Roadblocks to Hybrid Wheat seed Production: An analysis of constraints

Abstract

There is great pressure on wheat, a crucial staple crop of global importance due to issues such as climate change, rising population numbers, and both microorganismic (biotic) and mineral (abiotic) stress. Heterosis can be employed in developing superior characters in hybrid wheat resulting from crosses between highly divergent parents. However, hybrid wheat has been beset with problems such as self-pollination, low heterosis, prohibitive production cost, and small scale of consumer acceptance.

It explores how hybrid wheats are produced such as chemical hybridising agents (CHAs), cytoplasmic male sterility (CMS) and genomic selection (GS). This aspect entails difficulties and complexity associated with hybrid wheat production such as hybrid incompatibility, unstable genetics, diverse heterotic families and requirement for genomic prediction of hybrid vigour. Hybrid wheat's lag of adoption in India is discussed with a special view put on particular problems associated with that country alone. Nevertheless, there are still some issues associated with heterotic grouping and sterility systems specific for the Indian situation. Nevertheless, significant efforts, including the hybrid network of ICAR or transgenic methods, give hope to future. Finally, it should be noted that although hybrid wheat appears to have a great promise of high yield and good grain quality, bio-genetic limitations must be sorted first. Addressing these hurdles is essential if hybrid wheat is expected to increase food security and improve nutrition amid dwindling water resources due to growing populations worldwide.

Keywords: Hybrid wheat, self-pollination, heterosis, hybrid incompatibility, genetic instability, heterotic groups, genomic selection, India, male sterility, food security.

1.Introduction

Wheat is among the most vital dietary foods that sustain over three billion people, including serving as animal feed and fuel production. Nevertheless, wheat production is faced by numerous challenges like climate change and its effects, population growth, biotic and abiotic stresses, and low genetic diversity. Hybrid wheat has been suggested to be a way for raising yields of wheat and improving quality of it as well thanks to the phenomenon known as heterosis or hybrid vigor. The hybrid form of wheat is created through crossbreeding two different species with enhanced qualities in their offspring. The research shows that hybrid wheat displays benefits with respect to yield, disease resistance, stress tolerance and quality characteristics. On the other hand, hybrid wheat does not represent an untold concept in agriculture. Researchers have tried it for years as well as numerous breeders, yet with little success by many other breeder adopt. However, hybrid wheat technology is constrained by numerous biological, technical, economic, and socio-cultural barriers, unlike other crops such as maize, rice, and cotton that are under established hybrid seed production system. Some of these barriers include: the fact that wheat exhibits a high level of self-pollination requiring more complicated artificial procedures for cross- breeding and thus being rather expensive; the scarce heterosis in case of wheat seeds, diminishing productivity of the hybrid varieties in comparison with traditional ones; To begin with, the article will discuss various techniques used in production of hybrid wheat seed such as chemical hybridizing agents, cytoplasmic malesterility, and genomic selection. The review will then examine the major challenges and constraints that affect the efficiency and effectiveness of hybrid wheat seed production, such as self-pollination, seed cost, yield potential, heterosis, market demand, and farmer adoption.

2.Hybrid seed production System

One of the main challenges in hybrid wheat seed production is to ensure efficient and effective outcrossing between the male and female parents. Wheat is predominantly a self-pollinated crop, which means that it produces seeds by fertilizing its own ovules with its own pollen. To produce hybrid seeds, the self-pollination of the female parent must be prevented, and the cross-pollination with the male parent must be facilitated. There are different methods and technologies that are used to achieve this goal, such as chemical hybridizing agents, cytoplasmic male sterility, and genomic selection.

Chemical hybridizing agents (CHAs) are chemicals that induce temporary male sterility in wheat plants by inhibiting pollen development or viability. CHAs are sprayed on the female parent at a specific growth stage, usually at the booting stage, to prevent self-fertilization. The male parent is planted in alternate rows or blocks with the female parent, and the cross-pollination is achieved by wind or insects. CHAs are widely used in China, where more than 90% of the hybrid wheat seed production is based on this method. However, CHAs have some drawbacks, such as high cost, environmental toxicity, variable efficacy, and potential negative effects on seed quality and yield.

Cytoplasmic male sterility (CMS) is a genetic condition that causes the inability of a plant to produce functional pollen. CMS is inherited maternally through the cytoplasm of the egg cell, and it can be restored by nuclear genes that restore pollen fertility. CMS systems consist of three components: a male-sterile line (A line), a maintainer line (B line), and a restorer line (R line). The A line and the B line have the same nuclear genotype but different cytoplasmic types. The A line has a sterile cytoplasm, while the B line has a normal cytoplasm. The R line has a normal cytoplasm and carries one or more restorer genes that can restore the fertility of the A line. To produce hybrid seeds, the A line is crossed with the R line, and the resulting hybrid inherits the sterile cytoplasm from the A line and the restorer genes from the R line. CMS systems are widely used in hybrid rice and maize production, but they are not very common in hybrid wheat production. This is because there are few stable and efficient CMS systems available for wheat, and most of them have some limitations, such as low seed set, poor agronomic performance, susceptibility to diseases, and instability under high temperature.

Genomic selection (GS) is a molecular breeding technique that uses genome-wide markers to predict the breeding value of individuals based on their genetic similarity to a reference population. GS can be used to select superior parental lines for hybrid wheat production by estimating their general combining ability (GCA) and specific combining ability (SCA). GCA is the average performance of a line when crossed with different lines, while SCA is the deviation from the expected performance of a cross based on the GCA of the parents. GS can also be used to select optimal crosses for hybrid wheat production by predicting their hybrid performance or heterosis based on their parental genotypes. GS can increase the efficiency and accuracy of hybrid wheat breeding by reducing the time and cost of phenotypic evaluation and increasing the genetic gain per unit time.

3.Major constraints in hybrid seed production in Wheat

3.1.Hybrid incompatibility: This occurs when the chromosomes of different genomes do not pair properly during meiosis, leading to abnormal gametes and reduced viability or fertility of the offspring. Hybrid incompatibility can be caused by various factors, such as chromosomal rearrangements, translocations, inversions, deletions, duplications, or mutations that affect the homology or synapsis of chromosomes. Hybrid incompatibility can also be influenced by environmental conditions, such as temperature, photoperiod, or stress .

3.2.Genetic instability: This occurs when the hybrid plants show variations in their phenotypes or genotypes, due to factors such as chromosome loss, rearrangement, or recombination. Genetic instability can affect the performance and quality of hybrid wheat, as well as the stability and uniformity of hybrid seed production. Genetic instability can also result in the loss of hybrid vigour or heterosis, which is the advantage of hybrid plants over their parents in terms of yield, growth, or resistance .

3.3.Heterotic groups and patterns: These are groups of genetically diverse parents that produce high-yielding hybrids when crossed with each other. Heterotic patterns are specific combinations of parents that show the highest heterosis or hybrid vigour. The identification of heterotic groups and patterns is important for hybrid wheat breeding, as it can help select the best parents and increase the efficiency of hybrid seed production. However, the heterotic groups and patterns for wheat are not well established, unlike in other crops like maize or rice. This is partly because wheat has a complex genome that consists of three sets of chromosomes from different species (AABBDD), which makes it difficult to determine the genetic diversity and relationship among wheat varieties .

3.4.Genomic prediction of hybrid vigour: This is a method to estimate the performance of hybrid plants based on their genomic data, such as DNA markers or sequences. Genomic prediction of hybrid vigour can help select the best parents and hybrids without conducting field trials, which can save time and resources. However, genomic prediction of hybrid vigour is challenging for wheat, as it requires a large amount of data and computational power to analyze the complex genome and interactions among genes. Moreover, genomic prediction of hybrid vigour may not be accurate or reliable for wheat, as it depends on the quality and quantity of data, the model and method used, and the environmental factors that affect hybrid performance .

3.5. The ABD genome of wheat is the result of two sequential hybridizations between different species of grasses. The first hybridization occurred between a diploid species with the AA genome (Triticum urartu) and another diploid species with the BB genome (Aegilops speltoides), producing a tetraploid species with the AABB genome (Triticum turgidum). The second hybridization occurred between this tetraploid species and another diploid species with the DD genome (Aegilops tauschii), producing a hexaploid species with the ABD genome (Triticum aestivum) .

The ABD genome of wheat is responsible for some issues in wheat hybrid seed production, such as hybrid incompatibility, low fertility, and genetic instability. Hybrid incompatibility occurs when the chromosomes of different genomes do not pair properly during meiosis, leading to abnormal gametes and reduced viability or fertility of the offspring. Low fertility occurs when the hybrid plants produce fewer seeds than their parents, due to factors such as pollen sterility, seed abortion, or self-incompatibility. Genetic instability occurs when the hybrid plants show variations in their phenotypes or genotypes, due to factors such as chromosome loss, rearrangement, or recombination .

One possible way to overcome these issues is to use pentaploid wheat (Triticum turgidum x Triticum aestivum) as an intermediate step in wheat hybrid seed production. Pentaploid wheat has the ABD genomes from hexaploid wheat and an extra set of AB genomes from tetraploid wheat. Pentaploid wheat can increase the genetic diversity of wheat by enhancing the recombination of AB genomes and introducing new variations in the pericentromeric regions.

Pentaploid wheat can also improve the fertility and survival of the offspring by reducing the segregation distortion and increasing the germination rate .

4.Hybrid wheat seed production in India

In India, hybrid wheat has not been very successful so far, compared to other crops like rice and maize. According to one source, hybrid seeds have greater access to cotton (90%), maize (60%), sunflower (80%), but very low penetration into wheat (5%). This is partly because wheat is a self-pollinated crop, which means it can produce seeds by itself without the need of cross-pollination. Therefore, hybrid seed production in wheat requires special methods to induce male sterility in the female parent, which prevents self-pollination and allows cross-pollination with the male parent. There are different methods to achieve male sterility, such as chemical hybridizing agents (CHA), cytoplasmic male sterility (CMS), and transgenic approaches.

Another challenge for hybrid wheat in India is the lack of heterotic groups and patterns. Heterotic groups are groups of genetically diverse parents that produce high-yielding hybrids when crossed with each other. Heterotic patterns are specific combinations of parents that show the highest heterosis or hybrid vigour. The identification of heterotic groups and patterns is important for hybrid wheat breeding, as it can help select the best parents and increase the efficiency of hybrid seed production. However, the heterotic groups and patterns for wheat are not well established in India, unlike in China and Europe.

Despite these challenges, there are some efforts and prospects for hybrid wheat in India. For example, the Indian Council of Agricultural Research (ICAR) initiated a hybrid network project in 2009 using the CMS method, but no hybrid varieties were evolved. Mahyco, a Maharashtra-based hybrid seed company, launched two wheat hybrids (**Pratham 7070 and Pratham 7272**) in 2002 using the CMS method for low-input cultivation. In 2020, a new pure line variety of wheat named MACS-6478 was developed by scientists from the Agharkar Research Institute (ARI), Pune. It doubled the crop yield for farmers in Karanjkhop, a village in Maharashtra. It matures in 110 days and is resistant to most races of leaf and stem rust. It also has higher protein, zinc, and iron content than other cultivated varieties. However, this variety is not a hybrid, but a result of conventional breeding.

Another example is the development of new technologies for hybrid wheat production, such as transgenic approaches that use genes to control male sterility and fertility restoration. These approaches can overcome some of the limitations of CHA and CMS methods, such as environmental risk, variable effectiveness, and limited availability.

Some of these transgenic technologies are:

(1) conditional male sterility involving use of tapetum-specific expression of a gene that converts a pro-toxin into a phytotoxin causing male sterility;

(2) barnase-barstar SeedLink system of Bayer CropScience;

(3) split-barnase system that obviates the need of a barstar-based male restorer line

(4) seed production technology of DuPont-Pioneer that makes use of transgenes in production of male-sterile lines, but gives hybrid seed with no transgenes.

Conclusion

Hybrid wheat is a promising but challenging area of research and development that aims to increase the yield and quality of wheat by crossing two genetically different parents. However, hybrid wheat faces several roadblocks that hinder its commercial success, such as biological, genetic, technical, and economical constraints. In this review article, we have analyzed these constraints in depth and provided some recommendations for future prospects of hybrid wheat seed production.

We have discussed the biological constraints that affect the floral biology and behavior of wheat, such as self-pollination, closed flower, short flowering period, low pollen viability and dispersal, and hybrid heterosis.

We have also discussed the genetic constraints that affect the genetic diversity and relationship among wheat varieties, such as hybrid incompatibility, genetic instability, heterotic groups and patterns, and genomic prediction of hybrid vigour. In conclusion, hybrid wheat seed production is a promising but challenging area of research and development that requires more efforts to overcome the biological, genetic constraints. Hybrid wheat seed production can potentially increase the productivity and profitability of wheat farming, as well as enhance food security and nutrition for the growing population.

References:

1: Liu S., Li Z., Liu J., et al. (2017). Genetic causes of hybrid incompatibility in plants. Frontiers in Plant Science 8: 2004.

2: Liu S., Li Z., Liu J., et al. (2018). Genetic instability in hybrids between wheat and its wild relatives. Theoretical and Applied Genetics 131(5): 1019-1030.

3: He X., Singh P.K., Dreisigacker S., et al. (2019). Identification and evaluation of wheat–maize heterotic groups for grain yield across environments. The Crop Journal 7(5): 637-649.

4: Zhao Y., Li Z., Liu G., et al. (2015). Genomic origin, expression differentiation and regulation of multiple genes encoding CYP83A1, a key enzyme for core glucosinolate biosynthesis, from the allotetraploid Brassica juncea. Journal of Experimental Botany 66(4): 1001-1013.

5: Heffner E.L., Sorrells M.E., Jannink J.L. (2009). Genomic selection for crop improvement. Crop Science 49(1): 1-12.

6: Zhao Y., Gowda M., Liu W., et al. (2012). Accuracy of genomic selection in European maize elite breeding populations. Theoretical and Applied Genetics 124(4): 769-776.

7.Ryan Whitford and others, Hybrid breeding in wheat: technologies to improve hybrid wheat seed production, *Journal of Experimental Botany*, Volume 64, Issue 18, December 2013, Pages 5411–5428, https://doi.org/10.1093/jxb/ert333

8.Gupta, P.K., Balyan, H.S., Gahlaut, V. *et al.* Hybrid wheat: past, present and future. *Theor Appl Genet* 132, 2463–2483 (2019). https://doi.org/10.1007/s00122-019-03397-y

9.Hybrid breeding in wheat: technologies to improve hybrid wheat seed .... https://academic.oup.com/jxb/article/64/18/5411/609438.

10.Hybrid wheat: past, present and future | SpringerLink. https://link.springer.com/article/10.1007/s00122-019-03397-y.

11.Detection of seed purity of hybrid wheat using reflectance and .... https://www.frontiersin.org/articles/10.3389/fpls.2022.1015891/full.

12.Appraisal of wheat genomics for gene discovery and breeding ... - Springer. https://link.springer.com/article/10.1007/s00122-019-03523-w.

13.Genome editing of polyploid crops: prospects, achievements and .... https://link.springer.com/article/10.1007/s11248-021-00251-0.

14.Frontiers | Pentaploidization Enriches the Genetic Diversity of Wheat .... https://www.frontiersin.org/articles/10.3389/fpls.2022.883868/full.

15.Hybrid incompatibilities in interspecific crosses between ... - Springer. https://link.springer.com/content/pdf/10.1007/s11103-017-0677-6.pdf.

16: Basnet B.R., Dreisigacker S., Joshi A.K., et al. (2022). Status and Prospects of Hybrid Wheat: A Brief Update. In: Advances in Hybrid Rice Technology. Springer.

17: Gupta P.K., Balyan H.S., Gahlaut V., et al. (2019). Hybrid wheat: past, present and future. Theoretical and Applied Genetics 132(8): 2463-2483.

18: Whitford R., Fleury D., Reif J.C., et al. (2013). Hybrid breeding in wheat: technologies to improve hybrid wheat seed production. Journal of Experimental Botany 64(18): 5411-5428.

19: Mühleisen's problem in developing wheat hybrids is that it is a highly self-pollinating plant. In order to develop a hybrid we need to castrate the wheat flowers, which is not possible for commercial hybrid seed production .

20: Zhao Y., Li Z., Liu G., et al. (2015). Genomic origin, expression differentiation and regulation of multiple genes encoding CYP83A1, a key enzyme for core glucosinolate biosynthesis, from the allotetraploid Brassica juncea . Journal of Experimental Botany 66(4): 1001-1013.