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Enhancing Staple Crop Resilience to Environmental Challenges: Strategies for Nutrient Uptake and Carbon Usage in Climate Change

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ABSTRACT

With the increasing population, stress resilience in staple crops is necessary for the productivity of crops. These days, crop improvement is triggered by the unpleasant condition of abiotic stress, which affects the many metabolic pathways of yield and quality improvements globally. Carbon assimilation is necessary for the synthesis of organic compounds and the maintenance of cellular processes. To obtain vital nutrients, organisms utilize numerous strategies such as scavenging mechanisms, symbiotic relationships, and absorption kinetics. Acquiring nutrients and assimilation of carbon is significantly hindered by environmental changes. This article provides a concise overview that how crops should use their strategies for acquiring nutrients and assimilating carbon in response to varying environmental factors.

Introduction

Abiotic stresses are one of the main worldwide challenges to crop productivity and food security. It has a negative impact on a variety of plant developmental stages as well as transcriptome, cellular, and physiological processes in the plant, including flowering, grain filling, and maturation (1). Abiotic stress has historically drawn the attention of plant scientists and agronomists in the last fifty years because of the significant increase in the human population (which has negatively impacted world food security). It became necessary to look into the often-ignored causes of decreased crop productivity due to rising food demand (2). Crop quality and productivity are determined by the availability of nutrients. Although applying fertilizer is a common way to improve plant nutrition, its effectiveness can vary widely, and the process of producing and applying fertilizers often causes environmental issues. Many soil microorganisms can enhance plant nutrient uptake, offering sustainable means of fulfilling plant nutrition requirements.(3). Plants have developed a number of defense mechanisms against nutrient deficiency stress, including morphological changes like cluster roots that improve the plant's capacity to absorb nutrients. Transporters mediate the assimilation of carbon in leaves through light energy conversion and export to developing shoots and root systems in certain spatiotemporal patterns. The process through which plants transform atmospheric carbon dioxide (CO2) into organic carbon compounds primarily through photosynthesis is referred to as carbon absorption. Water availability affects carbon assimilation, which is important because carbon is a source of carbohydrates that plants need to thrive (4).

Nutrient Acquisition Strategies in Staple Crops

Root architecture plays a major role in how plants explore the soil to make it easier for them to absorb nutrients. To improve nutrient acquisition, especially in situations where nutrients are limited, altering the architecture of the roots is a crucially important strategy (5). Through their roots, plants absorb nitrogen nutrients mostly in the form of ammonium and nitrate from the soil. Due to a lack of essential nutrients in natural soils, plants have developed environmental adaptations. Regulating nitrogen acquisition efficiency is one of the most significant responses (6). Microbes have numerous roles in the development of plants and are essential partners in crop yield and stress response to a variety of biotic and abiotic conditions. Particularly, interactions between endophytic and rhizospheric bacteria can improve the nutrition of plants with minerals. For example, soil-borne bacteria or fungi can release phytotases or organic acids that solubilize phosphate, promoting plant uptake (7). Using breeding or engineering genes associated with significant features and signal transduction pathways are identified, resilience mechanisms have been deployed for crop development. Reaching resilience without compromising total yield is a major issue (8). Naturally occurring genetic variants can be quickly discovered and incorporated into cultivars through the use of marker-assisted selection (MAS) and genomic selection procedures. Further identification of the molecular mechanisms behind these natural differences through investigating the potential genes will lead to crop enhancement through genetic manipulation (9).

Carbon Assimilation Mechanisms in Staple Crops

Plants are classed as C3, C4, or CAM depending on which of the three carbon assimilation mechanisms they use. In comparison to C3 plants, C4 plants are thought to be the most common of all the varieties due to their low photorespiration and high water and nitrogen use efficiency. In addition to being essential for C4 photosynthesis and carbon absorption, these enzymes are also essential for the plant's defense mechanism against various biotic and abiotic stresses (10). The principal inorganic sources of nitrogen and sulfur in the soil, nitrate and sulfate, are assimilated more complexly when higher plants use carbon assimilation techniques. To develop plants with enhanced abiotic stress tolerance, a thorough understanding of ROS signaling and the regulatory roles played by various components, including protein kinases, transcription factors, and phytohormones, in the responses of photosynthetic machinery to abiotic stress, will be required. The use of bioenergetics techniques, like transient kinetics analysis of chlorophyll, has made it easier to comprehend plant vitality and evaluate PSII efficacy in challenging environmental circumstances (11). Through the development of engineering approaches, it has been possible to successfully improve plant growth and stress tolerance. Most of the approaches that have been employed thus far have involved the use of pesticides or transgenic technology. But in order to properly handle these problems and expectations in view of the rapidly changing environment, as well as the need to ensure sustainable agriculture and biomass production, innovative solutions must be developed (12).

Impact of Changing Climatic Conditions on Nutrient Availability and Carbon Assimilation

Temperature is a master variable that fundamentally affects metabolic rate, which in turn regulates biological activity. It has an impact on the acquisition, storage, and recycling of materials. Environmental variables have an impact on soil temperature by regulating the quantity of heat that is distributed throughout the soil profile and the amount of heat that is provided to the soil surface. The rate at which certain organic compounds mineralize and decompose depends on the temperature of the soil. Additionally, it affects the water content, conductivity, and availability of the soil to plants (13). There is an effective interaction between plant water state and mineral absorption. Increased photosynthesis in plants results from elevated CO_2 and this increases biomass and carbohydrate production. Certain plants allocate more sugars to their roots with higher (CO_2) where they may influence gene regulation and alter the intake and transport of nutrients. Moreover, glucose and sucrose enhance root growth, which is similar to the effects of high (CO_2) (14).

Strategies for Enhancing Abiotic Stress Resilience

Staple crop production is declining as a result of numerous abiotic stresses; therefore, for all countries to meet their growing food demands, these yield losses must be minimized. In addition to abiotic pressures, persistent climate change is creating significant barriers to achieving the levels of agricultural productivity needed to fulfill the growing demand for food. Thus, plant breeders have usually considered tolerance to abiotic stressors to be a goal for the future. One example of this is the breeding of reproducing under abiotic stress, even on land, to feed the world's growing population (15). Numerous biotechnological techniques have been used to study stress management strategies in plants, including cell and tissue culture, genomic, and proteomic

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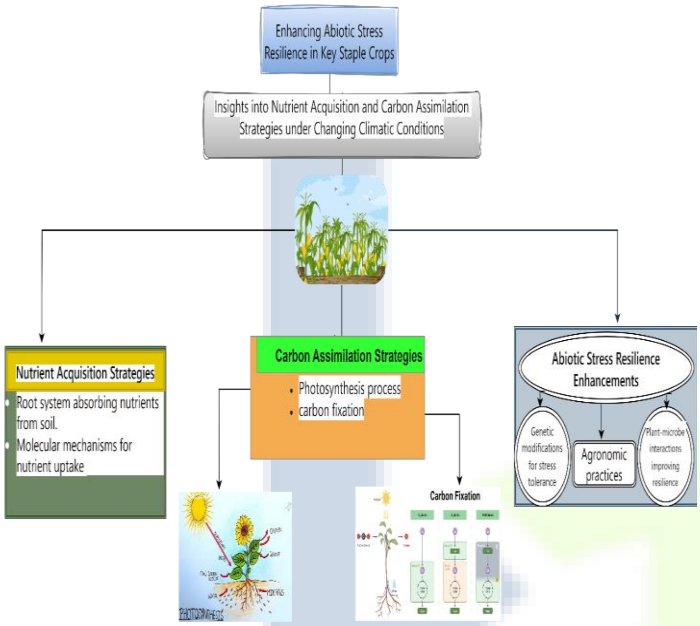
approaches. Plants have developed a thorough response to drought by activating defense mechanisms and implementing coping mechanisms for water deficits through the use of their genes and the regulatory pathways that regulate them (16). One possible strategy to successfully lessen the effects of climate change is adapt-led mitigation, which also encourages a variety of interested parties to use different technologies for mitigation and adaptation. Technology has been developed for use with improved planting techniques, rice cultivation systems, intercropping systems, agroforestry systems, agro-advisories, stress-tolerant cultivars, in-situ moisture conservation, water harvesting, and soil carbon sequestration (17).



Case Studies and Examples

Around the world, inadequate management practices and nutrient shortages in soil-crop environments are major causes of malnutrition in humans and animals as well as low crop productivity and decreased nutritional quality of agricultural products (18).Global concerns like climate change are perhaps the most difficult and complicated issues the world is currently facing. Climate change is widely acknowledged as a major threat to biological ecosystems in soil, which has an impact on crop productivity over the long run (19).Abiotic factors related to climate change that might cause yield variability include excessive heat, salinity in the soil, droughts, and flooding. By identifying genes linked to important features and signal transduction pathways, resilience mechanisms have been activated for crop development, and this has been achieved through breeding or engineering (20). Soil carbon sequestration is regarded as one of the agriculture sector's most significant options to mitigate greenhouse gas emissions, its potential can be exaggerated if it is not evaluated properly as part of an integrated system (21). For example, by promoting nitrification/denitrification and soil urease activity, the retention of residue may raise soil organic carbon levels while simultaneously increasing N2O emissions (22).

Future Directions and Challenges

New technologies for exploring and using plant genomes for crop improvement have emerged as a result of recent technological advancements. The large-scale "Omics" era of study has emerged with the best prospects for creating superior varieties in this environment. By analyzing the complete genome, these omics-based techniques hope to understand plant molecular reactions and develop targeted crop development techniques (23). Over the previous few decades, a number of potential omics technologies have become known. These omics-based methods have shown to be effective in examining the genetic and molecular roots of crop development by examining changes in proteins, metabolites, mineral nutrients, DNA, transcript levels, and physiological and environmental stress responses. Numerous molecular biological aspects have been disclosed by several omics techniques, including transcriptomics, phenomics, metabolomics, genomes, mutagenomics, proteomics, and ionomics, in conjunction with plant systems.

Conclusion

In this review paper we highlighted that how abiotic stress affects the productivity of the staple crops and also discussed the ways through which we can save theses crops through nutrients acquisition and carbon assimilation. Through these strategies future crops will need to be "smart" and "resilient" in order to enhance yields in real-world situations by adapting to variable stressors. Under changing the climatic conditions and growing world population the resources are depleting and their need is increasing day by day so its is necessary to implement these kinds of strategies. Plants transport nutrients that are transportable, like as nitrate, and amino acids from their roots to their leaves via xylem for assimilation. Global change may hinder or enhance C sequestration, depending on nutrient limitation and plant nutrient acquisition mechanisms. This has additional consequences for nutrient cycle and climate change. So, to increases productivity of these crops these strategies must be applied.

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