Triticeae Genomics and Genetics, 2024, Vol.15, No.1, 44-55
http://cropscipublisher.com/index.php/tgg

Feature Review Open Access

Triticeae in Global Food Security: Challenges and Prospects

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Triticeae Genomics and Genetics, 2024, Vol.15, No.1 doi: 10.5376/tgg.2024.15.0005
Received: 05 Jan., 2024
Accepted: 06 Feb., 2024
Published: 18 Feb., 2024

Preferred citation for this article:
Cai R.X., 2024, *Triticeae* in global food security: challenges and prospects, Triticeae Genomics and Genetics, 15(1): 44-55 (doi: 10.5376/tgg.2024.15.0005)

Abstract Against the backdrop of global population growth, intensified climate change, and resource scarcity, stable production of wheat crops such as wheat, barley, and rye is crucial for ensuring global food security. The Triticae plays a crucial role in global food security. This study focuses on analyzing the classification, genetic diversity, agricultural significance, and major challenges faced by the major species of the wheat family (wheat, barley, and rye), revealing the importance of Triticae crops in ensuring global food supply, providing nutritional value, and promoting sustainable agricultural development. At the same time, the impact of biotic and abiotic stress factors such as diseases and pests, drought, etc. on wheat yield was explored, as well as the prospects of improving wheat productivity through genetic breeding, biotechnology, and innovative agricultural practices. The aim is to provide scientific basis for the formulation of food security strategies and promote the healthy and stable development of the global food system.

Keywords Maizu (*Triticeae*); Global food security; Wheat family; Genetic breeding; Biotechnology

With the continuous growth of global population and the intensification of climate change, food security has become a common concern of the international community. As an important component of the global food system, wheat is not only one of the widely cultivated food crops in the world, but also an indispensable source of energy and nutrition in human diet. Therefore, a deeper understanding of the role of the wheat tribe in global food security, as well as the challenges and prospects it faces, is of crucial importance for ensuring global food supply and nutritional health.

The *Triticeae* tribe, belonging to the subfamily Pooideae and family Poaceae, encompasses approximately 30 genera and 360 species, including some of the most economically significant temperate cereal crops such as wheat (*Triticum* spp.) and barley (*Hordeum vulgare* L.) (Schnurbusch, 2019). These species are not only vital for their direct contribution to human nutrition but also for their role in agricultural sustainability and food security. The tribe also includes a substantial number of perennial species, which, despite their potential, have received less attention compared to their annual counterparts.

Wheat and barley are critical to global food security, ranking second and fourth in world production, respectively, in 2016 (Schnurbusch, 2019). These cereals are fundamental sources of carbohydrates and proteins, contributing significantly to the daily energy intake of populations worldwide, especially in developing countries where they can provide up to 80% of the dietary energy (Schnurbusch, 2019). However, the yield gains of these crops have stagnated over the past two decades, particularly in high-yielding regions, posing a significant challenge to meeting future food demands (Schnurbusch, 2019). Additionally, the *Triticeae* tribe's genetic diversity, particularly in wild relatives, offers substantial potential for improving crop resilience to abiotic stresses such as drought and salinity, which are major threats to global food supply (Nevo and Chen, 2010).

This study aims to comprehensively review and analyze the role, challenges, and future development prospects of the wheat tribe in global food security. By conducting in-depth research on the genetic characteristics, cultivation techniques, pest and disease control, and industrial chain optimization of the wheat family, scientific basis and technical support are provided for the sustainable development of the wheat industry. Meanwhile, this study will also explore the development prospects and response strategies of wheat crops, in order to better address the challenges of global food security and contribute to ensuring food security and nutritional health for people worldwide.

1 *Triticeae*: An Overview

1.1 Taxonomy and classification

The *Triticeae* tribe, part of the Poaceae family, includes some of the most important cereal crops such as wheat, barley, and rye. Taxonomically, *Triticeae* is complex due to its reticulate evolutionary history, which involves extensive hybridization and polyploidy. Various taxonomic treatments have been proposed over time, with significant contributions from different taxonomists aiming to classify the tribe based on morphological, cytogenetic, and molecular data (Barkworth, 2008). Historically, Linnaeus, Bentham, Hackel, and Nevski have all influenced the classification approaches, each bringing unique perspectives on defining genera and species within *Triticeae* (Bernhardt, 2015).

In the wheat family, the differentiation between different species often involves multiple aspects such as their growth habits, leaf morphology, inflorescence structure, and seed characteristics. For example, some species are perennial, while others are annual; Some species have wider leaves, while others are narrower; The structure of inflorescences and the shape, size, and color of seeds are also important criteria for distinguishing different species.

1.2 Major species in the *Triticeae* tribe

The Triticae tribe, as an important branch of the Poaceae family, has members widely distributed around the world and can grow under different climate and soil conditions.

1.2.1 Wheat (*Triticum* spp.)

Wheat (Triticum spp.) is the most widely cultivated and economically significant crop in the *Triticeae* tribe. It is a staple food for a large part of the world's population, providing essential nutrients such as carbohydrates and proteins. Wheat's taxonomy is particularly complex due to its numerous species and subspecies, hybridization events, and polyploidy. Modern classifications divide wheat into three main groups based on their ploidy levels: diploid (e.g., *Triticum monococcum*), tetraploid (e.g., *Triticum turgidum*), and hexaploid (e.g., *Triticum aestivum*) (Goncharov, 2011).

The Triticae tribe, as an important branch of the Poaceae family, has members widely distributed around the world. As one of the main food sources for human beings, wheat caryopsis can be ground into flour to make bread, Mantou, biscuits, noodles and other foods. In addition, wheat straw can also be used as feed for livestock, with extremely high economic value.

1.2.2 Barley (*Hordeum vulgare*)

Barley (*Hordeum vulgare*) is another critical cereal crop within the *Triticeae* tribe. It is known for its versatility and ability to grow in a wide range of environmental conditions. Barley is used for food, animal feed, and brewing. Its genetic diversity is considerable, with numerous wild and cultivated varieties contributing to its adaptability and resilience. Barley's taxonomy, like wheat's, has been subject to extensive research and reclassification efforts, reflecting its genetic and morphological diversity (Yen and Yang, 2009).

Barley is not only an important food crop, but also the best raw material for producing beer and whiskey. At the same time, malt, a processed product formed by the germination and drying of mature barley fruits, has medicinal value in promoting qi and digestion, invigorating the spleen and appetite, and reducing milk and swelling.

1.2.3 Rye (*Secale cereale*)

Rye (*Secale cereale*) is less widely grown than wheat and barley but plays a crucial role in agriculture, particularly in regions with poor soil quality and harsh climates. Rye is valued for its hardiness and ability to grow in less fertile soils where other cereals might fail. It is used for bread-making, animal feed, and as a cover crop to prevent soil erosion. The genetic and morphological characteristics of rye have been extensively studied to improve its agronomic traits and resistance to diseases (Kawahara, 2009).

Rye has a large amount of leaves, soft stems, rich nutrients, and good palatability. It can be used as both grain and high-quality feed. Meanwhile, rye is also widely used in the production of bread and other foods, and is favored by people for its unique nutritional value and health benefits.

1.3 Genetic diversity and evolution

The genetic diversity within the *Triticeae* tribe is vast, encompassing a wide range of species with different evolutionary histories. This diversity is crucial for breeding programs aimed at improving crop resilience, yield, and nutritional quality. Hybridization and polyploidy have played significant roles in the evolution of *Triticeae*, leading to the development of species with complex genomic structures. Advances in molecular biology and genomics have provided new insights into the evolutionary relationships and genetic diversity of *Triticeae* species, facilitating the identification and utilization of beneficial traits from wild relatives (Seberg and Petersen, 2007).

2 Agricultural Significance

2.1 *Triticeae* in crop production

The tribe *Triticeae*, which includes economically significant crops such as wheat (*Triticum* spp.) and barley (*Hordeum vulgare* L.), plays a crucial role in global crop production. Wheat and barley are among the most important temperate cereal crops, with wheat ranked second and barley fourth in terms of world production in 2016 (Schnurbusch, 2019). These cereals are vital sources of carbohydrates and proteins, contributing significantly to the daily energy intake of populations worldwide, especially in developing countries where they can provide up to 80% of the dietary energy (Schnurbusch, 2019). Despite their importance, yield gains for these crops have stagnated in recent decades, particularly in high-yielding regions like Europe, highlighting the need for innovative agricultural practices to meet future food demands sustainably (Schnurbusch, 2019).

2.2 Nutritional value and health benefits

Triticeae crops are not only essential for their caloric contribution but also for their nutritional value. Wheat and barley provide a substantial amount of daily carbohydrates and proteins, which are crucial for maintaining a balanced diet (Schnurbusch, 2019). The nutritional profile of these cereals includes essential vitamins and minerals, which are vital for human health. For instance, wheat and barley are significant sources of dietary fiber, which is important for digestive health. Additionally, the consumption of whole grains, such as those from *Triticeae*, has been associated with a reduced risk of chronic diseases, including heart disease and diabetes (Schnurbusch, 2019). The emphasis on the nutritional benefits of these crops underscores their role in addressing global health challenges related to diet and nutrition.

2.3 Role in sustainable agriculture

The role of *Triticeae* in sustainable agriculture is multifaceted. These crops are integral to crop rotation systems, which help maintain soil health and reduce pest and disease cycles. Moreover, the genetic diversity within the *Triticeae* tribe, including wild and weedy taxa, offers valuable resources for crop improvement and resilience against environmental stresses (Lu and Ellstrand, 2014). The use of beneficial phytomicrobiomes associated with *Triticeae* can further enhance plant health and productivity by improving resource use efficiency and resilience to biotic and abiotic stresses (Chouhan et al., 2021). Sustainable agricultural practices involving *Triticeae* also include the development of genetically modified (GM) crops with enhanced traits such as stress tolerance and improved nutritional profiles, which can contribute to food security and environmental sustainability (Anderson et al., 2016). These approaches are essential for meeting the twin challenges of increasing agricultural productivity and ensuring environmental sustainability in the face of climate change and resource limitations (Anderson et al., 2016; Chouhan et al., 2021).

In summary, *Triticeae* crops are indispensable for global food security due to their significant contributions to crop production, nutritional value, and sustainable agricultural practices. Addressing the challenges of yield stagnation and leveraging genetic and biotechnological advancements will be crucial for enhancing the role of *Triticeae* in a sustainable and food-secure future.

3 Challenges in *Triticeae* Cultivation

In the context of global food security, wheat, as one of the main food crops, faces multiple challenges in its cultivation process. These challenges not only come from biological factors, but also include non biological factors as well as socio-economic and policy challenges.

3.1 Biotic stress factors

Triticeae crops, including wheat, barley, and rye, are susceptible to a wide range of pests and diseases that significantly impact yield and quality. Common pests include aphids, mites, and cereal leaf beetles, which cause direct damage to plants and act as vectors for diseases. Key diseases affecting *Triticeae* crops are rusts (*Puccinia* spp.), powdery mildew (*Blumeria graminis*), and Fusarium head blight. These diseases can lead to substantial yield losses and reduce grain quality. Efforts to breed resistant varieties and develop integrated pest management strategies are ongoing but face challenges due to the evolving nature of pathogens and pests (Dong et al., 2008).

Weeds are a major issue in *Triticeae* cultivation as they compete with crops for nutrients, water, and light, leading to reduced crop yields. The competitive ability of *Triticeae* crops varies, with some varieties exhibiting better weed suppression than others. Effective weed management practices, such as crop rotation, mechanical weeding, and the use of herbicides, are crucial for maintaining high productivity. However, the development of herbicide-resistant weeds and the limited availability of effective and safe herbicides pose significant challenges (Feledyn-Szewczyk et al., 2020).

3.2 Abiotic stress factors

Drought and water stress are among the most critical abiotic factors affecting *Triticeae* crops, particularly in arid and semi-arid regions. Water scarcity reduces photosynthesis, hampers growth, and leads to significant yield losses. Breeding for drought-tolerant varieties and adopting water-saving irrigation techniques, such as drip irrigation and rainwater harvesting, are essential strategies to mitigate these impacts. Genetic improvement focusing on root architecture, water-use efficiency, and stress-responsive traits can enhance drought resilience (Sun et al., 2014).

Soil salinity is another significant abiotic stress that limits *Triticeae* crop production, particularly in irrigated and coastal areas. High salt concentrations in the soil can impair water uptake, cause ion toxicity, and reduce nutrient availability, leading to stunted growth and low yields. Breeding for salt-tolerant varieties and employing soil management practices, such as leaching excess salts and using salt-tolerant rootstocks, are critical for improving crop performance in saline soils (Dong et al., 2008).

Extreme temperatures, including heat and cold stress, adversely affect *Triticeae* crops by disrupting physiological processes and reducing grain quality and yield. Heat stress during flowering and grain filling can cause sterility and poor grain development, while frost damage can be detrimental during early growth stages. Developing heat and cold-tolerant varieties through conventional breeding and biotechnological approaches, along with the adoption of agronomic practices such as altering planting dates and using protective covers, are vital to mitigate temperature stress (Shao et al., 2006).

3.3 Socioeconomic and policy challenges

In addition to biotic and abiotic stress factors, wheat cultivation also faces socio-economic and policy challenges. With the growth of population and economic development, the demand for wheat continues to increase, which brings greater pressure to wheat production. Changes in agricultural policies and intensified market competition may also have adverse effects on wheat cultivation. For example, the reduction of government subsidies for wheat and the impact of imported wheat may have an impact on the enthusiasm of wheat producers. In addition, global issues such as climate change and water scarcity may also have profound impacts on wheat cultivation.

International cooperation and knowledge sharing can more effectively address these challenges (Timsina and Connor, 2001)

4 Advances in *Triticeae* Research

4.1 Genetic and genomic tools

Recent advancements in genetic and genomic tools have significantly contributed to the improvement of *Triticeae* crops. High-throughput sequencing and genome editing technologies, such as CRISPR/Cas systems, have enabled precise modifications in the genome, facilitating the development of crops with enhanced traits (Salgotra and Stewart, 2020; Razzaq et al., 2021). Functional genomics approaches, including transcriptomics and allele mining, have been instrumental in identifying functional markers (FMs) associated with important agronomic traits, thereby increasing the efficiency of breeding programs (Salgotra and Stewart, 2020). These tools are crucial for understanding the genetic architecture of trait variation and for the development of climate-resilient crops (Figure 1) (Harper et al.,2020; Razzaq et al., 2021).

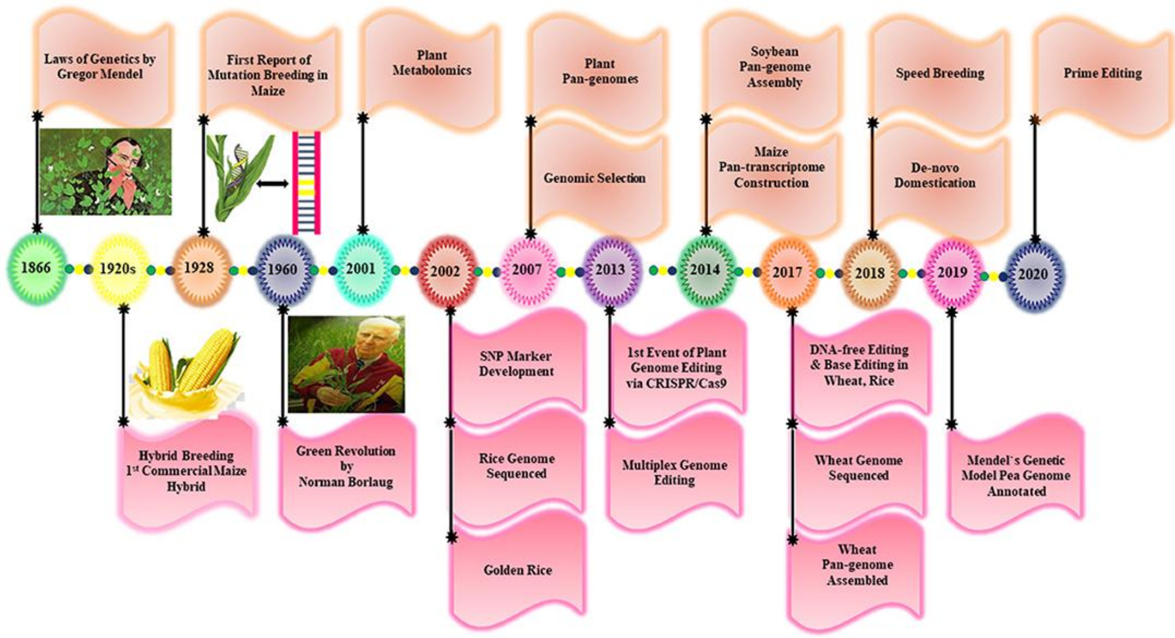

Figure 1 Important milestones in the field of plant genetics and breeding from 1866 to 2020 (Adapted from Razzaq et al., 2021)

Razzaq et al. (2021) compiled important milestones in the field of plant genetics and breeding from 1866 to 2020. In 2002, the development of SNP (single nucleotide polymorphism) markers provided a foundation for genome selection in crops such as wheat. In 2013, the application of CRISPR/Cas9 technology marked a new era in plant genome editing. In 2017, the application of DNA free editing and base editing techniques in wheat further improved the accuracy and efficiency of breeding. In 2018, the complete sequencing of the wheat genome provided researchers with a detailed genome blueprint. In 2020, the assembly of the wheat pan genome demonstrated genetic diversity among different wheat varieties. These milestones reflect the rapid development of wheat genome research, providing strong support for improving wheat yield, stress resistance, and nutritional value.

4.2 Breeding and biotechnology

Conventional breeding remains a fundamental approach in *Triticeae* crop improvement. It involves the selection of superior genotypes based on phenotypic traits and their subsequent propagation. This method has been successful in developing varieties with improved yield, disease resistance, and adaptability to different environmental conditions (Lu and Ellstrand, 2014). However, the process is time-consuming and often limited by the genetic diversity available within the cultivated species.

Marker-assisted selection (MAS) has revolutionized conventional breeding by incorporating molecular markers linked to desirable traits. This approach allows for the early and precise selection of superior genotypes, thereby accelerating the breeding process (Harper et al., 2020; Salgotra and Stewart, 2020). The use of associative transcriptomics platforms has further enhanced MAS by enabling the identification of genetic markers associated with key agronomic traits, such as seed weight and quality (Harper et al., 2020). These advancements have made it possible to develop elite crop cultivars more efficiently, contributing to global food security (Salgotra and Stewart, 2020).

Genetic engineering offers powerful tools for the direct manipulation of the *Triticeae* genome to introduce beneficial traits. Techniques such as CRISPR/Cas genome editing have been employed to enhance crop resilience, improve nutritional content, and increase yield (Razzaq et al., 2021; Anyshchenko, 2022). These methods provide solutions to overcome the limitations of conventional breeding and MAS, offering a faster and more precise approach to crop improvement. The alignment of scientific advancements with policy and regulatory frameworks is essential to fully realize the potential of genetic engineering in contributing to food security (Anyshchenko, 2022).

4.3 Innovative agronomic practices

Innovative agronomic practices are essential for maximizing the potential of *Triticeae* crops in the face of climate change and resource limitations. The integration of modern breeding techniques with efficient agronomic practices, such as optimized irrigation and fertilization strategies, can significantly enhance crop productivity (Razzaq et al., 2021). Additionally, the application of microbiome innovations and the exploitation of natural variations in underutilized crops offer promising avenues for sustainable agriculture (Razzaq et al., 2021). By adopting high-throughput phenotyping and big data analytics, agriculture is moving towards automation and digitalization, further supporting the development of climate-ready crops (Razzaq et al., 2021).

In summary, the integration of advanced genetic and genomic tools, modern breeding techniques, and innovative agronomic practices holds great promise for the improvement of *Triticeae* crops. These advancements are crucial for addressing the challenges of global food security and ensuring sustainable agricultural development.

5 Prospects for Enhancing *Triticeae* Productivity

5.1 Integrative approaches in breeding

Integrative approaches in breeding are essential for enhancing *Triticeae* productivity. Modern breeding techniques, such as genomic-assisted breeding (GAB), have shown promise in developing climate-resilient crops that can withstand various environmental stresses, including drought, heat, and salinity (Kole et al., 2015; Razzaq et al., 2021). The use of high-throughput sequencing and phenotyping platforms has transformed traditional breeding methods, allowing for the identification of quantitative trait loci (QTL) and genes associated with stress tolerance (Kole et al., 2015). Additionally, the integration of speed breeding with genomic and phenomic tools can accelerate the development of superior genotypes (Razzaq et al., 2021). The utilization of landrace diversity, as demonstrated in wheat breeding, can also provide access to untapped genetic variations that can enhance yield, stress resilience, and nutritional quality (Figure 2) (Cheng et al., 2023).

Cheng et al. (2023) investigated the contribution of local variety diversity to modern breeding. Research has shown that utilizing unique genetic variations in local varieties can enrich the gene pool of modern breeding, providing traits of disease resistance, stress tolerance, and high nutritional value. These mutations play an important role in adapting to changing environments and increasing yields. Through GWAS and SNP marker analysis, the study emphasizes the importance of local varieties in modern breeding, which can help enhance crop stress resistance and nutritional quality. In short, the diversity of local varieties provides valuable genetic resources for modern breeding.

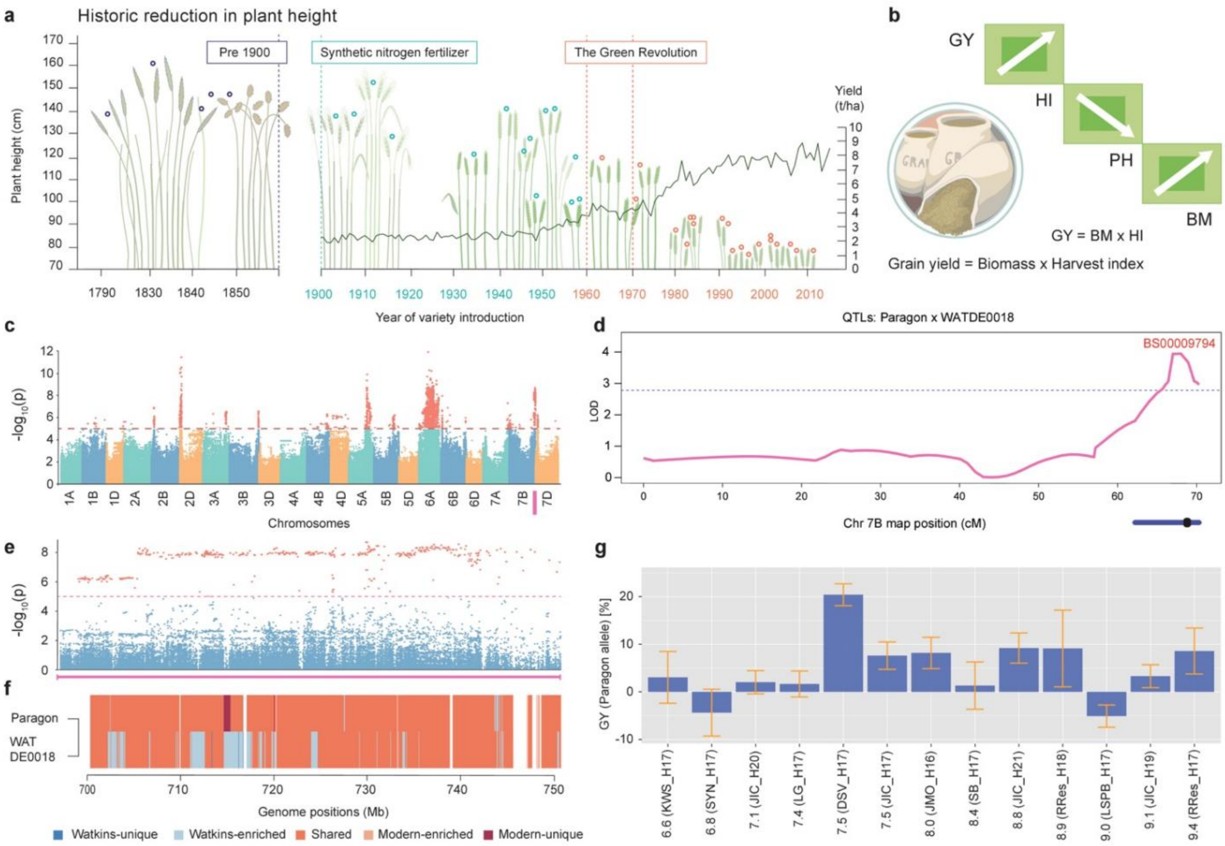

Figure 2 Key role of local variety diversity in wheat genetic improvement (Adapted from Cheng et al., 2023)

Image caption: Figure (a) shows the historical decrease in plant height; (b) Displayed the relationship between grain yield (GY), biomass (BM), harvest index (HI), and plant height (PH); (c) Manhattan map displaying genome-wide association studies (GWAS) of wheat chromosomes; (d) Displayed quantitative trait loci (QTL) analysis of grain yield on chromosome 7B; (e) Significant SNPs related to plant height; (f) Genomic location and allele frequency of Paragon and WAT DEO018 varieties; (g) Showcased the impact of Paragon alleles on grain yield in different environments (Adapted from Cheng et al., 2023)

5.2 Climate-smart agriculture

Climate-smart agriculture (CSA) is a critical strategy for ensuring the sustainability of *Triticeae* production under changing climatic conditions. CSA involves the adoption of practices that increase productivity, enhance resilience, and reduce greenhouse gas emissions. The development of climate-resilient crop varieties through genomics-assisted breeding and other advanced techniques is a key component of CSA (Kole et al., 2015; Hajj, 2023). For example, the identification and incorporation of stress tolerance alleles into high-yielding genetic backgrounds can mitigate the impact of climate change on crop productivity (Hajj, 2023). Furthermore, the use of next-generation breeding tools, such as CRISPR/Cas systems, can facilitate the development of crops with enhanced resistance to abiotic and biotic stresses (Razzaq et al., 2021).

5.3 Enhancing nutritional quality

Enhancing the nutritional quality of *Triticeae* crops is vital for addressing global food and nutritional security. Breeding strategies that focus on improving the nutritional content of crops, such as increasing protein, vitamins, and mineral levels, are essential (Kulkarni et al., 2018; Mekonnen et al., 2022). For instance, the development of cowpea genotypes with high nutritional value and resistance to biotic and abiotic stresses can contribute to food security and reduce malnutrition in regions like sub-Saharan Africa (Mekonnen et al., 2022). Additionally, the identification of functional variations in landrace collections can lead to the development of modern cultivars with superior nutritional traits (Cheng et al., 2023). Integrating these nutritional improvements into breeding programs can ensure that *Triticeae* crops meet the dietary needs of the growing global population.

5.4 Policy and institutional support

Policy and institutional support play a crucial role in enhancing *Triticeae* productivity. Effective policies that promote the adoption of innovative breeding technologies and climate-smart agricultural practices are essential for achieving sustainable food security (Singh et al., 2020; Anders et al., 2021). For example, harmonized global policy changes can facilitate the acceptance and implementation of novel gene technologies in plant breeding (Anders et al., 2021). Additionally, institutional support for quality seed systems, participatory plant breeding, and maintenance breeding can accelerate the varietal replacement rate, leading to higher crop productivity (Singh et al., 2020). Addressing socio-economic and technical constraints through policy interventions can also enhance the scalability and impact of breeding programs in developing countries (Singh et al., 2020).

6 Case Studies

6.1 Successful *Triticeae* cultivation practices

Successful cultivation practices of *Triticeae*, particularly wheat and barley, have been pivotal in enhancing global food security. One notable practice involves the utilization of wild relatives of these crops to improve their resilience to abiotic stresses such as drought and salinity. For instance, the genetic resources of *Triticum dicoccoides* and *Hordeum spontaneum*, the progenitors of cultivated wheat and barley, have been extensively studied and utilized to transfer drought- and salt-tolerant genes into modern cultivars. This has been achieved through advanced backcross QTL analysis and the development of introgression libraries, which have significantly improved the tolerance of these crops to harsh environmental conditions (Nevo and Chen, 2010).

Another successful practice is the use of endophytic fungi, such as certain strains of Trichoderma, which enhance the photosynthetic capability of plants. These fungi colonize the roots of crop plants, inducing up-regulation of genes and pigments that improve photosynthesis. This not only increases crop yields but also helps in mitigating the effects of climate change by enhancing carbon sequestration in the soil (Harmanet al., 2019).

6.2 Regional initiatives and programs

Various regional initiatives and programs have been instrumental in promoting the cultivation of *Triticeae* crops. For example, in China, the Ministry of Education Key Laboratory for Biodiversity and Ecological Engineering has been actively involved in the conservation and utilization of genetic resources of *Triticeae*. Their efforts have focused on identifying and preserving the genetic diversity of both cultivated and wild taxa, which are crucial for crop improvement and food security (Lu and Ellstrand, 2014).

In the Middle East, programs aimed at utilizing the genetic diversity of wild relatives of wheat and barley have been implemented to develop cultivars with enhanced tolerance to drought and salinity. These initiatives have involved extensive field trials and collaborations with international research institutions to ensure the successful transfer of beneficial traits to modern cultivars (Nevo and Chen, 2010).

6.3 Lessons from historical contexts

Historical contexts provide valuable lessons for the current and future cultivation of *Triticeae* crops. The domestication and subsequent cultivation of wheat and barley have been shaped by the need to adapt to diverse environmental conditions. The genetic diversity found in wild relatives of these crops has been a critical resource for breeding programs aimed at improving stress tolerance. For instance, the adaptation of *Triticum dicoccoides* and *Hordeum spontaneum* to a wide range of environments has provided a rich genetic pool for developing drought- and salt-tolerant cultivars (Nevo and Chen, 2010).

Moreover, historical agricultural practices, such as crop rotation and the use of organic fertilizers, have shown the importance of sustainable farming methods in maintaining soil fertility and crop productivity. These practices, combined with modern scientific advancements, can help address the challenges of food security and environmental sustainability (Harman et al., 2019).

In conclusion, the successful cultivation of *Triticeae* crops, supported by regional initiatives and informed by historical contexts, plays a crucial role in enhancing global food security. The integration of genetic resources from wild relatives and the adoption of innovative agricultural practices are essential strategies for improving the resilience and productivity of these vital crops.

7 Future Directions and Suggestions

7.1 Research gaps and priorities

Currently, although significant progress has been made in wheat cultivation and genetic improvement, there are still some research gaps and priorities. For example, understanding of the mechanisms of disease resistance in wheat, particularly at the genetic and molecular levels, is still limited (Bischof et al., 2011). In addition, the genetic diversity and adaptive characteristics of wild and weed wheat species have not been fully utilized for crop improvement (Bothmer et al, 2008)。

Therefore, it is necessary to have a deeper understanding of the molecular mechanisms of wheat growth and development, as well as the interactions between wheat and pests, non biological stress factors. This will help develop more effective control strategies and new varieties with strong stress resistance. It is necessary to strengthen research on wheat genomics and transcriptomics to reveal the complexity and diversity of the wheat genome, and to identify key genes related to yield, quality, and stress resistance. In addition, sustainable agricultural practices that improve soil health, reduce environmental footprint, and increase productivity should also be explored. This includes integrating agricultural ecological methods, precision agriculture, and organic agriculture technologies. Improving the nutritional composition and safety of wheat crops through biological enhancement and reducing pollutants such as fungal toxins will enhance their contribution to food security.

7.2 Collaboration and knowledge sharing

Strengthening international cooperation and knowledge sharing is crucial in the face of global food security challenges. Research institutions in various countries should strengthen cooperation, jointly carry out wheat research, share research results and technical experience. For example, genome sequencing and gene transformation technologies have shown great potential in improving wheat crops (Mochida and Shinozaki, 2013). Through cross-border cooperation, the advantages and resources of various countries in wheat research can be fully utilized to accelerate the progress of wheat research. Promote cooperation between public research institutions and private sector entities to utilize resources, expertise, and technology. These collaborations can promote the commercialization of research results and enhance the adoption of new technologies. Create open access databases and platforms to share research data, publications, and best practices. This transparency will enable research results to be more widely disseminated and applied.

7.3 Strategic policy development

In order to ensure global food security, it is necessary to develop scientific and reasonable agricultural policies. We should increase investment in wheat research and production to improve wheat yield and quality. At the same time, farmers should be encouraged to adopt new technologies and varieties to improve the stress resistance and adaptability of wheat. We should formulate policies that are conducive to wheat exports and trade, strengthen economic cooperation with other countries, and jointly address the challenges of global food security. In addition, attention should also be paid to the impact of climate change on wheat production, and policy measures should be formulated to address climate change. Efforts should be made to mitigate the impact of climate change on wheat crops by promoting drought and salt resistant varieties (Nevo and Chen, 2010).

7.4 Capacity building and education

Strengthening wheat research, production capacity building, and education is an important way to improve wheat yield and quality. Efforts should be made to increase the training and support of wheat researchers, in order to improve their research abilities and levels. We should strengthen training and education for farmers, improve their understanding and application ability of new technologies and varieties. We should also strengthen exchanges and cooperation with international organizations and other countries, introduce advanced technology and management experience, and improve the overall level of wheat research and production in China.

8 Concluding Remarks

The systematic review of *Triticeae*, particularly focusing on wheat and barley, highlights their critical role in global food security. Wheat and barley are among the most important temperate cereal crops, contributing significantly to the global carbohydrate and protein supply. Despite their importance, yield gains for these crops have stagnated in recent decades, particularly in high-yielding regions.

Research trends indicate a robust scientific interest in these crops, with numerous studies focusing on their agronomy, genetics, and molecular biology. Comparative evaluations have shown that while wheat has higher gluten strength, barley and rye possess higher essential amino acid proportions, which are crucial for developing healthier food products. The genetic diversity within the *Triticeae* tribe, including wild relatives, offers valuable resources for breeding programs aimed at improving disease resistance and other agronomically important traits.

Advancements in genome sequencing have provided detailed insights into the evolutionary history of *Triticeae*, revealing divergence times and phylogenetic relationships among species. Genetic and genomic research has also identified key determinants of grain yield, which can be harnessed to enhance yield potential through improved inflorescence architecture. Furthermore, genome editing and other advanced technologies hold promise for overcoming challenges related to climate change, population growth, and environmental sustainability.

The *Triticeae* tribe, encompassing wheat, barley, and rye, plays a pivotal role in ensuring global food security. These crops are not only fundamental to human and animal nutrition but also serve as essential genetic resources for breeding programs aimed at enhancing crop resilience and productivity. The integration of advanced genomic technologies and traditional breeding methods offers a promising pathway to address the challenges posed by climate change and increasing food demand.

Future research should focus on leveraging the genetic diversity within *Triticeae*, particularly the wild relatives, to develop cultivars with improved tolerance to abiotic stresses such as drought and salinity. Additionally, continued efforts in genome sequencing and functional genomics will be crucial for unlocking the full potential of these crops and ensuring sustainable food production systems.

Acknowledgments

Sincere thanks to the peer reviewers for their valuable feedback on the initial draft of this manuscript. Their profound insights and constructive suggestions have greatly enhanced the quality and readability of this article.

Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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