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Progression in yield and value addition of Indian bread wheat – An analysis

D. Mohan*, V. Tiwari and R. K. Gupta

ICAR-Indian Institute of Wheat and Barley Research, Karnal 132 001, Haryana

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Abstract

National wheat programme of India was examined for progress made in yield and quality in ten different production environments. During the period 2000-16, productivity improved in three environments namely timely-sown condition of north-western plains zone (NWPZ) and timely and late-sown wheats of central zone (CZ). Certain non-grain parameters like plant height, vegetative period and crop duration were the significant contributors in these environments. Improvement in grain quality was zone-specific but simultaneous increase in productivity and value addition was witnessed in the most important region of the country i.e., NWPZ. *Chapati* quality and physical grain quality improved in the Indo-Gangetic plains and peninsular zone (PZ). Amongst the baked products; quality of the cookies was improvised in the hills whereas progress in bread loaf volume was visible in NWPZ and PZ. In quality components, protein content was enhanced in PZ and gluten characteristics were improved in NWPZ. Except reduction in bread quality score, no major change occurred in grain quality of the new varieties developed for hot and dry climate of central India.

Key words: Indian wheat, value addition, wheat productivity, contributing traits, wheat zones

Introduction

Wheat research in India is upbeat and the country has witnessed tremendous growth in production of this staple food crop. Wheat production which was 70 million tons at beginning of the 21st century touched 95 in 2012, creating a landmark in wheat history of India. Improvement could also be noticed in wheat productivity which crossed 30q mark during this period. This progress had been a direct outcome of the All India Coordinated Wheat and Barley Improvement Programme (AICW&BIP) which addresses the research needs at the regional level by dividing the country into five mega zones. The yield potential, gluten characteristics and the end-product quality vary in these zones due to climate, latitude/ longitude and soil differences (Mohan et al. 2011; Mohan et al. 2013[a]; Mohan and Gupta 2015; Gupta et al. 2016). The present study examines the progress made in yield and value addition under different environments. Traditionally, enhancement in wheat yield is perceived with some decline in grain quality, especially the grain protein content (Asseng and Milroy 2006; Oury and Godin 2007). Therefore, it is important to gauge quality of grains and the end-products in the endeavours focused on yield improvement. This study examines the changes happening in each zone in productivity and value addition of bread wheat (*Triticum aestivum* L.) during the period 2000-16 and tries to understand the factors related to it.

Materials and methods

Experimental material

Study material included bread wheat genotypes evaluated in irrigated trials of the AICW&BIP as released cultivars and the pipe-line varieties in the five mega zones i.e. northern hills zone (NHZ), north-western plains zone (NWPZ), north-eastern plains zone (NEPZ), central zone (CZ) and peninsular zone (PZ) in two production conditions i.e. timely-sown and late-sown. During the period 2000 to 2016, 404 entries were evaluated in timely-sown trial of different zones (NHZ: 83, NWPZ: 97, NEPZ: 114, CZ: 52 and PZ: 58). In the same period, 392 entries were tested in the late-sown trial of five zones (NHZ: 56, NWPZ: 98, NEPZ: 86, CZ: 80 and PZ: 72). Year wise wheat yield was plotted

*Corresponding author's e-mail: devmohan@gmail.com
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against the years to examine the coefficient of determination (R^2) and linear trend for assessing progress in wheat productivity. Regression analysis was applied to same data to test significance level of the R^2 value which was same as recorded in the linear trend line. Regression analyses was also used to assess the relevance of component traits in grain yield and for this purpose all the genotypes tested in a given environment were included. For the end-products and other grain quality components, this exercise was restricted to the study material of 2003-16, as multi-location data for majority of the quality traits was available for this period only. For yield, yield determinants and grain protein; progress was separately assessed in timely-sown and late-sown wheats whereas for rest of the quality parameters; genotypes were pooled in each zone.

Traits studied

Grain yield of each zone was examined in every production condition along with plant height, thousand grain weight (TGW), heading days and maturity period. For grain quality, samples received from 3-5 locations of each zone were analyzed at ISO 9001:2008 certified laboratory of the institute. Besides the end-products (*chapati* quality score, bread loaf volume, bread quality score and biscuit spread factor), grain quality analysis included important parameters like grain hardness index, grain appearance score, sedimentation volume, grain protein content (GPC) at 14% grain moisture, wet gluten content, gluten index, test weight and extraction rate. AACC (2000) method was applied to examine processing and milling quality. Conventional approach was adopted to derive GLU 1 score (Payne et al. 1981) and *chapati* quality (Rao et al. 1986). Single kernel characterization system 4100 was used to measure grain hardness whereas Quadrumat Senior mill was used for flour recovery. Infra-red transmittance-based instrument Infra-tec 1125 was used to analyze grains for protein content. Grain appearance score (GAS) was a subjective test to collectively rate size, shape, soundness, colour and texture out total score 10.

Results

Productivity gain

Regression analysis for grain yield revealed that under timely-sown condition, the R^2 value was highly significant ($P \leq 0.01$) only in NWPZ and CZ (Table 1). Under the late-sown condition, it was only the CZ where yield improvement was highly significant. Some improvement was visible in PZ under timely-sown and NWPZ under late-sown condition also, but the yield gain (R^2) was not significant.

Linear trend in the year-wise yield harnessed in different environments revealed that in beginning of the 21st century average productivity in timely-sown wheats of NWPZ and CZ was 44-45q/ha and by the end of 2016, it got elevated to the level of 52-53q/ha (Fig. 1). In 2000, average productivity in NHZ, NEPZ and PZ was 40-41q/ha and by the end of 2016, just one quintal yield could be added in NEPZ and 2.0-2.5q in NHZ and PZ. Although high yield levels were obtained in some years as the yield range in NHZ, NEPZ and PZ was quite large but R^2 value remained low as productivity was highly variable.

Yield indicators

An attempt was made to realize relevance of the yield determinants in the environments where yield improvement was substantial. Since grain number is the major yield governing trait in any situation, focus was on the other yield determinants like height,

Table 1. Regression statistics in grain yield and grain protein

Zone	Grain yield				Grain protein			
	Timely-sown		Late-sown		Timely-sown		Late-sown	
	df (year)	R^2 value & direction	df (year)	R^2 value & direction	df (year)	R^2 value & direction	df (year)	R^2 value & direction
NHZ	15	0.05 (+)	16	0.07 (-)	12	0.02 (–)	13	0.03 (–)
NWPZ	16	0.54** (+)	16	0.15 (+)	13	0.07 (+)	13	0.04 (+)
NEPZ	15	0.05 (+)	14	0.09 (+)	12	0.01 (–)	12	0.19 (–)
CZ	15	0.76** (+)	15	0.44** (+)	12	0.00 (=)	13	0.00 (=)
PZ	16	0.20 (+)	14	0.01 (=)	13	0.37* (+)	12	0.11 (+)

,*significant at P 0.05 and ≤.01

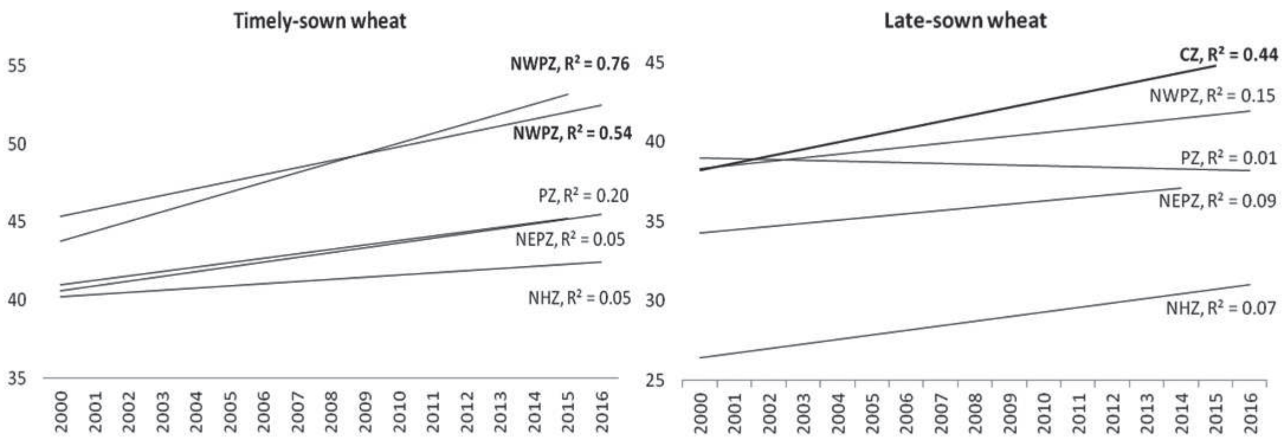

Fig. 1. Linear trend in wheat yield during the period 2000-16

vegetative period, reproductive period and grain weight. Regression analysis revealed that in the environments where significant yield improvement was witnessed, contribution of certain traits other than the grain number was also highly significant (Table 2). Contribution of were controlled by the vegetative period only. Investigation amply proved that plant height was the first field expression of enhanced productivity and crop phenolgy was the second major field expression strongly related with yield gain harnessed during the period 2000-16.

Table 2. Contribution of component traits (R^2 value) in productive environments

Zone	Production condition	Plant height	Heading days	Grain filling days	Maturity days	Grain weight
NWPZ	Timely-sown	0.20**	0.09*	0.00	0.22**	0.05*
CZ	Timely-sown	0.13**	0.10*	0.10* (-)	0.02	0.09*(-)
CZ	Late-sown	0.05*	0.12**	0.00	0.20**	0.00

,*significant at P 0.05 and ≤.01

plant height was highly significant in the timely-sown wheats of NWPZ and CZ. R^2 value indicated that 20% yield variations in NWPZ and 13% in CZ were regulated by plant height only. Although contribution of plant height was less in late-sown wheat of CZ, nevertheless it was significant. Maturity duration was the second major non-grain yield governing parameter in timely-sown wheat of NWPZ whereas in the late-sown wheat of CZ, it was the most important field expression related to wheat yield. Results indicated that 22% yield variations in timely-sown wheat of NWPZ and 20% in the late-sown condition of CZ were governed by maturity duration of the crop. When maturity period was split into vegetative and reproductive periods; it was the vegetative period (heading days) which expressed highly significant contribution in productivity of CZ late-sown varieties. Contribution of vegetative period was significant in timely-sown wheat of NWPZ and CZ also, but the significance level was low (P 0.05). Overall, 9 to 12% yield variations in all the three environments

Improvement in plant height and heading days had been noted as good signs of improved grain bearing in the Indian subcontinent (Laxman et al. 2014; Jamali and Ali 2008). Since productivity gain in the timely-sown wheat of NWPZ and late-sown wheat of CZ was accompanied by enhanced maturity duration, it showed that the total growth period is crucial to harness high yield in certain environments. If there is no atmospheric stress on plant growth or the genotypes possess ability to thwart such pressures, significant yield gain can be expected in timely-sown wheat of NWPZ and late-sown wheat of CZ. Although success of Mexican wheats is perceived through reduced plant height (Fisher and Quaile 1990) and lodging loss is also less in such genotypes (Calderini et al. 1995); it had been pointed by Snape et al. (1979) that the role of “tall-dwarfs” in the development of the high-yielding semi-dwarf wheats in the green revolution was also crucial. This study further added that height accompanied with unstressed maturity duration ensures higher wheat productivity.

In this subcontinent, similar observations were reported from Pakistan where selection for improved height and larger flowering and reproductive periods was suggested (Khan et al. 2000) and highly significant positive correlation of plant height was observed with main spike grain yield (Jamali and Ali 2008).

Significant contribution of grain weight was observed only in timely-sown wheat of NWPZ. Since significance of grain filling period could not be confirmed in that region, it was evident that either genetic factors or improved efficiency i.e. grain growth rate could have contributed in improved TGW. Grain growth rate and grain weight are the two positively correlated grain attributes (Laxman et al. 2014). Since this study pointed similar relationship in NWPZ (r: 0.49), TGW was benefitted in the region. Improved efficiency during reproductive period indicated that newly developed timely-sown genotypes in NWPZ must have possessed better heat tolerance to shield the process of grain development.

Grain protein content

Protein content is the most common grain component targeted in wheat quality. It's crucial not only to provide nutritional security but also to make good quality bread (Pena 2011, Mohan and Gupta 2013[a]). Study revealed that under timely-sown condition, significant improvement occurred in PZ (Table 1) and average GPC moved from 11.2% to 12.5% (Fig. 2). Some

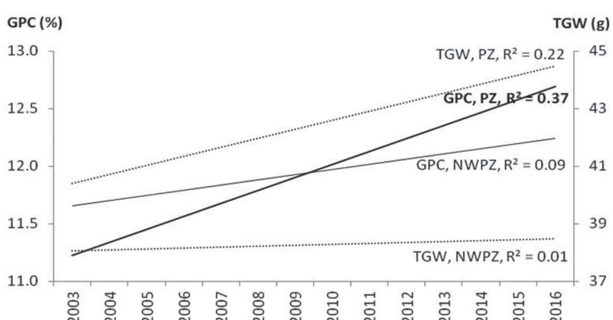

Fig. 2. Progress in grain protein content (at 14% grain moisture) and grain weight

improvement was sighted in late-sown wheat of PZ also, but it was not significant. The paradox that higher GPC is achievable at the cost of grain yield (Asseng and Milroy 2006) withered in this investigation as progression in grain yield caused no protein loss in the two most productive wheat zone of the country i.e., NWPZ and CZ. It was important that progress in GPC was not at the cost of reduced grain size either. Although strong inverse relationship between TGW and GPC had been reported in India (Nagarajan et al. 2007), this barrier seems to have overcome in PZ and NWPZ where this study found non-significant correlation between grain weight and protein content. It was important that TGW improved in timely-sown wheat of PZ (from 41 to 45g) along with significant protein enhancement in the grains. In NWPZ, there was little improvement in protein content (from 11.6 to 12.0%) when yield enhancement triggered in timely-sown condition with no change in TGW which remained static at 38g throughout the 17 years of study.

On the basis of this study, it was evident that the advance made in GPC was mainly because of the genetic factors rather than the environmental influences on the grain development. The national wheat improvement system has been successful in harnessing higher protein content as selection is rigorously practiced at some breeding centres of NWPZ. This strategy has ensured yield advancement without any GPC decline in NWPZ and enhanced protein content with no premium on yield or grain weight in PZ. Under late-sown condition, improvement in GPC was very limited and it even dropped in NEPZ, however, there was no definite trend as R^2 value was non-significant.

Gluten characteristics

Improvement in protein content is generally reflected in the gluten content but in the product making; strength of the gluten is more crucial which is gauged by the sedimentation volume. The Indian wheats are slated to have low sedimentation volume (Mohan et al. 2011). Study revealed no major deviation in the gluten content. It improved to certain extent in PZ but the improvement was not significant (Table 3). There was tremendous increase in the gluten strength of wheat varieties developed in NWPZ as sedimentation value increased from 35 to 50ml during the period 2003-16. In NEPZ, there was some decline in sedimentation value from 46 to 44ml but the fall was not significant. In all other zones, sedimentation value remained static and ranged between 40 to 45ml.

Quality of gluten content is important for quality of dough and refection of gluten quality is seen through GLU 1 score and gluten index (Pena 2011). It was observed that major changes in high molecular weight glutenin subunits had taken place in NWPZ and NHZ as genotypes possessing desired combination of

HMWGS increased in number. Several varieties of NWPZ like HD 2967, HD 3059, DBW 16, DBW 71 and DPW 621-50 had the maximum GLU 1 score i.e. 10. Such examples could also be noted in NHZ (HS 507, HPW 349), NEPZ (CBW 38) and PZ (RAJ 4083, HD 2987). It is hard to improve GLU 1 score in CZ and PZ as 2+12 type wheats are more frequent among the high yielding genotypes (Mohan and Gupta 2013[b]). Study revealed that overall gluten index had improved in NWPZ (from 55 to 65%) but no major reshuffle had taken place in rest of the country (Table 3).

Table 3. Progress made in quality component traits

Component trait	R^2 value and direction of change				
	NHZ	NWPZ	NEPZ	CZ	PZ
Extraction rate	0.68^{**} (–)	0.20 (+)	0.20 (–)	0.15 (–)	0.25 (+)
Sedimentation value	0.02 (–)	0.83^{**} (+)	0.25 (–)	0.05 (+)	0.02 (–)
Wet gluten content	0.06 (–)	0.03 (–)	0.21 (–)	0.02 (+)	0.28 (+)
Gluten index	0.02 (–)	0.67^{**} (+)	0.10 (–)	0.00 (=)	0.17 (–)
Grain harness index	0.29 (–)	0.47^{*} (–)	0.29 (–)	0.31 (–)	0.22 (–)
Grain appearance	0.09 (+)	0.70^{**} (+)	0.44^{**} (+)	0.13 (+)	0.38^{*} (+)
Test weight	0.04 (–)	0.09 (+)	0.01 (+)	0.14 (–)	0.30^{*} (–)

,*significant at P 0.05 and $\leq$.01

Extraction rate, physical properties and grain texture

Flour recovery is a highly important quality attribute for the millers. Although significant improvement in the extraction rate could not be noted in any zone (Table 3), some gain could be noticed in NWPZ (68 to 69%) and PZ (70 to 71%). Steep fall in extraction rate was noticed in NHZ where it dropped from 66 to 63%. Overall flour recovery in NEPZ and CZ remained static during the study period and stayed in 69-70% range. Physical appearance of wheat grains is an important attribute in the domestic grain market. Bold, attractive amber colour grains are preferred by the consumers. Study indicated that grain appearance was not compromised in the endeavours targeted to enhance the grain yield. Instead, physical quality of the grains improved significantly in three zones of the country namely NWPZ, NEPZ and PZ (Table 3). Test weight is another major characteristic for the miller as it affects flour recovery (Gwirtz et al. 1996; Mohan et al. 2013[b]). Test weight did not register progress in any of the zones rather it declined in PZ from 81.5 to 80.0kg/ha. Test weight is such a trait for which hardly any attention is paid by the breeders during the course of selection. Instead, attention is paid to TGW which is related with yield and good grain appearance. Data on grain hardness index was available only for the period 2006-16. Since degree of freedom for years was less than 12 in the regression analysis, it was hard to draw any shift in texture of the grains.

End-product quality

Investigations on end-usages revealed that the program was successful in improving quality of *chapati* in irrigated wheats of three zones as the R^2 value was highly significant in NWPZ, NEPZ and PZ (Fig. 3). Initially, *chapati* score in these three zones was between 7.3 and 7.4. By the end of this study period, it reached to the level of 7.9 in PZ, 7.8 in NEPZ and 7.6 in NWPZ. *Chapati* quality could not be enhanced in the zones where either the initial score was very high as in CZ (7.8) or very low as observed in NHZ (7.3). Traditionally, CZ has been recognised as the most suitable region for good *chapati* quality. By the end of 2016, there were regions like NEPZ and PZ where *chapati* score was as good as in CZ. Since grain appearance is an important constituent of *chapati* quality (Mohan and Gupta 2013[a]), improved grain appearance might have contributed in elating *chapati* score in NEPZ, NWPZ and PZ.

Amongst the baked products, there was some improvement in quality of the cookies which was largely because of gradual decline in the grain hardness index. Over the 13 years period, highly significant improvement was noticed in new varieties of NHZ and NEPZ (Fig 3). Improvement was significant in NWPZ (P 0.05) too, as there was significant decline in the grain hardness index from 82 to 75. In 2004,

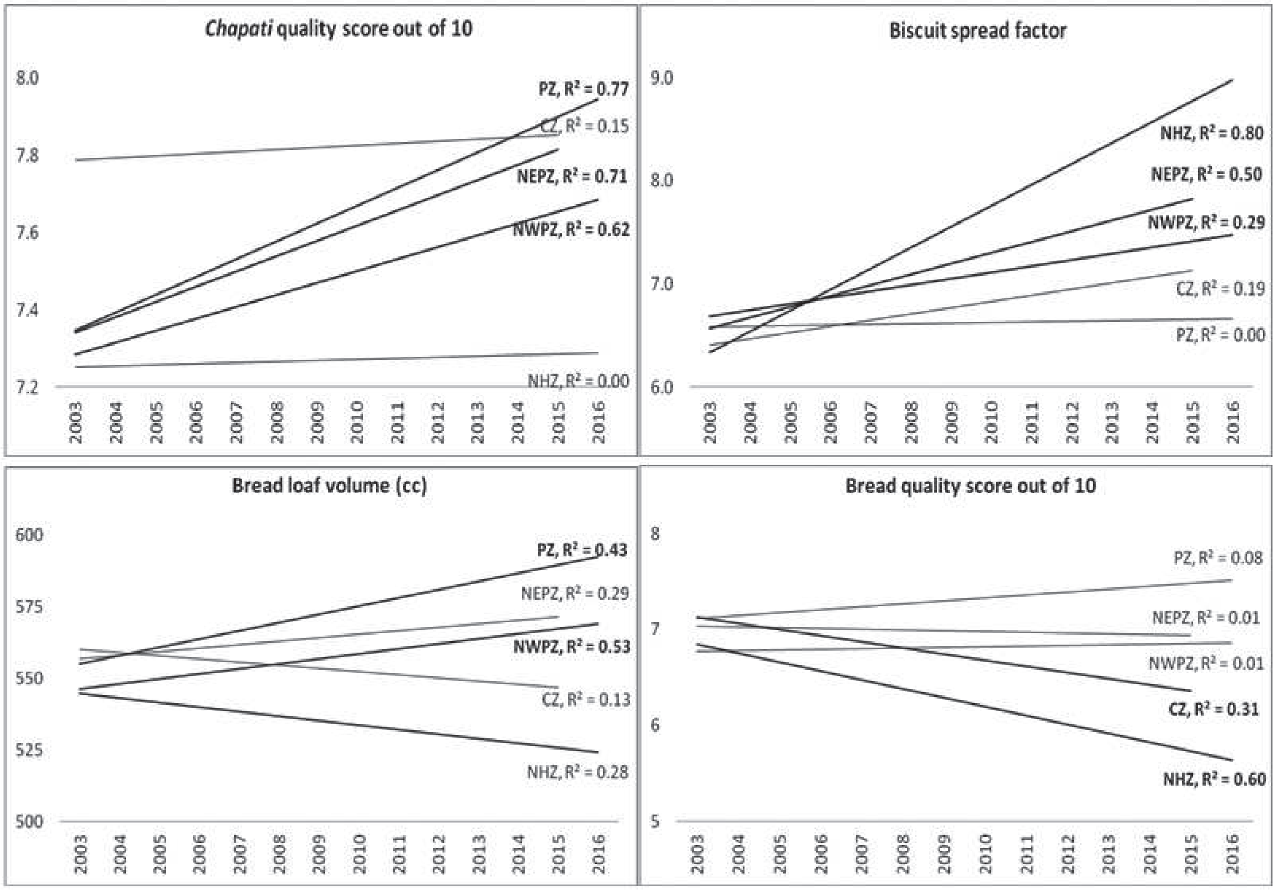

Fig. 3. Progress in end-product quality

biscuit spread factor in all the zones was around 6.0 to 6.5. By the end of 2016, biscuit quality improved at a faster rate in NHZ and the spread factor reached to the level of 9.0. Variety with spread factor more than 10 (HS 490) is also available in NHZ. Though varieties of comparable biscuit quality are not available in NEPZ, still some improvement could be seen in cookies made from wheat of the region as the mean spread factor had gone to 8.0. Besides reduction in grain hardness, the rise of biscuit quality in NEPZ could be attributed to decline in the gluten strength.

Trend line and coefficient of determination indicated that progress in bread loaf volume was highly significantly in PZ and NWPZ (Fig. 3). Improvement in bread loaf volume was faster in PZ (555 to 585cc) in comparison to NWPZ (545 to 560cc). However, improvement was not reflected in the bread quality score as R^2 was non-significant. There was a significant drop in bread quality score and bread loaf volume in NHZ. Bread quality score in the new varieties of CZ also registered significant drop. It showed that the kind of gluten, especially the extensibility, needed for good bread quality could not be developed in these regions. After LOK 1, there is hardly any variety suited for good bread making in CZ. In NEPZ, there was little improvement in the loaf volume but bread quality score remained static.

Way forward

Adjudging diverse climatic conditions, it is hard to register significant progress in yield and quality determinants in all corners of India. Situation becomes more complex when the abiotioc pressures and the yield/ quality related parameters vary zone-wise (Mohan et al. 2011; Mohan and Gupta 2015). Even though analogy between some important yield and quality parameters (Mohan et al. 2014) and the relevance of physiological efficiency and phenotypic expressions (Mohan and Gupta 2015 & 2016) had been demonstrated in grain characteristics of the Indian wheats; progression on two alternate pathways i.e. yield and quality, had not been addressed. The present study clearly illustrates that when environments are not similar, progress in yield and quality cannot be in equal proportion. Different scenarios had emerged in the country which can broadly be classified as i) improvement in yield and quality both as noticed in NWPZ; ii) improvement only in yield as in CZ iii) no gain in productivity but some progress in the quality parameters as observed in NHZ, NEPZ and PZ

Study revealed that during first 17 years of the 21st century, progression in wheat productivity was highly significant in NWPZ and CZ. It was interesting to observe that in a hot and dry zone like CZ, yield improved in both production conditions i.e. timely-sown and late-sown whereas in the zone where environment is most favourable for wheat growth i.e. NWPZ, yield could improve only in timely-sown condition. Advancement in yield eluded NEPZ and NHZ completely and gain in productivity was marginal in PZ. NEPZ has large acreage (nearly 10 million hectares) and is apprehended to have maximum influence of global warming. Therefore special breeding efforts are needed to elevate yield potential in this important region of the Indo-Gangetic plains. Relevance of yield governing traits, especially in the areas where productivity improved, was noted in height and traits related to crop phenology like vegetative period and maturity duration. Maturity duration can only be increased when genotypes express tolerance to heat during the grain development stage. If that is not possible, at least vegetative period should be increased within the same maturity duration. It is important therefore to give due consideration to these non-grain yield parameters in developing high-yield cultivars. Selection for improved grain weight can be other useful option to improve wheat productivity of the timely-sown wheats in NWPZ. In CZ, longer vegetative phase and addition to plant height can help to improve yield in both production conditions. In CZ, bold grain size (TGW: 45g) is achieved under timely-sown condition as the grain filling period is very large (50 days). This study has indicated that if this grain size is reduced a little bit by making the grain filling period short within the same maturity duration, some yield advantage can be harnessed in timely-sown condition as inverse relationship between grain weight and grain number was very strong in this environment (r: -0.87). This way, extended vegetative period will promote grain bearing in wheat varieties of central India.

It is important that both productivity and the overall grain quality had shown signs of improvement in wheat bowl of the country i.e. NWPZ. Utilization of the genetic resource and infrastructure developed in this region for quality evaluations has made big difference in the region. Well equipped laboratories at New Delhi, Karnal, Ludhiana, Hisar and Pantnagar have helped the breeding ventures focussed on improving wheat quality in the background of high yield. Newly developed varieties of the region like HD 3059, HD 2967, DBW 71, DPW 621-50, DBW 88, WH 1105, WH 1021, WH 1124 and PBW 590 have good yield and quality characteristics. Traditionally, gluten strength (sedimentation volume) and gluten quality (gluten index) had not been very good in NWPZ (Mohan et al. 2013; Gupta et al. 2016) which affected dough quality adversely. With concerted efforts, several grain quality attributes have been improvised in NWPZ which include sedimentation volume, gluten index, grain appearance score and high molecular weight glutenin subunits (GLU 1 score). Consequently, the end-product quality also improved in this region as all these component traits are related with end-use in the Indian wheats (Mohan and Gupta 2013[a]). Mohan and Gupta (2016) had reported positive contribution of plant height in *chapati* score. Even flour recovery cannot be improvised in wheat genotypes when there is restriction on plant height (Mohan and Gupta 2013[c]). This investigation also noticed that the newly developed materials in NWPZ (DBW 88, DPW 621-50 and HD 2967) are little taller in comparison to the old cultivars like WH 542, PBW 343 and HD 2329. The study indicated that such phenotypic expressions are also indicators of good biomass accumulation accrued from healthier vegetative growth. With the result, simultaneous improvement in productivity and *chapati* score could happen in NWPZ. History of wheat research in India indicates that varieties known for good *chapati* were tall in pre-green revolution era but with advent of semi-dwarf Mexican varieties, product quality drifted as sink capacity and biomass partitioning was diverted to increase grain number (Khush 2001).

Physical grain quality, especially the grain appearance, is crucial to enhance *chapati* quality (Mohan and Gupta 2013[a]). In this investigation, grain appearance improved in three zones namely NWPZ, NEPZ and PZ, consequently *chapati* score also increased in these zones. Improvisation in grain appearance can be a handy tool for the breeders as it does not require any lab. facility. Although improvement in grain yield was substantial in central India, progress in grain quality was missing. The high standards of good *chapati* quality and good grain appearance were maintained during the period 2000-16 but erosion occurred in bread quality of the new varieties. It's hard to elevate bread quality when majority of the high yielding genotypes carry 2+12 type HMWGS which do not possess dough quality suited for bread making quality (Mohan and Gupta 2013 & 2015), bread quality therefore is generally poor in central India. Since wheat harvested from central India is in great demand by the industry, it is important to invest in infrastructure development suited for enhancement in dough quality. In PZ, success was not eminent in yield improvement ventures but this region is well known for good bread quality and high protein content. This is the only zone in the country where bread quality score was always more than 7. If any area can be demarcated in the country for harvesting wheat of high protein content, perhaps peninsular India would be the best choice. During the study period, improvement was witnessed in bread loaf volume, *chapati* score, protein content and grain appearance in couple of new varieties developed in PZ like HD 2932, MACS 6222, UAS 304 and AKAW 4627. Instead of quality, major concern in PZ is to break the yield barrier. Environment in NHZ is most congenial for good biscuit making but flour recovery is always less in the hills in comparison to the plains. In new wheat varieties of the region, extraction rate has gone still lower. To promote varieties good for baking, it is important to improve flour recovery in the new cultivars of the hill region.

The study has clearly demonstrated that it is possible to simultaneously enhance productivity and value addition in wheat. Besides genetic background and climatic condition, exploitation of phenotypic expression can also be useful in promoting value addition in high-yield wheat genotypes. In this endeavour, it is essential to promote quality based selection criteria. To follow this practice, strategic planning to develop infrastructure suited for grain quality analysis is crucial.

Authors' contribution

Conceptualization of research (DM, VT, RKG); Designing of the experiments (VT, RKG); Contribution of experimental materials (VT, RKG); Execution of field/lab experiments and data collection (VT, RKG); Analysis of data and interpretation (DM); Preparation of manuscript (DM).

Declaration

The authors declare no conflict of interest.

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