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Exploiting Climate-Smart Agriculture through Breeding of Next-Generation High Yielding Genotypes of Wheat under Cropping System Perspective

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ABSTRACT

Wheat is one of the most affected cereal crops in the wake of global warming, and is facing great constraints in enhancing yields to meet the future demand and reducing cost-benefit ratio. Conservation agriculture (CA) is being promoted as adaptation option to address climate risks. However, there is a need for the integration of CA and responsive genotypes for suitable exploitation of the benefits of CA advantage and early sowing advantage; responsive genotype must harbor traits like longer duration for maturity with mild vernalization requirement, longer coleoptile length along with alternate dwarfing genes, early seedling vigor to cope up with previous crop residue, and higher biomass with strong sink. Two high-yielding wheat varieties have been developed in this direction, which are suitable for both maize-wheat and rice-wheat cropping systems. The yield gains can still be further enhanced by better understanding of plant-microbe interaction through induced epigenetic changes under the CA and integrating molecular breeding with traditional breeding.

Key words: Conservation agriculture, climate change, genotypes, yield

Introduction

Globally, more than 2.5 billion people are consuming wheat, and nearly a billion people are dependent on maize, particularly in poor sub-Saharan regions. To keep pace with the increasing population, wheat yield has to be increased by at least 15% by the end of this decade, and that too under the projected atmospheric temperature and rainfall changes. Climate-smart agriculture practices like conservation agriculture (CA) are increasingly being adopted by farmers throughout the world including India due to increasing awareness about conserving natural resources and minimizing the ecological footprint. Improved varieties have always acted as a fulcrum for the adoption of new technologies for securing the food production under diverse climatic and production conditions (Yadav *et al.*, 2010, 2017). A record food production has been continuously achieved by India in past few years, however, the water stress and drought situation are still continuing to affect wheat production in many pockets of India. Soils, especially the surface layer have been overstressed and is showing fatigue, especially in rice-wheat cropping system (Sapkota *et al.*, 2017; Ray *et al.*, 2014; Ladha *et al.*, 2009). Breeders have always played a crucial role in maximizing the yield potential of every

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cropping and production system by developing compatible diverse plant varieties. Agricultural production system is highly dynamic and evolving due to changing climatic conditions and social needs. Breeding plan should always accommodate these needs and be modified accordingly.

In absence of effective adaptation through genetic improvement and management, a one-degree Celsius increase in average temperature may reduce the wheat yield by 6.0% and maize yield by 7.4% (Zhao *et al.*, 2017) generally by induced earlier anthesis and maturity and reduction in biomass. The temperature rise may combine with drought, severe cold and flood, and therefore projected losses under changing climatic conditions could be even higher. Although the effect of changing climate may be offset marginally by increased CO_2 concentration in the atmosphere resulting in more photosynthesis. Wheat and maize yields fluctuate more strongly in Haryana, eastern and central Uttar Pradesh and Rajasthan in comparison to Punjab (Yadav *et al.*, 2017), largely because of sudden temperature rise. Moreover, plant growth stages impacted by the rise in temperature vary between years, making it difficult to address the issue of temperature rise through breeding. Potential yield in wheat can be realized when the temperature remains around 15°C beyond which rise in temperature reduces the grain yield by 3 to 4% (Tashiro and Wardlaw, 1989). An increase in temperature reduces the yield by forcing anthesis and maturity early (Rahman *et al.*, 2009; Gibson and Paulsen, 1999) resulting in reduction of kernel number per spike (Rahman *et al.*, 2009), and lower harvest index (Prasad *et al.*, 2008). Anthesis is the most vulnerable growth stage, and even a small period of higher air temperature (>32-36°C) during this stage greatly impacts the seed-setting and the yield (Prasad *et al.*, 2000; Wheeler *et al.*, 2000; Jagadish *et al.*, 2008). Impact on increased temperature on wheat yield will likely be greater in India as the temperature regime in wheat-growing areas of India is close to the threshold limit. Sudden rain along with high wind speed could be another factor of high yield loss. Despite increased understanding on the time of flowering under sub-optimal temperature condition, response of crop plants under supra optimal conditions is poorly understood (Craufurd and Wheeler, 2009). Such understanding becomes important due to more frequent occurrence of extreme events under projected climatic change. Identification of phenological traits leading to yield improvement over the years can throw lights on the pattern of adaptation to changing climatic conditions. Conservation agriculture practices encompassing crop rotation, minimum or no-tillage with residue retention can be important intervention to modulate extreme events like high temperature, sudden downpour and or even moisture stress.

These issues can be effectively addressed if breeding is tuned to climate-smart technologies like CA by developing resilient varieties adaptable to climate-smart technologies. However, it is well documented that variation at the species level is much stronger compared to the resilient variety of a particular crop to be adaptive to a sharp change in environment. With evolution of new fields and growing scientific information, integration of knowledge is going to be the biggest challenge in the future. Understanding the functional variability at molecule, organs, whole plant and at the population level, and its integration with diversity at the level of nucleotide and genes will be relevant for the development of new genotypes by integrating the genotype (G) × environment (E) × management (M) interaction. Plant ideotypes required for changing patterns of environmental stresses as well as evolving management practices will be guiding forces for the breeding outcome. The key physiological processes like phenology, water and other input use efficiencies, radiation and CO_2 use efficiency need to be assessed under changing climatic condition and evolving management practices. Modern breeding tools under such a situation could prove quite handy for steering recombination between desirable genetic factors and select on the basis of genetic values.

Exploiting CA for Developing Next-generation High Yielding Genotypes

The concept initially given by Edward Faulkner in 1945 was subsequently evolved by

Masanobu Fukuoka in 1978, and further refined as CA practice in Latin American countries for crop production in a sustainable way under both irrigated and dryland conditions. Crop residue management has been the most pertinent issue, which often restricts in full exploitation of CA in India and elsewhere. However, recent advances in planting machinery have provided great momentum to the adoption of CA. Genotype x management interaction (Trethowan *et al.*, 2005; Watt *et al.*, 2005; Sagar *et al.*, 2014, Yadav *et al.*, 2017) can be further exploited by developing varieties to harness genotype–tillage–cropping synergies (Gupta and Yadav, 2014). The selection of genotypes based on indices involving coleoptile length, weed competitiveness, improved biomass, genes with mild vernalization requirement, and increased duration could help in evolving CA-adopted genotypes (Yadav *et al.*, 2019). Slightly taller varieties with longer coleoptile is an example, where seedlings can emerge out of heavy residue at surface. Longer coleoptile can also help in overcoming the relatively high temperature in October month by facilitating deeper seeding. Mutation in Rht-B1 (Rht1) or Rht-D1 (Rht2) resulted in reduced production or perception of phytohormone (GA) (Peng *et al.*, 1999), which was exploited to develop semi-dwarf, lodging resistant and efficient assimilates allocating cultivars, giving scope for higher application of inputs and higher yield realization (Brooking and Kirby, 1981; Evans, 1996; Miralles and Slafer, 1995). However, the reduction in plant-height gene simultaneously reduces the coleoptile length due to which it became imperative to sow these varieties at a shallow depth. Alternate dwarfing genes like Rht8, Rht10 and Rht12 and QTLs with small and additive effects, identified on chromosome 1A, 2B, 2D, 3B, 3A, 5A, 6A (Rebetzke *et al.*, 2007; Spielmeyer *et al.*, 2007) can help in reducing plant height without reducing the coleoptiles length. Through a continuous practice of selection under the CA, the adapted genotypes with appropriate coleoptiles length can be identified. Addition of organic matter through residue degradation increases biological activity and the rate of mineralization in the soil (Singh and Bhogal, 2014). Genotypes with higher root biomass can respond better to the enhanced availability of minerals through higher biomass accumulation, and thus higher yields can be obtained. Yield of wheat crop in the northern plains of India can be enhanced by extending the duration of the variety (Yadav *et al.*, 2017; Kumar *et al.*, 2017) also by early sowing to avoid terminal heat stress. To conserve the residual soil moisture, and to smoother the weeds which germinate at the high temperature, wheat genotypes HD 3117 with spreading growth habits and large foliage can be highly suitable for CA. The genetic nature of weed competitiveness of wheat varieties has been established by the number of researchers (Wicks *et al.*, 2004; Cosser *et al.*, 1997; Lemerle *et al.*, 2001). The Indian Agricultural Research Institute has also released two wheat varieties HDCSW 18 and HD 3117 having spreading to semi-growth habit at the juvenile stage along with comparatively greater plant height (100 to 110 cm). Similarly, early seeding to consolidate the wheat yield may result in very early flowering due to high temperature in absence of suitable vernalization genes, and can reduce biomass and number of grains per spike, and adverse impact in yields. It is therefore important to exploit the allele of vernalization gene resulting in mild vernalization requirement in the plant. HDCSW 18, a product of systematic breeding for CA is highly suited for early seeding. This has outperformed all genotypes under testing in multilocation trials because of its mild vernalization requirement and ability to generate higher biomass.

Adding Cropping System and Agronomy Perspective in Breeding for CA

Conservation agriculture can reverse soil physical structural issues generated by intensive conventional practices. Poor water holding capacity with a compact layer within upper 20-30 cm of soil profile in the majority of the rice-wheat growing areas does not allow exploitation of strong head and higher biomass to realize more yields due to often lodging. However, CA modifies soil environment in such a way that genotypes with higher biomass will remain in standing. Changes in varietal and agronomic scenarios in other crops in wheat-based cropping systems can impact the varietal dynamics of wheat. Without keeping in view of the size of farming and diversity in the production environment including cropping systems in India, often fails at the farmer's field, or farmers find the technologies difficult to adopt or with inconsistent results over the years. Designing of production technologies (including varieties) which can get well in prevalent cropping systems will give a scope to farmers for long-term investment in better agronomy. Ideotype of wheat in rice-wheat cropping system will be generally different from the type suitable for maize-wheat system. The CA, if combined with designed breeding of wheat can provide a window of opportunity to prolong duration of wheat for 20-30 days for yield maximization with short-duration basmati rice in sequence. Wheat genotypes with recessive VRN-1a and VRN-1c alleles can head appropriately even if they are seeded early under the high temperature. Wheat genotypes with suitable vernalization requirements, higher biomass with a sturdy stem and sink capacity can further maximize yields. Various VRN, PPD and RHT genes along with number of QTLs were identified by researchers having adaptive role in wheat. Genotypes with differential adaptations were grown under three contrasting environments generated by different tillage-sowing methods. A positive but weak correlation was found among the grouping pattern based on molecular markers pertaining to various VRN, PPD and RHT genes and groupings based on phenotypic appearance. Therefore, molecular markers can also be utilized in selection of CA adaptive genotypes after further validation (Yadav *et al.,* 2014). CA under maize-wheat also provides an opportunity to increase the duration of maize hybrid by at least 10-15 days. Maize hybrids with a duration of 110 days in *kharif* can yield 8-9 t ha^{-1} easily and can be as remunerative as rice-wheat system. Just like wheat, high biomass maize hybrids can not be exploited traditionally because sudden downpour in monsoon season results in crop lodging. However, CA can increase percolation and thereby reduce the water stagnation in the field. In areas with comparatively less rain, CA can help in higher soil water availability through its better retention and of water in the soil.

Conclusions

Directed breeding toward improved agronomy including CA and cropping systems have yielded desirable results in both maize-wheat and rice-wheat cropping system. The gain can still be furthered by better understanding of plant-microbe interactions through induced epigenetic changes under the CA and integrating molecular breeding with traditional breeding.

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