Chapter

Stresses in Plants: Biotic and Abiotic

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Abstract

Plants are subjected to a variety of environmental stresses, which reduces and limits agricultural crop productivity. Environmental stresses that affect plants are of two types: biotic and abiotic stresses. Abiotic stress includes temperature, ultraviolet radiation, salinity, floods, drought, heavy metals, etc., which results in the loss of important crop plants globally, while biotic stress refers to damage caused by insects, herbivores, nematodes, fungi, bacteria, or weeds. Plants respond to all these environmental factors because the pants are fixed in a particular place. To cope with these stresses, a number of strategies have been developed by plants. They detect that the environmental stresses become activated and then generate the necessary cellular responses. Several investigations have been carried out to determine and understand plant assimilates partitioning and stress-tolerance plant genotype necessary for the understanding of the complexity of the response of a plant to biotic and abiotic stresses.

Keywords: biotic factors, environmental stresses, crop productivity, crop yield, tolerance mechanism

1. Introduction

Stress can be defined as any external and internal constraints that limit the photosynthetic rate and reduces the energy conversion ability of a plant to biomass [1]. Respond of a plant to stress is in different ways, some of which include variation in gene expression, cellular metabolism, growth rates, crop yields, and so on. Plant stress as a result of its response to varying environmental conditions. However, exposure to a particular stress by stress-tolerant plant species leads to the development of resistance with time to a particular stress [2]. The main types of stress that plants face are biotic and abiotic stresses. Abiotic stress is an environmental factor that is placed on plants, as a result of variation of physical or chemical stress [3], whereas biotic stress is a biological unit such as illnesses, insects, and other pests that are exposed to crop plants [4]. Some stresses cause injury in plants. These plants have a number of metabolic issues [5].

Plants can recover from injuries if the stress is light or only lasts a short time, as the effect is just transient; however, extreme stress results in death. However, many plants like xerophytic plants (Ephemerals) can escape the stress altogether. Biotic stress in plants is induced by living organisms, such as viruses, bacteria, fungus, nematodes, insects, arachnids, and weeds [2]. The agents that cause biotic stress deplete their hosts of nutrients, which can lead to plant mortality. Because of pre- and postharvest losses, biotic stress might become severe. Despite the absence of an adaptive immune system, plants have evolved sophisticated methods to deal with biotic stresses [6]. These stresses are controlled by the plant's genetic codes. Hence, there is a need to combat resistant varieties of crops so as to ensure food security and safety in subsequent growing seasons. Seed priming with growth and rooting hormones should also be considered.

2. Abiotic stresses and crop plants

Plants are subjected to a variety of abiotic stresses, all of which have an impact on crop yield around the world. The major biotic and abiotic stresses in plants are described in **Figure 1**. These include drought, salt, cold, heat, and toxins.

2.1 Drought

Water scarcity is a significant environmental limitation on plant productivity. Drought-induced crop output losses are likely to outnumber losses from all other sources because both the severity and duration of the stress are crucial [8].

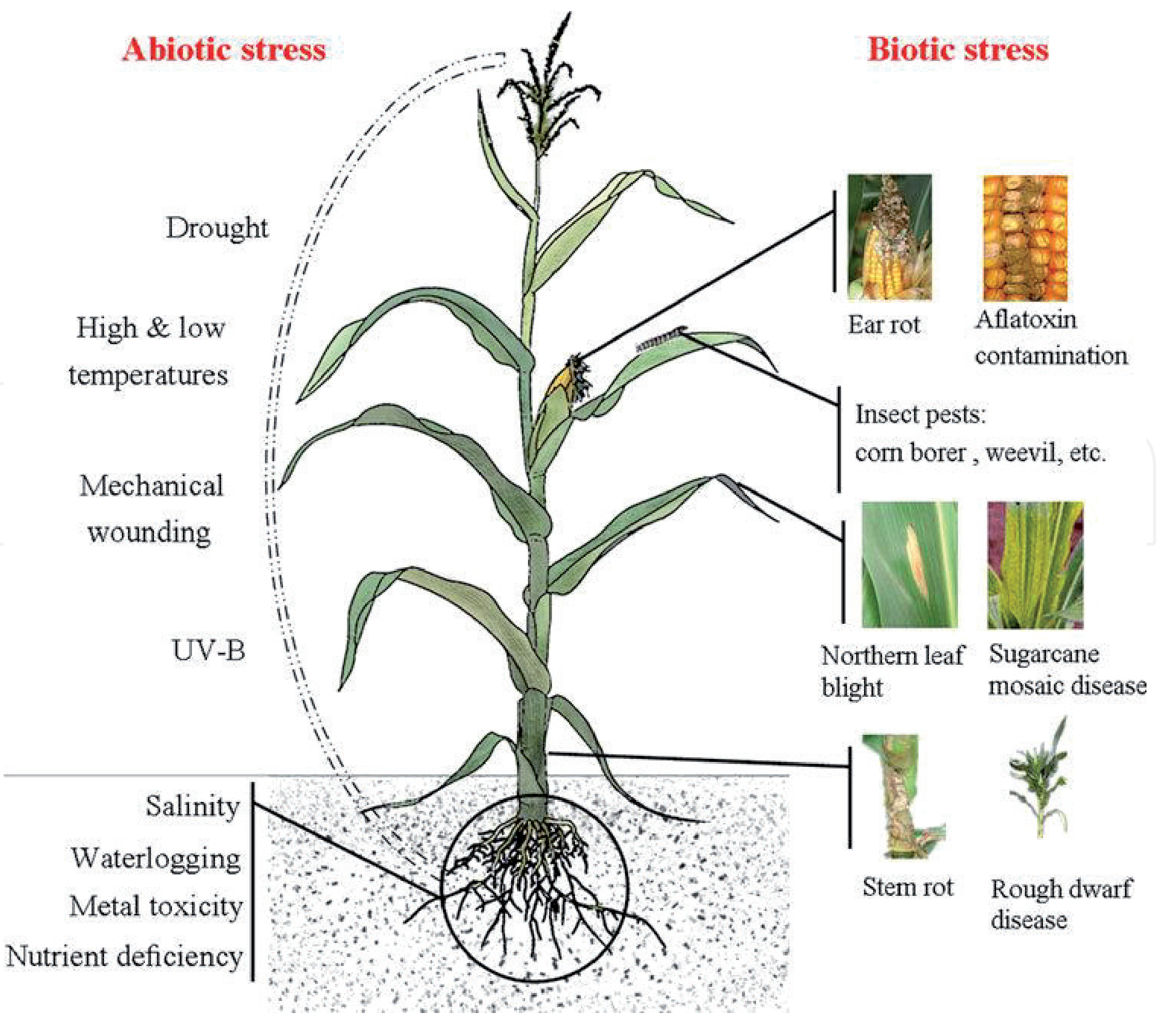

Figure 1.
An overview of major abiotic and biotic stresses [7].

The severity of the drought depends on the occurrence and distribution of rainfall, evaporative demands, and moisture storing capacity of soils, all of which are unpredictable [9]. Nowadays, climate has changed all around the globe by continuously increasing in temperatures and atmospheric CO_2 levels. The distribution of rainfall is unequal as a result of climate change, which functions as a major stress in the form of drought. Due to extreme drought conditions, the amount of soil water available to plants is steadily decreasing, causing plants to die prematurely. After drought is imposed on crop plants, growth will be arrested. Drought circumstances cause plants to lower their shoot growth, as well as their metabolic demands [7].

2.2 Salt

One of the most important limiting factors for crop growth and productivity is salt stress. Soil salinity is a global danger to world agriculture because it reduces crop yields and, as a result, crop productivity in salt-affected areas. Salinity is caused by the accumulation of salts in the soil or groundwater over a lengthy period of time as a result of natural processes or through human activities, for example, wethering of rocks or as a result of irrigation schemes using salt-rich irrigation water or having insufficient drainage [10]. There are several ways by which salt stress reduces the growth and yield of crops. Salt stress has two main effects on crop plants: osmotic stress and ion toxicity. These primary effects of salinity stress cause some secondary effects such as assimilate production, reduced cell expansion, and membrane function as well as decreased cytosolic metabolism [2].

2.3 Cold

Cold stress, as an abiotic stress, has been shown to be one of the most important abiotic stresses that reduce agricultural crop output by altering crop quality and post-harvest life. Many crop plant species have been found to be substantially hampered in their reproductive growth by chilling such as rice displaying sterility when exposed to chilling temperatures during anthesis [11]. Plants are sessile in nature; therefore, they have evolved unique ways to cope with temperature variations in their habitat [12]. In temperate conditions, plants are encountered by chilling and freezing conditions that are very harmful to plants as stress.

In order to adapt themselves, plants acquire chilling and freezing tolerance against such lethal cold stresses by a process called acclimation [13]. However, many important crops are still incompetent to the process of cold acclimation.

2.4 Heat

The temperature rises around the world have become a major problem, affecting not only plant development but also plant productivity, particularly in agricultural products. Heat stress has become the most important limiting factor to crop productivity and ultimately the food security [14]. When plants are subjected to heat stress, their seed germination rate, photosynthetic efficiency, and yield all suffer. Under heat stress, during the reproductive growth period, the function of a petal cell is lost, and the anther is dysplastic. For example, maize yields decrease sharply when the plants are exposed to temperatures greater than approximately 29–30°C [15].

2.5 Toxin

Toxic metals have been added to agriculture soils as a result of increased reliance on chemical fertilizers and sewage wastewater irrigation, as well as increasing industrialization, having detrimental consequences on the soil–plant environment system [16]. These metals bioaccumulate and slowly enter plants through air, water, and progression of the food chain over a certain period of time [17].

3. Crop plants and biotic stresses

Plants are subjected to a variety of biotic stress caused by various living organisms such as fungi, viruses, bacteria, nematodes, and insects [2]. These biotic stress agents induce a variety of diseases, infections, and damage to crop plants, lowering agricultural yields. However, different strategies for overcoming biotic stressors have been created through research methodologies. The biotic stresses in plants can be overcome by studying the genetic mechanism of the agents causing these stresses [18]. Genetically modified plants have proven to be a great effort against biotic stresses in plants by developing resistant varieties of crop plants.

Plant-parasitic nematodes feed on the contents of plant cells and can feed on all sections of the plant, but they predominantly cause soil-borne illnesses and affect the root system. They cause wilting and stunting, which are signs of nutritional inadequacy. Viruses cause not only local but also systemic damage to plants, causing stunting, chlorosis, and deformities in many areas of the plant, despite the fact that they rarely kill their hosts [19]. Plants are harmed when insects feed or lay eggs on them. Viruses can be transmitted to plants by piercing-sucking insects *via* their stylets. There are two types of fungus parasites: nectrotrophs, which use toxins to kill host cells, and biotrophs, which do not. They induce vascular wilts, leaf spots, and cankers, among other symptoms, and can infect different sections of the plant when combined with bacteria [20].

4. Plant defenses against abiotic stresses

Plants use five general botanical defenses against abiotic stresses. These include cuticle, unsaturated fatty acids, reactive species scavengers, molecular chaperones, and compatible solute, which are also an economic important trait [21].

4.1 Cuticle

This is the exterior translucent lipid structure in land plants, which seals the aerial surface of their organs. It is coated by cuticular waxes and is described as a hydrophobic layer. As the primary interface between plant and environment, the cuticle plays critical role in restricting liquid and gas fluxes, defending pathogen and insect attacks, and resisting various abiotic stresses. It is an elegant innovation of land plants to deploy an outermost shield derived from simple molecules, which is fundamental to their success in terrestrial colonization [22]. Wax accumulation in the cuticle is closely associated with multiple stress tolerance [23].

4.2 Unsaturated fatty acids

Unsaturated fatty acids containing 16 or 18 carbon atoms are the key ingredients of the membrane and the prime stocks for the cuticle. The unsaturated nature of fatty acids is a major determinant of membrane fluidity [21]. Dysfunction of biomembrane due to protein deactivation and ion leakage are caused by cold-driven rigidification and heat-driven fluidization, which makes membrane fluidity susceptible to various abiotic stresses, especially at high temperatures [24]. An increase in the level of normal alkanes with a decrease in the level of primary alcohols can lead to cold susceptibility, which can cause growth retardation, while an increase in the levels of both n-alkanes and primary alcohols resulted in better viability, where drought and freezing will have no effect on plant growth [25]. When polyunsaturated fatty acids are liberated by lipase form glycerolipids, they serve as raw materials for the synthesis of oxylipins, a bioactive molecule that is involved in the diverse physiological processes of stress resistance [26].

4.3 Reactive species scavengers

The reactive species scavengers include reactive carbonyl species (ROS) and reactive oxygen species (RCS). The ROS and RCS are interwoven, due to the fact that RCS can arise from ROS-induced lipid peroxidation, while ROS can be raised by RCS activities the other way round. Abiotic stresses can trigger a burst in both ROS and RCS thereby turning the two scavengers into a general defenses. Plants utilize both enzymatic and non-enzymatic means to developed sophisticated ROS scavenging system [21]. The application of excessive nitrogen fertilization in crop cultivation depresses the ROS scavenging system causing the increase in stress susceptibility [27].

4.4 Molecular chaperones

Molecular chaperones are induced to facilitate protein folding, assembly, transport, and degradation. Heat shock protein (HSP), which are good examples of molecular chaperon, is employed by all living organisms to counteract all detrimental conditions that can induce protein damage, wherein they function to prevent aggregation of denatured proteins, assist in their refolding, or present them to lysosomes or proteasomes for proteolysis, thereby restoring cellular homeostasis [28].

4.5 Compatible solutes

They are electrical neutral small organic compounds with high solubility and low toxicity. The molecules include sugar, amino acids, and their derivatives [21]. In an abiotic stress, these metabolites may accrue to act as osmoprotectants against dehydration, scavengers of RS, and/or stabilizers of proteins and membranes [29].

5. Conclusion

Plants are sessile organisms that are susceptible to environmental damages. In a broad sense, both biotic (viruses, bacteria, insects) and abiotic (heat, drought, salt, etc.) are adversaries facing world food production. Plants affected by these biotic and abiotic stress factors surfers physiological and metabolism changes. Hormonal and genetic defense mechanisms of the plant are also affected. Here, there is a need for phytologist and plant Breeders to develop tolerant varieties so as to combat these stresses to ensure good security. Plants will continue to be subjected to biotic and abiotic stresses until responsive mechanisms are created, and this will pose a significant threat to global agriculture. In plant cells, glycolysis operates as the principal source of this cytotoxin, due to the non-enzymatic dephosphorylation of two intermediates, glyceraldehyde 3-phosphate and dihydroxyacetone phosphate. Once over accumulated, methylglyoxal can also damage various biomolecules, especially with its aldehyde group.

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References

[1] Atafar Z, Mesdaghinia A, Nouri J, Homaee M, Yunesian M, Ahmadi M, et al. Effect of fertilizer application on soil heavy metal concentration. Environmental Monitoring and Assessment. 2009;**160**:83-89

[2] Fahad S, Bajwa AA, Nazir U, Anjum SA, Farooq A, Zohaib A, et al. Crop production under drought and heat stress: plant responses and management options. Frontiers in Plant Science. 2017;**29**:01147

[3] Fich EA, Segerson NA, Rose JK. The plant polyester cutin: Biosynthesis, structure, and biological roles. Annual Review of Plant Biology. 2016;**67**: 207-233

[4] Gimenez E, Salinas M, Manzano-Agugliaro F. Worldwide research on plant defense against biotic stresses as improvement for sustainable agriculture. Sustainability. 2018;**10**:391

[5] Godoy F, Olivis Hernadez K, Stange C, Handford M. Abiotic stree in crop science: Improving tolerance by applying plant metabolites. Plants. 2021;**10**:186

[6] Gong F, Yang L, Tai F, Hu X, Wang W. "Omics" of maize stress response for sustainable food production: Opportunities and challenges. OMICS: A Journal of Integrative Biology 2014;**18**(12):714-732

[7] Grime JP. Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory. The American Naturalist. 1977;**111**:1169-1194

[8] Gull A, Lone AA, Wani NUI. Biotic and abiotic stresses in plants. In: de Oliveira AB, editor. Abiotic and Biotic Stress in Plants. IntechOpen; 2019

[9] Hazel JR. Thermal adaptation in biological membranes: Is homeoviscous adaptation the explanation? Annual Review of Physiology. 1995;**57**:19-42

[10] He M, He CQ, Ding NZ. Abiotic stresses: General defenses of land plants and chances for engineering multistress tolerance. Frontiers in Plant Science. 2018;**19**:1171

[11] Jiang W, Lee J, Chu SH, Ham TH, Woo MO, Cho YI, Koh HJ. Genotype × environment interactions for chilling tolerance of rice recombinant inbred lines under different low temperature environments. Field Crops Research 2010;**117**(2-3):226-236

[12] Jones RAC. Global plant virus disease pandemics and epidemics. Plants. 2021;**10**:233

[13] Kong LA, Xie Y, Hu L, Si JS, Wang ZS. Excessive nitrogen application dampens antioxidant capacity and grain filling in wheat as revealed by metabolic and physiological analyses. Scientific Reports. 2017;**7**:43363

[14] Liliane TN, Charles MS. Factors affecting yield of crops. In: Amanullah, editor. Agronomy – Climate Change & Food Security. IntechOpen; 2020. DOI: 10.5772/intechopen.90672 Available from: https://www.intechopen.com/chapters/70658

[15] Liu X, Zhou Y, Xiao J, Bao F. Effects of chilling on the structure, function and development of chloroplasts. Frontiers in Plant Science. 2018;**22**:1715

[16] Nievola CC, Carvalho CP, Carvalho V, Rodrigues E. Rapid response of plants to temperature changes. Temperature. 2017;**4**(4): 371-405

[17] Rauwane M, Ntushelo K. Understanding biotic stress and hormone signalling in cassava (*Manhot esculenta*): Potential for using

hyphenated analytical techniques. Applied Sciences. 2020;**20**:8152. DOI: 10.3390/app10228152

[18] Rollins JA, Habte E, Templer SE, Colby T, Schmidt J, von Korff M. Leaf proteome alterations in the context of physiological and morphological responses to drought and heat stress in barley (*Hordeum vulgare* L.). Journal of Experimental Botany. 2013;**64**(11): 3201-3212

[19] Savchenko TV, Zastrijnaja OM, Klimov VV. Oxylipins and plant abiotic stress resistance. Biochemistry. 2014;**79**:362-375

[20] Schlenker W, Roberts MJ. Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change. Proceedings of the National Academy of Sciences of the United States of America. 2009;**106**: 15594-15598

[21] Slama I, Abdelly C, Bouchereau A, Flowers T, Savoure A. Diversity, distribution and roles of osmoprotective compounds accumulated in halophytes under abiotic stress. Annals of Botany. 2015;**115**:433-447

[22] Srivastava V, Sarkar A, Singh S, Singh P, de Araujo ASF, Singh RP. Agroecological responses of heavy metal pollution with special emphasis on soil health and plant performance. Frontiers in Environmental and Environmental Toxicology. 2017;**3389**:00064

[23] Visser EJW, Voesenek LACJ, Vartapetian BB, Jackson MB. Flooding and plant growth. Annals of Botany. 2003;**91**:107-109

[24] Wang W, Vinocur B, Shoseyov O, Altman A. Role of plant heat shock proteins and molecular chaperones in the abiotic stress response. Trends in Plant Science. 2004;**9**:244-252

[25] Wery J, Silim SN, Knights EJ, Malhotra RS, Cousin R. Screening techniques and sources and tolerance to extremes of moisture and air temperature in cool season food legumes. Euphytica. 1994;**73**:73-83

[26] Xue D, Zhang X, Lu X, Chen G, Chen ZH. Molecular and evolutionary mechanisms of cuticular wax for plant drought tolerance. Frontiers in Plant Science. 2017;**8**:621

[27] Yadeta KA, Thomma BPHJ. The xylem as battleground for plants hosts and vascular wilt pathogens. Frontiers in Plant Science. 2013;**23**:97

[28] Zaid H, Tamrakar AK, Razzaque MS, Efferth T. Diabetes and metabolism disorders medicinal plants: A glance at the past and a look to the future 2018. Evidence-based Complementary and Alternative Medicine. 2018:5843298

[29] Zhang JY, Broeckling CD, Sumner LW, Wang ZY. Heterologous expression of two *Medicago truncatula* putative ERF transcription factor genes, WXP1 and WXP2, in *Arabidopsis* led to increased leaf wax accumulation and improved drought tolerance, but differential response in freezing tolerance. Plant Molecular Biology. 2007;**64**:265-227