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Research Article

High yielding wheat lines carrying superior grain and processing quality introgressed from tall traditional cultivars

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Abstract
A set of 25 wheat lines derived from crosses of commercial varieties and advanced breeding lines with traditional tall varieties and other elite quality stocks were evaluated, along with 7 check varieties at 2 locations over 2 years, for their field performance as well as for grain and end-product quality. The pooled analysis of variance for agronomic traits (grain yield, days to heading, plant height, number of grains per spike and 1000-grain weight) revealed significant variation due to main effects (genotypes, locations, years) and interactions among these. Majority of the derived lines possessed yield levels at par with the highest yielding present day cultivars PBW 621 and HD 2967. Promising lines for grain yield and other agronomic traits were BWL 813, BWL 814, BWL 956 and BW 9022. Among the physico-chemical grain quality attributes, a major proportion of derived lines possessed good grain appearance and a very high grain hardness, whereas, a narrow range of variation was observed for test weight, protein content and sedimentation value. With respect to end product quality, BW 8361 was the best line for bread making. The greatest promise of the present set was found for *chapati* quality wherein the lines BWL 813, BWL 814, BWL 818, BWL 822, BWL 825, BWL 829, BW 9005 and BW 9022 possessed the *chapati* quality score of more than 8 (out of 10). The present study demonstrated the success achieved in combining high grain yield of present day cultivars with good *chapati* quality derived from tall traditional varieties, C 273, C 306, C 518 and C 591.

Key words
Triticum aestivum, yield performance, physicochemical grain quality, baking quality, gene introgression.

Introduction

Wheat improvement in the country has primarily focused on yield and protection of yield levels through resistance breeding. The breeding programmes operating initially in a food deficit context paid scant attention to quality parameters. Wheat as a staple food is consumed in many different forms in India but mainly as *chapati* (unleavened flat breads) prepared from whole meal, followed by bread and biscuits and to a much smaller extent as noodles, cakes, etc. It is widely acknowledged that the *chapaties* made from modern, improved, high yielding varieties do not have the desirable characteristics to the same extent as those found in *chapaties* prepared from indigenous wheat, especially the tall traditional Punjab wheat varieties such as C 518, C 273, C 591 and C 306. This set of improved, tall traditional wheats was released in the first era (1930s to 1960s) of hybridization based wheat breeding in India. All of them were directly derived from Indian wheat land race based purelines as parents. The superiority of tall traditional wheats grown in North India before the advent of semi-dwarf varieties has been documented for various quality traits such as grain hardness (Austin and Ram, 1971), keeping quality of *chapati* (Abrol, 1972), color, texture and flavour of *chapati* (Mishra, 1998), etc. In fact, out of about 180 released wheat varieties, Mishra (1998) [3], found none to surpass C 306 for *chapati* making quality. The situation reflected inadequate efforts for transfer of *chapati* quality traits to high yielding varieties of post dwarfing phase. Extensive use of tall traditional wheat as parents in the post dwarfing phase was probably thwarted by tall stature, lower yield and rust susceptibility of these varieties, besides problems of hybrid necrosis. Lack of segregation of produce on basis of quality and absence of a differential pricing system in the wheat procured for central food reserves promoted quantity over quality. Over the last one or two decades, however, consumer preference and concerns of industrial processing have brought greater focus on quality related objectives. The wheat breeding programme at Punjab Agricultural University, Ludhiana has also responded to this and the material for the present study represents one of the outcomes.

The study is based on a specially constituted set of wheat material consisting of different lines assembled from crosses of commercial varieties and advanced breeding lines with known quality stocks. Major part of the material (18 lines) is derived from crosses with tall traditional wheat lines. The objective was to evaluate the high yielding lines of wheat for field performance as well as quality traits, in order to identify promising lines combining quality and yield attributes for wider testing and commercial development.

Materials and Methods

The study was carried out on 32 bread wheat lines. The entire set of lines along with parentages is listed in Table 1. Eighteen lines have tall traditional cultivars (C306, C591, C273 and C518) as donor parents. The remaining part is represented by lines emanating from miscellaneous quality crosses, including three lines derived from crosses of *GpcB1* donor Glupro, besides parental and commercial checks. Out of the three Glupro derivatives, BWL 944 was found to be non-carrier of *GpcB1* gene whereas other two lines (BWL 942 and BWL 956) were positive for this gene when assayed with gene based markers .

Field trials were conducted at two sites located in two different experimental areas on the campus of Punjab Agricultural University, Ludhiana over two years (2011-2012 and 2012-2013) in order to evaluate agronomic performance and assess this set of wheat lines for quality traits including *chapati*, bread and cookies making characteristics. Plant material was sown in alpha lattice design with 3 replications with every plot consisting of 6 rows of 4m. length each. Standard agronomic practices were followed in terms of seed rate, row to row spacing, fertilization and irrigation etc.

The heading days were counted from the date of sowing to 50 percent spike emergence per plot for each line. Height of plants was measured in centimeters from ground level to tip of the spike excluding awns at physiological maturity at three random spots in each plot and average was worked out. For number of grains/spike, five spikes were taken per plot after maturity and hand threshed together. Grain counts were taken and divided by number of spikes. Grain yield in kilograms for each plot was recorded after threshing the harvested plots separately. To record 1000-grain weight, clean and intact grain samples were randomly collected from threshed produce of each plot, counted and weighed.

The grain protein content was estimated using the whole grain analyzer - Infratec 1241 (M/S Foss Analytical AB, Sweden). The sodium dodecyl sulphate (SDS) sedimentation value of whole meal samples was estimated according to the method of (Axford, *et al*. 1979). Grain hardness - the mean force (kg) required to crush the grain was measured by using the grain hardness tester supplied by M/S Ogawa Seiki Co. Ltd., Japan by crushing randomly taken ten grains one by one. The grain appearance score was based on size, shape, color and luster of the grain. It was evaluated subjectively out of a maximum score of 10. Test weight (kg/hl) was measured using the apparatus developed by the Directorate of Wheat Research, Karnal.

The whole meal was produced by grinding the grains, in a laboratory stone grinder (*Chakki*). The gap between the two stone discs was so adjusted as to pass the meal through 40 mesh sieves. The whole meal so produced was used in the chapatti studies. For baking *chapaties*, 50g. whole meal (*atta*) and optimum quantity of water were optimally mixed mechanically for about 2min using Swanson mixer. The dough was evaluated for stickiness out of maximum score of 5 while rounding it up manually and kept in the humidity cabinet maintained at 30°C and 80 percent RH for 30 min. The dough was divided into two equal parts and sheeted to 2mm thickness with the rolling pin. *Chapaties* were baked on an automatic chapati maker having thermostatically controlled constant temperature for 20 sec on one side and for 40 sec on the other. Finally it was puffed for 10sec by turning the chapatti and bringing the upper plate of the *roti* maker in contact with the *chapati*. *Chapaties* were cooled to room temperature in the humidity cabinet and evaluated by a panel of trained judges using scores (Maximum values given in brackets) for the each parameter such as colour (5), puffing (5), texture (5), taste (5), flavor (5), texture after 2hrs. (5) which were added up to give a single value out of a maximum of 30. The obtained values were converted to give a final score out of the maximum of ten considering the dough handling score also.

Conditioned samples of flour to be used in the bread and cookies baking studies were milled on the Brabender Quadrumat Senior Experimental Mill. Straight dough method with remixing (AACC, 1969), was followed by using optimum quantity of water. The baking formula consisted of flour (100g), compressed baker's yeast (2.5g), sugar (2.5g), shortening (1g) and water (optimum). All these ingredients were optimally mixed in the Swanson mixer. After mixing, the dough was evaluated subjectively for its stickiness and fermented in the fermentation cabinet at 86°F and 80 percent RH for 90min. The dough was then remixed for 15sec in the mixer. The dough was allowed to recover for 25min before sheeting and moulding. The moulded dough was proofed for 55min in the fermentation cabinet and baked in a revolving reel baking oven at 410°F. The loaves were cooled to room temperature and weighed. Volume was measured using rapeseed displacement method. The loaf volume score (LVS) was calculated using (LVS = (Loaf Volume - 300) / 20). The loaves were evaluated for crust and crumb characteristics the next day and the total score was finally calculated out of the maximum of ten.

For baking cookies the AACC (1969), method was followed using the following recipe: Flour (90g), sugar (52g), fat (25.6g), salt (0.84g), sodium-bicarbonate (1.0g), water (6.4ml), dextrose solution (13.2ml). The prepared dough was sheeted to a thickness of 0.7cm and cut into circular discs with a die (6cm) and baked for 10min at 400^{o}F. The baked cookies were cooled to room temperature and evaluated for spread factor by calculating the ratio of width to thickness. The measurements were averaged out for four cookies.

Results and Discussion

Out of the set of 32 lines evaluated in this study a major part represented introgression from tall traditional cultivars (C306, C591, C273 and C518) in the background of PBW550 (10 lines), PBW534 (3 lines) and PBW 343 (4 lines). PBW550 and PBW343 are widely grown varieties and PBW534 is an agronomically desirable advanced breeding line. Three lines had introgression from Glupro in DBW 16 background. Glupro is a winter wheat line which carries the high grain protein conferring gene *GpcB1* from *Triticum dicoccoides* while DBW16 is a released Indian wheat cultivar. Most of the lines in the set were derived after two backcrosses to the recurrent parent. The material was thus an outcome of a specific breeding initiative. A much larger number of lines had been generated and subsequently narrowed down to the present set based on grain appearance and field performance.

The multilocation evaluation of the lines was carried out for 2 years generating four sets of field data. A pooled analysis of variance of this data is present in Table 2. It is observed that among the field performance traits, genotypic mean squares were significant for all the traits including plot yield. Other sources of variation namely year and sites were also significant. A large proportion of interaction mean squares based on these primary sources of variation were also significant. The four environmental situations generated by years and sites thus impacted most of the traits under study. The pooling of data over these environments and comparison of averages in this study can therefore be useful only for revealing over riding genotypic trends which are likely to be persistent features of future performance as well. The overall mean across years and sites for the traits studied in field are given in the table 3.

Yield is a primary concern, particularly in case of lines which have received genetic input from parents which have low yield. The low yield of two tall, traditional cultivars, C 306 and C591 is evident from the table. Majority of the derivative lines (9) however possessed yield levels at par with the present day cultivars including PBW 621 (5062.50) and HD 2967 (4770.83). Thus any headway for quality traits in this set can pave the way for end-product specific commercial deployment of wheat lines. For commercial success however, yield performance in this material should be accompanied by appropriate crop duration (indicated by days to heading in the present study) and plant height to enable its use under standard agronomic practices. Table 3 reveals that these two parameters are in acceptable range when viewed in comparison to commercial checks. The two best yielding entries, BWL 813 and BWL 814, were however, slightly taller and lodging tolerance under high fertility irrigated conditions may need to be assessed further. The stature of C 306 (132.3) and C 591(117.0) was clearly indicative of their pre-dwarfing era status. All the derivative lines had recovered the dwarfing traits of recurrent parent. With respect to number of grains per spike, the donor parents C306 and C591 are known to possess smaller ears and consequently fewer grains per ear. The derivatives however showed adequate performance for this trait. Another important trait is 1000 grain weight, which serves as a yield component as well as a pre-requisite for superior milling and quality parameters. Several of the derivatives including BW9022 (49.7), BWL813 (49.0) and BWL819 (44.7) showed excellent grain weight comparable to the bold seeded check PBW 175 (48.4). Overall, the set of lines showed promise with respect to agronomic performance. This could by and large be attributed to strong selection pressure, adequate numbers in segregating phase and preliminary yield evaluation in previous years making these lines a highly selected set.

A strong selection for grain type followed by preliminary quality evaluation had also been practiced for this material. Important physico-chemical parameters of grain quality recorded on this selected set is given in table 4. The data of quality given in tables 4 and 5 are averages of the four trials (conducted at 2 sites over 2 years). The grain appearance score was recorded out of maximum score of 10. Well filled grains with attractive color indicative of ability to resist any stress during filling period lead to higher scores. Among commercial checks, PBW 550 is known to possess attractive grains grain appearance (6.2), while recently released varieties PBW 621(5.8) and HD 2967 (5.6), along with the widely grown PBW 343 (5.7) generally show a lower grain appearance score. Thus using PBW 550 and C-series varieties as benchmarks, a major proportion of the test entries were seen to possess good grain appearance. Wide variation was not observed for test weight and most of the test entries were comparable to the commercial as well as quality checks. Variation in grain hardness was evident in a much greater measure and was probably fuelled by harder grains of donor lines such as C 306 and C 591. A large set of lines showed high grain hardness. Among the quality traits known to contribute to *chapati* quality, grain hardness is the foremost and is estimated to contribute as much as 40% (Mishra, *et al*. 1998), Variation for protein content and sedimentation value was observed within a relatively narrow range. This was in accordance with the donor and recipients used in the present study. The only exceptions were two lines with *GpcB1* gene whose protein content was lower than expected. In a larger set evaluated in our laboratory earlier, *GpcB1* had been seen to clearly improve protein content though effect of the gene tended to vary with the background (Pal, 2010), The small sample of *GpcB1* carriers used in the present study seems to have led to the unexpected observations. Protein content and sedimentation value is not known to have significant implications for chapati quality, while high protein content and sedimentation value is preferred for bread making. In contrast, lower values of these parameters are known to promote cookie quality (Bansal, *et al.*2000).

The set of lines was subjected to extensive processing tests for bread, *chapati* and cookie quality (Table 5). Indian wheats are not known for excellent bread quality. The problem is generally perceived to be due to high temperatures that prevail during the grain filling period in Indian wheat growing environments. In accordance with genetic input the *GpcB1* carriers (BWL 942 and BWL 956) were expected to score better for bread quality. However, as discussed earlier, unexpectedly low protein content in these lines was not favourable for bread making quality. BWL 8361 showed the highest bread quality score (6.3). Its superiority might have accrued from the Kansas winter wheat parent KSWW1 of this line. Studies on a larger set of winter x spring wheat derivatives had been reported by our laboratory earlier (Jha, *et al.2010a* and 2010b), and this line was picked up for more extensive testing under the present study. Greatest promise of the present set was found for *chapati* quality. For evaluation of chapatti quality various parameters like water absorption, stickiness, *chapati* appearance, color, aroma, taste, puffing height and loss of water (after 2 hrs of baking) were considered and a composite score was given as per standard procedures. *Chapaties* scoring above 8 are considered to be of excellent quality. The best check in the trial was C591. This is in accordance with earlier studies and reports (Kumar, 2008), Test entries BWL813, BWL814, BWL818, BWL822, BWL825, BWL829, BW6864, BW9022 and BW 9005 were at par with the best check C 306 (8.0), C591(8.0) and several of them possessed numerically higher *chapati* quality scores. Most of these lines have tall traditional varieties as donor parent. BWL813, BWL814 and BWL9022 possess introgression from C591 in background of PBW343. These lines also possess resistance to stripe rust while recipient PBW 343 is highly susceptible (data not given here). BWL818, BWL822, BWL825, BWL829 and BW9005 have genetic input from C306, C 518,C 591, C273, and C306, respectively in PBW 550 background Moreover it was observed that good *chapati* quality need not be associated with medium protein content and nutritional and processing quality can be combined. Table 5 also carries data on cookie spread factor, but none of the lines could come up to the desirable level of about 7.5. Expectedly the line with best bread quality score (BWL 8361) possessed the lowest cookie spread factor.

Introgression of superior *chapati* traits from tall traditional cultivars in semi-dwarf wheats had received inadequate attention in wheat breeding programmes. Several problems as discussed earlier were perceived for this introgression. The present study overcomes these problems and demonstrates high feasibility of incorporating superior *chapati* quality in modern cultivars.

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Table 1. Set of wheat lines used in the study

S. No.	Line	Parentage
1	PBW 657	C273/2*PBW534
2	PBW 671	C273/2*PBW534
3	BWL 813	PBW343/C591//2*PBW 343+*Lr24*+*Lr28*
4	BWL 814	PBW343/C591//2* PBW 343+*Lr24*+*Lr28*
5	BWL 818	PBW550/C306//2*PBW550
6	BWL 819	PBW550/C306//2*PBW550
7	BWL 822	PBW550/C518//2*PBW550
8	BWL 823	PBW550/C518//2*PBW550
9	BWL 825	PBW550/C591//2*PBW550
10	BWL 826	PBW550/C273//2*PBW550
11	BWL 827	PBW550/C591//2*PBW550
12	BWL 828	PBW550/C591//2*PBW550
13	BWL 829	PBW550/C273//2*PBW550
14	BWL 942	Glupro/3*DBW16
15	BWL 944	Glupro/3*DBW16
16	BWL 956	Glupro/3*DBW16
17	BW 6864	Turco/PBW491
18	BW 7623	C273/2*PBW534
19	BW 8361	KSWW1/PBW552
20	BW 8987	C273/2*PBW534
21	BW 9005	C306/2*PBW534//PBW550
22	BW 9022	C591/3*PBW343
23	BW 9027	C273/2*PBW534
24	BW 9065	C518/3*PBW343
25	BW 9039	C273//3*PBW534
26	PBW 175	HD2160/HD2177
27	PBW 343	ND/VG9144//KAL/BB/3/YACO 's'/4/VEE#5
28	PBW 550	WH594/RAJ3856/W485
39	PBW 621	KAUZ//ALTAR84/AOS/3/MILAN/KAUZ/4/HUITES
30	C 306	REGENT1974/3*CHZ/2*C591/3/P19/C281
31	C 591	TYPE9/8B
32	HD 2967	ALD/COC//URES/3/HD2160M/HD2278

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Table2. Pooled analysis of variance for agronomic traits recorded on 32 lines planted at two sites over two years in alpha lattice design

Source	d.f	MS				
		Days to heading	**Plant height**	**Number of grains/spike**	**1000 grain weight**	**Grain Yield**
Year	1	1.00	809.39**	891.85**	176.99**	0.97*
Replication	8	9.03	33.65	94.17**	82.72*	0.57*
Location	1	5.90	364.84**	3.30	577.07**	6.63**
Genotype	31	14.50**	923.06**	93.95**	69.42**	1.22*
Block	36	6.58**	13.31*	22.14*	18.26*	0.18**
Location × Genotype	31	13.70**	37.17**	55.70**	46.98**	0.39**
Year × Genotype	31	18.92**	34.23**	31.59*	26.89*	0.371**
Year × Location × Genotype	31	7.53 **	50.33**	34.51*	28.22*	0.481**
Error	212	4.26	12.57	21.50	17.49	0.161

* Significant at 5% level of significance
** Significant at 1% level of significance

Table3. Average values for grain yield and other agronomic traits in 32 wheat lines.

S. No	Line	Grain yield (kg/ha)	Days to heading (days)	Plant height (cm)	Number of grains/ spike	1000 grain weight (g)
1	PBW 657	3604.17	97	83.0	48.4	43.4
2	PBW 671	4020.83	95	89.6	53.0	47.2
3	BWL 813	5666.67	99	106.6	55.4	49.0
4	BWL 814	5645.83	98	105.6	53.8	46.8
5	BWL 818	4833.33	99	86.6	49.0	42.8
6	BWL 819	4562.50	96	83.7	51.3	44.7
7	BWL 822	5416.67	97	96.0	50.3	39.3
8	BWL 823	3791.67	98	84.0	49.2	44.0
9	BWL 825	3937.50	97	85.7	49.6	44.9
10	BWL 826	4145.83	96	84.7	52.3	41.0
11	BWL 827	4000.00	98	85.3	50.3	41.2
12	BWL 828	4541.67	97	83.0	54.1	42.1
13	BWL 829	4604.17	97	90.1	46.3	42.5
14	BWL 942	4687.50	96	86.1	46.7	37.7
15	BWL 944	5041.67	97	91.3	50.4	40.5
16	BWL 956	5395.83	97	87.5	54.7	40.0
17	BW 6864	5208.33	97	83.6	45.9	45.4
18	BW 7623	4229.17	97	83.7	52.0	40.6
19	BW 8361	5625.00	96	97.0	53.5	50.4
20	BW 8987	4854.17	98	80.5	52.1	44.0
21	BW 9005	4562.50	96	82.9	54.3	41.8
22	BW 9022	5645.83	97	93.2	54.8	49.7
23	BW 9027	3958.33	96	81.1	49.0	42.0
24	BW 9065	4458.33	98	86.2	50.6	44.0
25	BW 9039	3812.50	99	84.2	49.0	43.7
26	PBW 175	4229.17	96	105.2	50.5	48.4
27	PBW 343	4458.33	98	93.0	50.9	44.8
28	PBW 550	4229.17	97	86.5	51.9	43.2
39	PBW 621	5062.50	101	98.0	53.1	43.8
30	C 306	3541.67	98	132.3	46.3	47.1
31	C 591	3520.83	98	117.0	45.9	41.8
32	HD 2967	4770.83	101	89.0	52.3	41.7
	C.D	700	3.32	5.7	7.4	6.7

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Table 4. Average values of physico-chemical grain quality attributes recorded on the 32 wheat lines

S. No	Line	Grain Appearance Score (Max10)	Test weight (Kg/hl)	Grain Hardness (Kg)	Protein Content (%)	Sedimentation Value (cc)
1	PBW 657	6.1 ± 0.18	76.9 ± 0.40	12.3 ± 0.13	11.0 ± 0.64	42.0 ± 2.56
2	PBW 671	6.0 ± 0.16	75.9 ± 0.96	11.6 ± 0.15	10.9 ± 0.43	41.0 ± 3.38
3	BWL 813	6.1 ± 0.19	76.9 ± 0.42	11.6 ± 0.78	11.1 ± 0.58	47.0 ± 1.97
4	BWL 814	6.3 ± 0.12	74.9 ± 0.95	11.7 ± 0.41	11.7 ± 0.27	48.0 ± 4.14
5	BWL 818	6.3 ± 0.12	76.8 ± 0.31	11.1 ± 0.42	11.1 ± 0.18	44.0 ± 2.66
6	BWL 819	6.1 ± 0.15	76.8 ± 0.58	11.4 ± 0.30	10.3 ± 0.42	39.0 ± 3.01
7	BWL 822	6.2 ± 0.09	77.7 ± 0.68	13.8 ± 0.40	10.7 ± 0.58	46.0 ± 3.97
8	BWL 823	6.2 ± 0.11	77.5 ± 0.34	12.0 ± 0.27	10.3 ± 0.55	42.0 ± 1.31
9	BWL 825	6.3 ± 0.09	76.9 ± 0.54	12.6 ± 0.22	11.2 ± 0.49	44.0 ± 1.49
10	BWL 826	6.2 ± 0.11	77.8 ± 0.90	11.4 ± 0.70	10.6 ± 0.60	43.0 ± 0.75
11	BWL 827	6.2 ± 0.02	76.9 ± 0.56	10.7 ± 0.66	10.5 ± 0.40	45.0 ± 1.80
12	BWL 828	5.9 ± 0.23	76.5 ± 0.94	11.2 ± 0.44	10.5 ± 0.48	42.0 ± 3.33
13	BWL 829	6.2 ± 0.10	77.3 ± 0.72	11.8 ± 0.66	11.0 ± 0.22	42.0 ± 4.59
14	BWL 942	6.0 ± 0.06	74.9 ± 0.92	9.6 ± 0.42	10.7 ± 0.53	35.0 ± 2.12
15	BWL 944	5.5 ± 0.38	73.4 ± 0.79	9.7 ± 0.71	10.7 ± 0.30	44.0 ± 2.16
16	BWL 956	5.8 ± 0.21	72.5 ± 10.7	9.5 ± 0.53	11.9 ± 0.68	41.0 ± 1.35
17	BW 6864	6.3 ± 0.15	77.8 ± 0.48	12.4 ± 0.82	12.1 ± 0.29	46.0 ± 1.11
18	BW 7623	6.1 ± 0.06	77.6 ± 0.57	11.8 ± 0.52	10.8 ± 0.62	44.0 ± 1.47
19	BW 8361	5.9 ± 0.13	75.1 ± 1.32	10.9 ± 0.96	11.6 ± 0.29	45.0 ± 2.38
20	BW 8987	6.2 ± 0.10	77.3 ± 0.66	11.5 ± 0.37	10.9 ± 0.32	43.0 ± 2.38
21	BW 9005	6.4 ± 0.18	77.0 ± 0.92	13.8 ± 0.84	11.0 ± 0.44	45.0 ± 2.35
22	BW 9022	6.1 ± 0.14	76.0 ± 0.86	10.8 ± 0.58	10.6 ± 0.20	41.0 ± 1.49
23	BW 9027	6.2 ± 0.13	77.6 ± 0.66	12.3 ± 0.61	10.7 ± 0.44	44.0 ± 1.11
24	BW 9065	6.1 ± 0.14	76.5 ± 0.89	11.6 ± 0.72	10.6 ± 0.20	42.0 ± 2.00
25	BW 9039	6.3 ± 010	77.0 ± 0.54	10.4 ± 0.28	10.9 ± 0.42	41.0 ± 2.02
26	PBW 175	6.2 ± 0.18	77.3 ± 1.08	10.9 ± 0.27	10.1 ± 0.67	39.0 ±1.65
27	PBW 343	5.7 ± 0.12	72.9 ± 1.25	9.8 ± 0.64	9.7 ± 0.38	36.0 ± 1.44
28	PBW 550	6.2 ± 0.40	77.2 ± 1.03	11.0 ± 1.05	10.8 ± 0.59	46.0 ± 2.06
39	PBW 621	5.6 ± 0.17	74.3 ± 1.30	10.0 ± 1.01	10.4 ± 0.64	45.0 ± 2.48
30	C 306	6.2 ± 0.21	76.2 ± 1.67	11.6 ± 0.82	11.2 ± 0.35	41.0 ± 0.48
31	C 591	6.2 ± 0.17	76.9 ± 0.45	12.2 ± 0.83	10.4 ± 0.36	42.0 ± 1.80
32	HD 2967	5.8 ± 0.15	74.1 ± 1.01	8.7 ± 0.41	10.5 ± 0.60	45.0 ± 2.12

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Table 5. Average values of baking quality attributes recorded on the wheat lines

S. No	Line	Bread Quality Score (Max.10)	Chapati Score (Max10)	Cookies Spread Factor (W/T)
1	PBW 657	5.1 ± 0.15	7.6 ± 0.12	6.3 ± 0.13
2	PBW 671	5.3 ± 0.22	7.8 ± 0.17	6.1 ± 0.11
3	BWL 813	5.9 ± 0.13	8.2 ± 0.13	6.7 ± 0.28
4	BWL 814	5.8 ± 0.06	8.1 ± 0.27	6.5 ± 0.38
5	BWL 818	5.5 ± 0.44	8.0 ± 0.13	6.5 ± 0.22
6	BWL 819	5.4 ± 0.17	7.8 ± 0.13	6.7 ± 0.11
7	BWL 822	5.2 ± 0.19	8.1 ± 0.16	6.0 ± 0.31
8	BWL 823	5.3 ± 0.19	7.9 ± 0.18	6.2 ± 0.19
9	BWL 825	5.4 ± 0.13	8.1 ± 0.07	6.2± 0.21
10	BWL 826	6.0 ± 0.76	7.6 ± 0.07	5.9 ± 0.25
11	BWL 827	5.4 ± 1.00	7.9 ± 0.15	6.6 ± 0.11
12	BWL 828	5.3 ± 0.17	7.7 ± 0.26	6.0 ± 0.22
13	BWL 829	5.4 ± 0.27	8.0 ± 0.13	6.3 ± 0.37
14	BWL 942	4.6 ± 0.23	7.6 ± 0.22	6.1 ± 0.25
15	BWL 944	4.8 ± 0.21	7.2 ± 0.20	6.3 ± 0.14
16	BWL 956	5.7 ± 0.26	7.8 ± 0.38	6.2 ± 0.31
17	BW 6864	5.8 ± 0.39	7.9 ± 0.18	6.1 ± 0.19
18	BW 7623	6.1 ± 0.25	7.8 ± 0.09	6.4 ± 0.34
19	BW 8361	6.3 ± 0.16	7.9 ± 0.13	5.6 ± 0.17
20	BW 8987	5.8 ± 0.06	7.8 ± 0.90	6.6 ± 0.25
21	BW 9005	5.7 ± 0.23	8.2 ± 0.13	6.2 ± 0.09
22	BW 9022	5.9 ± 0.12	8.0 ± 0.22	6.3 ± 0.36
23	BW 9027	5.9 ± 0.05	7.8 ± 0.22	6.1 ± 0.40
24	BW 9065	5.9 ± 0.14	7.6 ± 0.19	6.7 ± 0.37
25	BW 9039	5.7 ± 0.16	7.9 ± 0.24	6.4 ± 0.30
26	PBW 175	5.7± 0.34	8.0± 017	6.1 ± 0.09
27	PBW 343	5.1 ± 0.13	7.5 ± 0.19	6.5 ± 0.13
28	PBW 550	5.4 ± 0.31	7.8 ± 0.22	6.3 ± 0.26
39	PBW 621	5.8 ± 0.31	7.2 ± 0.25	6.4 ± 0.11
30	C 306	5.5 ± 0.32	8.0 ± 0.17	6.0 ± 0.07
31	C 591	5.5 ± 0.26	8.0 ± 0.24	6.2 ± 0.11
32	HD 2967	5.7 ± 0.21	7.6 ± 0.17	6.6 ± 0.14