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# Ecological and Agricultural Significance of *Triticeae*: From Forage to Food Security

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**Abstract** The *Triticeae* tribe, encompassing a diverse group of grasses including wheat, barley, and rye, plays a crucial role in global agriculture. This study aims to provide a comprehensive overview of the taxonomy, phylogeny, ecological roles, and agricultural significance of *Triticeae*. We explore the classification and evolutionary history of *Triticeae*, highlighting their adaptations to various environments and contributions to soil health and biodiversity conservation. Major Triticeae crops are discussed in terms of their agricultural uses, importance in livestock production, and role in food security. The study also delves into the genetic resources and breeding techniques that enhance *Triticeae* resilience to abiotic and biotic stresses, as well as the advancements in biotechnology and genetic engineering for improved traits. Challenges such as climate change, sustainable agricultural practices, and policy issues are addressed, along with regional perspectives on *Triticeae* cultivation. The study outline future research priorities, emphasizing the integration of ecological and agricultural approaches and the importance of collaborative global initiatives. This study underscores the vital contributions of *Triticeae* to agriculture and ecology and provides recommendations for future research and policy development.
**Keywords** *Triticeae*; Taxonomy; Agricultural significance; Genetic resources; Biotechnology

## 1 Introducion

The *Triticeae* tribe, also known as Hordeeae, is a festucoid tribe within the Poaceae family, encompassing approximately 325 species, of which about 250 are perennials. This tribe includes some of the most economically significant cereal crops such as wheat, barley, and rye, which have been cultivated since prehistoric times. Additionally, the tribe contains the synthetic cereal Triticale, a hybrid between wheat and rye, and several other species important for forage and pasture. The genomic diversity within *Triticeae* is vast, with species exhibiting various genomic constitutions, such as the complex genus Elymus, which includes around 150 species worldwide (Okito et al., 2009).

*Triticeae* species play a crucial role in global agriculture, contributing significantly to food security and livestock nutrition. Wheat, barley, and rye are among the most important cereal crops, with wheat being particularly vital on a global scale (Merker, 2008). These crops are not only essential for human consumption but also serve as key components in animal feed and forage systems (Simpson et al., 2014). The genetic resources within *Triticeae*, including both cultivated and wild taxa, offer immense potential for crop improvement, providing valuable traits such as disease resistance and stress tolerance (Merker, 2008; Lu and Ellstrand, 2014). The perennial species within the tribe, although less studied, represent a significant genetic reservoir that could enhance the resilience and productivity of annual cereals.

The main purpose of this study is to comprehensively examine the ecological and agricultural significance of the wheat family, by exploring the genetic diversity and evolutionary relationships of the wheat family, emphasizing the importance of cultivated and wild species, and evaluating the role of wheat family species in enhancing food security through their contributions to grain breeding and crop improvement. In addition, the potential of wheat species in sustainable agricultural practices was investigated, including their application in feed systems and their symbiotic relationship with endophytic fungi. By identifying gaps in current research, future research directions are proposed for the protection and utilization of wheat genetic resources. By integrating multiple research findings, we hope to provide a comprehensive understanding of the role of the wheat family in agriculture and its potential to address challenges in food security and sustainable agricultural practices.。

## 2 Taxonomy and Phylogeny of *Triticeae*

### 2.1 Classification and species diversity

The tribe *Triticeae*, also known as Hordeeae, encompasses approximately 325 species, with around 250 of these being perennials. This tribe includes some of the world's most significant forage grasses and major cereal crops such as wheat, barley, and rye. The *Triticeae* tribe is crucial for both ecological and agricultural purposes, providing a vast genetic reservoir that can be utilized to enhance the genetic diversity and resilience of annual cereals. Despite the importance of perennials within this tribe, they have historically received less attention from cytogeneticists and plant breeders compared to their annual counterparts.

### 2.2 Phylogenetic relationships within *triticeae*

The phylogenetic relationships within the *Triticeae* tribe are complex and have been the subject of extensive research. The tribe includes a wide range of species that are genetically diverse, forming a large gene pool that is essential for the improvement of temperate cereals and forages. The primary gene pools of the tribe have been prioritized for collection, evaluation, and utilization due to their direct relevance to crop improvement. However, there is a growing interest in the wild and weedy taxa within the tribe, which have been relatively understudied in terms of their genetic and botanical characteristics (Bothmer et al., 2008).

### 2.3 Evolutionary history and domestication

The evolutionary history and domestication of *Triticeae* species are pivotal in understanding their current genetic diversity and potential for future agricultural use. The tribe's species have evolved to occupy a wide range of habitats, contributing to their genetic diversity and adaptability (Bothmer et al., 2008). Despite the extensive collection efforts, there remain areas that have not been thoroughly explored, and many species within the tribe are still poorly understood in terms of their seed physiology, seed handling techniques, and genetic diversity. The domestication of major cereal crops within the *Triticeae* tribe has been a significant milestone in agricultural history, providing staple foods for human consumption and forage for livestock (Bothmer et al., 2008).

In summary, the *Triticeae* tribe is a diverse and ecologically significant group of plants that play a crucial role in both natural ecosystems and agricultural systems. The classification, phylogenetic relationships, and evolutionary history of this tribe highlight its importance as a genetic reservoir for improving crop resilience and food security.

## 3 Ecological Roles of *Triticeae*

### 3.1 Adaptations to various environments

The *Triticeae* tribe, which includes important cereal crops such as wheat, barley, and rye, exhibits remarkable adaptability to diverse environmental conditions. This adaptability is largely due to the genetic diversity present within both cultivated and wild species of *Triticeae*. For instance, the perennial species within the tribe, which constitute about 75% of the total species, have been less studied but hold significant potential for improving the resilience of annual crops through genetic hybridization. Additionally, the genetic resources of wild and weedy taxa within *Triticeae* are crucial for crop improvement, providing a vast gene pool that can be utilized to enhance the adaptability of cultivated species to various environmental stresses (Bothmer et al., 2008; Lu and Ellstrand, 2014).

### 3.2 Contributions to soil health and ecosystems

*Triticeae* species play a significant role in maintaining soil health and contributing to ecosystem services. For example, triticale, a hybrid of wheat and rye, is known for its ability to utilize soil nutrients efficiently, making it ideal for reducing excess soil nutrients such as nitrogen and phosphorus from manured sites (Baron et al., 2015). This nutrient utilization not only supports plant growth but also helps in maintaining soil fertility. Moreover, the presence of diverse plant species, including those from the *Triticeae* tribe, enhances soil biodiversity, which is crucial for sustaining agro-ecosystem functioning. Soil biodiversity contributes to nutrient and water use efficiencies, which are essential ecological functions in agricultural systems (Brussaard et al., 2007).

### 3.3 Role in biodiversity conservation

The *Triticeae* tribe contributes significantly to biodiversity conservation. The genetic diversity within this tribe, including both cultivated and wild species, is essential for the conservation of plant biodiversity. Wild taxa of Triticeae, although less prioritized in the past, have gained attention for their role in preserving genetic diversity and providing a genetic reservoir for crop improvement (Bothmer et al., 2008) (Figure 1). Additionally, ecological farming practices involving *Triticeae* crops, such as the cultivation of *Triticum aestivum* and T. spelta, have been shown to support a diverse community of epigeic arthropods, which are indicators of habitat quality and biodiversity (Langraf et al., 2022). These practices highlight the importance of integrating less invasive agricultural methods to promote biodiversity conservation while ensuring sustainable crop production.

In summary, the *Triticeae* tribe plays a multifaceted role in ecological and agricultural systems. Its adaptability to various environments, contributions to soil health, and role in biodiversity conservation underscore its significance in promoting sustainable agriculture and food security.

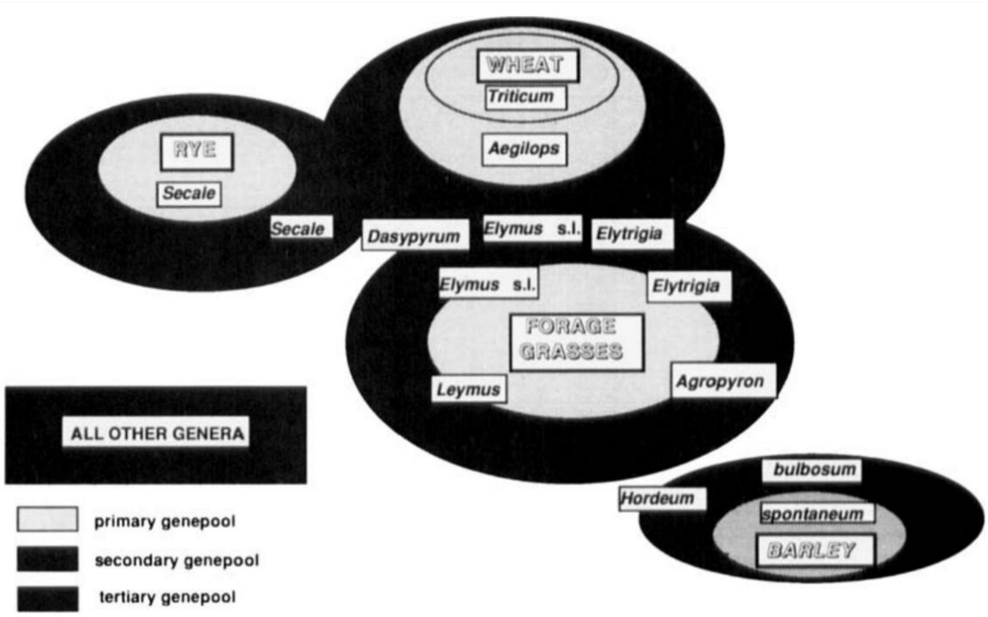


Figure 1 The gene pools of the cereals and forage grasses in the tribe *Triticeae* (Adopted from Bothmer et al., 2008)

## 4 Agricultural Significance of *Triticeae*

### 4.1 Major *Triticeae* crops and their uses

The *Triticeae* tribe encompasses some of the most significant cereal crops globally, including wheat (*Triticum* spp.), barley (*Hordeum vulgare*), and rye (*Secale cereale*). These crops are fundamental to human nutrition and livestock feed. Wheat is particularly notable for its global agricultural importance, serving as a staple food for a large portion of the world's population (Kawahara, 2009). Barley and rye, while regionally significant, also play crucial roles in food production and animal feed (Merker, 2008). Additionally, the tribe includes other valuable species such as triticale, a hybrid of wheat and rye, which combines the high yield potential and quality of wheat with the disease and environmental tolerance of rye (Bothmer et al., 2008).

### 4.2 Forage and fodder: importance in livestock production

The *Triticeae* tribe is not only vital for cereal production but also for forage and fodder, which are essential for livestock production. Many species within this tribe, particularly the perennials, are important forage grasses. These include genera such as Agropyron, Elymus, and Leymus, which are used extensively in grazing systems.

The perennial nature of these grasses makes them a sustainable option for forage, providing a continuous supply of feed for livestock and contributing to soil conservation and ecosystem stability. The genetic diversity within the *Triticeae* tribe offers a vast reservoir of traits that can be utilized to improve forage quality and resilience (Bothmer et al., 2008).

### 4.3 *Triticeae* in food security: grain production and nutrition

The role of *Triticeae* in food security is paramount, given their contribution to grain production and nutrition. Wheat, barley, and rye are critical for ensuring a stable food supply, particularly in regions where these crops are staple foods (Kawahara, 2009). Enhancing the yield potential and stability of these cereals is a priority for global food security. Advances in genetic and genomic research have led to significant improvements in grain yield by increasing the number of grains per inflorescence and reducing floral organ abortion (Sakuma and Schnurbusch, 2020) (Figure 2). Furthermore, the genetic resources within the *Triticeae* tribe, including wild and weedy taxa, are invaluable for crop improvement, offering traits such as disease resistance, drought tolerance, and improved nutritional content (Lu and Ellstrand, 2014; Hensel, 2019). These genetic advancements are crucial for meeting the growing food demands of the global population and ensuring nutritional security (Hensel, 2019).

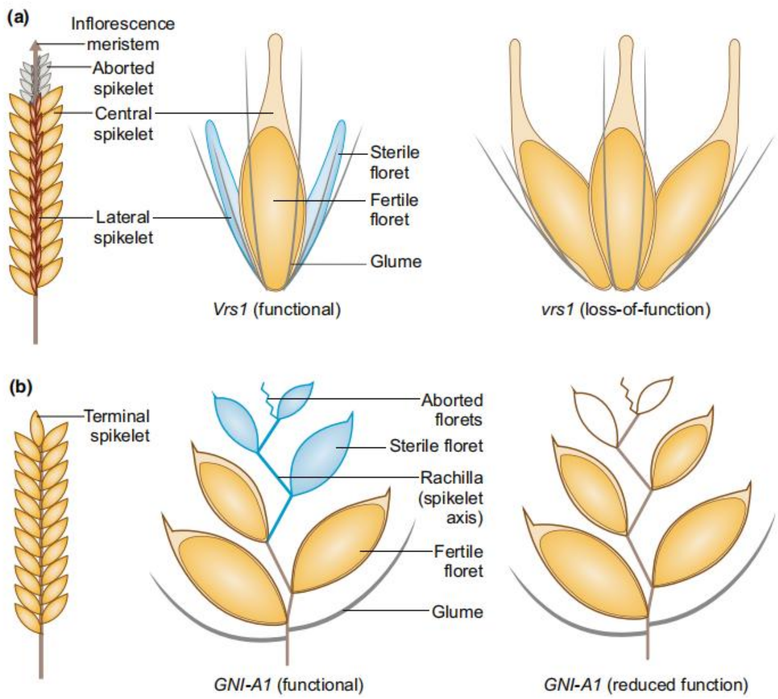


Figure 2 Key genes for floret fertility in barley and wheat (Adopted from Sakuma and Schnurbusch, 2020)

Image caption: (a) Structure of barley inflorescence showing two-rowed and six-rowed spikelets; Vrs1 mRNA localizes in the lateral florets (blue); (b) Structure and fertility of wheat inflorescences and spikelets with functional and reduced-function alleles of GNI-A1; Blue florets indicate GNI1 mRNA accumulation (Adopted from Sakuma and Schnurbusch, 2020)

In summary, the *Triticeae* tribe's agricultural significance is multifaceted, encompassing major cereal crops, essential forage and fodder species, and critical contributions to food security through grain production and nutritional improvements. The genetic diversity within this tribe provides a robust foundation for ongoing and future agricultural advancements.

## 5 Genetic Resources and Breeding

### 5.1 Genetic diversity and germplasm collections

The tribe *Triticeae*, which includes essential crops such as wheat and barley, holds significant genetic diversity that is crucial for crop improvement and food security. Genetic resources from both cultivated and wild taxa within *Triticeae* have been extensively studied and utilized for enhancing crop traits. For instance, wild relatives like *Triticum* dicoccoides and Hordeum spontaneum, the progenitors of cultivated wheat and barley, exhibit a broad range of genetic diversities that are invaluable for breeding programs (Nevo and Chen, 2010; Lu and Ellstrand, 2014). These genetic resources are conserved in germplasm collections worldwide, providing a reservoir of traits that can be harnessed to improve crop resilience and productivity.

### 5.2 Advances in breeding techniques

Recent advancements in breeding techniques have revolutionized the way genetic resources are utilized in *Triticeae*. Techniques such as advanced backcross QTL analysis and the development of introgression libraries have facilitated the transfer of beneficial traits from wild relatives to cultivated varieties (Nevo and Chen, 2010). Positional cloning of natural QTLs has further elucidated the molecular mechanisms underlying important traits such as drought and salt tolerance. These cutting-edge techniques enable breeders to combine multiple desirable traits, thereby accelerating the development of superior crop varieties (Tolmay, 2004; Nevo and Chen, 2010).

### 5.3 Breeding for abiotic and biotic stress resistance

Breeding for resistance to abiotic and biotic stresses is paramount to achieving stable crop yields and ensuring food security. The genetic diversity within *Triticeae* offers a wealth of resistance genes that can be exploited to develop stress-resistant varieties. For example, genes and QTLs associated with drought and salt tolerance have been identified in wild relatives and successfully introgressed into wheat and barley cultivars (Nevo and Chen, 2010). Additionally, functional genomics and molecular manipulation have made significant strides in enhancing resistance to various stresses, ensuring that future crops can withstand environmental challenges and contribute to global food security (Tolmay, 2004). The integration of these genetic resistances into breeding programs is essential for developing crops that are resilient to both biotic and abiotic stresses, thereby supporting sustainable agriculture and food production (Tolmay, 2004).

## 6 Biotechnology and Genetic Engineering

### 6.1 Genomic tools and resources

The tribe *Triticeae*, which includes significant cereal crops such as wheat, barley, and rye, as well as numerous perennial species, represents a vast genetic reservoir that can be harnessed for crop improvement. The genomic system of classification has been instrumental in guiding intergeneric hybridization efforts within the *Triticeae*, particularly among the perennial species. These perennials, despite their importance as forage grasses and their potential to enhance annual cereals, have historically received less attention from cytogeneticists and plant breeders compared to their annual counterparts. The development and utilization of genomic tools and resources are crucial for tapping into this genetic diversity, enabling the identification and transfer of beneficial traits across species.

### 6.2 Genetic modification for improved traits

Genetic modification has emerged as a powerful tool for enhancing desirable traits in *Triticeae* species. By leveraging the genetic resources of both cultivated and wild taxa, researchers aim to improve crop resilience, yield, and nutritional value. The integration of genetic resources from wild and weedy taxa into cultivated varieties holds promise for addressing global food security challenges. This approach not only enhances the genetic diversity of crops but also introduces traits that can improve resistance to pests, diseases, and environmental stresses (Lu and Ellstrand, 2014). The application of genetic engineering techniques, such as CRISPR/Cas9, has further accelerated the development of improved *Triticeae* varieties, offering precise and efficient methods for trait enhancement.

### 6.3 Future prospects and ethical considerations

Looking ahead, the future of biotechnology and genetic engineering in *Triticeae* research is poised to make significant contributions to food security and sustainable agriculture. The continued exploration and utilization of genomic tools will likely lead to the discovery of novel genes and pathways that can be harnessed for crop improvement. However, the advancement of genetic modification technologies also raises important ethical considerations. Issues such as the potential impact on biodiversity, the unintended consequences of gene editing, and the socio-economic implications for farmers and consumers must be carefully evaluated. Ensuring that the benefits of genetic engineering are equitably distributed and that ethical guidelines are adhered to will be critical for the responsible development and deployment of these technologies (Lu and Ellstrand, 2014).

In summary, the integration of genomic tools and genetic modification techniques holds great promise for enhancing the ecological and agricultural significance of *Triticeae* species. By addressing both the technical and ethical challenges, researchers can contribute to the sustainable improvement of these vital crops, ultimately supporting global food security.

## 7 Challenges and Opportunities

### 7.1 Climate change and its impact on *Triticeae*

Climate change poses a significant threat to agricultural productivity, including the cultivation of *Triticeae* species. The increasing frequency of extreme weather events, such as droughts and floods, along with rising temperatures, can adversely affect the growth and yield of these crops. One promising approach to mitigate these impacts is the use of Trichoderma species, which have been shown to enhance crop resilience to climate change. Trichoderma spp. improve photosynthetic efficiency, nutrient uptake, and nitrogen use efficiency, thereby supporting crop productivity under adverse conditions (Kashyap et al., 2017). Additionally, the genetic diversity within perennial *Triticeae* species offers a vast reservoir of traits that could be harnessed to improve the resilience of annual cereal crops like wheat, barley, and rye.

### 7.2 Sustainable agricultural practices

Sustainable agricultural practices are essential for maintaining the productivity and health of *Triticeae* crops. The integration of eco-friendly methods, such as the use of bioinoculants like Trichoderma spp., can play a crucial role in sustainable crop production. These fungi not only enhance plant growth and resistance to diseases but also improve tolerance to abiotic stresses, making them valuable for sustainable agriculture (Kashyap et al., 2017). Moreover, the perennial nature of many *Triticeae* species can contribute to soil health and reduce the need for frequent replanting, thereby promoting sustainability.

### 7.3 Policy and socioeconomic factors

The successful implementation of strategies to enhance the ecological and agricultural significance of *Triticeae* requires supportive policies and consideration of socioeconomic factors. Policies that promote research and development in sustainable agricultural practices, including the use of bioinoculants and the conservation of genetic diversity, are crucial. Additionally, socioeconomic factors such as market access, farmer education, and financial incentives play a significant role in the adoption of these practices. Ensuring that farmers have the necessary resources and knowledge to implement sustainable practices is essential for the long-term success of *Triticeae* cultivation (Kashyap et al., 2017).

In conclusion, addressing the challenges posed by climate change, adopting sustainable agricultural practices, and considering policy and socioeconomic factors are critical for enhancing the ecological and agricultural significance of *Triticeae*. By leveraging the genetic diversity within these species and utilizing innovative approaches like Trichoderma spp., we can improve the resilience and productivity of *Triticeae* crops, contributing to global food security.

## 8 Case Studies and Regional Perspectives

### 8.1 *Triticeae* in north America

In North America, the *Triticeae* tribe plays a significant role in both agriculture and ecology. The region has seen extensive research into the genetic resources of *Triticeae*, particularly focusing on their potential for crop improvement and food security. The perennial species within the *Triticeae* tribe, which constitute about 75% of the species, have been underutilized despite their importance as forage grasses and their vast genetic reservoir that could enhance annual cereals like wheat, barley, and rye. The genetic diversity within these species offers a promising avenue for developing more resilient and productive crops, which is crucial for addressing food security challenges (Lu and Ellstrand, 2014).

### 8.2 *Triticeae* in europe

Europe has a rich history of utilizing *Triticeae* species, both in agriculture and ecological management. The region's focus has been on the taxonomic classification and evolutionary relationships within the *Triticeae* tribe. Despite decades of research, there remain unresolved questions regarding the definition and classification of *Triticeae* species. These taxonomic challenges are critical as they impact the effective utilization of *Triticeae* genetic resources for breeding and crop improvement (Jun, 2013). The perennial species, known for their resilience to cold, drought, and alkaline conditions, are particularly valuable in Europe for both grazing and as genetic resources for improving crop breeds (Jun, 2013).

### 8.3 *Triticeae* in asia and other regions

In Asia, the *Triticeae* tribe has been integral to prehistoric and modern agricultural practices. Archaeobotanical studies in Southwest Asia have identified Triticoid-type grains from several prehistoric sites, revealing their significance in early agricultural societies. These grains, identified as Heteranthelium piliferum, highlight the historical importance of *Triticeae* species in subsistence strategies (Weide et al., 2021). The region's diverse climatic conditions have also fostered a high phenotypic plasticity among *Triticeae* species, making them adaptable to various environmental variables (Weide et al., 2021). This adaptability is crucial for modern agricultural practices, as it provides a genetic reservoir for developing crops that can withstand diverse and changing climates (Lu and Ellstrand, 2014; Weide et al., 2021).

In summary, the *Triticeae* tribe holds significant ecological and agricultural value across different regions. In North America, the focus is on utilizing the genetic diversity of perennial species for crop improvement. Europe grapples with taxonomic challenges that impact the effective use of *Triticeae* resources, while Asia's historical and modern agricultural practices underscore the adaptability and importance of these species in food security and ecological management. The global perspective on *Triticeae* highlights their potential in addressing food security challenges and improving agricultural sustainability.

## 9 Future Directions and Research Priorities

### 9.1 Emerging trends in *Triticeae* research

Recent advancements in *Triticeae* research have highlighted several emerging trends that are pivotal for both ecological and agricultural applications. One significant trend is the increasing focus on the genetic resources of both cultivated and wild *Triticeae* species. These genetic resources are crucial for crop improvement and food security, as they offer a vast reservoir of traits that can be harnessed to enhance disease resistance, stress tolerance, and yield (Bothmer et al., 2008; Merker, 2008; Lu and Ellstrand, 2014). Additionally, there is a growing interest in the genomic classification and intergeneric hybridization within the *Triticeae*, which can guide the development of new varieties with improved agronomic traits (Ayalew et al., 2018).

Another emerging trend is the application of biotechnological methods, such as genetic transformation and genome engineering, to accelerate the breeding process and incorporate desirable traits that are difficult to achieve through conventional breeding. This includes improving resistance to diseases, enhancing water and nitrogen use efficiency, and developing varieties suitable for challenging environments (Hensel, 2019) (Figure 3). Furthermore, the transcriptional reprogramming of *Triticeae* in response to pathogens is being extensively studied to understand the mechanisms of plant immunity and disease resistance, which can inform the development of more resilient crop varieties (Bischof et al., 2011).

### 9.2 Integrating Ecological and Agricultural Perspectives

Integrating ecological and agricultural perspectives is essential for the sustainable utilization of *Triticeae* species. The ecological significance of *Triticeae* extends beyond their role as food crops; they are also important for forage, soil stabilization, and maintaining biodiversity (Barkworth and Bothmer, 2009). To achieve a holistic approach, it is crucial to consider the ecological roles of wild and weedy *Triticeae* species, which contribute to the genetic diversity and resilience of agricultural systems (Bothmer et al., 2008).

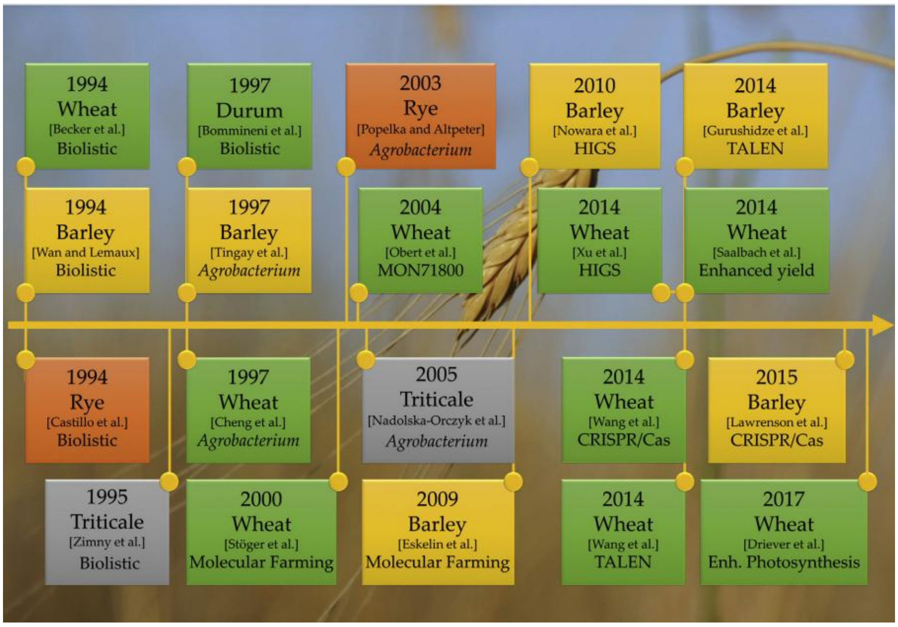


Figure 3 Graphical summary of the most important achievements in the field of genetic engineering in *Triticeae* cereals (Adopted from Hensel, 2019)

Image caption: After establishing the transformation technology by biolistic or Agrobacterium-mediated gene transfer, the most important discoveries with heritable modifications were presented. The use of cereal grains for molecular farming, the host-induced gene silencing (HIGS) mechanism, which confers resistance to fungal pathogens, the establishment of site-directed mutagenesis using transcription activator-like effector nucleases (TALEN) or clustered, regularly interspaced palindromic repeats (CRISPR) and the increase of yield and photosynthesis were highlighted (Adapted from Hensel, 2019)

Research should focus on understanding the ecological interactions of *Triticeae* species in their natural habitats, including their responses to environmental stresses and their roles in ecosystem functioning. This knowledge can inform agricultural practices that enhance ecosystem services, such as soil health and biodiversity conservation. Additionally, integrating ecological principles into breeding programs can lead to the development of crop varieties that are not only high-yielding but also environmentally sustainable (Jun, 2013; Ayalew et al., 2018).

### 9.3 Collaborative research and global initiatives

Collaborative research and global initiatives are vital for advancing *Triticeae* research and addressing the challenges of food security and environmental sustainability. International collaborations can facilitate the sharing of genetic resources, knowledge, and technologies, thereby accelerating the development of improved *Triticeae* varieties (Merker, 2008; Lu and Ellstrand, 2014). Global initiatives, such as gene banks and breeding networks, play a crucial role in conserving *Triticeae* genetic diversity and making it accessible for research and breeding programs (Bothmer et al., 2008).

Moreover, interdisciplinary collaborations that bring together plant breeders, ecologists, geneticists, and agronomists are essential for addressing the complex challenges associated with *Triticeae* research. Such collaborations can lead to innovative solutions that integrate genetic improvement with ecological sustainability. Additionally, engaging with policymakers and stakeholders can ensure that research outcomes are translated into practical applications that benefit both agriculture and the environment (Barkworth and Bothmer, 2009).

In conclusion, the future of *Triticeae* research lies in embracing emerging trends, integrating ecological and agricultural perspectives, and fostering collaborative efforts. By doing so, we can harness the full potential of *Triticeae* species to enhance food security, promote sustainable agriculture, and conserve biodiversity.

## 10 Concluing Remarks

Research on the *Triticeae* tribe highlights its significant role in both ecological and agricultural contexts. The study found that the *Triticeae* tribe, including cultivated and wild taxa, provides a vast genetic reservoir that can be harnessed for crop improvement, particularly in enhancing food security. A substantial portion of the *Triticeae* species are perennials, which are crucial forage grasses. Despite their importance, these perennials have been less studied compared to annuals like wheat, barley, and rye. Understanding the transcriptional patterns associated with pathogens in the *Triticeae* tribe is essential for improving plant immunity and resistance to diseases, which is critical for maintaining crop health and productivity. Additionally, triticale, a hybrid of wheat and rye, exhibits excellent resistance to environmental stresses and diseases, making it a valuable crop for food, forage, and industrial applications. In summary, these studies reveal the diversity and potential of the *Triticeae* tribe, providing valuable resources and new perspectives for modern agriculture.

These research findings have multiple important implications for agriculture and ecology. By utilizing the genetic diversity within the *Triticeae* tribe, especially from wild and weedy taxa, it is possible to develop more resistant and higher-yielding crop varieties, thus promoting global food security. The perennial species within the *Triticeae* tribe offer sustainable forage options, supporting livestock nutrition and reducing the need for annual replanting, thereby promoting ecological stability. Additionally, insights into the transcriptional responses of the *Triticeae* tribe to pathogens can inform breeding programs aimed at developing disease-resistant varieties, which are crucial for reducing crop losses and ensuring stable yields. The adaptability and resilience of triticale make it a versatile crop for various agricultural and industrial environments, enhancing its economic and environmental benefits. Through these studies, the diversity and potential of the *Triticeae* tribe are revealed, providing valuable resources and new perspectives for modern agriculture.

Research emphasizes the ecological and agricultural significance of the *Triticeae* tribe. To fully utilize its potential, research on perennial plants within the *Triticeae* tribe should be increased to explore their potential as forage and their genetic contribution to annual cereals. Priority should be given to the conservation and utilization of genetic diversity within the *Triticeae* tribe to enhance crop resilience and adaptability. Additionally, continued research on the molecular mechanisms of disease resistance in *Triticeae* is crucial for developing integrated disease management strategies to ensure crop health. Given its resistance and versatility, triticale should be promoted as a key crop for the agricultural and industrial sectors, with ongoing efforts to improve its breeding and utilization. By addressing these areas, the full potential of the *Triticeae* tribe can be realized, promoting sustainable agriculture and ecological balance..

## 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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