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Review Article

Combating the Plant Stresses through Innovations in Plant Ecology

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Abstract

Plant growth, productivity, and quality are all impacted by environmental factors such as abiotic stress and limited soil nutrients. Low phosphorus availability is a prevalent soil-related abiotic stress in both natural and agricultural ecosystems. Most mineral elements are absorbed by the action of nutrient-absorption proteins in plants. The absorption of nitrate ions by the root is regulated by high-affinity transport system. Soil may be supplemented with organic matter from several sources. The biochar is thought to have the potential to be a long-term carbon sink capacity. Carbon sequestration is an essential component of regenerative agriculture that helps to slow down global warming. Under these demanding circumstances, NPs can aid in protecting the photosynthetic machinery and enhancing photosynthesis. Certain nanoparticles, such cerium oxide and TiO2 nanoparticles, shield the photosynthetic apparatus from oxidative damage. Prolonged dryness has also been shown to impair root development, stomatal opening, leaf size, leaf water potential, and seed quantity, size, and tolerance, which prevents flowering and fruiting and lowers crop yield. By altering the availability and plant absorption of fertilizer nutrients in the soil, engineered nanomaterials can increase crop production. By directly acting on phytopathogens through the formation of reactive oxygen species, these can limit crop illnesses.

Keywords: Plant Growth, Productivity, Phosphorus, Carbon Sequestration, Global Warming.

INTRODUCTION

Heat waves and droughts often occur and sense ability, transduce, and react to stress signals is an important biological issue of great interest [1, 2]. In particular, transduction signals across the board have provided strong support for a variety of plant stress responses. In addition to controlling a range of inorganic and organic metabolites, osmotic stress which is triggered by both salt and drought stress damages plants by producing ion toxicity, reactive oxygen species (ROS) accumulation, plasma membrane disruption, and cell wall damage. Stress causes non-adaptive changes in plants that lead to misfolded proteins and broken cell walls, whereas adaptive changes increase plant resistance [3, 4].

Land plants are constantly subject to a range of adverse environmental conditions, some of which can even be dangerous. Abiotic stresses, such as salt, drought, heat, cold, heavy metals, ozone, UV radiation, and nutritional deficits, have a detrimental effect on plant growth and yield. The direct and indirect effects of climate change are making these pressures increasingly important. Plants respond to abiotic stresses in a number of ways, including physiology, gene expression, primary and secondary metabolism, and plant architecture. Due to their complex adaptations, plants can endure and or adapt to adverse circumstances [2-4]. The plant genotype, the combination of many stressors, the exposed tissue and cell type, the length and severity of the stress, and the developmental stage at which the stress is affected the growth. Plant growth, productivity, and quality are all impacted by environmental factors

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such as abiotic stress and limited soil nutrients. Low phosphorus (P) availability is a prevalent soil-related abiotic stress in both natural and agricultural ecosystems. It restricts crop output in about 70% of the world's arable land. The primary tactic to sustain crop production is the heavy fertilizer application, which compensates for the reduced availability of inorganic P in the soil. While extensive research has been done on the biochemical processes behind the low-P stress response, the mechanisms governing epigenetic modifications needed [5-7].

Heat stress lowers overall plant performance and crop quality by negatively affecting growth and other physiological processes such as photosynthesis, respiration, nutrient absorption, and water relations, as well as possibly causing membrane damage. In response to such abiotic stress, which is often complex, plants have evolved dynamic responses at the morphological, physiological, and biochemical levels. The decrease in photosynthesis and biomass focused on phenology, grain production, nutritional quality, phytochemicals, and key metabolites. Plants frequently suffer detrimental effects from heat stress, including membrane damage, decreased biomass, denaturation of proteins, a decrease in protein concentration, and the inactivation of enzymes that are particular [8, 9]. Most mineral elements are absorbed by the action of nutrient-absorption proteins in plants. The activities of nutrient-uptake proteins are determined by the concentration of uptake proteins per unit root and the rate of protein activity. For instance, plants may take nitrogen as either nitrate or ammonium. The absorption of nitrate by the root is regulated by two kinetically distinct nitrate uptake mechanisms: the high-affinity transport system and the low-affinity transport system. The low-affinity transport systems encoded the nitrate transporter 1 family, whereas the HAT is by the nitrate transporter 2 family. Similarly, plants can only absorb ammonium through the usage of ammonium transporter genes (AMTs) [10, 11].

Combating the Plant Stresses and Innovations in Plant Ecology

In wheat, a crop with a large and complex genome, many genes are shared in the property of heat tolerance. As a reverse genetic approach to target heat tolerance gene activation, genome-editing techniques such as zinc finger nucleases, transcription activator-like effector nucleases, and clustered regularly interspaced short palindromic repeats can be used in addition to MAS. Compared to other genome-editing techniques, CRISPR-Cas9 has developed a reliable mechanism to accurately alter the genome to explore the pathways associated with heat stress and enhance the thermotolerance of agricultural systems. The Cas9 nuclease and an RNA guide with around 20 nucleotides each is intended to complement the target gene. The development of innovative breeding strategies to increase the heat tolerance of wheat crops and the investigation of the mechanisms behind wheat's heat tolerance are of utmost importance. Biotechnology development of new methods for the breeding and genetic engineering of heat-tolerant wheat [9, 10]. This includes developing new tools for gene editing and using molecular markers to monitor the inheritance of genes that are heat-tolerant. The development of wheat varieties resistant to high temperatures is increasingly reliant on the incorporation of novel technologies, including genomic selection, precision breeding, and phenotyping. These technologies make it possible to evaluate a number of wheat varieties quickly and efficiently, identifying the ones with the highest amounts [12, 13].

Through its effects on the physicochemical and biological aspects of soil, biochar pyrolyzed residues with a longer residence period than unpyrolyzed wastes improves soil fertility. The adding biochar can improve crop yield, heavy metal remediation, and soil fertility. Nonetheless, biochar may have adverse effects in some scenarios. Various application techniques are used, such as soil infiltration and surface application. The applying biochar to the surface combined with nitrogenous fertilizers is a useful tactic for lowering nitrogen losses [14, 15]. Food poverty results from agricultural output being continuously restricted by inadequate nutrient use efficiency and ongoing reductions in soil condition. A number of issues, including urbanization, population expansion, and climate change, put more strain on agricultural systems and make them worse. As a result, in order to address the many issues affecting agricultural productivity, such as disconnects in nutrient supply, demand, and recycling as well as water consumption, agroecosystem design and function must be reevaluated. Recycling organic nutrients back into the soil to support soil organic matter best strategy. This usually leads to improvements in the physical and chemical characteristics of the soil. Soil may be supplemented with organic matter from several sources. The biochar is thought to have the potential to be a long-term carbon sink capacity. It can also increase soil carbon storage and reduce greenhouse gas emissions, as well as mitigate the effects of global warming on food production. Biochar also offers greater ecological and economic advantages and can enhance soil quality and farming crop. Thus, in order to maintain sustainable farmland growth, biochar may be utilized as an ecologically friendly soil addition to minimize greenhouse gas emissions, boost agricultural carbon sinks, and manage environmental pollution [16, 17].

Produced at high temperatures from woody biomass, biochar often has a pH, making it very alkaline. This makes it beneficial for crops cultivated in acidic, coarse and fine-textured soils to boost the pH of the soil. Additionally, it may exacerbate nutrient imbalances and salinization in soils that are already alkaline, such as those found in plateaus, loess landscapes, or some desert regions. This may cause the pH of the soil to go outside of a range that is acceptable for many crops, negatively impact nutrient availability, particularly phosphorus and trace minerals, and have a detrimental effect on crop development [17, 18]. For instance, new pH reduced the yield of potato tubers by more than 6% because it raised the soil's pH and conductivity. The ability of the soil to support and encourage plant growth and productivity is referred to as soil health in the context of agriculture. A soil is deemed fertile if it has no harmful materials that might impede plant growth and can provide the necessary amounts of water and nutrients. The fertility of the soil is determined by its physical, chemical, and biological properties. In many parts of the world, low soil fertility is a major problem. For example, soil in dry and semi-arid areas usually cannot store enough water for most crops, nor can it hold enough minerals. Rainforest locations struggle to maintain soil fertility because of heavy rainfall, low cation binding capacity, and fast loss of essential nutrients from the topsoil [19, 20].

The agriculture fields are greatly aided by biochar, a carbon-rich substance produced by pyrolyzing organic materials. Its numerous benefits promote sustainable practices, improve soil health, and lessen environmental problems. By acting as a steady supply of carbon, biochar enhances soil structure and nutrient retention. Because of its porous structure, it can store more water, which guarantees the ideal moisture content for plant development. Additionally, biochar serves as a reservoir for vital nutrients, enhancing their availability to plants and reducing leaching. Carbon sequestration is an essential component of regenerative agriculture that helps to slow down global warming. Because it is a carbon sink, biochar lowers atmospheric CO2 levels, which helps soils store carbon over the long run. The sustainable agricultural methods designed to increase climate variability resistance [20-22].

Application of biochar has significant effects on crop output, plant development, and the physical, chemical, and biological characteristics of the soil. It has an immediate impact on the bulk density, pH, water-holding capacity, and nutrient contents of the soil. The reactions of soils and plants to the application of biochar vary greatly between various experimental experiments because of the wide variations in biochar, its application techniques, and rates. The applying biochar increases soil fertility, increases soil water-holding capacity, improves crop yields, lowers greenhouse gas emissions, and increases soil carbon storage. The biochar had adverse effects on soil nutrient availability and plant growth. Comprehending the intricate relationships among plants, soil, and microorganisms is crucial for formulating conservation and management strategies that enhance soil qualities and boost agricultural output [22, 23]. The impact of mounted load carrying on equids also seen for mounted different weights with several animal properties [23-25]. A coordinated large-scale biochar field research may be required in order to precisely measure the impacts of biochar application on soil characteristics, crop biomass production and yield, GHG emissions, and soil C sequestration. In order to identify the causes of variation and expose the processes, it is imperative that the future studies follow the same design principles and incorporate various crop systems, soil types, biochar types and application rates, and fertilization status. Using the same field measurement procedures, biochar application should be conducted for a minimum of three to five years [23, 24].

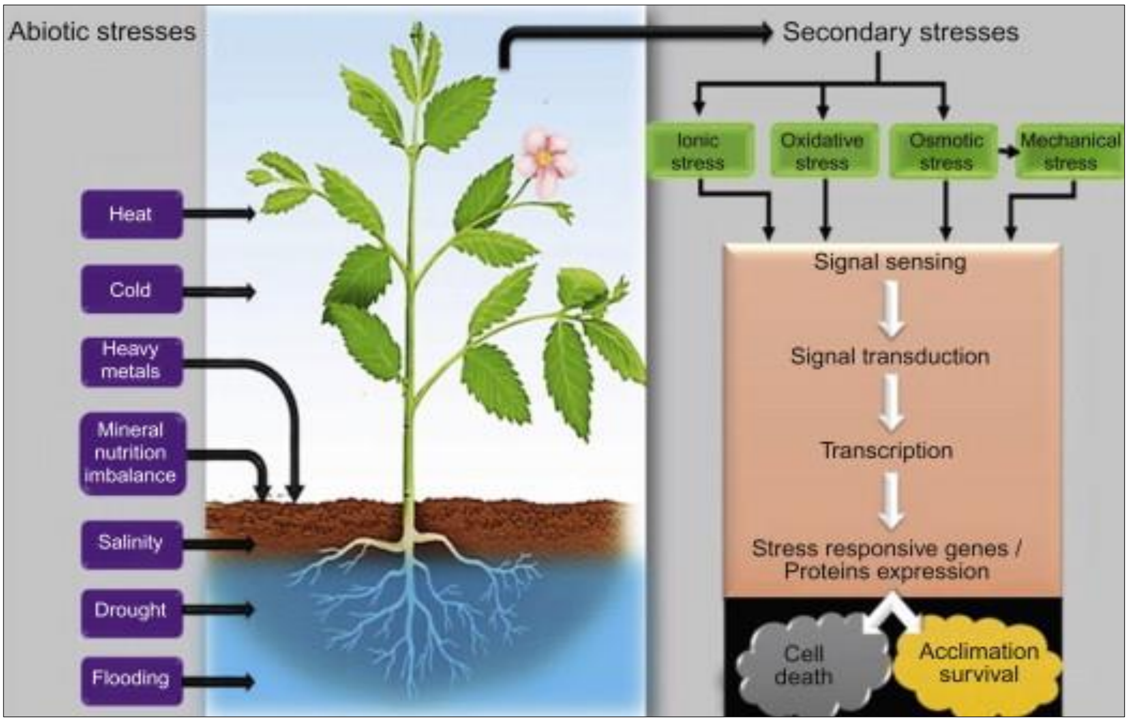

Fig. 1: Activating the various plant stresses through innovations in plant ecology

Guar gum is a novel agrochemical derived from the endosperm of cluster beans. In the form of guar gum powder, it is generally used as an ingredient in the food, pharmaceutical, paper, textile, explosive, oil well drilling, and cosmetics sectors. Guar gum's ability to form hydrogen bonds with water molecules makes it useful for industrial application. Its main use as thickener and stabilizer. It also aids in the management of certain medical conditions, including as diabetes, heart disease, colon cancer, and irregular bowel movements. A mechanical process that includes roasting, differential attrition, sifting, and polishing is used to extract gum from seeds for commercial usage [25, 26]. The broken seeds are removed from the endosperm and germ. The two halves of the endosperm that each seed produces are known as undehusked guar split. The process of polishing the endosperm halves separates them from the fine layer of fibrous material that makes up the husk, resulting in refined guar splits. Cattle are fed the hull (husk) and germ part of guar seeds, which are known as guar meal and are a substantial byproduct of the production of guar gum powder. Several techniques are used to further treat the refined guar splits to produce powders [26, 27].

Guar gum is primarily used in the food industry. GG has been extensively studied with respect to processing variables that are directly relevant to the food industry. The molecule is composed chemically of a mannose backbone with galactose side chains strewn throughout. For thickening, covering, stabilizing, binding, and suspending a range of liquid-solid systems, its solubility in cold water and capacity to create viscous systems even at low concentrations make it an invaluable food additive in the food business [28, 29]. Additionally, this widely available, low-cost gum showed unique properties that make it essential for usage in food applications, including improved frozen bowel movements, changed rheological properties, and lower evaporation rates. In addition to bread, like cakes, donuts, and biscuits due to their high nutritional value. Therefore, reducing the fat level of these products and replacing them with healthier alternatives enhances their sensory attributes. It has been noted that rice cakes with a mixture of xanthan-guar hydrocolloids without an emulsifier and fat were found to be the firmest. This is because the crumb walls thicken around the air holes in the rice cakes. GG is especially used to boost the nutritional value and crispness of baked items that are free of gluten [29, 30].

Smashed endosperm from *Cyamoposis tetragonolobus* L., a leguminous plant cultivated for millennia growing seed for human and animal consumption, yields guar gum, one of the most promising dietary fiber. The guar plant's seeds have been processed to create guar gum, which is now extensively utilized in the contemporary food business as an emulsion stabilizer and thickening for both food and industrial uses in growing quantities worldwide. The structural makeup of guar gum consists of long, straight chains of α-D-mannopyranosyl units joined by β-D-(1-4)-glycosidic bonding [24-27]. The hexose that is connected to this chain. The ideal water-soluble dietary fiber should dissolve quickly in liquids, have no taste or odor, and have a very low viscosity for the purpose of adding fiber to meals. The partly hydrolyzed guar gum (PHGG) that is produced by the enzymatic process has a molecular structure that is the same as intact guar gum, but it is shorter than a tenth of its original length. Because of this characteristic, PHGG can be used as a film-forming, swelling, and foam stabilizer. The viscosity of PHGG varies from 2,000 to 3,000 mPa·s in a 1% guar gum solution, and it is around 10 mPa·s in a 5% aqueous solution. Moreover, PHGG has excellent stability against heat, acid, low pH, and digestive enzymes [29, 30].

One of the most vulnerable parts of the body to the effects of salt and drought is the photosynthetic apparatus, which includes chloroplasts, pigments involved in photosynthesis, and photosystems. Stress situations like these cause an increase in ROS generation, which in turn causes oxidative stress, which damages the photosynthetic mechanism and reduces photosynthesis. Under these demanding circumstances, NPs can aid in protecting the photosynthetic machinery and enhancing photosynthesis. It has been demonstrated that certain nanoparticles, such cerium oxide (CeO2) and TiO2 nanoparticles, shield the photosynthetic apparatus from oxidative damage. By lowering oxidative stress and maintaining the integrity and functionality of chloroplasts and photosystems, they can serve as ROS scavengers [31, 32]. Under drought and salt stress circumstances, NPs considerable promise in enhancing plant growth, production, and quality. Their special qualities and interactions with plants can have positive impacts on the metabolism, physiology, and general health of plants. By enhancing nutrient absorption, controlling hormone levels, and reducing stress-induced damage, NPs can support plant development in stressful environments. The applying SiNPs to plants under salt and drought stress improves root development, shoot biomass, and overall plant Furthermore, NPs have a favorable impact on agricultural productivity. Even while NMs have been shown to have many beneficial benefits, their usage can also be phytotoxic, as well as the length and circumstances of exposure. ENMs have been shown to reduce the concentrations of chlorophyll and photosynthetic energy in a variety of crops, including barley, wheat, rice, lettuce, cucumber, onion, spinach, radish, so on. The soybeans more phytotoxic to CuO nanoparticles with a 25 nm diameter. The mild to moderate toxicity for terrestrial plants, despite a significant number of contradicting evidence regarding the eco-toxicological effects of nanoparticles [33-35].

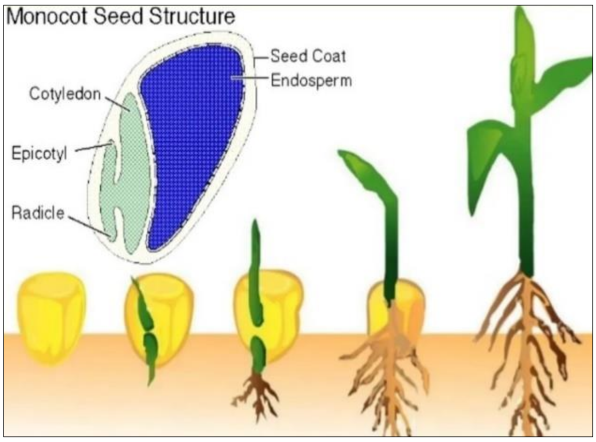

Fig. 2: Different features of the seed and its anatomy

Stress cold temperatures may physiologically affect to plants in a variety of ways because they can change the structure and integrity of proteins and lipids. The integrity of the membrane and related functions, such transport and permeability, which are essential for photosynthesis, gas exchange, and transpiration in plants, are impacted by lipid modification brought on by cold. In general, there is a reduction of chlorophyll along with a decrease in transpiration and CO2 absorption [35, 36]. The large subunit of ribulose-1,5-bisphosphate carboxylase oxygenase (RUBISCO) is molecularly inhibited, which causes the small subunit to degrade and CO2 fixation to decrease. When TiO2NP was applied to *Cicer arietinum* L. (chickpea) under cold stress, genes associated with chromatin expressed differently. Ionic and water equilibrium are disturbed by salt in the soil, which has detrimental physiological effects. Salinity stress causes a high concentration of reactive oxygen species to accumulate within cells, disrupting redox equilibrium. Furthermore, heat stress results in the production of ROS, which always affects oxidative activities. Prolonged dryness has also been shown to impair root development, stomatal opening, leaf size, leaf water potential, and seed quantity, size, and tolerance, which prevents flowering and fruiting and lowers crop yield. Various methods have been employed to manage abiotic stressors in plants, such as marker-assisted breeding, transgenic crop engineering, and traditional breeding. Plant growth and development are significantly influenced by fertilizers [36, 37]. However, for a variety of reasons, including leaching, photolysis, degradation, and hydrolysis, most fertilizers are still inaccessible to plants. Therefore, it's critical to minimize nutrient loss and enhance harvest yield by exploring novel uses for nanotechnology and nanomaterials. By altering the availability and plant absorption of fertilizer nutrients in the soil, engineered nanomaterials can increase crop production. By directly acting on phytopathogens through the formation of reactive oxygen species, these compounds can limit crop illnesses [34-37]. These can also improve plant defense mechanisms and restore crop nutrition, which could indirectly limit disease. The conservative insect control methods doesn't seem to be enough, and traditional pesticide applications haveNPs have emerged as a viable delivery system for plant genome editing and account for their capacity to target loading and transport plasmid DNA, mRNA, and RNPs, despite the fact that the cell wall substantially hinders the transfer of genome editing cargo to mature plants. To achieve more effective gene editing, direct cytoplasmic administration of the Cas9 protein with the sgRNA complex has been investigated. Lipid-based nanoparticles, CRISPR-Gold, DNA nanoclews, and polymer nanoparticles have all been reported to be utilized in the CRISPR/Cas system. Although CRISPR-Cas technologies are widely used, the efficiency and production of several mutants at once is limited by mono-sgRNA gene editing. Multilocus editing has instead been made possible by multiplexed CRISPR technology. It's important to note that certain research revealed a nano-biomimetic change [35-37].

CONCLUSION

Long-term field applications are conducted to explore the biogeochemistry between long-term climate change and heavy metals and to look for more ecologically sound methods of heavy metal adsorption and degradation, such as using biological materials to degrade and adsorb heavy metals and using microorganisms to reduce the impact of heavy metals on ecosystems. In order to better address the adverse effects of heavy metals on ecosystems and further compensate for the knowledge gap between global climate and environmental change and environmental heavy metals, it is necessary to investigate the impact of heavy metals in various types of ecosystems. Early evidence suggests that plants that have evolved to be highly tolerant of metal overload may be less susceptible to metal toxicity brought on by climate change, but more fundamental data collection is required to predict the long-term health and survivability of these plants in changing environments. A little knowledge of the possible direct effects of climate change on plant-metal interactions related to water bodies shows that warming may accelerate the accumulation of metals in water plants and decrease the bioavailability of trace metal nutrients on particular river floodplains.

REFERENCES

1. Shafiq, S., Ali, A., Sajjad, Y., Zeb, Q., Shahzad, M., Khan, A. R., ... & Widemann, E. (2020). The interplay between toxic and essential metals for their uptake and translocation is likely governed by DNA methylation and histone deacetylation in maize. *International Journal of Molecular Sciences*, *21*(18), 6959.
2. Skiba, E., Pietrzak, M., Gapińska, M., & Wolf, W. M. (2020). Metal homeostasis and gas exchange dynamics in Pisum sativum L. exposed to cerium oxide nanoparticles. *International Journal of Molecular Sciences*, *21*(22), 8497.

3. Gong, Z., Xiong, L., Shi, H., Yang, S., Herrera-Estrella, L. R., Xu, G., ... & Zhu, J. K. (2020). Plant abiotic stress response and nutrient use efficiency. *Science China Life Sciences*, *63*, 635-674.
4. Alpert, P. (2006). Constraints of tolerance: why are desiccation-tolerant organisms so small or rare?. *Journal of Experimental Biology*, *209*(9), 1575-1584.
5. Swain, R., Sahoo, S., Behera, M., & Rout, G. R. (2023). Instigating prevalent abiotic stress resilience in crop by exogenous application of phytohormones and nutrient. *Frontiers in Plant Science*, *14*, 1104874.
6. Markham, K. K., & Greenham, K. (2021). Abiotic stress through time. *New Phytologist*, *231*(1), 40-46.
7. Praveen, A., Dubey, S., Singh, S., & Sharma, V. K. (2023). Abiotic stress tolerance in plants: a fascinating action of defense mechanisms. *3 Biotech*, *13*(3), 102.
8. Giri, A., Heckathorn, S., Mishra, S., & Krause, C. (2017). Heat stress decreases levels of nutrient-uptake and-assimilation proteins in tomato roots. *Plants*, *6*(1), 6.
9. Huang, B., & Xu, Q. (2000). Root growth and nutrient element status of creeping bentgrass cultivars differing in heat tolerance as influenced by supraoptimal shoot and root temperatures. *Journal of Plant Nutrition*, *23*(7), 979-990.
10. Akter, N., & Rafiqul Islam, M. (2017). Heat stress effects and management in wheat. A review. *Agronomy for sustainable development*, *37*, 1-17.
11. Al-Karaki, G. N. (2012). Phenological development-yield relationships in durum wheat cultivars under late-season high-temperature stress in a semiarid environment. *International scholarly research notices*, *2012*(1), 456856.
12. Almeselmani, M., Deshmukh, P., & Sairam, R. (2009). High temperature stress tolerance in wheat genotypes: role of antioxidant defence enzymes. *Acta Agronomica Hungarica*, *57*(1), 1-14.
13. Wahid, A., Gelani, S., Ashraf, M., & Foolad, M. R. (2007). Heat tolerance in plants: an overview. *Environmental and experimental botany*, *61*(3), 199-223.
14. Abewa, A., Yitaferu, B., Selassie, Y. G., & Amare, T. (2014). The role of biochar on acid soil reclamation and yield of Teff (Eragrostis tef [Zucc] Trotter) in Northwestern Ethiopia. *Journal of Agricultural Science*, *6*(1), 1.
15. Abrishamkesh, S., Gorji, M., Asadi, H., Bagheri-Marandi, G. H., & Pourbabaee, A. A. (2015). Effects of rice husk biochar application on the properties of alkaline soil and lentil growth Original Paper. *Plant, Soil and Environment*, *61*(11).
16. Ali, K., Munsif, F., Zubair, M., Hussain, Z., Shahid, M., Din, I. U., & Khan, N. (2011). Management of organic and inorganic nitrogen for different maize varieties. *Sarhad J. Agric*, *27*(4), 525-529.
17. Bollmann, A., Schmidt, I., Saunders, A. M., & Nicolaisen, M. H. (2005). Influence of starvation on potential ammonia-oxidizing activity and amoA mRNA levels of Nitrosospira briensis. *Applied and environmental microbiology*, *71*(3), 1276-1282.
18. Brewer, C. E., & Brown, R. C. (2012). “Biochar,” in Comprehensive renewable energy. Editor A. Sayigh (Oxford, UK: Elsevier), 357–384.
19. Novotný, M., Marković, M., Raček, J., Šipka, M., Chorazy, T., Tošić, I., & Hlavínek, P. (2023). The use of biochar made from biomass and biosolids as a substrate for green infrastructure: A review. *Sustainable Chemistry and Pharmacy*, *32*, 100999.
20. Pan, X., Gu, Z., Chen, W., & Li, Q. (2021). Preparation of biochar and biochar composites and their application in a Fenton-like process for wastewater decontamination: A review. *Science of the Total Environment*, *754*, 142104.
21. Nguyen, B. T., & Lehmann, J. (2009). Black carbon decomposition under varying water regimes. *Organic Geochemistry*, *40*(8), 846-853.
22. Yi, Z., Jeyakumar, P., Yin, C., & Sun, H. (2023). Effects of biochar in combination with varied N inputs on grain yield, N uptake, NH3 volatilization, and N2O emission in paddy soil. *Frontiers in Microbiology*, *14*, 1174805.
23. Bukhari, S. S., & Parkes, R. S. (2023). Assessing the impact of draught load pulling on welfare in equids. *Frontiers in Veterinary Science*, *10*, 1214015.
24. Bukhari, S. S., McElligott, A. G., & Parkes, R. S. (2021). Quantifying the impact of mounted load carrying on equids: a review. *Animals*, *11*(5), 1333.
25. Bukhari, S. S., Parkes, R. S., Sneddon, L. U., & McElligott, A. G. (2024). The behavior and welfare of neglected species: some examples from fish and mammals. *PeerJ*, *12*, e17149.
26. Garti, N., & Leser, M. E. (2001). Emulsification properties of hydrocolloids. *Polymers for advanced Technologies*, *12*(1-2), 123-135.
27. Mohammadi Golchin, F., Movahhed, S., Eshaghi, M., & Ahmadi Chenarbon, H. (2021). Mathematical modeling of weight loss and crust temperature of toast bread containing guar gum during baking process. *Food Science & Nutrition*, *9*(1), 272-281.
28. Moradi, M., Bolandi, M., Arabameri, M., Karimi, M., Baghaei, H., Nahidi, F., & Eslami Kanafi, M. (2021). Semi-volume gluten-free bread: effect of guar gum, sodium caseinate and transglutaminase enzyme on the quality parameters. *Journal of Food Measurement and Characterization*, *15*, 2344-2351.
29. Marlett, J. A., Chesters, J. G. (1985). Measuring dietary fiber in human foods. *J. Food Sci*, *50*, 410–414. ADA (American Diabetes Association) (1987). Position statement; Nutritional recommendations and principles for individuals with diabetes mellitus. *Diabetes Care*, *10*, 120–132.
30. Trono, D., & Pecchioni, N. (2022). Candidate genes associated with abiotic stress response in plants as

tools to engineer tolerance to drought, salinity and extreme temperatures in wheat: an overview. *Plants*, *11*(23), 3358.

31. Adeleke, B. S., Chaudhary, A., Bhandari, G., Upadhayay, V. K., Chitara, M. K., Upadhayay, V. K., ... & Naitam, S. (2023). Synergistic impact of nanomaterials and plant probiotics in agriculture: A tale of two-way strategy for long-term sustainability. *Bioinoculants with Nano-compounds to Improve Soil Health: A Step Toward Sustainable Agriculture*.
32. Sharma, P., Bhatt, D., Zaidi, M. G. H., Saradhi, P. P., Khanna, P. K., & Arora, S. (2012). Silver nanoparticle-mediated enhancement in growth and antioxidant status of Brassica juncea. *Applied biochemistry and biotechnology*, *167*, 2225-2233.
33. Begum, P., Ikhtiari, R., & Fugetsu, B. (2011). Graphene phytotoxicity in the seedling stage of cabbage, tomato, red spinach, and lettuce. *Carbon*, *49*(12), 3907-3919.
34. Mahakham, W., Theerakulpisut, P., Maensiri, S., Phumying, S., & Sarmah, A. K. (2016). Environmentally benign synthesis of phytochemicals-capped gold nanoparticles as nanopriming agent for promoting maize seed germination. *Science of the Total Environment*, *573*, 1089-1102.
35. Mahmoud, L. M., Shalan, A. M., El-Boray, M. S., Vincent, C. I., El-Kady, M. E., Grosser, J. W., & Dutt, M. (2022). Application of silicon nanoparticles enhances oxidative stress tolerance in salt stressed ‘Valencia’sweet orange plants. *Scientia Horticulturae*, *295*, 110856.
36. Baig, N., Kammakakam, I., & Falath, W. (2021). Nanomaterials: A review of synthesis methods, properties, recent progress, and challenges. *Materials advances*, *2*(6), 1821-1871.