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Development of Wheat Varieties Suitable for Mechanized Farming

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Abstract This study examines the development of wheat varieties suitable for mechanized farming, emphasizing the integration of genetic improvements and agricultural practices to meet the demands of mechanized systems. Key traits such as uniform plant height, lodging resistance, appropriate maturation periods, and easy threshability are essential for optimizing mechanical harvesting and processing. The study highlights the importance of biotic and abiotic stress resistance in ensuring wheat's resilience under mechanized farming conditions. Traditional breeding techniques, such as hybrid and selection breeding, have significantly contributed to improving wheat yield, plant architecture, and adaptability. Modern technologies like marker-assisted selection (MAS), genomic selection, and CRISPR-Cas9 have further accelerated breeding efficiency, enabling the development of wheat varieties optimized for mechanization. The study also explores the challenges, such as balancing high yield with mechanization-friendly traits and addressing the complexity of environmental conditions, that must be overcome to meet global food security goals. The integration of advanced breeding technologies and sustainable practices is crucial for the future development of wheat varieties that can thrive in mechanized farming systems.

Keywords Mechanized farming; Wheat breeding; Genetic engineering; Abiotic and biotic stress tolerance; Sustainable agriculture

1 Introduction

Wheat is a cornerstone of global food security, serving as a staple food for a significant portion of the world's population. It is crucial for meeting the dietary needs of billions, particularly in regions where it forms the basis of daily nutrition. The development of high-yielding wheat varieties has been pivotal in enhancing food security, especially in developing countries where wheat is a primary food source (Dalrymple, 1985). In Egypt, for instance, wheat remains a vital crop, with significant efforts directed towards closing the gap between production and consumption through the improvement of wheat varieties and cultivation techniques (Abdelmageed et al., 2019). The continuous genetic improvement of wheat is essential to meet the demands of a rapidly growing global population (Shrawat and Armstrong, 2018).

Mechanized farming has become increasingly prevalent, driven by the need to enhance agricultural efficiency and productivity. This trend necessitates the development of wheat varieties that are compatible with mechanized operations. Mechanized farming demands wheat varieties that can withstand the physical stresses of mechanical harvesting and are adaptable to various tillage methods. For example, reduced tillage methods have been shown to preserve soil moisture and maintain wheat yield performance, which is crucial for mechanized farming systems (Sharifnasab et al., 2024). Additionally, the development of wheat varieties with traits such as resistance to abiotic stress and adaptability to mechanized operations is essential for optimizing yields in mechanized farming environments (Abdelmageed et al., 2019; Wu, 2024).

This study explores the development of wheat varieties that are suitable for mechanized farming, focusing on the integration of genetic improvements and cultivation techniques that meet the specific demands of mechanized agriculture. This study aims to highlight the advancements in wheat breeding and the adoption of modern agricultural practices that enhance wheat productivity and sustainability. Exam the challenges and opportunities in developing wheat varieties for mechanized farming, provides insights into how these innovations can contribute to global food security and agricultural efficiency. The significance of this study lies in its potential to inform future research and policy decisions that support the sustainable development of wheat varieties tailored for mechanized farming systems.

2 Requirements of Mechanized Farming for Wheat Varieties

2.1 Uniform plant height and lodging resistance

Mechanized farming requires wheat varieties with uniform plant height to facilitate efficient harvesting. Uniformity in plant height ensures that mechanical harvesters can operate effectively without missing or damaging crops. This is crucial for maximizing yield and minimizing losses during the harvesting process. In Egypt, the development of wheat varieties that are highly adaptable to mechanized operations has been emphasized, highlighting the importance of uniform plant height in mechanized farming systems (Abdelmageed et al., 2019).

Lodging resistance is another critical requirement for mechanized wheat farming. Lodging, which is the bending over of stems near the ground, can severely disrupt mechanical harvesting and reduce yield quality. Breeding programs have focused on developing wheat varieties with strong stems to resist lodging, thereby ensuring that the crops remain upright and accessible to machinery. This trait is essential for maintaining the efficiency and effectiveness of mechanized harvesting operations (Shrawat and Armstrong, 2018; Abdelmageed et al., 2019).

2.2 Appropriate maturation period and easy threshability

For mechanized farming, wheat varieties must have an appropriate maturation period that aligns with the timing of mechanical harvesting. This synchronization is vital to ensure that the wheat is harvested at its peak quality and yield potential. In Egypt, the adoption of modern agricultural techniques, including the development of varieties with suitable maturation periods, has contributed significantly to increased wheat yields (Abdelmageed et al., 2019).

Figure 1 Comparison of old (1960-1979, left) and new (1980-2016, right) wheat cultivation technologies (Adopted from Abdelmageed et al., 2019)

Easy threshability is another important trait for mechanized wheat farming. Threshability refers to the ease with which grains can be separated from the chaff. Varieties that are easy to thresh reduce the time and energy required for processing, thereby enhancing the overall efficiency of mechanized farming systems. The development of wheat varieties with improved threshability characteristics is crucial for optimizing the harvesting and processing stages in mechanized agriculture (Shrawat and Armstrong, 2018; Sharifnasab et al., 2024).

2.3 Resistance to biotic and abiotic stresses

Mechanized farming also demands wheat varieties that are resistant to biotic stresses such as pests and diseases. The development of genetically superior wheat varieties through genetic engineering and conventional breeding has focused on enhancing resistance to these biotic stresses, which is essential for maintaining crop health and yield in mechanized systems (Shrawat and Armstrong, 2018; Yigezu et al., 2021).

Abiotic stress resistance, including tolerance to drought and heat, is equally important for wheat varieties in mechanized farming. These stresses can significantly impact wheat yield and quality, especially in regions prone to extreme weather conditions. The development of wheat varieties that can withstand such stresses ensures stable production and reduces the risk of crop failure, which is critical for the success of mechanized farming operations (Dalrymple, 1985; Abdelmageed et al., 2019).

3 Contributions of Traditional Breeding Techniques

3.1 Hybrid breeding: improving yield and modifying plant architecture

Hybrid breeding has played a crucial role in enhancing wheat yield and modifying plant architecture to suit mechanized farming. By combining desirable traits from different parent lines, hybrid breeding has led to the development of wheat varieties that exhibit improved yield potential and adaptability to various environmental conditions. This approach has been instrumental in the success of the Green Revolution, where semi-dwarf wheat varieties were developed to increase productivity and prevent lodging, a common issue in taller wheat plants that can hinder mechanized harvesting (Tadesse et al., 2019a; Li, 2020). The integration of hybrid breeding with other technologies, such as genomic selection, has further enhanced the efficiency of developing high-yielding wheat varieties (Merrick et al., 2022).

Moreover, hybrid breeding has contributed to the modification of plant architecture, making wheat varieties more suitable for mechanized farming. By selecting for traits such as shorter stature and stronger stems, breeders have developed wheat varieties that are less prone to lodging and can withstand the mechanical stresses of modern agricultural machinery. This has facilitated the widespread adoption of mechanized farming practices, leading to increased efficiency and productivity in wheat cultivation (Voss-Fels et al., 2019).

3.2 Selection breeding: optimizing wheat quality and regional adaptability

Selection breeding has been pivotal in optimizing wheat quality and ensuring regional adaptability. Through careful selection of desirable traits, breeders have been able to enhance wheat quality parameters such as grain protein content, milling properties, and baking performance. This has been particularly important for meeting the diverse quality requirements of different markets and end-users (Ruiz et al., 2019; Rempelos et al., 2023). Selection breeding has also focused on improving the adaptability of wheat varieties to specific regional conditions, such as climate and soil type, ensuring stable yields across different environments (Mondal et al., 2016; Tadesse et al., 2019b).

In addition to quality improvements, selection breeding has been used to enhance the resilience of wheat varieties to biotic and abiotic stresses. By selecting for traits such as disease resistance and drought tolerance, breeders have developed wheat varieties that can thrive in challenging conditions, thereby supporting sustainable wheat production in regions with variable climates (Mondal et al., 2016; Voss-Fels et al., 2019). This adaptability is crucial for maintaining wheat yields in the face of climate change and other environmental challenges.

3.3 Successful examples of traditional approaches in developing mechanization-friendly varieties

Traditional breeding approaches have successfully developed wheat varieties that are well-suited for mechanized farming. For instance, the development of semi-dwarf wheat varieties during the Green Revolution is a prime example of how traditional breeding techniques have been used to create high-yielding, mechanization-friendly crops. These varieties not only increased yield but also improved harvest efficiency by reducing lodging and facilitating mechanical harvesting (Li, 2020).

Another successful example is the breeding of wheat varieties with enhanced nutrient use efficiency and disease resistance, which are critical for mechanized farming systems that rely on reduced agrochemical inputs. By focusing on these traits, breeders have developed wheat varieties that can maintain high productivity under both high-input and low-input farming systems, thereby supporting sustainable agricultural practices (Fischer and

Edmeades, 2010; Voss-Fels et al., 2019). These advancements demonstrate the continued relevance and effectiveness of traditional breeding techniques in meeting the demands of modern agriculture.

4 Regional Case Studies

4.1 Practices of mechanized farming in developed countries like the USA and Australia

Mechanized farming in developed countries such as the USA and Australia has significantly advanced wheat production through the integration of technology and improved management practices. In the USA, particularly in the central Great Plains, long-term variety performance trials have been utilized to optimize wheat yield by understanding the interactions between genotype, environment, and management practices. These trials have shown that water regime, sowing date, and fungicide application are critical factors influencing wheat yield, with drought tolerance being a key trait for dryland trials (Munaro et al., 2020). This approach has allowed for the development of region-specific recommendations that enhance the efficiency of mechanized farming.

In Australia, mechanized farming practices have similarly focused on adapting wheat varieties to local environmental conditions. The emphasis has been on improving water use efficiency and root health, which are crucial for sustainable wheat production in resource-conserving farming systems. The development of wheat cultivars that are resistant to foliar diseases and have enhanced nutritional value has been a priority, aligning with the needs of mechanized farming systems that aim to maximize productivity while conserving resources (Trethowan et al., 2005).

4.2 Regional adaptability of wheat varieties in developing countries for mechanized cultivation

In developing countries, the adaptability of wheat varieties to mechanized farming is crucial for enhancing productivity and food security. The Green Revolution played a pivotal role in transforming wheat production in these regions, with modern wheat varieties being rapidly adopted. However, there is a need to replace these varieties with new ones that are better suited to current environmental challenges and mechanized farming practices (Shiferaw et al., 2013). This includes developing varieties that are resistant to diseases and pests, and that can thrive in warmer climates with reduced inputs of water, fertilizer, and labor.

Efforts in regions such as Sub-Saharan Africa and Asia have shown potential for significant productivity gains through the adaptation of wheat varieties to local conditions. Technical advances, such as improved monitoring of soils and water conservation strategies, are essential for the success of mechanized farming in these areas. The development of wheat varieties that can withstand variable climatic conditions and management practices is key to achieving sustainable productivity growth (O'Leary et al., 2018).

4.3 Success stories of wheat variety development in different ecological zones

Success stories of wheat variety development are evident in various ecological zones, where targeted breeding programs have led to the creation of varieties that meet specific regional needs. In the Yaqui Valley, for example, on-farm trials have been instrumental in identifying wheat genotypes with high performance and stability under different irrigation and nitrogen fertilization levels. This approach has enabled the development of cultivars that are well-suited to the local farming systems and environmental conditions, demonstrating the effectiveness of combining genotype and environment analyses in breeding programs (Tabbita et al., 2023).

In Morocco, the diffusion and adoption of improved wheat varieties have been influenced by both institutional and farm-level factors. Despite challenges such as stringent variety testing procedures and market constraints, efforts to enhance private sector engagement and revise testing protocols have facilitated the introduction of new varieties. These initiatives have contributed to the successful adaptation of wheat varieties to local conditions, highlighting the importance of addressing both institutional and practical barriers to variety development (Tabbita et al., 2023).

5 Applications of Modern Breeding Technologies

5.1 The role of marker-assisted selection (MAS) in precise trait identification

Marker-assisted selection (MAS) has emerged as a pivotal tool in the precise identification and improvement of traits in wheat breeding. This technology leverages molecular markers to facilitate the selection of desirable traits, which are often difficult to score using traditional methods. MAS has been particularly effective in improving simple traits that are economically important, such as disease resistance and yield components. The integration of MAS in breeding strategies, including marker-assisted backcrossing and forward breeding, has shown significant promise in enhancing wheat varieties suitable for mechanized farming (Gupta et al., 2010).

Moreover, MAS is not only limited to simple traits but is also being adapted to tackle complex polygenic traits. The development of high-throughput genotyping technologies, such as diversity arrays technology (DArT) and single nucleotide polymorphism (SNP) arrays, has expanded the potential of MAS. These advancements allow for more comprehensive mapping and selection strategies, such as marker-assisted recurrent selection and genome-wide selection, which are crucial for the development of wheat varieties that can thrive in mechanized farming environments (Table 1) (Gupta et al., 2010; Song et al., 2023).

5.2 Advances in genomic selection and CRISPR-Cas9 technologies

Genomic selection represents a significant advancement in wheat breeding, offering a more holistic approach compared to traditional MAS. This method uses genome-wide markers to predict the performance of breeding lines, thereby accelerating the breeding cycle and improving the accuracy of selection. Genomic selection is particularly beneficial for complex traits that are influenced by multiple genes, making it a valuable tool for developing wheat varieties that are optimized for mechanized farming (Gupta et al., 2010).

In parallel, CRISPR-Cas9 technology has revolutionized the field of genetic engineering by enabling precise genome editing. This technology allows for the targeted modification of specific genes, providing breeders with the ability to introduce or enhance traits such as drought tolerance and disease resistance. The combination of genomic selection and CRISPR-Cas9 offers a powerful toolkit for the rapid development of wheat varieties that meet the demands of modern agriculture, including mechanization (Song et al., 2023).

5.3 The use of high-throughput phenotyping to accelerate breeding efficiency

High-throughput phenotyping (HTP) is transforming the landscape of wheat breeding by enabling the rapid and accurate assessment of phenotypic traits. This technology utilizes advanced imaging and sensor systems to collect data on plant characteristics, such as growth rate, biomass, and stress responses, at a scale and speed that were previously unattainable. HTP is particularly valuable in mechanized farming, where the ability to quickly evaluate large populations of wheat is essential for efficient breeding programs (Gupta et al., 2010; Wang and Li, 2024).

The integration of HTP with other modern breeding technologies, such as MAS and genomic selection, further enhances breeding efficiency. By providing detailed phenotypic data, HTP supports the identification of trait-marker associations and the validation of genomic predictions. This synergy accelerates the breeding process, enabling the development of wheat varieties that are not only high-yielding but also well-suited to the mechanized farming systems of the future (Song et al., 2023).

6 The Role of Biotechnology in Wheat Breeding

6.1 Applications of genetic engineering in enhancing resistance and quality traits

Genetic engineering has significantly advanced the development of wheat varieties with enhanced resistance to biotic and abiotic stresses. Techniques such as CRISPR-Cas9, TALENs, and ZFNs have been employed to introduce specific genetic modifications that improve wheat's resilience to diseases and environmental stresses like drought and salinity (Shrawat and Armstrong, 2018; Trono and Pecchioni, 2022). These technologies allow for precise editing of the wheat genome, enabling the introduction of beneficial traits without the lengthy process of traditional breeding. The use of transgenic approaches has also facilitated the development of wheat lines with improved nutritional quality and yield potential, addressing the growing global demand for food (Shrawat and Armstrong, 2018; Trono and Pecchioni, 2022).

Moreover, the optimization of transformation systems, including Agrobacterium-mediated and microprojectile bombardment methods, has enhanced the efficiency of genetic engineering in wheat. These systems have been crucial in overcoming the challenges associated with wheat's complex genome and limited transformable tissues (Shrawat and Armstrong, 2018). The integration of genetic engineering with conventional breeding strategies has led to the development of wheat varieties that not only exhibit improved agronomic traits but also contribute to sustainable agricultural practices by reducing the need for chemical inputs (Shrawat and Armstrong, 2018; Trono and Pecchioni, 2022).

6.2 Utilization of transcriptomics and proteomics for key trait identification

The application of transcriptomics and proteomics in wheat breeding has revolutionized the identification of key traits associated with stress resistance and yield improvement. Transcriptomic analyses, such as RNA sequencing, have enabled the identification of differentially expressed genes under various stress conditions, providing insights into the molecular mechanisms underlying stress responses (Alotaibi et al., 2020). This information is critical for selecting candidate genes for genetic engineering and breeding programs aimed at enhancing wheat's adaptability to changing environmental conditions (Alotaibi et al., 2020).

Table 1 Loci and linked or functional markers forsome key trais

Traits	QTL/Gene	Marker Name	Marker Type	Source
Resistance to bioticstresses				
FHB	*Fhb1*	TaHRC-GSM, TaHRC-KASP	Genespecific,KASP	Sumai3
	QFhb-2DL	KASP10238, KASP12056	KASP	J5265
Powderymildew	*Pm60*	M-Pm60S1, M-Pm60-2	/	*Trihiarm nrh*
	QPmcms-3BS	Str-IWB41105	STARP	Zhou8452B
Leaf rust	*Lr22a*	Kwh636, Kwh637 and Kwh638	KASP	RL4495
	QLr-2BS	B800092275_51 Kukri_c36783_91	KASP	Zhoumai22
Stripe rust	*QYr.AYH-5BL*	KASP_AX-109337325, KASP_AX-110400764	KASP	Amyuehong
Stemrust	*Sr13*	KASFSr13, rwgsnp37	KASP/STARP	tetraploid wheat
Resistance to abiotic stresses				
Drought	*TaWRK51*	AS, B-Hpall	ndel/CAIS	/
Cdld	*Fr-AZ*	S1862541, S1298957, S1051014	KASP	/
	qCT5A.3	k5A4692, k5A7728	KASP	/
Lodging	*TrCOMT-3B*	*ThCOMT-3BM*	Indel	/
Loci for yield-relatedtraits				
TKW	*TaTAP6*	/	KASP	/
	TaSDIRI	/	dCAPS	/
	QGoiB.4	TGW-4B	CAPS	Shannong 01-35
SL/SC	*QSc/Sl.cib-5A, QSc/Sl.cib-6A*	KASP_AX_110462709. KASP AX-109308935	KASP	*Chunmai*[4]*2*
FT	*FT-D1*	SFT-D1	STARP	Nongda4332
SNPS	*TKCo-B5*	TaCOL-B5	CAPS	CItr 17600
Loci for grainquality				
GPC	*GPC*	Kgp-2B, Kgp-2D, Kgpe-4A	KASP	/
Ghr-DI mul	*Gh-D1*	gwm642	SSR	NapHal
BLack point resistance	*QBp.ans-3BL*	/	KASP	Zhong892
PHST	*Qpls.ahan-1A*	LA1142	CAIS	/
	Qpls.ahnu-3B	WS5431	dCAPS	/
	Qpls.ahu-6B	EX06323	CAIS	/

Table caption: FHB, Fusarium head blight; TKW, thousand kernel weight; SL, spike length; SC, spike compactness; HD, heading date; PH, plant height; FT, flowering tine; SNPS, spikelet nodes per spike; GPC, grain protein content; PHST, pre-harvest sprouting tolerance

Proteomics complements transcriptomics by providing a comprehensive understanding of the protein expression profiles in wheat under different stress conditions. This approach helps in identifying proteins that play crucial roles in stress tolerance and can be targeted for genetic improvement (Alotaibi et al., 2020). The integration of these omics technologies with bioinformatics tools has facilitated the mapping of quantitative trait loci (QTLs) and genome-wide association studies (GWAS), which are essential for dissecting complex traits and accelerating the breeding of superior wheat varieties (Alotaibi et al., 2020; Babu et al., 2020).

6.3 Synthetic biology for innovation in wheat variety development

Synthetic biology offers innovative approaches to wheat variety development by enabling the design and construction of novel genetic circuits and pathways. This field leverages the principles of engineering to create synthetic gene networks that can introduce new traits or enhance existing ones in wheat (Paux et al., 2022). For instance, synthetic biology can be used to develop wheat varieties with enhanced photosynthetic efficiency, nutrient use efficiency, and stress resilience, thereby improving yield and sustainability (Paux et al., 2022).

The potential of synthetic biology in wheat breeding is further amplified by its ability to integrate with other biotechnological tools, such as genome editing and omics technologies. This integration allows for the precise manipulation of metabolic pathways and regulatory networks, leading to the development of wheat varieties that are better suited for mechanized farming and changing agricultural landscapes (Paux et al., 2022). By harnessing the power of synthetic biology, breeders can create wheat varieties that not only meet current agricultural demands but also anticipate future challenges posed by climate change and resource limitations (Paux et al., 2022).

7 Strategies for Improving Mechanization-Friendly Wheat Varieties

7.1 Optimizing plant height and spike architecture for better compatibility with machinery

Optimizing plant height and spike architecture is crucial for enhancing the compatibility of wheat varieties with mechanized farming. Shorter plant height can reduce the risk of lodging, which is essential for efficient mechanical harvesting. Lodging resistance is a key trait that needs to be improved alongside yield potential to ensure that wheat plants can withstand the mechanical forces exerted by harvesting equipment without collapsing (Foulkes et al., 2011; Reynolds et al., 2011). Additionally, optimizing spike architecture to maximize grain number and dry matter harvest index can further enhance the efficiency of mechanized harvesting by ensuring uniformity and ease of processing (Foulkes et al., 2011; Reynolds et al., 2012).

Moreover, the integration of advanced breeding techniques, such as genomic selection, can facilitate the development of wheat varieties with optimized plant height and spike architecture. By employing genomic selection, breeders can efficiently select for traits that improve the structural integrity of wheat plants, thereby enhancing their suitability for mechanized farming (Merrick et al., 2022). This approach allows for the rapid development of varieties that meet the specific requirements of mechanized agriculture, ultimately improving yield and processing efficiency (Reynolds et al., 2011; Merrick et al., 2022).

7.2 Enhancing root structures to improve tolerance to abiotic stresses

Enhancing root structures is vital for improving wheat's tolerance to abiotic stresses, which is crucial for mechanized farming systems that often involve large-scale operations with less frequent human intervention. Strong root systems can improve water and nutrient uptake, thereby increasing the plant's resilience to drought and nutrient-poor conditions (Foulkes et al., 2011; Reynolds et al., 2012). This resilience is essential for maintaining high yields in mechanized systems where environmental conditions can vary significantly (Romanenko et al., 2007).

In addition to improving stress tolerance, robust root systems can also contribute to better anchorage, reducing the risk of lodging during mechanical operations. This dual benefit of enhanced root structures supports both the physiological and structural needs of wheat plants in mechanized farming environments. Breeding programs that focus on root architecture, alongside other agronomic traits, can lead to the development of wheat varieties that are better suited to withstand the challenges posed by mechanized agriculture (Romanenko et al., 2007; Foulkes et al., 2011).

7.3 Achieving grain uniformity and improving auitability for processing

Achieving grain uniformity is a critical factor in improving the suitability of wheat varieties for processing, particularly in mechanized farming systems. Uniform grain size and weight facilitate efficient processing and reduce waste during milling and other post-harvest operations. Breeding strategies that focus on optimizing grain filling and potential grain size can significantly enhance grain uniformity, thereby improving the overall quality and marketability of wheat products (Foulkes et al., 2011; Reynolds et al., 2012).

Furthermore, the use of precision farming techniques can aid in achieving grain uniformity by ensuring optimal nutrient and water distribution across the field. This approach can help in maintaining consistent growth conditions, leading to more uniform grain development. The integration of precision farming with advanced breeding techniques can thus play a pivotal role in developing wheat varieties that meet the demands of mechanized processing systems (Romanenko et al., 2007; Wang, 2009). By focusing on these strategies, wheat breeding programs can enhance the compatibility of new varieties with mechanized farming, ultimately leading to increased productivity and efficiency.

8 Challenges and Bottlenecks

8.1 The trade-off between high yield and traits needed for mechanized farming

One of the primary challenges in developing wheat varieties suitable for mechanized farming is the inherent trade-off between achieving high yield and maintaining traits that facilitate mechanization. For instance, while increasing grain number can enhance yield, it often comes at the expense of grain size, which can complicate mechanized harvesting processes due to variability in grain quality and size (Cosgrove, 2021; Vicentin et al., 2024). This trade-off is a significant bottleneck because mechanized systems require uniformity in crop characteristics to function efficiently, and any deviation can lead to inefficiencies and increased costs.

Moreover, the genetic manipulation required to balance these traits is complex. For example, the introduction of genes like *TaExpA6* has shown potential in increasing grain weight without reducing grain number, thus offering a partial solution to this trade-off (Vicentin et al., 2024). However, such genetic modifications need to be carefully managed to ensure they do not inadvertently affect other desirable traits necessary for mechanized farming, such as plant height and stem strength, which are crucial for machine harvesting (Molero et al., 2018).

8.2 The complexity of meeting diverse agricultural machinery requirements

The diversity of agricultural machinery used across different regions presents another significant challenge. Wheat varieties must be adaptable to various types of machinery, which can vary significantly in terms of their operational requirements and efficiency (Fischer and Edmeades, 2010). This complexity is compounded by the need for wheat varieties to be resilient to different soil types and climatic conditions, which can affect how machinery interacts with the crop.

Additionally, the development of wheat varieties that can meet these diverse machinery requirements involves a deep understanding of both the genetic traits of the wheat and the mechanical properties of the machinery. For instance, traits such as stem strength and plant height must be optimized to ensure compatibility with harvesting equipment, which can vary widely in design and function (Ahmad et al., 2023). This requires a multidisciplinary approach, combining insights from plant genetics, agronomy, and mechanical engineering to develop varieties that can be efficiently harvested by a range of machinery (Sadras, 2021).

8.3 The impact of environmental changes on wheat breeding goals

Environmental changes pose a significant challenge to wheat breeding goals, particularly in the context of mechanized farming. Climate change affects the predictability of growing conditions, which in turn impacts the stability and reliability of wheat yields (Stella et al., 2023). This unpredictability makes it difficult to develop wheat varieties that can consistently perform well under mechanized farming systems, which rely on stable and predictable crop characteristics.

Furthermore, environmental changes can alter the effectiveness of existing wheat varieties, necessitating continuous adaptation and breeding efforts. For example, changes in temperature and precipitation patterns can affect the growth cycle of wheat, requiring breeders to focus on traits such as drought resistance and heat tolerance (Asseng et al., 2020). These environmental pressures necessitate a shift in breeding priorities, often requiring a balance between traditional yield-focused goals and the need for resilience to changing climatic conditions (Dalrymple, 1985; Ying et al., 2019).

9 Future and prospects

The integration of artificial intelligence (AI) and big data into wheat breeding holds significant promise for enhancing the efficiency and effectiveness of developing new wheat varieties. Advanced technologies such as genome editing, high-throughput genotyping, and phenotyping are already being utilized to improve wheat's genetic traits, which can be further optimized through AI-driven data analysis. AI can facilitate the identification of beneficial genetic traits and predict the performance of new cultivars under various environmental conditions, thereby accelerating the breeding process and improving yield potential. The use of AI in conjunction with big data analytics can also help in managing the vast amounts of genetic and phenotypic data generated, enabling more precise and targeted breeding strategies.

Global collaboration is essential to advance the development of wheat varieties suitable for mechanized farming. Collaborative efforts can lead to the sharing of genetic resources, breeding technologies, and best practices across different regions, enhancing the overall capacity to develop high-yielding and resilient wheat varieties. International projects like BREEDWHEAT have demonstrated the benefits of pooling resources and expertise to tackle global challenges such as climate change and food security. By fostering partnerships between public and private sectors, as well as among countries, the global wheat community can accelerate the development of varieties that are not only high-yielding but also adaptable to mechanized farming systems.

The future of wheat breeding must balance the need for increased productivity with ecological preservation. Sustainable intensification, which involves improving crop resistance to diseases and pests, adapting to climate change, and reducing inputs like water and fertilizers, is crucial for meeting future food demands without compromising environmental health. Breeding programs are increasingly focusing on developing varieties that require fewer agrochemical inputs while maintaining high yields, thus reducing the environmental footprint of wheat production. Innovations in breeding, such as the use of hybrid wheat and genome editing, offer opportunities to enhance both productivity and sustainability by creating varieties that are more resilient to environmental stresses and more efficient in resource use.

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Conflict of Interest Disclosure

The authors affirm 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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