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Plant resistance to abiotic stresses

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Abstract

Environmental phenomena often create stressful situations for plants, significantly impacting their metabolism. This can lead to development problems and, thus, drops in production and final quality. Depending on the plant, biotic and abiotic stresses can reduce average plant productivity by up to 90%. Abiotic stresses, in particular, are linked to environmental factors that are indispensable for development and production but can become limiting under certain conditions. For example, water is essential for plant growth in water stress, but deficiency can cause severe damage, as can excess, leading to water stagnation and root asphyxia, compromising final yield. All environmental factors, under extreme conditions, can be dangerous for crops, so it is necessary to know all the physiological aspects to which plants are subjected, which come into play following stress, to control it better.

Keywords: Abiotic stress; Heat stress; Light intensity; Plant growth; Resilience

1. Introduction

In agriculture, abiotic stresses are defined as environmental pressures that can reduce the potential productivity of plants. In agricultural production, environmental stresses of various kinds are considered the main factor that can affect quality. Stress related to sudden changes in temperature, light intensity, nutrient resources change from optimal values, plant damage can occur and, in the worst cases, lead to plant death [1-2]. Abiotic stresses cause a significant reduction in production potential and can cause major losses. The stresses that can cause the most damage and on which research is working to implement genetic improvement strategies are those induced by salinity, water shortages, thermal stresses, and the depletion of nutrient resources [3]. Undoubtedly one of the stresses that cause problems from an agronomic point of view is that of hypoxic conditions, which are often caused by prolonged flooding of the soil, excessive concentrations of nutrients or heavy metals, damage caused by rain or wind, or the mechanical stresses to which flowers and fruit are subjected during processing and storage [4-5]. Other critical stresses can be those related to the time of germination or transplanting or the reduction of the volume of soil or substrate, the high cultivation densities often found in greenhouses. In several cases, stress is linked to other stresses, the interaction of which may cause more significant damage [6]. Stresses can be divided into various levels according to their importance primary, secondary and tertiary. In cold stress, the leading cause is undoubtedly the sudden drop in temperature, which is associated with water imbalance.

On the other hand, water stress appears as a secondary cause in high temperatures, which is often associated with tertiary nutritional stress. In many cases, there is a combination of biotic and abiotic stresses occurring at the same time. Fungal attacks, which can lead to water stress due to blockages in xylem flow, result in plant death [7-8]. In many cases, on the other hand, plants are more susceptible to disease when optimal soil temperatures or substrates are not present, resulting in increased root death, for example. The degree of perception of environmental stimuli and adaptation to various types of stress varies in each plant species [9]. Indeed, adaptation involves hormonal changes that may increase

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or decrease depending on stress. The combination of several plant hormones enables the plant's response to different types of stress [10-11]. The hormones most involved in abiotic stresses are generally auxins and cytokinins, ethylene and abscisic acid, which, by changing their levels within the plant, play a fundamental role in the plant's adaptation to climatic and environmental stresses. This review describes different plant hormones' physiological processes and activity under different stress situations.

2. Influence and modulation of ethylene in plant physiological processes

The gas-type hormone ethylene is considered the simplest due to its chemical composition. For several years, its gaseous nature concealed its effect on plants. In the mid-1900s, several studies highlighted its importance in the various stages of plant development, from its synthesis to its role in leaf abscission. Ethylene is considered a natural product of plants capable of influencing many physiological processes throughout the life of plants in shallow doses [12-13]. All organs produce it, but its biosynthetic capacity varies from organ to tissue. It is mainly synthesized in biotic and abiotic stress situations. The productivity and quality of the plant are inversely proportional to the concentration of ethylene in the environment, an aspect found especially in post-harvest trials on Lilium (Figure 1). Generally, a significant reduction in production is found when the ethylene concentration reaches up to 100 nmol mol-1 in the air. The production of this hormone is linked to the presence of critical enzymes that act in consequential reactions. Methionine, s-adenosine-methionine and 1-aminocyclopropane oxidase lead to the formation of ethylene with the formation of carbon dioxide and cyanide. During the growth and differentiation phases, plants are characterized by high ethylene production, decreasing when they reach maturity. The ethylene peak in some cereals is found in the fast-growing stages when the plants' respiration, photosynthesis and nutrient uptake are at their maximum. An increase in ethylene production under temperature, water and mechanical stress has been found in various types of research [14-15]. Conditions of root asphyxia due to flooding or soil compaction lead to increased ethylene production. In many plants subjected to oxygen deficiency, ethylene activates the process of programmed death, with the formation of aerial pockets at the root level. Cell death is precisely at the expense of the cells that succumb under anoxic conditions [16]. The programmed cell death of root cells is all the faster; the higher the calcium concentration, the increased ethylene production under these conditions. Various research has shown that although ethylene production does not vary, the genes activated for the same biosynthetic pathway are the same, giving the plant certain flexibility that enables it to respond more precisely to any stress [17-18-19].

Figure 1 Analysis of ethylene production, senescence hormone in Asiatic Lilium

3. Growth hormones and their interactions with environmental stresses

Cytokinins are organic molecules that play a role in most aspects of plant growth and development, including cell division, sink/source relationships, vascular development, chloroplast differentiation, apical dominance and senescence. These effects of cytokinins often result from interactions with other plant hormones and signals from outside the plant: one of the first studies on this hormone indicated that the interaction between auxins and cytokinins was decisive for the type of organs regenerated from undifferentiated callous tissue in vitro. Other studies explained the elements involved in the cytokinin-related signal chain in more detail. Of the many compounds with auxinic activity, indol-3-acetic acid (IAA) is undoubtedly the most widespread in the plant world [20-21]. The simultaneous action of auxins and cytokinins has already been studied for several years since cytokinins were identified for their ability to stimulate, together with auxins, cell division in vitro cultures. The concentration of cytokinins and auxins is crucial in determining the type of organs regenerated from undifferentiated callous tissue in vitro: a callus placed on a substrate with a high cytokinin/auxin ratio produces many shoots and few roots.

In contrast, a callus placed in a substrate with a low cytokinin/auxin ratio produces mainly roots. Studies on auxins and cytokinins have shown how these phytohormones interact in plant physiological processes related to plant development, cell division, root development, senescence and tissue differentiation [22]. Studies have shown that the levels of auxins and cytokinins are intercorrelated; thus, changing the quantity of one hormone affects the other. The increase in auxins generally leads to a lowering of cytokinins. Auxins lead to an increase in cytokinin catabolism by stimulation of the cytokine oxidase enzyme and rapidly suppressing cytokinin biosynthesis. An increase in cytokinin levels leads to an increase in auxin levels, as found in Nicotiana plants. Applications of cytokinins to maize and pea increased IAA [23].

Many authors have pointed out that cytokinins probably influence auxin levels through developmental changes rather than direct effects [24]. Ethylene biosynthesis is modulated by various plant hormones such as cytokinins, jasmonic acid, brassinosteroids, auxins, and ethylene. Studies have shown that there are numerous interactions between these hormones. In Arabidopsis, auxins and cytokinins administered separately stimulate ethylene production, but with both hormones, a significantly increased biosynthesis is achieved [24-25]. Recent studies suggest that auxins and cytokinins increase the levels of transcripts from three ACS genes, whereas cytokinins alone stabilize the proteins obtained. Cytokinins also play a crucial role in delaying leaf senescence, usually linked to decreased cytokinin content in leaf tissue. Exogenous applications of cytokinins inhibit the degradation of chlorophyll and photosynthetic proteins. Decreases in cytokinin levels have been observed in response to water stress conditions. Mild water stresses showed no changes in cytokinin levels, whereas more severe water levels increased cytokinin levels [26]. Many experiments have shown interactions between abscisic acid and cytokinins at different levels. Cytokinins may operate not only at the level of guard cells by alleviating the effect of ABA but may also partially inhibit the accumulation of ABA-induced by water stress. However, changes in foliar ABA content and cytokinin content and composition during water stress and subsequent rehydration, as well as the interaction between ABA and cytokinins, are species-specific. However, a more rapid modification by the plant of the ABA/cytokinin ratio following water deficit exposure could result in a better and more efficient adaptation to stress situations [27-28].

4. Physiological processes involving gibberellins

Gibberellins (GA) are generally classified based on chemical structure and named with a sequence number, indicating the identification order. GA is usually produced in young tissues, including germinating seeds, but also in mature leaves. GA promote stem elongation by stimulating both cell division and distension; they stimulate flowering or pre-flowering in many plants; they break the dormancy of those seeds that require stratification as a pre-germination treatment; in cereal caryopses, they activate the synthesis of the enzyme alpha-amylase necessary for the mobilization of starch reserves; they can induce the development of parthenocarpic fruits in several cultivated species, and they slow down leaf and fruit senescence [29-30]. GA plays an essential role in shade syndrome, triggered by particular growing conditions and has important practical implications, especially in the greenhouse cultivation of potted ornamentals. Many environmental and cultivation factors are responsible for the spinning of greenhouse plants, such as abundant watering and fertilization, high temperature, absence of wind and UV radiation. The most important factor, however, is the high cultivation density [31]. The plants' quality of light is detected through various photoreception systems linked to the presence of pigments: phytochrome, cryptochrome and a more or less well-identified UV light receptor. The shading syndrome appears to be regulated by phytochrome. Through the phytochrome, the plant is thus able to perceive the presence of neighbouring plants and initiate morphological changes that increase its competitiveness, e.g. through increased interception of photosynthetically active radiation [32]. GA appear to be involved in signal transduction; several works have shown how stem elongation mediated by phytochrome or stimulated, in some aquatic plants, by ethylene, depends on an increase in GA activity, linked to increased synthesis and sensitivity of the tissues involved. Some authors have observed that specific morphological effects such as leaf hyponasty and stem and petiole elongation are regulated independently [33-34]. Hyponasty can also occur independently of ethylene, but GA synthesis is also required when this hormone is involved. In contrast, stem and petiole elongation always requires GA synthesis, regardless of the type of signal that induces the response.

5. Water stress in plants

Water can limit the growth and productivity of crops virtually everywhere, either because of sudden dry spells or because of typically low rainfall, which makes irrigation necessary. Cell growth appears to be the most sensitive response to water stress [35]. A decrease in external water potential leads to a significant decrease in cell growth and, thus, in both root and shoot growth. Some authors have attributed this sensitivity to the frequent observation that many plants grow mainly at night when there is less water stress. Usually, the inhibition of cell relaxation is immediately followed by a decrease in cell wall synthesis. Protein synthesis can be equally sensitive to water stress [36-37-38]. These responses are only observed in actively growing tissues; it has long been observed that cell wall synthesis is dependent on cell growth. The effects on protein synthesis are controlled at the translation level, i.e. at the level of ribosomal activity. Many types of research indicate that the activity of certain enzymes, particularly nitrate reductase and phenylalanine ammonia-lyase (PAL), decreases rapidly with increasing water stress [39].

In contrast, other enzymes, such as alpha-amylase and ribonuclease, increase activity. Nitrogen fixation also decreases with water stress, which is consistent with the decrease in nitrate reductase activity [40]. Cell division is also inhibited at the stress levels that cause the observed changes in enzyme activity. In addition, stomata begin to close, which leads to a decrease in transpiration and photosynthesis. ABA usually appears to play a role in plant water stress resistance. Most studies have been carried out with cultivars of both drought-sensitive and drought-resistant plants. Generally, resistant cultivars show a higher ABA content when stressed, whereas sensitive cultivars can be phenotypically converted to resistant types by ABA treatments. Plant growth is susceptible to water stress, and production can decrease significantly even in moderate drought conditions. During water stress, cells are smaller and leave develop less, so less surface area is available for photosynthesis. At certain stages, plants can also be susceptible to moderate drought, as occurs in maize during the formation of the stem inflorescence. Stress responses are, therefore, plastic, even in the case of moderate water stress [41].

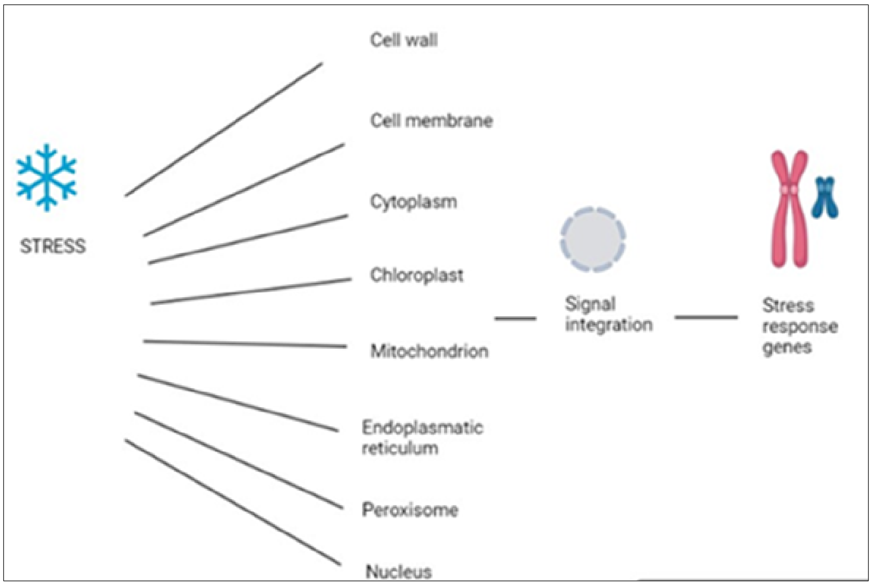

Figure 2 Abiotic stress signalling in plants

6. Plant resistance and response mechanisms to abiotic stresses

Plants can acclimate to different stressors, developing a tolerance to the stressor that induced the variation and often to other factors (Figure 3) [42]. Plants under conditions of low water potential, high light intensity or in the presence of other factors, such as high phosphorous and low nitrogen, become drought-tolerant compared to plants of the same species not treated in the same way. Most species that survive freezing temperatures tolerate some ice formation in their tissues [43-44]. Generally, more resistant plants survive with a higher frozen water content than less resistant plants. There are several mechanisms of resistance. Frost resistance typically develops when plants are subjected to relatively low temperatures (e.g. five °C) for several days. Sometimes temperatures of -5°C are necessary to achieve maximum acclimatization. In several species, acclimatization is induced by short-day conditions, and there are indications that a stimulus may be transported from the leaf tissue to the stem [45-46-47]. The development of frost resistance is a metabolic process that requires an energy source: apparently, this could be light and photosynthesis. Salt resistance can be significantly increased by exposure to high salinity conditions. Many hypotheses have been put forward to explain tolerance and acclimatization; some are shared by all types of stress [48]. Under severe water stress, the viscosity of the protoplasm usually increases, often to the point where the protoplasm becomes friable. Some plants retain protoplasmic plasticity much better than others at a certain degree of water stress, and their degradation of starches and proteins is less appreciable [49].

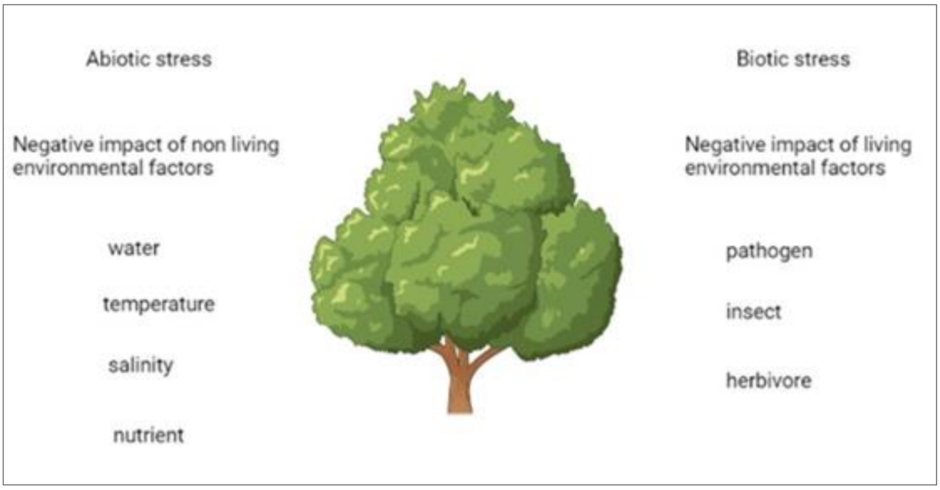

Figure 3 Causes of biotic and abiotic stresses on plants

7. Conclusion

An important branch of environmental physiology concerns how plants and animals respond to environmental conditions that differ significantly from those that appear optimal for the organisms in question, or in a broader sense, for organisms in general. This is stress physiology, a field of ecophysiology that can describe the limiting factors of plant distribution. Even in this area, studies are directed towards the study of the limitation of agricultural production under adverse environmental conditions. Furthermore, most studies on abiotic stresses are generally conducted in a controlled environment and therefore do not adequately reflect the conditions in the field. Furthermore, using the knowledge gained to obtain plants with high-stress tolerance makes it problematic. Therefore, it is necessary to expand the study of how plants react to environmental phenomena and the role that plant hormones play in the processes of perception and signal transmission in the presence of different types of stress.

Compliance with ethical standards

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References

[1] Ali RM, Abbas HM. Response of salt-stressed barley seedlings to phenylurea. Plant Soil Environ. 2003; 49: 158–62.

[2] Baena-Gonzalez E, Rolland F, Thevelein JM, Sheen J. A central integrator of transcription networks in plant stress and energy signalling. Nature. 2007; 448 (7156): 938–942.

[3] Baena-Gonzalez E, Sheen J. Convergent energy and stress signaling. Trends Plant Sci. 2008; 13 (9): 474–482.

[4] Ben-Zioni A, Itai C, Vaadia Y. Water and salt stresses, kinetin and protein synthesis in tobacco leaves. Plant Physiol. 1967; 42: 361–365.

[5] Christiansen JL, Jornsgard B, Buskov S, Olsen CE. Effect of drought stress on content and composition of seed alkaloids in narrow-leafed lupin, Lupinus angustifolius L. Eur J Agron. 1997; 7:307–14.

[6] Cramer GR. Abiotic stress & plant responses from the whole vine to the genes. Aust J Grape Wine Res. 2010; 16: 86–93.

[7] Daneshmand F, Arvin MJ, Kalantari KM. Physiological responses to NaCl stress in three wild species of potato in vitro. Acta Physiol Plant. 2010; 32:91–101.

[8] Dinneny JR, Long TA, Wang JY, Jung JW, Mace D, Pointer S, Barron C, Brady SM, Schiefelbein J, Benfey PN. Cell identity mediates the response of Arabidopsis roots to abiotic stress. Science. 2008; 320 (5878): 942–945.

[9] Gill SS, Tuteja N. Polyamines and abiotic stress tolerance in plants. Plant Signal Behav. 2010; 5: 26–33.

[10] Godoy F, Olivos-Hernández K, Stange C, Handford M. Abiotic Stress in Crop Species: Improving Tolerance by Applying Plant Metabolites. Plants. 2021; 10:186.

[11] Good AG, Zaplachinski ST. The effects of drought stress on free amino acid accumulation and protein synthesis in brassica napus. Physiol Plant. 1994; 90 (1): 9–14.

[12] Gosal SS, Wani SH, Kang MS. Water and agricultural sustainability strategies. Kang MS, Ed. CRC Press., 2010; 259.

[13] Hagemeyer J. Ecophysiology of plant growth under heavy metal stress. In: Prasad MNV, Hagemeyer J, Eds. Heavy Metal Stress in Plants, Berlin: Springer. 1999; 222.

[14] Hubbard KE, Nishimura N, Hitomi K, Getzoff ED, Schroeder JI. Early abscisic acid signal transduction mechanisms: newly discovered components and newly emerging questions. Genes Dev. 2010; 24 (16): 1695–1708.

[15] Hummel I, Pantin F, Sulpice R, Piques M, Rolland G, Dauzat M, Christophe A, Pervent M, Bouteille M, Stitt M, Gibon Y, Muller B. Arabidopsis plants acclimate to water deficit at low cost through changes of carbon usage: an integrated perspective using growth, metabolite, enzyme, and gene expression analysis. Plant Physiol. 2010; 154 (1): 357–372.

[16] Kamran M, Parveen A, Ahmar S, Malik Z, Hussain S, Chattha MS, Saleem MH, Adil M, Heidari P, Chen JT. An Overview of Hazardous Impacts of Soil Salinity in Crops, Tolerance Mechanisms, and Amelioration through Selenium Supplementation. Int. J. Mol. Sci. 2019; 21:148.

[17] Kaplan F, Kopka J, Haskell DW, Zhao W, Schiller KC, Gatzke N, Sung DY, Guy CL. Exploring the temperature-stress metabolome of Arabidopsis. Plant Physiol. 2004; 136 (4): 4159–4168.

[18] Kitano H. Systems biology: a brief overview. Science. 2002; 295(5560): 1662–1664.

[19] Kovacs Z, Simon-Sarkadi L, Szucs A, Kocsy G. Differential effects of cold, osmotic stress and abscisic acid on polyamine accumulation in wheat. Amino Acids. 2011; 38: 623–631.

[20] Leung J, Giraudat J. Abscisic acid signal transduction. Annu Rev Plant Physiol Plant Mol Biol. 1998; 49: 199–222.

[21] Mahajan S, Tuteja N. Cold, salinity and drought stresses: An overview. Arch Biochem Biophys. 2005; 444: 139–158.

[22] Morison JIL, Lawlor DW. Interactions between increasing CO2 concentration and temperature on plant growth. Plant Cell Environ. 1999; 22:659–682.

[23] Pedrazani H, Racagni G, Alemano S, Miersch O, Ramirez I, Pena-Cortes H. Salt tolerant tomato plants show increased levels of jasmonic acid. Plant Growth Regul. 2003; 412: 149–158.

[24] Pimm SL. Climate disruption and biodiversity. Curr Biol. 2009; 19: 595–601.

[25] Pitta-Alvarez SI, Spollansky TC, Giullietti AM. The influence of different biotic and abiotic elicitors on the production and profile of tropane alkaloids in hairy root cultures of Brugmansia candida. Enzyme Microb Technol. 2000; 26: 252–258.

[26] Posmyk MM, Balabusta M, Wieczorek M, Sliwinska E, Janas KM. Melatonin applied to cucumber (Cucumis sativus L.) seeds improves germination during chilling stress. J Pineal Res. 2009; 46: 214–223.

[27] Raj S, Brautigam K, Hamanishi ET, Wilkins O, Thomas BR, Schroeder W, Mansfield SD, Plant AL, Campbell MM. Clone history shapes Populus drought responses. Proc Natl Acad Sci USA. 2011.

[28] Rajput V, Harish Singh R, Verma K, Sharma L, Quiroz-Figueroa F, Meena M, Gour V, Minkina T, Sushkova S. Recent Developments in Enzymatic Antioxidant Defence Mechanism in Plants with Special Reference to Abiotic Stress. Biology. 2021; 10: 267.

[29] Rajput VD, Yaning C, Ayup M, Minkina T, Sushkova S, Mandzhieva S. Physiological and Hydrological Changes in Populus euphratica Seedlings Under Salinity Stress. Acta Ecol. Sin. 2017; 37:229–235.

[30] Shahid MA, Sarkhosh A, Khan N, Balal RM, Ali S, Rossi L, Gómez C, Mattson N, Nasim W, Garcia-Sanchez F. Insights into the Physiological and Biochemical Impacts of Salt Stress on Plant Growth and Development. Agronomy. 2020; 10: 938.

[31] Singh S, Sinha S. Accumulation of metals and its effects in Brassica juncea (L.) Czern. (cv. Rohini) grown on various amendments of tannery waste. Ecotoxicol Environ Saf. 2005; 62: 118–127.

[32] Skirycz A, Inze D. More from less: plant growth under limited water. Curr Opin Biotechnol. 2010; 21(2): 197–203.

[33] Smeekens S, Ma J, Hanson J, Rolland F. Sugar signals and molecular networks controlling plant growth. Curr Opin Plant Biol. 2010; 13 (3): 274–279.

[34] Stepanova AN, Alonso JM. Ethylene signaling and response: where different regulatory modules meet. Curr Opin Plant Biol. 2009; 12 (5): 548–555.

[35] Szakiel A, Paczkowski C, Henry M. Influence of environmental abiotic factors on the content of saponins in plants. Phytochem Rev. 2010; 2:25.

[36] Takahashi S, Seki M, Ishida J, Satou M, Sakurai T, Narusaka M, Kamiya A, Nakajima M, Enju A, Akiyama K, Yamaguchi-Shinozaki K, Shinozaki K. Monitoring the expression profiles of genes induced by hyperosmotic, high salinity, and oxidative stress and abscisic acid treatment in Arabidopsis cell culture using a full-length cDNA microarray. Plant Mol Biol. 2004; 56 (1): 2955.

[37] Tuteja N. Mechanisms of high salinity tolerance in plants. Methods Enzymol. 2007; 428: 419–38.

[38] Vanderauwera S, De BM, Van dSN, Van dCB, Metzlaff M, Van BF. Silencing of poly(ADP-ribose) polymerase in plants alters abiotic stress signal transduction. Proc Natl Acad Sci USA. 2007; 104 (38): 15150–15155.

[39] Wang P, Lombi E, Zhao FJ, Kopittke PM. Nanotechnology: A New Opportunity in Plant Sciences. Trends Plant Sci. 2016; 21: 699–712.

[40] Weston DJ, Gunter LE, Rogers A, Wullschleger SD. Connecting genes, coexpression modules, and molecular signatures to environmental stress phenotypes in plants. BMC Systems Biol. 2008; 2: 16-30.

[41] Wilkinson S, Davies WJ. Drought, ozone, ABA and ethylene: new insights from cell to plant to community. Plant Cell Environ. 2009.

[42] Xiao B, Huang Y, Tang N, Xiong L. Over-expression of a LEA gene in rice improves drought resistance under the field conditions. TAG Theoretical and applied genetics Theoretische und angewandte Genetik. 2007; 115 (1): 35-46.

[43] Xu Z, Zhou G, Shimizu H. Plant responses to drought and rewatering. Plant Signal Behav. 2010; 5: 649-654.

[44] Yadav B, Jogawat A, Rahman S, Narayan OP. Secondary Metabolites in the Drought Stress Tolerance of Crop Plants: A Review. Gene Rep. 2021; 23: 101040.

[45] Yamaguchi-Shinozaki K, Shinozaki K. Transcriptional regulatory networks in cellular responses and tolerance to dehydration and cold stresses. Annu Rev Plant Biol. 2006; 57: 781-803.

[46] Yoo SD, Cho Y, Sheen J. Emerging connections in the ethylene signaling network. Trends Plant Sci. 2009; 14 (5): 270–279.

[47] Yoshida T, Fujita Y, Sayama H, Maruyama K, Mizoi J, Shinozaki K, Yamaguchi-Shinozaki K. AREB1, AREB2, and ABF3 are master transcription factors that cooperatively regulate ABRE-dependent ABA signaling involved in drought stress tolerance and require ABA for full activation. Plant J. 2010; 61 (4): 672–685.

[48] Yun KY, Park MR, Mohanty B, Herath V, Xu F, Mauleon R, Wijaya E, Bajic VB, Bruskiewich R, de LRBG. Transcriptional regulatory network triggered by oxidative signals configures the early response mechanisms of japonica rice to chilling stress. BMC Plant Biol. 2010; 10: 16-10.

[49] Zia R, Nawaz MS, Siddique MJ, Hakim S, Imran A. Plant Survival Under Drought Stress: Implications, Adaptive Responses, and Integrated Rhizosphere Management Strategy for Stress Mitigation. Microbiol. Res. 2021; 242: 126626