Chapter

Effect of Abiotic Stress on Crops

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Abstract

Crop yield is mainly influenced by climatic factors, agronomic factors, pests and nutrient availability in the soil. Stress is any adverse environmental condition that hampers proper growth of plant. Abiotic stress creates adverse effect on multiple procedures of morphology, biochemistry and physiology that are directly connected with growth and yield of plant. Abiotic stress are quantitative trait hence genes linked to these traits can be identified and used to select desirable alleles responsible for tolerance in plant. Plants can initiate a number of molecular, cellular and physiological modifications to react to and adapt to abiotic stress. Crop productivity is significantly affected by drought, salinity and cold. Abiotic stress reduce water availability to plant roots by increasing water soluble salts in soil and plants suffer from increased osmotic pressure outside the root. Physiological changes include lowering of leaf osmotic potential, water potential and relative water content, creation of nutritional imbalance, enhancing relative stress injury or one or more combination of these factors. Morphological and biochemical changes include changes in root and shoot length, number of leaves, secondary metabolite (glycine betaine, proline, MDA, abscisic acid) accumulation in plant, source and sink ratio. Proposed chapter will concentrate on enhancing plant response to abiotic stress and contemporary breeding application to increasing stress tolerance.

Keywords: abiotic stress, drought, salinity, cold, heavy metals, morpho-physiological and biochemical changes

1. Introduction

Plants in their physical environment face several types of variation. Animals use techniques to prevent the impacts of this variation but plants fail because of the sessile nature of the growth habit. Plants therefore, rely on their internal processes to survive changes in the external environment. Plants are affected to function in an oscillating environment and normal external changes are countered by internal changes without any harm to growth or development. The possibility of abiotic or environmental stress is to cause physical harm to the plant due to serious or chronic adverse environmental circumstances. Any adverse influence of inanimate factors on living beings in a fixed setting is described as abiotic stress. To substantially impact the organism's demographic output or individual physiology, the non-living factor must alter the surrounding beyond its ordinary variation range. Due to the continuous climate change and environmental deterioration induced by human activity, physical surrounding stress has become a key threat to food security. Water deficit stress, salt stress, imbalances in nutrients (including mineral toxicity and deficiencies) and temperature extremes are significant environmental limitations on productivity of crops all over the world [1].

Plant growth and crop yield are majorly affected by cold, drought, salt, and heavy metals. Abiotic stress impacts plants to molecular levels from morphological levels and is visible at all phases of plant development where drought occurs [1]. There are three significant stages of plant: vegetative development, pre-anthesis and terminal phase that are impacted by the drought [2]. Plant physiological reactions to stress include wilting of the leaf, abscission of the leaf, decreased leaf region and decreased water loss through transpiration [3]. Under drought stress, crop development facilitates the issue of extreme water use in agriculture to a big extent. Turgor pressure is decreased, which is one of the most delicate physiological mechanisms that cause cell growth. Drought stress creates water flow disruption in higher plants from xylem to the neighboring elongating cells, thereby suppressing cell elongation. In addition, decreased leaf area, plant height, and development of crop result from drought pressure owing to cell elongation, impaired mitosis and expansion [1]. Abiotic stress resistance contains escape-avoidance and tolerance mechanisms. Detrimental impacts of stress can be decreased by osmotic modification, which helps with an active accumulation of solutes in the cytoplasm to maintain cell water balance [4].

Survival and geographical spreading of plants are also greatly affected by low temperatures. Significant loss of crop due to reduced plant growth and crop efficiency is usually caused by cold stress [5]. Cell and tissue dehydration and cellular water crystallization are caused by cold stress, thereby reducing plant growth and productivity. Reduced membrane conductivity, increased water viscosity, and hydro active stomata closure is inhibited resulting in water stress and increased leakage of electrolytes at low temperatures [6]. It also delays metabolism, dissipates energy, and causes free radicals to form as a result of oxidative stress [7].

For instance, up to 45% of the world's farming based land is encountered to frequent periods of time when there is scanty of rainfall in which 38% of the world's population resides and the world's mapped area is affected by salinity in more than 3106 km^2 area or about 6% of the entire area of land [8]. In addition, 19.5% of irrigated agricultural land is classified as saline. In addition, about 1% of world agricultural land is deteriorated by salinity (2 million ha) each year, resulting in decreased or no crop productivity [9]. Major abiotic stress affects the plants during their growth and development arises due to water limitation caused by inadequate rainfall, cold condition, and salinity. The worldwide land region impacted by drought, cold and salinity is 64, 57, and 6%, respectively, according to the FAO World Soil Resources Report, 2000. Comprehension of crop plant abiotic stress reactions has thus become component of plant studies to protect food security [10]. Abiotic stresses are interrelated and influence the relationships of plant water on the cellular and also the entire plant level, affecting certain and uncertain reactions resulting in a series of morphological, physiological, biochemical and molecular changes that affects the growth and development of plants adversely.

These abiotic stresses characterize the main cause of crop fiasco globally, introducing more than 50% of the average returns for significant crops [10]. Improving cultivation is therefore vital to fill the gap between population growth and food production, which is widening by initiating stress tolerance. Plants can introduce some molecular, cellular and physiological modifications to react to and acclimatize such stresses in order to deal with abiotic stress. Better knowledge of plant responsiveness to abiotic stress in both traditional and modern breeding application will assist to enhance stress tolerance. Studies with high stress tolerance on some wild plant species also make a significant contribution to our understanding of stress tolerance.

2. Types of abiotic stresses

Different abiotic stresses affect the plants due to global warming and fluctuations in the environmental conditions. Abiotic stresses like water scarcity, high salinity, extreme temperatures, and mineral deficiencies or metal toxicities significantly reduce the crop's productivity.

2.1 Drought stress

Drought is described as stress related to the water deficit. Drought is a climate word described as a period of moment with less rainfall. Drought stress in plants happens when environmental conditions result in a decrease in the quantity of water in the soil, leading in a constant loss of water through transpiration or evaporation. Water is a crucial element of plant survival and essentially needed for transportation of nutrients. Hence, deficiency of water leads to drought stress, which results in reduced vitality of plants [11]. Water stress may occur in plants due to high salt conditions. The soil water potential reduces because of elevated salt circumstances, because the osmotic potential of salt is smaller than water, which makes it hard for roots to absorb the soil's water. Also, owing to enhanced water loss via transpiration or evaporation, elevated temperatures can trigger drought stress. Not only greater temperatures, but reduced temperatures can also trigger stress from the water deficit. Lower freezing temperatures result in ice crystals being created in the extracellular spaces of plant cells, decreasing the water potential and leading to intracellular water efflux. Thus, in general, drought stress occurs due to various causes which further leads to the efflux of cellular water, leading to plasmolysis and thus causing cell death. Water deficit stress is damaging because it inhibits photosynthesis by affecting the thylakoid membranes. An increase in the toxic ions in all the cells of plants is the potential damage caused to the plants due to drought stress. Drought stress is therefore complicated abiotic stress that directly affects plant growth and advancement and leads to decrease in plant output.

2.2 Salinity stress

Salinity stress occurs due to an increase in salts contents in soil. Thus, an increase in salt content in soil is referred to as soil salinity or salinization [12]. It mainly occurs in arid as well as semi-arid environments where the plants have higher evaporation and transpiration rates compared to precipitation volume throughout the year. Salts in the soil may increase in the subsoil naturally which is referred to as primary soil salinity or it may be introduced due to anthropogenic conditions like environmental pollution which is called secondary soil salinity. Secondary soil salinity arises due to modification in soil content, an increase in fertilizers or due to the use of saline water in irrigation purposes [13]. Soil salinity is a global problem and a severe risk to the entire agricultural world as it reduces the output of plants. High salt concentration limits growth and development of crops in multiple ways. Two significant impacts in crops result from higher salt content: ionic toxicity and osmotic stress. The osmotic stress in plant cells is greater in ordinary circumstances than in soil. This increased osmotic pressure is used by plant cells to absorb water and the necessary minerals from the soil into the root cells. However, under circumstances of salt stress, the soils osmotic pressure solution surpasses the plant cells osmotic pressure owing to an increase in the salt content in the soil, thereby restricting plants 'ability to absorb water and minerals such as K^+ and Ca^{2+} while Na^+ and Cl^- ions move in the cells and have damaging effects on the cell membrane and metabolism in cytosol. Stress with salinity creates some adverse effects such as reduced cell growth, reduced membrane function, and reduced cytosolic metabolism and ROS production. High soil salinity adversely impacts plant production quality and quantity by inhibiting seed germination, damaging growth and development phases as a consequence of the combined impacts of higher osmotic potential and particular ion toxicity [14].

2.3 Extreme temperature stress (hot/cold)

Extreme temperatures are one of the prime causes of different abiotic stresses like drought. Increases or decreases in temperature, both undesirably affect the plant's growth, development, and yield. Cold stress occurs when plants are subjected to very low temperatures. Cold stress is a major abiotic stresses that reduce productivity of crops by affecting quality and life after harvest. Cold stress impacts all cellular function characteristics in crops. Plants are categorized into three kinds in reaction to cold temperatures: chilling delicate plants: plants that are highly damaged by temperatures above 0°C and below 15°C, chilling resistant plants: crops capable of tolerating low temperatures and wounded when ice formation begins in tissues and frost resistant plants: plants capable of tolerating exposure to very low temperatures. Cold stress causes injury to plants by changes in the membrane structure and decrease in the protoplasmic streaming, electrolyte leakage and plasmolysis which leads to cellular damage. The metabolism of the cells is damaged by an increase or decrease in respiration rate and depending on the intensity of the stress, synthesis of abnormal metabolites occurs due to abnormal anaerobic respiration. Due to cellular damage and altered metabolism, there is reduced plant growth, abnormal ripening of fruits, internal discoloration (vascular browning), and increased susceptibility to decay and also cause the death of the plant [15].

If crops are subjected to very elevated temperatures, heat stress happens. For adequate moment to cause permanent injury to functioning or development of plant. Heat stress is defined as elevated temperatures. High temperatures boost the rate of sexual development, which reduces the time needed to add photosynthesis to the production of fruit or seed. Also, high temperatures can cause drought stress due to increased water loss by transpiration or evaporation. High soil temperatures can decrease the emergence of plants. High temperature stress can influence seed germination, plant growth and development, and can trigger irreversible drought stress that can lead to death as well [16].

2.4 Metal stress

Heavy metal stress (HM) belongs to a group of non-biodegradables, determined inorganic chemicals having atomic mass more than 20 and a density exceeding 5 g cm^{-3} with toxic effects on cells and genes, which causes mutagenic impacts on crops by influencing and contaminating irrigation, soil, drinkable water, food chains and the surrounding environment [17, 18]. There are two categories of metals discovered in soils that are mentioned as vital micronutrients for standard plant growth (Fe, Mg, Mo, Zn, Mn, Cu, and Ni) and non-essential elements with unknown physiological and biological function (Ag, Cr, Cd, Co, As, Sb, Pb, Se, and Hg) [19]. Plant surfaces both underwater and above ground can take HMs. In the enzyme and protein structure, the vital elements play a main role. Plants need them in minute quantities for their metabolism, growth, and development; yet, the concentration of vital and non-essential metals is an only essential factor in the increasing crop cycle so that their excessive presence can cause a decline and inhibition of plant growth. HMs at poisonous concentrations hinder ordinary functioning in plants and act as an barrier to metabolic procedures in different ways, comprising the displacement or disturbance of protein structure construction blocks arising from the creation of blonds among HMs and sulfhydryl groups [20], interfering with functional groups of significant cellular molecules [21].

3. Major crops affected by abiotic stress

3.1 Chickpea

After dry beans and dry peas, chickpea is the third most significant food legume worldwide. It is grown on 12.4 million hectares, generating 11.3 million tons at an average output of 910 kg/ha, according to FAOSTAT information in 2012–2013. In chickpea manufacturing and productivity, climate change is a significant challenge (**Table 1**). Climate change's negative impacts seem to result from drought effects [15].

3.2 Wheat

Wheat is the major crop grown mainly in the Rabi season. Under various agro-ecological circumstances, it is commonly cultivated. Drought impacts vary from morphological to molecular. Many stages of plant development are influenced by drought. Drought has an impact on three major periods of plant development-vegetative, pre-anthesis and terminal stage. Physiological responses of plants to drought comprise leaf wilting, reduced leaf area, leaf abscission and thus reducing water loss through transpiration. Higher plants cell elongation is suppressed under serious water deficit by interrupted water flow from the xylem to the neighboring elongating cells. Cell elongation, impaired mitosis and expansion lead under drought to lower height of plant, leaf area, and crop development. There is a conservative water loss resulting in stomatal closure and disruption in cell structure as well as plant metabolism [22].

3.3 Maize

Maize (*Zea mays* L.) is one of the world's major staple food. It is used as cattle feed, meat supplement and also as biofuels. The crop is highly susceptible to elevated

Crops	**Stress**
Chickpea (*Cicer arietinum* L.)	Drought
	Cadmium (Cd) toxicity
	Copper (Cu) toxicity
Maize (*Zea mays* L.)	Drought
	Heat
	Arsenic (As) metal stress
Soybean (*Glycine max* L.)	Drought
Wheat (*Triticum aestivum* L.)	Drought
Rice (*Oryza sativa* L.)	Drought
	Heat
Black mustard (*Brassica juncea* L.)	Cadmium (Cd) toxicity

Table 1.
List of some of the crops that are affected by various abiotic stresses.

temperatures, resulting in significant crop yield losses [23]. Multiple abiotic stresses like salinity and drought can also affect the crop in semi-arid tropical regions [24]. Temperature increases above a threshold level have negative effects plant growth and development, that is, heat stress for an appropriate time span. Due to elevated temperature stress, the disruption in cellular homeostasis has the ability to cause retardation in plant growth, development and even death. High-temperature stress affects the phases of maize development differently. Drought stress resulted in maize yield loss ranging from 17 to 60% in Southern Africa. Sequential cycles of drought stress were subjected to maize inbred lines and their hybrid testcross progeny were at the seedling level. These cycles were done at diverse developmental stages of growth, that is, germination, survival and regeneration. The study revealed that the best parameter for secondary screening of maize under drought stress is seedling stage [23].

3.4 Soybean

A wealthy source of protein and edible oil is soybean (*Glycine max* (L.) Merr). Soybean is the major cultivated crop of the world (approximately 6% world's territory). Drought stress affects the plant's rate of germination and seedling vigor. Underwater scarcity, the length of hypocotyl, germination, and dry and new weight of root and stem are reduced while the length of the root is increased. Growth occurs through differentiation of cells and division of cells, which is negatively affected by water scarcity. Cell elongation decreases under drought conditions due to decrease in turgor pressure [25].

3.5 Rice

Rice (*Oryza sativa* L.) is a significant global staple food crop that provides food security and generates revenue, especially in developing countries. The anticipated global warming poses a severe danger to both rice manufacturing and the quality of the rice generated. In tropical and subtropical regions, temperature stress and drought are projected to increase to a greater degree, being the primary rice producing areas [26].

High temperature stress or drought conditions have adverse effects on plant development, including unalterable damage to plant growth and development, decreased photosynthesis [27], decreased amount of panicles in each plant and elongation of peduncle, limited pollen output, no pollen grain swelling, and reduced spikelet sterility. Low temperatures lead in inhibited growth of seedlings, decreased development of panicles, delay in heading, bad exertion in panicle, low fertility of spikelet and bad quality of grain. Water and temperature stresses, other than influencing development and grain yield, alter the chemical composition and quality of rice [28].

4. Effect of abiotic stress on crops

A complex set of biotic and abiotic pressures includes the natural environment of crops. Abiotic stresses are of greater importance because they include different environmental factors that cannot be prevented, that is, drought, salinity, cold, heat, metal, etc. The impacts of abiotic stress on crop manufacturing are hard to predict correctly. Plant reactions to abiotic stress are both dynamic and complicated and can be either elastic (reversible) or plastic (irreversible) [29].

4.1 Drought effect on crops

Drought stress affects the plants at all phenological developmental stages varying from morphological to molecular concentrations. In plants that determine yield, many physiological mechanisms are prone to drought [7]. Drought can trigger yield reductions in many plant species depending on their severity and period but the stress of drought after anthesis is detrimental to the output of grain regardless of its severity [30]. Prevailing drought stress limits the production of flowers and grain filling resulting in reduced quality and amount of grains. Micro and macronutrients like nitrogen (N), phosphorous (P) and potassium (K) are crucial for plant growth. Drought stress results in increased N significantly decreased P, in spite of this it has no definitive effects on K [31]. Overall, water deficit reduces nutrient accessibility in the root zone, absorption at root hair, translocation in xylem and phloem vessels leading to impaired metabolism of nutrients in cells and tissues [7]. The effectiveness of nutrient intake and utilization is also reduced due to less transpiration. Drought stress has significant on photosynthetic pigments like chlorophyll a, b, and carotenoid components and also impairs photosystem 1 and photosystem 2 [32]. It also reduces starch synthesis in plants by effecting Calvin cycle enzyme activity (Ribulose phosphatase). Plants can combat to drought stress by different mechanisms [33]. When the soil is scarce in water crops, their stomata tend to close, reducing CO_2 input into the leaves and spare more electrons for active oxygen species growth [34]. Environmental circumstances that improve the rate of transpiration also increase leaf sap pH, encourage abscisic acid deposition and at the same moment reduce stomatal behaviour [35]. Failure in Rubisco's activity restricts photosynthesis under very serious drought conditions [36]. Some studies revealed that under drought conditions the activity of the photosynthetic electron transport chain is finely adjusted to chloroplast CO_2 accessibility and photosystem II modifications [37]. The result of dehydration is a decrease in cell size. This improves the cellular content's viciousness. Protein-protein interaction increases outcomes in their aggregation and denaturation. An increased concentration of solutes may become toxic and may be detrimental to enzyme functioning, including photosynthetic equipment, leading in increased viscosity of cytoplasms [38].

4.2 Salinity effect on the crops

The magnitude of agricultural estate affected by high salinity is increasing worldwide as a result of both natural and agricultural occurrences such as irrigation schemes. In plant growth, salinity presents two primary concerns: osmotic stress and ionic stress. It also manifests oxidizing stress. The detrimental effects of salinity alter different physiological and metabolic processes of plants. Often, the answers to these modifications are accompanied by various symptoms such as decreased leaf area, increased leaf density and succulence, leaf abscission, root and shoot necrosis, and decreased internode lengths. Salinity stress inhibits growth and increases cell senescence during extended exposure. Inhibition of growth is the major injury resulting in other symptoms, while programmed cell death may also happen under serious salinity shock [39]. Abscisic acid synthesis is induced under salt stress that closes stomata during transportation to guard cells. Due to stomatal closure and inhibition of photosynthesis and oxidative stress, photosynthesis reduces. Osmotic stress can directly or indirectly inhibit the development of cells through abscisic acid metabolism and translocation. Potassium is not received by plant root surface due to excessive sodium ions near the root zone. Due to the comparable biochemical behavior of sodium and potassium ions, sodium has a powerful repressive impact on root potassium absorption. Deficiency of potassium predictably results in inhibition of growth as potassium maintains cell turgor, activity of enzyme and membrane potential as the most abundant cell cation. Once sodium enters the cytoplasm, the functions of many enzymes are inhibited. This inhibition also depends on the quantity of potassium present: the most deleterious is an elevated sodium/potassium ratio. Plant growth is decreased due to salinity related nutrient disturbances by altering accessibility, transport and partitioning of nutrients. High salt concentration can result in nutrient deficits or imbalances due to Na^+ and Cl^- competition with nutrients such as K^+, Ca^{2+} and NO_3^-. Under saline circumstances there are specific ion toxicity of Na^+ and Cl^- and ionic imbalances influencing biophysical components and/or metabolism of plant growth. Most of the crops combat salinity stress by deposition of low molecular weight organic solutes like linear polyols (sorbitol, glycerol or mannitol), amino acids (proline or glutamate) and betaine (betaine glycine or betaine alanine), cyclic polyols (inositol and other derivatives of mono- and dimethylated inositol) [40].

4.3 Cold effect on the crops

Cold stress is a significant abiotic stress which affects growth and development of crops, leading to loss of strength and lesions on the surface. These symptoms are triggered by changes in the physical and chemical organization of cell membranes, among other metabolic procedures [41]. It is estimated that rises in extreme temperature frequency, severity, and duration are a prevalent feature of our setting. Climate change controls greater changes in temperature, leading in frequent cold periods. Susceptible plants with cold temperatures have reduced growth and growth, restricted use of precious varieties, and reduced yields. Plants use separate strategies to cope with stressful conditions and integrate a variety of physiological, metabolic and molecular adaptations. These methods initially generate modifications to safeguard the plant, followed by cold acclimatization, which increases the survival of the plant under cold stress [9]. While a lot of these mechanisms are facilitated by transcription factors (TFs) that stimulate gene expression associated to stress, the transcription network is not restricted to the reaction of plants to cold [41, 42]. As a foremost element of plasma and endo-membranes, lipids play a significant organizational role in mitigating the effects of cold temperatures [43]. Cold stress decrease plants growth and development that affects the physical and chemical structure of the cell membrane, causes leakage of electrolytes, and reduces protoplasmic streaming and changes in the metabolism of cell [44, 45]. Additional cold reactions comprise changes in nucleic acid and protein synthesis, water and nutrient equilibrium, enzyme affinity and conformation and deficiency in photosynthesis, specifically down-regulation and photo-damage of Photosystem II (PSII) [16].

Changes in the structure of proteins and lipid membranes assist restore homeostasis of metabolites and are regarded a mechanism by which cells feel cold temperatures. For its metabolic and physical function, the liquid state of the plasma membrane is a structural and functional asset. When low temperatures are present, the plasma membrane transitions from a liquid state at elevated temperatures into a stiff gel stage [46]. Low temperature-mediated changes in the physical conformation of the membrane are mainly because of enhanced levels of unsaturated lipids, which increase the fluidity and stability of the membrane, enabling cells to adapt mechanically to cold [47].

4.4 Heat effect on the crops

The sequence of modifications in morphology, biochemistry, and physiology arising from high temperature stress also considerably disturbs growth and development of plant [48]. As a result of increasing atmospheric temperatures, heat shocks are currently primary limiting factors for crop productivity globally. This increasing temperature may result in changes in the phases of growth and distribution of agricultural plants [49]. High-temperature stress can cause serious protein damage, interrupt synthesis of protein, inactivate critical enzymes, and damage membranes. High temperature stress can have significant effects on the cell division process [50]. All of these harms can substantially restrict plant development and also promote oxidative damage. In addition, short exposure to elevated temperature in seed filling can lead to rapid filling, leading to low quality and lower yield. Under a restricted supply of water, the temperature rise is fatal. Overall, water loss due to heat stress is predominantly due to enhanced transpiration rate during the day, which eventually damages certain physiological procedures in crops. Heat stress also decreases the amount, weight and root growth and eventually decreases the accessibility of water and nutrients to the plant parts above ground [51, 52]. Light-dependent chemical reactions that happen in the stroma in the thylakoid and the carbon metabolism are the primary places of harm owing to elevated heat stress. Increased adjustment of PSII thermo-tolerance of PSII leaf temperature and density of photon flux [53]. The PSII is extremely temperature sensitive and significantly affects and even partly terminates its activity under elevated temperature stress [54]. Oxygen-evolving complex also experiences severe harm at elevated temperatures, which can lead to imbalanced electron flow to the PSII acceptor site [55]. At higher temperatures, the proteins D1 and D2 also suffer from denaturation [56]. High heat stress has a significant impact on the activity of significant enzymes like sucrose phosphate synthase, invertase, adenosine diphosphate-glucose pyrophosphorylase, and starch and sucrose synthesis [57]. The reduced CO_2 binding enzyme activation status, Rubisco, limits net photosynthesis in many species of plants. Although Rubisco's catalytic activity rises with greater temperatures, its low CO_2 affinity and O_2 binding ability limit the rise in net photosynthesis speed [58]. Despite all these negative photosynthesis impacts of elevated temperature, with elevated concentrations of CO_2 in the atmosphere, optimum photosynthesis temperature requirements are expected to rise [53].

4.5 Heavy metal

A prevalent and serious problem is heavy metal atmospheric pollution through human activities and/or natural processes. Often referred to as trace metals or heavy metals are potentially toxic elements. Trace metals are related to the trace quantities of components existing in soils. Heavy metals, a loosely specified group of components, constitute elements with an atomic mass exceeding 20 (excluding alkali metals) and specific gravity exceeding 5 [59]. Because of their differing solubility/bioavailability, heavy metals exist in different forms in soil. Many soil physicochemical characteristics change heavy metal geochemical conduct in soil, plant uptake, and effect on crop productivity. Excessive deposition of heavy metals in plant tissue is harmful to multiple biochemical, physiological, and morphological operations in plants either directly or indirectly and in turn affect crop productivity. Heavy metals decrease crop productivity by causing seed germination, accumulation, and re-mobilization of seed reserves during plant growth, germination and photosynthesis to deleterious effects on various plant physiological processes [60]. Heavy metal toxicity on the cell platform decreases the productivity of plants by forming reactive oxygen species, disrupting the redox equilibrium and causing oxidative stress. Metals mainly enter the plants through the root from the soil [61]. The cultivation of metals includes several processes, including desorption of metal from soil particles,, uptake of metals by roots, transportation of metals to plant roots and shoots [62]. Transport of heavy metal to aerial components of the plant is via the xylem and is most probably encouraged by transpiration [63]. The metals, after joining the central cylinder, move towards the aerial parts of the plant where evaporation of water occurs and metal stacks up through the water stream of the vascular system [64]. Only a slight percentage of heavy metals are translocated in most crops to the shooting tissues. In some cases, only if the plant is a hyper accumulator or chelate-assisted, there is sequestration of 95% or more of the metal in the plant's roots [65, 66].

5. Crops tolerance against abiotic stress

Plant resistance to abiotic stress includes escaping stress avoidance and tolerance. Escape: Before extreme stress begins, dry escape depends on efficient reproduction. The plants integrate brief life cycles with high growth rates and gas exchange, using the highest existing resources while soil moisture lasts. It also relies on escaping the unfavorable environmental conditions by shedding off the leaves, no germination, nighttime closure of stomata, compact growth, that is, shortening of any plant part [67].

Avoidance: reversible physiological changes involve decreasing water loss (closing stomata, decreasing light absorption through rolling leaves and condensed canopy leaf region) and growing water absorption (increasing root investment, morphological changes occurring in crops to decrease transpiration, re-allocation of nutrients stored in older leaves and greater photosynthesis rates [68].

Tolerance: abiotic stress tolerance appears to be the consequence of cellular and molecular level coordination of physiological and biochemical changes. These changes may include osmotic adjustment, stiffer cell walls, or smaller cells [69]. Changes happening rapidly at the concentrations of mRNA and protein consequence in an intolerant state. Various morphological, physiological, biochemical and molecular modifications happen in crops in order to fight different abiotic stresses [70].

5.1 Morphological changes

Under stress, roots extend their length in the soil in order to seep water around themselves and absorb a sufficient amount of water to persist against stressed conditions. Due to an increase in length and more absorption of water through soil, roots biomass also increases in abiotic stress conditions. Shoot length is higher due to sufficient transpiration and translocation mechanism whereas in water deficit plants, shoot length observed was comparatively dwarf as plants need to overcome water and nutrient deficit conditions caused by drought. Shoot dry weight depends on the inner mass and tillers of wheat. Irrigated plants can accumulate water inside tissues due to a sufficient amount of landed water whereas water deficient cannot do so due to which inner mass decreases in case of water stress plants [23, 71].

5.2 Physiological changes

Plants facing abiotic stress, respond at the molecular, cellular and whole plant levels through a number of physiological modifications.

5.2.1 Relative water content (RWC)

A leaf's relative water content (RWC; or' relative turgidity') is measuring its real water content at complete turgidity relative to its peak water holding capacity.

RWC provides a measurement of the decline in leaf water content and may involve a degree of stress in water deficit and heat stress. RWC includes leaf water potential (another helpful estimation of plant water status) with the impact of osmotic adjustment, a powerful mechanism for preserving cell hydration as a measure of plant water status. The development of leaves relies on the water content and the rate of transpiration. With the absorption of water from roots and passing on to leaves, plants will have high rates of transpiration and water content in leaves will elevate effectively in irrigated plants unlikely in water deficit plants and water potential reduced in drought-stressed plants [67].

5.2.2 Relative stress injury (RSI)

It is the relative injury caused to plants under stressed conditions. Relative stress injury is actuated under stressed conditions providing a measurement of injury caused to plants. Plants under such stressed conditions try to become resistant towards the extraneous factors where plants activate some genes and provide tolerance towards the environment. Abiotic stress tolerance appears to be the result of cooperation at the cellular and molecular levels between physiological and biochemical alternation. These modifications may include more rigid cell walls, osmotic adjustment, or smaller cells. There are rapid changes in the mRNA and protein concentrations that result in tolerance towards stress [71].

5.2.3 Water use efficiency (WUE)

Efficiency in water use (WUE) is a crucial variable responsible for the productivity of plants under restricted supply of water. In agronomic terms, it is defined as the percentage of total dry matter (DM) generated (or harvested) to (or applied) used water. Physiologically speaking, nevertheless, WUE is well-defined as the proportion between the set carbon rate and the transpired water rate. The connection between water use and crop production rate is defined as water use efficiency. It is measured in terms of biomass generated by transpiration unit. Greater biomass generated by limited amount of water under stress circumstances is crucial for higher crop yield. Combined stress can also occur to the plant at same time, for example, water shortage can lead to drought and salinity stress simultaneously, uttermost significant factors limiting crop effectiveness and yielding worldwide. Drought resistance in plants can be improved by escaping or avoiding drought condition using WUE mechanism to maintain water level or growing drought tolerant plants [30, 71].

5.2.4 Osmotic adjustment

Osmotic adjustment (OA) is the net elevation of intercellular solutes in response to water stress that allows turgor to be conserved at a lower water potential. OA has been considered as the primary mechanisms in adaptation of plant towards drought as it promotes the tissue's metabolic activity and enables for regeneration but varies considerably between genotypes. The efficiency of plants in arid conditions has been linked with OA in many species such as sorghum, wheat and oilseed brassicas. High levels of ions can critically inhibit cytosolic enzymes of plant cells [72]. Throughout osmotic adjustment, ion accumulation appears to be limited to the vacuoles where ions are kept out of contact with cytosol or subcellular organelles [73]. Because of this ion compartmentation, other solutes such as sugar alcohol, amino acid proline must be assembled in the cytoplasm in order to preserve the cell's water potential balance [74].

5.3 Biochemical changes

Under stress, crops experience a number of cellular and molecular-level biochemical modifications.

5.3.1 Chlorophyll and carotenoid

Chlorophyll and carotenoid content depend on ATP, photosynthetic reactions, NAD. Chlorophyll cannot capture sunlight straight, so it gives sunlight to chlorophyll with the aid of carotenoid, which is an accessory pigment, and transfers it to photosystem I and photosystem II, which transforms light energy into chemical energy acquired in the form of ATP and NADPH. Now, with the help of end products of photosystems and fixed carbon dioxide, plants produce glucose. So, we can say that in wheat more the carotenoid present in the chloroplast, more will be the sunlight captured and thus more will be the chlorophyll [7].

5.3.2 Starch

Starch also evolves as a main molecule in enabling the response to abiotic stresses by plants like water deficit, salinity or extreme temperatures. When photosynthesis is limited under stress conditions plants have a tendency to use starch as energy source. Adverse effect of stress is reduced in plant by releasing some compatible solutes, osmoprotectants, derived sugars and other metabolites to encourage plant growth [75].

5.3.3 Amino acid

Under stress circumstances, amino acids such as proline and arginine play a significant role in controlling osmotic pressure. Proline acts as an osmoprotectant and its accumulation can lead to improved synthesis of cells and their reduced degradation. This behaviour of higher accumulation of proline is because of the expression of the gene encoding pyrroline-5-carboxylate synthase. Additional proof for proline's defensive function was discovered in transgenic crops, where proline overproduction improves tolerance to osmotic stress. In addition to proline, the reaction to osmotic stress also involves other amino acids. Arginine was found to operate as a compatible solution to enhance stress tolerance in leaves. The enzyme involved in arginine biosynthesis is enhanced under hyperosmotic circumstances. In addition, osmotic stress in sunflower and wheat causes enhanced expression of asparagine synthase genes. Glutamine synthase overexpression enhances tolerance of osmotic stress in rice. These findings indicate that changes in osmotic pressure-induced amino acid levels may be due to modified gene expression encoding the enzymes engaged in their metabolism [76].

5.4 Molecular changes

5.4.1 Late embryogenesis abundant proteins (LEA)

LEA proteins are the group of elevated molecular weight proteins that are abundantly present during early embryogenesis and collect in reaction to water stress during seed dehydration. There are different LEA protein groups. The proteins belonging to group 3 are considered to play a part in the sequestration of focused ions between these groups during cell dehydration. LEA proteins of group 1 are expected to have increased water-binding ability, whereas LEA proteins of group 5 are presumed to be appropriate ions during water loss [77].

5.4.2 Detoxifying genes

Also, there are certain detoxifying genes that help to combat abiotic stress. Plants can be protected from damage by increase tolerance towards stress by the accumulation of some attuned solutes and reactive oxygen species (ROS) are scavenged. This action helps to maintain protein structures and functions. The genes responsible for activation of these three enzymes: ascorbate peroxidase, glutathione peroxidase, and glutathione reductase have revealed to have some effect on various abiotic stresses [78].

5.4.3 Heat shock protein genes

An increase in the transcription of a set of genes by heat exposure or other abiotic stress in all species is a heavily maintained biological reaction. The reaction is promoted by the heat shock transcription factor (HSF) in the form of a monomeric, non-DNA binding type current in unstressed cells. It is caused by stress in the form of a trimeric shape that can bind heat shock gene promoters. Gene stimulation encoding thermal shock proteins (Hsps) is one of the most noticeable responses in organisms that are subjected to high molecular temperature [79].

5.5 In reaction to abiotic stress, various genetic mechanisms begin in the crops

5.5.1 ABA pathway

Many genes responsible for response to stress are triggered under abiotic stress conditions. Abscisic acid (ABA) is a main plant stress-signaling hormone and its accumulation automatically increases as the harsh conditions are faced by plant to fight the stress effect. Two pathways are triggered in plant under osmotic stress condition, that is, ABA-dependent and ABA-independent pathways. In ABA-dependent pathway, a mixture of transcription factors, ABRE binding protein/ABRE binding factors (AREB/ABFs) demonstrate critical functions. A cis-element, dehydration-response element/C-repeat (DRE/CRT) and DRE-/CRT-binding protein 2 (DREB2) transcription factors play a main part in the expression of ABA-independent genes in response to osmotic stress. Continuous increase in expression of AREB1/ABF2, AREB2/ABF4 and ABF3 is triggered by drought and salinity in vegetative tissues. Over-expression studies indicate that in conditions of drought stress, these three AREB/ABFs are useful signals from ABA regulators. As shown in the figure, AREB/ABF transcription factors result in gene expression of the genes involved in abiotic stress reaction and tolerance [80].

5.5.2 Cold stress pathway

CBF/DREB1 homologs have been acknowledged in various species. CBF/DREB1 may bind CRT/DRE cis-elements (A/GCCGAC) in the promoter area of COR genes to control the expression of COR genes belonging to the transcription factor family ERF/AP2 (ethylene-responsive factor/APETALA2). The CRT/DRE cis-acting components express the RD29A gene that is believed to be involved in abiotic stress reaction and tolerance [80].

5.5.3 SOS pathway

The SOS signaling path includes three significant enzymes, SOS1, SOS2, and SOS3. SOS1 protein codes for Na^+/H^+ anti-porter plasma membrane. This protein is essential for cell-level regulation of Na^+ efflux. Na^+ long-distance transportation from root to shoot is also facilitated. This protein's overexpression is related to plant salt tolerance [81]. Salt stress-stimulated signals from Ca^{2+} activate the SOS2 gene encoding serine/threonine kinase. This protein includes a correctly established catalytic N-terminal domain and a regulatory C-terminal domain. The SOS3 protein is the third protein involved in the SOS stress signaling pathway. It is a myristylated Ca^{+} binding protein and contains an N-terminus myristylation site. In salt tolerance, this site shows an important role. In the C-terminal regulatory domain of the SOS2 protein, FISL motif is present (also known as NAF domain) that is approximately 21 lengthy sequence of amino acids, and helps to interact with the Ca^{2+} binding SOS3 protein [82]. Kinase activation is the consequence of the SOS2–SOS3 protein interaction. The kinase caused then phosphorylated SOS1 protein thus enhancing its initially identified yeast transportation activity. SOS1 protein is defined by a long cytosolic C-terminal tail composed of a putative nucleotide binding motif and an auto inhibitory domain, which is roughly 700 amino acids long [83]. The target site for SOS2 phosphorylation is this auto inhibitory domain. In relation to salinity tolerance, it regulates trafficking of membrane vesicle, pH homeostasis and functions of vacuole. There is thus a significant increase in intracellular Ca^{2+} level with the increase in Na^{+} concentration, which in turn encourages its binding with SOS3 protein. Ca^{2+} controls homeostasis of intracellular Na^{+} along with SOS proteins. Then the SOS3 protein interacts and activation of the SOS2 protein occurs by releasing its self-inhibition. The complex SOS2-SOS3 goes down to plasma membrane where SOS1 reacts. The result of phosphorylated SOS1 is improved Na^{+} efflux, reducing Na^{+} toxicity [84].

6. Conclusion

There are a broad variety of abiotic stresses that adversely influence the crops. In crops there are prevalent abiotic stresses such as drought, salinity, elevated temperature, low temperature, and metal toxicity. The symptoms of stress, of course, vary with its severity, from being elusive to disastrous. The crops undergo various kinds of modifications due to abiotic stresses, which can cause antagonistic effects on growth and development of plant. The complexity and type of abiotic stress reactions promote the use of extensive, integrative and multidisciplinary techniques to achieve the various levels of stress response regulation. The crops are undergoing modifications such as decreased relative water content, increased ROS output, enhanced relative stress injury, cell electrolyte leakage, decreased photosynthetic pigment amount, decreased root and shoot length, decreased yield, etc. The crops are undergoing numerous morphological, physiological, biochemical and molecular modifications to overcome the impacts of drought. Lately, there has been a lot of attraction in managing abiotic stress in plants. With the growing growth of high performance genomic instruments, crops have created many new methods to combat abiotic stress.

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References

[1] 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**:8. Available from: http://journal.frontiersin.org/article/10.3389/fpls.2017.01147/full

[2] Shavrukov Y, Kurishbayev A, Jatayev S, Shvidchenko V, Zotova L, Koekemoer F, et al. Early flowering as a drought escape mechanism in plants: How can it aid wheat production? Frontiers in Plant Science. 2017;**17**:8. DOI: http://journal.frontiersin.org/article/10.3389/fpls.2017.01950/full

[3] Fghire R, Anaya F, Ali OI, Benlhabib O, Ragab R, Wahbi S. Physiological and photosynthetic response of quinoa to drought stress. Chilean Journal of Agricultural Research. 2015;**75**(2):174-183

[4] Shanker AK, Shanker C. Abiotic and Biotic Stress in Plants—Recent Advances and Future Perspectives [Internet]. Rijeka: IntechOpen; 2016. Available from: http://www.intechopen.com/books/abiotic-and-biotic-stress-in-plants-recent-advances-and-future-perspectives

[5] Browse J, Xin Z. Temperature sensing and cold acclimation. Current Opinion in Plant Biology. 2001;**4**(3):241-246

[6] Pearce R. Plant freezing and damage. Annals of Botany. 2001;**87**(4):417-424

[7] Farooq M, Wahid A, Kobayashi N, Fujita D, Basra SMA. Plant drought stress: Effects, mechanisms and management. Agronomy for Sustainable Development. 2009;**29**(1):185-212

[8] Volkov V. Salinity tolerance in plants. Quantitative approach to ion transport starting from halophytes and stepping to genetic and protein engineering for manipulating ion fluxes. Frontiers in Plant Science. 2015;**27**:6. DOI: http://journal.frontiersin.org/Article/10.3389/fpls.2015.00873/abstract

[9] Flowers TJ. Improving crop salt tolerance. Journal of Experimental Botany. 2004;**55**(396):307-319

[10] Hirayama T, Shinozaki K. Research on plant abiotic stress responses in the post-genome era: Past, present and future. The Plant Journal. 2010;**61**(6):1041-1052

[11] Ashkavand P, Zarafshar M, Tabari M, Mirzaie J, Nikpour A, Kazem Bordbar S, et al. Application of SIO2 nanoparticles AS pretreatment alleviates the impact of drought on the physiological performance of *Prunus mahaleb* (Rosaceae). Boletin de la Sociedad Argentina de Botanica. 2018;**53**:207

[12] Bockheim JG, Gennadiyev AN. The role of soil-forming processes in the definition of taxa in soil taxonomy and the world soil reference base. Geoderma. 2000;**95**(1-2):53-72

[13] Carillo P, Grazia M, Pontecorvo G, Fuggi A, Woodrow P. Salinity Stress and Salt Tolerance. In: Shanker A, editor. Abiotic Stress in Plants—Mechanisms and Adaptations [Internet]. Rijeka: IntechOpen; 2011. Available from: http://www.intechopen.com/books/abiotic-stress-in-plants-mechanisms-and-adaptations/salinity-stress-and-salt-tolerance

[14] Akbari G, Modarres Sanavy SAM, Yousefzadeh S. Effect of auxin and salt stress (NaCl) on seed germination of wheat cultivars (*Triticum aestivum* L.). Pakistan Journal of Biological Sciences. 2007;**10**(15):2557-2561

[15] Devasirvatham V, Tan D. Impact of high temperature and drought stresses

on chickpea production. Agronomy. 2018;**8**(8):145

[16] Takahashi D, Li B, Nakayama T, Kawamura Y, Uemura M. Plant plasma membrane proteomics for improving cold tolerance. Frontiers in Plant Science. 2013;**4**:90

[17] Flora SJS, Mittal M, Mehta A. Heavy metal induced oxidative stress & its possible reversal by chelation therapy. The Indian Journal of Medical Research. 2008;**128**(4):501-523

[18] Wuana RA, Okieimen FE. Heavy metals in contaminated soils: A review of sources, chemistry, risks and best available strategies for remediation. ISRN Ecology. 2011;**2011**:1-20

[19] Schutzendubel A. Plant responses to abiotic stresses: Heavy metal-induced oxidative stress and protection by mycorrhization. Journal of Experimental Botany. 2002;**53**(372):1351-1365

[20] Hall JL. Cellular mechanisms for heavy metal detoxification and tolerance. Journal of Experimental Botany. 2002;**53**(366):1-11

[21] Hossain Z, Mustafa G, Komatsu S. Plant responses to nanoparticle stress. International Journal of Molecular Sciences. 2015;**16**(11):26644-26653

[22] Yadav S, Vijapura A, Dave A, Shah S, Memon Z. Genetic diversity analysis of different wheat [*Triticum aestivum* (L.)] varieties using SSR markers. International Journal of Current Microbiology and Applied Sciences. 2019;**8**(02): 839-846

[23] Tandzi LN, Bradley G, Mutengwa C. Morphological responses of maize to drought, heat and combined stresses at seedling stage. Journal of Biological Sciences. 2019;**19**(1):7-16

[24] Cairns JE, Sonder K, Zaidi PH, Verhulst N, Mahuku G, Babu R, et al. Maize production in a changing climate. In: Advances in Agronomy [Internet]. Elsevier; 2012. pp. 1-58. Available from: https://linkinghub.elsevier.com/retrieve/pii/B9780123942753000067

[25] Shaheen T, Rahman M, Shahid Riaz M, Zafar Y, Rahman M. Soybean production and drought stress. In: Abiotic and Biotic Stresses in Soybean Production [Internet]. Elsevier; 2016. pp. 177-196. Available from: https://linkinghub.elsevier.com/retrieve/pii/B9780128015360000086

[26] Oh-e I, Saitoh K, Kuroda T. Effects of high temperature on growth, yield and dry-matter production of rice grown in the paddy field. Plant Production Science. 2007;**10**(4):412-422

[27] Jagadish S, Craufurd P, Wheeler T. High temperature stress and spikelet fertility in rice (*Oryza sativa* L.). Journal of Experimental Botany. 2007;**58**(7):1627-1635

[28] Mukamuhirwa A, Persson Hovmalm H, Bolinsson H, Ortiz R, Nyamangyoku O, Johansson E. Concurrent drought and temperature stress in rice—A possible result of the predicted climate change: Effects on yield attributes, eating characteristics, and health promoting compounds. International Journal of Environmental Research and Public Health. 2019;**16**(6):1043

[29] Cramer GR, Urano K, Delrot S, Pezzotti M, Shinozaki K. Effects of abiotic stress on plants: A systems biology perspective. BMC Plant Biology. 2011;**11**(1):163

[30] Cattivelli L, Rizza F, Badeck F-W, Mazzucotelli E, Mastrangelo AM, Francia E, et al. Drought tolerance improvement in crop plants: An integrated view from breeding to genomics. Field Crops Research. 2008;**105**(1-2):1-14

[31] Samarah NH. Effects of drought stress on growth and yield of barley.

Agronomy for Sustainable Development. 2005;**25**(1):145-149

[32] Fu J, Huang B. Involvement of antioxidants and lipid peroxidation in the adaptation of two cool-season grasses to localized drought stress. Environmental and Experimental Botany. 2001;**45**(2):105-114

[33] Baker NR. Photosynthesis and the Environment [Internet]. Dordrecht: Kluwer Academic Publishers; 2006. Available from: http://accesbib.uqam.ca/cgi-bin/bduqam/transit.pl?&noMan=25127834

[34] Yokota A. Citrulline and DRIP-1 protein (ArgE homologue) in drought tolerance of wild watermelon. Annals of Botany. 2002;**89**(7):825-832

[35] Turner NC, Wright GC, Siddique KHM. Adaptation of grain legumes (pulses) to water-limited environments. In: Advances in Agronomy [Internet]. Elsevier; 2001. pp. 193-231. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0065211301710152

[36] Bota J, Medrano H, Flexas J. Is photosynthesis limited by decreased Rubisco activity and RuBP content under progressive water stress? The New Phytologist. 2004;**162**(3):671-681

[37] Loreto F, Tricoli D, Marco G. On the relationship between electron transport rate and photosynthesis in leaves of the C4 plant sorghum bicolor exposed to water stress, temperature changes and carbon metabolism inhibition. Functional Plant Biology. 1995;**22**(6):885

[38] Hoekstra FA, Golovina EA, Buitink J. Mechanisms of plant desiccation tolerance. Trends in Plant Science. 2001;**6**(9):431-438

[39] Parida AK, Das AB. Salt tolerance and salinity effects on plants: A review. Ecotoxicology and Environmental Safety. 2005;**60**(3):324-349

[40] Grattan SR, Grieve CM. Salinity-mineral nutrient relations in horticultural crops. Scientia Horticulturae. 1998;**78**(1-4):127-157

[41] Barrero-Sicilia C, Silvestre S, Haslam RP, Michaelson LV. Lipid remodelling: Unravelling the response to cold stress in Arabidopsis and its extremophile relative Eutrema salsugineum. Plant Science. 2017;**263**:194-200

[42] Zhu J, Dong C-H, Zhu J-K. Interplay between cold-responsive gene regulation, metabolism and RNA processing during plant cold acclimation. Current Opinion in Plant Biology. 2007;**10**(3):290-295

[43] Nishida I, Murata N. Chilling sensitivity in plants and cyanobacteria: The crucial contribution of membrane lipids. Annual Review of Plant Physiology and Plant Molecular Biology. 1996;**47**(1):541-568

[44] Thomashow MF. Plant cold acclimation: Freezing tolerance genes and regulatory mechanisms. Annual Review of Plant Physiology and Plant Molecular Biology. 1999;**50**(1):571-599

[45] Chen M, Thelen JJ. ACYL-LIPID DESATURASE2 is required for chilling and freezing tolerance in arabidopsis. The Plant Cell. 2013;**25**(4):1430-1444

[46] Miquel M, James D, Dooner H, Browse J. Arabidopsis requires polyunsaturated lipids for low-temperature survival. Proceedings of the National Academy of Sciences. 1993;**90**(13):6208-6212

[47] Janská A, Maršík P, Zelenková S, Ovesná J. Cold stress and acclimation—What is important for metabolic adjustment? Plant Biology. 2010;**12**(3):395-405

[48] Wahid A, Shabbir A. Induction of heat stress tolerance in barley seedlings by pre-sowing seed treatment with glycinebetaine. Plant Growth Regulation. 2005;**46**(2):133-141

[49] Porter JR. Rising temperatures are likely to reduce crop yields. Nature. 2005;**436**(7048):174-174

[50] Smertenko A, Draber P, Viklicky V, Opatrny Z. Heat stress affects the organization of microtubules and cell division in Nicotiana tabacum cells. Plant, Cell & Environment. 1997;**20**(12):1534-1542

[51] Wahid A, Gelani S, Ashraf M, Foolad M. Heat tolerance in plants: An overview. Environmental and Experimental Botany. 2007;**61**(3):199-223

[52] Huang B, Rachmilevitch S, Xu J. Root carbon and protein metabolism associated with heat tolerance. Journal of Experimental Botany. 2012;**63**(9):3455-3465

[53] Crafts-Brandner SJ. Sensitivity of photosynthesis in a C4 plant, maize, to heat stress. Plant Physiology. 2002;**129**(4):1773-1780

[54] Camejo D, Rodríguez P, Angeles Morales M, Miguel Dell'Amico J, TorrecillasA,AlarcónJJ.Hightemperature effects on photosynthetic activity of two tomato cultivars with different heat susceptibility. Journal of Plant Physiology. 2005;**162**(3):281-289

[55] De Ronde JA, Cress WA, Krüger GHJ, Strasser RJ, Van Staden J. Photosynthetic response of transgenic soybean plants, containing an Arabidopsis P5CR gene, during heat and drought stress. Journal of Plant Physiology. 2004;**161**(11):1211-1224

[56] De Las Rivas J, Barber J. Structure and thermal stability of photosystem II reaction centers studied by infrared spectroscopy. Biochemistry. 1997;**36**(29):8897-8903

[57] Vu JCV, Gesch RW, Pennanen AH, Allen Hartwell L, Boote KJ, Bowes G. Soybean photosynthesis, Rubisco, and carbohydrate enzymes function at supraoptimal temperatures in elevated CO2. Journal of Plant Physiology. 2001;**158**(3):295-307

[58] Morales D, Rodríguez P, Dell'Amico J, Nicolás E, Torrecillas A, Sánchez-Blanco MJ. High-temperature preconditioning and thermal shock imposition affects water relations, gas exchange and root hydraulic conductivity in tomato. Biologia Plantarum. 2004;**47**(2):203-208

[59] Rascio N, Navari-Izzo F. Heavy metal hyperaccumulating plants: How and why do they do it? And what makes them so interesting? Plant Science. 2011;**180**(2):169-181

[60] Uzu G, Sobanska S, Aliouane Y, Pradere P, Dumat C. Study of lead phytoavailability for atmospheric industrial micronic and sub-micronic particles in relation with lead speciation. Environmental Pollution. 2009;**157**(4):1178-1185

[61] Pourrut B, Jean S, Silvestre J, Pinelli E. Lead-induced DNA damage in *Vicia faba* root cells: Potential involvement of oxidative stress. Mutation Research/Genetic Toxicology and Environmental Mutagenesis. 2011;**726**(2):123-128

[62] Saifullah, Meers E, Qadir M, de Caritat P, Tack FMG, Du Laing G, et al. EDTA-assisted Pb phytoextraction. Chemosphere. 2009;**74**(10): 1279-1291

[63] Verbruggen N, Hermans C, Schat H. Molecular mechanisms of metal hyperaccumulation in plants: Tansley review. The New Phytologist. 2009;**181**(4):759-776

[64] Liao YC, Chien SWC, Wang MC, Shen Y, Hung PL, Das B. Effect of transpiration on Pb uptake by lettuce and on water soluble low molecular weight organic acids in rhizosphere. Chemosphere. 2006;**65**(2):343-351

[65] Duarte B, Delgado M, Caçador I. The role of citric acid in cadmium and nickel uptake and translocation, in Halimione portulacoides. Chemosphere. 2007;**69**(5):836-840

[66] Shahid M, Dumat C, Silvestre J, Pinelli E. Effect of fulvic acids on lead-induced oxidative stress to metal sensitive *Vicia faba* L. plant. Biology and Fertility of Soils. 2012;**48**(6):689-697

[67] Maroco JP, Pereira JS, Manuela Chaves M. Growth, photosynthesis and water-use efficiency of two C4Sahelian grasses subjected to water deficits. Journal of Arid Environments. 2000;**45**(2):119-137

[68] Chaves MM, Maroco JP, Pereira JS. Understanding plant responses to drought—From genes to the whole plant. Functional Plant Biology. 2003;**30**(3):239

[69] Wilson J, Ludlow M, Fisher M, Schulze E. Adaptation to water stress of the leaf water relations of four tropical forage species. Functional Plant Biology. 1980;**7**(2):207

[70] Ingram J, Bartels D. The molecular basis of dehydration tolerance in plants. Annual Review of Plant Physiology and Plant Molecular Biology. 1996;**47**(1):377-403

[71] Yadav S, Sharma KD. Molecular and morphophysiological analysis of drought stress in plants. In: Rigobelo EC, editor. Plant Growth [Internet]. Rijeka: IntechOpen; 2016. Available from: http://www.intechopen.com/books/plant-growth/molecular-and-morphophysiological-analysis-of-drought-stress-in-plants

[72] Tangpremsri T, Fukai S, Fischer K. Growth and yield of sorghum lines extracted from a population for differences in osmotic adjustment. Australian Journal of Agricultural Research. 1995;**46**(1):61

[73] El Hafid R. Physiological responses of spring durum wheat cultivars to early-season drought in a mediterranean environment. Annals of Botany. 1998;**81**(2):363-370

[74] Singh V, Singh AK, Raghuvanshi T, Singh MK, Singh V, Singh U. Influence of boron and molybdenum on growth, yield and quality of cauliflower (*Brassica oleracea* L. var. botrytis). International Journal of Current Microbiology and Applied Sciences. 2017;**6**(10):3408-3414

[75] Krasensky J, Jonak C. Drought, salt, and temperature stress-induced metabolic rearrangements and regulatory networks. Journal of Experimental Botany. 2012;**63**(4):1593-1608

[76] Ashraf M, Foolad MR. Roles of glycine betaine and proline in improving plant abiotic stress resistance. Environmental and Experimental Botany. 2007;**59**(2):206-216

[77] Galau GA, Bijaisoradat N, Hughes DW. Accumulation kinetics of cotton late embryogenesis-abundant mRNAs and storage protein mRNAs: Coordinate regulation during embryogenesis and the role of abscisic acid. Developmental Biology. 1987;**123**(1):198-212

[78] Diamant S, Eliahu N, Rosenthal D, Goloubinoff P. Chemical chaperones regulate molecular chaperones *in vitro* and in cells under combined salt and heat stresses. The Journal of Biological Chemistry. 2001;**276**(43):39586-39591

[79] Vierling E. The roles of heat shock proteins in plants. Annual Review of

Plant Physiology and Plant Molecular Biology. 1991;**42**(1):579-620

[80] Shinozaki K, Yamaguchi-Shinozaki K. Gene networks involved in drought stress response and tolerance. Journal of Experimental Botany. 2006;**58**(2):221-227

[81] Shi H, Ishitani M, Kim C, Zhu J-K. The Arabidopsis thaliana salt tolerance gene SOS1 encodes a putative Na+/H+ antiporter. Proceedings of the National Academy of Sciences. 2000;**97**(12):6896-6901

[82] Liu J. The Arabidopsis thaliana SOS2 gene encodes a protein kinase that is required for salt tolerance. Proceedings of the National Academy of Sciences. 2000;**97**(7):3730-3734

[83] Ishitani M. SOS3 function in plant salt tolerance requires N-myristoylation and calcium binding. Plant Cell Online. 2000;**12**(9):1667-1678

[84] Gupta B, Huang B. Mechanism of salinity tolerance in plants: Physiological, biochemical, and molecular characterization. International Journal of Genomics. 2014;**2014**:1-18