Pak. J. Bot., 52(2): 581-592, 2020. DOI: http://dx.doi.org/10.30848/PJB2020-2(40)

VARIABILITY OF SOME PAKISTANI COMMERCIAL WHEAT (*TRITICUM AESTIVUM* L.) VARIETIES FOR AGRO-MORPHOLOGICAL AND END-USE QUALITY TRAITS

HAJI MUHAMMAD UMER MEMON[1*], SAQIB ARIF[2], HADI BUX[1], MAHBOOB ALI SIAL[3], ALI MURAD RAHOO[4], WAZIR ALI MAITLO[5] AND S.M. MUJATABA[3]

[1]*Institute of Plant Sciences, University of Sindh, Jamshoro, Pakistan*
[2]*Food Quality and Safety Research Laboratory, SARC, PARC, University campus, Karachi, Pakistan*
[3]*Nuclear Institute of Agriculture (NIA), Tando Jam, Pakistan*
[4]*Wheat Research Institute (WRI), Sakrand, Pakistan*
[5]*Department of Molecular Biology & Genetics, Shaheed Benazir Bhutto University, Shaheed Benazirabad-Nawabshah, Pakistan*
**Corresponding author's email: hmumerm@gmail.com*

Abstract

An experiment was conducted to examine sixteen commercial wheat varieties (*Triticum aestivum* L.) varieties for agro-morphological, physicochemical and dough rheological traits variability. Agro-morphological attributes including height of plants (cm), main spike length (cm), grains per spike, heading/maturity days, spikes per meter and thousand kernels weight (g) were observed at two locations (Petaro and Sakrand) of Sindh, besides, physicochemical traits such as test weight (kg/hl), wet/dry gluten content (%), gluten index, grain protein content (%) and dough rheological characteristics including time for dough development (min.), softening degree of dough (ICC), dough stability (min.), water absorption (%) and farinograph quality number were also observed. Data were statistically analysed for combined ANOVA followed by DMRT and Pearson's correlation. Wheat genotypes expressed highly significant differences at $p<0.05$ for all the observed traits. Significantly highest means for thousand kernels weight (51.1g) and 10-kernels width (3.6cm) were observed in wheat variety Imdad-2005. TJ-83 yielded significantly the highest dry gluten content (12.0%), wet gluten content (24.2%) and grain protein content (14.1%). Besides, wheat varieties T.J-83, Pak-81 and Zardana possessed the excelled respective grain protein content means of 14.1%, 13.4% and 13.5%. Grain protein content established positive correlation to wet gluten (r = 0.92**), water binding in gluten (r = 0.84*) and dry gluten content (r = 0.99**), while its non-significant negative correlation existed with thousand kernels weight (r = -0.19) and test weight (r = -0.2). Dough stability had significant correlation to dough development time (r = 0.61*). Highly significant and negative correlation of degree of softening was developed to stability of dough (r = -0.80**) and farinograph quality number (r = -0.77**). Present studies provided a comprehensive knowledge of nutritional properties of wheat varieties and will be helpful while selection of potentially quality genotypes.

Key words: Spikes per meter, Kernels weight, Grain protein content, Water absorption.

Introduction

Wheat crop is highly important due to functionality of its grain to produce several end-use products. It adds approximately 20% of the total proteins and calories consumption in all over the world (Shiferaw *et al*., 2013) and is widely used for making of various food items such as "chappati", "naan" and other baking products (Ahmed & Fayyaz, 2015). Pakistan is world's eighth largest wheat producing country (Anon., 2016) and occupies the largest agricultural area than all the crops. Wheat is a leading cereal crop of Pakistan with the cultivation of 8.734 million hectares and grain yield production of 25.5 million tons, accounting 10% value in agriculture and 1.7% to GDP of Pakistan (Anon., 2018). Cultivation of the wheat crop in our country has central role in the food security, sustainable agriculture GDP, supporting boost the economy of the small agriculture growers and producing good quality baking products. However, all such aspects are associated with excelled grain yield and nutritional quality of the locally adapted commercial wheat varieties.

Rather than growing the plants in control conditions, potential grain yield of the cereal crops could be well judged when grown under natural field optimum conditions and evaluated through yield and yield associated agro-morphological traits. Agro-morphological yield associated traits and quality for high nutrients ratio of the wheat crop are the consumer's important considerations (Sial *et al*., 2012; Mladenov *et al*., 2001). Morphological characteristics are widely observed as criteria in selection and evaluation of genetic diversity in the breeding of wheat (Schut *et al*., 1997; Akcura, 2011). Grain yield linked traits such as number of grains and yield of main spike, spikes on a plant, grains weight and grains yield in a plot are frequently used in concerns of grain yield improvement (Mohammadi *et al*., 2012; Abbas *et al*., 2013; Wu *et al*., 2012; Kazi *et al*., 2012; Inamullah *et al*., 2006). Such secondary traits will be useful for the yield associated genetic progress in the plants other than yield itself (Gizaw *et al*., 2016).

Nutritional grain quality of the newly evolved wheat varieties is frequently neglected over the yield performance since its minimal effect on yield performance and consequently non-significant correlation with the income of the small wheat growers. Nevertheless, quality of the wheat grain is basic requirement in the well-being of humans (Kong *et al*., 2013) and wheat breeders of Pakistan are trying to release advance varieties having more yield potential along with great baking quality (Ikhtiar & Alam, 2007). Grain quality standards of the wheat varieties are not only necessary during export and import as a commodity but also a prerequisite from the baking industries and during the evolving new commercial wheat varieties.

Baking quality of the wheat genotypes can be enhanced by knowing physicochemical composition influencing end-use suitability (Panghal *et al*., 2019). Wheat varieties with better quality are demanded in the baking industries due to the increasing concerns for taste and nutrition of wheat products (Yang *et al*., 2014). However, wheat flour quality is combined effect of several interlinked internal and external factors including genotypic variability, agro-practices, environment and genotype × environment interaction (Anjum & Walker, 2000; Altindal, 2019).

About 80% to 85% of the grain protein portion is formed by two types of polymers; glutenins and gliadins; both are responsible for the formation of gluten (Shaista *et al*., 2011). Wheat flour dough exhibits extensibility and elasticity due to gluten proteins (Shewry *et al.*, 1999; Begum *et al*., 2019) and such proteins play a central role in the preparation of various food items. Wheat flour processing ability for various food items can be categorized through evaluating for gluten proteins (Weegels *et al*., 1996). Importance of the dough rheological traits in the wheat breeding is increased in the past several decades (He *et al*., 2006). Such traits are important for end-product quality of wheat flour dough (Chen *et al*., 2009; Uthayakumaran *et al*., 2000). Farinograph is one of the instruments, which uses shearing deformation to evaluate the rheological characteristics of the flour (Schluentz *et al*., 2000; Campos *et al*., 1997; Uygur & Şen, 2018).

Wheat yield has been increased around the world during the last half of the century due to genetic gain, proper water management and application of pesticides and fertilizers (Valipour *et al*., 2015), however, grain quality improvement still needs productive efforts. Due to varying climatic conditions, the grain quality and crop yield will have critical position and addressed on priority (Thornton *et al*., 2014). Thus, the breeder's objective now is to evolve high yielding well adapted wheat genotypes endowed with better quality for end-use (Li *et al*., 2013; Lopes *et al*., 2012). Evaluation of the end-use quality of the wheat grains falls in the three of the most important categories including physicochemical, dough rheological and baking quality traits (Arif *et al*., 2007). Development of wheat varieties bestowed with better nutritional quality along with improved grain yield performance has a central position in the wheat breeding programs. Objectives of this study were comprised of evaluation the variability of different commercial wheat varieties and correlations analysis for: (a) yield associated agro-morphological traits (b) physicochemical traits in relation to baking quality and (c) dough rheological properties involved in the dough making processes. Results will be helpful and beneficial in the selection of well performing wheat varieties for yield associated traits to boost the income of small agriculture growers. Besides, grain quality results will provide a choice to the baking industries in the selection of the resilient wheat varieties for making different baking items based on their better-quality performance. Wheat varieties expressing better performances will be subjected in conventional wheat breeding programs to evolve the wheat progenies endowed with both better grain yield and end-use baking quality traits.

Materials and Methods

Genetic material: A set of **s**ixteen-commercial wheat (*Triticum aestivum* L.) varieties was collected form Wheat Research Institute (WRI), Sakrand and evaluated for agro-morphological and physicochemical traits and dough rheological traits variability. List showing year of release and pedigree of wheat varieties is given in Table 1.

Growth conditions: An experiment was conducted in the field under natural environment of two agro-climatic locations including Petaro (Location 1) and the experimental field station of Wheat Research Institute (WRI), Sakrand (Location 2). Before sowing, land was levelled, harrowed and pulverized for the uniform distribution of irrigations. Wheat varieties were sown applying RCBD design into two rows of 2m length, each row was separated with 30cm gap with three replications at the Petaro agriculture field while with four replications at the Sakrand. Full four irrigations were applied at critical crop growth stages; (a) 8-9 leaves (b) tillering (c) booting and (d) grain filling respectively.

Table 1. Pedigree and releasing year of the commercial wheat varieties used in the study.

Year of release	Wheat varieties	Pedigree
2012	Hammal	LFN/1158.57//Prl/3/Hahn/4/Kauz
2012	Benazir	CHEN/AEGILOPS SQUARROSA (TAUS)//BCN/3/VEE#7/
2006	Imdad-2005	CHIL/2*STAR
2006	SKD-1	HD-2329
2004	TD-1	MAI'S'/NORTENO65/H68
2003	Bhittai	VEE/TRAP//SOGHAT-90 or VEE/TRAP#1//SOGHAT90
2002	Moomal-2002	BUC or BUCS/4/TZPP/IRN46
1993	Zardana	CNO67/8156//TOB66/CNO67/4/NO/3/12300//LR64A/8156/5/PVN
1991	Anmol-91	KVZ/TRM//PTM/ANA
1988	Mehran-89	KVZ/BUHO//KAL/BB
1984	TJ-83	TZPP/PL//7C
1983	Kohinoor-83	ORE F1 158/FDL//MFN/2*TIBA63/3/COC
1981	Pak-81	KVZ/BUHO//KAL/BB
1979	ZA-77	NOR67/7C
1978	Pavon	VCM//CNO/7C/3/KAL/BB
1974	Yecora	CNO67//SON64/KLRE/3/8156

Source: https://par.com.pk/wheat/varieties/pakistan

Data collection: Plants height was observed as length from base of the plant to the end of the main spike without awns. Heading days were examined as duration of sowing to the 80% of the spikes fully emergence. Maturity days were calculated as the duration as days from sowing to the 80% chlorosis of the plants. Flag leaf area was expressed in square centimetre (cm^2) after heading the plants. Other agro-morphological traits like main spike length, spikelets on spike, grains on spike and spikes along a meter were observed after maturation of the plants.

After harvesting plots and manual threshing of the plants, grain samples were collected and moved for physicochemical and dough rheological characterization in Food Quality and Safety Research Laboratory, SARC, PARC, University Campus, Karachi, Pakistan. Thousand kernel weight of the varieties was recorded by counting 100 grains (Dexter *et al*., 1984) using seed counter (Seedburo 801 Count-A-Pak, Des Plaines, Illinois IL, US), weighing on a high-resolution precision balance and multiplying by 10. Test weight of the wheat varieties was expressed following the method of Dexter & Tipples (1987).

Wheat samples were milled for whole wheat flour using laboratory mill (Perten-3100, Hagersten, Sweden). Whole wheat flour of the wheat varieties was assessed for moisture content (%) according to the ICC standard (110/1) using moisture tester (Brabender MT-C, Germany). Standard 10g flour of each variety was placed in the oven chamber at the temperature of 130°C for 60 minutes. Falling number of the wheat flour samples were expressed following AACC, 2000 (56-81B) using falling number instrument (Perten-1500, Hagersten, Sweden).

Wheat varieties were characterised for wet gluten and dry gluten according to the procedure of AACC-2000 (38-12) using Perten's glutomatic gluten index system instrument (Hagersten, Sweden). Sample's protein content was obtained according to the AACC 2000 method (46-10) using Kjeldhal's distillation unit (Metler-Toledo, Germany). Wheat samples each weighing 5g were transferred to digestion flask for the digestion in the presence of catalyst mixture and sulfuric acid (H_2SO_4) at 350°C for 180min. Samples were allowed for cooling at room temperature and added with 100ml water. Distillation involved the addition of 50ml of sodium hydroxide (40% NaOH). Liberating ammonia (NH_3) was captured by 50ml of 4% boric acid (H_3BO_4) solution containing 8-10 drops Tashiro's indicator. Samples were titrated against standard 0.1N H_2SO_4 solution.

Dough rheological attributes of wheat samples were determined following AACC method No. 54-21, AACC, 2000 using farinograph (Brabender, GmbH & Co. KG, Duisburg, Germany). Important traits associated with the dough of the wheat flour such as water absorption, time for dough development, softening degree, stability time of dough and farinograph quality number (FQN) were evaluated (Anon., 2001).

Statistical analysis

The data were statistically analysed for Analysis of variance (ANOVA), Duncan's multiple range test (DMRT) and Pearson's correlation using Statistix 8.1 (Analytical software, Tallahassee, FL, US). Graphs were made using PRISM 6.1c (GraphPad software Inc., San Diego, CA, 2017).

Results

Results from pooled analysis of variance (ANOVA) showed highly significant variability (p<0.05) among the wheat genotypes for all the observed agro-morphological traits at Petaro (Location 1) and Sakrand (Location 2) including days to booting, days to maturity, flag leaf area, grains per spike, plant height, main spike length, spikelets per meter, 10-kernels width, 10-kernels length and thousand kernels weight (Table 2), physicochemical traits viz. falling number, moisture content, wet gluten, dry gluten, water binding in wet gluten, gluten index and test weight (Table 3).

Coefficient of variance reflected wide variation among the means performance of the wheat varieties. Wheat varieties expressed the means performance of 48.7cm2, 75.7cm, 63.6, 128.8, 8.81cm, 39.5, 71.4, 7.07cm, 3.29cm and 43.3g for the respective flag leaf area, plant height, days to heading, days to maturity, main spike length, grains per spike, spikes per meter, 10-kernels length, 10-kernels width and thousand kernels weight at the location 1 (Petaro). Maximum coefficient of variation among the wheat varieties 22.2 was recorded for spikes for meter at location 1 (Table 4). Means of the wheat varieties for days to heading, days to maturity, flag leaf area grains, per spike, plant height, main spike length and spikes per meter were 62.7, 125.7, 50.7cm^2, 43.7, 79.8cm, 10.3g and 83.3 respectively at location 2 (Sakrand) (Table 4).

At location 2 (Sakrand), dry gluten content, wet gluten content, water binding in wet gluten, gluten index, moisture content and protein content coefficient of variance were found 8.68, 8.84, 9.33, 41.1, 1.81 and 6.70 respectively. Test weight, falling number, dry gluten content, wet gluten content, water binding in wet gluten, gluten index, moisture content and grain protein content respective means were 77.6kg/hl, 421.7min., 10.5%, 31.9%, 21.3%, 43.4%, 9.61% and 12.5%. Mean values range for dough development time, dough stability, degree of softening, farinograph quality number and water absorption were 3.2-14.2sec., 3.6-18.7sec., 11.0%-102.0%, 49.0-200.0 and 54.6-64.2% respectively (Table 5).

Agro-morphological traits: Duncan's multiple range test for agro-morphological traits means of the commercial wheat varieties is given in Tables 6-7. Means performance of the wheat varieties for agro-morphological traits from two locations is presented in Figs. 1-2. Genotypes × location interaction was found significant for all the traits (p<0.01) at both the locations.

Plant height: Respectively the highest means of 89.0cm and 87.9cm were produced among Kohinor-83 and Imdad-2005 at location 1. Wheat varieties Kohinoor and Moomal-2002 were tallest with the means of 93.5cm, 93.3cm, whereas the short plants with the means of 63.3cm and 63.6cm were Pavon and TD-1 wheat varieties at location 2.

Table 2. Mean squares from combined analysis of variance (ANOVA) for agro-morphological traits of some commercial wheat varieties.

Source of varieties	Degree of freedom	Mean squares (MS)									
		Flag leaf area (cm^2)	Plant height (cm)	Main spike length (cm)	Grains per spike	Days to heading	Days to maturity	Spikes per meter	10-Kernel length (cm)	10-Kernel width (cm)	Thousand kernel weight (g)
Genotypes (G)	15	143.6**	611.8**	2.17**	229.0**	26.9**	120.4**	1686.7**	0.62**	0.08**	116.1**
Location (L)	1	90.6**	376.2**	55.2**	492.8**	28.7*	247.0**	3684.0**	1.16**	0.07*	$79.8^{n.s.}$
Replications	3	5.87	1.1	0.69	11.5	7.37	2.12	78.34	0.07	0.03	103.1
G x L	15	12.6**	73.0**	4.38**	69.8**	20.7**	23.9**	251.9**	0.33**	0.03**	130.5**
Error	77	5.65	13.2	0.61	28.5	5.83	3.69	63.4	0.14	0.01	30.9
Total	111										

Significant (*) at $p<0.05$ and highly significant (**) at $p<0.01$

Table 3. Mean squares from analysis of variance (ANOVA) for different physicochemical traits of some commercial wheat varieties grown at Sakrand (Location 2).

Source of varieties	Degree of freedom	Mean squares (MS)							
		Falling number (sec.)	Moisture content (%)	Wet gluten content (%)	Dry gluten content (%)	Water binding in wet gluten (%)	Gluten index (%)	Grain protein content (%)	Test Weight (kg/hl)
Genotypes	15	12692.0**	0.09**	25.8**	2.45**	11.6**	1014.1**	2.10**	26.5**
Replications	2	41.6	0.00	0.10	0.01	0.88	5.15	0.09	0.32
Error	30	247.7	0.00	0.87	0.05	0.88	8.08	0.02	0.13
Total	47								

Significant (*) at $p < 0.05$ and highly significant (**) at $p < 0.01$

Days to heading: Wheat variety T.J.-83, Imdad-2005 and Hammal expressed late heading with the respective means of 69.7, 67.3 and 66.3 at Petaro (Location 1). According to the results, late heading at location 2 was expressed by the wheat varieties Pak-81, Hammal and Benazir with the respective means of 65.3, 65.0 and 64.5, besides, respective the lowest DH means of 60.3 and 56.8 were recorded among the wheat varieties Zardana and Pavon.

Days to maturity: Late maturity at location 1 was expressed by Pavon (134.5) and Mehran-89 (134.0). Wheat genotypes SKD-1 and Zardana were late maturing with the respective means of 131.5 and 131.0, while wheat varieties TD-1 and Anmol-91 were found as early maturing with the means of 117.3 and 119.3 at location 2.

Main spike length: Means range for main spike length was 8.66cm-12.2cm. Elongated spike was developed by wheat varieties TD-1 with the means of 12.2cm followed by Moomal-2002, SKD-1 and Imdad-2005 with the respective means of 11.9cm, 11.8cm and 11.8cm. At location 1, wheat varieties Benazir and Hammal produced the longest spike with the respective means of 10.2cm and 10.1cm.

Grains per spike: Grains per spike means were found in the range of 34.8-54.2. Highly significant and maximum means for grains per spike as 54.2, 50.0 and 49.3 were observed in Hammal and Benazir and Anmol-91 wheat varieties respectively. Hammal and Imdad-2005 had the better means of 53.3 and 50.8 for grains per spike at location 1 (Petaro).

Spikes per meter: Highly significant and maximum means for spikes per meter were produced by the wheat varieties TD-1 (109.8) and SKD-1, however, the reduced number for spikes per meter were observed in the ZA-77 (58.0) and Yecora (61.3). Three wheat varieties had better spikes per meter means at location 1.

Ten kernels length: Better kernel length values were expressed among the wheat varieties T.D.-1 (7.78cm) and Benazir (7.53cm), on the contrary, lowest kernel length values for 10-kernels length at location 1 were related with Pak-81 (6.47cm) and Anmol-91 (6.30). 10-kernels length of the wheat varieties showed a range of means from 6.46cm to 7.53cm. Wheat varieties Yecora (7.53cm), Benazir (7.47cm) and TD-1 (7.40cm) possessed the excelled means for 10-kernels length, simultaneously, lowest means for 10-kernels length were found in the Pavon (6.37cm) and Hammal (6.30cm).

Ten kernels width: Better 10-kernels width means at location 1 were recorded in Benazir and Hammal wheat varieties with the means of 3.60cm and 3.47cm. Wheat variety Imdad-2005 had the highest means (3.60cm) for 10-kernels width followed by Benazir (3.43cm) and Moomal-2002 (3.37cm), whereas, the lowest means for ten kernels width were produced by Zardana (3.10cm) and TD-1 (3.07cm).

Table 4. Agro-morphological traits variability of the commercial wheat varieties grown at Petaro (location 1) and Sakrand (Location 2).

Traits	Mean	S.E.	Range	C.V.
Location 1 (Petaro)				
Flag leaf area	48.7	1.1	40.4-54.0	8.9
Plant height	75.7	2.3	60.2-89.0	12.3
Days to heading	63.6	0.7	57.3-69.7	4.7
Days to maturity	128.8	1.1	122.0-134.5	3.3
Main spike length	8.81	0.22	7.00-10.2	9.92
Grain per spike	39.5	2.0	25.5-53.3	20.3
Spikes per meter	71.4	4.0	50.7-100.3	22.2
10-kernel length	7.07	0.10	6.30-7.78	5.63
10-kernel width	3.29	0.03	3.11-3.60	4.17
Thousand kernel weight	43.3	2.1	29.0-67.5	19.0
Location 2 (Sakrand)				
Flag leaf area	50.7	1.29	44.1-58.3	10.2
Plant height	79.8	2.66	63.3-93.5	13
Days to heading	62.7	0.56	56.8-65.3	3.56
Days to maturity	125.7	1.21	117.3-131.5	3.86
Main spike length	10.3	0.27	8.66-12.2	10.4
Grain per spike	43.7	1.20	34.8-54.3	11.0
Spikes per meter	83.3	4.42	58.0-109.8	21.2
10-kernel length	6.85	0.10	6.30-7.53	5.76
10-kernel width	3.24	0.03	3.07-3.60	4.18
Thousand kernel weight	41.4	0.96	36.4-51.1	9.31

Table 5. Physicochemical and dough rheological traits variability of the commercial wheat varieties grown at Sakrand (Location 2).

Traits	Mean	S.E.	Range	C.V.
Falling number	421.7	16.3	315.0-520.7	15.4
Moisture content	9.61	0.04	9.34-9.91	1.81
Wet gluten content	31.9	0.70	25.9-36.5	8.84
Dry gluten content	10.5	0.23	9.00-12.1	8.68
Water binding in wet gluten	21.3	0.50	16.9-24.4	9.33
Gluten index	43.4	4.46	10.0-78.0	41.1
Grain protein content	12.5	0.21	11.2-14.1	6.70
Test weight	77.6	0.74	72.5-82.5	3.82
Dough development time	6.4	0.8	3.2-14.2	49.0
Degree of softening	58.4	6.6	11.0-102.0	45.5
Dough stability	11.8	1.4	3.6-18.7	48.2
Farinograph quality number	128.4	14.5	49.5-200.0	45.3
Water absorption	59.2	0.6	54.6-64.2	3.9

Thousand kernels weight: According to the analysis, thousand kernels weight means were found in a range of 36.4g-51.1g. Wheat variety Imdad-2005 had the significant and highest thousand kernels weight means (51.1g) followed by Benazir (48.2g), whereas, the Pavon and Kohinoor-83 possessed the lowest thousand kernels weight with the respective means of 37.6g and 36.4g. SKD-1 (67.5g) and Anmol-91 (51.1) possessed highly significant and maximum means for thousand kernels weight at location 1.

Physicochemical traits: Physicochemical analysis included the traits for the whole grain evaluation such as thousand kernel weight and test weight along with whole wheat flour analysis such as falling number (sec.), moisture content (%), wet gluten content (%), dry gluten content (%) and grain protein content (%) of the wheat varieties. Means performance for physicochemical traits of the commercial wheat varieties were used in Duncan’s multiple range test given in Table 8 and presented in the Fig. 3.

Test weight: Wheat varieties showed the test weight means between the range of 72.5kg/hl-82.5kg/hl. Hammal, Benazir and Pavon had the respective highest values 82.5, 81.9 and 81.4 for test weight, however, Pak-81 and Mehran-89 expressed the lowest 73.5 and 72.5 test weight means.

Moisture content: Moisture content of the flour of the varieties ranged between 9.34-9.91% (Table 5). Wheat varieties Yecora and Pak-81 had the respective highest 9.91% and 9.87% moisture content means, while, Zardana and Imdad-2005-2005 possessed the lowest moisture content with the means of 9.34% and 9.37%.

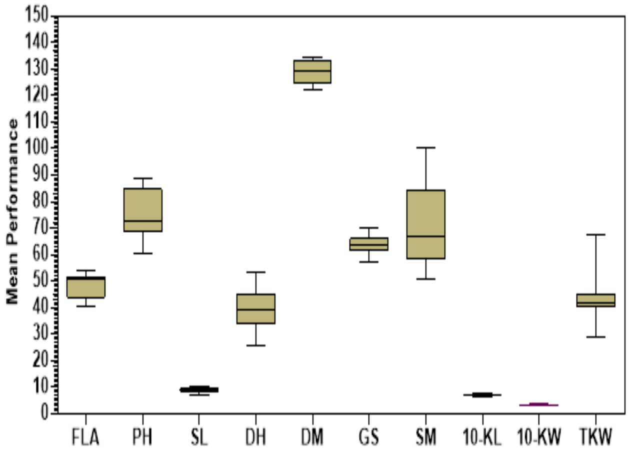

Fig. 1. Variability of the wheat varieties for agro-morphological traits including flag leaf area (FLA), plant height (PH), spike length (SL), days to heading (DH), days to maturity (DM), grains per spike (GS), spikes per meter (SM), 10-kernels length (10-KL), 10-kernels width (10-KW) and thousand kernels weight (TKW) at location 1 (Petaro).

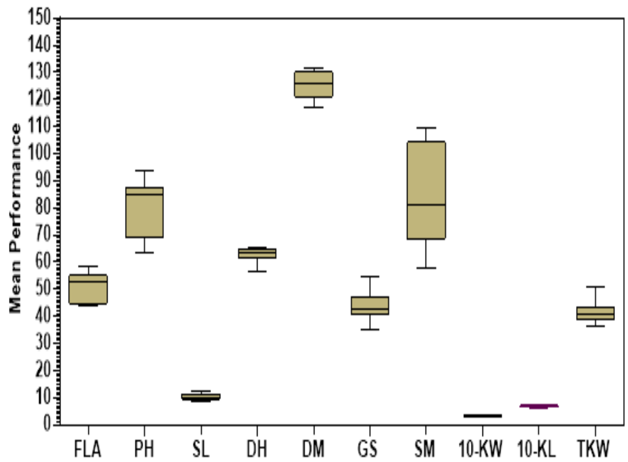

Fig. 2. Variability of the wheat varieties for agro-morphological traits including flag leaf area (FLA), plant height (PH), spike length (SL), days to heading (DH), days to maturity (DM), grains per spike (GS), spikes per meter (SM), 10-kernels length (10-KL), 10-kernels width (10-KW) and thousand kernels weight (TKW) at location 2 (Sakrand).

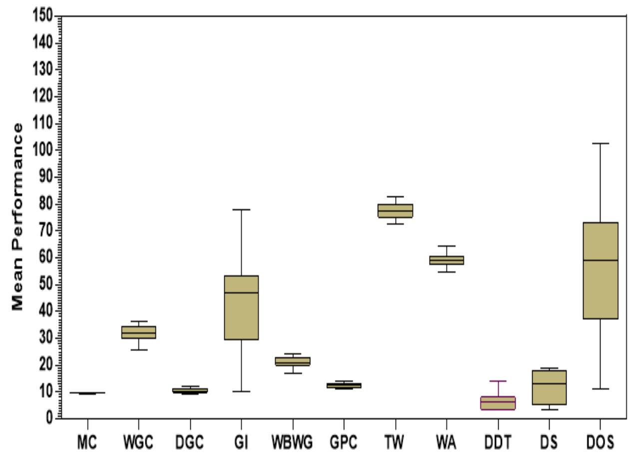

Fig. 3. Mean performance of the wheat varieties for grain quality traits including moisture content (MC), wet gluten content (WGC), dry gluten content (DGC), water binding in wet gluten (WBWG), grain protein content (GPC), test weight (TW), water absorption (WA), dough development time (DDT), dough stability (DS) and degree of softening (DS) of the wheat varieties at Sakrand (Location 2).

Table 6. Mean performance for agro-morphological traits of the wheat varieties grown at Petaro (Location 1).

Wheat varieties	Flag leaf area (cm^2)	Plant height (cm)	Days to heading	Days to maturity	Main spike length (cm)	Grains per spike	Spikes per meter	10-Kernel length (cm)	10-Kernel width (cm)	Thousand kernel weight (g)
Hammal	52.3^{AB}	86.4^{ABC}	66.3^{ABC}	127.7^{BCD}	10.1^{A}	53.3^{A}	99.7^{A}	7.07^{ABCD}	3.47^{AB}	45.3^{BC}
Benazir	51.0^{AB}	84.8^{ABC}	64.7^{ABCD}	126.3^{CDE}	10.2^{A}	49.7^{ABC}	100.3^{A}	7.53^{AB}	3.60^{A}	47.3^{BC}
Imdad-2005	51.7^{AB}	87.9^{AB}	67.3^{AB}	127.7^{BCD}	8.48^{BCD}	50.8^{AB}	69.7^{CD}	7.47^{AB}	3.35^{BCD}	41.9^{BC}
SKD-1	50.9^{AB}	81.8^{BC}	60.7^{DE}	133.5^{A}	8.27^{BCD}	27.2^{HI}	83.8^{B}	7.32^{ABC}	3.11^{E}	67.5^{A}
TD-1	50.6^{AB}	60.2^{F}	63.7^{BCD}	123.0^{E}	7.00^{D}	31.0^{GHI}	68.0^{CD}	7.78^{A}	3.30^{BCDE}	36.6^{CD}
Bhittai	54.0^{A}	70.0^{D}	57.3^{E}	133.2^{A}	7.92^{BCD}	35.0^{EFGH}	59.0^{DEF}	7.08^{ABCD}	3.20^{CDE}	42.0^{BC}
Moomal-2002	50.9^{AB}	73.1^{D}	62.0^{BCDE}	131.8^{AB}	8.83^{ABC}	42.8^{BCDE}	76.7^{BC}	7.17^{ABC}	3.28^{BCDE}	43.1^{BC}
Anmol-91	52.6^{AB}	84.3^{ABC}	63.2^{BCD}	130.7^{ABC}	9.05^{AB}	38.2^{DEFG}	66.2^{CDE}	6.30^{D}	3.22^{CDE}	51.1^{B}
Mehran-89	51.5^{AB}	71.1^{D}	66.3^{ABC}	134.0^{A}	7.45^{CD}	25.5^{I}	58.5^{DEF}	7.22^{ABC}	3.25^{BCDE}	45.0^{BC}
T.J.83	51.4^{AB}	81.0^{C}	69.7^{A}	126.3^{CDE}	8.50^{BCD}	39.7^{DEFG}	57.2^{DEF}	7.18^{ABC}	3.40^{ABC}	41.5^{BCD}
ZA-77	43.7^{CD}	72.2^{D}	63.0^{BCD}	124.0^{DE}	9.42^{AB}	45.7^{ABCD}	50.7^{F}	6.97^{ABCD}	3.27^{BCDE}	40.4^{BCD}
Kohinoor-83	42.3^{D}	89.0^{A}	64.0^{BCD}	123.0^{E}	9.40^{AB}	37.3^{DEFG}	84.6^{B}	6.80^{BCD}	3.13^{DE}	35.4^{CD}
Pak-81	40.4^{D}	72.5^{D}	64.3^{ABCD}	122.0^{E}	8.80^{ABC}	41.0^{CDEF}	89.1^{AB}	6.47^{CD}	3.27^{BCDE}	44.8^{BC}
Pavon	48.5^{BC}	61.8^{EF}	62.7^{BCDE}	134.5^{A}	8.83^{ABC}	34.0^{FGHI}	64.0^{CDE}	7.17^{ABC}	3.15^{DE}	40.9^{BCD}
Yacora	44.4^{CD}	67.7^{DE}	61.3^{CDE}	130.3^{ABC}	9.50^{AB}	42.5^{BCDEF}	53.8^{EF}	6.48^{CD}	3.18^{CDE}	40.3^{BCD}
Zardana	43.4^{D}	68.0^{DE}	60.7^{DE}	132.0^{AB}	9.25^{AB}	38.5^{DEFG}	60.5^{DEF}	7.12^{ABCD}	3.47^{AB}	29.0^{D}
Mean	**48.7**	**75.7**	**63.6**	**128.8**	**8.8**	**39.5**	**71.4**	**7.1**	**3.3**	**43.3**

Letter variability following the means indicates significant difference ($p < 0.05$)

Table 7. Mean performance different for agro-morphological traits of the wheat varieties grown at Sakrand (Location 2)

Wheat varieties	Flag leaf area (cm^2)	Plant height (cm)	Days to heading	Days to maturity	Main spike length (cm)	Grains per spike	Spikes per meter	10-Kernel length (cm)	10-Kernel width (cm)	Thousand kernel weight (g)
Hammal	56.0^{AB}	87.7^{B}	56.8^{H}	130.0^{B}	9.68^{BCDE}	54.3^{A}	103.5^{A}	6.30^{F}	3.23^{CDEF}	41.7^{E}
Benazir	53.7^{BCDE}	85.3^{BC}	60.3^{G}	125.5^{C}	10.3^{BC}	50.0^{AB}	104.8^{A}	7.46^{A}	3.43^{B}	48.2^{B}
Imdad-2005	53.0^{CDE}	85.4^{BC}	60.5^{FG}	125.8^{C}	11.6^{A}	44.3^{BCDE}	104.5^{A}	6.96^{BC}	3.60^{A}	51.1^{A}
SKD-1	55.8^{AB}	87.0^{BC}	61.3^{EFG}	131.5^{A}	11.8^{A}	34.8^{F}	107.3^{A}	6.93^{BC}	3.13^{EFG}	38.8^{H}
TD-1	58.3^{A}	63.6^{F}	61.8^{DEFG}	117.3^{F}	12.2^{A}	41.5^{DEF}	109.8^{A}	7.40^{A}	3.06^{G}	43.8^{C}
Bhittai	54.1^{BCDE}	71.6^{D}	62.3^{CDEFG}	130.5^{AB}	9.39^{CDEF}	41.0^{DEF}	76.8^{BC}	7.06^{B}	3.20^{DEFG}	40.8^{F}
Moomal-2002	55.1^{BC}	93.3^{A}	62.3^{CDEFG}	130.0^{B}	11.9^{A}	42.3^{CDEF}	85.5^{B}	7.10^{B}	3.36^{BC}	39.4^{G}
Anmol-91	51.6^{E}	87.2^{BC}	62.8^{BCDEF}	119.3^{E}	9.31^{DEF}	49.3^{ABC}	72.3^{CD}	6.63^{DE}	3.30^{BCD}	40.6^{F}
Mehran-89	52.0^{DE}	69.0^{DE}	63.5^{ABCDE}	130.3^{AB}	9.75^{BCDE}	42.3^{CDEF}	72.3^{CD}	6.46^{EF}	3.23^{CDEF}	37.8^{I}
T.J.83	54.6^{BCD}	87.2^{BC}	63.8^{ABCD}	122.8^{D}	10.3^{B}	47.5^{ABCD}	67.8^{CDE}	6.86^{BCD}	3.20^{DEFG}	38.7^{H}
ZA-77	44.4^{F}	83.9^{BC}	64.3^{ABC}	120.5^{E}	9.81^{BCDE}	43.5^{BCDE}	58.0^{E}	6.43^{EF}	3.20^{DEFG}	40.6^{F}
Kohinoor-83	44.3^{F}	93.5^{A}	64.5^{ABC}	124.5^{C}	9.57^{BCDEF}	39.5^{EF}	86.5^{B}	6.80^{CD}	3.13^{EFG}	36.4^{J}
Pak-81	44.8^{F}	70.2^{DE}	64.5^{ABC}	122.5^{D}	8.66^{F}	40.5^{DEF}	85.5^{B}	6.46^{EF}	3.26^{CDE}	41.6^{E}
Pavon	44.9^{F}	63.3^{F}	64.5^{ABC}	130.0^{B}	9.25^{EF}	44.8^{BCDE}	68.5^{CDE}	6.36^{F}	3.16^{DEFG}	37.6^{I}
Yacora	44.8^{F}	82.4^{C}	65.0^{AB}	120.0^{E}	10.5^{B}	39.0^{EF}	61.3^{DE}	7.53^{A}	3.16^{DEFG}	43.6^{C}
Zardana	44.1^{F}	65.5^{EF}	65.3^{A}	131.0^{AB}	10.2^{BCD}	44.8^{BCDE}	68.8^{CDE}	6.80^{CD}	3.10^{FG}	42.1^{D}
Mean	**50.7**	**79.7**	**62.7**	**125.7**	**10.3**	**43.7**	**83.3**	**6.85**	**3.23**	**41.4**

Letter variability following the means indicates significant difference ($p < 0.05$)

Table 8. Physicochemical traits variability of commercial wheat varieties grown at Sakrand (Location 2).

Wheat varieties	Falling number (sec)	Moisture content (%)	Wet gluten content (%)	Dry gluten content (%)	Water binding in wet gluten (%)	Gluten index (%)	Grain protein content (%)	Test weight (kg/hl)
Hammal	334.7^{F}	9.52^{D}	26.01^{H}	9.1^{I}	17.08^{G}	49.66^{CD}	11.20^{J}	82.46^{A}
Benazir	362.7^{E}	9.49^{DE}	31.21^{EF}	10.13^{FG}	21.08^{DE}	50.33^{CD}	12.30^{H}	81.89^{AB}
Imdad-2005	516.7^{A}	9.34^{H}	30.13^{F}	9.71^{H}	20.42^{EF}	52.66^{C}	11.80^{I}	76.00^{H}
SKD-1	520.7^{A}	9.75^{B}	28.28^{G}	9.14^{I}	19.14^{F}	62.00^{B}	11.40^{J}	77.50^{FG}
TD-1	374.3^{E}	9.70^{BC}	30.00^{F}	9.88^{GH}	20.12^{EF}	10.66^{G}	12.00^{I}	75.93^{H}
Bhittai	433.0^{BCD}	9.44^{EF}	34.79^{BC}	10.9^{CD}	23.87^{AB}	49.66^{CD}	12.90^{EF}	77.26^{FG}
Moomal	518.3^{A}	9.73^{B}	29.99^{F}	9.55^{H}	20.44^{EF}	47.00^{D}	11.30^{J}	80.20^{C}
Anmol	429.0^{CD}	9.54^{D}	33.57^{CD}	10.4^{EF}	23.15^{AB}	47.00^{D}	12.50^{GH}	77.06^{G}
Mehran	315.0^{F}	9.41^{FG}	30.12^{F}	10.25^{F}	19.87^{EF}	50.33^{CD}	12.30^{H}	72.46^{K}
TJ-83	449.3^{BC}	9.71^{BC}	37.40^{A}	12.03^{A}	24.21^{A}	39.00^{E}	14.10^{A}	77.73^{F}
ZA-77	429.3^{CD}	9.70^{BC}	32.13^{DE}	11.06^{C}	21.1^{DE}	32.0^{F}	13.00^{DE}	75.00^{I}
Kohinoor-83	440.3^{BC}	9.54^{D}	30.20^{F}	10.26^{EF}	19.9^{EF}	60.3^{B}	12.30^{H}	74.46^{I}
Pak-81	332.3^{F}	9.86^{A}	34.47^{BC}	11.63^{B}	22.8^{ABC}	28.6^{F}	13.40^{BC}	73.53^{J}
Pavon	456.0^{B}	9.65^{C}	35.18^{B}	11.45^{B}	23.7^{AB}	60.3^{B}	13.20^{CD}	81.36^{B}
Yecora	411.7^{D}	9.91^{A}	32.23^{DE}	10.61^{DE}	21.4^{CDE}	79.6^{A}	12.70^{FG}	79.43^{D}
Zardana	424.3^{CD}	9.37^{GH}	34.19^{BC}	11.62^{B}	22.6^{BCD}	9.00^{G}	13.50^{B}	78.^{E}
Overall mean	421.7	9.60	31.87	10.48	21.3	45.5	12.49	77.6

Table 9. Dough rheological mean performance of the wheat varieties grown at Sakrand (Location 2).

Varieties	Traits				
	WA (%)	DDT (min)	DS (min)	DOS (ICC)	FQN
Hammal	61.1 ± 0.1	7.25 ± 0.1	9.20 ± 0.3	75.5 ± 1.5	111.5 ± 0.5
Benazir	57.2 ± 0.2	14.2 ± 0.2	18.7 ± 0.3	66.0 ± 1.0	200.0 ± 0.0
Imdad-2005	59.4 ± 0.3	6.65 ± 0.2	12.4 ± 0.2	53.0 ± 1.0	129.5 ± 1.5
SKD-1	60.5 ± 0.3	3.35 ± 0.2	18.7 ± 0.1	11.0 ± 1.0	200.0 ± 0.0
T.D.-1	58.7 ± 0.1	3.85 ± 0.1	4.85 ± 0.2	66.0 ± 1.0	56.5 ± 1.5
Bhittai	60.4 ± 0.1	8.30 ± 0.3	10.3 ± 0.3	63.5 ± 1.5	126.0 ± 2.0
Moomal 2002	58.4 ± 0.1	10.4 ± 0.4	18.7 ± 0.2	53.0 ± 2.0	200.0 ± 0.0
Anmol-91	64.2 ± 1.7	6.40 ± 0.4	14.0 ± 0.1	40.5 ± 1.5	145.0 ± 5.0
Mehran-89	57.3 ± 0.3	7.45 ± 0.3	15.5 ± 0.2	55.0 ± 0.0	167.5 ± 2.5
T.J.-83	59.8 ± 0.1	4.65 ± 0.2	14.5 ± 0.4	36.0 ± 2.0	139.0 ± 1.0
ZA-77	56.0 ± 0.1	3.65 ± 0.2	3.60 ± 0.2	101.5 ± 3.5	52.5 ± 0.5
Kohinoor-83	54.6 ± 0.3	6.30 ± 0.1	18.7 ± 0.1	26.0 ± 1.0	200.0 ± 0.0
Pak-81	59.3 ± 0.0	3.55 ± 0.2	3.80 ± 0.1	95.0 ± 0.0	49.5 ± 0.5
Pavon	62.3 ± 0.3	3.35 ± 0.2	7.25 ± 0.3	63.5 ± 1.5	65.5 ± 0.5
Yacora	59.2 ± 0.1	9.50 ± 0.3	13.9 ± 0.1	29.5 ± 1.5	161.0 ± 1.0
Zardana	58.8 ± 0.1	3.15 ± 0.2	4.45 ± 0.4	102.5 ± 3.5	51.5 ± 1.5

WA = Water absorption, DDT = Dough development time, DS = Degree of softening, FQN = Farinograph quality number.
Values followed by ± are S.E. of means

Falling number: Falling number test evaluates the damage of the wheat due to pre-harvest sprouting of the wheat kernels through activity of alpha-amylase enzyme. Results showed means range between 315.0-520.7 for falling number among the wheat varieties. Wheat varieties SKD-1, Moomal-2002 and Imdad-2005 showed highly significant and excelled respective means of 520.7sec., 518.3sec. and 516.7sec. for falling number, besides, Hammal, Pak-81 and Mehran-89 had the respective lowest falling number values (334.7sec., 332.3sec. and 315.0sec.).

Wet gluten content: Wet gluten content mean values ranged from 26.01 to 37.40%. Wheat varieties TJ-83 and Hammal had the respective highest (37.40%) and lowest wet gluten content (26.01%).

Dry gluten content: Dry gluten content means were observed in the range of 9.1%-12.03%. Wheat varieties TJ-83, Pak-81, Zardana and Pavon had the respective 12.0%, 11.6%, 11.6% and 11.5% as the highest dry gluten content means, however, lowest dry gluten values were produced by SKD-1 and Hammal with the means values of 9.15% and 9.10%.

Water binding in the wet gluten: Results showed the means range for water binding in wet gluten between 17.08% and 24.21% and means for gluten index in the range of 79.66% and 9.00%. Wheat varieties TJ-83, Bhittai, Pavon and Anmol-91 had the highest means for water binding in wet gluten with the respective means of 24.2%, 23.9%, 23.7% and 23.2%, on the contrary, the lowest respective means of 19.1 and 17.1 were found in SKD-1 and Hammal wheat varieties.

Gluten index: Wheat variety Yecora had the highest means of 79.7% for gluten index followed by SKD-1 (62.0%) and Kohinoor-83 (60.3%), whereas the lowest means for gluten index were obtained in the wheat varieties TD-1 (10.7%) and Zardana (9.00%).

Grain protein content: Means for grain protein content among the commercial wheat varieties vary between 11.2%-14.1%. Wheat varieties TJ-83, Zardana and Pak-81 had the better and respective excelled means of 14.1%, 13.5% and 13.4% for protein content, while Hammal and Moomal-2002 had the lowest grain protein content with the means of 11.2% and 11.3%.

Dough rheological characterization: Mean performance of the wheat varieties for dough rheological traits such as water absorption (%), dough development time (min.), dough stability (min.), degree of softening (ICC), and farinograph quality number is given in Table 9. Fig. 3 expresses the means performance of the wheat varieties regarding dough rheological traits.

Water absorption: Dough developed from the whole wheat flour of the Anmol-91, Pavon, Hammal and SKD-1 wheat varieties needed more water absorption with the respective means of 64.2%, 62.3%, 61.1% and 60.5%, whereas, the lowest water absorption (%) was observed among the Benazir (57.2%), ZA-77 (56.0%) and Kohinoor wheat varieties required less water absorption during dough development.

Dough development time: Maximum time for dough development was observed among the whole wheat flour samples of Benazir (14.2min.), Moomal-2002 (10.4min.), Yecora (9.50min.) and Bhittai (8.30min.), besides, the the minimum time for dough development was characterized in the wheat varieties SKD-1 (3.35min.), Pavon (3.35) and Zardana (3.15).

Dough stability: Better dough stability time was observed in the whole wheat flour samples of Benazir, SKD-1, Moomal-2002 and Kohinoor-83 wheat varieties all with same means of 18.7min., besides, the weakest dough was developed by the wheat varieties Zardana, Pak-81 and ZA-77 with the respective means of 4.45min., 3.80min. and 3.60min.

Degree of softening: Respective highest means of 102.5, 101.5 and 95.0 for degree of softening of the dough were found in the wheat varieties Zardana, ZA-77 and Pak-81, simultaneously, the lowest means for degree of softening were recorded in the wheat varieties Kohinoor-83 and SKD-1 with the means of 26.0 and 11.0.

Farinograph quality number: Better farinograph quality with the means of 200.0 were recorded in the wheat varieties Benazir, SKD-1 and Moomal-2002, however, ZA-77, Zardana and Pak-81 had the respective lowest means of 52.5, 51.5 and 495.0 for farinograph quality.

Pearson's correlation: All the results pertaining Pearson's correlation coefficient (*r*) is given in the Table 10. Highly significant and positive correlation of grain protein content existed between water binding in wet gluten (r = 0.86) and dry gluten content (r = 0.99**) (Fig. 4), while its non-significant and negative correlation established with ten kernel length (r = -0.15), ten kernel width (r = -0.28), thousand kernel weight (r = -0.28) and test weight (r = -0.2). Spikes per meter showed positive significant and highly significant correlation with day to heading (r = 0.54*) and flag leaf area (r = 0.64**) respectively. Strong correlation (r = 0.61*) was found between dough development time and dough stability. Degree of softening showed highly significant and negative correlation (r = -0.80**) with dough stability and farinograph quality number (r = -0.77**) at $p<0.05$. Dough stability expressed highly significant and positive correlation with farinograph quality number (r = 0.99**). Gluten index had the positive and highly significant correlation with farinograph quality number (r = 0.80**). Dough development time showed significantly positive correlation (r = 0.53*) with gluten index. Negative but non-significant correlation of dough stability with water absorption (r = -0.13), water binding in wet gluten (r = -0.24) and wet gluten content (r = -0.35).

Discussion

Analysis of variance (ANOVA) indicated highly significant variability ($p<0.05$) among the wheat varieties for all the observed agro-morphological and physicochemical traits. Results revealed wide variation among the means performance of the wheat varieties for all the observed traits. Yield associated morphological traits showing positive correlation with the grain yield are considered to evolve new high yielding varieties necessary for a successful breeding program (Nawaz *et al*., 2013).

Excelled number of spikes per meter and grains per spike were expressed by Hammal, Benazir and Imdad wheat varieties. According to the results, positive and significant correlation of plant height with days to maturity was established indicates that prolonged maturity period results in the increase of the plant height of the plants. Ten kernel width means range in this study was observed between 3.60cm and 3.07cm is contemporary to the mean values range of 3.6cm to 2.8cm concluded by Pasha (2006). Grain diameter and weight highly influence wheat milling performance, hence, widely used as quality indicators in the wheat marketing (Khalil *et al*., 2002).

Thousand kernel weight means were obtained in the range of 36.4g-51.1g. Anjum *et al.*, (2002) reported the thousand kernels weight range of Pakistani commercial wheat varieties between 31.4g and 37.28g. Traits such as grains per spike, flag leaf area, spikelets per spike, thousand kernels weight, harvest index, main spike length can be considered for the selection of wheat varieties bestowed with better grain yield (Kazi *et al*., 2012). Ten wheat varieties including Hammal and Benazir expressed the test weight means above the 76kg/hl. Test weight is widely used to examine the performance of the cultivar under harsh environments and is considered as significant trait for grain values (Misic & Mladenov, 1998). Test weight, thousand kernel weight and kernel size are the most useful physicochemical traits that estimate wheat kernel density, yield and flour extraction potential of the wheat genotypes. Wheat samples with healthier wheat kernels results into better test weight values (Arif *et al*., 2009). In this study, positive but non-significant correlation of the thousand kernel weight existed with test weight and 10-kernel length.

Three wheat varieties including SKD-1, Moomal-2002 and Imdad-2005 had the highest falling number means. Falling number is accurate for most of the quality tasks and indirectly measures alpha-amylase, which affects the physical characters of starch (Every *et al*., 2002; Lessard, 2002). Results revealed that TJ-83 and Hammal had better wet gluten content values, whereas, dry gluten means were excelled in TJ-83, Pak-81. TJ-83 and Bhittai. Gluten acts as an important and central role in the baking quality of wheat through providing cohesiveness, viscosity and water absorption capacity to the dough. It plays central role in the preparation of different food products (Wrigley *et al*., 2006). Coefficient of variation among the mean performance of the commercial wheat varieties was highest for gluten index (41.1). Gluten index means were better in SKD-1 and Kohinoor-83 wheat varieties. Gluten index is a part of physicochemical traits of the wheat grain and therefore is lined with its grain quality performance (Oikonomou *et al*., 2015).

Grain protein content of the wheat varieties in this study was expressed in the range of 11.2%-14.1%. Results are contemporary with earlier findings Anjum *et al*., (2005), who reported the range of means for protein content among the Pakistani wheat varieties as 9.68%-13.45%. Twelve wheat varieties possessed the protein (%) above 12.0 including TJ-83, Zardana and Benazir. Excelled protein content makes gluten strong as a result bread with good quality is formed (Pasha *et al.*, 2010) on the contrary, low the protein content makes the gluten weak and consequently produce small loaves of inferior crumb structure (Bushuk, 1998; Tipples *et al*., 1994). Protein content affects dough expansion rate as well the baking quality of the wheat flour. Results expressed highly significant and positive correlation of the grain protein content with dry gluten content, wet gluten content and water binding in wet gluten. Grain protein content and gluten subunits highly influence the rheological traits performance of the wheat flour such as mixing tolerance index, dough development time, dough stability and water absorption (Bushuk, 1985; El-Khayat *et al*., 2006).

Table 10. A matrix of simple correlation coefficient (r) grain yield and quality traits of some commercial wheat varieties grown at Sakand (Location 2).

Traits	DDT	DGC	DH	DM	DOS	DS	FLA	FN	FQN	GI	GS	MC	GPC	PH	SL	SM	10-KL	TKW	10-KW	TW	WA	WBWG
DGC	-0.35																					
DH	0.32	-0.39																				
DM	0.08	-0.21	-0.16																			
DOS	-0.20	0.35	-0.19	0.01																		
DS	0.61**	-0.45	0.27	0.22	-0.80**																	
FLA	0.28	-0.59*	0.28	0.12	-0.30	0.34																
FN	-0.12	-0.11	-0.08	0.19	-0.44	0.33	0.07															
FQN	0.65**	-0.50*	0.35	0.23	-0.77**	0.99**	0.34	0.28														
GI	0.53*	-0.41	0.44	0.06	-0.74**	0.75**	0.07	0.22	0.80**													
GS	0.27	-0.01	-0.08	-0.02	0.33	-0.10	0.21	-0.34	-0.13	-0.19												
MC	-0.18	0.16	0.13	-0.43	-0.18	-0.07	-0.16	0.04	-0.06	0.11	-0.40											
PC	-0.36	0.99**	-0.35	-0.24	0.31	-0.43	-0.55*	-0.16	-0.48	-0.38	0.02	0.12										
PH	0.41	-0.42	0.53*	-0.07	-0.50*	0.67**	0.19	0.40	0.69**	0.65**	0.14	0.09	-0.41									
SL	0.09	-0.53*	0.16	-0.01	-0.33	0.28	0.57*	0.50*	0.27	0.05	-0.28	0.08	-0.54*	0.19								
SM	0.18	-0.72**	0.54*	0.12	-0.16	0.23	0.64**	0.01	0.24	0.04	0.04	-0.16	-0.69**	0.16	0.52*							
10-KL	0.53*	-0.16	0.32	-0.27	-0.35	0.36	0.31	0.20	0.39	0.26	-0.27	0.14	-0.15	0.12	0.60**	0.28						
TKW	0.52	-0.25	0.29	0.04	0.01	0.30	0.22	0.20	0.29	0.29	0.33	-0.32	-0.28	0.38	0.14	0.29	0.10					
10-KW	0.37	-0.21	0.39	-0.23	0.21	-0.09	0.21	-0.01	-0.07	0.03	0.26	-0.26	-0.19	0.02	0.34	0.44	0.48	0.65**				
TW	0.40	-0.18	-0.08	0.29	-0.03	0.15	0.20	0.15	0.14	0.08	0.51*	0.02	-0.20	0.18	0.12	0.15	0.20	0.11	0.18			
WA	-0.18	0.03	-0.25	0.08	-0.14	-0.13	0.25	0.13	-0.17	-0.03	0.30	0.05	0.02	-0.16	-0.12	-0.01	-0.19	0.05	0.00	0.38		
WBWG	-0.19	0.88**	-0.37	-0.18	0.11	-0.24	-0.34	0.12	-0.30	-0.29	-0.06	0.10	0.86**	-0.36	-0.39	-0.58	0.06	-0.11	-0.12	-0.08	0.28	
WGC	-0.26	0.95**	-0.39	-0.23	0.25	-0.35	-0.44	0.04	-0.41	-0.37	-0.03	0.13	0.93**	-0.38	-0.44	-0.65	-0.02	-0.16	-0.14	-0.13	0.16	0.98**

*Significant at $p<0.05$, **Highly significant at $p<0.01$ level. DDT=dough development time, DH=days to heading, DM=days to maturity, DOS=degree of softening, DS=dough stability , FLA=flag leaf area, FN=falling number, FQN=farinograph quality number, GI=gluten index, GS=grains per spike, MC=moisture content, GPC=protein content, PH=pl ant height, MSL=main spike length, SM=spikes per meter, 10-KL=ten kernel length, TKW=thousand kernel weight, 10-KW=ten kernel width, WA=water absorption, WBWB=water binding in wet gluten, WGC=wet gluten content, DGC=dry gluten content, TW=testweight.

All the rheological tests performed on dough seek to predict behaviour in response to bread-making processes, such as mixing or fermentation (Sanchez-Garcia *et al*., 2015). Dough characteristics including water absorption, dough development time, dough stability time, dough-softening and mechanical weakening are the parameters frequently used to describe the processing behaviour of the dough (Hadnadev *et al*., 2011). Farinograph results provide essential knowledge in relation to the required water quantity for dough making, effect of flour ingredients in dough mixing characteristics, checking the flour uniformity, blending requirements for the flour, dough stability, prediction of processing effects including dough development time, dough consistency, tolerance to over-mixing and predicting the textural attributes of the flour end-products.

Results revealed that wheat varieties Benazir, ZA-77 and Kohinoor had the lowest water absorption values. Grain protein content is considered as in important traits to estimate the water uptake of the flour (Sliwinski *et al*., 2004). However, results in this study expressed positive but non-significant correlation between water absorption in the dough and grain protein content. Highest values for dough development time were recorded in Benazir and Moomal-2002 wheat varieties. Strong wheat flour requires longer dough development time (Zaidel *et al*., 2010). Results showed that these varieties were also well performing in grain protein content. Dough development time had the non-significant negative correlation (r = -0.36) with grain protein content.

Dough stability was highest in the wheat varieties of Benazir, SKD-1 and Moomal-2002. Lowest values for degree of softening were expressed in the wheat varieties Kohinoor-83 and SKD-1. Highly viscous and less elastic dough results from the wheat flour with poor quality gluten as compared to the wheat possessing good quality (Bordes *et al*., 2008). More dough stability makes the dough to withstand longer fermentation period (Channa *et al*., 2015). Dough rheological traits can predict the quality of the grain proteins pertaining end-use suitability for various food items including pasta, noodles and baking items.

Conclusion

Improvement of wheat grain quality is one of prime objectives in the breeding programme. In this study negative correlation existed between observed grain quality and grain yield contributing traits of the commercial wheat varieties. Although, Hammal, Benazir and SKD-1 wheat varieties depicted excelled means for various agro-morphological, physiochemical and dough rheological traits. It is concluded that aforesaid wheat varieties could be appropriate choice to the farmers and baking industries regarding both the better grain yield outputs and making of quality baking items when grown in the optimum field conditions. Furthermore, progressive efforts must be taken on the priority basis in the development of new wheat varieties having both the better grain yield and nutritional quality and adapted to the fluctuating environmental conditions using Hammal, Benazir and SKD-1 wheat varieties; one of the approaches to address the food security issues and making food items with required better nutritional quality.

Acknowledgement

We are thankful to Amin Ahmed from Food Quality and Safety Research Laboratory, SARC, PARC, Karachi University Campus, Karachi, Pakistan, for his help in the physicochemical experiments. This research belongs to the Ph.D. thesis of the corresponding author.

References

Abbas, G., J.Z.K. Khattak, G. Abbas, M. Ishaque, M. Aslam, Z. Abbas, M. Amir and M.B. Khokhar. 2013. Profit maximizing level of potassium fertilizer in wheat production under arid environment, *Pak. J. Bot.,* 45(3): 961-965.

Ahmed, M., Fayyaz-ul-Hassan. 2015. Response of spring wheat (*Triticum aestivum* L.) quality traits and yield to sowing date. *PLoS One,* 10(4): e0126097.

Akcura, M. 2011.The relationships of some traits in Turkish winter bread wheat landraces. *Turk. J. Agri.*, 35: 115-125.

Altındal, D. 2019. Effect of seaweed extract (se) on seed germination characteristics of wheat in salty conditions. *Int. J. Agri. For. Life Sci*., 3 (1): 115-120.

American Assoc. of Cereal Chemists. 2000. Approved Methods of the AACC, 10th ed. Method 38-12; 56-81B. The Assoc. St. Paul, Minnesota.

Anjum, F.M., I. Ahmad, M.S. Butt, M.A. Sheikh and I. Pasha. 2005. Amino acid composition of spring wheats and losses of lysine during chapatti baking. *J. Food Comp. Anal.*, 18: 523-532.

Anjum, F.M., M.S. Butt, N. Ahmad and I. Ahmad. 2002. Phytate and mineral content in different milling fractions of some Pakistani spring wheats. *Int. J. Food Sci. & Technol.*, 37: 13-7.

Anjum, F.N., C.E. Walker. 2000. Grain, flour and bread making properties of eight Pakistani hard wheat spring wheat cultivars grown in three different locations for two years. *Int. J. Food Sci. & Technol.*, 35(4): 7-46.

Anonymous. 2001. Brabender, Farinograph-E, 2001. User manual.

Anonymous. 2016. Food and Agriculture Organization (FAO). FAOSTAT. Available at http://www.fao.org/faostat/en/#rankings/ countries_by_commodity

Anonymous. 2018. *Pakistan Economic Survey*. Government of Pakistan, Ministry of Food, Agriculture and Livestock, Federal Bureau of Statistics Islamabad, pp. 17-18.

Arif, S., M. Ahmed and A. Hasnain. 2009. Study of Variation in the Quality of Hard White Spring Wheat for the Development of New Product. *Amer-Euras. J. Sustain. Agri.,* 3(4): 755-763.

Arif, S., M. Ahmed, A. Ahmad and Q. Afzal. 2007. To study major chemical traits in various Sindh wheat varieties for suitable end-use. *Sarhad J. Agri.*, 23: 153-156.

Begum, K., H., Ahmad and A., Iqbal. 2019. Characterization of wheat germplasm with seed quality parameters and glutenin subunits. *Pak. J. Bot*., 51(3): 1041-1048.

Bordes, J., G. Branlard, F.X. Qury, G. Charmet and F. Balfourier. 2008. Agronomic characteristic, grain quality and flour rheology of 372 bread wheat in a worldwide core collection. *J. Cereal Sci.,* 48: 569-579.

Bushuk, W. 1985. Rheology: Theory and application to wheat flour doughs. In Rheology of Wheat Products, ed. H. Faridi, 1-26. St. Paul, MN: American Association of Cereal Chemists.

Bushuk, W. 1998. Interactions in wheat doughs. In: Hamer R.J. and Hoseney R.C. (Eds), Interactions: The Keys to Cereal Quality. St. Paul, Minnesota: American Association of Cereal Chemists Inc, pp. 1-16.

Campos, D.T., J.F. Steffe and P.K.W. Ng. 1997. Rheological behavior of undeveloped and developed wheat dough. *Cereal Chem.,* 74: 489-494.

Channa, M.J., A.B. Ghanghro, S.A. Sheikh and S.M. Nizamani. 2015. Physico-chemical characteristics and rheolgical properties of different wheat varieties grown in Sindh. *Pak. J. Anal. Environ. Chem.*, 16 (2): 11-18.

Chen, R.Y., B.W. Seabourn, F. Xie and T.J. Herald. 2009. A modified extensigraph method for evaluating dough properties of hard wheat breeding lines. *Cereal Chem.,* 86: 582-589.

Dexter, J.E., K.R. Preston, R.R. Matsuo and K.H. Tipples. 1984. Development of a high extraction flow for the GRL pilot mill to evaluate Canadian wheat potential for the Chinese market. *Cand. Inst. Food Sci. Tech. J.,* 17: 253-259.

Dexter, J.E., R.R. Matsuo and D.G. Martin. 1987. The relationship of durum wheat test weight to milling performance and spaghetti quality. *Cereal Foods World*, 32: 772.

El-Khayat, G.H., J. Samaan, F.A. Manthey, M.P. Fuller and C.S. Brennan. 2006. Durum wheat quality I: some physical and chemical characteristics of Syrian durum wheat genotypes. *Int. J. Food Sci. & Technol.*, 41: 22-29.

Every, D., L. Simmons, J. Al-Hakkak, S. Hawkins and M. Ross. 2002. Amylase, falling number, polysaccharide, protein and ash relationships in wheat millstreams. *Euphytica*, 126: 135-142.

Gizawa, S.A., K. Garland-Campbellb and A.H. Cartera. 2016. Evaluation of agronomic traits and spectral reflectance in Pacific Northwest winter wheat under rain-fed and irrigated conditions. *Field Crops Res.*, 196: 168-179.

Hadnadev, T.D., A. Torbica, M. Hadnadev. 2011. Rheological properties of wheat flour substitutes/alternative crops assessed by Mixolab. *Procedia Food Sci.,* (1): 328-334.

He, Z.H., Y.M. Yan, Q.S. Zhuang, Y. Zhang, X.C. Xia, Y. Zhang, D.S. Wang, L.Q. Xia, Y.K. Hu, M.H. Cai, X.M. Chen, J. Yan and Y. Zhou. 2006. Establishment of quality evaluation system and utilization of molecular methods for the improvement of Chinese wheat quality. *Sci. Agri. Sin*., 39: 1091-1101 (in Chinese with English abstract).

ICC Standard methods of the International Association for Cereal Science and Technology. 2003. Standard No. 115/1, ICC, Vienna, Austria.

Ikhtiar, K. and A. Zeb. 2007. Nutritional composition of Pakistani wheat varieties. *Zhejiang Univ. Sci. B*, 8: 555.

Inamullah, H. Ahmad, F. Muhammad, Sirajuddin, G. Hassan and R. Gul. 2006. Diallel analysis of the inheritance pattern of agronomic traits of bread wheat. *Pak. J. Bot.,* 38(4): 1169-1175.

Kazi, A.G., A. Rashid, T. Mahmood and A.M. Kazi. 2012. Molecular and morphological diversity with biotic stress resistances of high 1000-grain weight synthetic hexaploid wheats. *Pak. J. Bot.,* 44(3): 1021-1028.

Khalil, I.H., B.F. Carver, E.G. Krenzer, C.T. MacKown, G.W. Horn, and P. Rayas-Duarte. 2002. Genetic trends in winter wheat grain quality with dual-purpose and grain-only management systems. *Crop Sci*., 42: 1112-1116.

Kong, L., J. Si, B. Zhang, B. Feng, S. Li and F. Wang. 2013. Environmental modification of wheat grain protein accumulation and associated processing quality: a case study of China. *AJCS*, 7(2):173-181.

Lessard, F.F. 2002. Qualitative reasoning and integrated management of the quality of stored grain: a promising new approach. *J. Stored Prod. Res.,* 38: 191-218.

Li, Y., Y. Wu, N. Hernandez-Espinoza and R.J. Pena. 2013. The influence of drought and heat stress on the expression of end-use quality parameters of common wheat. *J. Cereal Sci.,* 57: 73-78.

Lopes, M.S., M.P. Reynolds, M.R. Jalal-Kamali, M. Moussa, Y. Feltaous and I.S.A. Tahir. 2012. The yield correlations of selectable physiological traits in a population of advanced spring wheat lines grown in warm and drought environments. *Field Crops Res,* 128: 129-136.

Misic, T., and N. Mladenov. 1998. Results of winter wheat breeding at the Novi Sad Institute. In: Proc. 2nd Balkan Symp. Field Crops. Inst. Field and Vegetable Crops: Novi Sad, Yugoslavia, pp: 15-22.

Mladenov, N., N. Przulj, N. Hristov, V. Djuric and M. Milovanovic. 2001. Cultivar-by-environmental interactions for wheat quality traits in semiarid conditions. *Cereal Chem.,* 78: 363-367.

Mohammadi, M., P. Sharifi, R. Karimizadeh and M.K. Shefazadeh. 2012. Relationships between grain yield and yield components in bread wheat under different water availability (dryland and supplemental irrigation conditions). *Not. Bot. Hort. Agrobot.,* 40: 195-200.

Nawaz, R., Inamullah, H. Ahmad, Sirajuddin and M.S. Iqbal. 2013. Agromorphological studies of local wheat varieties for variability and their association with yield related traits. *Pak. J. Bot*., 45(5): 1701-1706.

Oikonomou, N.A., S. Bakalis, M.S. Rahman and M.K. Krokida. 2015. Gluten Index for Wheat Products: Main Variables in Affecting the Value and Nonlinear Regression Model. *Int. J. Food Prop.,* 18: 1-11.

Panghal, A., N. Chhikara and B.S. Khatkar. 2019. Characterisation of Indian wheat varieties for chapatti (flat bread) Quality. *J. Saudi Soc. Agri. Sci.,* 18: 107-111.

Pasha, I, F.M. Anjum, C.F. Morris. 2010. Grain Hardness: a major determinant of wheat quality (A Review). *Food Sci. Technol. Int.,* 16: (06): 511-512.

Pasha, I. 2006. Biochemical characterization of Pakistani wheats in relation to grain hardness. Ph.D. Thesis, *Inst. Food Sci. and Tech., Univ. Agric., Faisalabad, Pakistan*.

Sanchez-Garcia, M., F. Alvaro, A. Peremarti, J.A. Martín-Sánchez and C. Royo. 2015. Changes in bread-making quality attributes of bread wheat varieties cultivated in Spain during the 20th century. *Europ. J. Agron.,* 63: 79-88.

Schluentz, E.J., J.F. Steffe and P.K.W. Ng. 2000. Rheology and microstructure of wheat dough developed with controlled doformation. *J. Texture Stud.,* 31: 41-54.

Schut, J.W., X. Oi and P. Stam. 1997. Association between relationship measures based on AFLP markers, pedigree data and morphological traits in barley. *Theor Appl. Genet.,* 95: 1161-1168.

Shaista, K., A.N. Memon, A.B. Ghanghro and I. Tahir. 2011. Fractionation and characterization of seed storage proteins from different wheat varieties cultivated in Sindh on SDS-PAGE Electrophoresis. *Pak. J. Nutr.,* 10: 139-142.

Shewry, P.R., A.S. Tatham and N.G. Halford. 1999. The prolamins of the triticeae. *In: Seed proteins. P.R. Shewry and R. Casey, Eds. Kluwer Academic Publishers: Dordrecht, the Netherlands.*

Shiferaw, B., M. Smale, H.J. Braun, E. Duveiller, M. Reynolds and G. Muricho. 2013. Crops that feed the world 10. Past successes and future challenges to the role played by wheat in global food security. *Food Security,* 5: 291-317.

Sial, M. A., M.A. Arain, K.A. Laghari and S. Khanzada. 2012. Evolution of new wheat variety NIA-amber for the general cultivation in Sindh province -A case study. *Pak. J. Bot.,* 44(1): 301-306.

Sliwinski, E.L., P. Kolster and T. Van Vliet. 2004. Large-deformation properties of wheat dough in uni- and bi-axial extension. Part 1. *Flour dough. Rheol. Acta,* 43: 306-320.

Thornton, P.K., P.J. Ericksen, M. Herrero and A.J. Challinor. 2014. Climate variability and vulnerability to climate change: a review. *Global Change Biol.,* 20: 3313-3328.

Tipples, K.H., R.H. Kilborn and K.R. Preston. 1994. Bread-wheat quality defined. In: Bushuk W. and Rasper V.F. (eds), Wheat: Production, Properties and Quality, Glasgow: Chapman and Hall, pp. 25-35.

Uthayakumaran, S., M. Newberry, M. Keentok, F.L. Stoddard and F. Bekes. 2000. Basic rheology of bread dough with modified protein content and glutenin to gliadin ratios. *Cereal Chem.,* 77(6): 744-749.

Uygur, V., M. Şen. 2018. The effect of phosphorus application on nutrient uptake and translocation in wheat cultivars. *Int. J. Agric. For. Life Sci*., 2 (2): 171-179.

Valipour, M., M.Z. Ahmadi, Raeini-Sarjaz, M. Raeini-Sarjaz, M.A.G. Sefidkouhi, A. Shahnazari, R. Fazlola and A. Darzi-Naftchali. 2015. Agricultural water management in the world during past half century. *Arch. Agron. Soil Sci.,* 61: 657-678.

Weegels, P.L., A.M. van de Pijpekamp, A. Graveland, R.J. Hamer and J.D. Schofield. 1996. Depolymerisation and re-polymerisation of wheat glutenin during dough processing. I. Relationships between glutenin macropolymer content and quality parameters. *J. Cereal Sci.,* 23: 103-111.

Wrigley, C.W., M.A. Augustin, I.L. Batey and L. Day. 2006. Wheat-gluten uses and industry needs. *Trends in Food Sci. & Technol.,* 17: 82-90.

Wu, X., X. Chang and R. Jing. 2012. Genetic insight into yield-associated traits of wheat grown in multiple rain-fed environments. *PLoS One,* 7, e31249.

Yang, X., L. Wu, Z. Zhu, G. Ren and S. Liu. 2014. Variation and trends in dough rheological properties and flour quality in 330 Chinese wheat varieties. *The Crop J.,* 195-200.

Zaidel, D.N.A., N.L. Chin and Y.A. Yusof. 2010. A review on rheological properties and measurements of dough and gluten. *J. Appl. Sci.,* 10: 2478-2490.

(Received for publication 20 August 2018)