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Physicochemical and rheological properties of Indian wheat varieties of *Triticum aestivum*

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RESEARCH ARTICLE

Abstract

Physical quality parameters of grains and functional and rheological properties of flours and dough prepared from eight newly released Indian wheat varieties of *Triticum aestivum* were analysed. Grain samples were evaluated for 1000 kernel weight, test weight, bulk density, equivalent diameter and hardness. Wheat flour samples were tested for protein content, ash content, sedimentation value, falling number value, solvent retention capacities and rheological properties including mixing and pasting characteristics. Significant differences were observed among the studied wheat varieties regarding the 1000 kernel weight (34.81-47.47 g) and test weight (79.25-83.99 kg/hl) indicating their high milling yield potential. The dry gluten content ranged from 7.0 to 9.3% suggesting the suitability of the selected varieties for biscuit making. All the flour samples exhibited high falling number values (365 to 485 s). The dough mixing properties derived from micro doughLAB differed significantly as a function of varietal differences ($P<0.05$). Dough development time for different varieties ranged from 1.23 to 1.76 min and it was not necessarily dependent upon the quantity of gluten but also upon its quality. The flow behaviour index was less than 1, which suggested high shear thinning behaviour of the dough samples. The pasting temperature of different wheat varieties ranged from 66.10 to 67.80 °C.

Keywords: *Triticum aestivum*, physicochemical properties, pasting properties, rheological properties

1. Introduction

Wheat cultivars are the result of extensive selection by breeders to meet both quality and agronomic requirements for the wide range of end products such as traditional bread, sponge and dough bread, flat or steamed breads, chapatti, frozen doughs, yellow alkaline or udon style noodles, confectionary, biscuits, cakes and high quality pastas (Gale, 2005). Flour quality affects a variety of baking products due to their different physicochemical and rheological characteristics (Ahmed *et al.*, 2015). The varieties of wheat analysed in different countries including Hungary (Diosi *et al.*, 2015), Korea (Kang *et al.*, 2014), China (Zhang *et al.*, 2007), India (Ram and Singh, 2004), Egypt (El-Porai *et al.*, 2013), etc., have shown relationship of the certain parameters with the baking performance of flour. The physical quality characteristics of the kernels are known to affect particle size of the flour, which in turn affect the damaged starch content, alkali water retention and solvent retention capacities of the flour (Barak *et al.*, 2014). The relationship between some of the physical density, test weight (TW), kernel size and kernel weight) and the chemical properties moisture, starch and protein content) of *Triticum aestivum* have been studied extensively (Chung *et al.*, 2003; Khatkar *et al.*, 2002; Kim *et al.*, 2003). Rheological studies are being utilised extensively for the evaluation of flour quality (Vizitiu *et al.*, 2012). The different viscoelastic properties of flour from different wheat cultivars have been reported by different authors (Larsson and Eliasson, 1996; Safari-Ardi and Phan-Thien, 1998; Van Bockstaele *et al.*, 2008; Wikström and Eliasson, 1998). Ahmed *et al.* (2015) studied physicochemical and rheological properties of soft wheat flours obtained from different wheat varieties grown in Pakistan, Ukraine and India. The rheological behaviour of Indian wheat flour showed high water absorption, high dough stability and less degree of softening. Different wheat varieties grown at same geographical location in India were reported to have difference in protein content (11.6

to 14.6%) and farinographic water absorption (70 to 76%) (Hemalatha *et al.*, 2007). Rheological properties of the flours from 15 Indian wheat varieties were studied by Dhaka *et al.* (2012) using Mixolab to assess their bread making quality. The dough characteristics of fifty popular Indian hexaploid wheat varieties were analysed by testing various rheological properties using Brabender farinograph and extensograph (Gajalakshmi and Reddy, 2007). Bread wheat (PBW-138, PBW-299, PBW-343 and PBW-373) and two durum wheat (PDW-215 and PDW-233) cultivars were investigated for physicochemical, milling and dough-handling properties to predict their end-use quality (Naik *et al.*, 2010). The present study was undertaken with an objective to evaluate the physicochemical and rheological properties of eight newly released cultivars of *T. aestivum* grown in India in order to assess the potential quality and suitability of these flours for making wheat-based food products.

2. Materials and methods

Grains from eight varieties of *T. aestivum* (WH-102, HD-2967, KRL-213, RAJ-4120, RATAN CG-5016, CBW-38, DPW 621-50 and KRL-210) were used in this study. All these varieties were released between 2008 and 2012 were collected from Directorate of Wheat Research, Karnal (India). Straight grade flours from the tempered (14% moisture content/24 h) grains of each variety were produced using Brabender Quadrumat® Senior Mill (Brabender OHG, Duisburg Germany).

Physical quality characteristics of kernels

Thousand kernel weight (TKW) and TW were determined using standard methods of AACC (2000). Bulk density (BD) was determined using the method as suggested by Boumans (1985). The dimensional characteristics of the grains including length (L), width (W), and thickness (T) were measured using the vernier calliper with accuracy of 0.01 mm. The equivalent diameter (D) of grains was calculated by using the relationship as used by Sahay and Singh (1994):

$$D = (L \times W \times T)^{1/3}$$

where, L = length; W = width; T = thickness.

The sphericity (ϕ) of grains defined as the ratio of the surface area of the sphere having the same volume as that of grain to the surface area of grain, was determined using following formula as given by Mohsenin (1986):

$$\phi = D / L$$

where, D = equivalent diameter; L = length.

Grain volume (V) and surface area (S) was determined by using the equations as used by Jain and Bal (1997):

$$\text{Grain volume (V)} = 0.25\ [(\pi / 6)\ L\ (W + T)^2]$$

$$\text{Surface area (S)} = \pi B L^2 / (2L - B)$$

where, L = length; $B = \sqrt{WT}$

The porosity is the ratio of free space between grains to the total of bulk grains. The porosity was calculated from the relationship as suggested by Mohsenin (1986):

$$\text{Porosity (P)} = 1 - (\text{B.D.} / \text{P.D.}) \times 100$$

where P is the porosity in %, B.D. is the BD in kg/m^3 and P.D. is the particle density in kg/m^3.

Wheat grain hardness was evaluated by compression test using a TA-XT-plus texture analyser (Stable Micro Systems, Godalming, UK) according to AACC (2000) method No. 55-31. The following parameters were used: load cell = 50 kg, probe = aluminium cylinder with P/35 (35 mm diameter), test speed = 0.5 mm/s, and trigger force = 5.0 g, strain = 40% (according to height). Grain hardness was defined as the maximum force needed to compress the grain to 40% of its height. The moisture content of the wheat kernels from different varieties used for hardness testing was ranged from 9.56 to 11.33%. Three replicates were used for determining each of the physical quality parameters of the grains.

Chemical composition of flours

The standard AACC (2000) methods were used to analyse the flour samples for their moisture (method No. 44-15, ash (method No. 08-01), and crude fat (method No. 30-10). The gluten content was estimated by using glutomatic system (Perten Instruments, Hägersten, Sweden) by using AACC method No. 38-12 (AACC, 2000). The total wet and dry gluten content were expressed as the percentage of the sample on the basis of 14% moisture. Whole grain protein content was determined using near infrared spectroscopy (Foss Infratec 1241 Grain Analyzer; Foss Tecator AB, Höganäs, Sweden) according to the AACC 39-10 approved method (AACC, 2000).

Physicochemical properties of flours

The pelshenke value (PV) and sodium dodecyl sulphate (SDS)-sedimentation volume of flour samples were determined using standard methods of AACC (2000). The alpha-amylase activity of flour samples was measured in terms of falling number (FN) value according to AACC method 56-81 B (AACC, 2000) using Falling number apparatus (Perten Instruments, Sweden). Alkaline water retention capacity (AWRC) of flour samples was determined according to the AACC (2000) method 56-10 by suspending 1.0 g flour in 5 ml of 8.4 g/l sodium bicarbonate. Solvent retention capacity (SRC) of flour samples was obtained according to the AACC (2000) method 56-11 using 5.0 g flour suspensions (in 25 ml of water, 50% sucrose, 5% sodium carbonate, and 5% lactic acid respectively). Solubility and swelling power of flour samples were evaluated at 30 and 90 °C (Leach *et al.*, 1959).

Pasting characteristics of flours

Pasting properties of straight-grade flours were determined using a rapid visco-analyser (Perten Instruments) according to method No. 76-21.01 of AACC (2000). Flour (3.0 g) was weighed into a rapid visco analyser canister and 25 g of distilled water was added to prepare flour suspension. It was equilibrated at 50 °C for 1 min, heated to 95 °C at a rate of 6 °C/min, maintained at 95 °C for 5 min, and cooled to 50 °C at a rate of 6 °C /min and held at 50 °C for 5 min for all measurements. Various pasting parameters were read from the pasting profile with the aid of thermocline for Windows software (TCW3). The viscosity was expressed in terms of rapid-visco units (RVU), which is equivalent to 12 centipoises.

Mixing properties of flours

Flour sample (4 g) was mixed with water (30 °C) at a constant speed of 30 rpm using Newport micro doughLAB mixer (Perten Instruments, North Ryde, Australia). The amount of water required to achieve a dough consistency of 500 Brabender units (BU) was determined. The mixing parameters obtained from the curve were water absorption, peak resistance, dough development time, arrival time, departure time, dough stability, and softening.

Dough flow behaviour properties

Flow properties of dough samples were determined by using a controlled stress rheometer (R/S Plus Rheometer; Brookfield, Lauda-Kaonigshofen, Germany). All measurements were conducted at 25±1 °C using 40 mm diameter parallel plate geometry with a gap of 2 mm between the plates. Dough sample (10 g) was prepared by adding about 4.5±0.5 g of water to flour yielding flour to water ratio of about 2:1. The shear tests were conducted by shearing the sample at 1-5/s for 20 s. Creep tests were conducted by applying a constant stress of 50 Pa for 60 s on the sample and allowing the sample to recover the strain in 180 s after the removal of the load.

Creep measurements

A constant stress (t) was applied to the sample from time t_0 to t_2 (phase of applied stress or load). During this stage, the deformation (γ) reached to its maximum value γ_{max} at time t_2 (creep). γ_{max} depends on stiffness (rigidity modulus) and zero shear viscosity (h). At time t_2 stress is removed instantly (load removed or creep recovery phase). During the creep recovery phase after the removal of the load, the entire stored deformation energy was used up for the restoration process. The compliance value $J = \gamma/t$ can be calculated and the recovery value = J_e/J_{max} is equivalent to the solid properties. The ratio of the elastic component of the creep compliance and the maximum creep compliance was considered as the elastic index. The flow ability (fluidity) at the end of the applied load phase was determined as zero shear viscosity:

Zero shear viscosity $h_0 = t/\gamma_s$

Ostwald Power law and Herschell Bukley regression models were applied to the shearing tests to find the consistency index (k), the flow behaviour index(n) and the stability index (R^2).

Statistical analysis

All observations were taken in triplicate and the results were reported as the mean ± standard deviation. The data were analysed using one-factor analysis of variance (ANOVA) in completely randomised design using Opstat exe.1 statistical software (Haryana Agricultural University, Hisar, India); whereas differences among individual mean values were determined by Duncan test at significance level of 0.05. In order to find the main variation trends among various physicochemical and rheological properties of the investigated wheat cultivars, principal component analysis (PCA) was performed using XLSTAT statistical software (Addinsoft, New York, NY, USA) to know the source of underlying variability.

3. Results and discussion

Quality characteristics of wheat kernels

The observed values of various physicochemical characteristics of the wheat kernels are given in Table 1. The present study revealed significant varietal differences ($P<0.05$) in respect to TKW and TW, which could be of great significance for the millers and breeders. The varieties with better grain weight have been reported to offer better milling yield (Anjum and Walker, 2000). TKW and TW ranged from 34.81 to 47.47 g and 79.25 to 83.99 kg/hl respectively among different wheat varieties. WH-1021 and RAJ-4120 showed the highest values for TKW and TW. Wheat kernels can be classified according to grain weight as 15-25 g (very small), 26-35 g (small), 36-45 g (medium), 46-55 g (large) and over 55 g (very large) (Williams *et al.*, 1986). Lin and Czuchajowska (1997) investigated 200 cultivars of soft white winter wheat and found a positive correlation between the TW and the flour yield. Michniewicz *et al.*

(2000) reported the positive correlation between wheat test weight and flour yield. TW depends on the shape, size and soundness of grains and should be more than 76 kg/l for industrial use (Dhaka *et al.*, 2012). Hence, all the wheat varieties used in the study are suitable for industrial use. TKW of the varieties was in the range of the TKW as observed by Zanetti *et al.* (2001) in 128 wheat varieties that varied from 42.4 to 48.7 g. Whereas, Anjum *et al.* (2002) have reported lower kernel weight (31.43 to 37.28 g) in different Pakistani wheat varieties.

The values for BD, particle density and porosity ranged from 830 to 882 kg/m^3, 1,250 to 1,388.8 kg/m^3 and 33.52 to 39.54%, respectively. Dobraszczyk *et al.* (2002) found that kernels of soft wheat cultivars had a broad density distribution with medians in the range of 1,280 to 1,395 kg/m^3, while kernels of hard wheat cultivars exhibited much narrower distributions and had higher mean density of around 1,410 kg/m^3. Average kernel length, width and thickness of the varieties varied between 6.47 mm to 7.07 mm, 3.0 to 3.50 mm, 2.10 to 2.60 mm, respectively. Mean values for grain width in the present study are in accordance with the findings reported by Pasha *et al.* (2006). Knowledge of the kernel size (average grain length, width, and thickness) helps to select screens for the grain cleaning operations and to adjust grain feeding rate gaps required for grain milling operations. Dziki and Laskowski (2004) reported that kernel size had the maximum influence on grinding process in the first grinding stage. The equivalent diameter and sphericity of grains from various wheat varieties were found to be 3.50 to 4.50 mm and 53.59 to 60.14%, respectively, being the highest for WH-1021 and HD-2967, respectively. The highest and lowest hardness of the kernels was reported for CBW-38 (169.24 N) and WH-1021 (87.51 N). The texture including the hardness of grain endosperm influences certain physical properties, including the tempering requirements, flour particle size, flour density, starch damage, water absorption and milling yield (Martin *et al.*, 2001). Wheat kernel hardness is one of the most important factors in determining the functionality of wheat.

Chemical composition of flours

The chemical composition of the straight grade flours from different wheat varieties is shown in Table 1. Ash content of wheat varieties was found to be 1.16 to 1.60% and it was the highest for HD-2967. Ash content indicates milling performance and indirectly reveals the amount of bran contamination in flour. Ideally, the ash content in flour should be in between 0.40-0.45%. The ash contents have been reported from different research laboratories in various ranges from 0.27 to 0.40% (Noorka *et al.*, 2009); 1.08 to 1.85% (Ahmad *et al.*, 2001; Butt *et al.*, 2001). The higher value of ash content in the present study could possibly be accounted for the bran contamination in the white wheat flour.

Total protein content of different varieties was found to be 10.9 to 14.2% being highest in HD-2967 and lowest in KRL-213 variety. Anjum and Walker (2000) reported protein contents in six most prevalent Pakistani bread wheat cultivars that ranged from 11.99 to 13.80%. Butt *et al.* (2001) estimated 10.06 to 11.89% protein content in white flour from 30 spring wheat cultivars. Differences in the genetic makeup of different varieties, as well as environmental and growing conditions may be responsible for the difference in the protein contents among the different varieties (Randhawa *et al.*, 2002).

The wet and dry gluten contents were found to be varied significantly among different varieties. The dry gluten content was found to be 7.0 to 9.3% among different wheat varieties being the highest in WH-1021. The results are consistent with findings of Randhawa *et al.* (2002) and Islam *et al.* (1998) who also reported wet and dry gluten contents in different wheat varieties within this range. Wet and dry gluten contents have been reported to be 29.45 to 33.56% and 8.72 to 10.69%, respectively in different wheat varieties (Mueenud-Din *et al.*, 2007). The lower values of gluten content in the studied varieties suggest their suitability for the bakery products like biscuits and cakes. The fat content of different wheat varieties was found to be 1.1 to 1.4%.

Functional properties of flours

The results of various functional characteristics of flours are given in Table 2. The alpha-amylase activity measured as FN value ranged from 363-485 s suggesting very low alpha-amylase activity. A falling number value above 300 indicates minimal enzyme activity and good quality of wheat with no sprout damage. The highest FN value was obtained for variety KRL-210 while the lowest was observed in the case of DPW 621-50. Anjum and Walker (2000) also observed FN exceeding 400 indicating low α-amylase activity possessed by Pakistani wheat cultivars. Hence, the varieties studied could be suitable for baking purpose because of their low alpha-amylase activity. SDS sedimentation volume is one of the most important tests being used to discriminate wheat genotypes based on their gluten quality and quantity (Carter *et al.*, 1999). In the present study, PV and SDS-S values were found to be 191 to 216 min and 9 to 16 ml respectively in different wheat varieties. The highest SDS-S value was observed in HD-2967, whereas, Ratan CG-5016 showed the lowest SDS-S value but the highest PV. The differences in SDS-S and PVs may be attributed to the different type of genetic makeup of the wheat varieties that affects their protein content. Higher SDS-S value is associated with the strength of protein (Williams *et al.*, 1986). Farooq *et al.* (2001) have reported SDS-S values and PV in the range of 17 to 21 ml and 165-187 min in 7 Pakistani wheat lines. Lower sedimentation test values in the present study suggest that these varieties are not suitable for making good quality yeast leavened bakery products like bread. Soft wheat flour

Table 1. Grain quality characteristics and chemical composition of flours.[1,2]

Variety	TKW (g)	TW (kg/ hl)	BD (kg/m^3)	Equivalent diameter (mm)	Sphericity (%)	Surface area (mm^2)	Grain volume (mm^3)	PD (kg/m^3)	P (%)	Hardness (N)	Ash (%)	Protein content (%)	DG (%)
WH-1021	47.47±0.23^{e}	82.21±0.04^{c}	869±2.02^{d}	4.00±0.06^{d}	56.90±0.29^{cd}	40.69±0.85^{f}	34.26±0.10^{g}	1,315.70±3.25^{b}	33.78±0.18^{a}	87.51±4.18^{a}	1.46±0.06^{d}	12.3±0.09^{cd}	9.30±0.03^{e}
HD-2967	42.55±0.26^{cd}	80.08±0.11^{ab}	834±1.66^{a}	3.87±0.03^{c}	60.14±0.32^{d}	36.32±0.20^{d}	30.18±0.00^{e}	1,315.70±7.65^{b}	36.48±0.17^{bc}	135.04±5.23^{d}	1.60±0.11^{f}	14.2±0.08^{e}	8.70±0.50^{d}
KRL-213	36.18±0.14^{a}	82.63±0.23^{cd}	858±1.15^{c}	3.60±0.00^{ab}	54.82±0.49^{ab}	32.98±1.53^{b}	25.25±0.10^{b}	1,315.70±9.65^{b}	34.81±0.04^{b}	111.13±6.20^{c}	1.53±0.06^{e}	10.9±0.09^{a}	8.20±0.03^{c}
RAJ-4120	43.97±0.08^{d}	83.99±0.41^{d}	882±2.02^{e}	3.90±0.00^{cd}	55.37±0.12^{ab}	38.82±0.70^{e}	32.66±0.00^{f}	1,315.70±8.52^{b}	35.58±0.95^{b}	160.42±4.10^{e}	1.16±0.03^{a}	11.5±0.05^{ab}	7.60±0.60^{b}
RATAN CG-5016	41.08±0.20^{c}	80.75±0.58^{b}	838±0.88^{a}	3.90±0.00^{cd}	56.53±0.25^{bc}	39.57±0.40^{e}	32.54±0.00^{f}	1,388.80±5.21^{c}	39.54±0.05^{d}	97.60±2.36^{b}	1.33±0.06^{b}	11.6±0.08^{ab}	7.00±0.07^{a}
CBW-38	34.81±0.29^{a}	79.79±0.02^{a}	830±1.20^{a}	3.50±0.00^{a}	53.59±0.18^{a}	31.46±0.00^{a}	23.26±0.00^{a}	1,250.00±8.96^{a}	33.52±0.07^{a}	169.24±9.65^{e}	1.40±0.01^{d}	13.7±0.09^{e}	7.80±0.09^{b}
DPW 621-50	38.82±0.04^{b}	82.23±0.20^{c}	844±0.33^{b}	3.67±0.03^{b}	56.54±0.20^{bc}	34.37±1.20^{c}	26.48±0.10^{c}	1,315.70±7.58^{b}	35.77±0.02^{bc}	142.42±7.41^{d}	1.33±0.13^{c}	12.0±0.06^{bc}	7.65±0.03^{b}
KRL-210	41.25±0.17^{c}	79.25±0.05^{a}	841±0.88^{b}	3.77±0.07^{bc}	58.79±0.96^{d}	36.07±0.00^{d}	27.59±0.00^{d}	1,315.70±3.41^{b}	36.33±0.33^{c}	137.88±8.87^{d}	1.40±0.11^{d}	12.7±0.08^{d}	8.20±0.17^{c}

[1] Values are mean ± standard deviation of determinations made in triplicate. Values having different superscripts in a column differ significantly ($P<0.05$).
[2] BD = bulk density; DG = dry gluten; P = porosity; PD = particle density; TKW = thousand kernel weight; TW = test weight.

Table 2. Functional properties of straight grade flours from different varieties.[1,2]

Variety	AWRC (%)	W-SRC (%)	SC-SRC (%)	S-SRC (%)	LA-SRC (%)	FN (s)	SDS-S vol (ml)	PV (min)	Swelling power (g/g)	Solubility (g/g)
WH-1021	78.66±0.33^{e}	72.43±0.57^{b}	91.03±1.35^{b}	103.83±0.49^{a}	95.33±2.02^{b}	471±3^{e}	12.0±0.0^{c}	210±0.00^{c}	9.26±0.12^{d}	0.14±0.01^{bc}
HD-2967	74.66±1.40^{d}	77.36±0.44^{d}	95.10±2.49^{c}	101.5±0.23^{a}	105.66±1.02^{c}	408±9^{d}	16.0±0.0^{f}	210±0.00^{c}	6.07±0.07^{a}	0.15±0.00^{c}
KRL-213	70.33±0.88^{c}	73.46±0.08^{b}	54.23±2.61^{a}	109.03±0.73^{c}	92.43±0.23^{b}	376±3^{b}	12.0±0.0^{c}	190±0.00^{a}	7.03±0.13^{b}	0.12±0.02^{ab}
RAJ-4120	61.33±1.76^{a}	77.96±0.12^{d}	91.00±0.57^{b}	103.03±0.66^{a}	108.50±0.60^{c}	400±7^{c}	11.0±0.6^{b}	210±1.76^{c}	7.61±0.25^{c}	0.12±0.03^{ab}
RATAN CG-5016	64.00±1.15^{b}	59.03±0.18^{a}	55.63±1.33^{a}	102.96±1.24^{a}	80.66±1.95^{a}	412±6^{d}	9.0±0.0^{a}	216±4.40^{d}	6.42±0.14^{a}	0.15±0.01^{c}
CBW-38	75.00±1.72^{d}	80.73±0.26^{e}	98.63±0.72^{d}	119.43±1.04^{e}	128.33±4.15^{e}	406±6^{cd}	15.0±0.3^{e}	205±1.73^{b}	6.71±0.02^{b}	0.18±0.04^{d}
DPW 621-50	64.00±1.15^{b}	75.43±0.23^{c}	112.30±2.16^{e}	105.96±1.51^{b}	106.23±1.43^{c}	363±4^{a}	13.0±0.3^{d}	202±0.00^{b}	7.13±0.15^{bc}	0.16±0.04^{cd}
KRL-210	75.33±0.88^{d}	77.50±0.51^{d}	91.63±0.63^{b}	112.20±2.76^{d}	117.83±0.93^{d}	485±9^{f}	9.3±0.3^{a}	191±0.57^{a}	7.68±0.01^{c}	0.11±0.01^{a}

[1] The values are mean ± standard deviation of determinations made in triplicate. Values having different superscripts in a column differ significantly ($P<0.05$).
[2] AWRC = alkali water retention capacity; FN = falling number; LA-SRC = lactic acid solvent retention capacity; PV = pelenshke value; S-SRC = sucrose solvent retention capacity; SC-SRC = sodium carbonate solvent retention capacity; SDS-S = sodium dodecyl sulphate sedimentation; W-SRC = water solvent retention capacity.

having sedimentation volume <20 ml is most suitable for the preparation of sweet biscuit/cookie/cakes (Al-Dmoor, 2013). PV is also an estimation of wheat protein quality and can be related to SDS-S value. On the basis of PV, all the varieties tested in the present study can be exploited by the bakers in biscuit/cookies manufacturing.

The swelling power and solubility of flour suspensions from wheat varieties at 30 °C were found to be 0.66 to 1.01 g/g and 0.04 to 0.07 g/g, respectively. As the temperature was increased to 90 °C, the values increased to 6.07 to 9.26 g/g and 0.11 to 0.18 g/g, respectively. The highest values of swelling power and solubility at 90 °C were recorded for wheat variety WH-1021 and HD-2967, whereas lowest for DPW 621-50 and CBW-38. Moorthy and Ramanujam (1986) reported that the swelling power of flour particles is an indication of the extent of associative force within the particles. Higher protein content in flour may cause the starch granules to be embedded within a stiff protein matrix that limits the water access to starch and restricts the swelling power (Pomeranz, 1990). The values of AWRC ranged from 61.33 to 78.66% being the highest for WH-1021 and lowest for RAJ-4120.

The flour fractions consisting of pentosans, proteins, glycoproteins and damaged starch are considered to be responsible for the retention of alkaline water (Yamazaki and Lord, 1988). The mean values for water SRC, lactic acid SRC, sodium carbonate SRC and sucrose SRC were recorded to be 59.03 to 80.73%, 80.66 to 128.23%, 54.23 to 112.30% and 101.56 to 119.43%, respectively, for different wheat varieties. In general, water SRC is affected by all flour constituents, sucrose SRC by pentosans, sodium carbonate SRC by damaged starch, and lactic acid SRC by glutenin. Water SRC is influenced by all flour constituents such as starch, arabinoxylans, gluten, and gliadins (Duyvejonck *et al.*, 2011; Kweon *et al.*, 2011). The SRC test has demonstrated the capacity to predict the functional quality and baking performance of soft wheat flours in relation to products like cookies and crackers (Gaines, 1996; Guttieri and Souza, 2003; Guttieri *et al.*, 2002; Ram and Singh, 2004). In general, higher the solvent retention capacity, better will be the baking quality of fermented products like bread. However, good cookie flours hold water poorly and hence higher solvent retention capacity value in case of cookie flour will indicate smaller diameter cookies.

Mixing properties

Table 3 summarises the results of mixing properties of straight grade flour samples. Percentage water absorption by the flours from different wheat varieties was in range of 53.7 to 56.8. Maximum and minimum water absorption was observed for KRL-213 and KRL-210varieties. Water absorption capacity ranging from 53.6-66.4% has been reported for different wheat varieties (Hruskova *et al.*, 2006; Paraskevopoulou *et al.*, 2010). However, higher water absorption range of 60-76% has been reported in Indo-Pakistan wheat varieties (Sila, 2010). Water absorption has been considered to be a function of starch damage, non-starch polysaccharide content and protein content (Mann *et al.*, 2009). Dough development time for different varieties was found to be in the range of 1.23 to 1.76 min being maximum for RAJ-4120 and minimum for KRL-210. Zecevic *et al.* (2013) reported the dough development time of nine wheat cultivars in the range of 1.0 to 3.5 min. Higher dough development time reflects strong flour while lower indicates weak flour. Dough development time depends on amount and quality of gluten, flour particles, the degree of milling (Voicu *et al.*, 2012). The results of the present study suggest that dough development time of different varieties is reflective of the quality of the gluten protein. The study also indicated that higher gluten content was not necessary for higher dough development time. Dough stability is a measure of the time needed for the curve to stay at or above 500 BU.

According to Mohamed *et al.* (2006), most of the commercial bread flours have a stability value of up to 10 min. In the present study maximum dough stability (9.13 min) was observed in the case of variety CBW-38 and minimum (1.43 min) for KRL-213. Dough stability indicates the time in which dough maintains maximum consistency and it is a good indicator of dough strength. Dough stability characterises dough resistance to mechanic stress and also to a lesser extent to enzyme influence (Figueroa *et al.*, 2012). Longer stability of dough makes its handling easier for the baker and reduces the possibility of over mixing. The results of the present study suggested that wheat varieties WH-1021, KRL-2013, RAJ-4120 and Ratan CG-5016 were weak because of low dough stability (≤4 min). The values for dough development time and dough stability has been reported to decrease with reduced protein content (Fu *et al.*, 2008) and the same has also been observed in the present study. Dough softening is connected with its destruction, shortening of gluten tissues, dissolving of swollen gluten parts which lower the resistance to kneading (Abang Zaidel *et al.*, 2008; Karaoglu, 2011). The dough softening values of different varieties were found to be 12.33 to 142.33 FU being maximum for KRL-210 and minimum for KRL-213.

Rheological properties

The dough flow properties are of great relevance for practical applications and various researchers have studied the flow behaviour of wheat dough (Berland and Launay, 1995; Launay and Bure, 1973) and rice dough (Ray *et al.*, 2014). Flow behaviour of dough prepared from different samples of flours was assessed using controlled shear rate rheometry. Various parameters analysed by two regression models and corresponding R^2 (stability index) are given in Table 4. The results of creep and recovery test are shown

Table 3. Dough mixing properties as measured with micro doughLAB.[1,2]

Variety	WA (%)	PR (FU)	DDT (min)	DT (min)	Softening (FU)	AT (min)	Stability (min)
WH-1021	55.30±0.11^{bc}	477±4.40^{a}	1.43±0.03^{bc}	2.40±0.06^{a}	116.66±4.41^{e}	0.83±0.09^{bc}	1.53±0.03^{a}
HD-2967	54.50±0.11^{ab}	495±7.26^{c}	1.33±0.03^{ab}	4.96±0.09^{d}	59.66±2.60^{c}	0.90±0.06^{cd}	4.33±0.09^{e}
KRL-213	53.73±0.88^{a}	485±4.40^{b}	1.30±0.00^{a}	2.23±0.03^{a}	142.33±1.45^{f}	0.80±0.00^{b}	1.43±0.03^{a}
RAJ-4120	56.63±0.12^{d}	495±7.26^{c}	1.23±0.03^{a}	4.10±0.06^{c}	77.66v±.45^{d}	0.70±0.00^{a}	3.40±0.06^{d}
RATAN CG-5016	54.43±0.17^{a}	485±4.40^{b}	1.46±0.03^{c}	3.40±0.06^{b}	115.00±2.88^{e}	0.63±0.03^{a}	2.70±0.06^{b}
CBW-38	55.63±0.12^{c}	499±7.88^{c}	1.73±0.03^{d}	10.00±0.00^{f}	27.33±1.45^{b}	0.93±0.03^{d}	9.13±0.03^{g}
DPW 621-50	56.46±0.23^{d}	488±4.78^{b}	1.56±0.03^{c}	7.30±0.06^{e}	30.00±2.88^{b}	0.90±0.05^{cd}	6.33±0.09^{e}
KRL-210	56.80±0.05^{d}	485±4.40^{b}	1.66±0.03^{d}	9.66±0.24^{f}	12.33±1.45^{a}	0.90±0.05^{cd}	8.63±0.18^{f}

[1] Values are mean ± standard deviation of determinations made in triplicate. Values having different superscripts in a column differ significantly (P<0.05).
[2] AT = arrival time; DDT = dough development time; DT = departure time; FU = Farinograph unit; PR = peak resistance; WA = water absorption.

Table 4. Flow behaviour properties of dough samples.[1]

Variety	Herschell Bukley model			Power Ostwald law model		
	Consistency index (k) m Pa^n	Flow behaviour index (n)	Stability index (R^2)	Consistency index (k) m Pa^n	Flow behaviour index (n)	Stability index (R^2)
WH-1021	4.21±0.37^{d}	0.67±0.03	0.95±0.07^{ab}	3.40±0.40^{c}	0.87±0.01^{c}	0.98±0.04^{b}
HD-2967	4.09±0.50^{d}	0.54±0.03^{a}	0.93±0.18^{a}	3.47±.035^{c}	0.69±0.04^{b}	0.98±0.03^{b}
KRL-213	2.94±0.29^{b}	0.67±0.02^{c}	0.95±0.03^{ab}	2.40±0.31^{a}	0.85±0.07^{c}	0.99±0.06^{b}
RAJ-4120	2.34±0.09^{a}	0.85±0.13^{d}	0.96±0.04^{b}	2.95±0.69^{b}	0.63±0.03^{a}	0.99±0.04^{b}
RATAN CG-5016	3.19±0.34^{b}	0.60±0.05^{b}	0.96±0.01^{b}	5.27±0.93^{a}	0.55±0.03^{a}	0.91±0.09^{a}
CBW-38	5.97±0.23^{f}	0.52±0.04^{a}	0.97±0.02^{b}	5.26±0.18^{f}	0.64±0.04^{b}	0.99±0.03^{b}
DPW 621-50	5.42±0.14^{e}	0.63±0.01^{bc}	0.94±0.01^{ab}	4.39±0.23^{e}	0.81±0.07^{c}	0.98±0.04^{b}
KRL-210	3.69±0.23^{c}	0.66±0.02^{c}	0.97±0.02^{b}	4.00±0.30^{d}	0.84±0.05^{c}	0.98±0.01^{b}

[1] Values are mean ± standard deviation of determinations made in triplicate. Values having different superscripts in a column differ significantly (P<0.05).

in Table 5. In general, both models are used to describe the flow behaviour of dough that deviates from the Newtonian flow. In the present study these models fairly well described the flow as indicated by R^2 values above 0.91. The flow behaviour index (h), a measure of deviation from the Newtonian flow, was less than 1 in both models, which suggested high shear thinning behaviour of the dough samples. The Herschell-Buckley model produced the best fit, showing a direct relationship between concentrations and pseudoplasticity of flours. Viscosity in the pastes is mainly related to the water binding capacities of the dry ingredients (Dogan *et al.*, 2005). The flour which binds the maximum amount of water exhibits a high viscosity and hence high value of consistency index. This relationship was observed in the current study as the cavities showed higher water absorption values and reasonably higher consistency index values with Raj-4120 being an exception.

There was a considerable variation in the creep behaviour among the dough samples from different wheat varieties. The creep-recovery results of the doughs revealed a typical viscoelastic behaviour. The zero shear viscosity h_0, which indicates the flowability of the material at the end of applied load, was found to be very high for KRL-210. The maximum creep compliance (J_{max}) was highest for WH-1021.The ratio of the elastic component of the creep compliance and the maximum creep compliance was considered as the elastic index that describes the elasticity of the doughs. The value of elastic index varied from 0.61 to 0.83 among the studied cultivars and the cultivars KRL

Table 5. Creep and recovery test of dough samples.[1]

Varieties	(Creep phase)		(Recovery phase)
	Max. creep compliance (10^{-4} Pa^{-1})	Zero shear viscosity (10^5 Pa.s)	Elastic index
WH-1021	8.3±0.5^f	0.73±0.05^c	0.71±0.08^{bc}
HD-2967	7.6±0.6^e	0.62±0.07^{bc}	0.70±0.13^{bc}
KRL-213	7.3±0.5^{de}	0.45±0.03^a	0.61±0.03^a
RAJ-4120	6.7±0.8^d	1.41±0.11^d	0.77±0.06^d
RATAN CG-5016	6.8±0.6^d	0.60±0.10^b	0.72±0.10^c
CBW-38	2.6±0.5^a	2.84±0.53^e	0.69±0.07^b
DPW 621-50	5.8±0.3^c	0.63±0.03^{bc}	0.70±0.02^{bc}
KRL-210	3.9±0.2^b	3.48±0.43^f	0.83±0.09^e

[1] Values are mean ± standard deviation of determinations made in triplicate. Values having different superscripts in a column differ significantly (P<0.05).

10 showed the maximum elastic index. Skendi *et al.* (2009) have reported elastic index of four wheat cultivars varying from 0.57 to 0.69 as measured using the creep-recovery test at a stress of 50 Pa. Wang and Sun (2002) compared the recoverable strain of 23 wheat doughs prepared from flours varying in protein content and physical dough properties. Measurements of large-deformation creep and shear stress relaxation properties were found to be useful to discriminate different wheat varieties of varying quality and closely associated with the baking volume (Safari-Ardi and Phan-Thien, 1998; Wikström and Eliasson, 1998). Rheological measurements of the doughs using creep and recovery tests have been reported in earlier studies also (Edwards *et al.*, 1999; Lazaridou *et al.*, 2007; Mohammad *et al.*, 2011; Sivaramakrishnan *et al.*, 2004). Creep compliance is a measure of the softness or flexibility of the material. Greater the compliance the more can the material be strained under the application of certain shear stress. Higher values of the maximum deformation, compliances and the recovery energy but lower values of the zero shear viscosity and shear modulus for wheat flour doughs indicates better flow properties of the dough.

Pasting properties

Pasting characteristics of the wheat flour suspensions are as given in Table 6. In addition to starch, the pasting properties of wheat flours are related to protein; particles size distribution, α-amylase activity and damaged starch. Wheat pasting properties are useful to predict the performance of wheat flour during processing and phenomenon of bread staling (Collar, 2003). Varietal differences contributed significantly to the variation in PV, HPV, BD among the wheat varieties but the variation in the pasting temperature and pasting time among different varieties was not significant (P<0.05). However, the pasting temperature

Table 6. Pasting properties of flour suspensions.[1,2]

Variety	PV (RVU[3])	HPV (RVU)	Breakdown (RVU)	CPV (RVU)	Setback (RVU)	Peak time (min)	Pasting temp (°C)
WH-1021	133.41±4.85^b	97.75±2.56^{cd}	35.66±2.23^b	191.16±5.36^{cd}	93.41±1.00^c	6.00±0.05^d	67.80±1.02^b
HD-2967	141.16±2.95^c	94.66±1.23^c	46.50±1.58^c	190.91±2.54^{cd}	96.25±2.56^d	5.60±0.10^a	66.90±0.53^{ab}
KRL-213	118.25±3.10^a	82.58±0.87^a	35.66±1.12^b	171.00±3.85^a	88.41±1.60^b	5.80±0.23^{bc}	67.70±0.79^b
RAJ-4120	172.75±5.10^d	106.41±3.25	66.33±3.87^e	191.41±3.25^{cd}	85.00±2.04^a	6.06±0.68^d	66.80±1.21^{ab}
RATAN CG-5016	168.58±3.25^d	100.00±3.65^d	68.58±2.69^f	186.25±3.89^c	86.25±2.83^a	5.86±0.52^{cd}	67.70±0.09^b
CBW-38	175.25±9.98	100.33±2.10^d	74.91±1.20^g	187.33±4.23^c	85.83±3.96^a	5.93±0.08^{cd}	66.80±0.59^{ab}
DPW 621-50	120.75±6.98^a	87.08±2.00^b	33.66±1.25^a	176.08±2.47^b	89.00±2.31^b	5.80±0.08^{bc}	67.80±0.78^b
KRL-210	166.00±2.14^d	104.91±4.36^e	61.08±1.47^d	194.75±2.11^d	89.83±1.40^b	6.00±0.36^d	66.10±0.69^a

[1] The values are mean ± standard deviation of determinations made in triplicate. Values having different superscripts in a column differ significantly (P<0.05).
[2] CPV = cool paste viscosity; HPV = hot paste viscosity; PV = peak viscosity; RVU = rapid-visco units.
[3] 1 RVU = 12 mPa·s.

of different wheat varieties ranged from 66.1 to 67.8 °C and WH-1021 and DPW 621-50 exhibited the highest pasting temperature whereas KRL-210 showed the lowest. Relatively higher pasting temperature indicates higher water binding capacity, higher gelatinisation tendency and lower swelling property of starch based flour due to a high degree of association between starch granules (Adebowale *et al.*, 2008).

Peak viscosity, which is an index of the ability of starch-based flours to swell freely before their physical breakdown (Adebowale *et al.*, 2008; Sanni *et al.*, 2006) ranged from 118.25 to 175.25 RVU being highest for KRL-213 and lowest for CBW-38. The relatively high peak viscosity indicates the suitability of flour for the products requiring high gel strength and elasticity (Ikegwu *et al.*, 2010). HPV for the eight wheat varieties were recorded to be 82.58 to 106.41 RVU. RAJ-4120 and KRL-213 showed the highest and the lowest HPV value. The flour prepared from CBW-38 had the highest (74 RVU) while flour from DPW 621-50 had the lowest (33.66 RVU) breakdown viscosity (PV-HPV). Adebowale *et al.* (2005) reported that breakdown in viscosity inversely associated with the ability of the sample to withstand heat and shear stress during cooking. The flour pastes which exhibit high peak viscosity are likely to have high breakdown values, leading to weak gels. Such gels are more likely to be disintegrated under shear and heat (Singh *et al.*, 2006). The same trend has also been obtained in the present study as the flour pastes from varieties having higher peak viscosities also exhibited higher breakdown values. The final viscosity or cool paste viscosity (final viscosity at 50 °C), which is the change in the viscosity after holding cooked starch at 50 °C, were found to be 171.0 to 194.75 RVU for KRL-213 and KRL-210, respectively. The pasting properties of wheat are largely related to cultivar (Singh *et al.*, 2011), irrigation practices and sowing time (Singh *et al.*, 2010).

Final viscosity is commonly used to define the quality of particular starch based flour since it indicates the ability of the flour to form a viscous paste after cooking and cooling. It also measures the resistance of paste to shear force during stirring (Adebowale *et al.*, 2005, 2008). CPV for all the flours was higher than their corresponding PV and HPV. The increase in CPV of all the flour samples could be attributed to aggregation of the amylose molecules on cooling (Kaur *et al.*, 2007). However, the differences amongst varieties with respect to CPV could be associated with differences in their amylose content. The setback (CPV-HPV) viscosity was highest for variety HD-2967 (96.25 RVU) and lowest for RAJ-4120 (85.0 RVU). The higher setback viscosity indicated the the high retrogradation tendency of the flour paste during cooling (Adeyemi and Idowu, 1990). Peak time which is a measure of cooking time, ranged from 5.60 to 6.06 min, being highest for wheat variety RAJ-4120 (6.06 min) and lowest in the case of HD-2967 (5.60 min).

Principal components analysis

The relationships among the quality parameters measured for eight wheat cultivars were evaluated by principal components analysis (PCA) to assess the source of the underlying variability. From a total 17 studied traits, PCA extracted seven principal components (Table 7). However, as a standard tradition, only the components having eigenvalues higher than the average were kept (Abdi and Williams, 2010). Hence, the first two components were considered. PCA of quality attributes of wheat cultivars showed 70.6% of the variations that could be explained by the first two principal components (48.1 and 22.5%, respectively). The loading plot of the principal components is shown in Figure 1. Considering the factor loadings, the first principal component was positively correlated with the hardness of kernels, water absorption, dough development time, departure time, dough stability and zero shear viscosity and negatively correlated with dough softening, maximum creep compliance and pasting temperature. Dough stability, departure time and zero shear viscosity were accounted for more variation among cultivars.

For the second principal component, the characteristics of TKW, falling number value, swelling power, elastic index and cold paste viscosity were positively correlated and TKW, falling number and cold paste viscosity contributed the most to the underlying variations among the studied cultivars. The scatter plots generated for different wheat

Table 7. Factor loadings, eigenvalues and cumulative variance (%) for the first three principal components.

Variables	PC1	PC2
Thousand kernel weight	-0.250	0.882
Kernel hardness	0.717	-0.306
Protein content	0.495	-0.056
Falling number	0.329	0.780
Swelling power	-0.114	0.620
Water absorption	0.691	0.311
Dough development time	0.756	-0.256
Departure time	0.957	-0.251
Dough softening	-0.919	0.121
Dough stability	0.960	-0.255
Dough consistency index	0.482	-0.522
Maximum creep compliance	-0.890	0.321
Zero shear viscosity	0.907	0.156
Dough elastic index	0.629	0.685
Peak viscosity	0.613	0.328
Cold paste viscosity	0.507	0.763
Pasting temperature	-0.799	-0.290
Eigenvalue	8.185	3.815
Variability (%)	48.14	22.44
Cumulative variance (%)	48.14	70.58

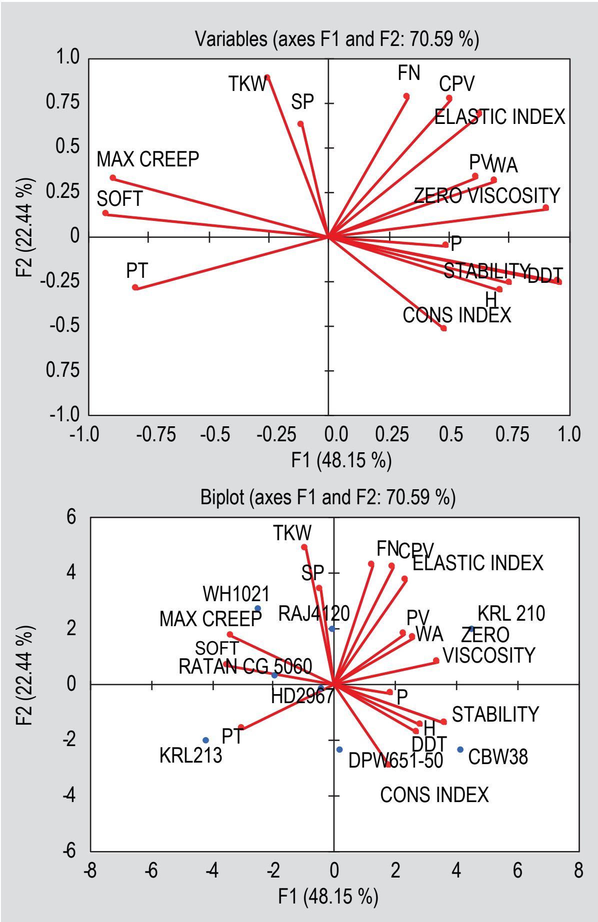

Figure 1. Principal components analysis of (A) the distribution of variables, and (B) variables and cultivars

cultivars revealed that there was no clear distribution pattern separating the cultivars. However, in quadrant one, four cultivars i.e. RATAN CG5060, RAJ 4120 and WH 1021 were grouped but well separated from each other. The other cultivars of were relatively more widely dispersed in terms of their quality characteristics. Based on the individual scores of the first two principal components for each of the investigated wheat cultivars revealed specific quality characteristics that could be exploited for the industrial applications. CBW 38 and KRL 2010 cultivars exhibited high PC1 score, which suggested that these cultivars could be characterised with high kernel hardness, higher dough stability, higher zero shear viscosity, and low dough softening. The results showed that the studied cultivars had variations among their physicochemical and rheological properties. Such separation of cultivars may be due to distinct and diverse nature of cultivars ascribed to their different agro-climatic conditions.

4. Conclusions

The results of the study demonstrated that the studied varieties of Indian wheat (*T. aestivum*) differed in their physicochemical, functional and rheological properties. Variations in the physical properties like TKW and hardness values of these varieties can have implications for the millers to optimise milling conditions to obtain maximum efficiency of good quality flour. Interestingly, all varieties exhibited gluten protein content between 7-9.3% suggesting that these could be more suitably exploited for biscuit and cake making rather than bread making. Low dough development times (1.23 to 1.76 min) and dough stability also suggested that their flours were weak. Comparatively low values of the elastic index suggested a low elasticity of the dough. A better understanding of the various physicochemical and functional quality characteristics of the selected wheat varieties will be very beneficial for the grain millers as well as processors to make an optimal exploitation of the characteristics for getting quality products.

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