Breeding Wheat for Conservation Agriculture (CA) in the Era of Climate Change

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Abstract

Wheat (*Triticum aestivum* L.) is one of the important food crops in the world. Among the developing countries, it is the second most important source of daily calories and protein. The increasing population and inadequate food supply in developing countries are making food security very relevant. In South Asian countries like India, where the rice-wheat cropping system is more predominant, farmers are now facing the challenges of degrading production environment, declining profit, and climate change. Therefore, climate-smart technologies like conservation agriculture (CA) need to be implemented on larger acreages. Globally, CA is accepted; however, in India, its acceptance is limited because of various issues. Stagnation in wheat productivity in major wheat-growing states in North Western Plain Zone is forcing researchers to new thinking and making strategies. Breeding wheat-adapted genotypes for CA is one strategy to address some issues mentioned above. Novel variation for the traits specific to CA needs to be introgressed for making new-generation wheat genotypes where CA is being adapted. Traits such as the capacity to germinate when seeded deep, better emergence through residue load, longer and stronger coleoptile, stronger root system architecture, early vigor, and multiple disease resistance are important in CA-adapted genotypes. Breeders need to find these traits from synthetic hexaploid wheat, alien introgression lines, and secondary gene pool if the variation is limited in elite lines. Breeders also need to assess germplasm and breeding lines under CA environments to find genotype × environment interaction and identify stable lines. Finally, modern breeding tools like genomic-assisted breeding may

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also play an important role in developing genotypes better adapted to CA environments. With advanced genomic tools and the availability of large genomic information, it is expected that newer QTLs will be identified and the molecular mechanism controlling CA responsive traits will be explained.

Keywords

Breeding strategies · Conservation agriculture (CA) · Climate change · Wheat breeding · Wheat improvement

15.1 Introduction

With increasing population, degrading production environment, limiting resources, and uncertain climate, the task to increase food production to meet food security needs becomes more challenging for agricultural scientists in India (Yadav et al. 2017). Policy planners and researchers are worried about the declining profit in intensively cultivated areas and limited resources in the marginal areas. The technological needs to achieve this should increase farmers' income without affecting the environment adversely. The much-needed impetus as large economic support provided by the government to the farming section should yield tangible results. There is no contradiction to the fact that with increasing income, the demand for diversified food is increasing, and this demand has to meet from a shrinking land base. Many factors responsible for the First Green Revolution like tillage, fertilizer, and water have almost been exhausted in most of India, and therefore, new technologies have to be developed which can sustain the production for a longer period (Yadav et al. 2019). Conservation agriculture (CA) can address the above issues through efficient use of natural resources by integrating management of soil, water, and biological resources. According to FAO, conservation agriculture comprises crop management practices that involve minimal disturbance of the soil, retention of residue mulch on the soil surface, and use of crop rotations to control pests and diseases (http://www.fao.org.ag/ca).

In India, the entire Indio-Gangetic Plains is one of the most intensively cultivated areas providing food security to millions of people mainly through a rice-wheat cropping system. Increasing water scarcity and degrading soil health are some important factors contributing toward yield stagnation in this zone. Continuous usage of unsustainable crop production practices has not only increased the cost of production and but has threatened the very survival of the rice-wheat cropping system. Conservation agriculture practices that can save natural resources and bring down the cost of production and can provide insurance against environmental fluctuation are therefore becoming increasingly important. Till now, researchers have placed the main emphasis on crop management practices to conserve the resources; however, it is now increasingly being realized that the development of varieties adapted to these crop management practices can provide the much-needed impetus for the adoption of conservation agriculture in wheat (Yadav et al. 2019).

CA is a sustainable, resource-saving concept with minimum environmental footprints leading to more profit to the farmers. There has been a sharp rise in area under CA in many countries. In 2008–2009, CA was under adoption on 106 M ha area. However, in 2015–2016, the area under CA was increased and was practiced globally on about 180 M ha, corresponding to about 12.5% of the total global area under crop cultivation. This change makes up an increase of 69% globally since 2008–2009 (Kassam et al. 2019). It has also grown in India covering around 1.50 M ha (Jat et al. 2012) and 2.5 M ha area in South Asia (Jat et al. 2020). Its acceptance is slow because of varied reasons, like the lack of knowledge on crop residue management, stand establishment under heavy load of crop residue, fertilizer application, and non-availability of CA-adaptable varieties. It interrelates most of these changes, and the causal factors often have a complex interaction which poses difficulty in prioritizing the breeding objectives (Yadav et al. 2017).

15.2 Challenges Before Indian Agriculture in the Era of Climate Change

There have been rising scientific shreds of evidence to establish that the climate is changing and the temperature in a major part of the world is rising. Such an increase in temperature, uneven distribution of rainfall, and climate extremes will affect the agriculture sector more adversely. The rise of Indian agriculture from the days of the Green Revolution to the present-day food sufficiency stage has been very remarkable. The united efforts of plant breeding, genetics, agronomy, and other allied sciences in making India plentiful in food grain production have made it possible. However, in these efforts, issues like environmental challenges and production environment degradation have emerged strongly. The frequent occurrences of climatic fluctuations like moisture stress, hail storms, and heavy downpour led to loss of produce and increase in farm distress. Taking care of food and nutritional security of the ever-growing population thus becomes an intimidating challenge in a changing climate.

The importance of agriculture in India in view of social and economic context is crucial as availability of food to the economically weaker and nutritionally deprived population of the society is not fulfilled. India, therefore, has a huge challenge of not only aiding 17% of the world population with only 2.4% of the world's geographical area and 4% of water resources but also addressing the expanding discrepancy in income from agricultural and non-agricultural sectors (Yadav et al. 2019). The major challenges before Indian agriculture, especially in the "food bowl of India," i.e., North Western Plain Zone (NWPZ) and North Eastern Plain Zone (NEPZ), are depleting natural resources, declining profit, and climate change.

15.2.1 Depleting Natural Resources

15.2.1.1 Overexploitation of Water

Overexploitation of underground water is seriously weakening soil health and production environment in major wheat-producing states of Punjab and Haryana. Preferential and continuous cultivation of rice-wheat in these areas has not only distorted the nutrient balance and its availability but also increased the problems related to soil health. The sustainability of agriculture in the "food bowl of India" is becoming questionable because of the decline in the contribution of wheat to the central pool. The overexploitation of groundwater has led to a rapid decline in the groundwater table, and it may get worse further because of stepped up climatic variability in the future (Fishman 2018). Major wheat-producing states like Punjab and Haryana are dealing with challenges in increasing wheat productivity because of diminishing natural resources and changing climate. According to the Punjab State Farmers' and Farm Workers' Commission policy outlined in 2018 (https://www.psfc.org.in), a substantial increase in the production of two major cereal crops, viz., wheat and rice, has become uneconomical and unsustainable. On the contrary, states like Madhya Pradesh are setting new trends in wheat productivity. For the first time, Punjab was no longer the largest wheat contributor to the central pool as Madhya Pradesh delivered the highest quantity for a single season by any state in the year 2020 (Fig. 15.1).

Overexploitation of groundwater by Punjab is continued, and it is badly influencing the production environment. According to the Central Ground Water Board (CGWB)'s report released in July 2019 (http://cgwb.gov.in), the annual groundwater withdrawal in Punjab has reached 165% of its annual extractable groundwater resources, which is the highest in the country. The state was

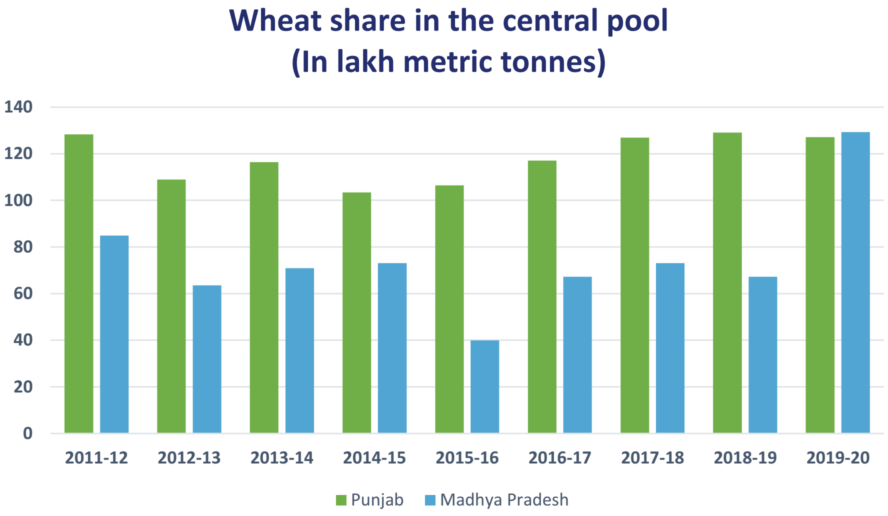

Fig. 15.1 Wheat contributor to the central pool by Punjab and Madhya Pradesh

Table 15.1 Top districts in Punjab with the high withdrawal of groundwater. Figures in billion cubic meters (bcm)

Districts in Punjab state	Annual extractable groundwater recharge in billion cubic meter (bcm)	Annual groundwater withdrawal (bcm)	Percent higher
Sangrur	1.44	3.74	260%
Jalandhar	1.17	2.80	239%
Moga	1.07	2.47	230%
Kapurthala	0.70	1.56	223%
Patiala	1.37	2.97	217%
Barnala	0.58	1.22	210%
Fatehgarh Sahib	0.55	1.15	209%
Ludhiana	1.94	3.54	182%
Overall	**21.58**	**35.78**	**165%**

overdrawing as much as 14 billion cubic meters (one cubic meter is equal to 1000 L) of groundwater every year to sustain its farming (Table 15.1).

If the farming community continues to lift the water at this rate, several thousand tube wells will become devoid of water, and agriculture sustainability will be unviable. Certain areas of the state of Punjab will lead toward desertification. Overexploitation of water is also disturbing lower aquifers; this water is becoming not fit for human consumption because of an increase in the concentration of heavy metals.

15.2.1.2 Soil Health

Healthy soil is imperative for food security, but the soil in the "food bowl of India" is rapidly losing its natural ability to support life. Overuse of chemical fertilizers for improving productivity form from limited land is leading to degradation of soil health. The predominance of rice-wheat cropping systems in NWPZ and NEPZ is largely because of economic reasons and supportive government policies to ensure food security (Yadav et al. 2019). Eductive farming practices such as burning of crop residues, uncontrolled use of groundwater, higher application of fertilizers, and indiscriminate use of pesticides and weedicides can degrade soil health. Soil organic matter content in most cropland soils of northwestern India and elsewhere is often less than 0.5%. However, in Punjab, Haryana, and Western Uttar Pradesh, soils are so degraded and depleted that soil organic matter content is as low as 0.1%. This leads to low and stagnating crop yields. Researchers are linking this declining soil organic content to reduced crop productivity (Bhandari et al. 2002; Regmi et al. 2002). However, contradictory reports have been published in a comprehensive study by ICAR National Bureau of Soil Survey and Land Use Planning (Bhattacharyya et al. 2007). The authors have studied changes in soil organic carbon from 1980 to 2005 in the Indo-Gangetic Plain zone and black cotton soil zone. They found that there is no change in or improvement in soil organic content over the years. In another study, Kukal and Benbi (2009) reported that the soil organic carbon content has been improved because of the continuous cultivation of the rice-wheat cropping system.

15.2.2 Declining Profit

Our planet's most important job is to produce food for humanity. The world's food demand is rising, but in most of the developing countries, farmers are leaving the profession of farming for one simple reason, i.e., decline in income and profit. We are heading toward a sitch where one of the world's largest food producing and consuming nations will be left with few farmers. According to the Census of 2011, every day 2000 farmers give up farming (https://www.thehindu.com/opinion). Income from farming has already lost the prime spot in a household's total earnings. In 1970, three-fourths of a rural household's income came from farm sources. After 45 years, in 2015, it is less than one-third (https://www.downtoearth.org.in). During 2004–05 to 2011–12, about 34 million farmers moved out of agriculture, as shown by National Sample Survey Office data, and this represents a 2.04% annual rate of exit from farming. Income and profit have declined, largely because of increases in prices of the farm inputs. The strongest reason for the marginal farmers leaving the profession of agriculture in Punjab was non-profitability (Singh and Bhogal 2014). One study by Guptha et al. (2014) on profit generation through rice cultivation in major rice-cultivating states, namely, Kerala, Tamil Nadu, and Odisha, reported that rice cultivation is a loss-generating livelihood and profit generation is reduced over the years. In another study by Narayanamoorthy (2013), profit earned through rice cultivation was negative in all data year points, whereas in wheat, it was profitable in three out of seven data year points. Though rice and wheat are the most productive and economically profitable crops in the Indian farming system, farmers have raised concerns about the economic sustainability of these crops (Yadav et al. 2017). According to a study by the Organisation of Economic Co-operation and Development (OECD), India's agriculture sector hasn't been generating enough revenues to keep farmers profitable for nearly two decades now. Out of 26 countries whose proportion of gross farm receipts was tracked over 2 years (2014–2016), only India, Ukraine, and Vietnam had negative farm revenues (https://www.hindustantimes.com). In India's agricultural scenario, gross farm revenues between the periods 2000 and 2016 were declined by 14% on average, whereas, between 2014 and 2016, this was fell by over 6% per year. This points to negative returns for the farmers (https://www.hindustantimes.com). However, on the positive side, in the fiscal year 2020–2021, agriculture share in GDP reached a record 20% for the first time in the last 17 years. The continuous supply of agricultural commodities, especially rice, wheat, pulses, and vegetables, helped in enabling food security in the time of COVID-19 pandemic.

15.2.3 Changing Climate

Changes in temperature, precipitation, and rising CO_2 concentration are making our food crops more sensitive to climate change (Rosenzweig et al. 2014). Among these stresses, an increase in temperature at important growth stages of crops has a most likely negative impact on economic yield (Ottman et al. 2012). Almost 60% of the variability in grain yield production of major food crops is explained by climatic uncertainties which will influence food production and farmers' income (Osborne and Wheeler 2013; Ray et al. 2015; Matiu et al. 2017). Crop-growing season is influenced by the magnitude of heat and moisture stress (Fiwa et al. 2014; Zhao et al. 2015; Lobell et al. 2015; Saadi et al. 2015; Lemma et al. 2016; Schauberger et al. 2017). A high-temperature regime during the vegetative stage leads to low biomass accumulation, and its conversion into grain yield is significantly reduced (Hillel and Rosenzweig 2015). Recently, Zhao et al. (2017) showed that in the areas where major food crops like wheat, rice, maize, and soybean are grown, the mean annual temperature has increased by ~1 °C during the last century and is expected to continue to increase over the next century. This 1 °C increase in global temperature would, on average, reduce global yields of wheat by 6.0%, rice by 3.2%, maize by 7.4%, and soybean by 3.1% (Zhao et al. 2017). In a similar kind of study, Guiteras (2009) reported that crop yields will decline by 4.5–9% in the short run (2010–2039) and by 25% in the long run (2070–2099) in the absence of adaptation of suitable mitigation strategies by the farmers. In India, interest of researchers on assessing the impact of climate change on the agriculture sector is growing rapidly. Studies carried out at the ICAR-Indian Agricultural Research Institute (IARI), New Delhi, have showed the possibility of a loss of 4–5 MMT in wheat production with every 1 °C rise in temperature (Kumar et al. 2012). Further, Burgess et al. (2014, 2017) reported that the climate change is more affecting the livelihood of rural population as compared to the urban population in India. They reported that one standard deviation[1] increase in high-temperature days in a year decreases agricultural yields and real wages by 12.6% and 9.8%, respectively, and increases annual mortality among rural populations by 7.3%. In urban areas, they find no evidence of an effect on incomes and a marginal increase in the mortality rate. Climate change is adversely influencing agricultural productivity of major food crops of India like wheat, rice, maize, sugarcane, barley, sorghum, and many pulses via fluctuations in temperatures and rainfall patterns, and thus it may threaten the food security of India (Kar and Kar 2008; Srivastava et al. 2010; Boopen and Vinesh 2011; Kumar et al. 2011; Geethalakshmi et al. 2011; Ranuzzi and Srivastava 2012; Singh 2012; Praveen and Sharma 2020). In South Asian countries, climate change will bring greater inconstancy in food grain production, farmers' income, food supplies, and market prices and will worsen the situation of food insecurity and poverty (Bandara and Cai 2014; Shankar et al. 2015; Wang et al. 2017; Aryal et al. 2019, 2020). These South Asian developing countries are more vulnerable to the effect of climate change on agriculture because of lack of resources, technological advancement, and greater dependence on agriculture for the livelihood of large populations (Nath and Behera 2011).

Overall, to mitigate the effect of changing climate on agricultural productivity, innovations from crop improvement and natural resource management disciplines should be integrated and applied in the right place. From crop improvement perspectives, identification of crop phenological traits under different abiotic and biotic stress leading to yield improvement over the years can show the way forward on the pattern of adaptation to changing climatic conditions. Breeding genotypes adapted to the CA environment will help in further consolidation of the yield of major food crops. A very important climate-smart natural resource management strategy, i.e., CA, can mitigate the effect of changing climate to some extent. CA practices encompassing minimum or no tillage along with residue retention and crop rotation can be important interventions to minimize the losses caused due to extreme climatic events like moisture stress, abnormally high temperature, and a sudden downpour.

15.3 The Exigency of Adaptation of Wheat to Climate Change

Wheat is an important crop in South Asia from the food security point of view. In South Asian developing countries specially like India, investment in developing appropriate adaptation strategies needs to be done on priority to minimize the risk of climate change in agriculture. Tesfaye et al. (2017) predicted that the annual average maximum temperature may increase by 1.4–1.8 °C in 2030 and 2.1–2.6 °C in 2050 and thus heat-stressed areas in the region could increase by 12% in 2030 and 21% in 2050 in South Asia. In India, it is projected that almost half of the Indo-Gangetic Plains (IGP) may become unfit for wheat production by 2050 because of heat stress (Ortiz et al. 2008). A comprehensive study on wheat yield from 208 districts over the period 1981–2009 by Gupta et al. (2017) reported that global warming has reduced wheat yield by 5.2% from 1981 to 2009 and a 1 °C increase in average daily maximum and minimum temperatures lows wheat yields by 2–4% each. In a study on the effect of average temperature and pollution variables on wheat yields in 9 Indian states Burney and Ramanathan (2014) finds that combined yield loss of 37 % from climate change and pollution, but with large uncertainty. Crop models are useful tools for assessing the impact of climate change on global and local food production. Using 30 different wheat crop models, Asseng et al. (2015) find that, for each degree Celsius increase in temperature, global wheat production is estimated to reduce by 6% and it will become more variable over time and space. To minimize the effect of climate change on wheat productivity, adaptation strategies need to be followed. Using multiple climate models, Tanaka et al. (2015) advocated adaptation pathways for major wheat-growing countries. For India, an increase in irrigation facilities and the cultivation of climate-resilient wheat varieties are required for minimizing yield loss. In another study by Kumar et al. (2014), using the InfoCrop-WHEAT model, it was predicted that climate change will reduce the wheat yield in India in the range of 6–23% by 2050 and 15–25% by 2080. Thus, new-generation climate-resilient wheat varieties need to be developed and deployed on large acreages for higher productivity under changing climate scenarios.

15.4 Need for Developing CA-Specific Wheat Breeding Program

The depleting natural resources, degrading production environment, and climatic change are the three important challenges before Indian agriculture (Yadav et al. 2017). The depletion of groundwater by an average rate of 4 cm (+/−1 cm) per year over Rajasthan, Punjab, Haryana, and Delhi during the year 2002 to 2008 is witnessed (Rodell et al. 2009). The drastic decline in the factor productivity of NPK in Punjab from 80.9 kg food grain in 1966–1967 to 16.0 kg food grain per kg NPK application in 2003–2004 in rice-wheat cropping system (Benbi et al. 2006) shows a developing imbalance of micro-nutrients, pH, and EC and soil organic carbon in the soil. Therefore, under these circumstances, the grain yield increment of wheat is a very challenging task. Wheat is one of the most suffered cereal crops from the effect of global warming. The wheat grain yield might be reduced by 6% with each degree rise in mean seasonal temperature (Zhao et al. 2017). Under warming conditions, grain yield is reduced by the crop duration, kernel number per spike, kernel weight (Rahman et al. 2009), and harvest index (Prasad et al. 2008). The wheat crop is the most vulnerable at anthesis. Therefore, in the Indo-Gangetic Plains region, the unpredictable fluctuation of temperature in March is the key factor for deciding wheat productivity. To rectify the facing problems, there is a need for integrating agronomic management and responsive genotypes. Conservation agriculture (CA) is one of the best agronomic management practices for wheat production as it provides prolonged availability of soil moisture and modulation of soil temperature, better anchorage and nutrients (Yadav et al. 2017). In the above zone, the short-duration basmati varieties, like Pusa 1121 and Pusa 1509, are regularly harvested to vacate the field in the mid of October for wheat seeding. Moreover, the advent of new machinery like happy-seeder makes it feasible to sow the wheat directly without field preparation in the conserved moisture of the field. The government policies are also being designed to increase the area under conservation agriculture since this approach is resource-saving, environment friendly, and also provides the best opportunities to further yield enhancement.

15.5 Characteristics of Genotypes Adapted for CA

To exploit CA advantage and early seeding advantage, responsive genotype must harbor some traits leading to adaptation to CA. These traits are a longer duration for maturity with mild vernalization requirement, longer coleoptile length along with semi-dwarf habit and early seedling vigor to cope with previous crop residue, etc. Under very early wheat sown condition, in the absence of proper care, chances of uneven plant stand in the field at 5 cm depth sowing remain high because of the rapid depletion of water soil under high temperature; therefore, deep sowing is recommended to ensure longer availability of moisture for getting uniform proper plant stand under CA.

Longer coleoptile length Deep seeding of existing and popular semi-dwarf variety results in low plant stand because of the presence of most common *Rht 1* and *Rht 2* dwarfing genes leading to shorter coleoptile length and plant height. Therefore, the heights of genotypes having alternate *Rht* genes, viz., *Rht 4*, *Rht 5*, *Rht 8*, *Rht 9*, *Rht 12*, and *Rht 13*, which shows the sensitivity to gibberellic acid, are reduced without affecting the coleoptile length (Chen et al. 2013; Rebetzke et al. 2012).

Initial vigor/weed competitive genotypes The basic aspect of CA is to sow the wheat directly in the field without much disturbing the soil surface at all. The problem of weed remains high in the initial years of conversion of the conventionally tilled field to the CA field. Therefore, the genotype must have a high early vigor along with good plant stand establishment to out-competes with weeds. The GA responsive genotypes could also improve early vigor and weed competitiveness (Amram et al. 2015; Rebetzke et al. 2012).

Mild vernalization requirement for a longer duration of genotypes As discussed earlier, for proper exploitation of extra time available because of the shorter duration of rice varieties, wheat genotypes must be of longer duration. The phenological adjustment with the exploitation of vernalization (Vrn) and photoperiod (Ppd) genes is a strategy to develop genotypes of longer duration suitable for CA environments. In this direction, the world's first very high-yielding bread wheat variety, i.e., HDCSW 18, adapted to conservation agriculture was developed and released for commercial cultivation by ICAR-IARI, Delhi, India (Yadav et al. 2017).

15.6 Exploring Novel Variation for the Traits Adapted to CA

Though wheat is adapted to a wider range of environments, maintaining and elevating the production will always remain a challenge and priority of any wheat breeding program. Improved yield potential, resistance to biotic and tolerance to abiotic stresses, and nutrient deficiencies or toxicities all have a role in improving overall productivity. However, genetic variation for some of these traits is limited in elite wheat germplasm (Ogbonnaya et al. 2013). Wheat improvement programs across the nations have delivered a notable increase in yield potential, however; yield plateau now seems to have reached. It has raised concerns that without breeding innovations, it will not be easy to meet the global wheat demand (Hawkesford et al. 2013). Hence, it is necessary to expand the germplasm base and enhance the useful genetic variation to meet this challenge (Tester and Langridge 2010; Moore 2015).

Synthetic hexaploid wheat (SHW) genotypes are a useful resource of new genes for wheat improvement. The wider adaptation provided by increasing the genetic diversity of bread wheat via SHW provides a means to enhance productivity gains in the face of climate change scenarios. The traits important under conservation agriculture are contributed by the "D" genome in SHW, e.g., better emergence through longer coleoptiles (Trethowan et al. 2012), larger seeds (Maydup et al.

2013), greater early vigor (Landjeva et al. 2010), deeper and extensive root system (Wasson et al. 2012), improved nutrient-use efficiency (Cakmak et al. 1999), and tolerance to heat (Ranawake and Nakamura 2011). One of the unexplored areas of research is the root system architectural traits in SHW and their potential to contribute to improved productivity via tolerance to moisture stress and lodging (Gaikwad et al. 2019a).

15.6.1 Strategies for Using Synthetic Hexaploids in Wheat Improvement

The genetic diversity in SHW can be utilized for the improvement of present-day elite wheat cultivars and developing new-generation genotypes for CA.

15.6.1.1 Phenotyping of the Traits

Phenotyping is the most common approach where SHW lines are tested for the genetic variation for biotic, abiotic stress tolerance, and traits related to root architecture (Gaikwad et al. 2019a). At IARI, New Delhi, we have tested SHW lines for the traits important in CA. Out of 55 primary synthetic lines and 20 mega wheat varieties screened at 55-day-old seedlings, SYN 2 (2130 cm) and CA-adaptable wheat variety HDCSW 18 (1781 cm) showed consistent vigorous and large root system as compared to mega wheat varieties like PBW 343 (1103 cm), HD 2733 (908 cm), HD 2967 (756 cm), and HD 3086 (912 cm) (unpublished data). Deeper rooting depth affects water use and could be beneficial in exploiting water at depth under drought conditions. SYN 36 and SYN 44 showed high grain weight, grain length, grain width, and grain surface area (unpublished data). Synthetic 25 recorded longer coleoptile length (6.25 cm), and SYN 4 recorded high coleoptile thickness (2.4 mm) (Fig. 15.2). These two traits are important in CA, as coleoptile has to come from the deeper layer of soil and through high stubble load. These lines are now used in a crossing program with rust-resistant high-yielding genotypes for developing synthetic backcross lines (SBL) adaptable to CA conditions.

15.6.2 Development of Synthetic Backcross Lines (SBLs)

Promising SHWs are crossed to elite varieties for the development of elite SBLs. Introducing the targeted trait from the SHW donor into agronomically elite germplasm and generating novel recombinants to widen the existing primary gene pool of common wheat are the most favored approach.

15.6.3 Development of Multiple Synthetic Derivative Populations

In this approach, a population harboring genomic fragments from the *A. tauschii* in the background of bread wheat is developed by crossing and backcrossing multiple

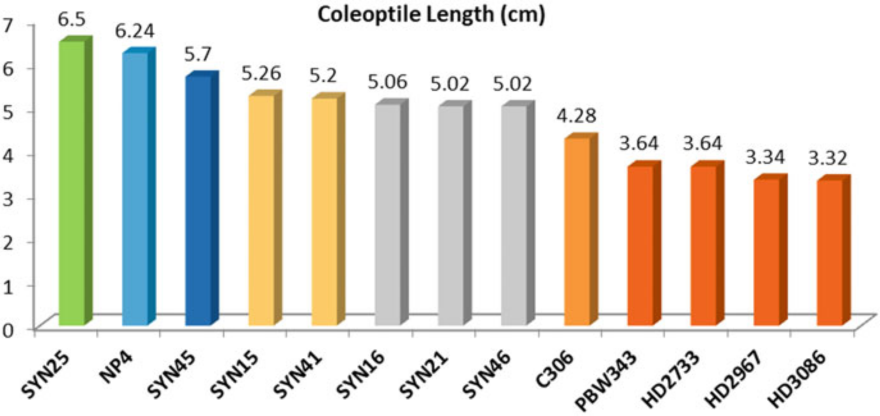

Fig. 15.2 Coleoptile length of few synthetic lines and mega wheat varieties

synthetic wheat lines with the common wheat cultivar (Gorafi et al. 2018). The availability of an efficient marker system will facilitate the mining of genomic regions/QTLs derived from *A. tauschii*, which is expected to contribute to wheat germplasm enhancement.

The worth of SHW is well proven as they show significant yield increase, tolerance to abiotic and biotic stresses, and thus enhanced yield performance across a diverse range of environments (Trethowan and Mujeeb-Kazi 2008; Dreccer et al. 2007; Jamil et al. 2016; Van Ginkel and Ogbonnaya 2007; Rosyara et al. 2019). Genetic diversity from SHW must be exploited on a larger scale in wheat breeding programs for the development of climate-resilient wheat cultivars and introgressing this novel genetic variability for developing CA-adaptable genotypes. A breeding program on the utilization of SHW lines in developing CA responsive lines is in progress at IARI, New Delhi; however, time is required for developing genotypes suitable for CA-specific environments.

15.7 CA-Directed Breeding Strategies to Develop High-Yielding Wheat Varieties

Conservation agriculture (CA) strives for sustainable productivity, quality, and economic viability while leaving a minimal footprint on the environment. Identifying the genetic variation for the traits adaptable to CA is the initial and most important step in breeding for CA. Genetic variation in elite breeding material needs to be screened first, as this material is easily incorporated in the hybridization program. If the variation is insufficient, then search could be expanded to landraces, local germplasm, alien introgression lines, synthetic lines, and other less-adapted breeding material.

The advanced breeding lines/released varieties developed on conventional tillage may not necessarily adapt/perform better to new agronomy of CA and cropping system. Hence, breeding program on developing specifically adapted genotypes needs to be executed (Trethowan et al. 2005; Joshi et al. 2005; Joshi et al. 2007; Yadav et al. 2017). Most of the crop breeding programs develop and evaluate their breeding material on complete tillage production environments, thus limiting the identification of crop genotypes responsive to CA (Mahmood et al. 2009). The agronomic aspects of CA have been studied more systematically (Liebman and Davis 2000; Cook 2006) than the genetic control of crop adaptation (Mahmood et al. 2009). Even though CA is widely adapted, in many countries, work on developing CA species crop varieties is still in infancy. Breeders in many crop breeding programs utilize the production environment of CA as an evaluation site for assessing the potential of fixed breeding material and not for developing new lines adapted to CA environment (Trethowan et al. 2012). Presence of genotype × cropping system or genotype × tillage interactions decides whether development of CA-specific genotypes is feasible or not. If such interactions are present, then genotypes better adapted to CA environments can be developed, and crop adaptations can be studied comprehensively. Some studies have reported limited or non-existence of genotype × tillage interactions (Gutierrez 2006; Zamir and Javeed 2010; Maich and Di Rienzo 2014; Kitonyo et al. 2017). The weaker or absence of genotype × tillage interaction indicates low frequency or absence of gene (s) that command adaptative response to CA. From thousands of years, our ancestors are growing food crops by tilling the land, and the crop cultivars had been started responding to it. It is imperative to understand that these crop cultivars have lost the gene(s) governing genetic adaptation to CA over the course of time due to undirected selection. In contrast, many other studies indicated the presence of significant genotype × tillage interaction in wheat (Kharub et al. 2008; Trethowan et al. 2012; Sagar et al. 2014a, b, 2016; Yadav et al. 2017) when genetically diverse genotypes were tested.

Landraces are traditional cultivars grown by farmers for many decades and are not subjected to modern plant breeding activities. These cultivars may possess novel variation for traits important in CA. These cultivars can be easily crossed with elite lines, and traits of interest can be transferred, followed by the selection of desirable recombinants and evaluation in the target environment.

Alien introgression is the introduction of novel and useful gene(s) from related/ distantly related species and has proved to be a valuable source of genetic variation, particularly for resistance/tolerance to biotic and abiotic stresses, nutritional quality, and improved grain yield (Gaikwad et al. 2020). In major food crops, utilizing this untapped genetic variation in breeding program has resulted in the development of several agronomically superior lines (Gaikwad et al. 2014, 2019b, 2021). A successful example of alien introgression is the 1B/1R translocation in wheat (Trethowan and Mujeeb-Kazi 2008). In India, wheat variety PBW 343 was extremely popular among the farmers due to its multiple disease resistance and wider adaption. This variety harbors 1B/1R translocation, and that’s the reason it became mega wheat variety of India. This translocation is harboring genes not only for disease resistance but also for larger root systems (Hoffmann 2008) and better water uptake (Ehdaie et al. 2003). The CA-specific wheat variety HDCSW 18 developed by IARI, New Delhi, has one of the parents (PBW 343) having 1B/1R translocation and may therefore have a larger root system, higher above-ground biomass, and better water uptake. Other alien wheat translocations may include many of the rust resistance genes like *Sr36*, *Sr40*, *Sr39/Lr35*, and *Sr32* (Bariana et al. 2007). These translocations may carry useful variation for adaptation to CA.

15.8 Genomic-Assisted Breeding in Developing CA-Adapted Varieties

Genomic-assisted wheat breeding for CA responsive traits is still in infancy. However, with the advent of advanced genomic tools and the availability of large genomic information, it is expected that newer QTLs will be identified and the molecular mechanism governing CA responsive traits will be elucidated. There are two major approaches to dissect/identify novel genes/QTLs governing CA responsive traits. The first classical approach is bi-parental mapping which relies on developing mapping populations involving diverse parents with extreme phenotypes for the target traits and then dissecting their genetic architecture. However, this is more effective if the traits are under the control of major genes and/or minor genes with significant effects. A limited number of studies are available where molecular markers are involved to study the genetics of traits associated with CA adaptability (Yadav et al. 2014; Kumar et al. 2018). A bi-parental mapping population developed from a cross Berkut/Krichauff was evaluated at multiple locations under contrasting tillage environments on different soil types (Trethowan et al. 2012). The authors have identified QTLs for grain yield under contrasting tillage regimes and advocated the use of linked molecular markers in breeding programs. The QTLs for grain yield expressed under zero tillage were located on chromosomes 2D, 5A, and 5B. The QTL on 5B chromosome shares a common region of earlier reported gene Tsn1 (Oliver et al. 2009; Faris et al. 2010) which confers resistance to yellow spot disease in wheat. This disease is very common where wheat-based cropping system is practiced and straw is retained on the soil surface. However, the authors did find very little infestation of this disease under CA and suspected that Tsn1 gene could have other effect on grain yield. These CA-specific QTLs for grain yield were reported in bi-parental population; if more diverse germplasm lines are evaluated under contrasting tillage regimes, then it would have been possible to identify novel QTLs for the traits specific for CA. This will help in understanding the genetic adaptation of the genotypes in CA. However, it is under enigma how much genetic variation still exists in the available germplasm and how much is lost due to directed breeding efforts (Joshi et al. 2007). Based on our studies at IARI, New Delhi, CA-adaptable (HDCSW 18 and HD 3117) and CA-non-adaptable (HD 2894 and PBW 550) genotypes have been identified (Yadav et al. 2017) and were crossed for the development of four mapping populations, viz., HDCSW 18/HD 2894, HDCSW 18/PBW 550, HD 3117/HD2894, and HD 3117/PBW 550. The identified genotypes

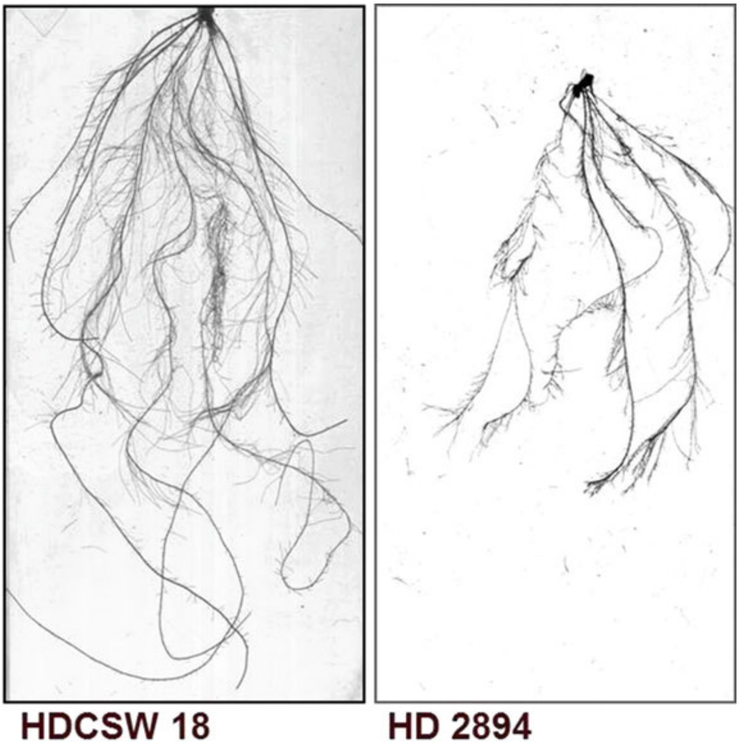

Fig. 15.3 Root architecture of HDCSW 18 and HD 2984 of 50-day-old seedlings

Table 15.2 The wide variation between HDCSW 18 and HD 2894 for root and yield contributing traits

Traits	HDCSW 18	HD 2894
Root length (cm)	1780.95	720.35
Root surface area (cm^2)	287.04	112.2
Root volume (cm^3)	3.68	1.39
No. of root tips	5253	2786
Days to heading	98	70
Grain per spike	85	45
Grain yield (q/ha)	70.2	25.68

have contrasting traits for root architecture, viz., root length, root volume, root surface area, number of root tips (Fig. 15.3), flowering time, biomass, grain number per spike, and grain yield (Table 15.2) (IARI, Annual Report 2018).

Many of the traits relevant for CA adaptation are generally below the ground and require destructive sampling for selection. QTLs related to these traits (root architecture, initial vigor, and biomass accumulation) can be effectively integrated into the breeding program for CA. Marker-assisted recurrent selection (MARS) can assist the development of wheat genotypes better adapted to CA (Fig. 15.4).

The second approach is genome-wide association studies (GWAS), which needs a diverse natural population, to capture historical recombinations that occurred during the evolution of an organism. This has several advantages over bi-parental mapping, as it covers greater allelic diversity spanning the entire genome, uses existing populations, and considers all the recombination events in the germplasm's history. Diverse breeding lines, landraces, and local germplasm could be used for GWAS, and marker-trait association for the traits specific to CA could be established. More efforts need to be done in this direction.

15.9 Conclusion

Wheat being central to the food security net, India cannot afford to be complacent despite the stupendous gain in production in the current year. Genetic gain by breeding effort throughout the world is slowing down, and India is no exception. Under changing climatic condition and deteriorating production environment, conservation agriculture practices along with CA-adapted genotypes can stabilize wheat yield at a higher level. The agronomic aspects of CA have been studied more methodically than the genetic control of crop adaptation. Development of CA-adapted genotypes requires a thorough understanding of genotype × environment interaction, more particularly many unexplored traits related to root system architecture. QTL identification for yield component and other difficult-to-measure traits can significantly increase breeding efficiency. To date, only one report is available from Australia, where researchers identified QTLs associated with specific adaptation to tillage regimes. In India and other major countries of the world where CA is practiced, no efforts have been made to identify and map the QTLs for specific adaptive traits, viz., traits related to root architecture, and important yield component traits to CA. Mapping the population generated through crossing among contrastingly adapted genotypes for CA is very helpful for the identification of such QTLs. The mobilization of such QTLs in the high-yielding background will provide the necessary base for furthering the genetic gain. CA-adapted high-yielding genotypes will not only maximize the production and return to the farmers but will also protect the environment by avoiding the residue burning.

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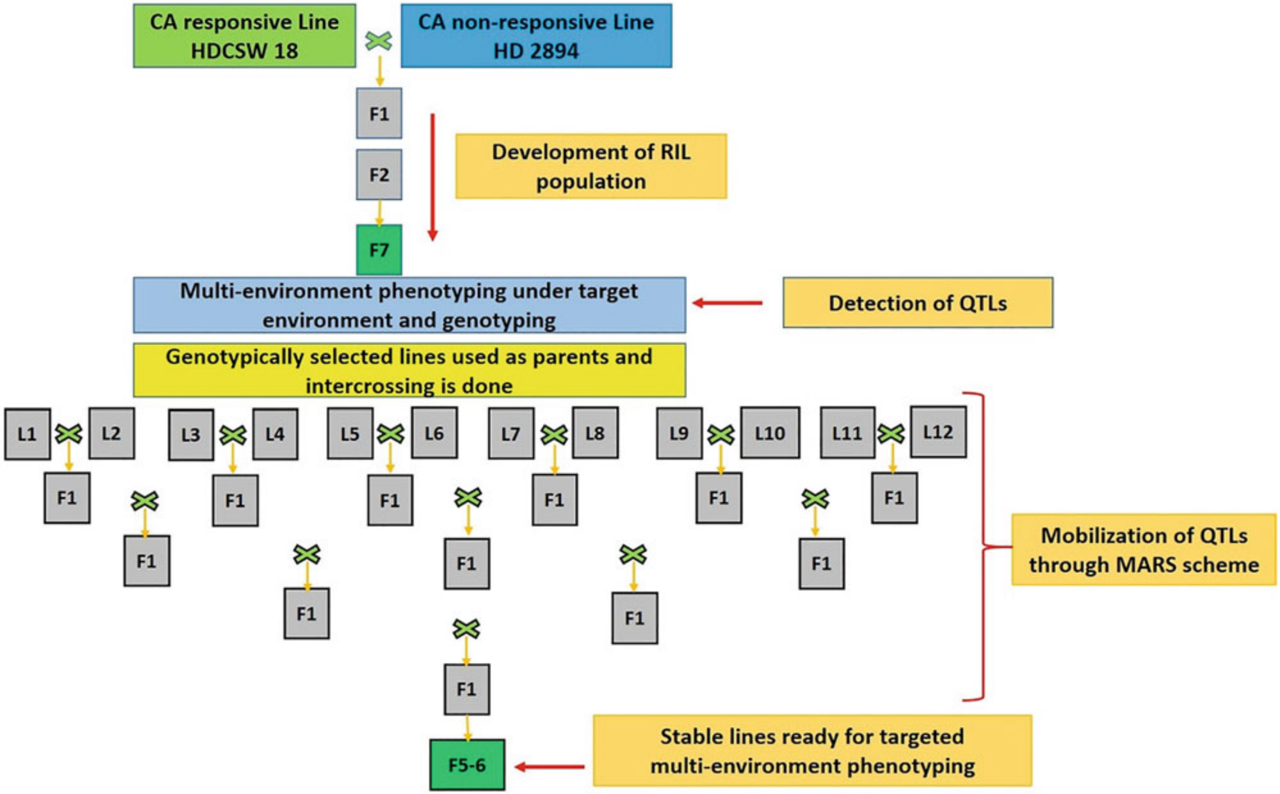

Fig. 15.4 MARS scheme for developing wheat genotypes adapted to conservation agriculture

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