Relevance of physiological efficiency in wheat grain quality and the prospects of improvement

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Abstract Released and pre-released bread wheat varieties evaluated in national wheat programme of India (503 genotypes) during 2005–14 under different environments were examined for the role of physiological parameters in grain quality. Genotypes with slow plant height growth but faster rate of grain filling enhanced protein content. Plants where growth in height and grain development was slow, grains were hard, provided proportionate vegetative growth phase is longer. Steady grain growth rate benefited gluten strength and gluten quality. Irrespective of total crop duration, longer reproductive phase was an effective indicator of higher flour recovery and test weight. Magnitude and significance of morphological attributes in grain quality was almost similar to that of physiological processes, therefore prospects of utilizing these field traits were examined to enhance grain properties. Early heading and longer grain filling was effective to increase test weight whereas delayed heading and shorter plant height enhanced protein content. Bold grains hampered grain hardness and delayed heading added more bran in the flour. Genotypes with poor grain bearing and quick grain ripening had lower sedimentation value. Instead of protein, it was wet gluten which expressed negative association with yield. To improve gluten quality, extended reproductive phase but with less grain weight was helpful. Contribution of longer post-anthesis period was observed crucial in flour recovery. These useful simple field expressions can be deployed to uplift quality of wheat grains.

Keywords Grain quality · Indian wheats · Morphological traits · Physiological parameters

Introduction

Significance of cultivar and environment in grain quality of bread wheat (*Triticum aestivum* L.) has been well emphasized all over the world. (Souza et al. 2004; Zhang et al. 2004; Williams et al. 2008; Sarkar et al. 2014). Relevance of environmental fluctuations on yield and quality of Indian wheats and zone specific characterization is also in reports (Mohan et al. 2011; Mohan et al. 2013a). Change in growth environment also affects agronomic traits and the physiological processes. De Vita et al. (2007) had reported that the physiologically efficient genotypes possess agronomic traits suitable for growth, development and grain formation. Crop phenology often changes in different climates and even when maturity duration remains same, differences do occur in vegetative and reproductive periods which can cause alterations in grain growth. Such processes and attributes have been examined in wheat for grain yield but their reflection on grain quality attributes has not been investigated. Few attempts had covered couple of quality parameters but such investigations were restricted to moisture/temperature stress or alterations in planting time (Guttieri et al. 2001; Gooding et al. 2003). Protein accumulation in wheat grains through rate and duration of grain filling had been touched in some studies (Wardlaw and Moncur 1995; Spiertz et al. 2006; Mladenove et al. 2012). Efforts to understand influence of the environment, genotype and their interactions on end-use quality had been done in India (Mohan and Gupta 2011) and other parts of the world (Zhang et al. 2004 and Souza et al. 2004) but the contribution of yield determinants or physiological parameters has not been properly examined. When agronomic and physiological

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attributes are known to affect grain yield significantly, their effect on grain quality also needs to be addressed with same intensity as both aspects relate to grain development processes.

While developing high yielding varieties, there is need to study the role of physiological processes and morphological attributes in grain quality. The data generated by the All India Coordinated Wheat and Barley Improvement (AICW&BIP) could be quite useful for this purpose. AICW&BIP evaluates and recommends wheat varieties suited for different environments and gathers data related to yield components like height, heading and crop duration along with grain properties related with processing quality. Huge information generated in this programme under different environments has been utilized to assess importance of physiological growth indicators in grain quality of wheat.

Materials and methods

Experimental material and observations

Study material included data on released cultivars and the pipe-line varieties in multi-location irrigated trials of AICW&BIP conducted in five major zones i.e. northern hills zone (NHZ), north-western plains zone (NWPZ), north-eastern plains zone (NEPZ), central zone (CZ) and peninsular zone (PZ). Test entries included genotypes evaluated under two production conditions i.e. timely-sown and late-sown and in total 503 entries, tested in five zones during the ten year period 2005–14, were examined. Data generated on height, flowering days, maturity, 1000-grain weight and grain yield were extrapolated to derive four physiological parameters i.e. i) rate of height increase during vegetative phase (HIR), ii) grain growth rate during grain filling (GGR), iii) ripening-maturity index (RMI) which represented percent crop duration utilized for grain filling and iv) yield-fill rate (YFR) during post-anthesis period. Agronomic attributes addressed in the study were plant height (HT), days to heading (DH), grain filling period (GFP), 1000 grain weight (TGW) and grain number per m² (GRN). Samples received from 3 to 5 locations of each zone were analysed at ISO 9001-2008 certified laboratory for quality attributes found important in end-product quality of Indian wheat like grain hardness index, sedimentation volume, grain protein at 14 % grain moisture, dry gluten content, gluten index, test weight and flour extraction rate (Mohan and Gupta 2013b). AACC (2000) method was applied to examine the processing quality. Protein content was measured by infra-red transmittance based instrument Infra-tec 1125. Single kernel characterization system 4100 was used to measure grain hardness whereas Quadrumat Senior mill was used for flour recovery.

Statistical analysis

Data pertaining to five zones and two production conditions are presented as means and Student t-test at P 0.05 is applied for comparison. To study association and contribution of field traits with grain quality, data were standardized according to each environment (zone and production condition) and statistical analysis was done using data analysis tool provided in Microsoft excel programme of computer. Multiple regression analysis was applied to workout contribution of the component traits and Pearson correlation was derived to establish association between two variables.

Results

Comparison of production conditions and zones

Due to shorter crop duration, reduction in plant height, crop duration, grain size and grain yield are obvious in late-sown wheats as they were planted 15–20 days late. Results indicated that physiological efficiency was also altered and changes could be observed in pre-and post-anthesis stages of crop growth. HIR and GGR were higher in late-sown wheats whereas YFR was better in timely-sown wheats (Table 1). Some parallelism could also be observed between grain quality and the physiological processes. Higher HIR and GGR in late-sown wheats were linked with better protein and gluten contents but reduction occurred in test weight.

Due to different agro-climatic conditions, crop morphology changes zone-wise and differences in grain quality parameters are obvious. To substantiate it, performance of timely-sown genotypes in different zones is presented in Table 1. Due to changes in crop duration and other yield determinants, physiological growth process also differed. All five zones expressed different values in four growth related physiological parameters and variations were quite large in RMI and HIR. The zones with highest test weight and flour recovery (CZ and PZ) also had high RMI and HIR values. A zone slow in physiological growth like NHZ was also poor in several grain properties like protein, grain hardness and flour recovery.

Physiological traits and grain quality

Realizing influence of certain growth indicators on grain quality, investigation was focused to check whether physiological processes contribute in grain quality, too. Contribution of quality linked physiological attributes was assessed through multiple regression analysis (Table 2). Regression coefficient (R value) revealed that collective contribution of physiological attributes was significant even at $P \leq 0.001$ in test weight, grain protein content, grain hardness index, sedimentation

Table 1 Growth pattern and grain quality in different environments

Parameters	Production condition [*]		Zones (Timely-sown) [*]				
	Timely-sown (249)	Late-sown (253)	NHZ (45)	NWPZ (61)	NEPZ (72)	CZ (35)	PZ (36)
<i>Morphological traits</i>							
Plant height (cm)	91	83	98	92	91	89	82
Days to heading	87	74	125	97	79	67	60
Grain filling period (days)	45	40	45	45	43	50	43
Crop duration	132	114	170	142	122	117	103
1000 grain weight (g)	40.8	38.6	40.6	38.8	40.2	44.8	41.6
Grain number/m ² (‘000)	11.2	9.98	11.1	12.8	10.2	11.2	10.7
<i>Physiological parameters</i>							
Height increase rate (cm)	1.09	1.17	0.79	0.95	1.16	1.34	1.35
Ripening-maturity index (%)	34.9	36.0	26.7	32.0	35.5	42.7	41.7
Grain growth rate (mg)	0.91	0.96	0.91	0.86	0.93	0.90	0.96
Yield-fill rate (kg)	101	95	99	109	95	100	102
<i>Grain quality</i>							
Test weight (kg/hl)	79.7	78.7	80.4	78.1	78.7	81.7	81.2
Grain protein content (%)	11.4	12.0	10.8	12.0	11.2	10.9	12.0
Grain hardness index	76	73	74	77	76	74	77
Sedimentation value (ml)	42	44	41	44	44	40	41
Dry gluten content (%)	9.75	10.3	9.12	10.1	9.43	9.72	10.5
Gluten index (%)	60	59	62	64	61	53	54
Flour extraction rate (%)	68.7	68.9	64.7	68.6	69.9	69.8	70.2

^{*} Figure in the parenthesis indicate number of entries

value and gluten index. Significance level was of lower order ($P: 0.05$) in case of gluten content and flour extraction rate.

Since contribution of all traits cannot be equal and some traits are also inter-linked, an exercise was done to identify the key components where direct contribution of each involved trait was also significant in multiple regression analysis (Table 2). This approach has been applied by Trethowan et al. (2001) to identify key contributors in yield and grain quality of wheat. In this analysis, emphasis was made to indentify the determinants where individual contribution was also significant. Significant contribution in test weight was

derived from HIR, RMI and YFR and the most assertive parameter amongst them was RMI and its contribution was positive. All four traits were involved in grain hardness and impact of each one was negative. For protein content, sole contributor was HIR and its effect was negative. Similarly, GGR was the sole contributor in gluten index and its impact was also negative. In wet gluten, two determinants were involved i.e. RMI and YFR and each one had inverse relationship. Flour recovery was benefited positively by RMI. Results showed that four traits were important in grain quality and impact of each one was character specific (Table 3).

Table 2 Individual and combined contribution of physiological traits

Quality parameters	Beta value				R value	
	HIR	RMI	GGR	YFR	Key traits	All 4 traits
Test weight	−0.186 [*]	0.635 ^{****}	—	0.170 ^{**}	0.495 ^{****}	0.496 ^{****}
Grain protein	−0.177 ^{****}	—	—	—	0.177 ^{****}	0.210 ^{***}
Grain hardness	−0.130 ^{**}	−0.342 ^{****}	−0.374 ^{****}	−0.241 ^{***}	0.413 ^{****}	0.413 ^{****}
Sedimentation value	0.104 ^{**}	—	−0.191 ^{****}	0.158 ^{***}	0.202 ^{****}	0.203 ^{***}
Wet gluten	—	−0.174 ^{**}	—	−0.180 ^{**}	0.135 ^{**}	0.152 [*]
Gluten index	—	—	−0.192 ^{****}	—	0.192 ^{****}	0.201 ^{***}
Extraction rate	—	0.125 ^{**}	—	—	0.125 ^{**}	0.137 [*]

^{*}, ^{**}, ^{***} and ^{****} denote significance at P 0.05, 0.01, 0.001 and 0.0001, respectively

Table 3 Individual and combined contribution of morphological traits

Quality parameters	Beta value					R value	
	HT	HD	GFP	TGW	GRN	Key traits	All 4 traits
Test weight	–	–0.329****	0.208****	0.184***	0.147**	0.468****	0.496****
Grain protein content	–0.136**	0.174***	–	–	–	0.174***	0.210***
Grain hardness index	–0.136**	–	–	–0.531****	–0.230****	0.474****	0.413****
Sedimentation value	–	–	0.111**	–	0.150**	0.164***	0.203***
Wet gluten	–	–	–	–0.149**	–0.192***	0.165***	0.152*
Gluten index	–	–	0.133**	–0.162***	–	0.179***	0.201***
Flour extraction rate	–	–0.115**	–	–	–	0.115**	0.137*

*, **, *** and **** denote significance at P 0.05, 0.01, 0.001 and 0.0001, respectively

Morphological traits and grain quality

Since all grain parameters were derived from morphological traits, attempt was made to study contribution of morphological traits in the same pattern. It was noticed that magnitude and significance of five morphological attributes was almost similar to that of physiological process. Key components were derived in agronomic traits as selection can effectively be exercised on the basis of field traits. Contribution of key morphological components was assessed at $P \leq 0.01$. In test weight, positive contributors were GFP, TGW and YFR whereas HD made negative contribution. HD and GFP alone could raise the R value up to 0.441 ($P < 0.0001$). HT and HD emerged as two main determinants for protein and the role of HT was negative in this association. For grain hardness; three components i.e. HT, TGW and GRN contributed significantly and impact of each one was negative. As an individual parameter, TGW expressed very strong negative correlation with grain hardness ($r: 0.40$, $P \leq 0.01$). Sedimentation value was derived from two determinants i.e. GRN and GFP and their impact was positive. GRN and TGW expressed negative contribution in wet gluten content. Gluten index was benefitted positively by GFP and negatively by GRN. HD was the only morphological contributor in flour recovery and its effect was negative.

Discussion

Quality of wheat grains is often related with cultivar's genetic background and the environment in which it is grown (Sial et al. 2000; Rharrabti et al. 2003; Veselinka et al. 2009; Nikola et al. 2010; Mohan and Gupta 2011). Differences in quality expression among different zones and production conditions had also been indicated in Indian wheats by Mohan et al. (2011). Could it be linked with morphological expressions and physiological growth processes? It could not be denied out-rightly because some parallelism was apparent in this

study between grain quality characteristics and the physiological parameters. It is well established that heading and grain filling duration are highly sensitive to abiotic variations (Bordes et al. 2008). Manifestation of environmental influences, be it production condition, climatic variation or any other abiotic stress, is first realized in field through height, phenological expressions and grain development. Besides, this investigation added another dimension that physiological processes related to such expression also matter in wheat grain quality as change in such expressions commensurate with grain formation, growth and development (De Vita et al. 2007). In different environments, physiological parameters like initial growth rate to attain height and the percent crop duration for grain filling did connect with grain quality parameters in this study; especially flour recovery, test weight and grain protein concentration.

In varietal development process, breeders want to enrich grain quality along with grain yield. Mohan et al. (2014) reported that extent of variations occurring in wheat due to non-grain parameters is similar for yield and quality related components. The study demonstrated that at genotypic level also, strong associations exist between quality traits and physiological parameters. Attaining height at faster rate benefits test weight but can be detrimental for protein content and grain hardness. In wheat, longer grain filling period benefits for higher test weight, flour recovery and gluten index but with some reduction in protein content. When growth rate is steady, genotypes get enriched test weight, grain hardness, sedimentation value and gluten index. Study indicates that higher yield filling rate during post-anthesis period is not good for test weight. Except gluten content where contribution of the correlated trait was significant at P 0.05 only, all other quality traits derived strong contribution from the physiological processes. Contribution of such parameters is highest in test weight, grain hardness and protein content followed by gluten index, sedimentation value and flour recovery. Significant association of high grain growth rate with high protein concentration was reported in winter wheats by Mou et al. (1993).

Effect of post-anthesis period on test weight was reported by Stone and Nicolas (1995) and Mladenove et al. (2012). This analysis reveals that physiological efficiency of the genotypes alters grain quality as GGR is related inversely with grain hardness. Higher GGR improvised kernel weight ($r = 0.57$; $P < 0.001$) which ultimately lowered hardness because of the negative association between hardness and kernel weight ($r = -0.40$; $P 0.001$) in this investigation. Relevance of GGR and GFP had been emphasized in bread wheat under drought (Sanjari et al. 2011) and heat stressed conditions (Spiertz et al. 2006). Mohan and Gupta (2014) reported RMI as a strong indicator of higher flour recovery and reported that higher flour recovery ($\geq 70\%$) is achieved under Indian conditions only when 40–45 % life span of total growth is spent on grain growth.

The strategy to enhance quality of wheat end-products depends upon the variations available in grain quality components. Route to end-products quality have been defined for the Indian wheats (Mohan and Gupta 2013b) and the key attributes have been laid for selection. Enrichment of wheat grain quality has attained attention of several wheat researchers but it is a complex and cost intensive exercise. Based upon this investigation, it is evident that physiological efficiency also articulates wheat grain quality and breeders can use them as selection tool. To increase protein content, genotypes with slower elongation growth rate (dwarf) and with higher grain filling duration should be selected. Plants where height and grain growth is attained at slow speed can produce hard grains provided proportionate vegetative growth phase is longer. Irrespective of crop duration, longer vegetative phase can be an effective indicator of higher flour recovery and test weight. Steady grain growth rate can be useful in enriching gluten strength (sedimentation value) as well as gluten quality (gluten index). At a time when biochemical and molecular interventions are being advocated in this venture, it is pertinent that some simple growth related indicators are also exploited. Since no single tool or approach has been proved sufficient or complete in quality improvement, it will be useful to exploit field related morphological traits.

Alteration in physiological efficiency for the purpose of improving grain quality can be tedious but this study suggested an alternate pathway. Instead of physiological efficiency, exploitation of morphological growth indicators in the field can also be equally effective in enriching grain properties of wheat. Early heading and longer grain filling can be effective to increase test weight. Tall and early flowering genotypes can be rejected to raise the protein levels. Study indicates that bold grains hamper grain hardness and delayed heading add more bran in the flour. Genotypes with poor grain bearing and quick grain ripening will not be useful in elevating gluten strength i.e. sedimentation value. Significant gain in wet gluten content will demand yield premium i.e. less grain bearing and lower grain weight. The study showed that instead of

protein, it is the wet gluten content which is negatively associated with grain yield. In this investigation, correlation between yield and wet gluten was negative and significant ($r = -0.17$, $P 0.01$) whereas yield and protein were not correlated. To improvise gluten quality (gluten index), extended reproductive phase but with less grain weight can be helpful. These simple interventions can effectively supplement the gains targeted in wheat quality through conventional breeding.

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