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Assessment of non-grain parameters in wheat quality under diverse climate of India

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Abstract

Influence of crop seasons, sites and their interactions was examined to compare wheat grain quality in two important and agro-climatically diverse wheat zones of India i.e. north western plains zone (NWPZ) and central zone (CZ). Six leading cultivars of each zone were evaluated for eleven important parameters at five locations during four year study period. Locations made big difference in congenial environments of NWPZ but under hot and dry environments of CZ, *chapati* quality and sedimentation value remained unaffected. Crop season variations made no difference in *chapati* and grain appearance scores of NWPZ whereas test weight and grain hardness registered no impact in CZ. Variations imposed by sites and years were of the same magnitude in NWPZ but not in CZ. Under hot climate, seasonal variations superseded site differences for traits like *chapati* quality score, biscuit spread factor and sedimentation volume. In contrast, site differences assumed greater relevance than crop seasons in test weight and gluten content under such climates. Site-year interactions assumed significance in majority of the cases but such variations could not exceed variations in sites or crop seasons. *Chapati* quality in CZ was not affected by site-year variations. Biscuit quality, protein and gluten contents registered very strong influence of sites, crop seasons and their interactions. Site-variety interactions were inconsequential in both regions. Year-variety interactions also remained non-significant in majority of the traits in both zones except for *chapati* and bread quality scores in central India. Variations caused by genotype-environment interactions proved insignificant in quality of Indian cultivars but year-site interactions assumed significance although its impact was very small in comparison to site or crop seasons. Character response to sites and crop seasons was examined under different climatic conditions.

Keywords: Consistency, grain quality, genotype-environment interactions, Indian wheat, site-year interactions, stability

1. Introduction

Wheat has attained importance in India as life line for food and nutritional security. Value addition therefore has become important in wheat research not only to cater growing domestic demand but also to capitalize opportunities that India perceives in global trading. There are two wheat zones where yield potential is high i.e. north-western plains zone (NWPZ) and central zone CZ). Wheat acreage in NWPZ is large (10 million hectares), productivity is high as crop faces the most congenial growth conditions (low winter temperature with 2-3 good rains) but quality of grains and the end-products is moderate. Climate of CZ is hot and dry which forces the crop to flower early. High grain weight attained due to longer filling period helps the cultivars to achieve good yields in this dry belt. Wheat cultivated under suppressive environments of central India also covers 5 million hectares and the harvest fetches good price in domestic market due to superior physical quality of the grains. Wheat harvested from central India also ensures better chapati quality (Mohan *et al.,* 2008 & 2011). The

concern of high yield potential and grain quality make both the regions very special in wheat research. Although wheat grain quality in these two regions had been well elaborated by Mohan *et al.* (2008 and 2011), it is essential to have critical analysis of the environmental influences to harness value addition in these important wheat zones. It is widely known that quality of wheat grain and the end-products is cultivar and environment specific (William *et al*., 2008; Pena *et al*., 2012). Therefore, it is imperative to examine the role of non-grain parameters i.e. locations, crop seasons, interactions of site with year and variety with site and year; in these two important zones. Present study has addressed such issues by examining six important bread wheat (*Triticum aestivum L.*) cultivars of each zone for grain quality attributes. Primary aim of the investigation is not to compare quality status but to highlight differential response of the non-grain parameters on value addition of wheat under diverse climates.

2. Material and methods

Six cultivars each of NWPZ (PBW 343, DBW 17, PBW 550, PBW 373, PBW 590 and WH 1021) and CZ (LOK 1, GW 322, HI 1544, DL 788-2, MP 4010 and HD 2932) were analyzed for grain quality characteristics during the four year study period 2008-11. Samples were drawn from Advance Varietal Trials of All India Coordinated Wheat and Barley Improvement Project (AICW&BIP) pertaining to five locations i.e. Ludhiana, Delhi, Pantnagar, Hisar and Durgapura in NWPZ; and Kota, Indore, Powarkheda, Vijapur and Junagarh in CZ.

Grain samples were analysed at ISO 9001:2008 certified laboratory of Karnal as per international standards (AACC, 2000) and *chapati* score was derived as suggested by Rao *et al.* (1986). Grains were evaluated for flour recovery; three end-products i.e. c*hapati* score, bread loaf volume and biscuit spread factor. Quality attributes rated important under Indian conditions for product quality (Mohan and Gupta 2013) and flour yield (Mohan *et al.,* 2013a) were also analysed and it included test weight, grain hardness index, sedimentation value, grain protein percentage at 14% grain moisture, wet gluten content and gluten index. Grain appearance score was a subjective test to collectively rate size, shape, soundness, colour and texture out total score 10. Single kernel characterization system 4100 was used to measure grain hardness index. Protein content was measured by infra-red transmittance based instrument Infra-tec 1125 whereas Quadrumat Senior mill was used to measure flour recovery.

Significance of environments was studied by single factor RBD analysis taking six varieties replications. To compare mean values among zones, Student t-test was applied and difference was highlighted at P ≤0.01. Significance of locations, crop seasons and site-year interactions was investigated by two factor RBD analysis treating varieties as six replications. Variety-location and variety-year interactions were also examined by two factor analysis, treating years as replication in the first case and locations in the second. Comparison of variance between two zones was done by F test at P ≤0.01.

3. Results and discussion

3.1 Grain quality and environmental variations: Zone-wise comparison of grain quality characteristics revealed striking differences in few parameters (Table 1).

Overall grain quality of NWPZ wheat varieties was significantly better than CZ in grain protein content and gluten index. Varieties of CZ were significantly superior in chapati quality, grain appearance score and some milling traits like flour yield and test weight. Grain quality among two zones matched in rest of the parameters like bread loaf volume, biscuit spread factor, sedimentation volume, grain hardness index and wet gluten content.

Table 1. Overall performance and significance of environments

Quality parameters	Overall mean		Variance (MSS)		Range	
	NWPZ	CZ	NWPZ	CZ	NWPZ	CZ
Bread loaf volume (cc)	563	561	454***	965***	552-583	539-582
Chapati score	7.51	7.83	0.07**	0.05	7.33-7.71	7.66-8.00
Biscuit spread factor	6.61	6.89	1.47***	1.73***	5.75-7.66	5.80-7.63
Flour recovery (%)	68.8	69.8	11.6***	6.19***	65.7-71.2	67.8-71.9
Grain appearance score	5.6	6.5	1.23***	1.84***	5.4-6.7	5.4-7.4
Test weight (kg/hl)	77.2	81.4	31.2***	9.13***	73.1-80.7	79.0-83.3
Grain protein content (%)	12.5	11.5	10.3***	5.34***	11.0-15.5	10.8-14.2
Sedimentation value (ml)	41.7	40.8	27.5***	33.0***	36-45	37-45
Grain hardness index	75.7	72.5	218***	132***	64-86	61-83
Wet gluten content (%)	31.7	31.8	80.8***	58.5***	25-40	26-37
Gluten index (%)	59.3	53.3	83.8	54.9	51-65	46-60

*Note: **, *** denote significance at P 0.01 and 0.001, respectively*

Changes in gliadin-glutenin ratio, synthesis of HMWGS and heat shocked protein under high temperature (Wrigley *et al.,* 1994, Blumenthal *et al.,* 1998), differences arising due to crop rotation and soil fertility (Lopez-Bellido *et al.,* 1998, Souza *et al.,* 2004) and role of zones, latitudes and water regimes (Rharrabti *et al.,* 2003) are well known for differential grain quality characteristics and must be relevant under Indian conditions, too.

Single factor RBD analysis done to test significance of environments revealed that majority of the parameters barring gluten index were highly influenced in each zone. The only deviation was *chapati* score in central India. Even though gluten index appeared unfazed by the environments, the big margins suggest that it must have been equally sensitive to the environmental fluctuations (Table 1). Investigations revealed that relevance of environments can even be higher than cultivars in certain situations (Table 2). It was obvious in case of protein content, extraction rate and biscuit spread factor in NWPZ mainly because varieties of NWPZ had non-significant varietal differences in protein content (12.9-13.5%), flour recovery (68.3-69.3%) and biscuit spread factor (6.36-6.87). In CZ however, such pattern was observed only for flour recovery where cultivars expressed a very narrow range (69.7-70.0%). Genetic make-up and the growth environment both accounted for such peculiarities among test varieties.

3.2 Crop season and location effects: Investigations asserted that crop season fluctuations and location differences make big difference in grain quality (Table 2). Study revealed highly significant ($P < 0.001$) site differences in NWPZ for all traits except gluten index. In CZ, variations accrued by sites were significant in fewer grain quality parameters as in addition to gluten index; *chapati* score and sedimentation value also showed non-significant location effect. Location effect in wheat quality has been realized in many parts of the world (Sial *et al.,* **2000,** Rharrabti *et al.,* 2003, Veselinka *et al.,* 2009). In India also, location specificity for quality parameters had been described in NWPZ (Mohan and Gupta 2011). High order site variations in this investigation illustrated instability of quality traits under varying environments.

Table 2. Significance of variance (mean sum of squares) in ANOVA of site-year interactions

	North-Western Plains Zone					Central Zone				
Trait/ parameter	Variety	Year	Site	Site-year	Error	Variety	Year	Site	Site-year	Error
Degree of freedom	5	3	4	12	95	5	3	4	12	95
Bread loaf volume	2002***	179	1054***	322**	140	5299***	761*	2272***	581*	286
Chapati score	0.24***	0.06	0.17***	0.04	0.03	0.46***	0.11*	0.02	0.04	0.03
Biscuit spread factor	0.66	3.40***	1.24***	1.06***	0.23	0.85**	7.71***	1.06***	0.46**	0.20
Flour extraction rate	2.69	11.1***	17.3***	9.84***	1.37	0.39	9.57***	8.00***	4.74***	1.21
Grain appearance	0.43	0.13	1.14***	1.53***	0.17	1.19***	1.45***	4.10***	1.19***	0.25
Test weight	53.4***	18.2*	37.7***	32.3***	5.18	35.4***	2.37	22.7***	6.32***	1.62
Protein content	1.35	8.58***	24.9***	5.86***	0.47	17.8***	4.80***	17.8***	1.62***	0.32
Sedimentation value	570***	58.5***	39.5***	15.7**	6.71	131***	146***	11.6	11.9	8.50
Hardness index	188***	386***	458***	96.6**	36.2	502***	35.0	202***	132***	23.4
Wet gluten content	41.9***	85.8***	213***	35.5***	5.90	144***	13.5***	190***	25.9***	3.79
Gluten index	1818***	172*	63.1	68.5	54.3	62.5	30.3	71.3	55.5	39.6

Note :, **, *** denote significance at P 0.05, 0.01 and 0.001, respectively*

Significance of crop season variations in wheat grain quality had been demonstrated by several researchers (Mohan and Gupta 2011, Blumenthal *et al.,* 1991). Year to year variation in the crop seasons are upshot of global environmental change (GEC) which make quality traits inconsistent. In this investigation, parameters depicting highly significant crop season differences ($P \leq 0.001$) under both climates were biscuit spread factor, flour extraction rate, protein content, sedimentation value and wet gluten content. Rest of the parameters expressed differential response under two regions.

Investigations clearly asserted that crop season fluctuations and location differences are equally relevant in wheat quality under normal growth conditions but their relative importance can vary in regions of hot climate. In such environments, seasonal variations can supersede site differences in traits like *chapati* quality score, biscuit spread factor and sedimentation volume. Under hot climate, there can also be instances where site differences assume greater relevance than crop seasons as observed in test weight and gluten content. This investigation amply proved that consistency in quality traits is trait specific and can vary in different climates.

3.3 Site-year interactions: Empowering crop season and location effects can make wheat quality unreliable in any climate. Interaction between location and year can further add fragility in value addition. Location and year interaction had been reported in few parameters of wheat quality (Blumenthal *et al.,* 1991, Abbate *et al.,* 2010, Mohan and Gupta 2011). Except *chapati* score and gluten index, highly significant site-year variations were recorded under NWPZ conditions in this study (Table 2). In CZ, sedimentation volume was another trait with insignificant interactions. Besides, *chapati* score also registered lower order significance (P = 0.05) in CZ. Highly significant site-year interactions in this investigation point that a crop season favourable for a particular location may not necessarily have similar impact at other locations. Under such scenario, it often becomes difficult to rank grain quality of a test site under varying crop seasons. Even though site-year interactions were significant in many quality parameters, such variations were either at par or significantly lower (P = 0.05) in comparison to sites or years. None of the traits could exhibit site-year variance statistically higher than sites or years in any region. It clearly demonstrates that even though site-year interactions are relevant in wheat quality, their impact is very small in comparison to varying crop seasons or locations.

3.4 Interactions of location and crop season with cultivars: Importance of GxE in some wheat quality parameters has been examined in many countries (Ereifej *et al*., 1999, Luo *et al.,* 2000, Zhu and Khan 2001, Hristove *et al.,* 2010, Mut *et al*., 2010). This investigation was distinctive for the reason that environment was split between year and locations and interactions with genotypes were examined with both variables. As indicated earlier, Year-variety and site-variety interactions were derived from two separate ANOVA. Since MSS of varieties, years and sites were already presented earlier (Table 2), variance of only year-variety and site-variety interactions are given in Table 3. It was interesting to observe that year-variety interactions were non-significant in all parameters under NWPZ conditions (Table 3). Situation was altogether same in CZ but for bread and *chapati* quality where such interactions proved highly significant (P = 0.01). It was interesting to observe that site-variety interactions were non-significant for all grain parameters under both climates. It assures that cultivars raised in these two regions maintain their ranking in different crop seasons and at various locations. Variations accrued through cultivar interactions with sites/years were significantly lower than site-year interactions indicating that site-year interactions have greater relevance than GxE in value addition of wheat. Since year-variety interaction was significant in central India for *chapati*, it indicates a variety with overall lower *chapati* score can also attain top ranking in some year as happened with HD 2932 which matched the best variety LOK 1 during 2011. In loaf volume also, the best check HD 2932 held similar position as that of DL 788-1 in 2008.

Table 3. Variance (mean sum of squares) of varietal interactions with year and site

Trait	Year-variety interaction		Site-variety interaction	
	NWPZ	CZ	NWPZ	CZ
Bread loaf volume	125	706**	121	199
Chapati score	0.01	0.06**	0.03	0.02
Biscuit spread factor	0.12	0.28	0.26	0.15
Flour extraction rate	2.44	0.93	0.67	1.40
Grain appearance score	0.30	0.46	0.19	0.21
Test weight	7.43	0.51	5.90	3.19
Grain protein content	0.76	0.11	0.60	0.29
Sedimentation value	6.63	4.58	5.54	12.0
Grain hardness index	45.0	25.9	47.3	33.9
Wet gluten content	7.75	3.92	10.3	2.86
Gluten index	65.7	52.2	50.6	36.6

*Note: ** denote significance at P = 0.01*

Studies on GxE in wheat had reported that its impact might not be similar for all quality parameters (Zhu and Khan, 2001, Pena *et al*., 2012). A major component in GxE studies is the genotypes. If the genotypes under study are not adaptive to that particular region, more variability is released which make GXE more complex. Incidentally, varieties in India are released by the national system at the zone basis after evaluation for 3-4 years. In NWPZ and CZ, this testing is carried at 20-25 sites by AICW&BIP. The varieties released through multilocation testing are therefore highly adapted to a particular climate. The acclimatized varietal material under testing might have helped to checkmate the GXE interactions at the grain level.

3.5 Specificity for traits, locations and climates: The study gave enough hints that response of non-grain parameters in value addition is trait and climate specific. Effort therefore was made to highlight the differential response of quality parameters and also examine whether sites with consistently high performance can be identified under varying environments.

3.5.1 End-products quality: Taking into account the levels of significance and the range of environmental variations, it might appear that *chapati* quality does not change much in

different environments and similar observation had been recorded in Indian wheat varieties earlier also (Peterson *et al.,* 1992, Mohan and Gupta 2011). Since *chapati* score is a number derived from four to five different tests like puffing height, colour, texture etc; it may not be easy to find clear cut environmental differences in the cumulative score specially when the range of genotypic variations is very small (7.33 to 7.63 in NWPZ and 7.60 to 8.01 in CZ). However when split between years and sites, it becomes clear that significant differences among sites can be observed in NWPZ (Fig 1). *Chapati* score therefore emerged as stable grain quality attribute only under hot climate of CZ. In the hot and dry environments where kernel and test weights are usually high and the grains are hard, the *chapati* quality not only gets elevated but also remains stable over the locations. Study made it clear that consistency in *chapati* score is better observed under congenial environments (as observed in NWPZ) and site differences cease to exist under hot climate of CZ. *Chapati* quality turned out to be the only quality attribute where site-year interaction had no relevance in any climate which shows that locations good for *chapati* making maintain high standards in all crop seasons. Significance of year-variety interactions in CZ shows that not only *chapati* quality is influenced by crop season fluctuations in hot environment; the cultivars also fail to maintain the quality standards in different years.

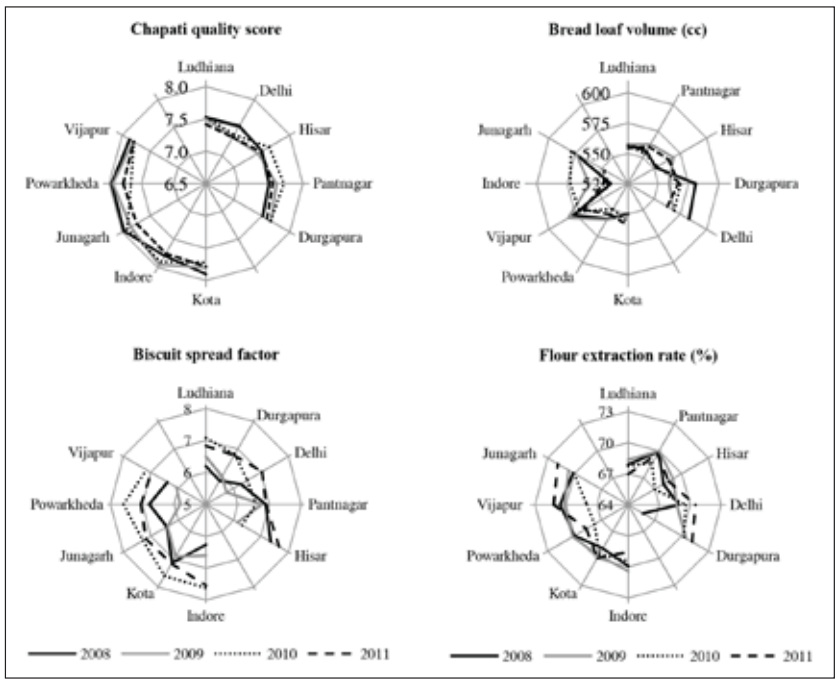

Fig 1. Location and crop season effects on end-products quality and flour recovery

In bread loaf volume, site-year interaction also counts along with location (Fig 1). In comparison to *chapati* therefore, environments register greater relevance in this baked product. Just like *chapati*, consistency in bread quality is better ensured in NWPZ. Bread loaf volume is also an attribute where year-variety interaction registered significance in CZ. It indicates that loaf volume is not only inconsistent under hot environments; the cultivars also fail to maintain the quality standards in different years. Among all these complexities, it was interesting to observe that at Vijapur location of central India; high loaf volume was consistently maintained. In contrast, good bread making sites of NWPZ remained variable in different crop seasons.

Biscuit spread factor is one such trait where site, years and their interactions remain highly significant in any climate (Fig 1). Study reflects that variations imposed by years can be far greater than sites in CZ. It shows that biscuit quality is highly sensitive to crop season fluctuations under high temperatures. Among all sites, Pantnagar emerged as the only site where biscuit quality can be relatively high and consistent.

3.5.2 Flour recovery and grain protein: As noticed in biscuit spread factor, flour extraction rate and grain protein content is also highly influenced by non-grain parameters. These two traits can be inconsistent and unstable in any climate and impact of seasonal variations and locations remain equally strong (Fig.1 & 2). Site-year interaction in grain protein content can be of higher magnitude in NWPZ (11.0-15.5%) in comparison to CZ (10.8-14.2%) and no location assures consistency in both zones. Sites to harness good extraction rate or protein content might exist in both zones but they might fail to give consistent performance.

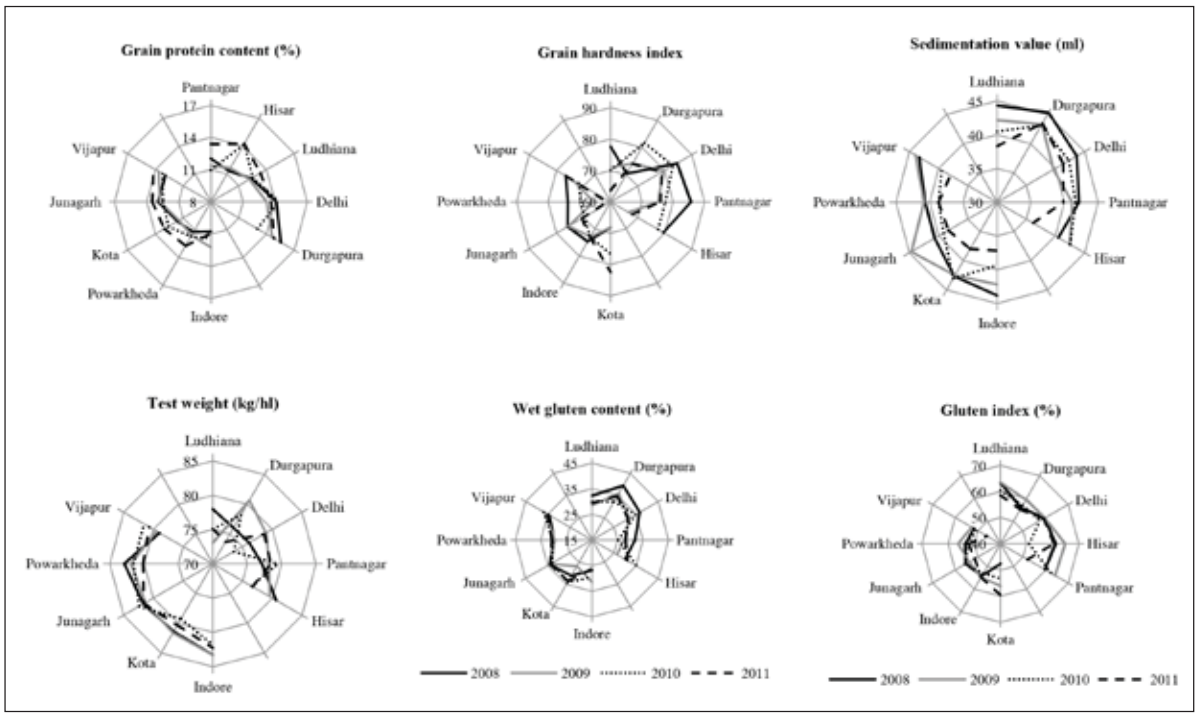

Fig. 2. Location and crop season effects on physic-chemical properties of wheat grain

3.5.3 Physical grain characteristics: Test weight, grain hardness index and grain appearance score are account for physical appearance of the grains. Results indicate that test weight and grain hardness are the two traits where cultivars of CZ are least affected by crop season fluctuations (Fig 2). Scenario however changes in the cooler climate of NWPZ where significant differences can be noticed year-wise. Both parameters remain unstable in NWPZ and CZ and sites are generally not able to maintain their standards year-wise. However, Indore and Junagarh in CZ and Pantnagar are locations where test weight remains high and unaffected by yearly variations. In grain hardness, similar advantages can be drawn at Delhi in NWPZ and Indore in CZ. Pattern in grain appearance was very similar to test weight in this investigation except that crop season variations can make no difference in NWPZ (Fig 2). Indore location of central India was the only site where grain appearance score was high and consistent over the years.

3.5.4 Gluten characteristics: Influence on content, strength (sedimentation value) and quality of gluten (gluten index) was peculiar and differential response of environmental influences was recorded (Fig 2). Impact of sites, crop seasons and their interactions in gluten content can be realized in both zones but variation among sites can be higher than seasonal fluctuations in hot climate. In both the zones, there was hardly any site where consistency could be observed which implies that impact of site-year interaction is very strong in gluten content. Scenario among two zones varied when consistency and stability was examined for strength of the gluten. Inconsistency in sedimentation value was a concern in both zones but instability was observed in NWPZ only. It reveals that sites make no difference in sedimentation value under CZ conditions. The north-western plains might contribute in better sedimentation value but effect of the non-grain factors is greater in this environment. However, location with high sedimentation value and good consistency can be observed like Durgapura in NWPZ and Powarkheda in CZ. Amongst all parameters, gluten index was one such parameter where statistically environments made on difference but the differences between sites/ crop seasons were quite wide. Graphics show that gluten index is also a highly complex quality attribute as interactions between site-years were visible at Hisar, Pantnagar and Kota. It indicates that significance of such variations might have missed in gluten index due to high error variance.

Bread wheat cultivars of India have some distinguish features like good *chapati* quality and hard grain-texture but flour recovery and gluten characteristics are not well suited for the baked products (Mohan *et al.*, 2013b). Intensive studies have been made to harness grain protein, flour recovery and end-product quality in the back ground of high grain yield (Mohan and Gupta 2013 & 2014, Mohan *et al.*, 2013b & c) but an equally important aspect in breeding ventures is the role of environment. This investigation underscores non-grain parameters in value addition of wheat and defines role of i) locations, ii) crop seasons, iii) site- year interactions and iv) cultivar interactions with sites and crop seasons in two important but highly diverse wheat zones of India. Character-wise comparison of important quality parameters between congenial and harsh environments will help the breeder community in strategic planning of augmenting value addition in wheat.

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