Wheat

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Abstract

Wheat, a preeminent crop as a food of mankind, is originated in the Central Asian region, which has 225 million ha with global production of 750 million tons. India holds the second position with 109.52 million tons of production and contributes 13% share to the global wheat basket. Wheat acreage has five zones in India where bread, durum, and dicoccum wheat are grown during the rabi season under different production conditions. Wheat improvement was initiated in 1905, and since then, it has reached present-day advancements after its journey through the green revolution. There have been many research advancements in the last 75 years, especially in the post-green revolution period, in the form of the development of more than 500 cultivars for commercial cultivation, different resource conservation and plant protection technologies, crop diversification strategies, product and nutritional quality traits, etc. Nowadays, stagnating yield potential, unavailability of sufficient quantity of quality seeds, low seed replacement, biotic and abiotic stresses in climate change conditions, restrictions to germplasm exchange in new IPR regime, reduced total factor productivity, imbalanced use of fertilizers and yield gaps at farm level have been identified as major challenges to wheat production in the country. The current pace of research efforts needs to be maintained to meet our future demands of 140 million tons by 2050, for which future research efforts would be focused on evolving new and innovative production technologies which can fit into the framework of changing wheat production scenarios. Some key strategic issues for enhanced

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production levels include breaking yield barriers through genetic enhancement, molecular approach for precision breeding, tailoring wheat genotypes with cropping system perspective, improved varieties for abiotic stresses, focused disease resistance breeding, access to quality seeds of wheat, conservation agriculture technologies, integrated input management, crop diversification, quality improvement, strengthening inter-institutional linkages and support in policy issues. Bridging the yield gap between experimental and farmers' fields can solve the problem to a considerable extent. With support from farmers, policymakers, and extension units, it is expected that present technologies can be further refined and popularized so that wheat production can be enhanced to fulfill future demand for ensured national food security.

Keywords

Wheat · Bread wheat · Durum wheat · Dicoccum wheat · Improvement · Production technologies · Challenges · Strategies

7.1 Introduction

Among the world's crops, wheat (*Triticum species*) is preeminent both in regard to its antiquity and its importance as a food of mankind. In prehistoric times, it was cultivated throughout Europe and was one of the most valuable cereals of ancient Persia, Greece, and Egypt. According to paleo-botanists and archaeologists, the modern domesticated form of wheat originated in South-eastern Anatolia, around the region of Diyarbakir Province in present-day Turkey, at about 8500 BC. In India, evidence from Mohen-Jo-Daro excavations indicated wheat cultivation more than 5000 years ago. Globally wheat is cultivated in approx. 225-million-ha area with production of more than 750.0 million tons of grain. India, one of the greatest success stories of historical Green Revolution in India, made it the second largest producer of wheat in the world after China, with approximately 13% share of global wheat production, and recognized it as the wheat surplus nation. On the other hand, India is also the second largest wheat consumer after China and thus, wheat and its various products play an increasingly important role in managing India's food security.

7.2 Trends in Wheat Area, Production, and Productivity

Wheat is the second most important crop after rice in India and occupies an approximately 31.76-million-ha area. Wheat production in India touched a new height of 109.52 million tons in 2020–2021 (DAC & FW 2021). The major wheat-growing states in India are Uttar Pradesh, Punjab, Haryana, Madhya Pradesh, Rajasthan, and Bihar, which contribute approx. 91.5% of India's wheat production. The trend of area, production, and productivity indicated a significant quantum jump in wheat in post-independence period (Table 7.1, Fig. 7.1), where an increment of 2.23 times in area under wheat (+21.91 million ha: 222.50%), 15.49 times in wheat production (+102.15 million tons: 1548.73%), and 4.11 times in wheat productivity (+2754 kg/ha: 411.23%) was recorded. This gargantuan jump in production, post-independence, is attributed to the increased crop productivity followed by area. Precisely, the impact was more evident since the inception of the All India Coordinated Research Project leading to semidwarf wheat-based Green revolution. Despite recent risks of climate change, decade-wise analysis indicated increasing trends in area, production, and productivity in recent decades.

Globally, wheat is the most widely cultivated and traded cereal. In India, owing to surplus production, wheat imports have reduced considerably from 37.6 lakh tons (triennium ending 1970) to 0.4 lakh tons (triennium ending 2000). In contrary, the exports witnessed a surge from 0.01 to 5.56 lakh tons for the same period. Wheat is one of the major food staples for a majority of Indians; the consumption also registered an increase from 21 to 97.08 million tons between the triennium ending 1970 and 2020 (Sendhil et al. 2021).

7.3 Wheat Species and the Zones

The three species of wheat, namely *Triticum aestivum* (Bread wheat), *Triticum durum* (Macaroni wheat), and *Triticum dicoccum* (Emmer or Khapli), grown on a commercial basis in India are of spring type but cultivated during the winter season. Of these species, *T. aestivum* is the most important, accounting for about 90–95% of the total wheat area of the country, and is grown in almost all the wheat-growing states. *T. durum* occupies approximately 5% of the total wheat area and is confined mostly to central and southern parts of India. The cultivation of *T. dicoccum* is confined largely to the southern region, mainly Karnataka and southern Maharashtra. Another wheat species, *T. sphaerococcum* (Indian dwarf wheat), has now almost vanished and cultivated in some pockets in Gujarat. Wheat in India is cultivated in almost every state except Kerala, thus representing diverse crop-growing conditions and situations. Wheat cultivation in India extends from 9°N (Palni hills) to above 35° N (Srinagar valley of J & K), thus the wheat crop is exposed to a wide range of agroclimatic changes such as humidity, temperature, photoperiod during crop season, soil types, altitudes, latitudes and cropping systems. Based on the agroclimatic conditions and varying agroecological production conditions, the country is broadly divided into five wheat growing zones, namely, Northern Hills Zone (NHZ), North Western Plain Zone (NWPZ), North Eastern Plain Zone (NEPZ), Central Zone (CZ), and Peninsular Zone (PZ). NWPZ, NEPZ, and Central Zones are the main contributors to wheat production. The growing period of wheat is variable from one agroclimatic zone to another, which affects the vegetative and grain filling duration leading to differences in attainable yield. The maximum wheat growing duration is in Northern Hill Zone and the minimum in Peninsular Zone.

Table 7.1 Growth in national area, production, and productivity in wheat

Period	Quantum change			Percent change (%)		
	Area (million ha)	Production (million tons)	Productivity (kg/ha)	Area	Production	Productivity
Pre-Independence	−1.42	−1.48	−47	−12.60	−18.35	−6.58
Post-Independence	21.91	102.15	2754	222.50	1548.73	411.23
• 1947–1948 to 1959–1960	3.53	3.72	102	35.87	56.46	15.26
• 1960–1961 to 1969–1970	3.70	9.09	357	28.62	82.64	41.95
• 1970–1971 to 1979–1980	3.93	8.00	129	21.55	33.57	9.87
• 1980–1981 to 1989–1990	1.22	13.54	491	5.48	37.29	30.12
• 1990–1991 to 1999–2000	3.32	21.23	497	13.74	38.50	21.79
• 2000–2001 to 2009–2010	2.73	11.12	131	10.61	15.96	4.84
• 2010–2011 to 2020–2021	2.69	21.88	436	9.26	25.18	14.57

Pre-independence: 1885–1886 to 1946–1947 and Post-independence: 1947–1948 to 2020–2021

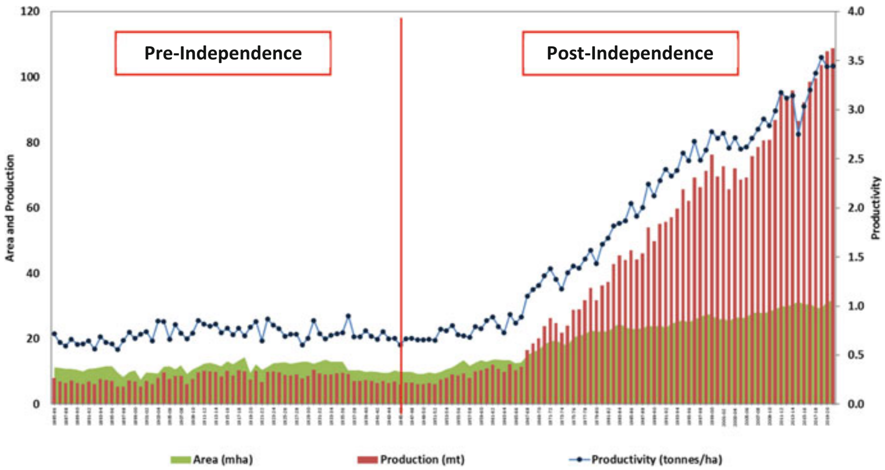

Fig. 7.1 Trends in wheat area, production, and productivity (pre- and post-independence)

7.4 Wheat Growing Season and Cultural Condition

Wheat is cultivated during the winter season from mid-October to April (except in higher hills of north India, where harvesting of wheat is done in the month of May) Sowings of wheat are initiated when the average day-night temperatures are equal to 23 °C. The months of December and January remain to be the coldest, followed by comparatively warmer and higher temperatures in the months of March-April, coinciding with later growth stages of the crop till maturity. Wheat is mainly grown under three production conditions: timely sown, irrigated; late sown, irrigated; and timely sown, restricted irrigation. Nearly, 89% of the wheat area in the country is irrigated and most of it lies in north India. The central, peninsular, and hilly areas have comparatively lower coverage of area under irrigation and grow mostly rainfed. In recent years, a new situation of timely sown, restricted/limited irrigation has emerged in some of the areas of the central and peninsular parts where water for irrigation is not available in sufficient quantity, and thus, the wheat crop is grown with one to two irrigations only.

7.5 Wheat Research in India: Chronological Perspective

7.5.1 Pre-independence Era

Wheat grown in India prior to the twentieth century mostly consisted of mixtures of various botanical forms usually referred to as ‘sorts’ among which Sharbati, Dara, Safed Pissi, Chandausi, Karachi, Choice White, Hard Red Calcutta, Lal Kanak, Lal Pissi Jaipur Local, Kharchia Local, Mondhya 417, Muzaffar Nagar White, Buxar

White, etc. were some prominent local bread wheat sorts utilized nationally and internationally. A systematic bread-wheat improvement work was initiated by Sir Albert Howard and his wife Lady G.L.C. Howard in 1905 at Imperial (now Indian) Agricultural Research Institute (IARI) at Pusa in Bihar. At the same time, Government Agricultural Colleges and Research Institutes were established at Lyallpur (now in Pakistan), Kanpur, Sabour, Coimbatore, and Pune to undertake research on crops, especially wheat, and later wheat improvement was also undertaken at Powarkheda (Madhya Pradesh), Nagpur, Akola, and Niphad (Maharashtra). In the era of pre-semidwarf bread wheat varieties (1905–1962), the selection from the mixtures resulted in some important pure lines like NP4, NP6, NP12, NP22, Type9, Type11, Pb type8A, C13, C46, AO13, AO49, AO68, AO69, AO85, AO88, AO90, etc. Some of these varieties earned international recognition due to their excellent grain appearance and are still considered a valuable genetic resources. Many Indian local collections, viz. Indian, Indian A, Indian B, Indian 4E, Indian F, Indian G, Indian H, Indian 8, Indian 9, Indian 17, Nabob, Sindhi, Etawah, Indian Pearl, Indian Dwarf, Ranjit, Khapli, Kaali, Muzzafar Nagar Variety, Hindi D, Hindi 7, Hindi 39, Hindi 62, Hindi 90, Hindi 144, Hard Red Calcutta, etc. were utilized in Australia, Egypt, Canada, South Africa, USSR, France, Brazil, and other countries (Jain 1994) for wheat improvement. Hybridization among these varieties and the exotic wheat was utilized in wheat breeding from the early years of the twentieth century which resulted in varieties like NP52, NP80-5, NP120, NP165, NP710, NP770, NP783, NP824, PbC518, PbC591, Niphad4, AO113, etc. Exotic sources such as Ridley, Padova I, and Padova II gained acceptance, and Federation 41, Kononso, Thatcher, Kenya C 10854, Kenya 48F, Democrat, Spalding's, Ridit, Reliance, prolific, Gabo, Timstein, Bobin, Gaza, Regent, etc., contributed significantly in the Indian wheat breeding program as donor lines for incorporating rust resistance leading to the development of disease-resistant cultivars like K53, K54, RS31-1, and Kenphad25. The varieties developed until the early 1960s were tall in stature and prone to lodging and therefore, nonresponsive to high fertilizer usage, e.g., K 65, K 68, Hyb 65, etc. Similar to those of the bread wheat improvement program, the durum improvement was initiated by H.M. Chibber in 1918–1919 in the erstwhile Bombay Presidency by making single plant selections out of the cultivated landraces like Bansi, Kathia, Gangajali, Haura, Jalalia, Jamli, Khandwa, Malvi, etc. These selections yielded superior lines like Bansi103, Bansi 162, Bansi 168, Bansi 224, and Baxi 228-18. The durum wheat evolved in India is a good source of genes for drought and heat tolerance, and they are mostly used as chapati or Dalia due to their unique quality characteristics. Subsequent efforts using exotic germplasm led to the development of improved durums like A 206, A 624, Amrut, N 59, NP 404, A-9-30-1, N 5749, Hybrid 23, Ekdania 69, Narasingarh 111, Bijaga yellow, and Bijaga red.

7.5.2 Post-independence Era

The real breakthrough in productivity occurred from the introduction of the semi-dwarf Mexican wheat in the early 1960s when India took advantage of Norin (having *Rht* dwarfing gene) based germplasm including four semidwarf wheat varieties, viz, Lerma Rojo 64-A, Sonora 63, Sonora 64, and Mayo 64 possessing a unique set of high productivity traits such as non-lodging habit, high fertilizer responsiveness, and resistance to rust and foliar diseases. After extensive evaluation of these varieties during 1963–1964, Lerma Rojo 64-A and Sonora, 64 carrying the genes for dwarfism and resistance to rusts, were released by the Central Varietal Release Committee in 1965, which laid the foundation for increased wheat production. At the same time, the establishment of the All India Coordinated Wheat Improvement Project (AICWIP) in 1965 was an important milestone for systematic developments in wheat research resulting in a major breakthrough in wheat production and productivity. Later on, the advanced lines from CIMMYT provided the base material for the development and commercial release of important amber-colored varieties, namely S227 (Kalyansona), S307, S308 (Sonalika), S331, Chhoti Lerma, and Safed Lerma. Among these, Kalyansona and Sonalika were very popular, occupying nearly 10-million-ha area because of their high yield, rust resistance, amber grains, and adaptability to different agroclimatic conditions of the country and became the harbingers of the 'Wheat Revolution' in India, which was later termed as the "Green Revolution." The red color of Sonora 64 was improved through mutagenesis at IARI, New Delhi, and released as "Sharbati Sonora." Afterward, hybridizations between Mexican and Indian varieties led to the release of WG357, WG377, WL711, HD2009, WH147, and HD1981 for NWPZ; HD1982, UP262, HP1102, HUW12, K7410, and HP1209 for NEPZ; HD2189 and NI5439 for PZ and many others which not only sustained the impact of green revolution but also took the wheat revolution to newer heights. India was the first country to release three multiline wheat varieties, namely MLKS11, KSML3, and KML7406 (Bithoor), for commercial cultivation in 1978. Varieties such as Lok1, HUW234, HD2285, HD2329, HD2189, and some derivatives of *Veery* of CIMMYT, viz. HUW206 and HS207, were very popular among the farmers during the 1980s and provided the necessary boost to wheat production and productivity. The development of wheat varieties CPAN3004, WH542, PBW343, and PBW373 having 1B/1R translocation through the utilization of winter wheat gene pool provided a quantum jump in wheat productivity by way of resistance to diseases, enhanced morphophysiological traits, and wider adaptability. Later HD2687, UP2338, RAJ3765, K9107, NW1014, HP1744, GW273, GW322, GW366, and MACS2496 covered significant wheat acreage in different parts of the country. During the early 2000s, PBW343 was the dominant wheat variety and after its susceptibility to yellow rust, DBW17 caught the farmers' attention as a suitable replacement for PBW343 in NWPZ. The release of mega varieties such as HD2967 in 2011 and HD3086 in 2014 has brought out a revolution in the highly productive environments of northern India. The robust and tall plant types with thick stems have led to changes in the plant type of the varieties, with the newer genotypes being more efficient and adaptive. The

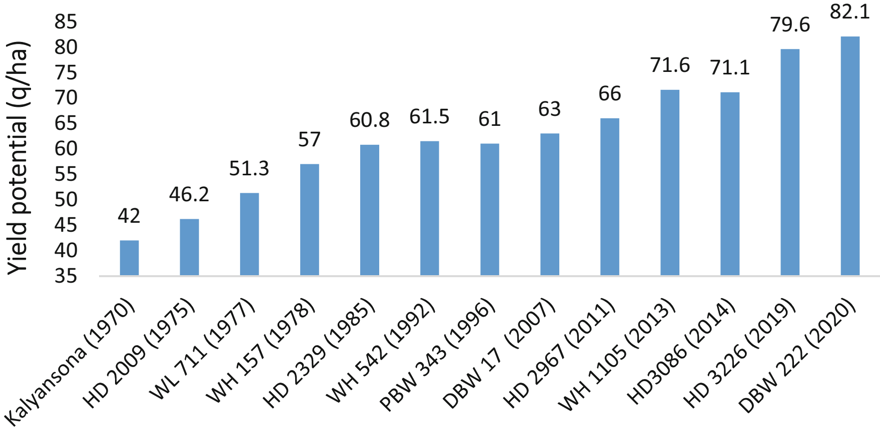

Fig. 7.2 Improving yield potential (q/ha) in high fertility conditions of NWPZ

improvement in yield potential of wheat cultivars under high fertility conditions of the north-western wheat zone—the wheat bowl, is shown in Fig. 7.2. This decade also saw the release of two zinc bio-fortified wheat varieties (HPBW01 and WB2) for cultivation at the farmers' fields in 2017 hence enhancing the nutritional status of farm families. Also, for the first time, the wheat variety PBW723, developed through marker-assisted selection (MAS), was released in 2017. Recent releases DBW187, DBW222, and DBW303 have revolutionized wheat cultivation in the breadbasket of India with a yield potential of more than 8.0 tons/ha.

7.5.3 Wheat Improvement for Biotic Constraints

The most important fungal disease that badly hampered wheat production in India are rust diseases, namely stem or black rust (*P. graminis* f. sp. *tritici*), leaf or brown rust (*Puccinia triticina* Eriks), and stripe or yellow rust (*Puccinia striiformis* f. sp. *tritici*). Historical rust epidemic accounts revealed the first stem rust epidemics in 1786, 1829, and 1946–1947 in the central parts of India (Sleeman 1839; Nagarajan and Joshi 1975; Joshi et al. 1986). The research advances in the intensification of the agriculture system in post green revolution resulted in the rise of pest and pathogen incidences as indicated by brown and yellow rust epidemics in the north-western part of India during 1971–1973 and 1993 (Nayar et al. 1997). At present, yellow (stripe) rust is a potential threat to 10 million ha area of northern India, whereas stem (black) rust is to ~7 million ha of Central and Peninsular areas of India. Leaf or brown rust is of major concern in all the wheat-growing zones of the country. Although virulent pathotypes of yellow rust were identified on Yr9 in 1996 and Yr27 in 2002 (Prashar et al. 2007), cultivars possessing 1BL.1RS wheat-rye (*Secale cereale*) translocation (Singla and Krattinger 2016) like PBW373, PBW343, PBW175, UP2338, UP2425, UP2418, UP2382, and CPAN3004 showed resistance towards multiple fungal diseases including yellow rust (*Yr9*), leaf rust (*Lr26*), stem rust (*Sr31*) and powdery mildew (*Pm 8*). The emergence of 78S84 virulence for *Yr9* in stripe rust led to the elimination of mega wheat variety PBW343. Later virulent pathotypes 46S119, 110S119, 110S84, and 238S119 were detected, and currently, 238S119 has become the most prevalent. It is important to mention that Indian wheat germplasm remained resistant to rusts due to the presence of multiple genes complexes for stem (*Sr31* + *Sr24*, *Sr2*, Sr5, and Sr8), leaf (*Lr26* + Lr13, Lr23, Lr34, *Agropyron* segment carrying Lr24/Sr24), and stripe (Yr9 + Yr2, Yr18, and some unknown adult plant resistance genes) rusts. At present, about 10 million tons of wheat are protected every year from fungal diseases by deploying strategic and integrated disease management modules (Bhardwaj et al. 2019). Efforts have been made to decipher the genome structure, molecular basis of variation, and pathogenicity of rust fungus in wheat, and the genome of three races (K, 31, and 46S119) of *P. striiformis* f. sp. *tritici* (wheat yellow rust fungus) has been unzipped (Kiran et al. 2017). Recently, in India, a major rust resistance gene *Lr80* was identified from the local wheat landrace, Hango-2, and mapped on the 2DS chromosome (Kumar et al. 2021).

Another important foliar disease, Spot blotch (*Bipolaris sorokiniana* (Sacc.) Shoemaker Syn. *Helminthosporium sativus*), is reported to affect nearly 9 million ha of the rice–wheat belt in Northern plains with an average yield loss of about 15–20% (Chand et al. 2003; Duveiller and Sharma 2009). Recent studies have revealed that the resistance to spot blotch is imparted by the presence of at least two or more genes or QTLs and so far, eight quantitative trait loci (QTLs) linked to spot blotch resistance have been identified (Kumar et al. 2010). Besides, powdery mildew (*Erysiphe graminis* DC. f. sp. *tritici* Em. Marchal syn. *Blumeria graminis* (DC.) E. O. Speer), flag smut (*Urocystis agropyri* (G. Preuss) Schrot.), loose smut (*Ustilago tritici* (Pers.) Rostr. Syn. *U. segetum tritici*), head scab (*Fusarium graminearum* Schwabe), etc., are diseases of minor importance due to their localized effects. Powdery mildew hindered wheat cultivation in the north-western plain zone, northern and southern hill zone and was documented to cause 10–15% yield losses under congenial conditions (Kashyap et al. 2021). It has been observed that head scab disease is on the rise under the influence of global warming and the fast adoption of reduced tillage practices in North-western parts of India (Saharan et al. 2021). Flag smut and Loose Smut are also gaining concern in the present climate change scenario.

Karnal bunt (*Tilletia indica* Mitra syn. *Neovossia indica* (M. Mitra) Mundk.) is another disease that has importance in trade perspectives. It was first identified by *Manoranjan Mitra* in the year 1931 and remained a little-known wheat disease localized in North-West India. With the introduction of semidwarf wheat varieties, KB incidences became unusually frequent in North-West India (Joshi et al. 1983). Moreover, intense irrigation and large-scale fertilizer application also added to the aggravation of the intensity and number of KB incidences in the entire Northern India. The KB-infected grains are of low quality as they harbor an unacceptable smell, color, and taste and at as low as 1% infection, the grains/flour become unpalatable and categorized as a disease of quarantine significance (Bishnoi et al. 2020).

A particular concern is the threatening emergence of wheat blast disease (*Magnaporthe grisea* pathotype tritici) in our neighboring country Bangladesh. To prevent its entry in Indian territory, especially in the bordering districts of West Bengal, the most proactive role has been made by ICAR-Indian Institute of Wheat and Barley Research (IWBR) under the aegis of the Indian Council of Agricultural Research (ICAR) to thwart any scope of wheat biosecurity in the county. Under this initiative, a wheat crop holiday i.e. banning wheat cultivation in Murshidabad and Nadia districts of West Bengal, India, with support and incentive for alternate crops (non-poaceaous crops like gram, *urad*, oilseed crops such as rapeseed, mustard, and potatoes) and "no wheat zone" within 5 km along the border area have been recommended. In addition to this, research and development activities related to the characterization of Indian wheat lines for WB resistance in collaboration with CIMMYT, Mexico, have been initiated since 2016 and successfully identified and recommended five resistant/tolerant, high-yielding wheat varieties such as HD3249, DBW187, HD2967 for irrigated timely sown conditions and HD3293, DBW252, and HD3171 for restricted irrigation timely sown conditions. Apart from this, the available potential donors (BH1146, Milan, SHA7, *Aegilops tauschi* derivatives, varieties carrying *Lr34*, and genotypes possessing 2NS translocation) are being exploited for introgression of WB resistance in Indian cultivars as part of the WB anticipatory breeding research initiative.

7.6 Advances in Technological Development

7.6.1 Cultivar Development

The agroclimatic conditions, local preferences, and wheat-based food habits, prevalence of diseases and pests, wheat-based cropping systems, availability of irrigation, and related input factors have a direct bearing on the types of wheat varieties to be developed for commercial cultivation in the country. The farmers of the country have been provided with a choice of varieties during the last 60 years since the inception of the All India Coordinated Wheat and Barley Improvement Program in 1965. The Indian wheat improvement program has significantly contributed to the release of 501 wheat varieties, including *Triticum aestivum*, *T. durum*, *T. dicoccum*, and triticale, through Central Variety Release Committee (CVRC) or State Variety Release Committee (SVRC) for different agroclimatic zones along with relevant

Table 7.2 Released wheat varieties in India (1965–2021)

Crop species	CVRC	SVRC	Total
Bread wheat (*T. aestivum*)	267	155	422
Durum wheat (*T. durum*)	45	23	68
Dicoccum wheat (*T. dicoccum*)	6	1	7
Triticale	4	–	4
Total	322	179	501

production technology (Table 7.2). This included 422 bread wheat, 68 durum, 7 dicoccum, and 4 triticale varieties.

Some varieties released in the recent past have contributed significantly to enhancing wheat production and among them, DBW17, PBW550, HD2967, HD3086, WH1105, K0307, GW 322, GW 366, HI 1544, and MACS 6222 are notable in different areas. The recently released cultivars are presented in a table which is becoming popular among the farmers (Table 7.3). Besides this, more than 300 wheat genetic stocks have been registered with the National Bureau of Plant Genetic Resources (NBPGR), New Delhi, for various biotic and abiotic stress tolerance, yield and quality component traits for their further utilization in wheat improvement programs.

7.6.2 Resource Conservation Technologies

Among the wheat-based cropping systems in India, the rice–wheat cropping system was adopted on a significant area of more than 12 million ha. The intensive tillage under this system needed to optimize energy usage by improving tillage practices and developing efficient machinery. The focused research efforts have resulted in the development of eco-friendly resource conservation technologies, viz., zero tillage, bed planting, rotary tillage, and rotary disc drill, to reduce the cost of cultivation, increase productivity, and improve the soil health and environment. The zero tillage technology, covering about 2.0 million ha area for seeding wheat without any field preparation, besides saving energy, reduces the cost of cultivation, advances the time of wheat sowing by 4–5 days, requires less water for the first irrigation, and results in less infestation of the notorious weed *Phalaris minor* as compared to the conventional tillage. The furrow irrigated raised bed-planting system (FIRBS) is a promising resource conservation tillage technology that saves about 25% seed and fertilizer along with reduced water usage by 25–40% depending upon the soil type and agro-climatic conditions. Rotary tillage technology is another option that completely pulverizes the top 10 cm soil with simultaneous placement of seed and fertilizer and gives the highest productivity with the least specific energy requirement. In some part of the country, like Punjab and Haryana, the burning of crop residues often lead to environmental pollution, loss of soil organic carbon, depletion of plant nutrients such as nitrogen, and loss of soil microflora. To avoid residue burning, a new machine “Rotary Disc Drill” has also been developed at the IIWBR which is capable of seeding under loose residue conditions.

7.6.3 Crop Diversification

Diversification of wheat-based cropping system, especially rice–wheat systems, by introducing short-duration legume crops for grains or green manuring, helps in restoring soil health by enhancing the organic matter content and improving the soil physicochemical properties. These systems also help in controlling weeds

Table 7.3 Latest wheat varieties for diverse agroclimatic and production conditions

Production condition		Improved cultivars
North Western Plains Zone (NWPZ)		
Early sown, irrigated	:	DBW 303, WH 1270
Timely sown, irrigated	:	DBW 222, DBW 187, HD 3226, WB 02, HPBW 01, PBW 723, DBW 88, HD 3086, WH 1105, HD 2967, DPW 621-50, DBW 17, WHD 943 (d), PDW 314 (d), PDW 291 (d)
Late sown, irrigated	:	PBW 752, DBW 173, DBW 90, WH 1124, DBW 71, HD 3059, PBW 590
Very late sown, irrigated	:	PBW 757, HI 1621, HD 3271
Timely sown, rainfed	:	PBW660, PBW644, WH1080
Timely sown, restricted irrigation	:	NIAW 3170, HD 3237, HI 1620, WH 1142, HD 3043
Sodic soils/others	:	KRL-19, KRL 210, KRL 213
North Eastern Plains Zone (NEPZ)		
Timely sown, irrigated	:	HD 3086, DBW 187, K 1006, HD 2967, NW 5054, DBW 39, RAJ 4120, K 0307
Late sown, irrigated	:	DBW107, HD3118, HD2985, HI1563
Very late sown, irrigated	:	HI1621, HD3271
Timely sown, rainfed	:	K1317, HD3171
Timely sown, restricted irrigation	:	DBW252, HI1612
Sodic soils/others	:	KRL-19, KRL 210, KRL 213
Central Zone (CZ)		
Timely sown, irrigated	:	HI 1544, GW 366, GW 322, HI 8759 (d), HD 4728 (d), HI 8737 (d), HI 8713 (d), MPO 1215 (d)
Late sown, irrigated	:	HI 1634, CG 1029, RAJ 4238, MP 3336, MP 1203
Timely sown, rainfed	:	HI 1500, MP 3173, MP 3288
Timely sown, restricted irrigation	:	DBW 110, DDW 47 (d), UAS 466 (d), HI 8627 (d)
Sodic soils/others	:	KRL-19, KRL 210, KRL 213
Peninsular Zone (PZ)		
Timely sown, irrigated	:	DBW 168, MACS 6478, UAS 304, MACS 6222, DDW 48 (d), MACS 3949 (d), WHD 948 (d), UAS 428 (d), UAS 415 (d), HW 1098 (dic), MACS 2971 (dic), DDK 1029 (dic), DDK 1025 (dic)
Late sown, irrigated	:	HI1633, HD3090, AKAW4627, HD2932
Timely sown, rainfed	:	NIAW 1415, PBW 596, UAS 375, UAS 347, MACS 4028 (d), HI 8777 (d), UAS 446 (d) NIDW 1149 (d), GW 1346 (d), HI 8802 (d), HI 8805 (d), MACS 4058 (d)
Timely sown, restricted irrigation	:	NIAW 3170, HI 1605, DBW 93
Northern Hills Zone (NHZ)		
Timely sown, irrigated	:	HS 562, HPW 349, VL 907, HS 507
Late sown, irrigated/ rainfed	:	HS 490, VL 892
Timely sown, rainfed	:	HS 542, HPW 251, VL 829
For high altitude areas	:	VL 832

without herbicide application as the wheat is sown late when the environment is not conducive for the germination of Phalaris minor. Among various diversified cropping sequences, rice–vegetable peas–wheat rotation gave the highest net return per unit area, and it appears to be the best option for maximization of net returns and sustainability of the rice–wheat system.

7.6.4 Plant Protection Technologies

Indian wheat production has been free from disease epidemics during the last four decades mainly because of the systematic deployment of rust resistance genes in high-yielding varieties. The survey and surveillance of rust virulence and identification of resistance donors against important diseases and pests were very crucial activities in this direction. Pest risk analysis has been carried out for Karnal bunt to safeguard the national export potential. Integrated Pest Management (IPM) modules have been developed and validated for cost-effective and eco-friendly control of pests and diseases of wheat. In post green revolution period, a large number of research initiatives have been taken to diagnose and monitor pathogen inocula inside plants and soil with special reference to Karnal bunt, flag smut, leaf rust, and head scab diseases in wheat (Kashyap et al. 2020; Gurjar et al. 2017; Manjunatha et al. 2018; Gupta et al. 2020). The long-term experiments under AICRP on Wheat and Barley have recommended the application of fungicides such as Propiconazole 25% EC (Tilt), Tebuconazole 25% EC (Folicur), Triadimefon 25% EC (Bayleton), and Difenaconazole for control of initial inoculum load or high disease pressure of fungal pathogens and their effective management. Efficient protection technologies have also been developed to control aphids (spray of imidacloprid @ 20 g a.i./ha) and termites (endosulfan, chlorpyriphos, and carbosulfan). Besides, several advanced breeding lines have been evaluated and screened under AICRP on wheat and barley against multiple pathogens to support the breeding program at various hot spot locations under artificially inoculated conditions in different agroecological zones, and potential resistance donors were identified for further utilization (Table 7.4).

7.6.5 Quality of Indian Wheat

A number of physical and biochemical parameters are associated with the quality of wheat. Targeting the surplus wheat and export potentials, the quality parameters have been standardized, and special emphasis was given to identify specific varieties of *chapati*, bread, biscuit, and pasta products. The quality requirements differ for various products like *chapati*, bread, biscuit, and pasta. Hard wheat with strong gluten (>60 mL sedimentation value), >12.0% protein, 5 + 10 high molecular weight glutenin subunit with 9 or 10 Glu-1 scores is required for making good bread, whereas weak and soft wheat with <10.0% protein, weak gluten of <30 mL sedimentation value, and ~50% alkaline water retention capacity (AWRC) is required for biscuits. Good pasta products can be prepared from hard durum wheat

Table 7.4 Current spectrum of wheat diseases in different agroecological zones and identified potential resistance donors

Diseases	Distribution	Potential disease-resistance donors
Stripe rust (yellow rust)	NHZ and NWPZ	DBW 187, DBW 237, DBW 302, DBW 303, HI 1628, HPW 467, HS 660, HS 661, PBW 752, PBW 757, PBW 763, PBW 771, PBW 796, PBW 797, PBW 800, PBW 801, PBW 820, PBW 821, PBW 822, PBW 823, PBW 825, UP 3043, VL 3020, VL 3021, WH 1270, DDW 47 (d), DDW 48 (d), GW 1339 (d), GW 1348 (d), HI 8800 (d), HI 8802 (d), HI 8805 (d), HI 8807 (d), HI 8808 (d), HI 8811 (d), HI 8812 (d), MPO 1336 (d), NIDW 1149 (d), NIDW 1158 (d), WHD 963 (d)
Leaf rust (brown rust)	All the six agroecological zones but more prevalent in NEPZ, CZ and PZ, whereas in NWPZ, it appears late	AKAW 4924, CG 1029, DBW 187, DBW 237, DBW 302, DBW 303, GW 491, GW 492, GW 509, HI 1624, HI 1628, HI 1633, HI 1634, HPW 451, HPW 459, HPW 467, HS 660, HS 661, MACS 5051, NIAW 3171, PBW 752, PBW 757, PBW 763, PBW 771, PBW 796, PBW 797, PBW 800, PBW 801, PBW 820, PBW 821, PBW 822, PBW 823, PBW 825, UP 3016, UP 3043, VL 3020, VL 3021, WH 1270, DDW 47 (d), DDW 48 (d), GW 1339 (d), GW 1346 (d), GW 1348 (d), HI 8800 (d), HI 8802 (d), HI8805 (d), HI 8807 (d), HI 8808 (d), HI 8811 (d), HI 8812 (d), MACS 4059 (d), MPO 1336 (d) NIDW 1149 (d), NIDW 1158 (d), WHD 963 (d), DDK 1054 (dic)
Stem rust (black rust)	PZ and CZ	AKW4924, CG 1029, DBW 302, GW 491, GW 492, GW 509, HI 1624, HI1628, HI 1633, HI 1634, HPW 451, HPW 459, MACS 5051, NIAW 3171, PBW 820, UP 3016, GW 1346 (d), GW 1348 (d), HI 8802, HI 8807 (d), HI 8811 (d), MACS4059 (d), NIDW 1149 (d), NIDW 1158 (d), DDK 1054 (dic)
Karnal bunt	Major problem in NHZ, NWPZ, minor in NEPZ	AKAW4924, ALDAN, Altar 84, CG 1029, CPAN 3045, DBW 110, DBW 187, DBW 237, DBW 302, DBW 303, GW 491, GW 492, GW 509, HD 29, HI 1624, HI 1628, HI 1633, HI 1634, HP 1531, HPW 451, HPW 459, HS 660, HS 661, KBRL 22, KBRL57, MACS 5051, NIAW

(continued)

Table 7.4 (continued)

Diseases	Distribution	Potential disease-resistance donors
		3171, PBW 34, PBW225, PBW 752, PBW 757, PBW 763, PBW 771, PBW 796, PBW 797, PBW 800, PBW 801, PBW 820, PBW 825, UP 3016, UP 3043, VL 3021, W48, W285, W382, W485, DDW 47 (d), DDW 48 (d), GW 1339 (d), GW 1346 (d), GW 1348 (d), HI 8800 (d), HI 8802 (d), HI8805 (d), HI 8807 (d), HI 8811 (d), MACS4059 (d), MPO 1336 (d) NIDW 1149 (d), NIDW 1158 (d), DDK 1054 (dic)
Spot blotch	NEPZ, moderate in CZ, PZ and NWPZ	HI1628, NIAW 3171, PBW 763, PBW 800, UP 3016, VL 3020, WH 1270, HI 8805 (d), DDK 1054 (dic)
Powdery mildew	NHZ and NWPZ but occurrence is erratic	DBW 187, DBW 237, GW 491, GW 492, HI 1628, HPW 451, HPW 459, HS 660, HS 661, MACS 5051, NIAW 3171, PBW 757, UP 3016, GW 1339 (d), GW 1346 (d), HI 8800 (d), MACS 4059 (d), MPO 1336 (d)
Head scab	NWPZ, NEPZ	AKW4924, DBW 187, DBW 237, GW 491, GW 492, HI 1624, HI 1628, HS 660, HPW 451, HPW 459, HS 661, MACS 5051, NIAW 3171, PBW 757, PBW 763, PBW 797, PBW 800, PBW 801, UP 3016, GW 1339 (d), GW 1346 (d), HI 8800 (d), MACS 4059 (d), MPO 1336 (d), DDK 1054 (dic)
Loose Smut	NWPZ, NHZ, and NEPZ	PBW 752, UP 3043
Flag smut	NWPZ	AKAW 4924, CG 1029, DBW 187, DBW 237, DBW 302, DBW 303, GW 491, GW 492, GW 509, HI 1624, HI 1628, HI 1633, HI 1634, HPW 451, HPW459, HPW 467, HS 660, HS 661, MACS 5051, NIAW 3171, PBW 752, PBW 757, PBW 763, PBW 771, PBW 796, PBW 797, PBW 800, PBW 801, PBW 820, PBW 821, PBW 822, PBW 823, PBW 825, UP 3016, UP 3043, VL 3020, VL 3021, WH 1270, DDW 47 (d), DDW 48 (d), GW 1339 (d), GW 1346 (d), GW 1348 (d), HI 8800 (d), HI 8802 (d), HI8805 (d), HI 8807 (d), HI 8808 (d), HI 8811 (d), HI 8812 (d), MACS4059 (d), MPO 1336 (d) NIDW 1149 (d),

(continued)

Table 7.4 (continued)

Diseases	Distribution	Potential disease-resistance donors
		NIDW 1158 (d), WHD 963 (d), DDK 1054 (dic)
Wheat blast	Not yet reported in India	BH 1146, DBW 187, DBW 252, HD 2967, HD 3171, HD 3249, HD 3293, Milan, SHA7 and *Aegilops tauschi* derivatives

d durum, *dic* dicoccum, *NHZ* Northern Hills Zone, *NWPZ* North Western Plains Zone, *NEPZ* North Eastern Plains Zone, *CZ* Central Zone, *PZ* Peninsular zone

Table 7.5 Product-specific varieties

Product	Varieties
Chapati (score > 8.0/10.0)	DBW 71, DBW 303, HD 2888, HD 2967, HD 3086, HD 3237, HI 1500, HI 1634, K 0307, MP 3288, NIAW 1415, PBW 757, PBW 771, WH 1124
Bread (loaf volume >600 mL)	DBW 71, DBW 93, DBW 173, DBW 187, DBW 222, HD 2733, HD 3059, HD 3226, HD 3298, NIAW 1415, WH 1080, WH 1105, WH 1124, WH 1254
Biscuit (spread factor >10.0)	DBW 168, HS 490, NIAW 3170
Durum for pasta (Yellow pigment >7.0/9.0)	UAS 446 (d), DDW48 (d), DDW 47 (d)

with >12.0% protein and strong gluten strength of >40 mL sedimentation value. The yellow berry incidence below 10%, >7 ppm β-carotene content, and γ-gliadin 45 is also required for good quality pasta products. A large number of genotypes were evaluated for product quality and promising varieties were identified as mentioned in Table 7.5. Quality analysis was carried out on large scale with samples collected from different markets and warehouses across the country for the purpose. A wheat quality atlas of the country was also developed, and potential regions have been identified for product-specific varieties.

7.7 Challenges Ahead

7.7.1 Stagnating Yield Potential

After realizing the benefits of the green revolution, steep growth in wheat productivity in frontline states of north-western India was achieved from 1975 to 1995 through the churning of the gene pool and deployment of rust resistance genes in better agronomic backgrounds that resulted in the release of some of the landmark varieties. The increasing trend of wheat productivity in all the wheat areas has reached a kind of saturation. Recently released varieties in NWPZ have shown yield superiority, but the cultivars in other zones are not coming with desired yield superiority which is one of the major concerns for the enhancement of wheat productivity. India is expected to produce 140 million tons of wheat by 2050 (ICAR 2018). Progress made in irrigated and high-fertility wheat regions is significantly higher than that in marginal areas experiencing water stress conditions coupled with heat stress during different crop growth stages. Since significant scope exists for improvement in these new areas, one of the major challenges is to develop high-yielding varieties having tolerance to abiotic stresses, especially heat, drought, salinity, and waterlogging.

7.7.2 Unavailability of Quality Seeds and Low Seed Replacement

Physical and genetic purities of seed are of utmost importance for realizing the actual yield potential of the variety. The rate of seed replacement of newer varieties to the older ones is also an important factor to put the yield levels in high momentum. The major constraints in most of the area are the unavailability of pure-quality seeds and a substantially lower seed replacement rate at the farm level. An enhanced rate of seed replacement with advanced varieties will certainly result in a significant increase in total wheat production in the country. Thus, there is an urgent need to strengthen the seed production system and efficient distribution channel to bring more area under new wheat varieties in a lesser time period.

7.7.3 Global Climate Change

An impact of changing climate on crop production is expected for various latitude limits for all the crop seasons, and the wheat crop is the most affected during the winter season. Wheat is sensitive to high temperatures (both early and late heat), but the magnitude of damage depends on the existing ambient temperature, stage of crop development, and variety. The rise in temperature during December, the period of tillering, and subsequently higher temperatures above 30 °C during the February and March at the stages of anthesis, grain formation, and filling has affected the productivity of varieties having high yield potential. Effects of increased CO_2 on wheat yields will normally be positive but the benefits vary with the prevailing temperature regime and availability of other inputs (water and nutrients). It is predicted that with the doubling of CO_2, the ambient temperature in India would increase by 3 °C and will affect both the area and productivity of wheat. The encounter of negative effects of varying temperature regimes with the benefits of increased CO_2 activity is, therefore, a critical issue for any assessment of wheat production under changing climate. It has been observed that an increase in temperature (about 2 °C) reduced potential wheat grain yields at most places. A net reduction in wheat production is anticipated due to a reduction in the growth period as a result of increased temperature. Besides, increased water requirements may be anticipated in all regions, which will highlight the importance of irrigation management in mitigating climate change.

7.7.4 Restrictions to Germplasm Exchange in New IPR Regime

The success of the green revolution in the early sixties and the later varietal improvement programs were dependent on the exchange of germplasm lines from exotic sources especially International Maize and Wheat Improvement Center (CIMMYT) that were used directly as a variety or as a donor parent in wheat improvement programs. However, due to the emergence of Intellectual Property Rights (IPR) as one of the major global issues, germplasm exchange between the countries is likely to be restricted, and this may influence the pace of genetic improvement in wheat. In the post-GATT scenario, the issue of Intellectual Property Rights gained significant importance and has become a major hurdle in germplasm exchange. Therefore, the Indian wheat program has to focus on prebreeding activities by utilizing unexploited elite sources like landraces, synthetics, and other available wheat genotypes for broadening the genetic diversity for higher yield potential.

7.7.5 Reduced Total Factor Productivity and Imbalanced Use of Fertilizers

The intensive tillage and over-exploitation of the natural resources i.e. soil and water, resulted in the situation where the benefits per unit input used in wheat cultivation are continuously declining, as evident from experimental as well as on farm trials. The earlier fertilizer recommendation of 120:60:40 kg NPK/ha has been enhanced to 150:60:40 or 150:60:60 kg NPK/ha in some soils. Over-mining of essential plant nutrients and burning of crop residues have increased widespread incidences of nutrient deficiencies. The deficiency of Zn in the rice–wheat system and S, Fe, Mn, and Bo from various pockets in the intensive cropping areas are severely reported. Farmers, in general, are not applying potash, and in some areas, soil status has dropped to such an extent that further nutrient mining may change soil nutrient status substantially. Potash and, to some extent, zinc are going to play a major role in sustaining and enhancing production and productivity. Further, an increase in fertilizer requirement in the future to get the same productivity level is also predicted in case of continuing unbalanced fertilization. The depleting soil organic carbon due to intensive tillage is also a very crucial factor at present that has reduced the water and nutrient-holding capacities of the soils. As a consequence, the frequency of irrigation has increased in those areas where water is not a limiting factor. This is further leading to deep percolation of water that often leaches down plant nutrients such as nitrogen and ultimately pollutes groundwater.

7.7.6 Yield Gaps at the Farm Level

The yield gaps were observed between the frontline demonstrations (FLDs) and the farmers' practice at their own fields. The zone-wise analysis indicated the maximum

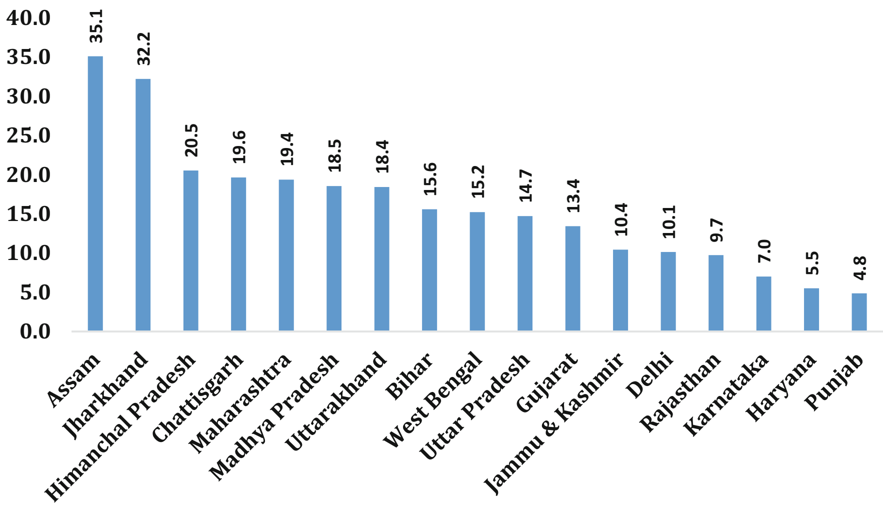

Fig. 7.3 Wheat yield gaps (%) in different states. (Source: AICRPW & B Progress report (Social Sciences), 2019–2020)

yield gap in CZ (13.26 q/ha) followed by NEPZ (9.46 q/ha), PZ (7.6 q/ha), NWPZ (7.35 q/ha), and NHZ (6.18 q/ha). The state-wise yield gap scenario (Fig. 7.3) indicated the highest yield gap in Assam (35.1%) and Jharkhand (32.2%), whereas a low gap was observed in the states of Haryana (5.5%) and Punjab (4.8%). This gap may be due to many related factors to seed, water, and technological adoptions, which can be bridged for enhanced overall production.

7.8 Future Strategies for Enhanced Production

The major thrust for increased wheat production will be in the agroclimatic regions of Indo-Gangetic plains, especially the northeastern plains zone, the plateau region of central India, and the hill regions. In potential regions, the production is expected to increase at a higher rate, whereas a slight increase in yield levels may be achieved in the remaining regions. These expectations are possible with technologies available at present; however, future research efforts would be focused on evolving new and innovative production technologies which can fit into the framework of changing wheat production scenario. Some key strategic issues are discussed for enhanced production levels.

7.8.1 Breaking Yield Barriers Through Genetic Enhancement

The existing yield plateau in the main wheat growing areas is a major concern, and enhanced efforts are being made to break the yield barriers. Genetic diversity will continue to be the key factor, and new approaches need to be adopted to enhance the yield potential of wheat genotypes. In this regard, the future strategy will be aimed to introgress desirable gene complexes from unexploited germplasm and wild progenitors for creating new variability. There is ample scope in prebreeding activities, which has been evident in the better performance of synthetic wheat genotypes and their hybridization with bread and durum wheat. The winter × spring wheat hybridization has been an attractive tool to introgress genes for disease resistance, and resistance/tolerance to various abiotic stresses like drought and cold, etc. Among the other approaches, the exploitation of hybrid vigor through the development of hybrids is very promising for yield gains in marginal climatic conditions.

7.8.2 Molecular Approach for Precision Breeding

One of the important goals of molecular biology is to expedite the breeding program with precision and accuracy to develop cultivars with specific traits within a short period of time. Significant achievements were made in the development of diverse types of molecular markers, the construction of molecular genetics, and physical maps with a reasonably high density of markers. The new molecular tools are potential armaments to revisit the origin and evolution of the wheat genome for the development of more precise QTL/gene analysis for the identification of markers associated with major economic traits for integration of marker-assisted selection (MAS) as a complementary strategy to conventional breeding methodologies of wheat improvement. The transformation approach, including newer techniques of CRISPER/Cas, can also be explored for improving popular varieties for missing traits like disease resistance, abiotic stress tolerance, and quality traits.

7.8.3 Tailoring Wheat Genotypes in Cropping System Perspective

Among the wheat-based cropping systems, the most extensively followed is rice–wheat cropping system. The continuity of this cropping sequence over the years showed a tendency for a decrease in wheat yield though the total productivity per year has increased. Other cropping systems like maize-wheat, potato-wheat, sugarcane-wheat, green pea-wheat, and cotton-wheat are being used in different parts. New resource conservation technologies have been developed for high output from wheat cultivation in a profitable and sustained manner. This needs to be accomplished with specific genotypes for cultivation under different RCTs. In this regard, the experiments showed a significant interaction between varieties and RCTS, suggesting differential behaviors of wheat genotypes. The hybridization and handling of segregating populations under different tillage options is the future thrust for developing tillage-specific genotypes for different agro-climatic zones.

7.8.4 Improved Varieties for Abiotic Stresses

The major abiotic stresses affecting wheat crops are heat, drought, salinity-alkalinity, waterlogging, etc. The wheat crop in the northern plains is exposed to higher ambient temperatures at the time of grain filling, whereas in central and peninsular parts, the crop is exposed to both early and late heat stress which significantly reduces productivity. Hence, breeding for heat tolerance is one of the major issues under prevailing stress environments. Most of the areas in the central and peninsular parts also experience water stress condition and suffers due to moderate to extreme drought conditions. The salinity and alkalinity condition is another threat that severely affects the productivity of wheat. Although resistant genotypes like KRL 19, KRL 210, and KRL 21319 have been released for these suppressive soils, more efforts are needed to reclaim and provide highly tolerant genotypes for these conditions. It has also been observed that a large area sown to wheat (about 3–-6 million ha) is subjected to irregular waterlogging at early stages of growth, particularly where soils are sodic. Genotypes tolerant to waterlogging have been identified, which need to be incorporated in high-yielding background.

7.8.5 Disease-Resistance Breeding

Among biotic stresses, rusts pose a major threat to wheat production in India. A limited number of known resistance genes are being used in our breeding programs so far. Also, isolated efforts have been made in characterizing the phenomenon of slow rusting (a trait of durability) in Indian wheat germplasm. At this juncture, none of the genes or their compatible combinations in use is capable of providing complete protection from stripe and leaf rusts. Therefore, it becomes imperative to make use of other unexploited genes, especially those derived from alien sources, to keep the rust epidemics under check in the Indian subcontinent. Although the resistant sources have been identified in international collaboration, the need is to develop high-yielding varieties with resistance to these races. Leaf blight and flag smut, Karnal bunt are other diseases of importance that needs to be taken care of for wheat production and exports.

7.8.6 Access to Quality Seeds of Wheat

The varietal diversity under commercial cultivation plays a barrier to any probable pathogenic hazard. From 1967 to 1977, there were only two varieties, namely Sonalika and Kalyansona, which occupied the largest area in the country. In 1984–1985, there were 62 wheat varieties under the breeder seed program, of which indents of only 11 varieties were higher than 50 quintals, and a similar trend was continued till 2000 AD, although there was a mosaic of many promising varieties like HUW 234, HD 2285, HD 2329, WH 542, UP 2338, Raj 3765, PBW 343, and PBW 373. There was a paradigm shift in seed demand with the development of new varieties like GW 322, DBW 17, PBW 550, HD 2967, HD 3086, among which PBW 343, HD 2967, and HD 3086 have larger areas and are considered mega varieties. Nowadays, although the seed indent of new varieties, including DBW 187 and DBW 222, is more than 1500 q, a large area under few varieties is also a concern in the event of the spread of disease. For quicker replacement of old, susceptible, and otherwise uneconomical varieties, the research institutes of the Indian Council of Agricultural Research (ICAR), State Agricultural Universities (SAUs), and State Departments of Agriculture should have tuned to develop a strategy to distribute and popularize a large number of newly released cultivars. To provide quality seed to the farmers, an extensive breeder seed production program has been taken up under coordinated projects every year, and it has been further strengthened through the ICAR initiative of mega seed project involving SAUs and ICAR institutes to enhance seed research and production capabilities.

7.8.7 Conservation Agriculture

The new resource conservation technologies have shifted the thrust to conservation agriculture. These technologies are capable of placing seeds of wheat directly in the presence of residues left after the harvest of rice/wheat by the combines, which at present is being burnt. This can tremendously contribute to conserving soil health by preventing the loss of nutrients. Conservation agriculture will help to retain the residue on the surface of the soil which will act as biological tillage, conserve the soil moisture, release nutrients to the plant as and when required, reduce soil erosion, keep a check on weeds and provide enabling environment that will ultimately help in the sustenance of soil and crop productivity.

7.8.8 Integrated Water, Nutrient, and Weed Management

Water management is the key to the development of sustainable agriculture for both irrigated as well as rainfed areas for which issues like water conservation, watershed management, sprinkler, and drip irrigation and FIRB (Furrow Irrigated Ridge-till and Bed-planting) system of wheat cultivation needs to be addressed with respect to increased nutrients and moisture use efficiency, avoiding lodging, reducing seed rates, minimizing weed infestation, better residue management and thus reducing cost of wheat cultivation without affecting the productivity. Attention is also needed for the balanced use of chemical fertilizers, the use of biofertilizers, and other sources for improving soil structure and texture. Sustained yield and soil productivity can be accomplished with balanced nutrient addition using animal manures/ locally available organic manures with commercial fertilizers. Some of the measures suggested to improve the micronutrient status of soils under intensive cultivation include the use of a leaf color chart for saving nitrogen, in situ green manuring without additional water, diversification with pulses, residue incorporation/retention, balanced application of fertilizer including micronutrients and development of efficient micronutrient cultivars. Weeds play an important role in realizing the yield potential of any crop, and unfortunately, they are more resistant to abiotic stresses and their nutrient absorption capacity is also more than the wheat crop. As most of the area follows the wheat-based cropping system, there is a need to focus on integrated weed management and succession of weeds in a cropping sequence. Besides physical, cultural, and chemical means, biological weed control in wheat crops using plant pathogens, especially in the form of mycoherbicides, needs to be focused on in the future that will reduce the hazards of groundwater contamination and promote the food safety and protection of endangered species.

7.8.9 Diversification/Intercropping/Companion Cropping

Since the area under wheat is not going to expand further, there is a need to evolve suitable genotypes and production technologies for various synergistic and parallel intercropping/companion-cropping systems. Under irrigated conditions, opportunities for intercropping of wheat exist with autumn-planted sugarcane and potato. This could be achieved by establishing inter-institutional linkages and an effective extension network. Continuous use of rice–wheat system is depleting the soil health and lowering the water table. Hence there is also a need to opt for the possible replacement of rice by some other remunerative crops i.e., maize, baby corn, soybean, etc., through FIRB technology so that burden on the water is reduced. Alternatively, there is a possibility to intensify the system through the introduction of leguminous crops like moong bean, which can also improve soil nutrient status. This will reduce the cost of cultivation and enhance crop productivity and water use efficiency. The present efforts to diversify the rice–wheat system need to be enhanced through support from policymakers and extension workers.

7.8.10 Quality Improvement

In changing socioeconomic scenarios and wheat consumption patterns, high demand is expected for value-added wheat products of bread, biscuit, and pasta. With tremendous human resources and emerging food processing technologies, India has a large scope to develop instant food industries; thus, the Indian wheat program has to strengthen to meet the quality requirement of the domestic and international markets. Increasing global demand, value addition potential, better price in the market, and resistance to Karnal bunt make durum an export commodity. Although high-yielding varieties with better quality are available, efforts are in progress to create variability for beta-carotene, protein content, semolina recovery, and hectoliter weight, besides enhancing resistance against stripe, leaf, and stem rust. A systematic breeding program is also required to improve the nutritional and industrial quality of bread wheat. Food processing industries can take maximum benefit from superior varieties of wheat if procurement and processing of grains at the market level are attended to with special care. Small-scale industries for wheat-based value-added products needs to be encouraged in the rural sector to improve the livelihood of farmers and especially of the rural woman.

7.8.11 Strengthening Linkages and Policy Issues

Strengthening research capabilities of centers for efficient transfer of technology through frontline demonstrations is crucial to bridge the yield gap between the experimental field and farmer's field that can increase an additional wheat production to the tune of approximately 30.0 million tons by the adoption of currently available technologies. Cooperation from state agricultural extension units and Agricultural Universities would be a key factor in this process. Krishi Vigyan Kendras (KVKs) can also play a significant role in the rapid transfer of technologies and needs to be strengthened and their activities should be strongly linked to national wheat research centers. The availability of agricultural inputs in time for the timely sowing of wheat can lead to a remarkable increase in wheat production. Policy support is needed to popularize and spread eco-friendly production technologies such as zero tillage, crop diversification, production and marketing of high-quality product-specific wheat, installation of modern silos to prevent post-harvest losses of grains, and development of wheat-based rural industries and cooperatives for producing and marketing value-added products. Support for human resource development through training at national and international institutes to acquire expertise in advanced science and technologies is also crucial.

7.9 Conclusions

The present yield plateau in most of the wheat zones except NWPZ is the major concern for achieving the targeted wheat production of 140 million tons by 2050. However, bridging the yield gap between experimental and farmers' fields can solve the problem to a considerable extent. For future needs, the genetic enhancements of yield potential through the integration of conventional and molecular approaches with special reference to the changing climatic conditions, integrated management of resources, and incorporation of resistance genes to various biotic and abiotic stresses are very significant factors. The quality of wheat will continue to be one of the major foci of research. With support from farmers, policymakers, and extension units, it is expected that present technologies can be further refined and popularized so that wheat production can be enhanced to fulfill future demand.

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