FG0020.gif>

Gibberellins have been found from both phloem and xylem exudates from a variety of plants. Unlike auxins, the transport of gibberellins in plants is non-polar. It is believed that gibberellins are translocated through phloem according to a flow pattern which is similar to those of carbohydrates and other organic solutes. However, gibberellins transport may also occur in xylem due to its lateral movement between the two vascular tissues i.e.xylem and phloem. The gibberellins are not translocated in plant as free molecules but probably in their bound form as gibberellins-glycosides.

CYTOKININS

DISCOVERY AND CHEMICAL NATURE

The discovery of kinetin is comparatively more recent. Its credit goes to Miller *et al* (1950) who were working in Prof. Skoog's lab at the University of Wisconsin on the growth of tobacco pith callus in culture and wanted it to grow indefinitely. They added various growth substances, nutrients, vitamins etc, into the culture medium but failed till they noticed an old bottle of DNA kept for several years in their lab. They added the contents of that bottle to the culture medium and observed that the tobacco pith callus could grow for longer periods. They obtained similar results with Yeast extract. But they did not get positive results with fresh DNA and thought the active substance to be some degradation product of DNA. They isolated this substance by autoclaving (heating under pressure) the DNA which had been stored for long. It could easily be precipitated by silver salts and was soluble in 90% alcohol, indicating that possibly it was a purine compound. Later on, they identified it as 6-furfurylaminopurine. Because of its specific effect on cytokinesis (i.e.) cell division, it was called as kinetin.

Although kinetin has profound influences in inducing cell division, still it has not been isolated from any plant. But, certain substances which show kinetin like activity have in fact been isolated from a variety of higher plants. These substances are collectively called as cytokinins. There is now sufficient evidence to show that cytokinins do occur in plants and regulate growth and hence, they are also considered as natural plant growth hormones. Some of the very important and commonly known naturally occurring cytokinins are as follows.

ZEATIN

Zeatin is the most abundant and widely distributed natural cytokinin in higher plants and in some bacteria. Although this cytokinin was known earlier but it was obtained in pure crystalline form in 1963 by Letham from immature corn grains and named as Zeatin. It was identified as 6-(4-hydroxy-3-methylbut-trans-2enyl) amino purine by Letham *et al.* (1964) and was synthesized by Shaw and Wilson (1964).

- Zeatin exhibits strong kinetin like activity in stimulating plant cell to divide in presence of auxin in culture media.
- Zeatin resembles kinetin in molecular structure because both are adenine or amino purine derivatives.
- Zeatin is remarkably more active than any other cytokinin probably because of the presence of a highly reactive allylic-OH group in its side chain.

OTHER NATURAL CYTOKININS

Apart from zeatin, some other substituted amino purines have been isolated from higher plants and some bacteria which are also considered as natural cytokinins. These are di-hydrozeatin (DZ) and N6-(Δ2 - isopentenyl) adenine (or ip) which differ from Zeatin in nature of their side chain.

CYTOKININS IN t-RNA

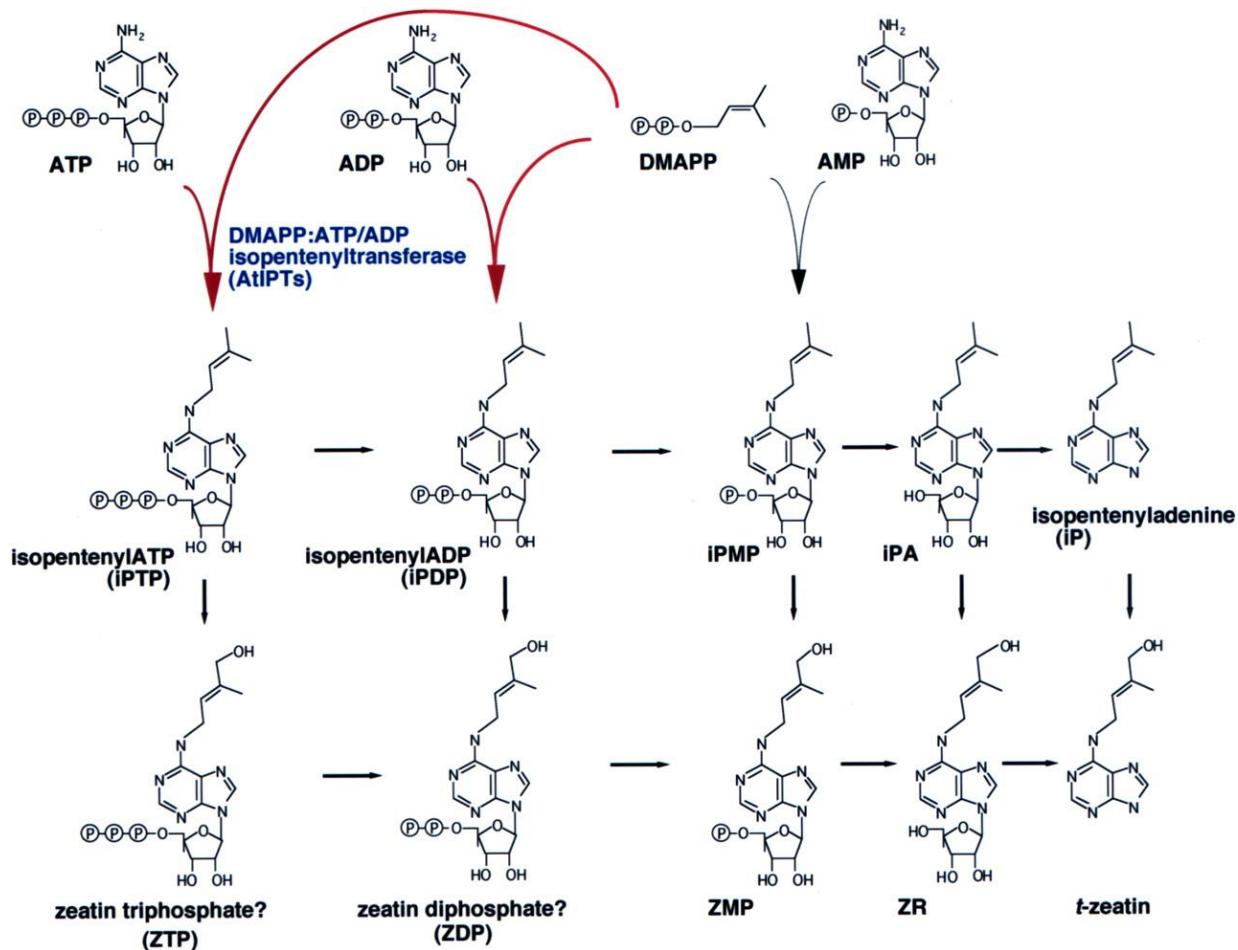
In 1966 Zachau *et al.* identified cytokinin 2iPA as a constituent of two serine t-RNA species from brewers yeast and showed this cytokinin to be adjacent to the 3' end of the anticodon in both the species. Apart from yeast, cytokinins have now been found in t-RNA preparations from a wide variety of organisms such as bacteria including *E.coli*, animals including man and higher plants viz., frozen peas, tobacco callus tissue.

Synthetic cytokinins

Some synthetic chemical compounds which show cytokinin activity but have not been isolated from plants are known. Benzyl adenine (BA) is one such example. Although there are a few reports of this compound in plants but it's uncommon in plants and is

largely a synthetic cytokinin. Another synthetic cytokinin is thidiazuron that is used commercially as defoliant and a herbicide.

Biosynthesis of cytokinins



A model for cytokinin biosynthesis in plants. Cytokinins that directly bind to cytokinin receptors are *shaded*

<http://pcp.oxfordjournals.org/content/42/7/677/F6.expansion.html>

PHYSIOLOGICAL EFFECTS OF KINETIN

(CYTOKININS)

(1) Cell division

One of the important biological effects of kinetin on plants is to induce cell division in the presence of sufficient amount of auxin (IAA), especially in tobacco pith callus, carrot root tissue, soybean cotyledon, pea callus etc.,

(2) Cell enlargement

Like auxins and gibberellins, the kinetin may also induce cell enlargement. Significant Cell enlargement has been observed in kinetin treatment in leaf discs cut from etiolated leaves of *Phaseolus vulgaris*, pumpkin cotyledons, tobacco pith cultures, cortical cells of tobacco roots excised Jerusalem artichoke tissue etc.,

(3) Initiation of inter-fascicular cambium

Kinetin can induce formation of inter - fascicular cambium. This has in fact been shown by Sorokin *et al* (1962) in pea stem sections.

(4) Morphogenesis

Kinetin also has ability to cause morphogenetic changes in an otherwise undifferentiated callus. For instance the tobacco pith callus can be made to develop either buds or roots by changing the concentration of kinetin and auxin.

(5) Counteraction of apical dominance

Cytokinins play a role in initiating the growth of lateral buds has also been proved by physiological studies made on cytokinin overproducing mutants of tobacco.

(6) Dormancy of seeds

Like gibberellins, the dormancy of certain light sensitive seeds such as lettuce and tobacco can also be broken by kinetin treatment in dark. The inhibitory effect of far-red light treatment on the germination of the above seeds is also overcome by kinetin treatment.

(7) Delay of senescence: The Richmond –Lang Effect

The ageing process of the leaves usually accompanies with loss of chlorophyll and rapid breakdown of proteins. This is called senescence. Richmond and Lang showed that this

senescence could be postponed to several days in detached *Xanthium* leaves by kinetin treatment. This effect of kinetin in delaying the senescence is called as Richmond-Lang effect. One of the important factors in delay of senescence in kinetin treated leaves is their physiological age. Mature leaves of *Nicotiana rustica* have been found to be more responsive to kinetin treatment in delaying senescence than the younger leaves.

(8) Promotion of chloroplast development

Cytokinins are known to enhance conversion of etioplasts into chloroplast when etiolated seedlings after treatment with cytokinins are exposed to light. In such cases, the chloroplasts develop extensive grana and chlorophylls and the rate of synthesis of photosynthetic enzymes is much greater in comparison to those etiolated seedlings which are illuminated without cytokinin treatment.

Study questions

1. What are all the physiological functions of auxins ?
2. What are all the physiological functions of GA ?
3. What are all the physiological functions of Cytokinins ?
4. Enumerate the commercial applications of these hormones

Role of hormones in plant growth and yield enhancement, stress management and quality improvement –Abscisic acid, Ethylene and Brassinosteroids

Ethylene

The scientific studies to understand phenomenon and technology of fruit ripening were initiated as early as 1900s, understanding the process of fruit ripening and identification of the causative factor was possible only in 1924. Since then, detailed studies have been made on ethylene and its effect on plants. He observed that dark grown pea seedlings growing in the laboratory exhibited symptoms that were later termed as triple response includes reduced stem elongation, increased lateral growth and abnormal horizontal growth.

Ethylene, another class of hormone with a single representative, is a simple gaseous hydrocarbon with the chemical structure $H_2C=CH_2$. Ethylene is apparently not required for normal vegetative growth, although it can have a significant impact on the development of roots and shoots. Ethylene appears to be synthesized primarily in response to stress and may be produced in large amounts by tissues undergoing senescence or ripening. It is commonly used to enhance ripening of fruits.

Occurrence

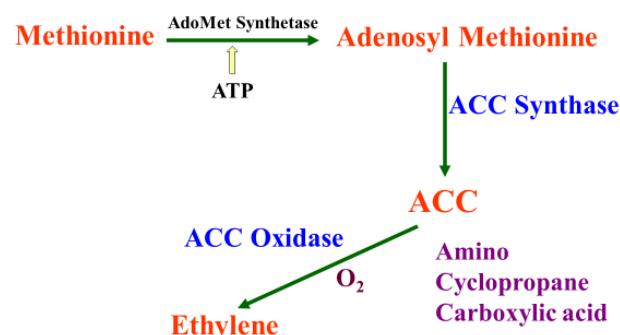
Ethylene can be produced by almost all parts of higher plants. Ethylene occurs in all plant organs - roots, stems, leaves, bulbs, tubers, fruits, seeds, and soon, although the rate of production may vary depending on the stage of development. Ethylene production will also vary from tissue to tissue within the organ, but is frequently located in peripheral tissues. In peach and avocado seeds, for example, ethylene production appears to be localized primarily in the seed coats, while in tomato fruit and mung bean hypocotyls it originates from the epidermal regions.

Ethylene production increases during leaf abscission and flower senescence, as well as during fruit ripening. Any type of wounding can induce ethylene biosynthesis, as that of physiological stresses such as flooding, disease and temperature or drought stress. In addition, infection by various pathogens can also elevate ethylene biosynthesis.

Biosynthesis

The ethylene biosynthesis is a three-step pathway in higher plants. The amino acid methionine is the precursor of ethylene and ACC (1-amino cyclo propane 1-carboxylic acid) serves as an intermediate in the conversion of methionine to ethylene. In the first step, an adenine group is donated to methionine by a molecule of ATP, thus forming S-adenosyl methionine (SAM). This reaction is mediated by the enzyme SAM synthetase. In the next step, SAM breaks into 5'-methyl thio adenosine (MTA) and amino cyclo propane carboxylic acid (ACC). This reaction is carried out by the enzyme ACC synthase. ACC is oxidized to ethylene with the release of HCN and CO₂. Ethylene biosynthesis is stimulated by several factors, including developmental state, environmental conditions, other plant hormones and physical and chemical injury. Ethylene biosynthesis also varies in a circadian manner, peaking during the day and reaching a minimum at night.

Bio synthesis - Ethylene



Ethylene inhibitors

Ethylene inhibitors are frequently used to study biosynthes is of ethylene and ethylene activity. AVG (aminoethoxy vinyl glycine) and AOA (amino oxy-aceticacid) are inhibitors of ethylene biosynthesis. AVG andAOA block the conversion of SAM to ACC.1-methylcyclopropane (1-MCP), NBD (2,5-norbomadiene),Silvernitrate and Silver thio sulphate(STS) are the specific inhibitors of ethylene action.They inhibit an ethylene response by binding to and blocking of the ethylene receptor.

Physiological roles of ethylene

Fruitripening

Fruits can be broadly classified into two types on the basis of their respiratory pattern during ripening. In some fruits like apple and banana as the fruit matures and attains its maximum size, the rate of respiration decreases and becomes very low. After the fruit is harvested and stored for ripening, there is a great increase in the rate of respiration and the rise continues till it attains a sharp peak. This is called climacteric peak and the fruits are called climacteric fruits. In climacteric fruits ripening occurs even after harvesting. The climacteric rise is soon followed by a sharpdecline.

The non-climacteric fruits like grapes and lemon, the respiratory rate gradually decrease after the fruit is harvested without showing any abrupt rise. The peak respiratory rate in climacteric fruits usually corresponds to peak ethylene production. Application of ethylene hastens ripening of climacteric fruits such as banana, mango, apple and tomato. This is being commercially employed. In non- climacteric fruits such as lemon and orange ethylene application does not hasten ripening however rate of respiration increases greatly.

Abscission and senescence

Ethylene promotes both abscission and senescence of flowers. The flowers of orchids and roses are the most sensitive to externally applied ethylene. Ethylene also promotes leaf abscission. In general, olderleaves are more sensitive to ethylene and abscise faster than younger ones.Older leaves produce more ethylene than younger ones. This is probably responsible for the abscission of older leaves.

Root and shootgrowth

Ethylene inhibits linear growth of the stem and root of dicotyledons. The effect increases with increasing concentrations.

Flowering and sexexpression

Application of ethylene causes flowering in pine apple and shift the sex ratio of flowers towards femaleness in several cucurbits and cannabis.

Epinasty

Ethylene causes swelling of cells on the upper part of the petiole of the leaf resulting in drooping of leaves (down ward curvature). This is termed as epinasty. It is best exhibited in leaves of tomato, potato and pea etc.

Thinning in apple

Thinning of fruits in apple eliminates biennial bearing and also improves fruit size and quality. Application of ethephon at 100 to 300 ppm reduces fruitset in cotton also ethylene induces fruit thinning.

Exudation of sap and latex

When ethrel is applied to rubber plants, flow of latex continues for a longer duration. Ethrel probably prevents coagulation of latex and consequent blocking of latex synthesis.

Abscissic acid

In 1961, Liu and Cams isolated a substance from mature cotton fruits which stimulated abscission of cotton petioles. The structure of this compound, which they called abscisin I, was never determined. Frederick T. Addicot and his coworkers (1963) in California isolated a substance from young cotton fruits which also caused abscission of cotton petioles. They partially characterized it and named as abscisin II, which proved to be ABA. In the same year, P.F. Waring in England isolated an inhibitory substance from birch leaves exposed to short days. It caused buds of growing seedlings to go dormant when applied to them and therefore, named it as dormin. In 1965, Warering working in collaboration with Shell Research Laboratory in England showed that dormin and abscisin II were the same compound named as Abscisic acid (ABA).

Occurrence and transport

ABA is widely distributed in higher plants, mosses, green algae, fungi and recently in rat brains.. All parts of the plants such as stem, root and leaves, fruits and seeds are also capable of ABA

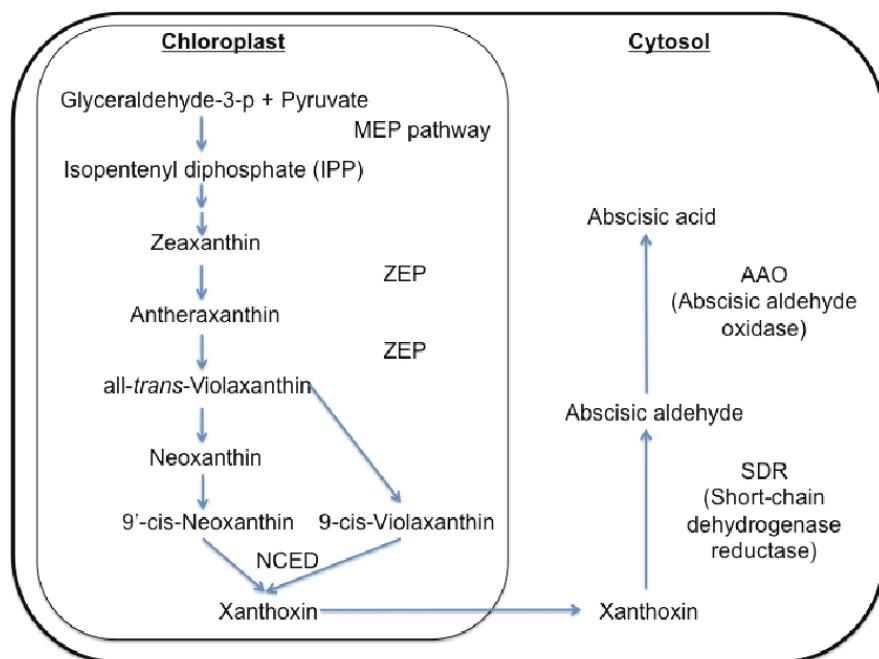
synthesis. Chloroplasts in leaves contain the carotenoids from which ABA arises, whereas in roots, fruits, seed embryos and certain other plant parts, the necessary carotenoids are in chromoplasts, leucoplasts or proplastids. ABA is present in very low concentrations in plants. In most tissues, it varies from 10 to 50 ng g⁻¹ fresh weight. In water stressed leaves, developing and mature seeds and dormant buds, its level may be higher than 10⁻⁶ M.

Biosynthesis

Abscisic acid (ABA) is a 15-carbon compound which is partially synthesized in the chloroplasts and other plastids via the Mevalonic acid pathway with two potential routes from isopentenyl pyrophosphate.

Thus, early reactions in ABA synthesis are identical to those of isoprenoids such as gibberellins, sterols and carotenoids. The first route is via farnesyl pyrophosphate to ABA and second via carotenoids through a series of steps to ABA. In second pathway, farnesyl pyrophosphate leads to the synthesis of the C40 xanthophyll violoxanthin. It is catalysed by zeaxanthin epoxidase (ZEP).

The violoxanthin is then converted to the C40 compound 9-cis-neoxanthin, which is then cleaved to form C15 compound xanthoxal, previously called xanthoxin. The cleavage is catalysed by 9-cis-epoxycarotenoid dioxygenase (NCED). NCED synthesis is a key regulatory step for ABA biosynthesis as its synthesis induces rapidly under stress conditions. Finally, xanthoxal is converted to ABA via oxidative steps involving the intermediate(s) namely ABA-aldehyde and/or possibly xanthoxioacid.



Physiological effects of ABA

Abscisic acid plays primary regulatory roles in the initiation and maintenance of seed and bud dormancy and in the plant's response to stress, particularly water stress. In addition, ABA influences many other aspects of plant development by interacting, usually as an antagonist, with auxin, cytokinin, gibberellin, ethylene and brassinosteroids.

Synthesis of storage proteins and lipids, during seed development

The ABA content of seeds is very low during early embryogenesis, reaches a maximum at about the half way point and then gradually falls to low levels as the seed reaches maturity. Thus there is a broad peak of ABA accumulation in the seed noted corresponding to mid-to late embryogenesis. This early accumulation of ABA helps to suppress vivipary. During mid to late embryogenesis, when seed ABA levels are the highest, seeds accumulate storage compounds that will support seedling growth at germination. Another important function of ABA in the developing seed is to promote the acquisition of desiccation tolerance. As maturing seeds begin to lose water, embryos accumulate sugars and so-called late embryogenesis-abundant (LEA) proteins. Physiological and genetic studies have shown that ABA affects the synthesis of LEAs and of storage proteins and lipids.

Seed dormancy and germination are controlled by the ratio of ABA to gibberellic acid

Seed dormancy may result from coat-imposed dormancy, embryo dormancy, or both. Seed dormancy that is intrinsic to the embryo and is not due to any influence of the seed coat or other surrounding tissues is called embryodormancy. Embryo dormancy is due to the presence of inhibitors, especially ABA, as well as the absence of growth promoters, such as GA. Loss of embryo dormancy is often associated with a sharp decrease in the ratio of ABA to GA.

ABA inhibits hydrolytic enzymes in germinating seeds

In addition to the ABA-GA antagonism affecting seed dormancy, ABA inhibits the GA-induced synthesis of hydrolytic enzymes that are essential for the breakdown of storage reserves in germinating seeds. GA stimulates the aleurone layer of cereal grains to produce α-amylase and other hydrolytic enzymes that break down the stored resources in the endosperm during germination.

ABA promotes root growth and inhibits shoot growth

ABA restricts shoot growth only under water stress conditions. When ABA levels are high, endogenous ABA exerts a strong positive effect on primary root growth by suppressing ethylene production. The overall effect is a dramatic increase in the root: shoot ratio at low water potentials, which, along with the effect of ABA on stomatal closure, helps the plant cope with

water stress. Furthermore, the temporary inhibition of lateral root growth promotes exploration of new areas of soil, and permits replacement of dehydrated laterals following rehydration.

ABA accelerates senescence

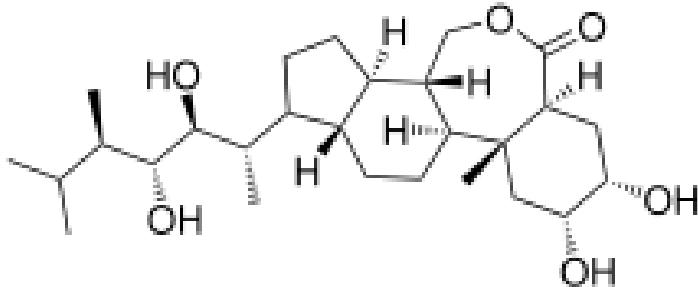
Abscisic acid was originally isolated as an abscission causing factor. However, it has since become evident that ABA stimulates abscission of organs in only a few species and that the hormone primarily responsible for causing abscission is ethylene. On the other hand, ABA is clearly involved in leaf senescence and through its promotion of senescence it might indirectly increase ethylene formation and stimulate abscission.

Abscisic acid closes stomata under water stress

ABA accumulates in water-stressed leaves and exogenous application of ABA is a powerful inhibitor of stomatal opening. The stomata close in response to soil desiccation well before there is any measurable reduction of turgor in the leaf mesophyll cells. Furthermore, ABA is readily translocated from roots to the leaves in the transpiration stream, even when roots are exposed to dry air. These results suggest that ABA is involved in some kind of early warning system that communicates information about soil water potential to the leaves.

BRASSINOSTEROIDS

Brassinosteroids (BRs) are a class of polyhydroxysteroids that have been recognized as a sixth class of [plant hormones](#). These were first explored nearly forty years ago when Mitchell *et al.* reported promotion in stem elongation and cell division by the treatment of organic extracts of [rapeseed](#) (*Brassica napus*) pollen. [Brassinolide](#) was the first isolated brassinosteroid in 1979 when it was shown that pollen from [Brassica napus](#) could promote stem elongation and cell divisions, and the biologically active molecule was isolated. The yield of brassinosteroids from 230 kg of [Brassica napus](#) pollen was only 10 mg. Since their discovery, over 70 BR compounds have been isolated from plants.



Brassinolide

The BR is biosynthesized from [campesterol](#). The biosynthetic pathway was elucidated by Japanese researchers and later shown to be correct through the analysis of BR biosynthesis mutants in *Arabidopsis thaliana*, tomatoes, and peas. The sites for BR synthesis in plants have not been experimentally demonstrated. One well-supported hypothesis is that all tissues produce BRs, since BR biosynthetic and signal transduction genes are expressed in a wide range of plant organs, and short distance activity of the hormones also supports this. Experiments have shown that long distance transport is possible and that flow is in an [acropetal](#) direction, but it is not known if this movement is biologically relevant. Brassinosteroids are recognized at the cell membrane, although they are membrane-soluble.

BRs have been shown to be involved in numerous plant processes:

- Promotion of cell expansion and cell elongation; works with [auxin](#) to do so.
- It has an unclear role in cell division and cell wall regeneration.
- Promotion of [vascular](#) differentiation; BR [signal transduction](#) has been studied during vascular differentiation.
- Is necessary for pollen elongation for pollen tube formation.
- Acceleration of [senescence](#) in dying [tissue cultured cells](#); delayed senescence in BR mutants supports that this action may be biologically relevant.
- Can provide some protection to plants during chilling and drought stress.

Extract from the plant *Lychnis viscaria* contains a relatively high amount of Brassinosteroids. *Lychnis viscaria* is said to increase the disease resistance of surrounding plants. In Germany, extract from the plant is allowed for use as a "plant strengthening substance."

[24-Epibrassinolide](#) (EBL), a brassinosteroid isolated from *Aegle marmelos* Correa (Rutaceae), was further evaluated for the antigenotoxicity against maleic hydrazide (MH)-induced genotoxicity in *Allium cepa* chromosomal aberration assay. It was shown that the percentage of chromosomal aberrations induced by maleic hydrazide (0.01%) declined significantly with 24-epibrassinolide treatment.

BRs have been reported to counteract both abiotic and biotic stress in plants. Application of brassinosteroids to cucumbers was demonstrated to increase the [metabolism](#) and removal of pesticides,

which could be beneficial for reducing the human ingestion of residual pesticides from non-organically grown vegetables.

Table 1. Physiological effects of brassinosteroids in plants.

Cell level	Whole plant level
Stimulation of elongation and fission	Growth promotion
Effect on hormonal balance	Increase in the success of fertilization
Effect on enzyme activity; H.-pump activation	Shortening the period of vegetative growth
Activation of protein and nucleic acid synthesis	Size and quantity of fruits increase
Effect on the protein spectrum and on the amino acid composition of proteins	Effect on the content of nutritive components and fruit quality improvement
Effect on the fatty acid composition and on the properties of membrane	Increased resistance to unfavourable environmental factors, stress and diseases
Enhancement of the photosynthetic capacity and of translocation of products	Crop yield increase

Study questions

1. Write the physiological functions of ABA
2. Write the physiological functions of Ethylene
3. Write the physiological functions of BR
4. Enumerate the role of ABA in abiotic stress tolerance
5. Write the biosynthetic pathway of ABA, Ethylene and BR

14. Role of other phytohormones - triacontanol, polyamines, jasmonates and salicylic acid.
New generation PGRs - 1- MCP, Triazoles, strigolactone, pro-hexadione Ca.

Functions and applications of triazoles

The triazoles are the largest and most important group of systemic compounds developed in the 1960's for the control of fungal diseases in plants and animals. Commercial triazole derivatives have been recommended for the use as either fungicide or PGR's. The heterocyclic nitrogen

atom of the triazole binds to the protoheme iron atom in CytP-450 systems, thereby excluding oxygen. This inhibits the conversion of lanosterol to ergosterol in fungi and *ent*-kaurenoic acid, a precursor of GA in plants. This accounts for their fungitoxic and PGR properties, and their relative activity is dependent on the stereochemical configuration of the substituents on the carbon chain. It has been reported that an R configuration at the chiral carbon bearing the hydroxyl group has fungicidal activity and an S configuration at this carbon exhibits activity as a PGR. Compared to other PGR's, triazoles are effective at relatively low doses and are nonphytotoxic. It has been proposed that the broad spectrum PGR properties of the triazoles are mediated through an alteration in the balance of plant hormones, including GA, ABA, and cytokinins, whereas auxin levels are not affected. In addition to their action as fungicides and PGR's, triazoles increase the tolerance of various monocot and dicot species, including conifers, to biotic and abiotic stresses, such as fungal pathogens, drought, air pollutants, and low and high temperatures. Hence, they have been referred to as "plant multiprotectants"

Representative examples of triazole compounds recommended for use as fungicides or plant growth regulators

Common name	Trade name	Applications
Diconazole	Spotless	Fungicide
Paclobuteazol	Clipper	Plant growth regulator
Propiconazole	Tilt	Fungicide
Tridemefon	Bayleton	Fungicide
Triadimenol	Baytan	Fungicide
Uniconazole	sumagic	Plant growth regulator

Triazoles and hormonal changes

Inhibition of GA biosynthesis is the primary plant growth regulatory effect of the triazoles, and the relevance of this inhibition to plant stress protection will be discussed later. A transient increase in ABA levels following triazole treatment in bean plant was first noted by Asare-boamah and colleagues, and similar observations in cell suspensions, excised leaves, and whole seedlings have been reported. It has been suggested that increase ABA levels in triazole-treated plants were associated with prevention of its catabolism to phaseic acid, an enzymatic reaction.

Senescence has been delayed by the triazoles in several plant species and this has been associated with the increased cytokinin levels. Although it has been reported that triazoles have cytokinin like activity with antisenescent properties, subsequent studies showed that triazoles are not active as cytokinins but induce plants to produce more cytokinins. Triazoles-treated plants are typically darker green and have higher levels of chlorophyll and carotenoids, characteristic of higher cytokinin level

Triazoles inhibit ethylene biosynthesis in a wide range of species. Following heat stress in wheat, or the application of auxinic herbicide triclopyr to soybeans, there was a higher accumulation of 1-aminocyclopropane carboxylic acid(ACC) in the triazole-treated seedlings. From these results, it has been suggested that triazoles inhibit the conversion of ACC to ethylene by the ethylene forming enzyme (EFE). Subsequent studies with EFE suggested that cyt P-450 monooxygenase reactions could be involved in the conversion of ACC to ethylene. From the studies it has been suggested that triazoles inhibit the enzyme that converts ACC to ethylene. Delayed senescence in oilseed rape and soybean cotyledons by triazoles has been associated with decreased ethylene production. The triazole induced effects are mediated by a change in the balance of plant hormones.

Triazoles and morphological changes

Characteristic effects of triazoles on plants include reduced height and stem width, along with increased compactness, the extent of which is dependent on plant species, age, as well as dose and method of application. Reduced height is a consequence of triazoles-induced GA inhibition, exemplified by reduced internodal elongation. Shorter stems have been correlated with decreased cell number, short cortical cells, and reduced xylem length. This compacting effect of triazoles has been exploited commercially for many crops. Triazoles stimulate or inhibit root formation, depending on the plant species and concentration of chemical applied; and at stimulatory concentrations, they increasesroot:shoot ratio.

Triazole-treated plants characteristically have smaller leaves, but they are wider and thicker with more cuticular wax than controls. The leaves, therefore, have increased leaf dry weight per unit area. Increased leaf thickness has been correlated with increased cell depth and diameter and/or additional cell layers. Leaves from triazole treated plants have been reported to exhibit altered orientation, with partially closed or sunken stomata. Light-scattering spectroscopy and microscopy has been established that the cross-sectional areas of triazole treated chloroplasts are significantly larger than those in untreated leaves. An increase in cytokinins by triazoles could lead to the observed enhanced chloroplast in cytokinins by triazoles could lead to the observed enhanced chloroplast size and chlorophyll levels. In maize, paclobutrazol (pbz) treatment did not change the number of chloroplasts, but there was more chlorophyll per chloroplast . the treatment increased stromal lamellae and reduced the number of grana stacks in mesophyll chloroplasts

Triazoles and stress protection

Triazoles-treated plants characteristically use less water, have increased tolerance to drought and higher water potential than controls. Increased drought resistance in wheat seedlings was associated with reduced transpiration caused by decreased leaf area and increased diffusion resistance indicating partial closure of stomata could be caused by the observed transient rise in ABA levels. Under conditions of water deficiency, triadimefon increased yield of peas and soybeans and fresh weight of tomato. PBZ has been shown to induce drought resistance in

conifers and this effect, along with reduced water usage by treated plants, has been exploited commercially in products such as “conifer”. In wheat seedlings, PBZ treatment increased rooting and reduced the loss of membrane integrity and photosynthetic efficiency associated with waterlogging in the treated controls. It has been suggested by triazoles may, in part, be the result of their effects on increasing the concentrations of ABA and amino acids, specially proline.

Triazoles increase the tolerance of several plant species to chilling and freezing temperature. Enhanced chilling tolerance in triazole treated cucumber and tomato was associated with increased antioxidant enzyme concentrations. In treated tomatoes,besides the increase in the antioxidants alpha-tocopherol and ascorbate, free fatty acids were higher and there was a reduction in the loss of membrane phospholipids as compared to the untreated controls. Triazoles-induced tolerance to low temperature stress has been associated with increased levels of endogenous ABA, which has been reported to trigger the genetic processes for hardening. In field studies, winter survival of peas and cereal crops and resistance to frost damage in corn and tomatoes were enhanced by triazoles.

Triazoles have been reported to increase the tolerance of plants to high temperature stress. It was suggested that this increased thermotolerance was related to changes in the hormonal balance which could harden the plants to subsequent stress. In wheat, uniconazole-increased thermotolerance was associated with lowering of leaf temperature through increased evapotranspiration. Exposure of wheat seedlings to 50 degrees C for 5 h causing thermal injury and induced several heat shock proteins in the controls, but not in the thermotolerant PBZ treated plants. It was concluded that HSP's did not play a significant role in protection of treated seedlings from thermal injury. PBZ- induced thermal protection of wheat was associated with increased levels of ascorbate, glutathione, ascorbate peroxidase, SOD, guiacol peroxidase and catalase. This suggests that an increased ability of treated plants to scavenge free radicals play a significant role in triazole induced thermotolerance.

Protection from Sulphur dioxide and ozone damage by triazoles has been observed in several plant species and it has been proposed that this protection is mediated, in part, through decreased stomatal aperture and increase in lipid-soluble antioxidants. Triazoles have been reported to increase tolerance of soybean seedlings to destructive levels of UV—B radiation and this protection was correlated with triazoles-induced leaf thickening, enhanced cultivar wax deposition and increased levels of SOD and catalase. The hypothesis that triazole-induced protection of plants from several environmental stresses including water, low and high temperatures, and air pollutants, is mediated by an increase in antioxidant potential was confirmed by demonstrating that leaves from triazole treated plants was protected from herbicide paraquat, a free radical generator. From these observations we concluded that plants have an intrinsic stress protective mechanism and triazoles allow this potential to be expressed.

Although the triazoles are capable of protecting plants from a variety of biotic and abiotic stresses, their use has been limited due to their persistence in the environment. To dress this

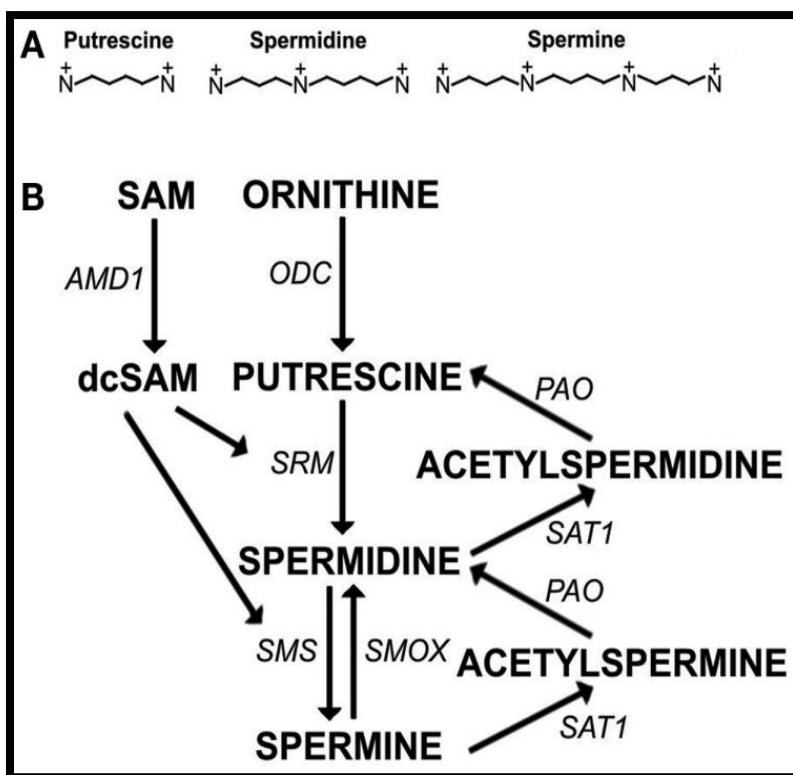
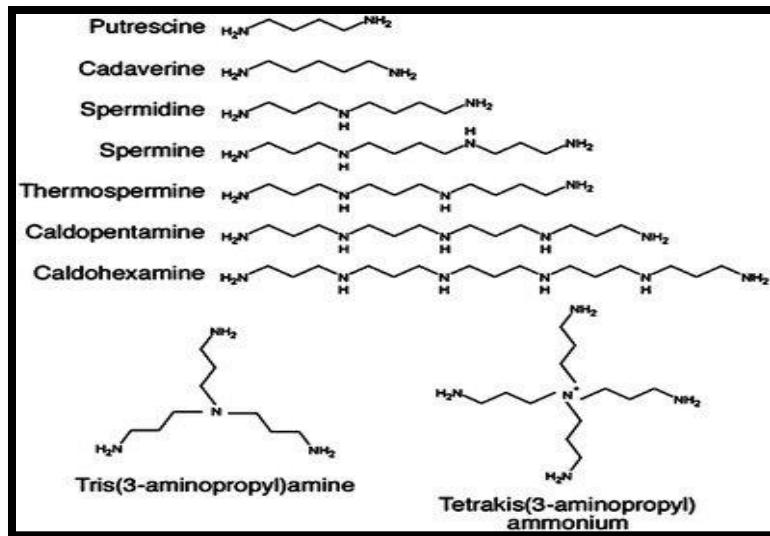
concern, a novel seed treatment procedure which incorporates the triazoles via imbibition has been developed and used successfully with several crops.

Gibberellins reverse Triazole-induced effects

Inhibition of GA biosynthesis as the primary effects of the triazole PGR's is supported by the evidence that triazoles-treated plants have lower concentrations of endogenous GA like substances. Furthermore, the PGR, biochemical and physiological properties of triazoles can be reversed by the application, since similar results were obtained when GA was applied before. Based on the interactions of triazoles and GA, it is logical to conclude that the PGR and stress protective effects of the triazoles are a consequence of their primary actions as inhibitors of GA biosynthesis.

POLYAMINES

- Polyamines (PAs) are low molecular weight aliphatic nitrogenous bases containing two or more amino groups, and they have potent biological activity.
- In living organisms, PAs mainly exist in free (F-PAs), covalently conjugated (CC-PAs) or non-covalently conjugated (NCC-PAs) forms
- The CC-PAs can be divided into perchloric acid-soluble covalently conjugated polyamines (PSCC-PAs) and perchloric acid-insoluble covalently conjugated polyamines (PISCC-PAs).
- Putrescine (Put), spermidine (Spd), and spermine (Spm) are the main PAs in plants, and they are involved in the regulation of diverse physiological processes such as flower development, embryogenesis, organogenesis, senescence, and fruit maturation and development.
- They are also involved in responses to biotic and abiotic stresses.



- The salt sensitivity in rice was associated with excessive accumulation of putrescine and with low levels of spermidine and spermine in the shoot system of salt-sensitive cultivars Co36, CSC2, GR3, IR20, TKM4, and TKM9 under saline condition.

- During the early stage of drought stress, an increase of PLD activity played a major role in stomatal closure.
- The polyamines regulated PLD activity and in turn affected membrane damage under prolonged drought.
- The higher activities of S-adenosylmethionine decarboxylase and Spd synthase in grains promotes the synthetic route from Put to Spd and Spm and notably increases the free Spd and Spm concentrations in grains, which promotes grain filling and drought resistance in wheat.
- Under high temperature stress, PAs can promote photosynthesis, and increase the antioxidant capacity and osmotic adjustment ability of plants.
- Recent studies have suggested that abiotic stress tolerance is mainly affected by the role of PAs in signal transduction rather than their accumulation.
- Salt and drought stress are the two major abiotic stresses in agriculture, and both of them lead to reduced water potential in plants.
- Polyamines are considered to be a class of growth regulators in plants. Many studies have shown that exogenous PAs and PA synthesis inhibitors can affect flower bud differentiation.

JASMONATES

Introduction

- Jasmonate (JA) and its derivatives are lipid-based plant hormones that regulate a wide range of processes in plants, ranging from growth and photosynthesis to reproductive development.
- In particular, JAs are critical for plant defense against herbivory and plant responses to poor environmental conditions and other kinds of abiotic and biotic challenges.
- Some JAs can also be released as volatile organic compounds (VOCs) to permit communication between plants in anticipation of mutual dangers.

FUNCTIONS AND ROLE IN PLANTS

In Wound Healing

- Although jasmonate (JA) regulates many different processes in the plant, its role in wound response is best understood.
- Following mechanical wounding or herbivory, JA biosynthesis is rapidly activated, leading to expression of the appropriate response genes.
- For example, in the tomato, wounding produces defense molecules that inhibit leaf digestion in the insect's gut.

In Herbivory

- Another indirect result of JA signaling is the volatile emission of JA-derived compounds.
- MeJA(methyl jasmonate) on leaves can travel airborne to nearby plants and elevate levels of transcripts related to wound response.
- In general, this emission can further upregulate JA synthesis and signaling and induce nearby plants to prime their defenses in case of herbivory.

Roles In Flower Development

- Mutants in JA synthesis or in JA signaling in Arabidopsis present with male sterility, typically due to delayed development.
- The same genes promoting male fertility in Arabidopsis promote female fertility in tomatoes.
- Overexpression of 12-OH-JA can also delay flowering.

In Germination

- JA and MeJA inhibit the germination of nondormant seeds and stimulate the germination of dormant seeds.

In The Accumulation of Storage Proteins

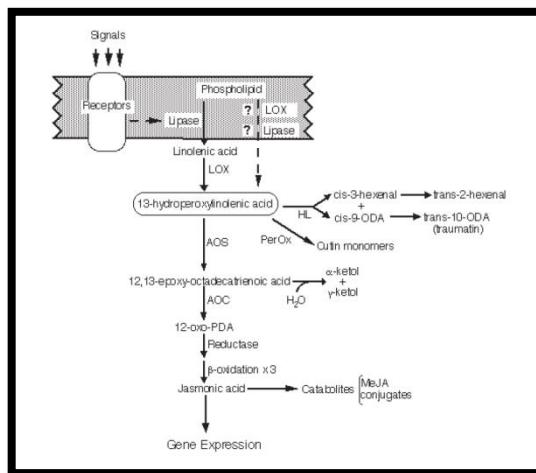
- High levels of JA encourage the accumulation of storage proteins; genes encoding vegetative storage proteins are JA responsive.
- Specifically, tuberonic acid, a JA derivative, induces the formation of tubers.

Role in pathogenesis

- *Pseudomonas syringae* causes bacterial speck disease in tomatoes by hijacking the plant's jasmonate (JA) signaling pathway.

- This bacteria utilizes a type III secretion system to inject a cocktail of viral effector proteins into host cells.
- One of the molecules included in this mixture is the phytotoxin coronatine (COR). JA-insensitive plants are highly resistant to *P. syringae* and unresponsive to COR; additionally, applying MeJA was sufficient to rescue virulence in COR mutant bacteria.
- Infected plants also expressed downstream JA and wound response genes but repressed levels of pathogenesis-related (PR) genes. All these data suggest COR acts through the JA pathway to invade host plants.
- Activation of a wound response is hypothesized to come at the expense of pathogen defense.
- By activating the JA wound response pathway, *P. syringae* could divert resources from its host's immune system and infect more effectively.
- Plants produce N-acylamides that confer resistance to necrotrophic pathogens by activating JA biosynthesis and signalling.
- Arachidonic acid (AA), the counterpart of the JA precursor α -LeA occurring in metazoan species but not in plants, is perceived by plants and acts through an increase in JA levels concomitantly with resistance to necrotrophic pathogens.
- AA is an evolutionarily conserved signalling molecule that acts in plants in response to stress similar to that in animal systems.

BIOSYNTHETIC PATHWAY AND REGULATION



- The biosynthesis of jasmonates begins with LA.

- This fatty acid is converted to 13-hydroperoxylinolenic acid by lipoxygenase.
- 13-hydroperoxylinolenic acid is a substrate for allene oxide synthase [also known as hydroperoxide dehydratase or hydroperoxide dehydrase and allene oxide cyclase resulting in the formation of 12-oxo-phytodienoic acid (12-oxo-PDA)]
- Following reduction and three steps of beta oxidation, (-)-7-iso-JA is formed.
- Jasmonic acid can be catabolized to form MeJA and numerous conjugates and catabolites that may have biological activity. The accumulation of JA in plants in response to wounding, or treatment with elicitors and systemin, can be blocked using inhibitors of lipoxygenase. Therefore, increases in JA level mediated by these inducers results from de novo synthesis rather than release from JA conjugates.

Biosynthetic pathway of jasmonic acid. It is postulated that signals (such as elicitors) interact with a membrane receptor, which causes the eventual production of 13-hydroperoxylinolenic acid. Production of 13-hydroperoxylinolenic acid is believed to occur with the release of linolenic acid via either a phospholipase or lipase followed by oxidation by lipoxygenase (LOX), but a preliminary oxidation of linolenic acid while still esterified to a phospholipid and subsequent release by a lipase cannot be ruled out. 13-hydroperoxylinolenic acid can then be catabolized by hydroperoxy lyase (HL), eventually forming volatile aldehydes and traumatic acid, or via peroxygenase pathway to cutin monomers. Jasmonic acid arises from 13-hydroperoxylinolenic acid via an allene oxide synthase (AOS) and an allene oxide cyclase (AOC)-dependent pathway with 12 oxophytodienoicacid (12-oxo-PDA) as an intermediate. Jasmonic acid then acts to modulate gene expression or can be further catabolized.

Study questions

1. Write physiological functions triacontanol, polyamines,
2. Write physiological functions of jasmonates and salicylic acid
3. Write the short notes on 1- MCP, Triazoles, strigalactone, pro-hexadione Ca.

15. Physiological limitations of crop productivity, Physiological and genetic basis of crop environment interaction, Plant architecture – Ideotype concept.

The [ideotype](#) approach (also called analytical or physiological trait-based approach) was proposed by Donald (1968) to overcome the limitations of the methods used by breeders, namely ‘selection for yield (empirical method)’ and ‘defect/default elimination’. Although these two empirical methods had been effective for improving disease resistance and [grain yield](#), Donald proposed as an alternative first to define an efficient plant type theoretically, based on our knowledge of [crop physiology](#) and then breed for it. **He defined an ideotype as ‘a biological model which is expected to perform or behave in a predictable manner within a defined environment’ (Donald, 1968).** This conceptual plant model was supposed ‘to yield a greater quantity or quality of grain, oil or other useful product when developed as a cultivar’.

Features of Crop Ideotype

The crop Ideotype consists of several morphological and physiological traits which contribute for enhanced yield or higher yield than currently prevalent crop cultivars. The morphological and physiological features of crop Ideotype is required for irrigated cultivation or rainfed cultivation. Ideal plant whether the Ideotype is required for irrigated cultivation or rainfed cultivation. Ideal plant types or model plants have been discussed in several crops like wheat, rice, maize, barley, cotton, and bean.

The important features of Ideotype for some crops are briefly described below:

Wheat:

The term Ideotype was coined by Donald in 1968 working on wheat. He proposed Ideotype of wheat with following main features.

1. A short strong stem. It imparts lodging resistance and reduces the losses due to lodging.
2. Erect leaves. Such leaves provide better arrangement for proper light distribution resulting in high photosynthesis or CO₂ fixation.
3. Few small leaves. Leaves are the important sites of photosynthesis, respiration, and transpiration. Few and small reduce water loss due to transpiration.
4. Larger ear. It will produce more grains per ear.
5. A presence of awns. Awns contribute towards photosynthesis.
6. Presence of awns. Awns contribute towards photosynthesis.
7. A single culm.

Thus, Donald included only morphological traits in the Ideotype. However, all the traits were based on physiological consideration. Finally (1968) doubted the utility of single culm in wheat

Ideotype. Considered tillering as important features of wheat flag type a wheat plant with moderately short but broad flag leaf, long flag leaf sheath, short ear extrusion with long ear, and moderately high tillering capacity should give yield per plant (Hsu and Watson, 1917).

Rice:

The concept of plant type was introduced in rice breeding by Jennings in 1964, through the term Ideotype was coined by Donald in 1968.

He suggested that the rice an ideal or model plant type consists of

- 1) Semi dwarf stature.
- 2) High tillering capacity, and
- 3) Short, erect, thick and highly angled leaves (Jennings, 1964, Beachell and Jennings, 1965). Jennings also included morphological traits in his model. Now emphasis is also given to physiological traits in the development of rice Ideotype.

Maize:

In 1975, Mock and Pearce proposed ideal plant type of maize. In Maize , higher yields were obtained from the plants consisting of

- 1) Low tillers,
- 2) Large cobs, and
- 3) Angled leaves for good light interception.

Planting of such type at closer spacing resulted in higher yields.

Barley:

Rasmusson (1987) reviewed the work on Ideotype breeding and also suggested ideal plant type of six rowed barley. He proposed that in barley, higher yield can be obtained from a combination of

- 1) Short stature,
- 2) Long awns,
- 3) High harvest index, and
- 4) High biomass.

Kernel weight and kernel number were found rewarding in increasing yield.

Cotton:

In cotton, genotypes with zero branch, short stature, compact plant, small leaves and fewer sympodia were considered to enhance yield levels. Singh et al. (1974) proposed and ideal plant type of upland cotton growing belt. The proposed Ideotype includes

- 1) Short stature (90-120 cm),
- 2) Compact and sympodial plant habit making pyramidal shape,
- 3) Determinate the fruiting habit with unimodal distribution of bolling,
- 4) Short duration (150-165 days),
- 5) Responsive to high fertilizer dose,
- 6) High degree of inter plant competitive ability,
- 7) High degree of resistance to insect pests and diseases, and
- 8) High physiological efficiency,

Singh and Narayana (1993) proposed an Ideotype of above two species for rainfed conditions. The main features of proposed Ideotype include, earliness (150-165 days), fewer small and thick leaves, compact and short stature , interminate habit, spares hairness, medium to big boll size, synchronous bolling , high response to nutrients, and resistance to insect and diseases.

Sorghum and Pearl millet:

Improvement in plant type has been achieved in Sorghum and Pearl millet through the use of dwarfing genes. In these crop dwarf F1 hybrids have been developed which have made combine harvesting possible.

Genetic improvements have been achieved thorough modification of plant type in several crop species. New Ideotype have been proposed for majority of crop plants. Swaminathan (1972) has listed several desirable attributes of crop Ideotype with special reference to multiple cropping in the tropics and sub tropics.

These features include:

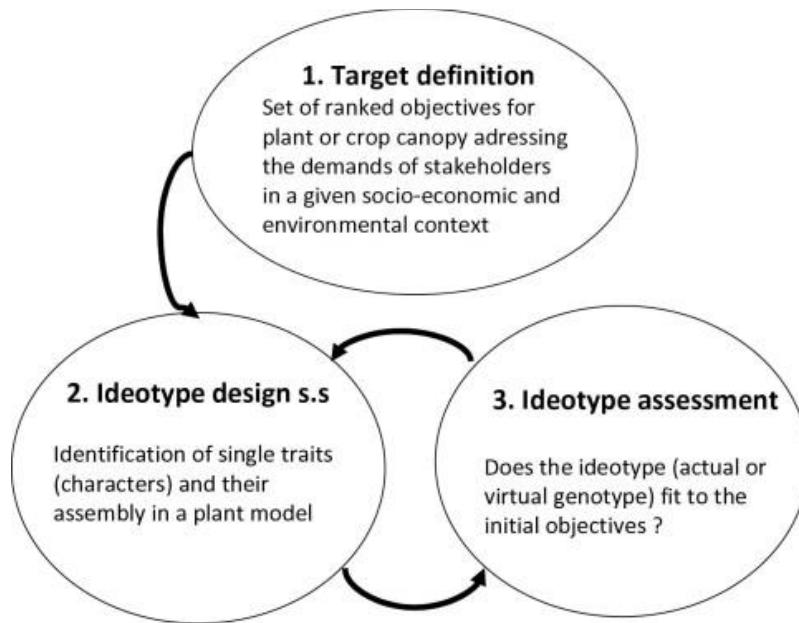
- 1) Superior population performance,
- 2) High productivity per day,
- 3) High photosynthetic ability,
- 4) Low photo respiration,
- 5) Photo and thermo sensitivity,
- 6) High response to nutrients,
- 7) High productivity per unit of water,
- 8) Multiple resistances to insect and diseases,
- 9) Better protein quantity and quality
- 10) Crop canopies that can retain and fix a maximum of CO₂, and
- 11) Suitability to mechanization.

In the literature, the ideotype concept generally refers to the breeding process, but it can also be extended to the seeking of the best crop phenotype to grow in given environments, with defined [cropping systems](#) and for targeted end uses. Commercial varieties can be far from an ideotype viewed as a theoretical objective, the variety choice can be optimized even with a limited range of traits opportunities. Therefore, we suggest broadening the ideotype definition, to the combination of morphological and physiological traits (or their genetic bases) conferring to a crop a satisfying adaptation to a particular biophysical environment, [crop management](#), and end use.

The initial ideotype of Donald was built for low- or non-stress environments where light capture was the major limitation to grain yield. For water-limited environments, the difficulty to design an ideotype is that water deficit affects crop growth and development to a different extent depending on the timing, severity and duration of stress episodes, the history of stresses during the growing season and the interactions between water deficit and other factors such as temperature and [nutrient availability](#). Therefore, it is unlikely that a single trait will improve plant performance in all scenarios of water deficit (Tardieu, 2012). Therefore, specific [ideotypes](#) should be conceived for targeted environments.

Recently, Andrivon et al. (2013) considered three views of ideotypes: (1) the historical, ‘genetic’ view, as described above; (2) the ‘agronomic’ view, where new [genotypes](#) are designed for specific cropping systems; (3) the ‘modeling’ view, where the best combinations of traits (usually represented by model parameters) are identified from formal or simulation experiments. They concluded that these views of the ideotype should lead to different breeding strategies. The emergence of new objectives (e.g. low input systems, double purpose crops) and new constraints (e.g. increasing risk of extreme weather events, price volatility) is now arguing for both new breeding objectives and new design methods. Designing crop ideotypes for these new targets is a burning point and no review has recently addressed this subject.

The ideotype [design process](#) (ideotyping) could be split into three steps



Scheme of the three main steps for ideotype design (ideotyping).

1. Definition of the main goal (target) for the breeding process (e.g. breeding for improved water-deficit tolerance)
2. Identification of morpho-physiological traits to reach the defined goal and the way to assemble them within an ideotype (e.g. developing early maturing cultivars or cultivars maintaining [photosynthesis](#) under stress or both)
3. Multicriteria assessment of the suggested ideotypes to prove the agronomic relevance of trait integration in target environments (through simulations or field experiments).

Generally, the ideotype is thought of in terms of crop improvement via breeding, but crop management (e.g. sowing density, row width, nitrogen fertilization, irrigation) may also produce the desired ideotypes by exploiting [phenotypic plasticity](#) (Box 14.1). For instance, this is the case when dealing with [plant architecture](#) traits and crop [canopies](#) to limit the epidemic development of pests (Andrivon et al., 2013; Desanlis et al., 2013). So ideotyping may result from breeding and varietal choice but also from crop management and cropping system strategies. While crop management is often added in a second step as an effective driver to complement genetic gains, greatest productivity improvement may arise when combining together both breeding and agronomic practices (e.g. Duvick et al., 2004) (Fig. 14.1). Part 1 of this book presents further examples of the synergy between breeding and [agronomy](#) in contrasting cropping systems.

PYSIOLOGICAL LIMITATIONS OF PRODUCTIVITY

The crop breeder who attempts to increase economic yield potential traditionally proceeds in an empirical fashion. This approach has worked well in the past, but it has its obvious drawbacks. First, it is slow, particularly in the case of tree crops, and, second, the results are not necessarily general. That is to say, the yield of a crop is as much a reflection of its genetic make-up as it is of the environment in which it grew. By attempting to isolate specific attributes that control productivity we may hasten the selection process and make the results more generally valid. But, in fairness to crop breeders, it must be recorded that neither crop physiologists nor crop ecologists have set out specific goals for breeders to attain. We will indicate here two principal aspects of productivity in which both environment and crop interact to result in a physiological ceiling of performance. The first is light utilization in photosynthesis and the second is the water balance. Light Utilization A given site is characterized by a given photosynthetic light climate as measured by the spectrally distributed radiant energy per unit horizontal surface and per unit time (day, month, year) in the wave band from 0.4 to 0.7 microns. On the basis of present knowledge, there is no important difference in the effectiveness for photosynthesis of light within this broad band (Federer and Tanner, 1966). There is some difference in light absorption in that the green light is absorbed less than the other colors, giving foliage its color, both in reflected and transmitted light. Again, within the 0.4 to 0.7 micron waveband, the spectral composition of natural light does not vary greatly. We can, therefore, measure the "plantwatts" per square meter or PAR (photosynthetically active irradiance), in first approximation, with a standard pyranometer with a heat absorbing filter that cuts off at 0.4 and 0.7 microns, (McCree, 1966). Sometimes, a standard fraction of the total measured short wave radiation (0.3 - 2.3 microns) is used to arrive at PAR but this is a much worse approximation. The question is what use the crop canopy can make of the incident radiant flux so defined and measured. First of all, this is a physical problem in light interception and it is laid out in terms of sun angle, leaf angle, leaf area index, and other geometrical and morphological characteristics of the canopy. The calculations become very complicated and solutions can be found only by computer simulation.

. Further, d is the depth of the rooting zone, K the hydraulic conductivity of the soil and r the root radius. The important thing about this equation is that it shows how the potential drop involved in water transfer from soil to root is directly related to both depth and density of rooting. The product dL could be called a root proliferation index and it could well be an important basis for early selection.

So far, work of this sort has been done for broadleaved canopies only and it has given us some insight into the optimum morphology of plant stands (Duncan, et.al., 1967). No efforts have been made to deal in the same way with canopies of needle-shaped leaves. The fate of intercepted light depends upon radiative properties of foliage. It remains yet to be seen whether there are significant differences between species and within progenies in a breeding program, that could be the basis of selection. Finally, the utilization efficiency of absorbed light in photosynthesis may also vary as the result of differences in internal leaf structure or in biochemical factors. Experimentally, the two categories of effects are lumped together when we measure the CO₂ fixation rates of individual leaves as affected by varying levels of incident light. It appears that a consideration of the growth habits of trees in regard to leaf angle, leaf area index distribution, leaf size and shape is one parameter that deserves study and could be the basis of rational

selections. Another possible useful parameter is the "light-saturation" curve of individual leaves at standard levels of carbon dioxide concentration and at standard leaf temperatures. Water Balance The potential of a leaf array in a given light environment for photosynthesis and growth can only be realized when a favorable water balance in the leaf exists. The explanation of adverse effects of water deficits upon photosynthesis is not fully established (Slatyer, 1967), but at least a partial explanation resides in the closure of leaf stomata that results from a decrease in water potential and water content. Regardless of cause, the necessity for minimizing water deficits calls attention to at least three physiological factors with physical significance. First, we must consider the nature of root systems. The leaf water potential is always lower than the root water potential and the latter is lower than that of the soil water potential by the following amount (Gardner, 1960):

Study questions

1. Define ideo type?
2. What are all demerits of yield based selection
3. What are all the features of Ideotype for rice, wheat and maize ?

Lecture 16. Crop photosynthetic efficiency – C₃, C₄ and CAM- Strategies to improve the crop photosynthesis, Source- sink balance and harvest index.

PHOTOSYNTHETIC PATHWAYS - C₃ and C₄

Dark reaction or Blackman's reaction or Path of carbon in photosynthesis

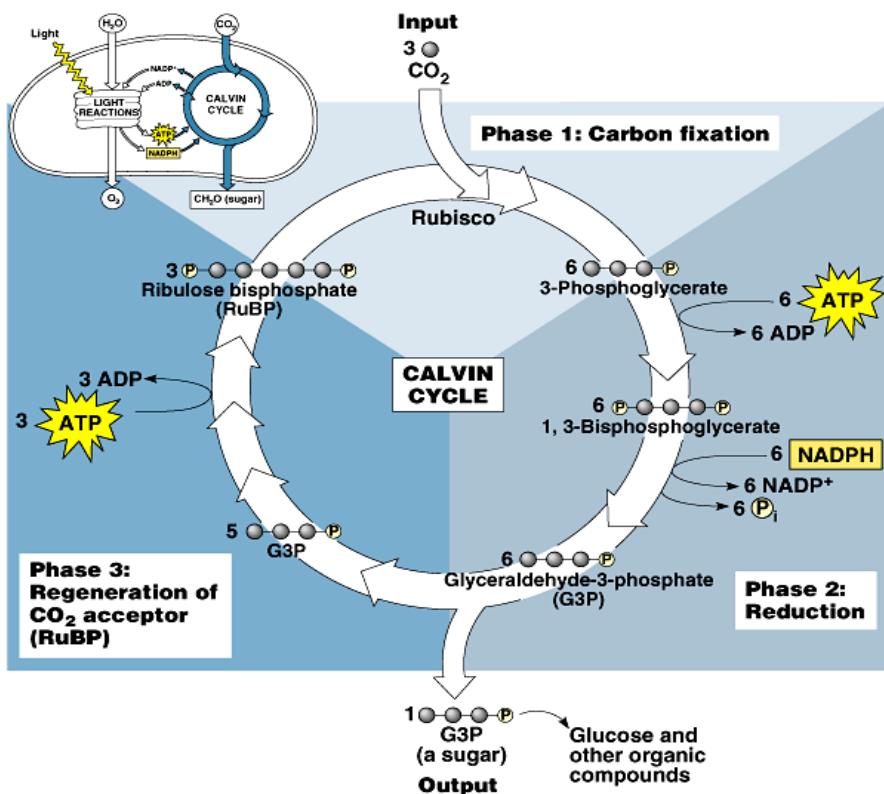
This is the second step in the mechanism of photosynthesis. The chemical processes of photosynthesis occurring independent of light is called dark reaction. It takes place in the stroma of chloroplast. The dark reaction is purely enzymatic and it is slower than the light reaction. The dark reactions occur also in the presence of light where the sugars are synthesized from CO₂. The energy poor CO₂ is fixed to energy rich carbohydrates using the energy rich compound, ATP and the assimilatory power, NADPH₂ of light reaction. The process is called carbon fixation or carbon assimilation. Since Blackman demonstrated the existence of dark reaction, the reaction is also called as Blackman's *reaction*. In dark reaction two types of cyclic reactions occur

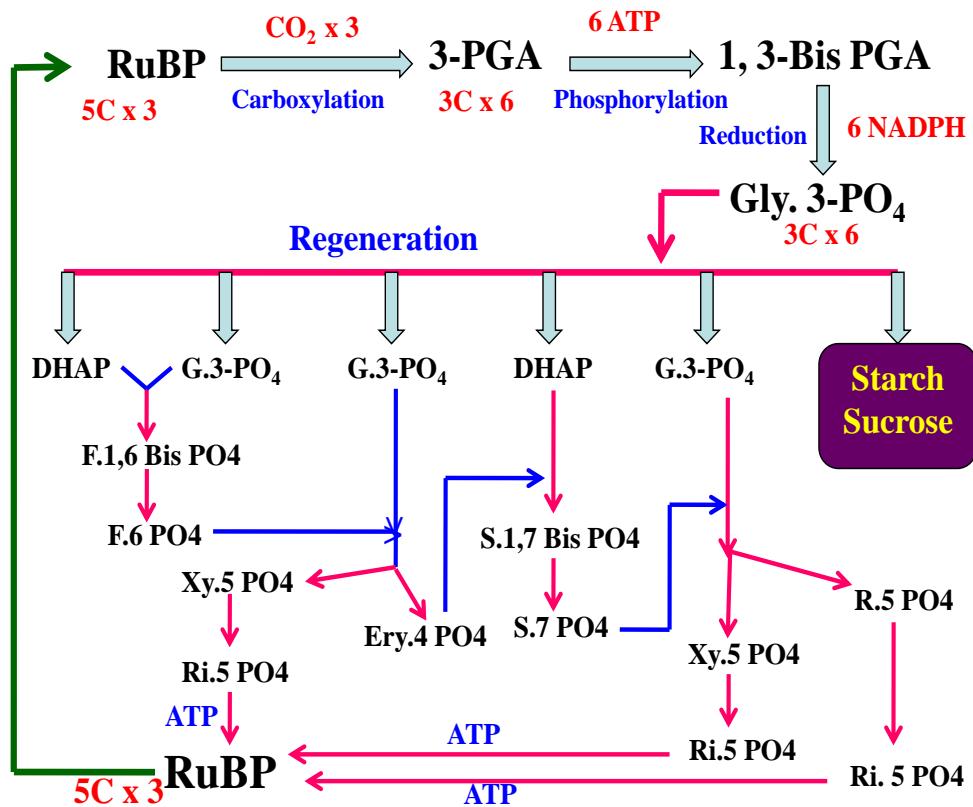
1. Calvin cycle or C3 cycle
2. Hatch and Slack pathway or C4 cycle

Calvin cycle or C3 cycle

It is a cyclic reaction occurring in the dark phase of photosynthesis. In this reaction, CO_2 is converted into sugars and hence it is a process of carbon fixation. The Calvin cycle was first observed by Melvin Calvin in chlorella, unicellular green algae. Calvin was awarded Nobel Prize for this work in 1961. Since the first stable compound in Calvin cycle is a 3 carbon compound (3 phosphoglyceric acid), the cycle is also called as C3 cycle. The reactions of Calvin's cycle occur in three phases.

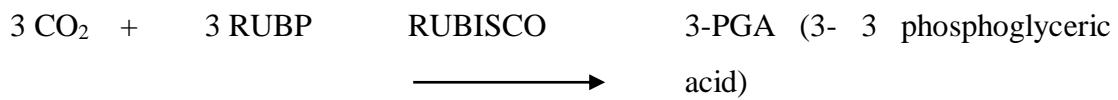
1. Carboxylation
2. Reduction
3. Regeneration





1. Carboxylative phase

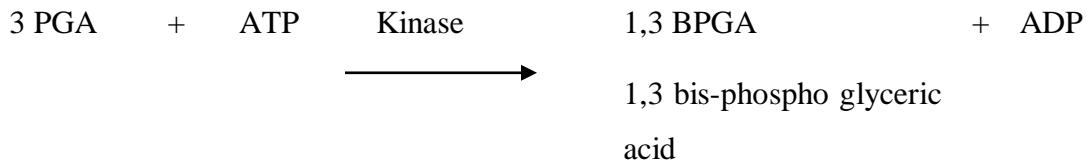
Three molecules of CO₂ are accepted by 3 molecules of 5C compound v ribulose bis-phosphate (RUBP) to form three molecules of an unstable intermediate 6C compound. This reaction is catalyzed by the enzyme, RUBisCO. Ribulosebisphosphate Carboxylase Oxygenase is a bifunctional enzyme. It can do both carboxylation and oxygenation function.



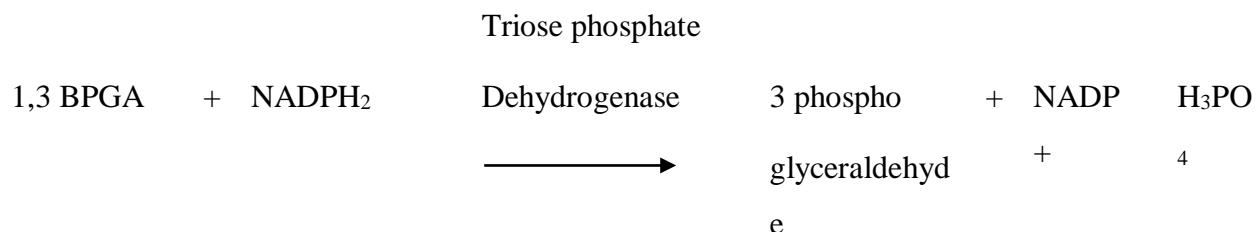
3 phosphoglyceric acid (PGA) is the first stable product of dark reaction of photosynthesis and since it is a 3 carbon compound, this cycle is known as C3 cycle.

2. Reductive phase

Six molecules of 3PGA are phosphorylated by 6 molecules of ATP (produced in the light reaction) to yield 6 molecules of 1-3 diphospho glyceric acid and 6 molecules of ADP. This reaction is catalyzed by the enzyme, Kinase



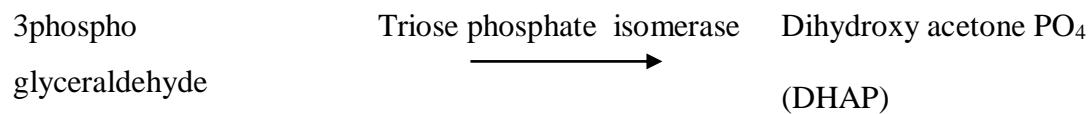
Six molecules of 1,3 BPGA acid are reduced with the use of 6 molecules of NADPH₂ (produced in light reaction) to form 6 molecules of 3 phospho glyceraldehyde. This reaction is catalysed by the enzyme, triose phosphate dehydrogenase.

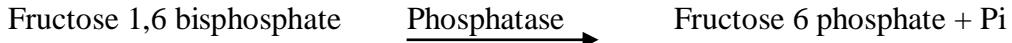


3. Regenerative phase

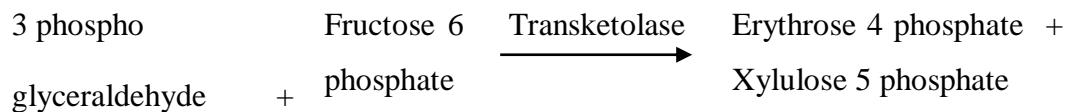
In the regenerative phase, the ribose diphosphate is regenerated. It involves the following steps.

- Some of the molecules of 3 phospho glyceraldehyde into dihydroxy acetone phosphate. Both 3 phospho glyceraldehyde and dihydroxy acetone phosphate then unite in the presence of the enzyme, aldolase to form fructose, 1-6 diphosphate.

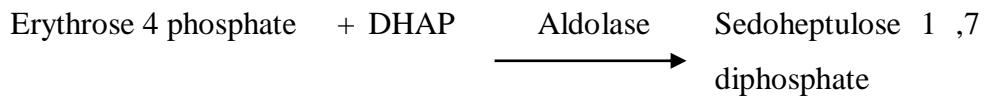




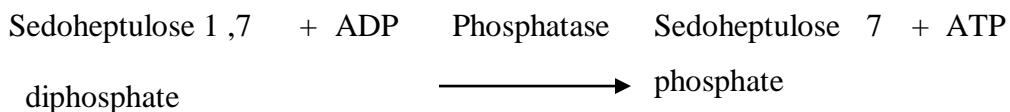
- 3 phospho glyceraldehyde reacts with fructose 6 phosphate in the presence of enzyme transketolase to form erythrose 4 phosphate (4C sugar) and xylulose 5 phosphate(5C sugar)



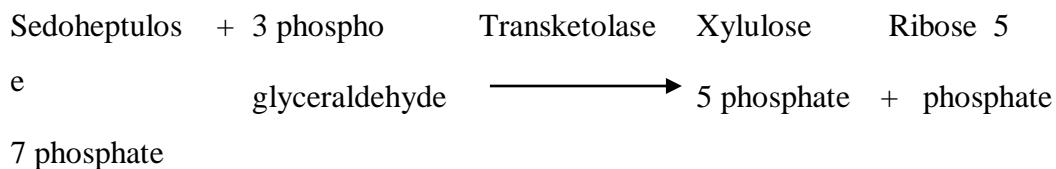
- Erythrose 4 phosphate combines with dihydroxy acetone phosphate in the presence of the enzyme aldolase to form sedoheptulose 1,7 diphosphate(7C sugar)



- Sedoheptulose 1, 7 diphosphate loses one phosphate group in the presence of the enzyme phosphatase to form sedoheptulose 7 phosphate.

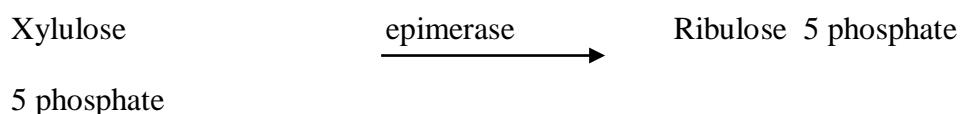


- Sedoheptulose phosphate reacts with 3 phospho glyceraldehyde in the presence of transketolase to form xylulose 5 phosphate and ribose 5 phosphate (both % c sugars)

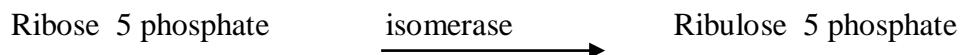


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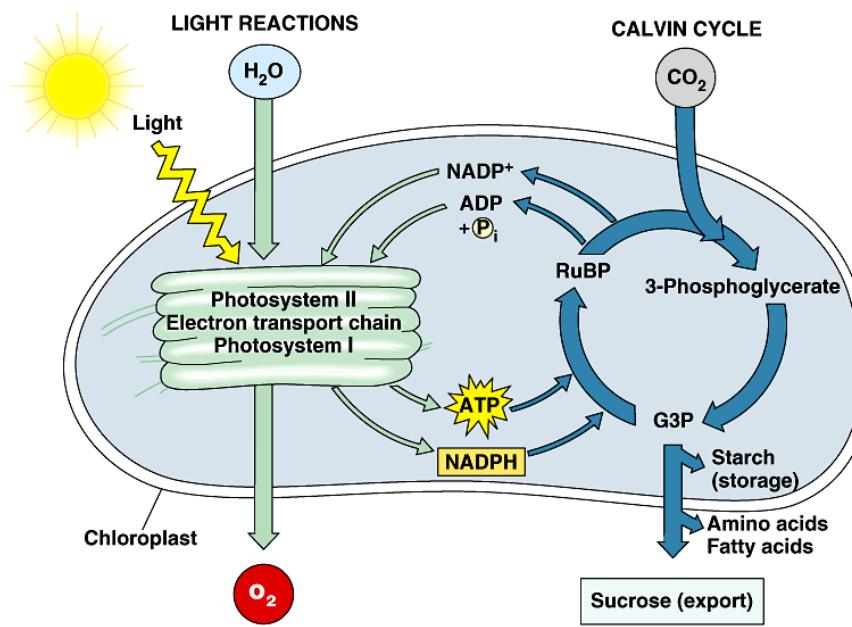
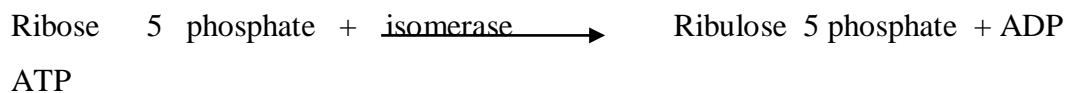
Formation of Ribulose 5 phosphate from xylulose 5 phosphate.



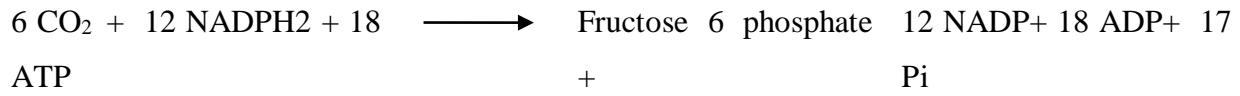
- Formation of Ribulose 5 phosphate from Ribose 5 phosphate



- Formation of Ribulose1,5 bis phosphate from ribulose 5 phosphate



In the dark reaction, CO₂ is fixed to carbohydrates and the CO₂ acceptor ribulose diphosphate is regenerated. In Calvin cycle, 12 NADPH₂ and 18 ATPs are required to fix 6 CO₂ molecules into one hexose sugar molecule (fructose 6 phosphate).



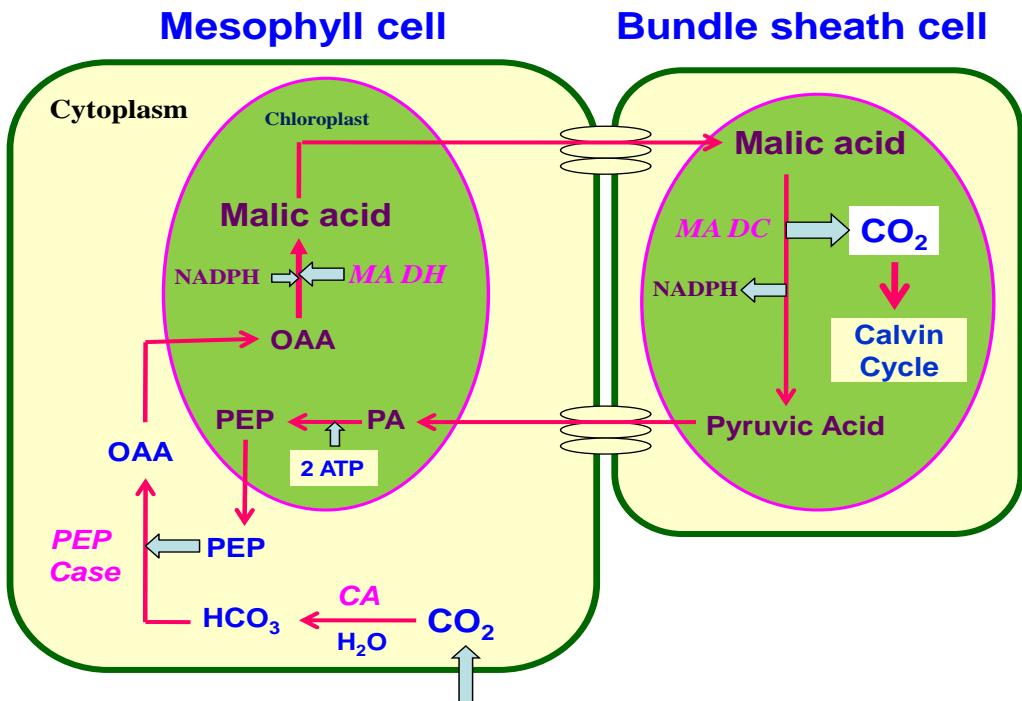
C4 CYCLE OR HATCH AND SLACK PATHWAY

It is the alternate pathway of C3 cycle to fix CO₂. In this cycle, the first formed stable compound is a 4 carbon compound viz., oxaloacetic acid. Hence it is called C4 cycle. The pathway is also called as Hatch and Slack as they worked out the pathway in 1966 and it is also called as C4 dicarboxylic acid pathway. This pathway is commonly seen in many grasses, sugar cane, maize, sorghum and amaranthus.

Characteristics feature of C₄ plants

1. Most are tropical in origin
2. They have high temperature optima for growth and high light intensity for photosynthesis.
3. They have very high Water Use Efficiency and high Nitrogen Use Efficiency
4. Have high crop growth rate
5. Thrive well in low water, low Nitrogen soil
6. They have kranz anatomy

Eg. Maize, Sugarcane, Millets, Bajra, Sorghum

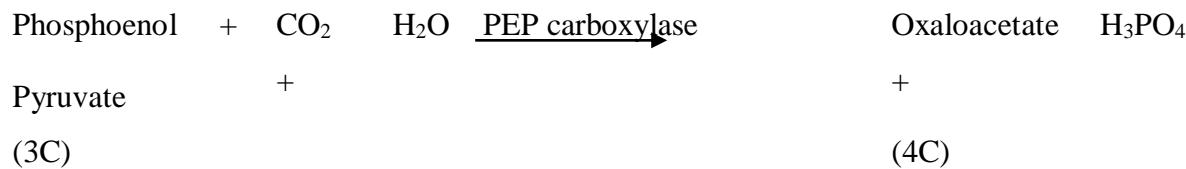


The C4 plants show a different type of leaf anatomy. The chloroplasts are dimorphic in nature. In the leaves of these plants, the vascular bundles are surrounded by bundle sheath of larger parenchymatous cells. These bundle sheath cells have chloroplasts. These chloroplasts of bundle sheath are larger, lack grana and contain starch grains. The chloroplasts in mesophyll cells are smaller and always contain grana. This peculiar anatomy of leaves of C4 plants is called Kranz anatomy. The bundle sheath cells are bigger and look like a ring or wreath. Kranz in German means wreath and hence it is called Kranz anatomy. The C4 cycle involves two carboxylation reactions, one taking place in chloroplasts of mesophyll cells and another in chloroplasts of bundle sheath cells. There are four steps in Hatch and Slack cycle:

1. Carboxylation
2. Breakdown
3. Splitting
4. Phosphorylation

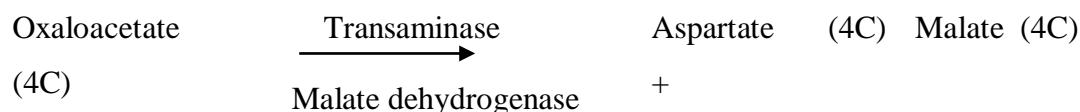
1. Carboxylation

It takes place in the chloroplasts of mesophyll cells. Phosphoenolpyruvate, a 3 carbon compound picks up CO₂ and changes into 4 carbon oxaloacetate in the presence of water. This reaction is catalysed by the enzyme, phosphoenol pyruvate carboxylase.



2. Breakdown

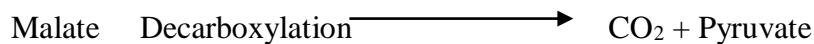
Oxaloacetate breaks down readily into 4 carbon malate and aspartate in the presence of the enzyme, transaminase and malate dehydrogenase.



These compounds diffuse from the mesophyll cells into sheath cells.

3. Splitting

In the sheath cells, malate and aspartate split enzymatically to yield free CO₂ and 3 carbon pyruvate. The CO₂ is used in Calvin's cycle in the sheath cell.

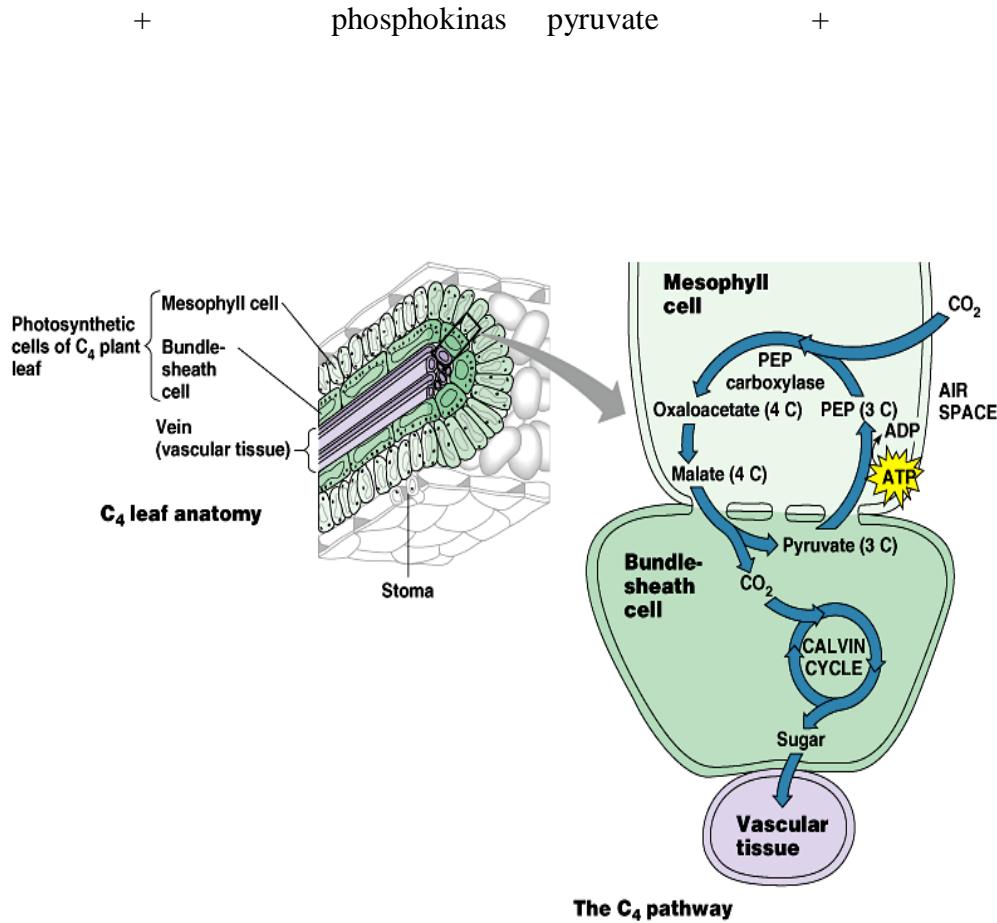


The second Carboxylation occurs in the chloroplast of bundle sheath cells. The CO₂ is accepted by 5 carbon compound ribulose diphosphate in the presence of the enzyme, carboxy dismutase and ultimately yields 3 phosphoglyceric acid. Some of the 3 phosphoglyceric acid is utilized in the formation of sugars and the rest regenerate ribulose diphosphate.

4. Phosphorylation

The pyruvate molecule is transferred to chloroplasts of mesophyll cells where, it is phosphorylated to regenerate phosphoenol pyruvate in the presence of ATP. This reaction is catalysed by pyruvate phosphokinase and the phosphoenol pyruvate is regenerated.





In Hatch and Slack pathway, the C₃ and C₄ cycles of carboxylation are linked and this is due to the Kranz anatomy of the leaves. The C₄ plants are more efficient in photosynthesis than the C₃ plants. The enzyme, phosphoenol pyruvate carboxylase of the C₄ cycle is found to have more affinity for CO₂ than the ribulose diphosphate carboxylase of the C₃ cycle in fixing the molecular CO₂ in organic compound during

SOURCE –SINK RELATIONSHIP

PHLOEM TRANSPORT

Translocation of organic solutes

The movement of organic food materials or the solutes in soluble from one place to another in higher plants is called as Translocation of organic solutes

Directions of translocation

Translocation of organic solutes may take place in the following directions.

1. Downward translocation

Mostly, the organic material is manufactured by leaves and translocated downward to stem and roots for consumption and storage.

2. Upward translocation

It takes place mainly during the germination of seeds, tubers etc. When stored food after being converted into soluble form is supplied to the upper growing part of the young seedling till it has developed green leaves. Upward translocation of solutes also takes place through stem to young leaves, buds and flowers which are situated at the tip of the branch.

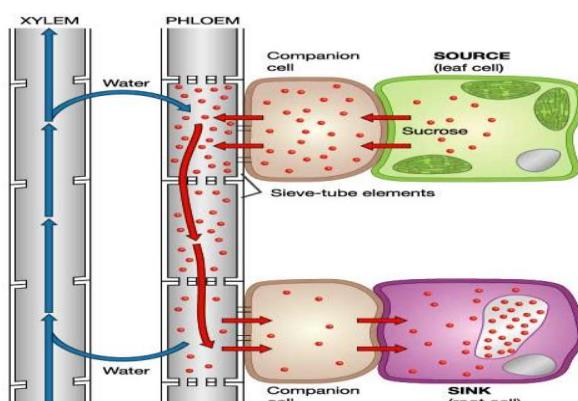
3. Radical translocation

Radical translocation of organic solutes also takes place in plants from the cells of the pith to cortex.

Mechanism of translocation

Various theories have been put forward to explain the mechanism of phloem conduction. Among them Munch's (1930) hypothesis is most convincing.

Munch mass flow on pressure flow hypothesis



According to this hypothesis put forward by Much translocation of

place though phloem along a gradient of turgor pressure from the region of higher concentration of soluble solutes (supply end) to the region of lower concentration (consumption end).

According to this theory, Mesophyll cells draw water from the xylem of the leaf due to higher

osmotic pressure and suction pressure of their sap so that their turgor pressure is increased. The turgor pressure in the cells of stem and the roots is comparatively low and hence, the soluble organic solutes begin to flow en masse from mesophyll through phloem down to the cells of stem and the roots under the gradient of turgor pressure. In the stem and the roots, the organic solutes are either consumed or converted into insoluble form and the excess water is released into xylem through cambium.

Strategies to improve the crop photosynthesis

Doubling agricultural production will be essential by 2050 to satisfy the demand of food of a constantly growing population, but climate change brings a lot of uncertainty and complexity to this challenge for agriculture. One of the most important changes that must be addressed is the increase in atmospheric CO₂, which has increased from approximately 280 ppm in pre-industrial times to about 400 ppm nowadays and will further increase to values of 470–570 ppm by 2050 depending on the climate scenario (IPCC Synthesis report, Climate Change 2007). Although this increase in CO₂ is expected to have a positive and significant effect on C₃ crops production, it is counteracted by the rise in temperature and the higher evaporative demand, with the increased risks for drought and heat likely to be progressive in all regions of our planet. As a matter of fact, the average stimulation of C₃ leaf photosynthesis under field conditions at elevated CO₂ has been reported to be only 14% on average across FACE (550–600 ppm in Free Air CO₂ Enrichment) experiments, much lower than the expected increase of 38%. Down-regulation of photosynthesis can be ascribe to multiple factors. These include the limited sink strength of the plants and the consequent accumulation of inhibitory photo-assimilates, the “hysterical” behavior of photosynthetic organisms to excess illumination, by either triggering EED (Excess Energy Dissipation) beyond the level effective for photo-protection or retaining a relevant fraction of quenching for extended periods after return to limiting light conditions, and the complex and multi-factorial network that controls CO₂ fixation and carbon allocation. Here the genetic constraints that limit yield potential and prevent it from being realized on the farm, in order to improve the understanding of plant responses under elevated CO₂, and provide tentative biotechnological solutions to overcome the crop yield limitations. It is worth noting that the huge improvements in agricultural production gained during the ‘Green Revolution’ were not directly

related to manipulation of photosynthesis, therefore its modification remains an unexplored target for crop improvement.

Harvest Index (HI):

Harvest index (HI) is the ratio of **harvested** grain to total shoot dry matter, and this can be used as a measure of reproductive efficiency.

Economic yield

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

Biological yield

Study questions

1. Describe Calvin cycle with energy requirement
2. Describe C₄ pathway with energy requirement
3. Differentiate C₃ and C₄ pathways
4. Differentiate C₄ and CAM pathway
5. Why there is no photorespiration in C₄ plants

SENESCENCE AND ABSCISSION

Like human beings, plants also grow old and undergo aging and then they die. Aging is the sum total of changes in the total plant or its organs. During aging, the plants undergo chemical and structural changes. Aging leads to senescence and later phase of development that ultimately terminates to death.

Senescence

The deteriorative process which naturally terminates the functional life of an organ, organism or other life unit is collectively called senescence. Senescence is a phase of the aging process. The major characteristic of senescence is that the metabolic processes are catabolic and eventually become irreversible and terminate to death.

Senescence is not confined only to whole plant. It may be limited to a particular plant organ such as leaf and flowers or cells or cell, organelles. Senescence is closely associated with the phenomenon of aging. Aging leads to senescence. Wheat plant dies after the development of fruit. This is the senescence of an entire plant. Leaf fall in a coconut tree is an example of senescence.

Types of senescence

Leopold (1961) has proposed types of senescence patterns in plants which are as follows.

(a) Overall Senescence

This type of senescence occurs in annuals where whole plant is affected. It is also called whole plant senescence. The entire plant dies after the development of fruit and seeds. E.g. Paddy, wheat, soybean etc.

(b) Top Senescence

In top senescence, the parts remaining above the ground or (shoot system) may die, but the root system and underground system remain viable. It is also called shoot senescence. E.g. Dock, perennial herbs.

(c) Deciduous Senescence

In deciduous woody plants, all the leaves die but the bulk of the stem and root system remains viable. It is called deciduous senescence or simultaneous or synchronous senescence. E.g. Leaf fall in deciduous trees.

(d) Progressive Senescence

It is a gradual death of old leaves from the base to the top of the plants. It may occur at any time. It is also called sequential senescence. E.g. Leaf fall in a coconut tree.

Causes of Senescence

1. Leaf senescence is accompanied by early loss in chlorophyll, RNA and enzymes.
2. Cellular constituents are decreased due to slower synthesis or faster break down.
3. Competition between vegetative and reproductive organs for nutrients.
4. A senescence factor (a hormone) is produced in soybean fruits that move to leaves where it causes senescence.
5. Short-day and long-night conditions induce flowering and leaf senescence.
6. Degradation of food reserves and loss of integrity in food storage cells of seeds.
7. Senescence is also hormonally controlled.

Physiology of Senescence

The following physiological changes occur during senescence.

1. Photosynthesis stops.
2. Chlorophyll degradation: The colour of leaf changes from green to yellow.
3. Anthocyanin pigments accumulation in the leaves causing reddening in leaves.
4. The vacuoles function as lysosomes and digest the cellular materials.
5. The starch content decreased.
6. RNA and proteins are decreased.
7. DNA molecules are degraded by the enzyme DNase.
8. Growth promoting hormones such as cytokinin decrease.
9. The deteriorative hormones such as ethylene and abscisic acid (ABA) content are increased.

Senescence Promoters

Senescence is promoted by hormones such as abscisic acid and ethylene. The senescence accelerating ability of abscisic acid is well documented. The function of ABA as a promoter of flower tissue senescence including initiation of colour fading or bleaching has been established. The ABA content of aging leaves increases markedly as senescence is initiated. Ethylene plays a very important role in the senescence of certain plant parts, particularly fruit and petals and in the abscission process. It is an inducer in the senescence of flower tissue.

Senescence Retardants

The primary plant hormones involved here are auxin, gibberellin and cytokinin.

Significance of Senescence

1. The whole plant senescence occurs in monocarpic plants coinciding the seed setting and seed dispersal.
2. Due to the formation of abscission layer, the older leaves tend to fall down so that the nutrients will be diverted to the next young leaf.
3. The senescence process helps the mobilization of nutrients and of the vegetative parts of the plant into the fruits.
4. Plants escape the influence of seasonal adversity by undergoing senescence of its organs. Leaf fall in deciduous trees reduces the rate of transpiration to survive under adverse conditions.

Fruit ripening

Fruit ripening process is closely associated with senescence. Senescence of a plant organ is usually defined as final stage in its growth and development (i.e ontogeny) during which a series of essentially irreversible or deteriorative events occur leading to cellular breakdown and death. Fruit ripening on the other hand, refers to changes occurring during early stages of senescence of fruits which make them fit for consumption. Such changes typically include change in colour, texture, taste and flavour (aroma) of the fruit.

From botanical point of view, fruit ripening means that the seeds are ready for dispersal and the attractive colours, sweet or tasty juicy pulp and characteristic aroma of the ripened fleshy fruit might be related to this function. In case of seeds whose dispersal depends on ingestion by animals, fruit ripening is in fact synonymous with edibility. But in dry fruits where the seeds require mechanical or other means for dispersal, fruit ripening may be considered as drying followed by splitting.

Fruit ripening may occur while the fruit is still attached to plant as is usual in non-climacteric fruits or after their harvest as in climacteric fruits. If not consumed in time, the ripened fruits begin to rot due to invasion by saprophytic organisms.

The role of ethylene gas in promoting ripening of fruits is known to scientists for about a century. In many cases, treatment of unripe fruits with ethylene hastens ripening with dramatic increase in production of ethylene during initiation of ripening. But, not all fruits if respond to ethylene treatment.

Climacteric fruits

In 1920s, *Kidd & West (1925)* were the first to show that onset of the visible ripening in apples was marked by dramatic increase in the rate of respiration and they coined the word *respiration climacteric* to describe this critical phase in the life of the fruit however, it is now known that respiration climacteric is exhibited by certain fruits only and not by all types of the fruits. Those

fruits which ripen in response to ethylene treatment and also exhibit respiration climacteric and are called as climacteric fruits such as apple, banana, tomato, mango etc.

Non-Climacteric Fruits

Those fruits which do not respond to ethylene treatment, neither show respiration climacteric nor they exhibit significant increase in ethylene production and are called as non-climacteric fruits. Examples are citrus fruits, grapes, strawberry etc.

Whether the fruit is climacteric or non-climacteric *i.e.*, it responds to ethylene treatment or not, a minimum threshold level of endogenous ethylene is necessary for ripening of all types of fruits. This has unequivocally been proved by experiments with transgenic plants such as transgenic tomatoes. By making expression of antisense version of ACC Synthase or ACC Oxidase (*i.e.*, by blocking the biosynthesis of ethylene) in such plants, ripening of tomatoes was completely inhibited which could be restored by treatment with externally applied ethylene only.

Hormonal Control of Fruit Ripening

The control of maturation and initiation of fruit ripening is believed to be due to interaction and balance between promotory and inhibitory effects of different phytohormones. Ethylene is one promoting factor, Abscisic acid is another. The role of other phytohormones in ripening is briefly discussed below

Abscisic acid (ABA)

ABA plays an important regulatory role in fruit ripening. There is marked accumulation ABA in fruit tissues during ripening. In climacteric fruits such as avocado and pear, the level of ABA is constant during maturation but rises rapidly during ripening and coincides with rise in ethylene production during ripening. Adato *et al.*, (1976) have shown threefold increase in free ABA level during ripening of detached avocado pear at 19°C to a maximum level of about 7000 ug/kg fresh weight. Even in non-climacteric fruits such as citrus fruits and grapes where there is no rise in ethylene production during ripening, the ABA level increases markedly. Application of ABA to mature fruits is known to enhance ripening processes.

Auxins

Indole-acetic-acid (IAA) is probably an endogenous hormonal inhibitor of ripening. It acts both as an inhibitor of ripening and at the same time promotor of ethylene biosynthesis. Conflicting results have been obtained with synthetic auxins on fruit ripening. For instance; certain synthetic auxins such as 2,4,5- trichlorophenoxy propionic acid and 2,4,5- trichlorophenoxy acetic acid are known to improve anthocyanin colouration of apples along with other ripening processes. Whereas, 2, 4-dichlorophenoxy acetic acid delays yellowing of lemons and is used commercially to delay ripening of citrus fruits after harvest.

Gibberellins

Gibberellins are also known to delay fruit ripening in plants. Gibberellins interfere with degradation of chlorophyll and biosynthesis of carotenoids and anthocyanins. Application of GA₃, in concentrations as low as 0.1mg/l effectively

delays degreening of detached citrus fruits. Gibberellins are also known to promote regreening of Valencia oranges.

Cytokinins

The role of cytokinins in delaying senescence in plants is well known and this effect of cytokinins has also been obtained in delaying ripening processes of fruits

especially those related to chloroplasts (i.e., degreening). However, olives are exceptions where cytokinins promote accumulation of anthocyanins in the fruit.

Changes during Fruit Ripening

1. Texture

The changes in the texture of fruit during ripening result due to changes in the structure and composition of their cell walls. During ripening of fruit, there is extensive degradation of cell walls due to increased activities of cell wall degrading enzymes such as cellulases and pectinases etc. resulting in softening of the fruit.

2. Colour

The factors responsible for changes in colour of fruit during ripening may be due to changes in pigments localised in chloroplasts or those which are stored outside chloroplasts in vacuoles.

Colour changes due to conversion of chloroplasts into chromoplasts

The carotenoids, major factor in the colour changes of fruit ripening is the transition from chloroplasts which are rich in green pigment chlorophyll into chromoplasts which are rich in red or yellow carotenoid pigments. During conversion of chloroplasts into chromoplasts, the chlorophyll disappears and the structure of the chloroplasts is disorganised.

Carotenoids are important constituents of chloroplasts and are present in green fruit tissue even before maturation. Maturation does not always involve accumulation of carotenoid pigments. For instance, yellowing in many varieties of apples, pears, grapes, olives and mature bananas results from pre-existing carotenoids which are unmasked due to disappearance of chlorophyll. A large number of other fruits such as citrus, tomato, Capsicum etc., accumulate large amounts of carotenoids which are biosynthesized during later stages of maturation. The complement of carotenoid pigments in these fruits, however, differs greatly from one species to another.

In tomatoes, the carotenoid pigments are dominated by lycopene and β -carotene. Mature citrus fruits contain over 115 different carotenoids (about 1/3 of the total carotenoids occurring in nature). Besides 40-C carotenoids, the citrus peel also contains 30-C carotenoids such as α -citraurin which is responsible for bright orange and red colour of oranges and tangerines. In oranges, besides increase in xanthophyll conc., there is also an increase in their esterification. Up to 60% esterification of the xanthophylls has been reported by scientists in orange peel.

Colour changes due to pigments stored outside chloroplasts (i.e., in vacuole)

Anthocyanins are water soluble phenolic pigments which accumulate in vacuole and impart red, blue and purple colours to many fruits such as ripening fruits of apple, grape, straw- berry etc. Anthocyanins exist as complex conjugates of parent aglycones called as anthocyanidins. There are six main anthocyanidins which occur in fruits as 3-glycosides. These are pelargonidin, cyanidin, peonidin, delphinidin, petunidin and malvidin. Cyanidin -3-galactoside is the chief pigment responsible for the colour of red apple varieties Pelargonidin-3-glucoside is the chief pigment of ripe strawberries. In some fruits such as grapes, acylated anthocyanins are found. Frequently, many different anthocyanins are present in the same tissue each contributing to the colour of the fruit.

3. Taste

Generally, there is decrease in acidity and increase in sweetness during fruit ripening. Some fruits like bananas are however, exceptional, where acidity actually increases from pH 5.4 to 4.5 during ripening due to increase in content of organic acids such as malic acid and citric acid.

In fruits such as melons which have essentially no reserve carbohydrates, there is no increase in sugar content during ripening after harvest although it does increase during ripening when the fruit is attached to parent plant because of transport from leaves. In most fruits, however, starch occurs as chief carbohydrate reserve which is converted into sugars to impart sweetness to the ripe fruit.

The absolute levels of sugars and acids and-also the ratio of sugars to acids, play an important role in taste of ripe fruit. In many fruits, disappearance of phenolic compounds including tannins during ripening also contributes to characteristic taste of the fruit.

Unripe green fruits of banana, contain 20-25% starch and almost all of it is converted into simple sugars such as sucrose, glucose and fructose during ripening and ultimately constituting 15-20% of the dry weight of ripe fruit (some amount being utilized in respiration). Among fruits, grapes are known to accumulate highest concentration of sugars during ripening.

The pH of the cell sap of fruit cells is frequently below 7 and it may be as low as 3 in lemon. Citric acid and malic acid are the two most frequently occurring organic acids in fruit cells. Citric acid predominates in Citrus fruits, guava, figs, strawberry, raspberry and pineapple etc., while malic

acid predominates in apple, apricot, banana, cherry, peach, plum, pear etc. Tomato and gooseberry contain a mixture of almost equal amounts of malic acid and citric acid. Besides malic acid and citric acid, many fruits also store a number of other organic acids but in comparatively very low amounts. However, in grapes, tartaric acid is the major stored acid and its level may be more or less the same as that of malic acid.

4. Aroma

Apart from sugar to acid ratio, an important factor in the flavour of the fruit is aroma which arises from the production of volatile compounds by the fruit during ripening. These volatile compounds include many different classes of organic compounds such as organic acids, alcohols, esters, carbonyl compounds, lactones, hydrocarbons, terpenoids etc.

The contribution of a particular volatile compound to aroma of the fruit depends upon, (i) the quantity of the compound produced,

- (ii) the quality of aroma of each compound and
- (iii) sensitivity of the olfactory epithelium tissue of nose to a range of cones, of that compound.

The quantity of total volatiles produced by fruit is typically from 1 to 20 ppm, but in certain varieties of bananas it may be up to 300 ppm. In banana, over 200 volatile' compounds have been detected each present at below 1 ppm and in some cases only at one part per thousand million. A volatile compound although produced in very low amounts, may contribute to aroma of ripe fruit if its olfactory threshold level is very low.

There are two major categories of precursors of volatile compounds, (i) the long chain amino acids leucine, isoleucine and valine and (ii) the unsaturated fatty acids, linoleic acid and linolenic acid.

Environmental Control of Fruit Ripening

Environmental factors such as light, temperature, gaseous composition of atmosphere (O_2 and CO_2), and atmospheric pressure have controlling influence on

ripening processes and their USES have important implications in storage of fresh fruits prior to marketing.

1. Temperature

The process of ripening occurs in a relatively narrow range of temperatures only. In many fruits of tropical and subtropical origin, fruit ripening is inhibited below a certain critical temperature. For instance, in bananas and tomatoes, this critical temp, is in between 10—13°C whereas in certain temperate fruits such as Cox's orange Pippin variety of apples, it may be as low as 3°C.

Besides critical low temp., there is also an upper temp, limit above which fruits fail to ripen properly. Biale and Young (1971) have shown that at temperatures above 25.,C, the extent of respiration climacteric in avocado pears decreased markedly. Degering of tomatoes is

inhibited in storage at temperatures above 30°C and bananas fail to ripen properly beyond 30–35°C and their pulp becomes soft and watery.

2. Light

Light also has controlling influence on ripening especially degreening or colouration of fruit. Jen (1974) has observed loss of chlorophyll by red light in detached tomatoes. Other workers have shown that accumulation of the pigment lycopene in tomatoes could be induced by red light and reversed by far-red light. Citrus fruits wrapped in black polythene show low levels, of chlorophylls and carotenoids in their peels, probably due to poor development of chloroplasts in dark.

In apples, grapes and other fruits, exposure to light is essential for biosynthesis of anthocyanins. Light intensity is also important in degreening process. Winkler *et al.*, (1974) have shown that over 54% of sunlight intensity was sufficient for full development of colour in grapes. With decrease in sunlight intensity, there was proportional decrease in anthocyanin levels, so much so that in complete darkness the anthocyanins were completely absent.

3. Gaseous composition of atmosphere

i). O₂ Tension

Low levels of O₂ (between 1—5%) in the atmosphere are known to delay ripening in number of different fruits. It has been shown by many scientists that inhibition of ripening at low levels of O₂ in the atmosphere is chiefly because of its

effect on involvement of ethylene in initiation of ripening. The biosynthesis of ethylene from methionine is an aerobic process which is completely inhibited in absence of O₂. However, inhibition of ripening due to low levels of O₂ can be reversed by inclusion of

some ethylene in low O₂ atmosphere.

ii). CO₂ Tension

An increase in atmospheric CO₂ from 3-10% around some fruits delays onset of climacteric and ripening. However, in some fruits such as apples, high conc. of CO₂ may lead to physiological disorders.

The effect of CO₂ in delaying ripening has been related to its effect on action of ethylene, O₂ is known to act as competitive inhibitor of ethylene action. According to Burg (1965), relative affinity of active site for ethylene and CO₂ is 100000: 1.

4. Atmospheric Pressure

Burg and Burg (1966) have shown complete inhibition of ripening of banana fruits stored one fifth of the normal atmospheric pressure in pure O₂ (to maintain atm. O₂ tension). This inhibitory effect of low atmosphere can be reversed by adding

small amount of ethylene in the atmosphere.

Study questions

1. Physiological and Biochemical changes during Senescence and Factors influencing ripening
2. Describe the measures to enhance the shelf life of fruits and vegetables
3. List out types of senescence with examples