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Priyam Vandana
[a]Division of Crop Protection, ICAR-Indian Institute of Sugarcane Research, Lucknow, India
[b]Department of Molecular & Cellular Engineering, Sam Higginbottom University of Agriculture Technology & Sciences, Allahabad, India

Dinesh Singh
Division of Crop Protection, ICAR-Indian Institute of Sugarcane Research, Lucknow, India

Guru Dayal Ram Guru
Department of Molecular & Cellular Engineering, Sam Higginbottom University of Agriculture Technology & Sciences, Allahabad, India

Sangeeta Srivastava
Division of Crop Improvement, ICAR-Indian Institute of Sugarcane Research, Lucknow, India

Correspondence
Priyam Vandana
[a]Division of Crop Protection, ICAR-Indian Institute of Sugarcane Research, Lucknow, India
[b]Department of Molecular & Cellular Engineering, Sam Higginbottom University of Agriculture Technology & Sciences, Allahabad, India

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Plant response to the abiotic and biotic stresses: A review

Priyam Vandana, Dinesh Singh, Guru Dayal Ram Guru and Sangeeta Srivastava

Abstract
Biotic and abiotic stresses are the major factors affecting the crop productivity in terms of quality and quantity. Drought, water logging, salinity, air pollution, wind, heavy metal stress and extreme temperatures such as heat and chilling effect are the abiotic stresses responsible for the crop losses. Like abiotic stresses there are several biotic stresses such as insect-pest and disease stress which causes threat to the plants and effecting its growth and development. Most of the plant diseases are caused by biotic agents such as bacteria, fungi, virus and nematodes. Plants are not able to move but they have highly specialized immune system and are constantly being exposed to a number of stresses for which they exhibits intricate mechanisms like numerous physiological, molecular and cellular adaptations to make them survive under abiotic and biotic stresses. Plants also posses multiple morphological characters which are associated with different biochemical and physiological pathway for the responses under several stress conditions.

Keywords: plant response, biochemical activity, abiotic and biotic stresses

Introduction

Climate is the most crucial parameter for harnessing the maximum potential of any crop irrespective of any location. Change in climate causes serious threat to food security affecting crop productivity. Agricultural productivity is very dependent on the weather phenomena, and the use of germplasm that has to be continuously improved and replaced by the scientists as per need of tolerant to various biotic and abiotic stresses. Researchers try to understand the pathway associated with stress responses and provide knowledge for the exploitation in breeding programs.

In terms of Agriculture, stress is defined as a phenomenon that reduces crop productivity (Grime, 1979) [7]. There are several stresses that create an adverse effect in an individual organisms, populations or communities. Stress can also be defined as the conditions in which plants are prevented from fully expressing their genetic potential for growth, development and reproduction (Levitt, 1980) [13]. Plants are constantly being exposed to a number of stresses that seriously reduce their productivity. Due to condition that plants are not able to move makes the able to have highly specialized immune system. They also exhibits intricate mechanisms and involve numerous physiological, molecular, and cellular adaptations to survive under abiotic and biotic stresses.

Abiotic Stresses

Development of stress resistance crops is the need of hour due to climate change and ever increasing human population. Climate change and its effect on agriculture production are of two types direct and indirect. The direct effect are increase in atmospheric temperature causing glacier melting, flood, ozone hole depletion whereas indirectly it encompasses serious issues related to salinity and drought. There is an estimate that about 70% of the crop yield loss can be attributed to abiotic stresses. In the modern era agriculture land is reducing therefore abiotic stress is a problem of great concern for the growth and productivity of crop.

In order to acclimatize to abiotic stresses, plants accumulate certain bio molecules that are harmless and do not interfere in its productivity. Abiotic stresses such as salinity, drought, alkalinity, flood, cold, heat, different type of radiation, heavy metal, air pollution and several others are the major causes restricting agriculture produce and adversely influencing plant growth processes. Among several abiotic stresses drought, salinity and extreme temperature are the major stresses responsible for huge crop losses throughout the world.

Drought stresses

It is a water deficit condition defined as period of dryness or a severe moisture deficit below expected level and the one that causes an extensive damage to crop and restricts the growth and development of the crop. Drought is one of the major environmental factors that badly affects the growth of the crop and reduces the yield. Deficit of soil moisture status results the drought condition in agriculture which leads the adverse impact on productivity of the crop growing in the field. The severity of the drought stress is directly hits on the water requirement of different crops. It also depends on the different stages of their growth and development. Low soil moisture affects the crop in various ways such as reduced seed germination and seedling development, vegetative growth is poor, reproductive growth is also affected, rate of photosynthesis is lowered, normal development and growth rate pattern is disturbed and finally the yield of the crop is reduced. The study conducted by Singh and Singh, (1981) [16] at Pusa, Bihar indicated that the high osmotic pressure and high root pressure are associated with drought tolerance. Drought tolerance of the sugarcane variety Co 997 was related to its capacity of producing fresh functional roots under very low moisture conditions. The varieties with low respiration of roots should be selected for the rain fed conditions (Raheja, 1957) [14]. Plants posses multiple physiological, morphological and biochemical responses such as accumulation of proline, trehalose, polyamine, increase of nitrate reductase activity and storage of carbohydrate at cellular and organism levels are certain defined biochemical responses under drought stress condition. Abscisic acid also plays an important role in response to the tolerance of drought. The production of proline content and its deposition is increased in the leaf tissues under drought condition. Drought tolerant varieties accumulated more proline than the drought susceptible varieties (Rao and Asokan, 1978) [15]. Proline rapidly accumulated and rapidly declined after addition of water in drought tolerant varieties like F 172 when compared to susceptible variety F 146 and moderately tolerant F 160 variety of sugarcane from Taiwan (Anon., 1985) [1]. Ho *et al.* (1987) [12] emphasised that accumulation of proline could be used as an index for drought tolerance. During drought, reduction in nitrate reductase activity was more in a drought tolerant variety My 54129 than in the susceptible variety My 5514 variety of sugarcane from Mexico (Gomez *et al.* 1985) [8]. Accumulation of abscisic acid was also associated with stress resistance (Grantz *et al.* 1988) [10]. In drought tolerant varieties index of unsaturated fatty acids was higher (Tan, 1988) [19].

Water logging stress

Flood is one of the most serious threats to crop and it effects the production of crops which reduces the yield even up to hundred percent as per severity and duration of flood. Damage to crop due to flood also depends on the age and height of the crop. When flood occurs and crop is sufficiently tall the damage to the crop is relatively less as compared to smaller crops. Fast growing variety might be desirable for the selection of water logging tolerant variety. In case of sugarcane crop, bobbin shaped internodes varieties of sugarcane are related to water logging tolerance.

The effect of flooding stress on plants leads to severe physiological disruptions such as wilting, abscission, death and decay of leaves, epinasty and lenticels formation. Nutritional deficiency of metal phytotoxicity for any crop is the after effects of the flood due to loss of nutrients and deposition of metals in agriculture land. In anaerobic condition iron (Fe) toxicity is high which leads to increase the polyphenol oxidase activity, leading to the production of oxidized polyphenols. Water logging also causes leaf bronzing and reduced root oxidation of plants. In flood tolerant varieties of sugarcane, the phosphorus content is increased more in the sugarcane stalk than the flood susceptible varieties. The nitrate reductase activity is delayed and slow in flood tolerant varieties in water logging condition as compared to relatively fast and steep decline in susceptible varieties. Flood tolerant varieties had higher polyphenol oxidase activity in the roots months than the flood susceptible varieties. (Anon., 1987) [2].

Salinity stress

Salinity stress is defined as the presence of excess amounts of soluble salts in the soil which affects or hinders the normal growth and functioning of the plant. It is measured in terms of electrical conductivity (ECe). Salinity is a form of physiologically dry habitat under which plants are unable to uptake substantial amount of water which results in disturbed physiological and metabolic activity of the plant. Salinity is a major problem in arid and semiarid regions of the world where there is an insufficient rain to leach away the soluble salts from the root zone. Salt stress affects the plants by reducing the plants ability to take up water which leads to slower growth and this effect is known as osmotic or water-deficit effect of salinity. The presence of soluble salts in the root zone of plant disturbs water uptake and utilization of essential minerals such as calcium. Sodium chloride, sodium carbonate and calcium chloride are the cause of saline soil. And among these increased accumulation of Na^+ and Cl^- ions leads to stunted plant growth, effects seed germination, ultimately reduces the crop yield and is toxic to plant cell as it affects the enzyme activity. Salinity stress affects the plants in certain ways such as alteration in metabolic pathways, water stress, ion toxicity, nutritional disorders, oxidative stress, reduction in cell division, expansion, genotoxicity and membrane disorganization.

In case of sugarcane crop, the varieties having high fibre are more tolerant to salt stress as compared to varieties having low fibre content irrespective of their sucrose content. Sugarcane varieties such as LG 9107, LG 9202, LG 9203, LG 9208 and CoLk 7810 have the ability to restrain chloride uptake and its accumulation in the leaf lamina (Shrivastava *et al.* 2000) [17]. In sugarcane, pink pigmentation and waxiness can be used as morphological markers for evaluating alkalinity tolerance (Geetha and Balasubramanyam, 2000) [6].

Heat stress

Temperature is considered as one of the major abiotic stresses which restrict the production of plants. The responses of plants to heat stress vary with the extent of temperature increases, its duration and the type of plants. High temperature and low temperature both have negative effect on the plant growth. High temperatures may be experienced by plants on a daily or seasonal basis. Levitt (1980) [13] classified plants into psychrophiles, mesophiles, and thermophiles according to their tolerance to low, medium, or high temperatures. High temperature effects the plant growth through alteration in photosynthesis, reduction in plant growth, affecting pollen development, hampering seedling establishment, spilkelet sterility, affecting grain and fruit development, crop quality and yield. Protein denaturation, inactivation of enzymes, production of reactive oxygen species and disruption of membrane structure are also some of the primary damage caused by high temperature. The metabolism of plants is altered in response to high temperature. Antioxidants, hormones, metabolites, osmoprotectants, signalling molecules, polyamines and other essential bio molecules are modulated in order to defend against the high temperature stress tolerance.

Low temperature stress

Low temperature, damage plants by a chilling effect which also leads to physiological and developmental abnormalities. Low temperature i.e., freezing causes cellular damage to plants directly or indirectly. Physiological processes are sensitive to low temperatures such as flowering in rice. Browning, wilting, injury to leaves, bleaching due to photo oxidation of pigments, water logging of the intercellular spaces, leaf necrosis and plant death are some of the common visible symptoms of low temperature stress. (Levitt, 1980) [13]. Freezing and chilling occurs due to low temperature which causes injury to crops. Low temperature directly affects the crop growth and development and also causes physical damage to crop by interfering with the physiological and biochemical function of the plant and thus reducing the crop yield. Low temperature exposure to the plants can be a daily or seasonal factor.

Air Pollution stress

Plants surface is in a permanent contact with various pollutants of the atmosphere. Under the polluted conditions, plants develop different morphological and physiological changes. Pollutants damage cuticle, trichomes and stomatal guard cells of the plant which affects foliar morphology and further leads to damage to plants. Scanning electron microscopy investigations of the plant leaves growing in polluted sites revealed a remarkable difference in size of the stomatal pores, ruptured of the guard cells, damage of cuticle and epicuticular wax. Photosynthesis is the basic physiological event that is being affected because of direct exposure of plant to air pollutants. High concentrations of sulphur dioxide, ozone and nitrogen oxides present in the atmosphere induce stomatal closure limiting the availability of carbon dioxide for photosynthesis. Changes in stomata due to air pollutants which seem to be small can be of great consequence with respect to survival of the plant during stress. These effects can further lead to disturbing the water balance of leaf or whole plant. Reduction in leaf area, closure of stomata and the damage to the photosynthetic apparatus limit the photosynthetic capacity of plants. Reactive oxygen species (ROS) generated during oxidative stress damage photosynthetic apparatus via alteration in thylakoid structure and function. The photosynthetic electron transport, carboxylation efficiency of RuBisco and chlorophyll biosynthesis are the major processes negatively affecting the photosynthetic efficiency of plants. Respiration also gets affected because of the exposure of plants to air pollutants. Gostin, 2016 [9] studied that the plants originating from extensively polluted areas shows substantial changes in their anatomy; assimilatory tissues contain elevated amounts of tannin or polyphenolic compounds; frequency of the calcium oxalate crystals is increased; and transfusion parenchyma shows the highest degree of alterations. Fluctuating asymmetry (FA) is expected to increase with increasing stress.

Wind stress

Wind is one of the most pervasive environmental stresses, and can strongly affect growth, development and reproductive yield in plants (Biddington, 1986 [4]; Cleugh, 1998 [5] and Bang, 2010 [3]). Wind often enhances water stress by reducing leaf boundary layers and reduces plant temperature by transpiration cooling. Plants adaptability to such variable external forces depends on the intensity and frequency of stress and also on the structure of plant. Some plant species show a resistance strategy in response to wind stress by increasing tissue strength and stem thickness. But other plant species show an avoidance strategy by a reduction in stem or petiole thickness and flexural rigidity in response to wind stress. These different strategies might be associated with plant size and structure as small plants experience smaller drag forces. In the analysis of leaf petiole anatomy it was observed that the vascular fraction in the petiole cross-section was increased by wind suggesting that higher water transport was required under wind stress (Onoda and Anten, 2011) [18].

Heavy metals stress

Plants have a series of defence mechanisms to counter the deleterious effects of heavy metal stress. The primary defence mechanisms include the reduced absorption or their sequestration in root cells and secondary mechanisms include the binding of heavy metal ions by phytochelatins, glutathione, and amino acids and modulation of antioxidant defence systems. (Hameed *et al.* 2016) [11].

Ultraviolet radiation stress

Plants are highly sensitive to UV-B radiation because of their immobile nature. In plants, UV-B radiation damages cell membranes and all organelles present within the cell, including the mitochondria, chloroplasts, and DNA within the nucleus. Damage to these cell organelles directly or indirectly affects basic plant metabolic processes, such as photosynthesis, growth, respiration, reproduction and water management. The most common response of field-grown plants to elevated level of UV-B is an increase in levels of different UV-absorbing phenolics. UV radiation effects crop yield and quality. However, the effect of UV-B radiation varies with intensity and duration of irradiation and stage of plant development. In addition, sensitivity to UV-B radiation varies widely among plant species and cultivars of the same species. The negative effects depend on the species and on the balance between potential damage and the induction of protective and repair mechanisms. Anthocyanins are colourful water-soluble flavonoids pigments produced by plants to protect foliage from the damaging effects of ultraviolet radiation. Anthocyanins are responsible for the showy colours of many plants and are present in high concentrations in flowers, fruits, and the leaves of deciduous plants in fall.

Biotic Stresses

Biotic stresses are developed by interaction between organisms. Biotic stresses results from competition between organisms for resources. It can be also developed by parasitism and predation due to the actions of allelopathic chemicals released by one organism and inhibiting the growth of the other. Diseases are also a kind of biotic stresses. Diseases are caused by biotic agents such as bacteria, fungi, virus and nematodes. Certain barriers such as cell wall, bark, waxy epidermal cuticles act as a defence mechanism. The exterior surface of plants have waxy cuticle which act as antimicrobial and prevent the entry of disease causing organisms. The cell wall of the plant act as second barrier to any organism those were able to cross the first barrier. If any invader that overcome first and the second barrier they still have to face the task of overcoming the plant immune response.

Disease stress

Plants have a developed multilayer surveillance system for detecting /identifying the pathogen and immediately response before causing any damage to plant by the pathogen. These surveillance systems of the plant are linked to specific pre-programmed defence responses. Innate immunity is the first line of defence mechanism that protects the plants from the pathogens. Innate immunity is also called basal resistance. Basal resistance is activated when plants cells recognizes micro-associated molecular patterns (MAMPs) such as specific proteins, lipopolysaccharides and cell wall components that are commonly found in microbes. Pathogens and non-pathogens both are capable of triggering basal resistance in plants due to the widespread presence of these molecular components in their cells. Pathogens have developed certain counter measures by which they suppress the basal resistance in certain plant species. If a pathogen is capable of suppressing basal defence, plants may respond with another line of defence i.e., hypersensitive response (HR). The hypersensitive response is characterized by deliberate plant cell suicide at the site of infection in order to save whole of the plant. The hypersensitive response is more pathogen-specific than basal resistance. Hypersensitive response is often triggered when gene products in the plant cell recognize the presence of specific disease causing molecules introduced into the host by the pathogen. Once the hypersensitive response has been triggered, the plant tissues may become highly resistant to a broad range of pathogens for an extended period of time and this phenomenon is called systemic acquired resistance (SAR). Artificially trigger SAR is developed by spraying plants with chemicals called plant activators. Plants can also defend themselves against viruses by a certain mechanisms including a sophisticated genetic defence system called RNA silencing. Certain viruses produce double-stranded DNA or RNA during replication in a host cell. Plants are able to recognize these foreign molecules and respond by digesting the genetic strands into useless fragments and stop the infection. The Plants infected with viruses often exhibit chlorosis and mottling, but disease symptoms may eventually disappear if RNA silencing is successful and this process is called recovery.

There are certain compounds that produced by plants in response to microbial attack/ stress. Lignin, highly branched heterogeneous polymer found in the secondary cell walls of plants. Lignin is a primary component of wood and consists of thousands of phenolic monomers. Lignin provides a good physical barrier against pathogen attack because of its rigid, insoluble and virtually indigestible character. Phytoalexins are isoflavonoids having antifungal and antibacterial component produced in response to pathogen attack. These toxic molecules such medicarpin produced by alfalfa, rishitin produced by the *Solanaceae* family, and camalexin produced by *Arabidopsis thaliana* disrupt the cellular structure and metabolism of the pathogen. Hydrolytic enzymes are produced by some of the plants in response to pathogens attack. These hydrolytic enzymes are accumulated in the extracellular spaces where they degrade the cell walls of pathogenic fungi. Hydrolytic enzymes such as chitinase catalyze the degradation of chitin, present in the cell walls of the fungi. Glucanase enzyme catalyzes the degradation of glycosidic linkages in glucans present in fungus cell walls. Transgenic plants expressing high levels of these anti-fungal enzymes exhibiting increased resistance to a wide range of pathogens. Lysozymes are hydrolytic enzymes that are capable of degrading bacterial cell walls.

Insect-pest stress

Plants have well developed surveillance systems designed to recognize insect pest’s damage and respond with specific defence mechanisms. Plants are capable to differentiate between general wounding and insect feeding by the presence of elicitors contained in the saliva of chewing insects. And in response to it, plants releases volatile organic compounds (VOCs) such as monoterpenoids, homoterpenoids and sesquiterpenoids. These chemicals may repel harmful insects or attract beneficial predators that prey on the destructive pests. For example, Lima beans and apple trees produce volatiles that attract predatory mites when damaged by spider mites. Feeding on one part of the plant can induce systemic production of these chemicals in undamaged plant tissues, and once released these chemicals can act as signals to neighboring plants to begin producing similar compounds in order to prevent from the damage.

Phenolics are the secondary metabolites produced by plants to defend themselves against pathogens. They are produced in plants via malonic acid pathways and shikimic acid pathways and include a wide variety of defense-related compounds such as flavonoids, lignin, tannins, anthocyanins, phytoalexins, and furanocoumarins. Furanocoumarins are phenolic compounds produced by a wide variety of plants in response to pathogen attack. They are activated by ultraviolet light and can be highly toxic to certain vertebrate and invertebrate herbivores due to their integration into DNA, which contributes to rapid cell death. Tannins are water-soluble flavonoid polymer produced by plants and are stored in vacuoles. Tannins are toxic to insects because they bind to salivary proteins and digestive enzymes including trypsin and chymotrypsin resulting in protein inactivation. Insect herbivores that ingest high amounts of tannins fail to gain weight and may eventually die. Protease inhibitors are produced in response to herbivore attack and inhibit digestive enzymes including trypsin and chymotrypsin. Alkaloids are nitrogenous compounds that are found in many vascular plants and include caffeine, cocaine, morphine, and nicotine. They are derived from the amino acids aspartate, lysine, tyrosine, and tryptophan, and many of these substances have powerful effects on animal physiology. Caffeine is an alkaloid found in plants such as coffee, tea and cocoa. It is toxic to both insects and fungi. High levels of caffeine produced by coffee seedlings inhibit the germination of other seeds around the growing plants and this phenomenon is called allelopathy. Nicotine is an alkaloid that is produced in the roots of tobacco plants, transported to leaves and it is stored in vacuoles. It is released when herbivores graze on the leaves and break open the vacuoles. Atropine is a neurotoxin and cardiac stimulant produced by the deadly nightshade plant. Cyanogenic glycosides are nitrogenous compounds that break down to produce hydrogen cyanide (HCN), a lethal chemical that halts cellular respiration in aerobic organisms. Cyanogenic glycosides producing plants also produce enzymes such as glycosidases and hydroxynitrile lyases but they are stored in separate compartments or tissues within the plant. When insects feed on plant tissues, the enzymes and substrates mix and produce lethal hydrogen cyanide. Herbivore induced plant volatiles (HIPVs) - Plants defend themselves from insect feeding by emitting certain volatiles and non-volatile compounds and which vary according to the insect and plant species. HIPVs are the lipophilic compounds having higher vapour pressure which are released from the leaves, flowers and fruits into the atmosphere and also from roots of the plant into the soil in response insect attack. Depending upon the modes of feeding of insect pests, different defense signaling pathways are activated for the production of specific volatile compounds (Walling, 2000) [20].

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