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Plant physiology has significantly contributed to the feeding of human beings. Applications of our knowledge of key concepts and processes in plant physiology are continuously evolving with time. Plants face a number of constraints in their optimal growth right from seed germination. They have to face challenges of weeds which compete with crop plants for limited availability of nutrients. Through our current understanding of the process of water and nutrient absorption and photosynthesis, farmers in the current era are able to optimize nutrient uptake and eradicate weeds in the crop fields. Early observations on the significance of ethylene in senescence and fruit maturation got extended into our present-day extensive knowledge of plant growth regulators and their derivatives in controlling fruit maturation, lodging, grapevine production, vegetable production, and fruit maturation. Of late, biotechnological approaches have also encouraged scientists to explore the possibility of producing transgenic fruits, reduce caffeine content in tea and coffee, and produce key metabolites in bulk for use by mankind. This chapter focuses on the key applications of the principles of plant physiology which have led to enhanced crop productivity.

34.1 Optimizing Nutrient and Water Uptake

An integration of the current knowledge about the water and nutrient uptake by plants and concepts of soil science has led to significant optimization of the techniques for water and nutrient mobilization by plants. Some of the major achievements in this aspect are presented below.

34.1.1 Plant and Soil Elemental Analysis Facilitates Correct Application of Fertilizers

Fertilizers play a major role in increasing nutrient availability in soil for crop growth. Plant analysis, with improved diagnostic interpretation, has also played a key role in crop revolution. Assessment of nutrient status is based on the relationship between nutrient concentration in soil and yield and growth of a plant. The relationship between yield and nutrient concentration in plant tissues generally follows a bell-shaped curve. **Critical concentration (of an element)** is defined in plant analysis as the concentration of element that results in 90% of maximum yield or growth. Essential elements show two critical levels—"lower critical level," which is indicative of element deficiency, and "upper critical level," indicative of toxicity due to an element. The **critical toxicity level** of an element is the concentration of the element in tissue which results in 10% reduction in dry matter. NPK (nitrogen, phosphorus, potassium) fertilizers mixed with other micronutrients are commonly used. Foliar sprays are widely used to apply micronutrients in many crops. Major advantages of foliar sprays are (1) lower cost of compounds, (2) less utilization of nutrients, (3) uniform application, and (4) the nutrient deficiencies which can be corrected in the same growing season as the response to nutrient application is fast. However, there are certain disadvantages of the foliar application of nutrients as well. For example, high salt concentration may lead to leaf burn. In case of small leaf size, insufficient foliar adsorption can result in deficiency symptoms.

34.1.2 Managing Soil Acidity Through Liming for Better Nutrient Absorption by Plants

Mobility of nutrients within the soil is related to chemical properties of the soil, such as CEC (cation exchange capacity) and AEC (anion exchange capacity), as well as the soil conditions, such as moisture, pH, etc. Soil pH is a useful indicator of the relative acidity or alkalinity of the soil. Soil pH controls the nutrient availability of essential nutrients. When soil is flooded and becomes anaerobic, soil pH rises toward neutrality even when the pH was originally acidic. If the soil is subsequently drained and becomes more oxygen rich, then the pH will return to acidic state. However, care must be taken if the soil contains manganese oxide minerals, as flooding condition may lead to manganese toxicity. Acidic soils have low levels of basic ions like Ca^{2+} and Mg^{2+} but high levels of acidic ions especially Al^{3+} , Mn^{2+} , and Fe^{2+} . Some of these are not susceptible to leaching and occur at particularly high concentrations in acid soils, for example, aluminum. Under acidic conditions, phosphate is precipitated as AlPO_4 that increases Al^{3+} . Also, K and S availability decrease in acidic conditions. Cu^{2+} and Zn^{2+} are much more available in acid soils than in basic soils. Thus, in both acidic and basic soils, there is low availability of certain macronutrients, but the additional problem of high Al^{3+} is found only in acidic soils. Attempts have been made to produce transgenic tobacco and papaya plants by expressing citrate synthase gene from the bacterium *Pseudomonas aeruginosa* since

overproduction of citrate has been shown to enhance aluminum tolerance. In addition, acidic pH also limits oxidation of ammonium to nitrate ions. Soil pH also affects the growth of microorganisms and the type of plants which can grow in the soil. The relative amount of aluminum and hydrogen ions can change soil pH. Soil exhibits a buffering capacity. For example, removal of aluminum and hydrogen ions from the soil solution leads to replenishment of acid cations in soil solution. Minerals containing aluminum and hydrogen ions dissolve and release these cations as they are removed from the exchangeable pool. Finely textured clay soil tends to offer greater buffering capacity than coarse-textured soil. This has a great implication on **nutrient management** since buffering capacity determines the amount of resources, such as lime, that must be added to correct soil acidity. Soil with high buffering capacity requires large amounts of liming resources to raise the pH to a target value than soil with low buffering capacity. Heavy rainfall significantly lowers the soil pH by leaching out basic chemicals like calcium, magnesium, potassium, and sodium. The remaining elements like hydrogen, aluminum, and manganese contribute to an acidic soil profile. Soil erosion also contributes to elevation of soil acidity. Various liming materials may be added to the soil to neutralize or counteract soil acidity. **Liming materials** are bases that react with hydrogen ions in the soil solution to form water. Examples of common liming materials are limestone (calcium carbonate), dolomite (calcium/magnesium carbonate), hydrated lime (calcium hydroxide), and quicklime (calcium oxide). Calcium and magnesium silicates are also used as liming agents. There are four guidelines that help in determining the lime requirement of soil: (1) desired change in pH, (2) buffering capacity of soil, (3) type of lime material, and (4) the fineness or texture of the liming material. The optimal pH range for the growth of most plants is between 6.0 and 6.5. To avoid aluminum and manganese toxicity, a soil should be limed if the pH is less than 5.4. Since finer-textured soils have greater buffering capacity than coarse-textured soils, more lime must be added to the finer-textured soil to achieve the same effect and attain the target pH. Arbuscular mycorrhizal (AM) association with plant roots are also known to enhance nutrient uptake by plants in moderately acidic soils.

Addition of organic matter is another viable option to manage problems associated with the soil acidity. Organic matter increases the cation exchange capacity of the soil. Organic matter forms strong bonds, known as “chelates,” with aluminum. Chelation reduces the solubility of aluminum and soil acidity. If soil is prone to manganese toxicity, it is advised not to add organic matter. Like organic matter, wood ash increases base saturation and forms chelates with aluminum.

34.1.3 Green Manure as an Alternative to Chemical Fertilizers

Green manure refers to the manure generated from crop plants by leaving them to wither and get incorporated into the soil, either uprooted or still rooted in the soil. Green manure, when turned into the soil, is broken down by soil-dwelling microorganisms to release nutrients and form humus. Humus is the dark organic matter which is composed of decaying remains of the plants, and animal tissue

formed as a result of microbial action in the soil. It serves as a source of essential nutrients, such as nitrogen and phosphate. Green manure also generates **humic acid** and **acetic acid** and thus decreases the alkalinity of **soils**. Green manure has several advantages over the chemical fertilizers that have been long used extensively all over the world. Deep root systems of green manure crops keep the soil particles bound together and help improve the soil structure and prevent soil erosion and leaching of nutrients. In contrast, expensive inorganic fertilizers supply only nutrients and do not aid in improving the soil structure. The non-leguminous plants that are employed as green manure crops include wheat (*Triticum* sp.), mustard (*Brassica* sp.), carrot (*Daucus carota*), radish (*Raphanus sativus*), Jowar (*Sorghum vulgare*), and sunflower (*Helianthus annuus*), while the leguminous crops include river hemp (*Sesbania rostrata*), sann hemp (*Crotalaria juncea*), djainach (*Sesbania aculeata*), mung (*Phaseolus aureus*), cowpea (*Vigna catjang*), fenugreek (*Trigonella foenum-graecum*), sweet clover (*Melilotus officinalis*), lentil (*Lens esculenta*), senji (*Melilotus alba*), crimson clover (*Trifolium incarnatum*), and vetch (*Vicia sativa*). Fleshy green manures which are especially rich in nitrogen, such as leguminous plants, decompose quickly and release nitrogen and other nutrients fast allowing them to be available only after few weeks of incorporation into the soil, whereas other plants, like grasses, break down more slowly and thus are much slower to release nutrients.

The characteristics of plants used for green manure include fast growth to provide large yield within a short period, more leafy growth for a rapid decomposition, and deep root system to allow efficient nutrient acquisition from deeper parts of the soil. Deep root systems of plants also allow to bring up nutrients from deep layers of soil and make them available to next crop and also help to improve physical structure and properties of soil. Green manure plants grow quickly and are more efficient at acquiring nutrients from the soil, thus suppressing growth of **weeds**. Some green manures including many clovers and grazing rye, upon decomposition, release allelopathic chemicals in the soil and prevent the germination of seeds of weeds in the soil. Long-term green manures are generally grown for more than one season in order to prevent weed growth. They are grown as a part of crop rotation or intercropped with crop plants. During crop rotation, the plants are grown on the land when there is no crop. This helps to prevent weeds from growing on the land and nutrients from leaching out of the soil. It is particularly useful in building soil fertility before growing the crops which require nutrients in large quantities. During intercropping, the green manure plants are grown among the crop plants either at the same time as crop or sometimes slightly later to reduce competition between the green manure plants and the crop plants. Under sowing is one of the methods employed during intercropping in which green manure plants are sown under the crop plants such that the green manure is ready by the time crop is harvested and no extra time is required for preparing the soil and the next crop can be sown. Green manures have also been used in agroforestry where trees and shrubs are grown together along with crop plants and animals. The trees and shrubs provide large amounts of green leaves to be incorporated into the soil as green manure and provide

nutrition during the crop growing period. They also provide food, fodder, and fuel wood along with other benefits. Green manure plants have been shown to reduce pest and controlling diseases in crops by providing habitats for natural predators of insect pests so as to reduce attack on the whole crop. Some green manure crops, when grown up to **flowering stage**, provide **forage** for pollinating **insects**. They also provide habitat for beneficial insects that act as natural predators for insect pests which allows for a reduction in the application of insecticides. Some green manure crops also provide fodder for livestock and can also be used for grazing.

The many advantages that green manures hold make them a sustainable and a rather inexpensive alternative to chemical fertilizers. Incorporation of green manures into agriculture thus can drastically reduce, if not eliminate, the need for supplementation of fertilizers, herbicides, and pesticides. They can also help to reclaim alkaline soil and to make the land usable for farming by improving its physical properties.

34.1.4 Antitranspirants for Enhancing Water Stress Tolerance in Ornamental Plants

Plants are often exposed to adverse environmental conditions, such as inadequate irrigation and high temperature, leading to acceleration of surface drying and plant wilting. Ornamental plants often lose water in large quantity during transportation, thereby causing considerable loss to floriculture industry. Water stress results in ABA production in the roots and its translocation to the leaves through the transpiration stream. In the leaves, ABA binds to ABA receptors causing activity of ion efflux and reduction of turgor pressure in the guard cells. Loss of turgidity in the guard cells leads to stomatal closure. As a result, transpiration is inhibited, and plants can withstand water stress by decreasing water loss. Floriculturists often use antitranspirants to reduce water loss by transpiration during shipping of ornamentals. Antitranspirants are a group of compounds which enhance water stress tolerance by preventing/reducing transpiration in plants. Antitranspirants can be either physical or physiological in nature. Physical antitranspirants include the use of polymers, resins, latex, and waxes to coat the leaf surface and minimize water loss by blocking the stomatal aperture. Physical antitranspirants have been successfully used to minimize loss of crop due to water stress in pepper (*Capsicum annuum*), peach (*Prunus persica*), and some herbaceous plants. Physiological antitranspirants reduce transpiration by inducing plants to close stomata. They include ABA or some chemicals which increase ABA concentration in the plants. Physiological antitranspirants have been successfully used in various horticultural crops, although plant responses to antitranspirants vary depending on the developmental stage, the species, and the concentration of the antitranspirant applied. Some sugar alcohol-based compounds (SACs) and biologically active ABA (*S*-ABA) have recently been used to enhance the shelf life of begonia (*Begonia semperflorens-cultorum*), petunia (*Petunia x hybrida*), marigold (*Tagetes erecta*), and impatiens (*Impatiens hawkeri*). *S*-ABA has been found to delay wilting symptoms in these plants as is also evident by the use

of β -pinene polymer (β P) – a physical antitranspirant. To sum up, use of antitranspirants offers great potential in their exploitation by floriculturists to enhance the longevity of ornamental plants and maximize their aesthetic quality.

34.2 Eradicating Weeds

34.2.1 Parasitic Weeds in Crop Fields

Parasitic plants cause serious damage to the host plants resulting in substantial loss of yield. It is difficult to eradicate parasitic weeds because of enormous number of seeds produced by them, and these seeds generally have long life. *Orobanche* (broomrape), a genus from Orobanchaceae, consists of 10–60 cm tall, herbaceous parasitic plants with over 200 species which are known to parasitize tomato, eggplant, potato, bell pepper, cabbage, and beans by attaching haustoria to the host plants to draw nutrients. Another genus of Orobanchaceae, *Striga* (witchweed), is known to parasitize cereal crops. They are obligate hemiparasites of roots of the host plants. One of the crop practices employed is to stimulate germination of the parasitic seeds in the absence of the host, resulting in loss of seed bank of parasitic plants. If germinated in the absence of host, these seedlings will die because of lack of nutrients, thereby reducing population of parasitic plants. Germination in the absence of host is known as *suicide germination*. Both natural and artificial (man-made) compounds have been investigated as stimulants of suicide germination of seeds of parasitic plants. Such compounds should remain stable in soil for a long period of time. Strigol is the natural stimulant for germination of seeds of *Striga* sp. Low concentrations of synthetic analogs of strigol, such as GR24 and Nijmegen 1, stimulate germination of seeds of parasitic plants. However, high cost of production of these compounds at times limits their commercial use. Ethylene released into the soil has also been used as a measure to promote germination of weeds, triggering their germination in the absence of host, leading to their death. Inoculation of legumes with nitrogen-fixing bacteria coupled with ethylene-producing bacteria also has a great potential for stimulating “suicide germination” of weed seeds. Methyl jasmonate and some fungal toxins have also been found to stimulate germination of these seeds. One of the effective strategies seems to be planting nonhost crops to induce suicide germination.

34.2.2 Weed Control by Introducing Glyphosate-Resistant Crops

The enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) catalyzes the conversion of shikimate to chorismate in plants. Broad-spectrum systemic herbicide glyphosate (N-phosphonomethyl glycine) inhibits EPSPS activity, thereby blocking the conversion of shikimate-3-phosphate to 5-enolpyruvylshikimate-3-phosphate. This leads to accumulation of shikimate in plant tissues. The synthesis of aromatic amino acids, such as phenylalanine and tyrosine, is blocked in plants treated with

glyphosate. Growth stops within hours and after few days leaves starts turning yellow. **Glyphosate** was discovered as an herbicide by Monsanto chemist JE Franz in 1970 and marketed by the name “Roundup” in 1974. Monsanto introduced glyphosate-resistant crops which enabled farmers to kill weeds selectively without killing the main crop. Weeds die in response to glyphosate spray as blocking of shikimic acid pathway leads to inhibition of biosynthesis of aromatic amino acids and their protein derivatives.

34.2.3 Blockers of Photosynthetic Electron Transport as Potential Herbicides

Herbicides have been used in agriculture since long to kill unwanted plants. Different herbicides act by disrupting the metabolism of the plants, such as blocking the synthesis of amino acids, carotenoids, or lipids. Photosynthesis inhibitors constitute a significant portion of the commercially important herbicides which are used to control annual and perennial broad-leaved weeds as well as grasses. These act by disrupting the photosynthetic ability of the susceptible plants via binding to specific sites within the chloroplast and interfering with or blocking electron transport. On the basis of site of their actions, herbicides can be classified into three categories. First category includes atrazine (2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine) and DCMU (3-(3,4-dichlorophenyl)-1,1-dimethylurea) which are inhibitors of PSII. Second category includes the inhibitors which bind with the reducing site of PSI. As a result, they inhibit the reduction of ferredoxin, e.g., paraquat. Paraquat acts as an electron acceptor and intercepts electrons between ferredoxin and NADP. The third category of potent inhibitors of photosynthetic electron transport includes DBMIB (dibromothymoquinone) which blocks electron flow to cytochrome b_6/f at the Q_P site of the complex. The photosynthetic blockers are used mainly for pre- and/or postemergence control of broad-leaved weeds. Grass crops, such as wheat and corn, benefit the most from photosynthetic inhibitors since these inhibitors primarily act on dicot weeds. DCMU is used as inhibitor of photosynthesis generally in laboratory and not commercially, since dosage required is high, and its degradation is slow. Atrazine works slowly and is a selective herbicide. Paraquat is a nonselective and broad-range herbicide and causes injury to the plants on contact. The visual injury symptoms to herbicides in weeds include chlorosis, desiccation, or browning of plant tissue. Susceptible plants exposed to photosynthesis-inhibiting herbicides show interveinal and veinal chlorosis. Necrosis of leaves begins around the edges of the oldest leaves, followed by similar damage to younger leaves. Sometimes, yellow spots may also appear on affected leaves. Chlorosis of leaf tissue results from photo-destruction of chlorophyll and other pigments. Excessive use of these herbicides has also been reported to induce oxidative damage in crop plants as well. Treatment of herbicides has been shown to result in accumulation of O_2^{2-} and H_2O_2 in leaves, significant decrease in chlorophyll content, and inhibition of shoot

and root growth and reduce the fresh weight. Apart from these damages to crop plants, incessant use of these herbicides has also been reported to cause low to high toxicity in humans.

34.3 Making Plants More Energy Efficient

Some microbial products help in protection of their host plants against a variety of stresses, such as drought, flooding, high salinity, heavy metal accumulation, and also against pathogens. One of the mechanisms to evade drought stress in plants is to produce more **trehalose** which helps in stabilizing the membranes and enzymes. Trehalose, a disaccharide formed by 1,1-glucoside bond between two α -glucose units, is synthesized and utilized by some bacteria, fungi, insects, and plants, as a source of energy. Its cleavage by the enzyme trehalase releases two molecules of glucose. This is double the efficiency of glucose released from starch. Instead of using biotechnological techniques for plants to produce more trehalose, it would be more effective to use bacteria which will provide surplus trehalose in association with plants.

34.4 Plant Growth Regulators (PGRs) in Agriculture and Horticulture

A wide variety of PGRs are currently in use in horticulture, viticulture, and agriculture in order to obtain varied advantages such as changes in plant constituents, ease of harvesting, enhancement of yield, and greater tolerance toward abiotic and biotic stress conditions (Table 34.1). Generally, PGRs are applied to crop plants using foliar sprays with water as a carrier. While doing so, due care has to be taken to ensure penetration of the active ingredient through epidermis and membranes by making an appropriate choice of the solvents and surfactants. Furthermore, application of the PGR treatment has to be given at the right stage of plant development and in “ideal” weather conditions.

Auxins are extensively used to stimulate root proliferation in the cuttings of a wide range of ornamental plants, vines, shrubs, and trees. 2,4-D is used to improve preharvest fruit retention in apples and pears. Auxins are also used to improved fruit set in tomatoes. 2,4-D and some other synthetic auxins also serve as herbicides. Auxin-type herbicides earned a bad name during the Vietnam War when they were used by the enemy to destroy crops. This included 2,4,5-trichlorophenoxy acetic acid (2,4,5-T) mixed with an extremely toxic 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDF). A combination of cyclanilide (an inhibitor of auxin transport) with ethephon is used to facilitate harvest of cotton bolls. Cyclanilide treatment promotes lateral branching in nursery trees.

Almost 140 gibberellins (*GA*) are known to occur in *GA*-producing fungi and in higher plants. Most of them are precursors and catabolites of active *GAs*, and very few of them possess biological activity. Commercial production of GA_3 and a

Table 34.1 Active ingredients of some PGRs and their major applications

Plant growth regulators	Commercial products in use	Major applications
Auxins and related compounds	2, 4-D (synthetic auxin)	Fruit setting and preharvest fruit retention
	Cyclanilide (transport inhibitor)	Promotes lateral branching
Cytokinins and related compounds	Thidiazuron (Diphenylurea type of cytokinin)	Defoliation in cotton
	Forchlorfenuron (synthetic cytokinin)	Increased size of fruits like kiwi and table grapes
	6-Benzyladenine	Regulation of flowering and fruit set in grapevines
Ethylene and related compounds	Ethephon (commercial source of ethylene)	Fruit ripening (promoter), floral induction in pineapple
	Aviglycine (inhibitor of ethylene biosynthesis)	Delays harvest in pome fruits
	Silver nitrate (antagonist of ethylene action)	Prevention of abscission of flowers, leaves, and fruits
	Silver thiosulfate (ethylene receptor blocker)	Improved vase life of carnations
	1-Methylcyclopropene (ethylene receptor blocker)	Delays preharvest ripening of pear and kiwi fruits and enhances fruit set in tomato and pepper
Gibberellic acid and related compounds	GA ₃	Seedless grapes
	Tebuconazole (inhibitor of GA biosynthesis)	Improves winter hardiness
	Metconazole (inhibitor of GA biosynthesis)	Anti-lodging agent
	Chlormequat chloride (inhibitor of GA biosynthesis)	Anti-lodging in cereals
	Mepiquat chloride (inhibitor of cyclases involved in GA biosynthesis)	Anti-lodging in barley and other cereals
	Paclobutrazol (inhibitor of GA synthesis)	Growth control in fruit trees and ornamentals, anti-lodging in rice
	Cycocel (inhibitor of GA biosynthesis)	Growth retardant in wheat, rye, and oats
Abscisic acid	S- ABA	Pigment (anthocyanin) enhancement in red grapes
Jasmonic acid	Prohydrojasmon	Anthocyanin production in apple and degreening of mango fruits
Others (“atypical” PGRs)	Maleic hydrazide, chlorpropham	Regulation of flowering and fruit set in grapevines
	Hydrogen cyanamide	Dormancy breaker in apples

mixture of GA₄ and GA₇ (active GAs) is mostly undertaken by fermentation of the fungus *Gibberella fujikurii*. Commercially, GA₃ is most widely used followed by a mixture of GA₄ and GA₇. It is generally difficult to separate GA₄ and GA₇ during extraction by fermentation because of the structural similarity. Chemical synthesis of GAs is, however, a complex and expensive process for commercial use. Most of the GAs production worldwide originates from China. Applications of GA in agriculture and horticulture are mainly based on its unique ability to promote longitudinal growth in long-day plants, induce the activity of hydrolytic enzymes in germinating seeds, and promote the setting and development of fruits. Long-lasting effects of GAs are observed with the application of GA₃ or GA₇-GA₄ mix, the latter being less persistent. More than 40 plant species have been reported to be exploited commercially through GA application. GA₃ is useful in the production of seedless grapes for increasing the fruit size in pears, for accelerating seed germination, and for improving the quality of citrus fruit. A mixture of GA₄ and GA₇ is, on the other hand, useful for reducing fruit **russetting** in apples (*russetting among apples is a disorder of the fruit skin due to microscopic cracks in the cuticle, leading to periderm formation. This phenomenon is also observed in pears*). GA inhibitors reduce longitudinal shoot growth and are commercially very useful in reducing the risk of lodging among cereals and oil seed rape and in rice cultivation. They are also used to control excessive vegetative growth in cotton plants, hedges, and ornamental trees. Some of the commercially useful GAs biosynthesis inhibitors are (1) chlormequat chloride and (2) mepiquat chloride (inhibit cyclases involved in early stages of GA metabolism). In Germany-based company, BASF introduced Cycocel (2-Chloroethyltrimethylammonium chloride) in 1965 as a growth retardant, and it is still the most widely used PGR in cereal production, particularly in oats, rye, triticale, and wheat. In view of its extensive use among various cultivated plants, Cycocel remains one of the most extensively used PGR for commercial use on global scale. Mepiquat chloride (a quaternary ammonium compound) has also found extensive applications as a growth retardant particularly in cotton. Mepiquat has also been detected in processed roasted coffee beans, barley seeds, and crust of bread. Paclobutrazol, another established PGR, is used to control vegetative growth of fruit trees, such as mango, litchi, avocado, and also for controlling lodging in rice.

Cytokinins have been exploited commercially in agriculture and horticulture because of their unique ability to induce meristematic activity in plant cells, delay leaf senescence, promote photoassimilate transport, and antagonize auxin-induced apical dominance. Thidiazuron, a diphenylurea type of cytokinin, is commercially used for defoliation in cotton plants as a consequence of cytokinin-induced ethylene formation, leading to leaf abscission. 6-Benzyladenine is commercially used in grapevines for the regulation of flowering and subsequent fruit set. A synthetic cytokinin commercially available as for chlorofenuron [N1-(2-chloro-4-pyridyl)-N₃-phenylurea, CPPU] is known to influence fruit set among several fruit crop species such as water melon, kiwi, grapes, and apples. CPPU application has been observed to increase fresh weight of kiwi fruit through cell expansion and modulation of carbohydrate metabolism and water accumulation. In other words, CPPU application increases fruit sink strength (i.e., the capacity to attract carbohydrate).

Abscisic acid (ABA) plays significant role in inhibiting precocious seed germination and in protecting plants against abiotic stress. It is involved in stomatal closure both in normal growth conditions and under stress. Naturally occurring ABA is a (+)-*cis,trans*-isomer (=S-ABA). S-ABA is nowadays commercially produced from a phytopathogenic fungus *Botrytis cinerea*.

Ethylene is known to accelerate ripening of climacteric fruits. Gaseous application of ethylene is a difficult and an inefficient process. It is ideally applied as aqueous solution of acetylene or ethephon which decompose into ethylene upon getting absorbed by the plant. Ethephon is commercially used in agriculture for reducing stem elongation in cereal crops, particularly in barley, so as to reduce the risk of lodging. It is also useful as a defoliant and boll opener in cotton and to intensify the flow of latex from rubber trees. Ethephon is also commercially available as ethrel and florel. Aviglycine is a well-known inhibitor of ethylene biosynthesis which is produced on commercial scale from the fermentation of soil microorganism—*Streptomyces* sp. It is mainly used in horticulture for delaying the harvesting of pome fruits. Silver nitrate is an antagonist of ethylene action and is used to prevent abscission of flowers, leaves, and fruits although, in commercial applications, it has been found to exhibit relatively low mobility in plant tissues and is also phytotoxic. Silver thiosulfate does not show these limitations and is, therefore, used to enhance the shelf life of cut flowers. 1-methylcyclopropene (1-MCP) is a gaseous antagonist of ethylene with high affinity for ethylene receptors in plant tissues. 1-MCP complexed with α -cyclodextrin dissolved in water is commercially used for delaying preharvest ripening in pear and kiwi fruits, to improve fruit set in tomato and pepper and to enhance heat and drought resistance in maize, soybean, cotton, sunflower, rice, and wheat. A synthetic derivative of jasmonic acid called prohydrojasmon is relatively more stable than jasmonic acid in solution and is used to promote anthocyanin production in apple. Degreening of mango fruits is also enhanced by methyl jasmonates treatment. Jasmonate treatment can be used to enhance plant resistance to pests. This has been particularly observed in tobacco plants. JA can also be used to repel herbivores through volatile emissions in tomato. *Brassica rapa* treated with JA is less prone to attack by some insects.

Several compounds which do not directly interfere with plant hormone system are referred to as “atypical” PGRs because of their commercial applications. More than 40 “atypical” PGRs are currently in use either as a single component or in various combinations. Thus, maleic hydrazide (1,2-dihydro-3,6-pyridazinedione) and mefluidide [*N*-(2,4-dimethyl-5-[[trifluoromethyl]sulfonyl]amino)phenyl]acetamide] are known to act by inhibiting cell division in the meristematic tissues. Chlorpropham [isopropyl (3-chlorophenyl)carbamate] and maleic hydrazide are commonly used to suppress shoot formation from the resting buds following the removal of flowers. These two compounds are also used to suppress sprouting of onions and tomatoes in storage. Among apples and grapevines, hydrogen cyanamide is commonly used as a dormancy breaker because of its ability to transiently inhibit respiration which leads to induction of α -amylase activity causing dormancy release.

34.4.1 Some Specific Applications of PGRs in Agriculture and Horticulture

Lodging Several crop plants with tall shoots, panicles, or other fruiting structures exhibit a tendency to fall over in response to wind and rain. This is commonly observed in rice, oilseed rape, linseed, and small grain cereals such as rye, oats, barley, and wheat. Use of stem-shortening PGRs on these crops reduces the risk of this kind of lodging. Stem lodging occurs due to break at the stem base in response to strong winds, intense rainfall, and thunder storms. Root lodging is generally caused after prolonged rainfall as the plant roots are unable to hold the weight of heavy aerial parts in water-soaked soils. Lodging can lead to loss of grain yield up to as high as 40%. Chlormequat chloride was the first PGR to be used as an anti-lodging agent. This compound increases the number of fertile tillers and also reduces stem length when applied to winter wheat crop at early stage of tillering. Barley crop is less responsive to chlormequat chloride than wheat, oats, and rye. Earlier varieties of rice were also prone to lodging although modern semidwarf cultivars are lodging-resistant. Loss of crop yield due to lodging can also be reduced by applying stem-shortening agents (triazole tebuconazole and metconazole) to oilseed rape (*Brassica napas*).

Cotton Cultivation Cotton is a perennial plant with indeterminate fruiting habit. It simultaneously produces vegetative and fruiting structures. The developing seeds inside the capsule (boll) develop cotton fibers on their surface. A mature boll ruptures to expose seeds with fibers for harvesting. Mepiquat chloride and chlormequat chloride are commonly used to control vegetative growth of cotton plants. Mature cotton bolls can be prompted to open by ethephon treatment, thereby increasing the harvest of cotton fibers. Prior to harvesting, cotton plants are generally subjected to defoliation by the application of some herbicides such as carfentrazone-ethyl and fluthiacet-methyl or PGR-type products containing ethephon or thidiazuron. None of these compounds kills cotton plants.

Grapevine Production Shoot growth in grapevines has to be controlled in order to have optimal production of berries. Hydrogen cyanamide, chlormequat chloride, and mepiquat chloride are commonly used to control vegetative growth in grapevine. GA₃ is used globally in the production of seedless grapes. Its application at the right time of plant growth is used to create space (by the extension growth of rachis), thereby allowing larger berries formation. In the case of red grapes, ethephon, or S-ABA, sprays are commonly used to intensify pigmentation.

Pineapple Production The production of pineapple fruits requires an average of 18–22 months from planting to harvesting. Pineapple plants are induced to flower with ethephon treatment. Aqueous solution of ethylene gas containing activated charcoal for delayed release of gas is also applied over the whole plant for floral induction in a gradual manner.

Vegetable Production GA₃ plays a major role in vegetable development. It effectively enhances seed germination, combats the problem of seed dormancy, induces flower formation, and elevates total fruit yield. Mepiquat chloride (N, N-dimethylpiperidinium chloride, well known as PIX) and chlormequat chloride (2-chloroethyltrimethylammonium chloride) are commonly used to enhance productivity and quality of bulbs in onion and garlic. While mepiquat chloride is an inhibitor of GA biosynthesis and regulates plant height and initiated defoliation, chlormequat enhances GA activity and is involved in enhancing the property of cell elongation. Use of synthetic gibberellin, auxins, and ethephon is known to enhance the yield of tomatoes. Pretreatment with GA₃, 2, 4-D, and ethephon enhances seed germination in tomato. Fruit ripening is enhanced by the use of ethephon-releasing compounds. Poor fruit set and yield is countered by soaking in a solution of GA₃, 2, 4-D, or thiourea or by foliar application of GA₃ or planofix (α -naphthylacetic acid). This plant growth regulator is used for inducing flowering and preventing premature shedding of flower buds and unripe fruits. It helps in enlarging fruit size and increasing and improving the quality and yield of fruits.

Parthenocarpy Absence of need for pollination and fertilization for fruit development provides a great advantage in horticulture when the fruit set rate is slow because of unfavorable environmental conditions since pollen maturation and fertilization are affected by factors like light, humidity, temperature, etc. Use of parthenocarpy to promote fruit set under unfavorable environmental conditions could also improve the quality and quantity of pollinator-dependent fruit production by reducing the number of poorly formed fruits caused by insufficient pollination. The method of production of fruit bypassing pollination and fertilization is referred as “**parthenocarpy**” (such fruits are called virgin fruits). Parthenocarpy occasionally occurs as a mutation in nature (usually considered as a defect), as the plant can no longer sexually reproduce but may propagate by asexual means. It is different from “**stenospermocarpy**” in which seedless fruits are formed because of early abortion of seeds after fertilization. Parthenocarpy is often confused with **parthenogenesis** in animals. Parthenogenesis is a method of asexual reproduction, wherein embryo is formed without fertilization. However, parthenocarpy involves fruit formation without seed (embryo). In plants, the term equivalent to parthenogenesis is “**apomixis**.” “Seedlessness” is a desirable condition for the production of some fruit plants, such as fruits with hard seeds, for example, pineapple, banana, oranges, and grapes. Furthermore, some seeds produce chemical substances that speed up the deterioration of fruits. For example, in eggplant fruit, the presence of seeds results in browning and texture reduction of the pulp. In dioecious plants, parthenocarpy is of great help as it increases fruit production at lesser cost because it eliminates the need for the plantation of staminate trees. Some plants also use parthenocarpy as a method of defense. Wild parsnip plants (*Pastinaca sativa*) produce both seeded and parthenocarpic fruits during their reproductive phase. Parthenocarpic fruits produced by parsnip plants are preferred by herbivores over their seeded fruits and thus act as a decoy (as in “decoy defense mechanism”) in the scheme to protect the desired product (seeded fruits). Many agricultural practices employ phytohormones for the

production of parthenocarpic fruit. Auxins, gibberellins, and cytokinins or mixtures of these phytohormones are effective in inducing fruit development in the absence of fertilization and increase productivity in various horticultural crops. Scientists are also increasingly finding ways to exploit genetic parthenocarpy. Approaches to genetic parthenocarpy have largely focused on selective breeding programs for seedlessness. For example, selective breeding of parthenocarpic sweet pepper, papaya, and summer squash varieties has all been shown to increase productivity. More recently, scientists have focused on genetic engineering approaches for parthenocarpic fruit set through modification of auxin synthesis, auxin sensitivity, auxin content, and auxin and gibberellin signal transduction.

34.5 Biotechnological Approaches

34.5.1 Transgenic Fruits

Vegetable and fruit production suffers from many biotic stresses caused by pathogens, weeds, and insects. Commercial sale of genetically modified (GM) food began in 1994 when scientists from Calgene Inc. (USA) developed Flavr Savr which exhibited delayed ripening in tomato. It was engineered to have a longer shelf life by inserting an antisense gene that delayed ripening. To withstand the rigors of shipping, tomatoes must be picked up at “mature green stage” which have already absorbed all the vitamins and nutrients from the plants but have not started producing ethylene that triggers ripening. Calgene, Inc. developed a tomato with a gene that slows down the natural softening process accompanying ripening. Pectin in fruits, which is responsible for their firmness, is degraded by an enzyme called polygalacturonase (PG). As pectin is destroyed, the cell walls of tomatoes break down, leading to softening of fruits, making them difficult to ship. Reducing the amount of PG in tomatoes slows cell wall breakdown and produces a firmer fruit for a longer time. Calgene scientists isolated PG gene in tomato plants and converted it into a reverse image of itself, called antisense orientation. The “reversed” tomato gene (the Flavr Savr gene) was reintroduced into the plants. In order to tell if Flavr Savr gene was successfully reintroduced into the plants, Calgene scientists attached a gene that makes a naturally occurring protein that renders plants resistant to the antibiotic kanamycin. By exposing the plants to the antibiotic, Calgene scientists could tell which plant had accepted that Flavr Savr gene. The ones unaffected by kanamycin grow to have designed traits of Flavr Savr. Once in a tomato plant, the Flavr Savr gene attaches itself to the PG gene. With the Flavr Savr gene adhering to it, the PG gene cannot give necessary signals to produce PG enzyme that destroys pectin. Thus, these tomatoes retain their peak flavor. In 1994, US Food and Drug Administration (FDA) announced that Flavr Savr tomatoes are as safe as conventional tomatoes.

A number of other transgenic fruit crops are being developed to enhance their host plant resistance to insects and plant pathogens for herbicide tolerance and to improve features such as slow ripening to enhance their shelf life. Transgenic papaya

carrying coat-protein gene provides effective protection against papaya ringspot virus. The transgenic plum cultivar (honey sweet) provides germplasm for plum pox virus control. Transgenic bananas with enhanced resistance to *Xanthomonas campestris* have also been developed. In 2013, the USDA approved import of a GM pineapple that is pink in color and “overexpresses” gene derived from tangerine, increasing the production of lycopene. Subsequently, Arctic apples were approved in which gene silencing was used to reduce polyphenol oxidase activity, thus preventing the fruit from browning when cut. The European Union also undertook field tests for transgenic lemon, which exhibited fungal and kanamycin resistance.

34.5.2 Genetic Engineering and Conventional Breeding Approaches to Reduce Caffeine Content in Coffee and Tea

Flavor of coffee is due to caffeine, an essential oil. Likewise, tea is also an important beverage having distinctive character due to three components, i.e., essential oils, alkaloids, and polyphenols (tannins). The ethereal oil, theol is responsible for the aroma and flavor of tea, alkaloid theine gives refreshing and stimulating property, and tannins give the bitterness and astringency to tea. Worldwide the demand for decaffeinated coffee is increasing, and currently it accounts for about 10% of the sale. A similar market for tea is also emerging. Generally, to obtain decaffeinated coffee chemical methods using organic solvents (such as benzene) are employed. However, chemical methods lead to loss of flavor and antioxidants. So researchers have searched for plants which produce caffeine-free berries, so that the flavor is retained. For the plants to be economically viable, the berries must ripen synchronously and have a shape and size that can be harvested easily. In 2000, researcher Paulo Mazzafera and coffee breeder Silvarolla, in search of naturally low caffeine varieties of coffee, started working with plants collected from Ethiopia, and promising strains were discovered in 2003. These naturally decaffeinated plants contain only 0.08% caffeine in contrast with routinely used coffee which contain 1.2% caffeine in *Coffea arabica* beans and 2–3% in *C. canephora* beans. These plants have caffeine-free leaves as well as berries and are defective in final step of metabolic pathway which converts theobromine to caffeine. Subsequently, Japanese scientists were also able to produce coffee having 70% less caffeine than traditional varieties. Breeding experiments with these plants have been conducted to produce high-quality coffee beans which are decaffeinated naturally. These mutant varieties have mutation in the gene coding for caffeine synthase. Similar research is ongoing for tea as well. Another approach adopted recently is to produce genetically modified plants. Cloning of genes encoding enzymes for the biosynthesis of caffeine allowed generation of *C. canephora* seedlings having 70% less caffeine content. The pathway involves conversion of xanthosine to caffeine. Genes responsible for these steps have been isolated, and transgenic plants with reduced expression of theobromine synthase have been produced. The results were achieved using RNA interference technique. Both the coffee species have been successfully transformed. However, since theobromine and caffeine are involved in defense against herbivores, the

ultimate aim is to generate plants having these metabolites in all tissues except beans. Otherwise such plants will be more susceptible to attacks from insects and herbivores, leading to loss in final production.

34.5.3 Bulk Production of Secondary Metabolites

In the quest for alternatives for higher production of medicinal compounds from plants, various biotechnological approaches have proved beneficial. One of the avenues explored is plant tissue culture, which holds immense potential for controlled and selective production of many useful secondary metabolites. Investigations on the production of secondary metabolites by callus and cell suspension cultures started as early as in 1956. Plant tissue culture offers an opportunity to exploit cells, tissues, organs, or the entire organisms by growing them *in vitro* and to genetically manipulate them to get desired compounds. These methods offer alternative to traditional ways for industrial production of plant secondary metabolites. Secondary metabolites can be produced by using different tissue culture approaches, such as callus, cell suspension, and organ cultures. These approaches have made the production of a variety of pharmaceuticals like alkaloids, terpenoids, steroids, saponins, phenolics, flavonoids, and amino acids possible in laboratories. Cell suspension culture systems are used for large-scale culture of plant cells from which secondary metabolites could be extracted. Cell cultures not only yield defined standard phytochemicals in large volumes but also eliminate the presence of interfering compounds that occur in the field-grown plants. This method can provide a continuous, reliable source of natural products. The major advantages of the cell cultures include synthesis of bioactive secondary metabolites, in controlled environment, independent of climate and soil conditions. A number of different types of **bioreactors** have been used for mass cultivation of plant cells. The first commercial application of large-scale cultivation of plant cells was carried out in stirred-tank reactors to produce shikonin by cell culture of *Lithospermum erythrorhizon*. Cells of *Catharanthus roseus*, *Dioscorea deltoidea*, *Digitalis lanata*, *Hypericum perforatum*, *Maackia amurensis*, *Panax ginseng*, *Taxus wallichiana*, and *Sophora flavescens* have been cultured in various bioreactors for the production of secondary plant products. Production of secondary metabolites in cell suspension cultures overcomes the problem of variable product quantity and quality from whole plants by avoiding the effects of different environmental factors, such as climate, diseases, and pests. *Maclura pomifera* cell suspension culture showed a greater level of metabolite accumulation (0.91%) than stems (0.26%), leaves (0.32%), and fruits (0.08%) of the parent plant. Non-embryogenic callus cultures, containing more or less homogeneous clumps of dedifferentiated cells, are also used for production of flavonoids. The isoflavones and pterocarpanes are produced by *Maackia amurensis* cultures. Elicitors markedly increase the production of flavonoids in comparison to the control cultures. The production of flavanones is stimulated up to five times by the addition of 2 mg/mL yeast extract. Moreover, the production of prenylated flavanones also can be

increased, two to five times by addition of cork pieces. Organ cultures are relatively more stable for the production of secondary metabolites than cultures of undifferentiated cells, such as callus or suspension culture. Generally, two types of organ cultures are considered, i.e., root cultures and shoot cultures. Many of the secondary compounds, for example, the tropane alkaloids, hyoscyamine, and scopolamine, are produced quite well in root cultures. Root systems of higher plants, however, generally exhibit slower growth than the cultures of undifferentiated plant cells, and they are difficult to harvest. Therefore, alternative methods for the production of compounds synthesized in plant roots are being investigated. The most promising one of them is the use of plant hairy root cultures. Different types of bioreactors have been used for culture of plants roots and shoots. Till date, the only example of the commercial use of plant organ cultures for secondary metabolite production is the cultivation of ginseng (*Panax ginseng*, a medicinal herb) roots to obtain ginsenosides (a class of steroid glycosides).

Transformed roots have been widely used for in vitro production of secondary metabolites in many plant species. Hairy root cultures produce secondary metabolites over successive generations without losing genetic or biosynthetic stability. Also, production of two different secondary metabolites is possible simultaneously from adventitious root co-cultures. This vast potential of hairy root cultures as a stable source of biologically active chemicals has provided the exploitation of in vitro system through scaling up in bioreactors. Hairy root cultures of *Lithospermum erythrorhizon*, *Harpagophytum procumbens*, and adventitious roots of *Panax ginseng* and *Scopolia parviflora* have been analyzed in bioreactors to obtain shikonin, harpagide, ginsenosides, and alkaloids, respectively. Ginsenoside has also been produced in 5 L stirred-tank bioreactor using adventitious root culture. Hairy root culture of *Stizolobium hassjo* to yield 3,4-dihydroxyphenylalanine has been reported using 9 L mist bioreactor. Present scale-up technology dictates the use of stainless steel tanks for growth of plant cells on an industrial scale. Hairy root cultures continue to attract interest as a potential resource for large-scale production of commercially valuable compounds. *Catharanthus roseus* hairy root cultures are induced by pectinase and jasmonic acid and lead to enhanced accumulation of ajmalicine, serpentinine, tabersonine, and other secondary metabolites. Agrobacterium-transformed root cultures produce a wide variety of secondary metabolites and other bioactive compounds. Co-culture of hairy roots and microorganisms has been tested to produce novel secondary metabolites. For example, co-culture of *Hordeum vulgare* roots with *Glomus intraradices* (VAM fungi) induces synthesis and accumulation of terpenoid glycoside. The most famous plant-derived pharmaceuticals include digitalin from *Digitalis purpurea* which is prescribed for heart disorders, codeine obtained from *Papaver somniferum* (sedative), vinblastine and vincristine from *Catharanthus roseus* (for leukemia cancer treatment), artemisinin from *Artemisia annua* (for malaria treatment), quinine from *Cinchona officinalis* (for malaria), and paclitaxel (taxol from *Taxus brevifolia* and other species). Plant tissue culture methods have been developed for profitable production of these biochemicals. Such useful compounds have been reported to

be successfully produced in callus as well as in suspension culture. Callus culture of *Catharanthus roseus* produced ajmaline (antihypertensive), and *Stizolobium hassjo* produced 1,2-dihydroxybenzene (also known as L-dopa, an antiparkinsonian drug). Suspension cultures of *Hyoscyamus niger* produced hyoscyamine derivative (anticholinergic). As sought, some of the secondary metabolites produced are in much higher concentrations in cultures as compared to intact plants from the same species. Such examples include *Panax ginseng* (ginsenoside) which has been reported to produce 27% of cell dry weight in culture, whereas only 4.5% is produced in whole plants, anthraquinones from *Morinda citrifolia* (18% in culture, 2.5% in plant) and shikonin from *Lithospermum erythrorhizon* (12% in culture, 1.5% in plants).

Promising results have been observed not only in research laboratory but large-scale suspension cultures have also been successfully executed. Mitsui Petrochemical Industries of Japan has developed plant cell cultures producing large quantities of berberine, ginseng, and shikonin. Reactors having a capacity of 75,000 liters are used in Germany for production of paclitaxel (produced by *Taxus* sp. in nature). Some of these compounds are now commercially available, such as shikonin and paclitaxel (Taxol). Developments in scale-up approaches and immobilization methods have enhanced the production of such compounds, and plant tissue culture represents the most promising area for further progress in pharmaceutical industry.

Perspective

Some of the aims of plant physiologists in human welfare are to produce varieties of crop plants with modified shoot architecture leading to ideal leaf shape, number and position for enhanced light interception, and varieties with improved panicle/ear. The “green revolution” of the last century leads to production of high-yielding crops such as dwarf and semidwarf varieties of cereals through crop genetic approaches. These cereals pool up most of their photoassimilates into grains and less in vegetative growth. They also provide plants which can resist damage due to wind. The dwarfing genes responsible for these traits include semidwarf genes (*sd*) in rice and reduced height (*Rht*) in wheat. Gibberellic acid (GA) is often referred as “green revolution hormone” since the *sd-1* gene in rice encodes for GA 20-oxidase which is responsible for oxidative elimination of carbon at position 20, leading to biosynthesis of 19 carbon bioactive gibberellins- GA₁ and GA₄. Future improvements in crop production will also include emphasis on better water use efficiency and tolerance to abiotic stress conditions through coordinated activities of various plant hormonal and nonhormonal molecules. Advances in our understanding of rhizobial and mycorrhizal symbiotic associations and ways to modify root architecture shall facilitate better nutrient use efficiency. Understanding defense hormonal signaling mechanisms will help in controlling tolerance to pests and pathogens. Keeping in view the ever-diminishing availability of agriculture land, future methods of enhancing crop productivity will benefit tremendously from our deeper understanding of all facets of plant development at physiological and molecular level.

Summary

- Essential elements show two critical levels—“lower critical level,” which is indicative of element deficiency, and “upper critical level,” indicative of toxicity due to an element. The **critical toxicity level** of an element is the concentration of the element in tissue which results in 10% reduction in dry matter. Mobility of nutrients within the soil is related to chemical properties of the soil, such as CEC (cation exchange capacity) and AEC (anion exchange capacity), as well as the soil conditions, such as moisture, pH, etc. Under acidic conditions, phosphate is precipitated as AlPO_4 that increases Al^{3+} . Minerals containing aluminum and hydrogen ions dissolve and release these cations as they are removed from the exchangeable pool. Finely-textured clay soil tends to offer greater buffering capacity than coarse-textured soil.
- *Liming materials* are bases that react with hydrogen ions in the soil solution to form water. Calcium and magnesium silicates are also used as liming agents. To avoid aluminum and manganese toxicity, a soil should be limed if the pH is less than 5.4. Since finer-textured soils have greater buffering capacity than coarse-textured soils, more lime must be added to the finer-textured soil to achieve the same effect and attain the target pH. Addition of organic matter is another viable option to manage problems associated with the soil acidity. Organic matter forms strong bonds, known as “chelates,” with aluminum.
- Green manure refers to the manure generated from crop plants by leaving them to wither and get incorporated into the soil, either uprooted or still rooted in the soil. Green manure, when turned into the soil, is broken down by soil-dwelling microorganisms to release nutrients and form humus. Humus is the dark organic matter which is composed of decaying remains of the plants and animal tissue formed as a result of microbial action in the soil. The characteristics of plants used for green manure include fast growth to provide large yield within a short period, more leafy growth for a rapid decomposition, and deep root system to allow efficient nutrient acquisition from deeper parts of the soil. Green manure plants have been shown to reduce pest and controlling diseases in crops by providing habitats for natural predators of insect pests so as to reduce attack on the whole crop. They can also help to reclaim alkaline soil and to make land usable for farming by improving its physical properties.
- Antitranspirants are a group of compounds which enhance water stress tolerance by preventing/reducing transpiration in plants. Antitranspirants can be either physical or physiological in nature. Physical antitranspirants include polymers, resins, latex, and waxes to coat the leaf surface and minimize water loss by blocking the stomatal aperture. Physical antitranspirants have been successfully used to minimize loss of crop due to water stress in pepper (*Capsicum annuum*), peach (*Prunus persica*), and some herbaceous plants. Physiological antitranspirants reduce transpiration by inducing plants to close stomata. They include ABA or some chemicals which increase ABA concentration in the plants. Physiological antitranspirants have been successfully used in various horticultural

crops, although plant responses to antitranspirants vary depending on the developmental stage, the species, and the concentration of the antitranspirant applied.

- Parasitic plants cause serious damage to the host plants resulting in substantial loss of yield. Both natural and artificial (man-made) compounds have been investigated as stimulants of suicide germination of seeds of parasitic plants. Methyl jasmonate and some fungal toxins have also been found to stimulate germination of these seeds. One of the effective strategies seems to be planting nonhost crops to induce suicide germination. Monsanto introduced glyphosate-resistant crops which enabled farmers to kill weeds selectively without killing the main crop. Weeds die in response to glyphosate spray as blocking of shikimic acid pathway leads to inhibition of biosynthesis of aromatic amino acids and their protein derivatives.
- A wide variety of PGRs are currently in use in horticulture, viticulture, and agriculture in order to obtain varied advantages such as changes in plant constituents, ease of harvesting, enhancement of yield, and greater tolerance toward abiotic and biotic stress conditions. Generally, PGRs are applied to crop plants using foliar sprays with water as a carrier. While doing so, due care has to be taken to ensure penetration of the active ingredient through epidermis and membranes by making an appropriate choice of the solvents and surfactants. Furthermore, application of the PGR treatment has to be given at the right stage of plant development and in “ideal” weather conditions.
- A number of other transgenic fruit crops are being developed to enhance their host plant resistance to insects and plant pathogens for herbicide tolerance and to improve features such as slow ripening to enhance their shelf life. Transgenic papaya carrying coat-protein gene provides effective protection against papaya ringspot virus. The transgenic plum cultivar (honey sweet) provides germplasm for plum pox virus control. Transgenic bananas with enhanced resistance to *Xanthomonas campestris* have also been developed.
- Plant tissue culture offers an opportunity to exploit cells, tissues, organs, or the entire organisms by growing them in vitro and to genetically manipulate them to get desired compounds. A number of different types of **bioreactors** have been used for mass cultivation of plant cells. Transformed roots have been widely used for in vitro production of secondary metabolites in many plant species. Hairy root cultures produce secondary metabolites over successive generations without losing genetic or biosynthetic stability. Also, production of two different secondary metabolites is possible simultaneously from adventitious root co-cultures.

Multiple-Choice Questions

1. Parasitic weeds are difficult to be removed from crop fields because:
 - (a) Enormous numbers of seeds are produced by them.
 - (b) Seeds have long life.
 - (c) Seeds are covered with water impervious material.
 - (d) Both a and b.

2. Trehalose is a disaccharide formed by:
 - (a) Two alpha glucose units
 - (b) Glucose and fructose
 - (c) Two fructose units
 - (d) Glucose and galactose
3. Which of the following is used for reducing fruit russetting in apples?
 - (a) Auxins
 - (b) Mixture of GA4 and GA7
 - (c) GA3
 - (d) Cytokinins
4. Which of the following agents was used to destroy crops during the Vietnam War?
 - (a) GA3
 - (b) Zeatin
 - (c) A mixture of 2,4-D and 2,4,5-T
 - (d) Ethephon
5. Loss of crop yield due to lodging can be reduced by applying:
 - (a) Chlormequat chloride
 - (b) Metconazole
 - (c) Triazole tebuconazole
 - (d) All of the above
6. The production of fruit bypassing the need for pollination and fertilization is called as:
 - (a) Parthenogenesis
 - (b) Stenospermocarpy
 - (c) Parthenocarpy
 - (d) Vegetative propagation
7. The enzyme responsible for degradation of pectin in fruits is:
 - (a) Trehalase
 - (b) Phosphatase
 - (c) Polyphenol oxidase
 - (d) Polygalacturonase
8. The genetically modified Flavr Savr tomato was engineered to:
 - (a) Increase the production of secondary metabolites
 - (b) Prevent lodging
 - (c) Have a longer shelf life
 - (d) Produce pulpier fruits
9. The distinctive character of tea is due to:
 - (a) Theol, theine, tannins
 - (b) Tannins, caffeol, theine
 - (c) Tannins, theobromine, caffeine
 - (d) Theol, theine, caffeine

10. Glyphosate-resistant crops were first introduced by:

- (a) Monsanto
- (b) BASF
- (c) Calgene Inc.
- (d) Mitsui petrochemical industries

Answers

1. d 2. a 3. b 4. c 5. d 6. c
7. d 8. c 9. a 10. a

Suggested Further Readings

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