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Opinion Article

A Simplified Selection Strategy for Simultaneous Improvement in Product Quality and Grain Yield in Wheat Varieties of North-Western Plains of India

Devinder Mohan

ICAR - Indian Institute of Wheat and Barley Research, Karnal-132001, Haryana, India

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****Corresponding author:***
E-mail: devmohan@gmail.com

Abstract

Twenty years performance of high yield genotypes evaluated under timely sown and late sown conditions in the Received: national wheat research program of India were examined separately for the North-Western Plains region, to devise a simple and inexpensive strategy of simultaneous improvement in end-products and productivity. Relationship of four basic grain quality (test weight, protein content, sedimentation value and grain hardness index) and yield related parameters (plant height, days to heading, maturity period and thousand-grain weight) of bread wheat was analyzed with quality of the three end-products (bread, *chapati* and biscuit) to formulate a suitable selection criteria. Amongst the yield governing traits, plant height emerged as the most powerful indicator of improved product quality in majority of the cases. The grain hardness generally remained inconsequential and influenced only the biscuit quality of timely-sown wheat. This investigation underlines that it's not necessary to accomplish everything in the labs; field-based phenotypic evaluation during material generation can effectively also vary when sowing time differ. Crop phenology, a key factor under timely planting loses relevance when planting is done late. Selection criteria formulated for each product, suggests that highly significant improvement in product quality and grain yield is achievable in this highly productive region with the help of only one to three key factors.

Keywords: Bread wheat, crop phenology, plant height, selection criteria, quality traits, wheat end-products

1. Introduction

Improvement in quality of the bread wheat (*Triticum aestivum* L.) has gained attention all over the world. The wheat breeders need to choose not only the most appropriate production environment for developing a product but also assess feasibility of carrying such ventures successfully. In view of the food and nutritional security (Bekes, 2012; Grote *et al.,* 2021), breeding for better quality has now become a research priority, especially after attaining self-sufficiency in wheat production (Asseng and Milroy, 2006; Guzman *et al.,* 2016). Any quality improvement venture will find favour only when productivity is addressed simultaneously. A balance between wheat productivity and quality of the end-products is essential to meet food demands of ever-growing population in the country. In this context, significant progress has been made across various regions of the country especially the North-Western Plains Zone (NWPZ), globally known as part of the western Indo-

Gangetic plains (Khan *et al.,* 2023; Mohan *et al.,* 2017 & 2023).

Breeding for wheat quality is both labour intensive and expensive, requiring extensive laboratory testing across large number of samples. It becomes more complex when the aim is to improve quality of the end-products. For selection in the early generations, only those traits are likely to be preferred that are easy to handle and can be employed by non-destructive methods (Fisher *et al.,* 1989). Protein estimation, grain hardness and test weight fit well for such analysis. Besides these parameters, quality evaluation can easily be supported by sedimentation value, a test that demands just a few seeds for estimation of the gluten strength (Quick and Donnelly, 1980). All other tests, including gluten properties are applicable only in the last phase of varietal development when lines are genetically fixed (Michel *et al.,* 2018). Although the components related to wheat grain yield have been examined in detail, the studies related to relevance of the grain quality traits is rather limited (Asseng and Milroy, 2006; Uthayakumaran and Wrigley, 2010). In India, efforts have been made to identify the key component traits that define the quality of wheat end-products at the national level (Mohan and Gupta, 2013). Every agro-ecological region has unique characteristics related to value addition, crop phenology, and yield expression (Abbate *et al.,* 2010; Zecevic *et al.,* 2013; Mohan *et al.,* 2017 & 2023; Ma *et al.,* 2021). It is very likely that plant morphology or the growth stages that regulate the grain yield also have some influence on the quality of the grains and it shall be immensely useful if such plant characteristics are also given importance in the selection process (Reynolds *et al.,* 2011; Awulachew, 2019). Role of the crop phenology, especially plant height and days to heading has been reported to supplement augmentation of wheat flour recovery in Indian wheat (Mohan and Gupta, 2014). Relevance of physiological efficiency in wheat grains has also been mentioned by the wheat researchers of India (Mohan and Gupta, 2015a). It is crucial therefore to examine the relationship of major quality and yield components with the end-products and identify the key influencing factors for each production environment. Any strategy based on this study can be useful to harness simultaneous enhancement in grain yield and quality of the end-products.

The national wheat program of India i.e. All India Coordinated Research Project on Wheat and Barley (AICRPW&B) provides a good platform to examine all such issues and the wheat varieties are specific for each production environment (Mohan *et al.,* 2013a; Sharma *et al.,* 2015; Gbegbelegbe *et al.,* 2017). It is well known now that wheat productivity and quality of the harvested produce is cultivar and environment-specific (Williams *et al.,* 2008; Abbate *et al.,* 2010; Pena *et al.,* 2012; Zecevic *et al.,* 2013; Mohan and Gupta, 2015a; Ma *et al.,* 2021). Although this program conducts trials in five diverse production environments (zones), NWPZ was chosen for this study. In India, NWPZ appears to be the most suitable region for such studies as the crop gets the most conducive environment for wheat growth (Mohan *et al.,* 2022 & 2022a). This region represents a continuum of nearly 12 million hectares, highly productive area of spring wheat and CIMMYT has globally crafted it in mega-environment region (ME 1). Over the time, grain quality has attained importance in this region and some good quality wheat varieties have been developed (Mohan *et al.,* 2017 & 2023).

Advanced Varietal Trials data reported in the annual progress reports of AICRPW&B on quality and yield traits for the twenty-year period 2006-2025 was examined in this analysis. Study material involved released and pre-release wheat varieties (genotypes in the final year of testing) of NWPZ evaluated in such trials at multi-locations under two production environments i.e. timely-sown wheat (TSW) and late-sown wheat (LSW). Sowing of TSW starts with the onset of winter and is mostly completed by the middle of November. LSW is planted 20-30 days later as compared to TSW. Since LSW gets shorter life span, only the short-duration genotypes fit in this category. Fertilizer dose in TSW remains 150N:60P:40K kg/ha in TSW and 90N:60P:40K kg/ha in LSW. Since the study material involved high yielding varieties with high degree of rust resistance, the biotic stress was no major cause of concern and no chemical was sprayed to control the occurrence of any disease. The study material evaluated in the trials comprised multiple test sites therefore, annual mean was computed for each genotype for the three end-product i.e. bread loaf volume (BLV), *chapati* quality score (CQS) and biscuit spread factor (BSF); the four grain quality traits i.e. test weight (TW), grain protein content (GPC), grain hardness index (GHI) and sedimentation value (SV);

and the four productivity related parameters, like plant height (PH), days to heading (DH), days to maturity (DM) and 1000-grains weight (TGW). Samples for grain quality parameters were received from five locations namely Ludhiana, Hisar, Delhi, Pantnagar and Durgapura. This exercise explores the potential for improving the product quality through the support of basic yield-governing growth parameters and four basic grain quality parameters. Attention is also drawn to analyse whether plant selection exercised in the field can complement the influence of basic grain quality components examined in the labs. Any quality breeding strategy becomes irrelevant if it has negative impact on grain yield. Therefore, influence of the key constituents on yield was also examined in this analysis. This investigation suggests simple and inexpensive selection criteria to breed product-specific wheat varieties with significant enhancement in quality and grain yield for the most productive wheat land of the country.

2. Quality and yield status in NWPZ

The coordinated trial reports of AICRPW&B suggest that during the 20-year study period, there were only 107 entries of TSW and 100 of LSW, where observations on all three aspects i.e., product quality, grain quality and yield components were available in NWPZ. Earlier reports suggest product quality in NWPZ is quite satisfactory (Mohan *et al.,* 2017 & 2022). Although the best region for bread quality is the peninsular India (PZ) where BLV was 572cc in TSW and 571cc in LSW, the NWPZ is not far behind and the difference is not that big as BLV was 562cc in TSW and 564cc in LSW (Table 1). BLV range in NWPZ suggests that there were instances when bread quality was very good as BLV exceeded 600cc in many genotypes. Similarly, central India (CZ) is best known for *chapati* quality and the CQS was 7.89 in TSW and 7.79 in LSW during this period. In comparison, the NWPZ also exhibited satisfactory *chapati* quality, with mean CQS values of 7.56 under TSW and 7.60 under LSW. Several genotypes recorded excellent *chapati* quality, with CQS values of ≥8.0 in NWPZ as well. Of course, biscuit quality is best in northern hills zone (NHZ) but that's only under late sown conditions. Overall biscuit quality in NHZ was better than other regions only in LSW (BSF: 8.30); otherwise it was just 7.26 in timely-sown wheat of the hill region. In comparison, biscuit quality in NWPZ was

Table 1. Overall performance in quality and yield related parameters

Parameter	Timely sown wheat (107)			Late sown wheat (100)		
	Mean	Range	CV (%)	Mean	range	CV (%)
End-product quality						
Bread loaf volume (cc)	562	508 – 648	4.32	564	448 – 618	3.82
Chapati quality score	7.56	6.95 – 8.00	2.90	7.60	7.09 – 8.32	2.61
Biscuit spread factor	7.27	5.94 – 8.90	9.42	7.33	6.10 – 8.82	7.51
Grain quality traits						
Test weight (kg/hl)	78.4	74.2 – 82.1	2.19	78.0	72.9 – 80.2	1.88
Grain protein content (%)	11.9	10.2 – 14.0	6.83	12.3	10.9 – 14.6	5.71
Sedimentation value (ml)	49.0	26.0 – 69.0	20.1	46.9	30.0 – 70.0	22.0
Grain hardness index	76.9	54.0 – 92.9	10.4	79.5	59.0 – 96.0	9.23
Yield attributes						
Grain yield (q/ha)	53.8	44.6 – 69.1	11.4	43.4	35.9 – 53.5	11.4
Days to maturity	143	134 – 152	2.33	122	118 – 129	1.97
Days to heading	97.1	84.0 – 107	4.73	83.0	74.0 – 89.0	4.09
Days to grain filling	47.0	38.0 – 56.0	6.26	39.2	33.0 – 45.0	6.75
Plant height (cm)	95.8	80.0 – 112	7.36	88.6	76.0 – 98.0	5.71
1000 grains weight (g)	39.8	32.0 – 51.0	7.98	36.5	33.0 – 45.0	5.98

Figure in the parenthesis indicate number of test entries equally competitive (TSW: 7.28; LSW: 7.33). There were many instances in this region when BSF exceeded the 8.00 mark in both categories of wheat. Although GPC is moderate in NWPZ, the grains are generally hard textured (GHI ≥ 75). Gluten strength (SV) and gluten quality (GI) in NWPZ have been the highest amongst all five zones of the country. NWPZ has consistently registered the highest productivity in the country. Since the abiotic stress is minimal in this region, the crop expression measured through plant height and crop phenology is generally superior. Although late sowing exposes the crop to terminal heat stress, causing significant reductions in plant height and crop duration, the extent of variation (coefficient of variation, CV) remains nearly the same under both sowing conditions for yield as well as the grain quality parameters.

3. Relevance of chosen yield and quality governing traits on product quality

In a wheat breeding program, the first priority is always yield enhancement and then comes the product quality. To develop product-specific wheat varieties, it is imperative to identify the traits that are associated in each product under the background of high-yield. Regression analysis revealed that in high yield timely-sown varieties of NWPZ, the bread quality (BLV) was strongly influenced by the variations occurring in SV, HT, DH and DM (Table 2). The crucial factor for *chapati* under normal planting was solely the test weight. The relevance of fundamental grain traits differed in case of biscuit. Since the genotypes and the environment differed in LSW, the associated grain components also differed. Highly significant grain constituent was GPC in bread, SV and GPC in *chapati* and SV in case of biscuit. A highly significant impact of protein can also be realized only in bread and *chapati* quality of LSW and the impact was negative in this environment. Test weight registered highly significant association with *chapati* and biscuit quality of TSW but the impact was negative in case of BSF.

Results indicate that the least important component amongst the four fundamental quality traits is the grain hardness. It can have relevance at best only in biscuit quality of TSW and the impact is highly negative. This suggests that in the high-yielding varieties of the NWPZ, grain softness is influential only under timely-sown conditions. It indicates that further improvement in grain hardness of wheat varieties may remain inconsequential for quality of bread and *chapati*. This study highlights that yield-governing traits play a crucial role in determining end-product quality of wheat in NWPZ (Table 2). The crop phenology and plant height are highly important, at least in bread and biscuit quality of TSW. In LSW, however, it is just the plant height that matters and that also only in bread and biscuit.

Table 2. Association of grain quality and yield related traits in product quality

Parameter	Regression coefficient (R^2)							
	Timely-sown wheat				Late-sown wheat			
	BLV	CQS	BSF	Yield	BLV	CQS	BSF	Yield
Grain quality traits								
Test weight	0.002	0.148***	0.065** (-)	0.086***	0.038* (-)	0.000	0.000	0.035
Grain protein content	0.009	0.004 (-)	0.030	0.246*** (-)	0.064**	0.066** (-)	0.047* (-)	0.158*** (-)
Sedimentation value	0.099***	0.000	0.225***	0.192***	0.042*	0.067**	0.064**	0.184***
Grain hardness index	0.024 (-)	0.021 (-)	0.062** (-)	0.007 (-)	0.005 (-)	0.034	0.001 (-)	0.147***
Yield attributes								
Plant height	0.101***	0.022	0.191***	0.523***	0.060**	0.001	0.136***	0.199***
Days to heading	0.091***	0.000	0.090***	0.016	0.018	0.000	0.024	0.013
Days to maturity	0.202***	0.000	0.093***	0.139***	0.006	0.001	0.003	0.158***
Days to grain filling	0.001	0.000	0.015	0.057*	0.011	0.000	0.021 (-)	0.057*
1000 grain weight	0.033 (-)	0.023	0.000	0.395***	0.019 (-)	0.018	0.000	0.067**
Grain yield	0.036*	0.064**	0.070**	-	0.060**	0.111***	0.013	-

(-) indicates negative impact; ***, ** and * indicates the significance level at *P* 0.001, 0 01 and 0.05.

It was evident that phenology of wheat crop had no role to play in high-yield derivatives developed for late planting. It was also very clear that TGW had no significant role to play in product-quality of wheat. In NWPZ, the most striking outcome of the wheat breeding program has been a simultaneous improvement in yield and product quality (Mohan *et al.,* 2017 & 2023), and it is reconfirmed by this study but for the biscuit quality of LSW.

4. Comparative contribution of yield and quality traits to uphold product quality

It's very clear from this study that many basic grain quality parameters and the yield-governing trait have a definite role to play in high-yield wheat varieties of NWPZ. Contribution of these two categories of traits was further compared by regression analysis. Comparison of multiple coefficient of determination (R^2) in each group separately and in combination revealed that in high yielding varieties of NWPZ, there was marked increase in the R^2 value when the morphological traits were also regressed along with quality parameters (Table 3). The grain traits were of course useful too, but their impact was complemented by a highly significant margin when the morphological traits were also clubbed. Regression analysis has revealed that the contribution of yield traits was highly significant in bread quality of TSW and biscuit quality of both categories of wheat. There were also instances when individual contribution of crop morphology wasn't significant, but it gave a big boost to grain quality traits as noticed in *chapati* quality of TSW where R^2 value jumped from 0.196 to 0.311. This analysis has clearly demonstrated that in wheat breeding, it's not only the grain quality traits but the yield-contributing components can also be useful in elevating standard of the wheat end-products. Analysis made it amply clear that in NWPZ, highly significant improvement can be sought by a handful of quality and yield traits. It also emphasizes that the influence of quality parameters on end-product quality can be further enhanced when morphological traits are also considered in.

Table 3. Relationship of grain quality and yield related parameters with the wheat end-products

End-product	Regression coefficient (R^2)					
	Timely-sown wheat			Late-sown wheat		
	Quality traits	Yield traits	Quality + yield traits	Quality traits	Yield traits	Quality + yield traits
Bread	0.120^{**}	0.221^{***}	0.382^{***}	0.143^{**}	0.094^{*}	0.239^{***}
Chapati	0.196^{***}	0.042	0.319^{***}	0.137^{**}	0.019	0.177^{*}
Biscuit	0.319^{***}	0.231^{***}	0.369^{***}	0.133^{**}	0.155^{***}	0.334^{***}

***, ** and * indicates the significance level at *P* 0.001, 0 01 and 0.05.

5. Key traits associated with products quality

Though collective contribution of the quality and morphological traits is quite distinct in each group, every trait might not register significant participation in this relationship. In such a conditions, the key constituents can be identified which are supposed to be the main factor for bringing highly significant improvement in the product quality (Table 4). To identify the main factors, the multiple regression analysis is highly useful and while computing it, only those components were retained which had registered significance individually as well. These traits can be marked as the key predictors of wheat product quality in NWPZ. This analysis revealed that 31 to 37 percent variation in end-products of TSW could be attributed to handful key constituents (Table 4). Since the role of phenology was negligible in bread and *chapati* quality of LSW, its relevance was also limited as the R^2 value was reduced to 0.13- 0.14. In comparison, the contribution of key components was quite high in biscuit quality of LSW as well (R^2: 0.30^{***}). This analysis revealed that all four yield-governing traits express very high significance in establishing bread quality of TSW. Besides, high test weight and grain protein content also contribute in this highly significant relationship (R^2: 0.37^{***}).Amongst all the components, highest contribution was derived from maturity days. In LSW wheat, however, the key predictors were restricted to just two i.e. protein content and plant height. Both the constituents registered positive and very high contribution in this relationship (R^2: 0.14^{***}). In *chapati* quality of TSW, every trait except sedimentation value and grain weight mattered in NWPZ but the largest contribution was derived from test weight. In LSW of this region, only height and lesser protein content was noted suitable in *chapati* quality of high yield bread wheat varieties (R^2: 0.13***). Only three factors contributed in biscuit quality of TSW namely, high sedimentation value, delayed flowering and lesser protein content (R^2: 0.32***). Number of key factors was doubled in BSF of LSW and only sedimentation value and grain size were observed irrelevant in this situation. In biscuit quality of LSW, protein content, grain hardness and crop duration exerted negative influence in this relationship; whereas height, delayed heading and test weight contributed positively in this relationship (R^2: 0.32***).

Table 4. Key components in the end-products

Product	R^2 value	TW	GPC	SV	GHI	HT	HD	DM	TGW
Timely sown wheat									
Bread loaf volume	0.373***	0.252*	0.222*			0.435***	-0.336***	0.583***	-0.404***
Chapati quality score	0.308***	0.636***	0.237*		-0.191*	0.335**	0.358*	-0.350*	
Biscuit spread factor	0.322***		-0.204*	0.425***			0.284***		
Late sown wheat									
Bread loaf volume	0.141***		0.288***			0.280***			
Chapati quality score	0.127***		-0.247**	0.247**					
Biscuit spread factor	0.303***	0.193*	-0.360***		-0.273**	0.422***	0.499***	-0.388***	

***, ** and * indicates the significance level at *P* 0.001, 0.01 and 0.05.

The relevance of height and phenology had been reported in product-quality of the Indian wheat (Mohan and Gupta, 2014& 2016). Strong relationship of early anthesis, long grain-filling period, and high grain growth rate with high protein concentration had also been reported in winter wheat by Mou *et al.* (1993). Earlier reports have indicated that early heading, extra plant height and steady grain ripening help in improvement of *chapati* score under Indian conditions (Mohan and Gupta, 2016). It was a pointer that short height and delayed heading is detrimental to the quality of this domestic product. They had also mentioned that the taller genotypes fail to make good bread. Their work had also suggested that long pre-anthesis and short post-anthesis growth phases were detrimental to the quality of the cookies. In contrast to *chapati* score, biscuit quality was presumed to require delayed heading and faster grain development. Strong associations of the morphological traits in these three end-products of the Indian varieties had been reported across the zones by Mohan and Gupta (2016).

6. Relationship of key product specific components on grain yield

Since the motto of this investigation was to improve the products quality without losing yield, the relationship of the key associated factors has to be examined with yield. It is important, therefore, to examine the impact of the yield governing traits on the basic grain quality constituents in high-yield genotypes of NWPZ. It's interesting to observe that sedimentation and grain yield express very strong positive association, as R^2 was highly significant in both categories of wheat (TSW: 0.19***; LSW: 0.18***). Test weight also expressed a positive impact on yield, but the association was highly significant only in TSW (R^2: 0.086***). An inverse relationship between protein content and grain yield is well known in wheat and it is affirmed in the background of high yield also as the impact was negative and R^2 was highly significant between these two components (TSW: 0.25***; LSW: 0.16***). Grain hardness presumably has a positive influence on wheat yield but this relationship was not significant in TSW varieties of NWPZ. In LSW, however, this association was positive and highly significant in the region (R^2: 0.15***). Impact of some of these traits on the grain yield of wheat is well known. Negative impact of GPC on wheat grain yield has been reported in many studies by Oury and Godin (2007), Mohan *et al.* (2013) and Geyer *et al.* (2022). The relevance of height, heading and maturity in productivity enhancement of wheat under different production environments of India has also been reported by Mohan *et al.* (2022).

7. Selection criteria for simultaneous improvement in yield and products quality

This study was aimed to have an insight into selection criteria that can be useful in NWPZ to breed wheat varieties that have not only the good product quality but have better grain yield as well. To formulate such a selection criteria, it is imperative to exclude the traits that have either little significance or exert negative influence on yield. Breeding prospects in any production environment depends upon the relationship of yield with the given product. Involvement of the agronomic traits in the selection strategy has been suggested by Mohan and Gupta (2015& 2016) and Maich (2017). The direction of correlation is independent of breeding objectives and may change from one production environment to another (DePauw, 2007). This was reaffirmed in high yield genotypes of NWPZ as well. If high grain weight is not conducive for bread and *chapati* making (Table 4), it's better to exclude it while formulating selection criteria for simultaneous improvement in quality and grain. Similarly, bolder grains might not be conducive for bread making, but a compromise on grain weight would hamper the yield.

Re-evaluating the multiple regression models after excluding grain weight and protein content demonstrated that prospects of improvement are still quite high in TSW of NWPZ. With just 2-3 parameters, highly significant improvement can be sought in both aspects of breeding. In TSW, the key traits were the crop duration and sedimentation value in the case of bread, whereas test weight and plant height were instrumental in chapati making. In biscuit quality of NWPZ, sedimentation value and heading days were paramount. Besides, lower protein content was also useful to improve the quality of the cookies. In comparison to TSW, association of the key components was weak in LSW as just 13-14 percent variation in chapati and biscuit could be related with the key components. Though the R2 (0.06**) value was highly significant in BLV but prospects were not so good when compared to the other two products. Under late sown condition, only one trait was associated in bread as well as biscuit and that was the plant height. For chapati score, however, protein and sedimentation value emerged as significant key components. Though the impact of protein was negative in the relationship, it suits the grain yield. The majority of the Indian wheat is consumed for chapati making (Hemalatha *et al.,* 2007) and this study illustrates that the prospects of elating the chapati score along with this simple selection strategy can work very well in NWPZ. A study on wheat varieties of Haryana in India has revealed the absence of any association between protein and chapati score, but within an individual variety, usually higher protein resulted in a higher chapati score (Coventry *et al.,* 2011). An overview of the parameters associated in Table 5 indicates that plant height is the most useful attribute in the breeding adventures aimed to improve the product's quality along with grain yield. Grain-weight has no role to play in wheat improvement research activities when focus is both on products quality and the yield. If yield is ignored, then TGW can matter but negative selecting will be the choice in that case.

Table 5. Key components for simultaneous improvement in product and grain yield

Product	R^2		Beta value of key components						
	Product	Yield	TW	GPC	SV	GHI	HT	HD	DM
Timely sown wheat									
Bread loaf volume	0.242***	0.260***			0.207*	-			0.393***
Chapati quality score	0.190***	0.681***	0.413***			-	0.207*		
Biscuit spread factor	0.322***	0.444***		-0.204*	0.425***	-		0.284***	
Late sown wheat									
Bread loaf volume	0.060**	0.199***				-	0.244***		
Chapati quality score	0.127***	0.328***		-0.247**	0.247**	-			
Biscuit spread factor	0.136***	0.199***				-	0.369***		

***, ** and * indicates the significance level at P 0.001, 0 01 and 0.05.

Endosperm texture (grain hardness), in wheat is the single most important and defining quality characteristic, as it affects milling, baking and end-use quality (Pasha *et al.,* 2010; Nucia *et al.,* 2021; Ni *et al.,* 2022). Grain hardness directly dictates wheat milling behavior, fracture dynamics, and starch damage, separating wheat into distinct processing paths: hard wheat fracture along cell boundaries producing coarser, starch-damaged particles ideal for yeast breads, while soft wheat fractures through starch-protein interfaces creating fine, undamaged flour suited for pastries (Dziki and Laskowski, 2005). Grain hardness variation has large effects on many different end-use properties of wheat (*Triticum aestivum*). The *Hardness (Ha)* locus consisting of the *Puroindoline a* and *b* genes (*Pina* and *Pinb*) controls the majority of grain hardness variation (Feiz *et al.,* 2008). Grain hardness in Indian wheat dictates milling performance, water absorption, and final food uses, primarily sorting varieties into hard types for *chapati* and bread versus soft types for biscuits. Hard wheat milling produces higher levels of damaged starch; soft wheat produces minimal starch damage. Most commercial Indian bread wheat (*Triticum aestivum*) falls into medium-hard to hard categories.

Though soft grain texture has been emphasized as paramount in biscuit making (Ram and Mishra, 2008; Mohan *et al.,* 2013), it didn't emerge as the key component in NWPZ. Generally, grain softness is slated to be the prime factor for biscuit quality. But when it is equated with yield, it's not only the grain softness but other quality attributes like lower grain protein content, test weight, and plant height also become equally important under certain environmental conditions. A negative relationship between grain softness and wheat yield is primarily a trade-off and a central challenge in wheat breeding, as farmers seek high yields while millers and bakers require specific hardness levels for end-use quality. The relevance of grain hardness and milling yield of wheat is well known (Hruskova and Švec, 2009; Pasha *et al.,* 2010; Choy *et al.,* 2015), but its impact on yield of the grains has not been evaluated under diverse environments. Milling yield i.e. extraction rate, was examined in the test entries only up to 2017. During those 12 years, extraction rate was calculated in 70 entries of TSW and 72 of LSW. In both wheat categories, relationship between the milling yield and grain hardness was non-significant and the R2 value was 0.041 in TSW and 0.011 in LSW. It shows that the existing grain hardness level in high yield varieties seem to sufficient to harness balancing between end-product quality, milling yield and productivity of this crop.

8. Way forward

Prediction of wheat products quality is slated to be a highly very complex process. Some recent advances in predicting products quality (Zieger *et al.,* 2026) have advocated the use of near-infrared (NIR) spectroscopy and a flour fractionation approach (sieve fractionation, dough preparation, gluten washing). Use of spectroscopic, rheological and analytical measurements is also in reports (Azizinia *et al.* 2023; Zieger *et al.,* 2025; *Akiyima et al.,* 2026). Numerous linkage mapping studies have shown that a large number of QTL with small effects control most end-product quality related traits to be useful in breeding programs. MAS is unlikely to be able to capture sufficient variance of these traits useful in wheat breeding (Kristensen, 2018; Yang *et al.,* 2020). Genomic selection can now be routinely implemented through establishment of prediction models. But these advance techniques are quite expensive and can only be adopted at few wheat research centers. Breeding for enhancing end-use quality in India requires the simple techniques that are easy to follow, don't demand high expenses and premium on productivity of this staple crop.

A quantum jump in wheat quality improvement is hard to find and every breeding centre can't afford good quality labs. However, it will be immensely useful if a breeding strategy could be formulated to enhance productivity and quality by a highly significant margin and with minimal effort. As underlined in this investigation, the breeding strategy to improve grain yield and grain weight varies in different production environments (Mohan *et al.,* 2022a). This study demonstrates that for such ventures, it's not necessary to accomplish everything in the labs; some efforts can be done in the field as well while raising the breeding materials. It has been convincingly underlined that selection made in the field for morphological traits like plant height and crop phenology also proves useful for quality of the product and can complement the impact of grain quality attributes. This selection procedure is highly useful, as it involves no extra expenditure. Equipment required to examine grain hardness is quite expensive and these investigations demonstrated that it's not all that necessary when the focus is on grain yield and quality of the wheat products. It has been established in this study that just three simple grain parameters, namely test weight; grain protein content and sedimentation value are good enough for further enhancement in product quality. And this exercise has simplified the breeding procedure to a great extent, as it highlights the relevance of just 1-3 parameters for improving the end-products in high yield wheat varieties of NWPZ.

It is amply clear now that in the high-yield wheat land of India, early-maturing genotypes will not be useful for bread quality under timely-sown conditions. To maximize the return, negative selection for crop duration and positive selection will ensure significant improvement in this situation. For *chapati* score, test weight and plant height are the two prominent indicators. To optimize biscuit quality, high-protein and early-flowering genotypes should be selected against, while lines with higher sedimentation values should be prioritized. Similar benefits can be achieved in late-sown wheat also, but success is rather limited. However, preference for plant height definitely ensures significant improvement in bread and biscuit quality, along with highly significant grain yield. A combination of high gluten strength i.e., sedimentation value and lesser protein content is equally important to improve *chapati* quality of the late-sown wheat crop grown in the western Indo-Gangetic plains.

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