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ROLE OF PLANT BREEDING TO MAINTAINING FOOD SECURITY IN THE FACE OF GLOBAL CLIMATE CHANGE

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Abstract *As the global population expands and the number of individuals employed in agriculture rises, these elements exert an adverse influence on global production. Since crop output and population growth are not maintaining pace, it is becoming increasingly difficult to provide food for the world's expanding population, which is expanding geometrically while crop productivity is increasing arithmetically. Thus, plant breeding plays a key role in the development of high-yielding cultivars to ensure food security. Modern biotechnological techniques along with traditional plant breeding practices can speed up the laborious and lengthy process of variety development having high yields and quality.*

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Introduction

Several significant manufacturing concerns have surfaced on a global scale. Each of these variables has a substantial impact on the production and yield of agricultural plants. As the global population expands and the number of individuals employed in agriculture rises, these elements exert an adverse influence on global production. Since crop output and population growth are not maintaining pace, it is becoming increasingly difficult to provide food for the world's expanding population, which is expanding geometrically while crop productivity is increasing arithmetically. The direct consequences of global climate change are evident in the present state of affairs on a global scale. To feed an expanding global population, the agricultural sector must transition its emphasis from expansion to sustainable modern agriculture. Agriculture has to produce 60–100% more food by 2050 than it does presently (Tilman et al. 2011). It is imperative to ensure adequate food production to satisfy the increasing need for food security, notwithstanding the adverse effects of climate change such as elevated temperatures, limited water resources, and land scarcity. Plant breeders have employed a diverse range of breeding techniques and strategies to augment food production for millennia. Conversely, monoculture reduces agricultural productivity through the inhibition of genetic diversity and the impediment to cultivating suitable food crops (Khoury et al., 2014). During the period from 1960 to 2015, advanced agronomic technologies were integrated with conventional plant breeding methods to genetically enhance agricultural yields. Increased agricultural output was a result of the introduction of high-yielding varieties, irrigation, novel productivity-boosting techniques, and the availability of synthetic fertilizers during the first green revolution. Nevertheless, when compared to preceding generations, the impact of the green revolution on certain critical food commodities across the globe has been comparatively limited (Grassini et al., 2013). At this time, the annual growth rate of agricultural yields, which fluctuates between 0.9%

and 1.6%, is inadequate to satisfy forthcoming demand. To fulfill worldwide demand, annual growth in food production must equal 2.4% (Ray et al., 2013). With the escalating global population, the search for cereals that possess both economic viability and resistance to climate change assumes heightened significance. The expansion of the global population presents a threat to food security. Enhanced agricultural productivity is indispensable for resolving these challenges (Varshney et al., 2018; Gruhn et al., 2000; Eigenbrode et al., 2018; Wang et al., 2018).

Climate change's effects on food security

It is only possible to guarantee that a person's dietary needs and preferences are satisfied if they have physical, social, and economic access to enough amounts of nutritious food. Food security is influenced by food availability, accessibility, and consumption (Connolly-Boutin & Smit, 2016). Renzaho and Mellor (2010) have highlighted three fundamental components of food security, including availability, access, consumption, and long-term food stability. Several measures, including animal ownership, national food accounting, and food production and yield, can be used to evaluate the availability of food (Sen, 1997). According to Yimer (2015), food access is the variety of commodity bundles that a member of a community can acquire by integrating all of their rights and opportunities. The ability of a person to receive resources through social, political, or economic channels is referred to as accessibility. Food consumption refers to the act of ingesting enough food to meet one's physiological needs while maintaining proper hygiene, making sure that a balanced diet is available, getting clean water, and getting medical care. Food use is defined as "the nutritional value of the diet, including its composition and methods of preparation; the social values of foods, which dictate what types of food should be served and eaten at various times of the year and on various occasions; and the quality and safety of the food supply, which, if inadequate, can lead to food waste and the spread of food-borne diseases (Turral et al., 2011)." Food security is the state of having enough food to support a household, an entire population, or a single person. Or, put another way, "stability" refers to the ease and security of obtaining food supplies.

Consequently, all aspects of food security are inextricably related to agricultural productivity, which gives rural populations a means of subsistence and income. Numerous environmental, economic, and sociological aspects impact the challenges to food security brought about by climate change (Keane et al., 2009). Climate change has a major impact on food security in four areas: stability, availability, access, and usage. Cascade effects and worries about food security are to blame for this. Climate change has an impact on all aspects of food security. (Thompson & Scoones, 2009) examines the impact of climate change on global trade, human well-being, economic development, and food aid policies. Climate change's effects endanger people's capacity to make a living as well as agricultural security. Climate change presents a threat to Africa's food, water, and production systems. Climate change is expected to affect all aspects of food security, including availability, accessibility, endurance, and use. Examine Figure 1.

Diversity among landraces

Landraces are the scientific term used to describe domesticated plants that have adapted to life in the wild, despite having been raised in confinement. Genetic resources are made available to producers residing in challenging agricultural environments (Dwivedi et al., 2016). A multitude of nutrient-rich landraces thrive in diverse ecological settings. These include characteristics such as early maturity, resistance to cold, and a high crude protein content, among others. Keilwagen et al. (2014) stated that by employing multi-trait optimization and a normalized rank product, it is possible to identify plant breeding accessions with the desired qualities. By employing omics technology to enhance comprehension of landraces, researchers might discover genes and characteristics that confer superior responsiveness to diverse crop yields in novel cultivars. This is a method that can benefit produce despite inclement weather.

Contrast breeding

In plant breeding, phenotype-based selection is still employed to select populations that possess distinct genetic compositions. When numerous growing seasons pass and a genetic variant of that trait is selected from the original breeding material, the trait adapts to the local environment. This is particularly true regarding characteristics that are sensitive to climate change, such as digestible yield. Cultivars exhibiting diverse life cycles are compelled by climate change to possess characteristics of numerous species, whereas host plants must fortify resistance against the development of parasites and diseases. The genetic composition of a crop determines its adaptability, or capacity to react to environmental fluctuations (Chloupek & Hrstkova, 2005). In optimal conditions, a cultivar exhibiting a high degree of adaptability ought to generate greater yields. Frequently, the yield of a particular cultivar is ascertained through a comparison with the mean value of all conducted experiments (Finlay and Wilkinson, 1963). Quantitative genetics analysis investigates difficult-to-evaluate multigenic traits by employing a variety of statistical models and methodologies grounded in plausible assumptions (Hill, 2010). By shedding light on the interplay between genetic and nongenetic elements, quantitative genetics can facilitate a more comprehensive comprehension of the mechanisms through which traits adjust to dynamic environmental conditions. This illustrates elements of plant reproduction that are even more fundamental. The utilization of a substantial quantity of DNA markers, phenotypic data, and quantitative genetic analysis facilitates the anticipation of future offspring's quality or reproductive value, as well as the comprehension of trait evolution.

Contrary to breeding According to Smith (1993), "germplasm enhancement" or "pre-breeding" refers to "any modification of germplasm that leads to domestication." It is essential to research expanded germplasm plant reproduction to produce more domestic varieties than are currently imported. Plant breeding techniques are linked to genetic resources in genebanks via pre-breeding. In contrast, germplasm augmentation necessitates a substantial allocation of both time and resources, spanning a duration of five to ten years. Collaboration between the public and private sectors is required to guarantee the success of a genetic pool expansion initiative. Identifying advantageous qualities in genetic resources that are either unique or unsuitable for augmentation (i.e., ineffective for plant reproduction) is the initial step in the process of germplasm upgrading. Germplasm, or genetic material, is only biocompatible when it has undergone modifications to promote growth in an alien environment. A large number of advantageous alleles can be found in an exotic population that serves as a selection base population. Germplasm enhancement results from the transfer of these traits to intermediate breeding populations, which are subsequently utilized in the development of cultivars.

Role of Biotechnology for Cultivar Breeding

The development of novel crops will be aided by genomic-led breeding and genetic engineering as the climate changes as presented in Figure 1. Utilizing genomic estimated breeding values, marker-assisted recurrent selection, and marker-assisted backcrossing are all approaches to utilizing quantitative trait loci inbred germplasm. Genetic engineering enables the generation of germplasm amenable to crossing to develop hardy cultivars through the use of candidate genes that possess the proper promoters. The most effective methods for cultivating plants with the greatest genetic value and economic efficacy are generated by in-silico breeding. These solutions may subsequently be implemented in computer simulations and evaluated in real-world environments. Varshney et al. (2011) state that it has applications in network analysis, gene mapping, crop modeling, and simulation of genotype-environment interactions.

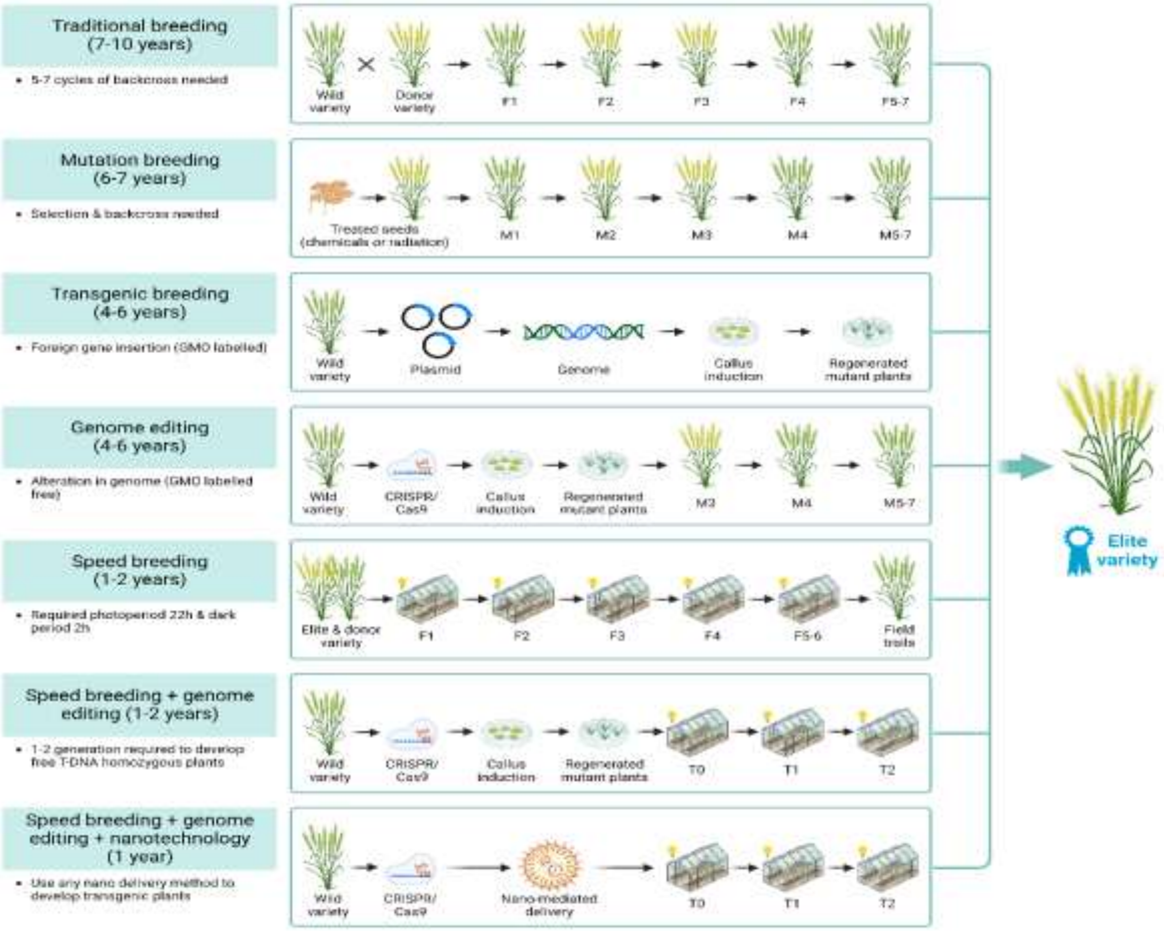

Figure 1: Integration of traditional plant breeding and modern biotechnological techniques to speed up the variety development process

Breeding and Phenotyping

Abiotic stressors influence the output and productivity of agriculture. Increased temperatures, extreme weather, and inundation all reduce agricultural production in the tropics. Thus, both food security and crop yields are enhanced. Adaptive breeding to climate change seeks to generate cultivars that exhibit resilience against adverse environmental conditions. Phenotypic plasticity, which refers to the capacity of plants to alter their phenotype in reaction to changes in their environment, has been observed (Nicotra et al., 2010). Physiology-assisted plant reproduction must thus consider this adaptability. Considering how genes are utilized to generate the contested attributes, this is entirely genetic. Sub-emergence-tolerant cultivars that are resistant to waterlogging, high nocturnal temperatures, and drought stress, all of which reduce rice production, have been developed through plant breeding in South Asia (Septiningsih et al., 2009). The internodes of sub-emergence-resistant rice are shorter, according to one study. Rice is a low-energy plant capable of surviving 14 days underwater and maintaining sufficient glucose reserves to develop as the water level lowers. Submergence results in the loss of gibberellic and abscisic acids, whereas the equilibrium is maintained by the phytohormone ethylene (Fukao & Bailey-Serres, 2008). Drought and rising temperatures have affected wheat production. Conversely, plant breeding has been shown to enhance the resistance of wheat to various forms of thermal stress (Gourdji et al., 2013). Wheat yield potential in high temperatures could potentially be increased by breeding for rising temperature trends throughout the development cycle, as evidenced by the presence of significant genetic benefits at high temperatures. To ascertain heat-tolerant wheat varieties, an infrared thermometer was employed to evaluate leaf conductivity, chlorosis (as determined by a self-calibrating chlorophyll meter), and membrane thermostability. Sharma et al. (2008) suggest that kernel weight loss can serve as a criterion for selecting wheat breeding lines that exhibit enhanced potential for yield when subjected to exceedingly high temperatures. Abiotic stress is induced by fluctuations in soil, climate, and agricultural practices, as well as by the temporal, duration, and frequency of such variations. Since the genes governing abiotic stress adaptation and resource utilization are separate, breeding for the former does not invariably lead to improved resource utilization (Fritsche-Neto & DoVale, 2012). In the absence of any interaction between the two processes, both features may be chosen. Errors may arise in the administration of plant breeding projects due to misunderstandings. A drought-resistant trait, for instance, ought to be assessed according to its capacity to generate substantial quantities of food, endure periods of drought, and make use of water in arid environments. The timing and severity of stress avoidance, escape, and tolerance breeding are influenced by stress in the target areas (Araus et al., 2002).

Adaptation to Abiotic Stress and Resource Management Efficiency

Breeding for abiotic stress tolerance becomes problematic when adaptive traits, which are frequently influenced by genotype-environment interactions, are prioritized over consumable yield. Reynolds et al. (2007) suggest that these attributes may have been inherited from landraces or closely related feral species. It is imperative to comprehend the physiological systems implicated and how genes impact them to formulate an ideotype breeding strategy. Gaining insight into the operation of specific traits via genetic and genomic investigations will enhance our understanding of the physiological reactions of plants to exogenous stress. Additionally, investigations into plant tissue metabolites, proteins, and transcripts will aid in the identification of characteristics that can be utilized to develop stress-resistant cultivars. By employing plant physiology and gene, metabolite, and protein profiling techniques, one can quantify crop productivity by assessing the efficiency with which crops utilize resources including nitrogen uptake, absorption, recycling, and seed storage. This is achievable for crops requiring high or minimal inputs. To assess input reactions, physiologically significant yield-determination functions were also developed (Sylvester-Bradley and Kindred, 2009). Conversely, to ensure yield stability, selection should occur under conditions of minimal input as opposed to high input (Cormier et al., 2013).

Large-Scale and Precise Phenotyping

The terminology employed by Falhgren et al. is "high-throughput phenotyping using the non-destructive acquisition of traits from time-series measurements of individual plants developing under stress using robotic-assisted imaging equipment and computer vision-assisted analysis tools". Phenomics is the scientific study of the temporal evolution of plant phenotypes. This contributes to the advancement of knowledge regarding the function of genes in the formation of predictive models for plant responses to their environment. For instance, bushy, deeply rooted vegetation has the potential to increase agricultural productivity by enhancing soil structure, as well as retaining carbon, water, and nutrients. Bucksch et al. (2014) stated that high-throughput field phenotyping with images is a dependable and economical method for investigating localized root system characteristics in the open. This approach, which is also employed in the laboratory, enhances the statistical power. To account for plant variability in greenhouses with plants on conveyor belts, statistical designs are implemented.

Trait introgression and genomics-driven breeding utilizing DNA markers

Genomic data are advantageous to quantitative genetics because they facilitate the organization of genetic marker information. Additional mechanisms by which genetic information can be converted into biological activity are provided by various omics, including metabolic signaling pathways and transcriptional and translational control (Keurentjes et al., 2008). The establishment of biological data-driven regulatory networks, which integrate the flow of information from genes to functions, is the consequence of this transition. Through the examination of a vast array of genetic markers in individuals from various regions of the globe, population genomics attempts to identify the genes responsible for generating environmental traits (Stinchcombe and Hoekstra, 2008). Quantitative genetics and population genomics data are utilized to gain a deeper understanding of how natural selection modifies the genetic architecture of adaptive traits and how genes contribute to adaptation to similar environments. Genomic research contributes to the improvement of breeding precision for a variety of crops and permits the assembly of distinct genomes from exceptional germplasm. The investigation of association genetics and transcriptome research can contribute to a greater comprehension of gene-environment interactions and the factors that contribute to diverse symptoms under various conditions. The investigation of plants' capacity to withstand abiotic stress is also a subject of intense genomics research (Roy et al., 2011). The cultivation of commodities that are more resistant to the impacts of climate change will be facilitated by these findings, ultimately leading to a warmer climate.

The Practice of Transgenic Breeding

Genetic engineering is employed in plant breeding to assist crops in adapting to the adverse effects of climate change, including drought and salinity (Ortiz et al., 2014). As an additional measure to mitigate climate change, transgenic crops will optimize the utilization of existing resources. Consequently, genetic engineering will undoubtedly contribute to the development of climate change-adaptive agricultural cultivars. Jewell et al. (2010) provided evidence that crop tolerance to abiotic stress could be increased through transgenic breeding. It is possible to introduce desired genes into plant germplasm through engineering; this method may be more precise than cross-breeding. The process of proof of concept establishment in plant genetic engineering commences with the identification of target genes and continues through a series of laboratory, greenhouse, and field research and testing phases (Ortiz, 2008). Distribution of transgenic cultivars is contingent upon the evaluation of potential environmental, biodiversity, food safety, and human health concerns. In recent times, molecular networks, signal transduction, and stress sensing in plants have been identified by scientists. This, according to Cinelli and Tonelli (2010) and Hu and Xiong (2013), permits the modification of regulatory and functional genes at the level of the plant to modify its response to water stress.

Conclusion

Thus, plant breeding plays a key role in the development of high-yielding cultivars to ensure food security. Modern biotechnological techniques along with traditional plant breeding practices can speed up the laborious and lengthy process of variety development having high yields and quality.

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Declarations

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All data generated or analyzed during the study are included in the manuscript.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

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Conflict of Interest

Regarding conflicts of interest, the authors state that their work was carried out independently without any affiliations or financial ties that could raise concerns about biases.