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Environmental stress factors effecting the life process of agricultural plant production: A Review

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Abstract

Due to their sessile nature, plants are vulnerable to a variety of environmental hazards, including heat, cold, drought, heavy metals, and salinity, which pose serious risks to plant growth and yield. An endogenic, dynamic system like a biological one constantly seeks a steady inflow of energy to maintain its meta-stable state, known as homeostasis. Any disruption of this homeostasis caused by the environment can be explained as biological stress. Abiotic and biotic stresses are two broad categories of biological stress that restrict a crop's ability to grow and produce. Although both of these stresses are unavoidable, they can both be reduced to some extent in order to boostp crops' potential for productivity. Breeding, biotechnology, and agronomic approaches are some of the management techniques for successful crop production under stress conditions. The basic concepts of various types of stress and their effects on crop production, as well as some management strategies to lessen the effects of stress on crops, have been attempted to be clearly presented in this review. The methodological approach described in this publication was developed using significant analysis articles and related literature that had undergone peer review. The selection of literature was based primarily on Google search engines and platforms from Research Gate, Google Scholar, Web of Science, Science Direct, MDPI, PubMed, and many other national and international scientific journals and publishing websites. It was decided to classify additional related publications by paying attention to important papers' citations. This review did not attempt to cover all topics; instead, it concentrated on those that were most relevant. Peer-reviewed literature, background data, institutional publications, a very small number of unpublished sources (affiliated Ph.D. dissertations and M.Sc. theses), and institutional publications were all taken into account.

Keywords: Stress, abiotic stress, temperature stress, heavy metal stress, salinity stress

Introduction

Being sessile organisms, plants are constantly exposed to a variety of biotic and abiotic environmental stressors, with rapidly changing climatic conditions being a major contributor. Heat, cold, drought, flood, salinity, and heavy metals/metalloids have historically posed the greatest threats to agriculture because they interfere with both physiologically and molecularly essential life processes (Hasanuzzaman, 2020; Saddiq *et al*., 2021) [39]. Regarding yield reduction, abiotic stresses have always been a top concern for agronomic crops. Abiotic stresses, such as salinity, drought, and the buildup of heavy metals, can be harmful to plants. According to the data, abiotic stresses, which are regarded as the main factor limiting crop productivity, have resulted in a 70% reduction in crop yield (Ma *et al*., 2021; Jewell *et al*., 2010) [26]. The management of the food demand for a rapidly expanding population is a serious concern for agriculture stakeholders as natural resources are depleting. When grown in natural environments, plants are constantly in danger and frequently experience abiotic stresses (Ernst *et al*., 2008) [16]. In these circumstances, plants have evolved some strategies that they use in accordance with the environmental conditions. While some plants can escape the harmful effects of the stresses, others attempt to do so (Cramer *et al*., 2011) [7]. But some plants develop a tolerable defence. Even so, each of the aforementioned strategies results in a certain amount of yield loss, but the tolerant mechanism is in some ways less harmful to plants than the other strategies used. According to scientists, this process is extremely complicated and involves a number of different mechanisms, such as significant alterations at the metabolic and biochemical levels that change morpho-physiological pathways (Janicka-Russak *et al*., 2008). Additionally, some modifications to the transcription and translational processes have been observed. According to WHO, there are currently 55 million drought-affected people in the world, and by 2030, 700 million people are predicted to be at risk of being displaced as a result of drought (WHO 2020; Yadav *et al*., 2021) [48]. In fact, water is the element that plants need the most. Plants mainly rely on moisture to initiate activities, from emergence to growth. Long-term water shortage at any stage of growth results in structural instability and shortens the life cycle of the organism (Garzón *et al*., 2011).

Heavy Metals and Their Sources

Numerous unfavourable environmental factors, including HM pollution, have an impact on plant production (Rai *et al*., 2019) [37]. IHMs released from increased industrial activity can contaminate wastewater-contaminated soil in both urban and agricultural areas, and the resulting sewage sludge that seeps into the soil can pose very serious risks. Another source of HM pollution, aerosol particles from the burning of fossil fuels or other sources can easily contaminate our agricultural areas by spreading in the atmosphere. Furthermore, Zafar-Ul-Hye *et al*. (2020) found that increased phosphate fertiliser use also affects soil contamination levels, leading to high levels of HMs when these fertilisers are used over an extended period of time. In recent years, strict regulations have reduced the amount of toxic HMs that are released into the soil. Reduced atmospheric emissions, restrictions on wastewater's HM content and lead removal from paints and fuels are a few regulatory examples (Alloway, 2013) [13]. Essential and nonessential HMs are the two main categories of HMs. Zinc (Zn), cobalt (Co), manganese (Mn), molybdenum (Mo), nickel (Ni), copper (Cu), vanadium (V), and iron (Fe) are the most significant essential HMs acting as microelements. Despite having a dominant function in living things, they have the potential to be toxic in high concentrations (Rai *et al.*, 2019) [37]. Microelements play a significant physiological role because they can serve as active sites for enzymes or atoms of prosthetic groups, even though they are only minimally required for plant metabolism (Tripathi *et al.*, 2015) [42]. With regard to essential elements, there are two potential issues: a deficiency could prevent plants from developing, which would typically result in a decrease in photosynthetic production and, ultimately, a lower yield. Excess can result from high doses or prolonged low-dose poisoning, which can cause toxic symptoms that eventually cause death (Dimkpa and Bindraban, 2016) [14]. One of the most frequent effects of stress brought on by HMs is the inhibition of plant growth (Zhang *et al.*, 2019) [49].

Zinc effects on plants

According to Rout and Dass (2000) [38], zinc (Zn) is an important micronutrient with a lengthy biological half-life that has an impact on a number of plant metabolic processes. Zn and Cd phytotoxicity is demonstrated in a variety of plant species, including *Phaseolus vulgaris* (Cakmak and Marshner, 1993), *Brassica juncea* (Prasad and Hagmeyer, 1999), and tobacco (Tkalec *et al.*, 2014), by reductions in growth and development, metabolism, and an induction of oxidative damage. *Phaseolus vulgaris* and pea plants, respectively, have both reported that Cd and Zn can alter the catalytic efficiency of enzymes (Van Assche *et al.*, 1988) [44]. Zn concentrations that are frequently higher than those needed as nutrients and may result in phytotoxicity can be found in contaminated soils. Polluted soils have been found to contain Zn concentrations between 150 and 300 mg/kg (Devries *et al.*, 2002) [13]. High soil Zn concentrations impair a variety of plant metabolic processes, slow growth, and hasten senescence. According to Malik *et al.* (2011) [31], zinc toxicity in plants inhibited the growth of the root and shoot. After prolonged exposure to high soil Zn levels, zinc toxicity also results in chlorosis in the younger leaves, which can spread to the older leaves (Ebbs and Kochian, 1997) [15].

Cadmium effects on plants

According to Salt *et al.* (1995) [40], the legal limit for cadmium (Cd) in agricultural soil is 100 mg/kg soil. Chlorosis, growth inhibition, browning of root tips, and ultimately death are all visible symptoms of injury in plants grown in soil with high levels of Cd (Wojcik and Tukiendorf, 2004; Mohanpuria *et al.*, 2007 [33]; Guo *et al.*, 2008) [20]. As a result of Cd-induced root Fe (III) reductase inhibition, there was a severe Fe (II) deficiency, which adversely affected photosynthesis (Alcantara *et al.*, 1994). The uptake, transport, and utilisation of several elements (Ca, Mg, P, and K) as well as water by plants have all been shown to be hampered by Cd (Das *et al.*, 1997) [11]. By inhibiting the activity of nitrate reductase in the shoots, cadmium also decreased nitrate absorption and its transport from roots to shoots (Hernandez *et al.*, 1996). In nodules of soybean plants exposed to Cd, nitrogen fixation and primary ammonia assimilation decreased (Balestrasse *et al.*, 2003).

Copper effects on plants

According to Gang *et al.* (2013) [18], copper (Cu) is regarded as a micronutrient for plants and is crucial for ATP synthesis and CO_2 uptake. The respiratory electron transport chain's cytochrome oxidase and the photosynthetic system's plastocyanin both require copper as essential building blocks (Demirevska-Kepova *et al.*, 2004). But increased mining and industrial activity has helped to explain why there is now more copper in ecosystems. Various human activities, such as the mining and smelting of copper-containing ores, also add copper to soils. Waste rocks and tailings from mining operations are produced in large quantities and are deposited on the surface. An excessive amount of copper in the soil has cytotoxic effects, stresses plants, and harms them. This results in leaf chlorosis and slowed plant growth (Lewis *et al.*, 2001) [30]. Oxidative stress and ROS are produced when plants are exposed to too much copper (Stadtman and Oliver, 1991).

Mercury effects on plants

Due to its existence in various forms, including HgS, Hg2+, Hg, and methyl-Hg, mercury is a special metal. However, ionic form (Hg2+) predominates in agricultural soil (Han *et al.*, 2006) [21]. By adhering to sulphides, clay particles, and organic materials, mercury that has been released into the soil primarily stays in the solid phase. Hg2+ can easily accumulate in higher and aquatic plants, according to mounting evidence (Kamal *et al.*, 2004) [28]. Strong phytotoxicity is caused by high levels of Hg2+ in plant cells. Plants that are exposed to toxic levels of Hg2+ may experience physical harm as well as physiological issues (Zhou *et al.*, 2007) [50]. For instance, Hg2+ can bind to water channel proteins, causing plants to physically obstruct water flow by closing their leaf stomata (Zhang and Tyerman, 1999).

Chromium effects on plants

Compounds containing chromium (Cr) are extremely harmful to plants' growth and development (Davies *et al.*, 2002) [12]. The capacity of a seed to germinate in a medium containing Cr would be indicative of its level of tolerance to this metal since seed germination is the first physiological process affected by Cr (Peralta *et al.*, 2001) [36]. With 20 ppm Cr, the weed Echinochloa colona seed germination was decreased to 25% (Rout *et al.*, 2000) [38]. *Phaseolus vulgaris* bush bean germination was reduced by up to 48% when soil with high levels of hexavalent Cr (500 ppm) was present (Parr and Taylor, 1982) [35]. Peralta *et al.* (2001) [36] discovered that the ability of Lucerne (Medicago sativa cv. Malone) seeds to germinate and grow in the contaminated medium was reduced by 23% at 40 ppm of Cr (VI). With 20 and 80 ppm Cr, respectively, reductions of 32–57% in sugarcane bud germination were noted (Jain *et al.*, 2000) [25]. The impact of Cr on photosynthesis in higher plants and trees is well established (Van Assche and Clijsters, 1983) [43]. However, both photosystems in plants as a whole were impacted.

Nickel effects on plants

With the exception of ultramafic or serpentinic soils, nickel (Ni), a transition metal, is present in trace concentrations in natural soils. However, human activities like mining, smelter emissions, coal and oil burning, sewage, phosphate fertilisers, and pesticides are causing Ni2+ concentration to rise in some areas (Gimeno-Garcia *et al.*, 1996). In comparison to the range of 10 to 1,000 mg/kg found in natural soil, the concentration of Ni2+ in polluted soil may be 20 to 30 fold (200-26,000 mg/kg) higher (Izosimova, 2005) [24]. Numerous physiological changes, including chlorosis and necrosis, are brought on by excessive Ni2+ in the soil in a variety of plant species, including rice (Das *et al*., 1997), (Pandey and Sharma, 2002) [34]. Plants raised in soil with high Ni2+ levels displayed nutrient imbalance impairment and abnormal cell membrane function. As observed in Oryza sativa shoots, Ni2+ altered the plasma membrane's lipid composition and H-ATPase activity (Ros *et al*. 1992). According to Gonnelli *et al*. (2001), Ni2+-sensitive plants had higher MDA concentrations than Ni2+-tolerant plants did. Such modifications might affect how well the membrane functions and the ion balance in the cytoplasm, especially for K2+, the ion that travels the fastest across plant cell membrane. Dicot and monocot plant species experienced a decline in water content as a result of high Ni2+ uptake. Indicators of the development of Ni2+ toxicity in plants include a decline in water uptake (Pandey and Sharma, 2002) [34].

Manganese effects on plants

Reduced photosynthetic rate results from excessive manganese (Mn) buildup in leaves **(**Kitao *et al*., 1997 b). Mn is easily transported through the transpiration stream from the root to the shoot, but it is less easily remobilized through phloem to other organs once it has reached the leaves (Loneragan, 1988). A typical sign of Mn toxicity is necrotic brown spotting on leaves, petioles, and stems (Wu, 1994) [47]. Starting on the lower leaves, this spotting gradually moves up towards the upper leaves (Horiguchi, 1988) [22]. According to Elamin and Wilcox (1986a), the speckles can grow in size and number over time, causing necrotic lesions, browning, and death of the leaves. Cucumis sativus has been shown to exhibit general leaf bronzing and internode shortening (Crawford *et al*. 1989) [8]. If the toxicity is acute, the symptom advances to leave marginal and interveinal necrosis (Bachman and Miller, 1995) [5]. This symptom begins at the leaf margins and progresses to the interveinal areas.

Iron effects on plants

Iron plays a number of significant biological roles in processes as diverse as photosynthesis, chloroplast development, and chlorophyll biosynthesis. Iron is an essential element for all plants. According to Marschner (1995), iron is a key component of the cellular redox systems found in heme proteins like cytochromes, catalase, peroxidase, and leghemoglobin as well as iron sulphur proteins like ferredoxin, acontiase, and superoxide dismutase (SOD). The symptoms of iron toxicity in leaf tissues only manifest under flooded conditions, which involves the microbial reduction of insoluble Fe3+ to insoluble Fe2+ (Becker and Asch, 2005) [6], despite the fact that the majority of mineral soils are rich in iron. According to Sinha *et al*. (1997) [41], iron toxicity in plants such as tobacco, canola, soybeans, and Hydrilla verticillata results in decreased photosynthesis and yield as well as an increase in oxidative stress and ascorbate peroxidase activity.

Lead effects on plants

Land plants typically take up lead from the soil and store the majority of it in their roots. There is some evidence to suggest that plant foliage may also absorb lead (and that this lead may move to other plant parts). By adding calcium and phosphorus to the soil, it may be possible to reduce the amount of lead that plant roots absorb. One of the most prevalent and widely dispersed toxic elements in soil is lead (Pb). Plant morphology, growth, and photosynthetic processes are negatively impacted by it. According to Morzck and Funicclli (1982), lead prevents the germination of Spartiana alterniflora and Pinus helipensis seeds. The interference of lead with crucial enzymes may prevent germination. In addition, lead prevented the growth of the roots, stems, and leaves in Raphanus sativa and barley from the Allium species (Juwarkar and Shende, 1986). According to Goldbold and Hutterman (1986) [19], root elongation is inhibited to varying degrees depending on the medium's pH, ionic composition, and lead concentration. Sesamum indicum has shown concentration-dependent inhibition of root growth (Kumar *et al*., 1992) [29]. Many plant species exhibit abnormal morphology when there is a high lead content in the soil. Lead, for instance, alters cell walls of the endodermis, lignifies cortical parenchyma, and causes irregular radial thickening in pea roots (Paivoke, 1983).

Drought Stress

Plants re-arrange their entire growth cycle and major physiological characteristics in response to drought stress, including osmotic potential, relative water content, transpiration, and leaf water potential (Sheteiwy *et al*., 2021). Plants gradually reduce the essential processes of photosynthesis as a result of a meagre water supply to the leaves, which is associated with deficiencies in nitrogen and carbon assimilation (Cui *et al*., 2019) [9]. Chlorophylls, which play crucial roles in harvesting sunlight, are less effective as a result of defects in the metabolism of photosynthetic pigments (Anjum *et al*., 2017) [3]. In the end, distorted chloroplast structures reduce plants' ability to photosynthesize effectively. Under water-scarce circumstances, the main contributor to the limited CO2 concentration that lowers the photosynthetic rate and results in stomatal closure is the reduction in intercellular CO2 diffusion to carboxylation sites (which favours the reduction in electron transport chains). Therefore, by restricting diffusion actions, water losses resulting from a decrease in CO2 intake can be accomplished (Cui *et al*., 2019) [9]. Due to reduced nutrient absorption and decreased diffusion from the soil to the roots of plants, water scarcity makes essential mineral nutrients unavailable even in fertile soil (Da Silva *et al*., 2011). Under these harmful effects, roots become disorganized and less effective at absorbing nutrients and water, which lowers plant productivity. Reactive oxygen species (ROS) and the scavenging system become unbalanced due to a lack of water, which causes oxidative stress, protein and lipid peroxidation, and membrane damage in the cellular organelles of plants. By lowering the capacity for CO2 fixation, the elevated ROS levels control the increased photorespiration. To combat drought stress, plants mobilize their enzymatic and non-enzymatic antioxidant defence system. However, the effectiveness of anti-oxidative defence systems is constrained by severe drought conditions (Hussain *et al*., 2018) [23].

Salinity Stress

One of the main obstacles to the agriculture industry's sustainability is salt stress, which reduces crop production by interfering with plant physio-biochemical and molecular processes. Osmotic, ionic, and secondary stressors are imposed by salt stress. Salt enforces oxidative damage, which results in a limited water supply from roots to shoots, and it mediates an ionic imbalance, which is a significant barrier that affects nutrient accessibility (Afridi *et al*., 2019 [1]; Wang *et al*., 2021 [46]; Arif *et al*., 2020) [4]. Salts are intrusive in soil environments and actively threaten overall growth characteristics by, for example, lowering the germination percentage and growth and obstructing vegetative, development, and reproductive ontogeny. Salt stress lowers biomass production, soluble sugar and protein levels, seed germination rates, and crop yield while limiting plant growth traits (such as leaf area, number, length/height, etc.). Salt stress has a significant impact on several important physio-chemical processes, including photosynthesis, stomatal conductance, and transpiration rates (Methenni *et al*., 2018 [32]; Betzen *et al*., 2019).

Heat Stress

Since greenhouse gas accumulation is being significantly accelerated by human activity, including gaseous emissions and other related activities, plant scientists are becoming increasingly concerned about global warming. According to a number of global circulation models, greenhouse gases, especially CO_2, methane, nitrous oxide, and chlorofluorocarbons, will cause a gradual rise in the average global temperature. According to the Inter-Governmental Panel on Climatic Change (IPCC), the average global temperature will rise by 0.3 °C every ten years (Jones *et al*., 1999) [27]. At this rate, the world's temperature is predicted to rise by about 1°C by 2025 (Wahid *et al*., 2007) [45], which could be very problematic given that by 2050, nine billion people will need to be fed (Stratonovitch and Semenov, 2015).

Conclusions

Worldwide debate has successfully demonstrated that severe losses in crop yields are primarily caused by environmental stresses. Plants employ a three-step process that includes (i) maintaining cellular homeostasis, (ii) detoxification, and (iii) resuming the growth process as a reliable way to deal with stress and ensure survival. A variety of abiotic stresses, such as heat, cold, drought, salinity, heavy metals, etc., have been reported to be effectively counteracted by the phytohormone BR (Brassinosteroid hormones) and various other related compounds**.** BRs are regarded as being extremely important in this situation because they regulate a specific group of genes to mediate the stress tolerance responses. Since these genes encode essential proteins and enzymes. Numerous studies have been done on this subject, yielding a wealth of information, but the list is still largely unchecked. More research will shed light on the molecular-genetic processes that BRs and other related compounds use to modulate the antioxidant defence system, which in turn regulates the damaging stress responses in plants.

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