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Plant Biotechnology and Molecular Breeding for Global Food Security

Cite This: https://doi.org/10.1021/acsagscitech.4c00187 Read Online

It is anticipated that the global human population will reach 10 billion in the next 30 years.[1] Thus, the global food supply is facing severe challenges under a changing climate, with limited agricultural land and freshwater resources. To meet the nutritional needs of the expanding population, greater and more consistent crop production under fluctuating climate conditions must be achieved, meanwhile reducing resource inputs and minimizing environmental impacts. Therefore, the pursuit of green, efficient, and sustainable agriculture has emerged as a focal point of research in the global scientific community.

With the rapid progress of plant biotechnology, such as marker-assisted selection, genomic selection, transgenic technology/gene modification, haploid induction, gene editing, synthetic biology, molecular design, and intelligent breeding, plant breeding has entered a new and more efficient era of molecular breeding.[2] For example, many male sterility genes were identified via CRISPR/Cas9 gene editing,[3] and their derived multicontrol sterility system[4] and dominant genic male sterility system[5] in maize were constructed using transgenic technology and molecular design strategies, which led to a decrease in the cost of seed production and a increase in crop grain yield.[6] Consequently, important traits such as yield, quality, abiotic and biotic resistance, and nitrogen use efficiency (NUE) have been significantly improved, and thus, the global food security crisis has been eased to some extent.[7]

The virtual special issue "Plant Biotechnology, Molecular Breeding, and Food Security" aims to systematically summarize and promote the development of plant biotechnology, molecular breeding, and their applications in improving crop varieties to ensure food security. Key ideas and topics of the collected reviews and articles are summarized here.

The viewpoint paper by Grieger and Kuzma[8] puts forward an approach for establishing formalized research programs to develop a suite of tools and approaches required for evaluating the sustainability of novel plant biotechnologies befitting the 21st century. The paper highlights the joint effort of establishing a central coordinating office, coordinating federally funded research, developing funding mechanisms, developing a common set of sustainability assessment parameters, and engaging more stakeholders. Another viewpoint paper by Smyth[9] compares the total opposite regulatory policy systems on genetically modified (GM) innovation and application in Canada and the EU. As a consequence, the widely adopted GM crops with reduced tillage and chemical use position Canadian prairie farmers among the most sustainable farmers on the planet, while agricultural production in the EU remains relatively unchanged despite several decades of transformative agricultural innovation.

With respect to the regulatory, economic, societal, and policy considerations on plant biotechnology and molecular breeding, Zhao et al.[10] assert that grain loss and waste (GLW) pose significant challenges to global food security, sustainability, and climate change mitigation. Through bibliometric analysis, they underscore the crucial roles of technological advancements, dietary consciousness, and the principles of a circular economy in mitigating GLW. Chen et al.[11] analyze the pathways for ensuring food security in the context of the Chinese Bioeconomy Landscape. This study highlights the demand for agricultural biotechnology in the context of China's food security, summarizes the development experiences of representative countries and regions in the field of bioeconomy, and proposes specific ways to fully leverage the supportive role of bioeconomy in ensuring China's food security.

Several articles highlight the advances in plant biotechnology and their applications in addressing climate change and food security. Misra et al.[12] contend that the advent of CRISPR/Cas9 genome editing has significantly accelerated the creation of resistant sugar beet varieties by facilitating precise genetic modifications. This work elucidates the revolutionary impact of CRISPR/Cas9 on sugar beet cultivation, reveals crucial regulators of disease resistance, and provides insights into interactions of pathogens and the sugar beet microbiome. Brower-Toland et al.[13] provide an overview of approaches that integrate biotechnology and new breeding techniques to protect the yield into a conservation framework to accelerate sustainable intensification. The authors conclude that by designing crops to function in the optimal planting configurations, improved crop rotational systems, and smart soil nutrient management, the concept of "grow even more with less" will be realized. Furthermore, Lemke et al.[14] summarize the legal authority and regulatory framework that underpins safety assessment of foods derived from new plant varieties in the United States, the process used by breeders to create new lines that meet commercial specifications mean-

Received: April 10, 2024
Accepted: April 10, 2024

while limiting unintended effects, and the application of food safety principles to products based on gene-edited crops. The paper highlights that breeders will continue to use best practices for the selection and commercialization of new plant varieties that ensures product quality for growers and safe food for consumers. The authors further propose that the U.S. Food and Drug Administration's authority and specific guidance continue to be relevant for the safety assessment of foods derived from these new plant varieties. Tyagi et al.[15] provide a comprehensive overview of plant defense strategies and biomarkers against heavy metal-induced stress, which has been a serious concern in the scientific community due to its yield-limiting effects on crop plants. This work highlights the heavy metal stress, various defense strategies employed by plants, and potential biomarkers used to detect heavy metal stresses and tries to draw a possible roadmap toward smart and sustainable agriculture.

There are also several reports on molecular breeding strategies and their applications for breeding of green and high-efficiency varieties in plants. He et al.[16] summarize the recent advances of modern breeding strategies and their applications in the maize Breeding 3.0 (biological breeding) stage. The modern breeding strategies, including marker-assisted selection, genomic selection, genetic engineering, haploid-induced breeding, gene editing, and synthetic biology, act as breeding accelerators and lead to maize improvement in different important traits, such as male sterility, grain yield, grain quality, biotic and abiotic stress resistance, and nitrogen use efficiency. The authors also propose several promising breeding strategies in the next era of Breeding 4.0 (intelligence breeding), which will improve maize production greatly for ensuring global food security.

Aldehyde dehydrogenase (ALDH) oxidizes endogenous or exogenous aldehydes into carboxylic acids to reduce the toxicity of aldehydes and respond to stress. Zhang et al.[17] report and characterize a total of 35 members of the *ALDH* gene family in the maize genome. They find that 15 *ZmALDH* genes display high expression levels in maize anthers and may play potential roles in male fertility. This work provides potential value for discovering more male sterility genes that can contribute to maize hybrid breeding and seed production. Sweet corn is cultivated worldwide in tropical and temperate regions, and it is consumed favorably due to its sweet taste but is poor in provitamin A carotenoids. Rathinavel et al.[18] adopt a marker-assisted backcross breeding (MABB) approach to enhance the β-carotene concentration in sweet corn inbreds, which are used to produce hybrids with improved vitamin A content. The hybrids produced by crossing improved lines are on par with the original hybrids regarding grain yield and sweetness with an added advantage of β-carotene. These improved β-carotene-rich sweet corn inbreds and hybrids have enormous potential to reduce malnutrition in a sustainable and economical way.

Ravindran et al.[19] investigate the genetic variability of 22 turmeric (*Curcuma longa* L.) genotypes selected from the germplasm collected from different regions through 26 SSR markers. This work demonstrates that the SSR markers could be a useful tool in the introduction process of new and modern turmeric cultivars possessing tailor-made essential traits, such as better adaptation and resilience to current climatic change scenarios along with high performance in terms of productivity as well as production of curcumin, oleoresin, and essential oil compounds, which together make turmeric a promising industrial crop in the near future.

Furthermore, there are three papers about the advanced technologies to support plant breeding. Sharma et al.[20] summarize the factors affecting production, nutrient translocation mechanisms, and light-emitting diodes (LED) that emitted light in the growth of microgreen plants in soilless culture, such as light, temperature, water, growth media, type of system, harvesting time, storage, nutrients, pH, total dissolved solids, plant size, root length, and electrical conductivity, regularly induce cellular, biochemical, and molecular processes in the microgreen plants. Similarly, Sharma et al.[21] also highlight the regulations and factors affecting LED artificial light in crop production under soilless culture, and they conclude that the total and net energy production must be investigated with respect to the effect of light and plants raised in tissue culture, breeding, and gene manipulation under a closed system. Pang et al.[22] explore a high-efficiency genetic transformation system for engineering *Saccharopolyspora pogona* ASAGF58 to improve the production of butenyl-spinosyn, which is a potent insecticide potentially useful as a broad-spectrum pesticide.

In summary, plant biotechnology and molecular breeding strategies, such as transgenic technology/genetic transformation,[22] gene editing,[12,23] marker-assisted selection,[18,19] and synthetic biology,[16] have advanced over the past decades and play an important role in breeding improved crop varieties, thereby contributing to a sustainable agriculture and global food security.[1,7,24] In the future, emerging technologies such as artificial intelligence, big data and machine learning, biosensing and smart agriculture, efficient use of sunlight, factory farming, and digital agriculture will further revolutionize plant breeding and field production. Integrating these cutting-edge technologies into breeding pipelines will be pivotal in establishing a green, efficient, and cost-effective agri-food system. This holistic approach is essential for meeting the growing demand for adequate, nutritious, and sustainable food to support the ever-expanding global population throughout the 21st century.

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Notes

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https://doi.org/10.1021/acsagscitech.4c00187
ACS Agric. Sci. Technol. XXXX, XXX, XXX−XXX