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Hybrid Wheat: A perspective to fill current yield gap

Harmeet Singh Bakala

Punjab Agricultural University, Ludhiana

Corresponding author: harmeet-pbg@pau.edu

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Introduction

Being one of the most important food grains globally, wheat acts as major staple food for over one-third of world's population and provides about 20% of dietary energy. Wheat is second main food crop after rice consumed by humans, therefore playing a vital role for global food security. In addition to ever-rising population, global food production is threatened by competition for arable land between food and non-food uses, increasing input costs and weather anomalies as a result of climate change. Since arable land is finite, there required smart and sustainable agricultural innovations to increase yield along with climate resilience to meet the challenges of future food security. Plant breeders take a front seat to feed the world and must therefore adopt state of the art breeding technologies to substantially contribute to the required increase in crop production.

Hybrid wheat is one such promising approach, which could substantially enhance global wheat production in the era of climate change. Particularly in the context of climate change, the higher yield stability of hybrid wheat and its generally higher tolerance to biotic and abiotic stress is of great relevance and makes the hybrid technology very attractive. Hybrid wheat has been reported to have lower susceptibility to *Fusarium* head blight, frost, leaf rust, stripe rust and *Septoria tritici* blotch, making it an attractive option in era of climate change and future food security.

Historical background

After the discovery of heterosis in maize, during the beginning of the 20th century, it took more than 20 years, before the economic success of commercial hybrid breeding was realized. In contrast to this, hybrid breeding in autogamous crops has long been considered as unattractive mainly due to several layers of complexity. However, these crops can greatly benefit from the hybrid technology to achieve enhanced yield through the exploitation of heterosis, higher yield stability and a higher return on investment. Initial interest in research and development of hybrid wheat started in 1960s.

During the first wave of hybrid wheat breeding with its peak in the 1980s, studies reported a mid-parent heterosis for grain yield of about 10%. Despite exploitation of heterosis, early hybrid wheat varieties in 60s and 70s lagged behind due to accelerated improvement of semi-dwarf pureline wheat varieties during "Green revolution", leading to great success for the latter ones. After hybrid wheat gained its revival in early 1990s in USA and Europe with commercial authorization of chemical hybridizing agents (CHAs), there were new concerns regarding its use and efficiency in producing commercial hybrids.

Systems for Hybrid Seed Production

Due to autogamous nature of wheat, there are several methods devised for pollination control in wheat flower to ensure force out-crossing, a basic requirement for hybrid seed production. Most commonly adopted approaches are cytoplasmic genetic male sterility (CGMS) and chemically induced male sterility. The CGMS system is basically a 3-line ABR system including a male sterile line (female-A), maintainer line (B) and a restorer line (male-R). There are more than 50 different cytoplasms reported to induce male sterility, most explored and robust being *Triticum timopheevii* cytoplasm. However, this system suffers from incomplete fertility restoration, laborious maintenance of all 3-lines, adverse alloplasmic interactions etc.

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In contrast to this, CHAs could potentially convert any normal line to be used as female by inducing male sterility in it. This method expands the possible number of hybrid combinations to be explored for most heterotic hybrid. However, this approach does have some drawbacks like toxicity residues, cost, and inefficient seed production. Some other techniques currently under exploration are temperature sensitive genetic male sterility (TSGMS), photo genetic male sterility (GMS) and transgenic male sterility (TMS) etc.

Challenges

There have been, however a number of challenges in establishing the efficient scientific and economic framework for a successful hybrid wheat program. Despite many known merits of adoption of hybrid wheat, it has eluded the plant breeders for more than four decades since its initial promise in 1960s.

- The establishment of heterotic groups is crucial for successful hybrid wheat breeding program in long run, which currently remains unavailable.
- The available systems of hybrid seed production are very costly and labor intensive, adding to the cost of hybrid seed.
- Also, the hybrids have to compete with continuous development and wide adoption of cheaper pureline wheat cultivars, owing to more research efforts and investment in latter.
- The male and female parents must be compatible with each other, with crucial traits being flowering synchronization and plant height.
- The initial CMS systems proved to be unsuccessful for commercial wheat hybrids.
- Among major constraints were the polygenic nature of fertility restoration, deleterious nucleus-cytoplasmic interactions etc. CHAs were known to be genotype specific, expensive, adversely affecting female fertility, narrow application window and environmental unfriendly hindering its wider global adoption.

Hybrid Wheat Status

Hybrid wheat so far enjoyed some success especially in Europe, China and USA. During the last 30 years, nearly 70 varieties have been released in Europe and USA (majorly France, UK and Germany). A report suggests that the area under the hybrid wheat has increased to 560,000 ha (~450%) in 2017-18 during last 16 years. In USA some private

(BASF, Agripro Syngenta) and public sector (University of Nebraska-Lincoln) groups are actively working on research and development of hybrid wheat. Public sector groups are specifically focusing on traits QTL mapping, genomic selection using CHA based hybrids, unlike the private sector that are currently perfecting CGMS facilitated hybrid development. In China, there are so far more than 50 hybrids released using both the approaches. However, recently they are more involved in producing stress tolerant wheat hybrids using 2 line systems (PGTMS).

In India, a few CGMS based commercial wheat hybrids were released in 2002 by Mahyco for central and peninsular India. Despite generous initial adoption (>60000 acres), hybrids soon succumbed to newly developed high yielding pureline varieties. Now, Syngenta is heavily investing in India for the development of better yielding wheat hybrids especially for north western plains besides some public institutes like Punjab Agricultural University (Ludhiana), Indian Institute of Wheat and Barley Research (Karnal) and Indian Agricultural Research Institute (New Delhi).

Future Prospects

Hybrid wheat has great potential to increase the global wheat yield levels particularly in view of the increasing abiotic and biotic stress challenges as well as variable climatic conditions. However, unsubstantial progress has been made yet as evident from its global R & D and adoption scenarios. To achieve greater success with wheat hybrids, a number of areas are needed to be targeted extensively. Hybrid seed production system needs to be efficient and cost effective at the same time with extensive research efforts and investments at global scale. Also, the floral biology of the parental genotypes (anther extrusion, pollen production, viability & dispersion, female receptivity, lodicules) demands to be deeply

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explored and engineered to facilitate the higher seed set (hybrid seed) on female parent when crossed with compatible male parent in a crossing block.

The present extent of heterosis in wheat (10-15%) further needs to be enhanced by tapping and utilizing the global diverse wheat groups (spring and winter) to study haplotype based associations with heterosis and ultimate development of heterotic groups. Novel technologies like genome editing may offer solution to problems (oligogenic fertility restoration) in promising approaches like CGMS, which would then be potentially more feasible and thus, would override costly and toxic CHA based system. Moreover, genetic gains over time can be enhanced by adopting genomics based predictions for single cross performance. These major prospects in combination with huge investment and commitment would surely have potential to deliver cost effective high yielding wheat hybrids in coming 5-7 years.