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ORIGINAL PAPER

Genetic gains in grain yield in wheat (*Triticum aestivum* L.) cultivars developed from 1965 to 2020 for irrigated production conditions of northwestern plains zone of India

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Abstract

Field trials with 13 landmark wheat cultivars released between 1965 and 2020 were conducted at 15 different locations during 2019–2020 and 2020–2021, providing data from 30 environments. The study of the historical set of spring wheat varieties from the North-Western Plains Zone (NWPZ) of India developed in the last 55 years demonstrated an improvement of grain yield from 3208 to 6275 kg ha^{-1} or a genetic gain of 1.21% $year^{-1}$ over long-term check cultivar C306. In real terms, the yield has increased at a rate of 44.14 kg ha^{-1} $year^{-1}$. To compare the present genetic gain study, a trend analysis based on historical grain yield data in standard AVT in the zone from 1980 to 2020 was also attempted, which revealed that the percent yield increase was 0.78 per annum. To achieve a higher rate of genetic gain, it requires greater breeding efficiency in the national breeding program through more systematic use of genetic diversity to introduce novel alleles as well as application of new breeding approaches like speed breeding and genomic selection.

Keywords Wheat · Genetic gain · Genetic progress · Grain yield · Mega-environment

Introduction

Wheat (*Triticum* spp.) is an important staple cereal in many countries across the globe including India, which contributes approximately 20% of calories to the dietary requirement. Advances in plant breeding tools and techniques, mostly through conventional methods and agronomic approaches during the era of the Green revolution and thereafter have contributed greatly to the annual productivity gain in wheat. The incorporation of dwarfing genes *Rht1* and *Rht2* in wheat cultivars by Borlaug and his team in the early 1960s was one of the most significant achievements to usher green revolution (Rajaram and Braun 2008). However, demand for wheat-based food products is increasing as the world's population grows, per capita income rises, and food consumption patterns become more diverse. Recent success in the field of biofortification through the development of nutri-rich wheat varieties further enhanced the global importance of wheat for nutritional security as well. China followed by India, are the two major global wheat producers and also consumers. In India, total wheat-growing area is divided into five agro-ecological zones i.e. Northern Hills Zone (NHZ), North Western-Plains Zone (NWPZ), North-Eastern Plains Zone (NEPZ), Central Zone (CZ), and Peninsular Zone (PZ). NWPZ is one of the most conducive environments for wheat productivity and International Maize and Wheat Improvement Center (CIMMYT) has included this wheat continuum of around 12.3 million hectares with 55% of wheat production (Singh et al. 2019a) in the mega-environments 1 (ME 1)

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region, which represents the most productive areas of global spring wheat cultivation (Rajaram et al. 1994). This wheat growing area is further featured as irrigated production environment with intensive rice (*Oryza sativa* L.)—wheat double cropping management systems and high yield potential.

Wheat grain yield improvement through conventional and modern approaches is always one of the top priorities of Indian wheat improvement programs because of India's wheat-based growth coupled with enhanced consumption of wheat-based food products. The country's urgent need for wheat has greatly boosted the national wheat production in the food-deficient country, increasing the wheat grain yield has been an important aim of the national wheat improvement effort in India since the inception of the All India Coordinated Research Project on Wheat and Barley (AICRPW&B) in 1965 (Singh et al. 2019b). The national wheat breeding program has led to significant yield improvement in different production environments. NWPZ region is always considered to be the wheat bowl of India and the seat of the green revolution and CIMMYT has included this highly productive wheat zone in the ME 1 region which represents the most productive areas of global spring wheat cultivation (Rajaram et al. 1994).

The concept of genetic gain (GG) has been used to characterize the breeding progress. GG is defined as the quantity of performance improvement obtained annually through artificial selection. GG was described by Rutkoski (2019a) as the expected or realized change in a population's average breeding value over at least one cycle of selection for a given trait or index of characteristics. The rate of genetic gain varies among different wheat-growing areas during the last century for grain yield. CIMMYT has assessed the rate of GG for global grain yield in wheat trials between 1994 and 2010, which revealed that approximately 1.0% year^{-1} has increased over a period of 17 years, further in real terms, 31.0 kg ha^{-1} has increased annually (Manes et al. 2012). The rate of genetic gain varied from 0.56 to 1.4% year^{-1} in a study of 50 wheat varieties released from 1950 to 2009 in the eastern United States (Green et al. 2012). The Canadian wheat breeding progress was evaluated with 100 wheat varieties released from 1885 to 2012 through multi-environment testing from 2011 to 2013. The results suggested that the grain yield improved at a rate of 0.28% year^{-1} for red spring class wheat cultivars and which is much lower than that of prairie spring class with 1.2% year^{-1}(Iqbal et al. 2016). Similarly, several researchers in China studied genetic progress in wheat for different provinces and time period. The leading cultivars from 1950 to 2012 were studied in two wheat-growing provinces of China during 2013–2014 and 2014–2015, which revealed that the annual percent genetic progress for yield was 0.7 or 57.5 kg ha^{-1} year^{-1} in real terms (Gao et al. 2017). Wheat growing region-specific genetic progress studies in China from 1949 to 2000 revealed that the genetic progress attained ranged from 0.31% year^{-1} to 0.74% year^{-1} or 13.96 kg ha^{-1} year^{-1} to 40.80 kg ha^{-1} year^{-1} in real terms (Zhou et al. 2007). To understand the important characteristics contributing to genetic gain in wheat varieties developed between 1964 to 2007 in China's Hebei province, a multi-environment study with nine milestone cultivars was conducted, which revealed that the genetic progress was linear at an annual rate of 0.71% or 47.4 kg ha^{-1} in real terms for wheat yield (Yao et al. 2019). A similar attempt to study the genetic gain for wheat yield and physiological characteristics in China's Henan Province was carried out by Zhang et al. (2016) using 30 landmark varieties from 1940, which revealed that the yearly genetic progress in the province was 1.09%.

Genetic progress study with different tillage practices in wheat was also reported by Yadav et al. (2021) in India comprising mega cultivars developed from 1900 to 2016, resulting in the genetic progress of 0.82% year^{-1}. A large multi-environmental study with 21 environments and 22 wheat cultivars developed from 1931 to 2006 for rainfed production conditions were studied in Turkey. The annual genetic progress in drought conditions was slightly higher with 0.75% year^{-1} as compared to normal conditions of 0.6% year^{-1} (Keser et al. 2017). In an attempt to study the Turkish spring wheat breeding progress, a group of 35 varieties developed between 1964 to 2010 was evaluated for yield and quality traits, which resulted in the genetic gain of 0.75% year^{-1} or 30.9 kg ha^{-1} year^{-1} in real terms (Nehe et al. 2019). Brazilian wheat breeding progress was studied by Beche et al. (2014) with 10 landmark varieties developed for cultivation from 1940 to 2009. The annual yield gain was reported to be 0.92%, whereas, in real terms, it was 29 kg ha^{-1}. Siberian breeding progress was also studied with a group of 47 wheat cultivars developed between 1900 and 2000 for the Western Siberian region for grain yield, which revealed that the genetic progress achieved was 0.7% year^{-1} (Morgounov et al. 2010).

Periodic evaluation of breeding progress for agronomic and physiological traits, as well as their contribution to yield gain over time in a specific environment can benefit wheat breeding approaches (Reynolds et al. 1999; Xiao et al. 2012). Understanding the historical genetic progress in major wheat-producing countries is of paramount importance to re-orient the future breeding programs (Green et al. 2012; Zhou et al. 2007) to achieve the 2.4% genetic gain to meet the global food production demand of the predicted world population of 9.5 billion by the year 2050 (Krishnappa et al. 2021; Hickey et al. 2019, 2018; Ray et al. 2012, 2013). The evaluation of historical genetic progress with multi-environment testing for landmark wheat varieties has not been attempted in India. In this direction, a systematic attempt has been made to study the breeding progress or genetic gain in wheat cultivars developed from 1965 to 2020 for irrigated production conditions in mega wheat-growing zone (NWPZ) of India.

Materials and methods

Plant materials and environments

A set of 13 landmark wheat varieties released for irrigated production conditions between the years 1965 to 2020 were evaluated at 15 different locations in NWPZ for two consecutive years 2019–2020 and 2020–2021. The details including geographical coordinates, rainfall, and soil type of test sites are presented in Table 1. The landmark wheat cultivars (Table 2) were selected for the present study, as they were grown over a large area over a period of time. The varieties selected for the experiment included C306 a tall popular cultivar released before the onset of green revolution in India, whereas, Sonalika was a highly popular wheat variety in the early years of the green revolution. From the decade 1970 onwards two most important cultivars in NWPZ irrigated ecology every decade (except only one cultivar for the 80 s) were included in the experiment for the estimation of genetic gain in grain yield. Breeding Management System® (BMS v13, 2019) of the Integrated Breeding Platform (IBP) (https://www.integratedbreeding.net) was used to create the trial design of randomized complete block design (RCBD) with three plot replications. Trials in each environment had different randomization. The trials were planted between 1–15 November during both the years at all the test sites under irrigated production conditions. The genotypes were planted in a plot size of 14.4 m^2 with 12 rows of six-meter length with a spacing of 20 cm × 10 cm between and within the row. Recommended package of practices was applied for raising the healthy crop with 150 kg of nitrogen (in the form of Urea and DAP), 60 kg of phosphorous (in the form of DAP), and 40 kg of potassium (in the form of Muriate of Potash) per hectare. In all the trials, 50% N was applied at pre-planting and the remaining was applied in two split doses at 20–25 days and 40–45 days after sowing. Biotic stresses were optimally controlled with the application of effective fungicide (Tebuconazole 25%EC), pesticide (Imidacloprid 30.5 SC) and pre-emergence herbicide(Pendimethalin 30% EC). Grain yield per plot (GYP) was recorded in grams and later converted into quintals per hectare for further statistical analysis. The trial plots were kept completely free from diseases like stripe and leaf rust, powdery mildew, Karnal bunt and foliar blights.

Trend in wheat yield realized in NWPZ

For comparison of the present genetic gain study with that of yield gain realized in the same zone and production conditions of standard Advanced Varietal Trial (AVT) under the All India Coordinated Research Project on Wheat and Barley (AICRPW&B), historical data from 1980 to 2020 was used for the trend analysis. The trend analysis did not include the data before 1980 due to variable zoning patterns. The agro-climatic area in the present NWPZ is exactly the

Table 1 The details of test sites during 2019–2020 and 2020–2021

Location	Geographical coordinates	Soil Type	Long-term average annual precipitation (mm)*	Number of irrigations	
				2019–20	2020–21
Bathinda	30.19 N, 74.95E	Sandy loam	518	5	6
Faridkot	30.18 N, 74.95E	Sandy loam	449	5	5
Gurdaspur	32.05 N, 75.42E	Loam	1113	5	5
Kapurthala	31.39 N, 75.36E	Sandy loam	894	5	6
Ludhiana	30.91 N, 75.79E	Loamy sand	876	5	6
Jammu	32.65 N, 74.80E	Clay loam	1313	4	4
Hisar	29.15 N, 75.70E	Sandy loam	450	6	6
Karnal	29.70 N, 76.99E	Sandy loam	582	4	5
Delhi	28.64 N, 77.16E	Sandy loam	617	6	6
Bulandshahr	28.42 N, 77.84E	Sandy loam	618	5	6
Nagina	29.44 N, 78.41E	Sandy loam	437	5	5
Pantnagar	29.02 N, 79.48E	Loam	1450	4	5
Durgapura	26.84 N, 75.79E	Loamy sand	536	6	6
Tabiji	26.37 N, 74.59E	Red Sandy Loam	525	6	6
Sriganganagar	29.93 N, 73.89E	Sandy loam	379	6	6

*Data source http://cgwb.gov.in/

Table 2 Description of the 13 landmark wheat varieties tested in 2019–2020 and 2020–21

Variety	Release year	Pedigree	Organization	1B/IR Translocation
C306	1965	RGN/CSK3//2*C591/3/C217/N14//C281	CCS HAU, Hisar	Absent
Sonalika	1969	II54-388/AN/3/YT54/N10B/LR 64	ICAR-IARI, New Delhi & GBPUA&T, Pantnagar	Absent
HD2009	1975	PJ'S'/GB55	ICAR-IARI, New Delhi	Absent
WL711	1977	S 308/CHR//KAL	PAU, Ludhiana	Absent
HD2329	1985	LR 64A/NAI 60	ICAR-IARI, New Delhi	Absent
UP2338	1995	UP 368/VL 421//UP 262	GBPUA&T, Pantnagar	Present
PBW343	1996	ND/VG9144//KAL/BB/3/YACO'S'/4/VEE#5 'S'	PAU, Ludhiana	Present
DBW17	2007	CMH79A.95/3*CNO79//RAJ3777	ICAR-IIWBR, Karnal	Present
PBW550	2008	WH 594/RAJ 3858//W485	PAU, Ludhiana	Present
HD2967	2011	ALD/COC//URES/HD2160M/HD2278	ICAR-IARI, New Delhi	Absent
HD3086	2014	DBW14/HD2733//HUW468	ICAR-IARI, New Delhi	Absent
HD3226	2019	GRACKLE/HD 2894	ICAR-IARI, New Delhi	Absent
DBW187	2020	NAC/TH.AC//3*PVN/3/MIRLO/BUC/4/2*PASTOR/5/KACHU/6/KACHU	ICAR-IIWBR, Karnal	Absent

same as that of the agro-climatic area in the past NWPZ from 1980 onwards.

Statistical analysis

The linear mixed model via restricted maximum likelihood (REML) approach was used for analyzing the trial data (individual and pooled) considering variety as a fixed effect and all other main and interaction effects as random. The parameters of genotypic mean, coefficient of variation, and broad-sense heritability were calculated to assess the trial quality. The heterogenous season and location residual variances were modeled into combined analysis and adjusted means for all varieties were estimated through the ASReml-R package (Butler et al. 2018). All random effects follow an independent and identically distributed multivariate normal distribution. These adjusted variety means were regressed against the year of release of the variety, and the realized rate of genetic gain was calculated using the slope of the regression line. The relative gain was also calculated using the variety's first year of release.

To capture the progress of yield level in historical advanced varietal trials (1980–2020) under irrigated timely sown conditions in the NWPZ, a linear trend model was fitted and is given below:

$$y = \alpha + \beta x$$

where y is the yield level in NWPZ (q/ha), α is the intercept, $\beta$is the trend coefficient and x is the time period. In the functional formulation, yield (y) was regressed against time ($x = 1981$ to 2020). The model has been estimated using the ordinary least square approach (Gujarati 2004).

Results

Genetic variability and heritability

Grain yield data of 30 environments comprising 15 test sites over two years were utilized for further statistical analysis. Location, year, and replication-wise grain yield (kg ha^{-1}) distribution of 13 test genotypes are presented in Fig. 1. Whereas, the location-wise pooled data are presented in Table 3. The location means yield ranged from 4626 kg ha^{-1} (Tabiji) to 5251 kg ha^{-1} (Ludhiana) (Table 3).

The individual site-specific variance components were used to estimate the genetic parameter of heritability, which showed high heritability ($H^2 > 85\%$) for all the tested sites. The location-wise heritability ranged from 85.3 (Delhi) to 99.3 (Nagina) (Table 3). The coefficient of variation was of low to moderate level ranging from 2.9 (Nagina) to 6.2 (Delhi) with a mean value of 5.2. None of the trials was excluded from statistical analysis, as all the test sites showed significant heritability ($H^2 > 0.25$), and low coefficient of variation ($CV < 10$).

Correlation and genotype interaction

The correlation study of 13 landmark wheat varieties grown at 15 sites in 2019–2020 and 2020–2021 is presented in

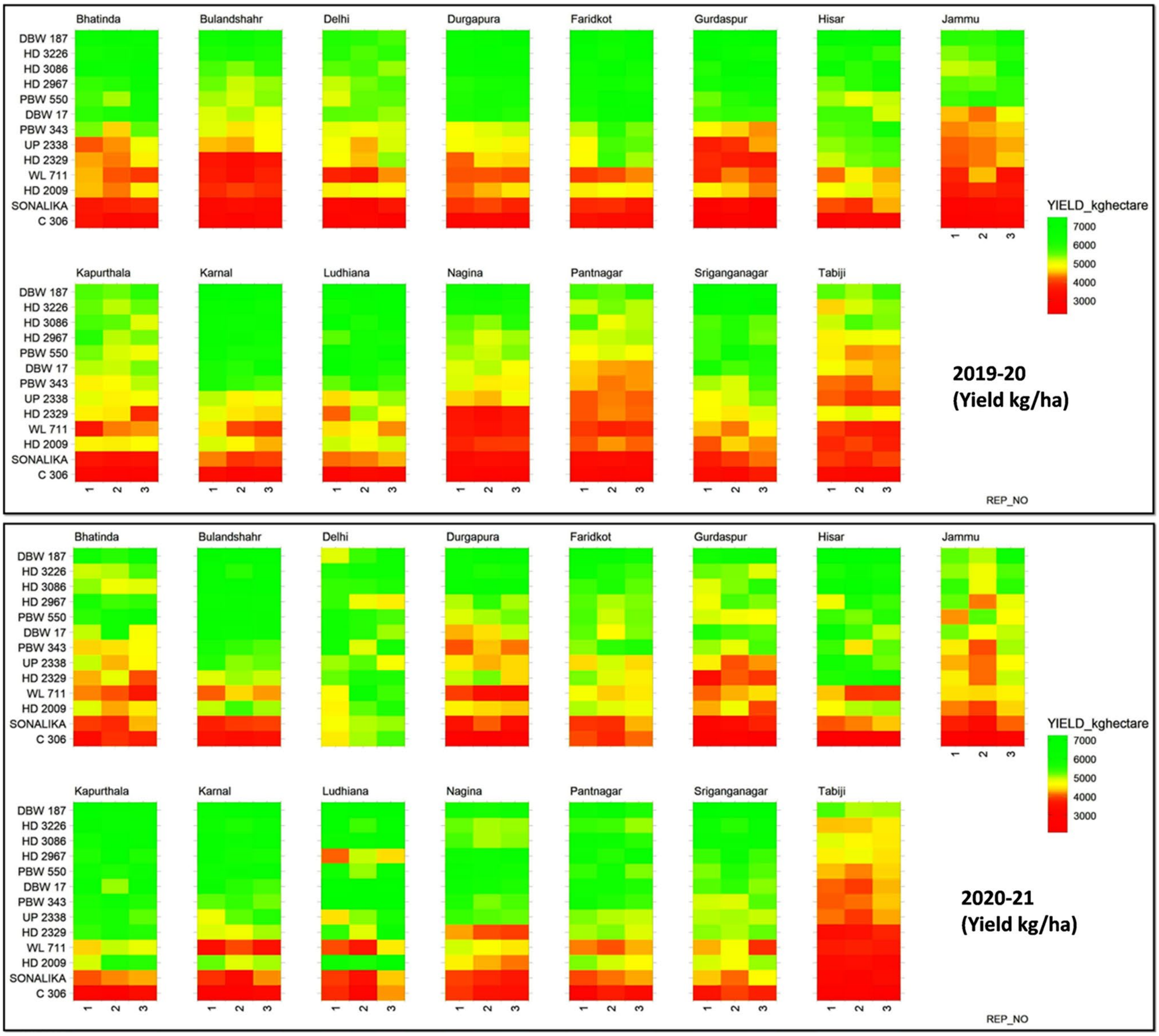

Fig. 1 Data distribution of 13 wheat varieties for grain yield (kg ha^{-1}) in 30 environments with three replications

Fig. 2. There were significant positive correlations for grain yield among the test sites during both the tested years i.e. 2019–2020 and 2020–2021. The interaction plot for wheat grain yield with a set of 13 landmark varieties tested at 15 test sites in 2019–2020 and 2020–2021 is presented in Fig. 3. Generally, all the varieties exhibited non-crossover type interactions. This kind of genotype-environment interaction (GEI) is expected due to high test site heritability ($H^2 > 85\%$) and also low CV for all the test sites.

Genetic progress in grain yield

The historical genetic gain both in terms of rate of genetic gain (% year^{-1}) and rate of genetic gain in real terms (kg ha^{-1} year^{-1}) are presented in Table 4 and Fig. 4. The analysis showed that the wheat grain yield has steadily increased over a period of time. The mean yield was reported to be lowest (3208 kg ha^{-1}) for the wheat variety C306, which is the oldest variety in this study, whereas, highest mean yield was recorded for DBW187 (6275 kg ha^{-1}). The mean yield data

Table 3 Genetic parameters over locations and year

Location	Heritability (H^2)			Coefficient of variation (%)	Grain yield kg ha^{-1}
	2019–2020	2020–2021	Mean		
Bhatinda	98.3	93.8	96.0	5.5	4999
Faridkot	98.0	94.9	96.5	4.9	5127
Gurdaspur	98.5	97.0	97.8	6.0	4895
Kapurthala	96.5	96.0	96.2	5.7	5057
Ludhiana	97.3	97.0	97.2	5.9	5251
Jammu	98.1	95.0	96.6	5.8	4788
Hisar	97.7	97.1	97.4	5.6	5214
Karnal	99.1	98.1	98.6	4.2	5161
Delhi	97.6	73.0	85.3	6.2	5048
Bulandshahr	99.3	98.8	99.0	3.5	5012
Nagina	99.3	99.3	99.3	2.9	4926
Pantnagar	98.9	97.3	98.1	3.8	4904
Durgapura	99.6	98.1	98.9	3.8	4997
Tabiji	97.2	98.2	97.7	4.2	4626
Sriganganagar	98.1	97.0	97.6	4.6	5132
Overall	98.2	95.4	96.8	5.2	5009

showed that the yield increase is steady over a period of time in varieties released in chronological order except WL711 which had lower yield than the immediate predecessor landmark variety HD2009 (Table 4). The maximum yield gain between the two adjacent period varieties was recorded with 801 kg ha^{-1} for Sonalika (1969) and HD2009 (1975). Whereas, the minimum yield gain between the two adjacent period varieties was recorded with 1.0 kg ha^{-1} for HD3086 (2014) and HD3226 (2019). However, DBW187 released just a year after HD3226 showed a significant jump in the productivity. The compound annual growth rate (CAGR) for grain yield was reported to be 1.21 percent for the period between 1965 and 2020 (Table 4 and Fig. 4). The compound rate of genetic gain in real terms was 44.14 kg ha^{-1} year^{-1}.

Trend analysis based on historical trial data

The perusal of time-plot of grain yield trial mean data of Advanced Varietal Trial (AVT) for irrigated timely sown conditions in NWPZ (Fig. 5), it is explicit that the yield level has increased from 38.9 q/ha (1981) to 59.1 q ha^{-1} (2020). Capturing the linear trend visually, a linear regression model was fitted which resulted in a R^2 value of 0.7233. It implies the 'Goodness of Fit' with 72.33% variation in the yield accounted by the time factor. On an average, in absolute terms, the yield has increased by 0.37q/ha (~ 37 kg/ha) per annum. However, in terms of percentage, the yield level has increased by 0.78% per annum for the period under study.

Discussion

Several breeding programs in both crops and livestock particularly in model species have been analyzed to estimate the realized genetic gain per year ΔG_t and also genetic gain trend analysis (Rutkoski 2019b). The genetic gains can be estimated using a variety of methods and for better comparison with realized ΔG_t method of estimation, true values of realized ΔG_t should also be determined. To estimate the genetic progress in NWPZ, a set of 13 landmark varieties that occupied a large acreage in the zone since 1965 were tested at 15 test sites for 2 consecutive years i.e. 2019–2020 and 2020–2021. Although the 15 test sites are situated in different geographical areas within the mega-zone NWPZ, they differed in some important micro-environmental variables affecting wheat crop growth. The location-wise heritability was reported to be very high and ranged from 85.3 (Delhi) to 99.3 (Nagina). This high site heritability is partially due to the exposure of experimental material to similar macro-environmental conditions within the mega zone. The high trait heritability among the test sites is further supported by positive and high magnitude correlation coefficients among the test environments and also low site coefficient of variation. This was also reflected by non-crossover type interactions.

The Genetic gain study revealed that the annual genetic progress was 1.21% for the period of 55 years starting from 1965 to 2020 in the zone for wheat grain yield. A Similar kind of annual genetic progress with ≥ 1.0% was realized in CIMMYT and the United States wheat breeding programs (Manes et al. 2012; Green et al. 2012). The rate of genetic gain greatly varies within the country among different wheat growing zones and study material. Trend analysis based on historical grain yield data in standard AVT in the zone from 1980 to 2020 revealed that the yield level has significantly increased. In absolute terms, the yield has increased by 0.37q/ha (~ 37 kg/ha) per annum. However, in terms of percentage, the yield level has increased by 0.78% per annum (CAGR) for the period under study. Similar kind of studies with historical data from national varietal trial programs was also attempted in South Africa and the percent yield gain ranged from 0.40 to 0.82% year^{-1} (Dube et al. 2018).

Recently, global efforts to accelerate the genetic gains in wheat grain yields through the breaking of yield barriers have gained momentum. An attempt was made in India, a new High Yield Potential Trial (HYPT) was designed in NWPZ during 2018–19 to harness the higher wheat yields

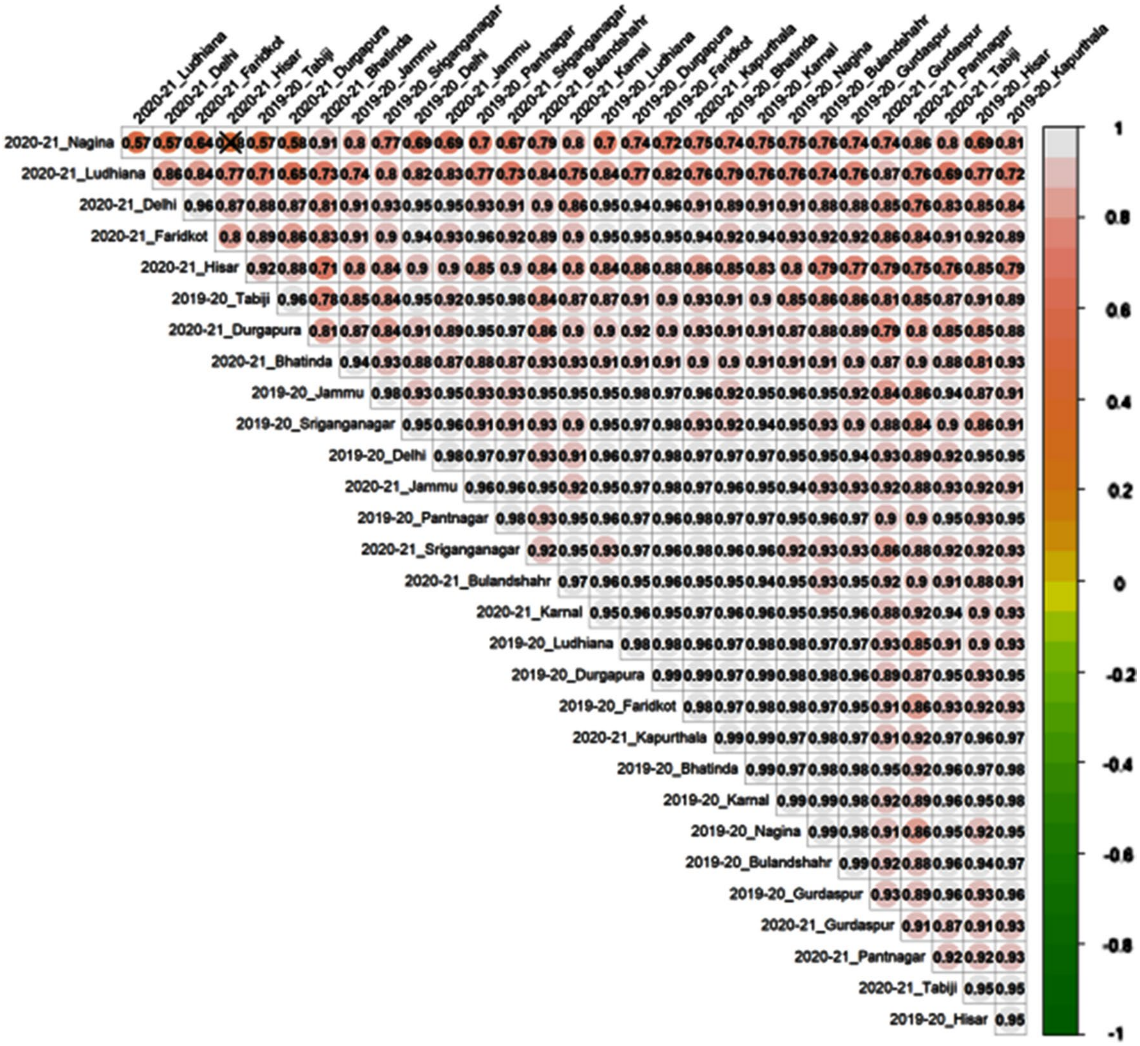

Fig. 2 Correlation coefficients for wheat grain yield with a set of 13 landmark varieties tested at 15 test sites in 2019–2020 and 2020–2021

through the identification of genotypes suitable for early sowing (25th October) along with high input responsiveness. The mean yield of HYPT was 19.4% superior compared to the mean yield of the standard advanced varietal trial (unpublished data). Furthermore, grain filling duration, biomass, harvest index, normalized difference vegetation index, chlorophyll content index, grain weight per spike and 1000-grain weight were found to be key contributing traits to enhanced grain yield. Reynolds et al. (2011) suggested three approaches viz. increasing photosynthetic capacity and efficiency, optimizing partitioning to grain yield while maintaining lodging resistance, and breeding to accumulate yield potential traits and delivery of new germplasm to break the yield barriers in wheat. The 1RS/1BL translocation, in which 1BS of wheat is replaced with 1RS of rye, is one of the most extensively used sources of alien chromatin in wheat breeding (Sharma et al. 2021). This translocation carries multiple disease resistance genes (*Yr9*, *Lr26*, *Sr31*, and *Pm8*) and yield-enhancing traits but the major disadvantage is reduced bread-making quality (Lukaszewski 2000). Several successful varieties released in India after 1980 such as PBW343, UP2338, DBW17, etc. carried 1B/1R translocation. However, the recent popular Indian cultivars like HD2967, HD3086, and DBW187 do not carry 1B/1R translocation and impart better bread and chapati quality. These new wheat cultivars free from 1B/1R translocation have shown continuous genetic gain for grain yield and the rate need to be improved further.

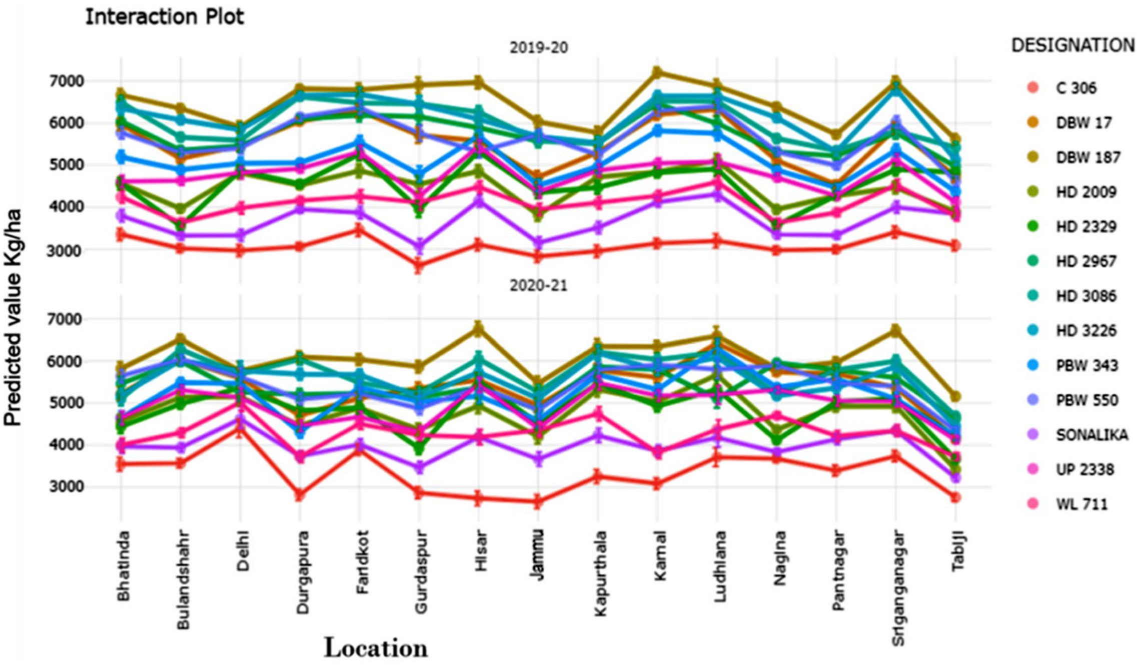

Fig. 3 Interaction plot for wheat grain yield with a set of 13 landmark varieties tested at 15 test sites in 2019–2020 and 2020–2021

Table 4 Mean grain yield (kg ha^{-1}) and genetic gain in relation to the base year 1965

Variety	Year of release	Grain yield (kg ha^{-1})
C306	1965	3208
Sonalika	1969	3818
HD2009	1975	4619
WL711	1977	4195
HD2329	1985	4676
UP2338	1995	4835
PBW343	1996	5133
DBW17	2007	5478
PBW550	2008	5534
HD2967	2011	5575
HD3086	2014	5842
HD3226	2019	5843
DBW187	2020	6275
Mean LSD	485	
Standard error	3.5	
Compound rate of genetic gain in absolute terms (kg ha^{-1} year^{-1})	44.14	
Rate of genetic gain (% year^{-1})	1.21	

Systematic study of 13 landmark wheat varieties released for commercial cultivation in the past 55 years was evaluated at 15 different test sites for two consecutive years i.e. 2019–20 and 2020–21 to assess the genetic progress. Wheat grain yield has been improved from 3208 to 6275 kg ha^{-1} orgenetic gain of 1.21% year^{-1}. Whereas, the compound rate of genetic gain in absolute terms was 44.14 kg ha^{-1} year^{-1}. To compare the present genetic gain study, a trend analysis based on historical grain yield data in standard AVT in the zone from 1980 to 2020 was also attempted, which revealed that the percent yield increase was 0.78% per annum. To achieve the objective of 2.4% year^{-1} genetic gain, it requires greater efficiency in national crop improvement programs through more systematic use of genetic diversity through pre-breeding activities to introduce untapped new alleles for crop yield and also the use of new crop improvement approaches like speed breeding and genomic selection. Currently, leading crop research groups across the globe suggest that integration of genomic selection with speed breeding could accelerate the rate of genetic progress, particularly for traits governed by polygenes and also complex traits. Also, there exists the need to harness the available genomic resources in the wheat to accelerate the genetic gain.

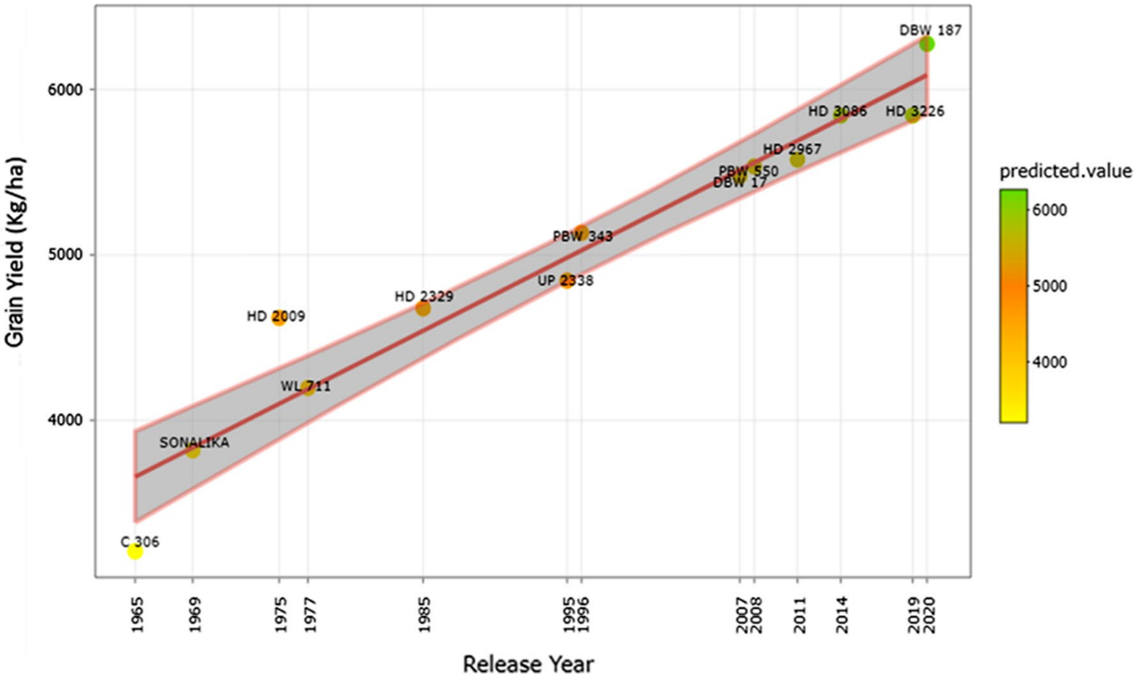

Fig. 4 Graphical representation of genetic gain in grain yield (kg ha^{-1}) in relation to the base year 1965

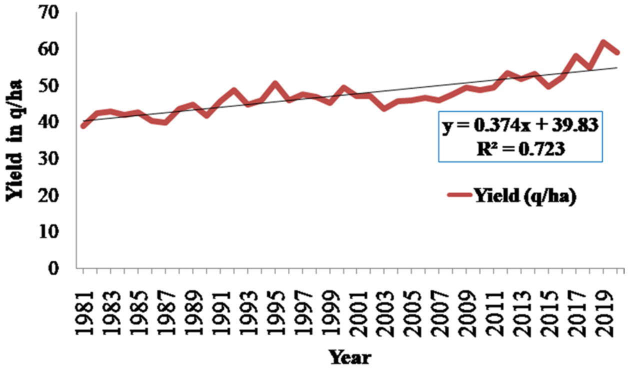

Fig. 5 Trend in wheat yield realized in the NWPZ

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Author contributions Conceptualization: HK, GS and GPS; Formal analysis: AR, RRD and SR; Investigation: HK, GK, SK, CNM, OP, RY, Harikrishna, OPB, VS and SSY; Project administration: GPS; Writing of original draft: HK and GK; Review & editing: SR and GS.

Declarations

Conflict of interest All the authors declare no conflict of interest.

Ethical statement This investigation does not involve any studies with animals at any stage of experimentation.

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