



# Characterization of selected wheat (*Triticum aestivum*) cultivars for their physicochemical and cookies making quality characteristics

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## Abstract

The physicochemical properties of grains and their whole grains flour from selected newly released cultivars of wheat (*Triticum aestivum*) were investigated to assess their suitability for cookie making. The whole wheat flour-based cookies were examined for their physicochemical and textural properties. The relationship of flour properties with quality characteristics of cookies was evaluated through Pearson correlation and principal component analysis. The protein content showed a highly significant positive correlation with grain hardness index (GHI) ( $r=0.889$ ,  $p<0.01$ ). This showed that cultivars with higher protein content had high GHI. A highly significant positive correlation was noted between GHI and damaged starch (DS). Spread ratio (SR) of cookies showed a negative correlation with water absorption capacity and DS content of wheat flour. The SR was negatively correlated with lactic acid, sodium carbonate and water retention capacities and protein content of flour. On the basis of spread ratio and fracture strength, PBW752, DBW187, H1620 and H1612 wheat cultivars could be recommended more suitable for the preparation of whole wheat flour cookies.

**Keywords** *Triticum aestivum* · Whole wheat flour · Physicochemical properties · Cookies quality · Principal component analysis

## Introduction

Wheat (*Triticum aestivum*) is the most extensively cultivated cereal crop in the world. The wheat cultivars vary in their chemical composition as well as functionality due to variations in climatic conditions and genetic factors. About 80% of the wheat grown in India is generally consumed as chapatti, whereas 20% is utilized in the preparation of bread, cakes, cookies, noodles, etc. Wheat quality indicates its adequacy for the specific end product and intended usage. The quality and quantity of protein is a significant parameter influencing the end product quality (Zabed et al. 2017). The particle size is another important factor influencing the functionality of flour and quality of product (Khilberg et al. 2004).

The understanding of the physical properties of grains (thousand kernel weight, grain hardness, length/breadth (L/B) ratio, sphericity, and porosity) is vital for assessing the milling potential. Similarly, chemical composition and physicochemical properties of flour are also important to assess its suitability for end product quality. Wheat research institutes and baking industries analyze the quality of wheat flour on the basis of protein content, wet and dry gluten content, gluten performance index (GPI), damaged starch content, and sedimentation value etc. Flours acceptable for biscuit making usually require low gluten content, water absorption capacity (WAC) and damaged starch (Kweon et al. 2011). The SRC (solvent retention capacity) analysis measures the functional role of damaged starch, pentosans, and proteins for end-product development. The high content damaged starch increases the WAC of wheat flour, which is generally not preferable for good quality biscuit.

Today, there has been increasing awareness and interest among the consumers to select for the whole grain products and multigrain products, thus drawing the focus on the production of whole wheat-based products. Whole wheat flour (WWF) is a good source of nutrients especially vitamins, minerals and fiber for human health but at the same time

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it also presents a big challenge for the baking industry to produce WWF products of desired quality. The functional properties of flour are affected by several factors like cultivars type, grain hardness, protein content, crop season, and growing condition (Nemeth et al. 1994). Therefore, newly released and less studied wheat varieties needs extensive studies to assess their suitability for different processed bakery products like biscuit, bread and cakes. The purpose of the present study was to analyze the various physico-chemical properties of grains and their WWF from some newly released wheat (*Triticum aestivum*) cultivars to make an assessment of their suitability for the development of cookies with desired traits. The correlation among grain physical properties, various physico-chemical properties of WWF, and cookies quality were also assessed through Pearson's correlation and principal component analysis.

## Materials and methods

### Procurement of wheat cultivars

Ten cultivars of *Triticum aestivum* released during the year of 2018–2019 were procured from different authorized sources; UAS375 (UAS, Dharwad) (75°00' E, 15°45' N, 738 m altitude), HI1620, HI1612 (ICAR- IARI Regional station, Indore) (75°86' E, 22°72' N, 554 m altitude), PBW752, PBW757 (PAU, Ludhiana) (75°80' E, 30°90' N, 241 m altitude), DBW168 (MACS—Agharkar Research Institute (ARI), Pune) (73°83' E, 18°52' N, 577 m altitude), HD2967, HD3226 (IARI- Pusa, Delhi) (77°15' E, 28°63' N, 229 m altitude), DBW187, DBW173 (Indian Institute of Wheat and Barley Research, Karnal) (76°58' E, 29°41' N, 340 m altitude). The chemicals used to analyze the different physico-chemical properties of wheat flour were of analytical grade.

### Physical quality characteristics of wheat grain

Thousand kernel weight (TKW) was measured using the standard method (AACC 2000). The dimensional parameters of the kernels, such as thickness (T), width (W), and length (L) were measured by vernier caliper with a precision value of 0.01 mm. The equivalent diameter was calculated from L, W, and T using the following equation:

$$\text{Equivalent diameter} = (\text{Length} \times \text{Width} \times \text{Thickness})^{1/3}$$

For bulk density (g/ml), 50 g grains were put into a 100 ml measuring cylinder and tapped many times. The true density was analyzed by applying the toluene displacement procedure. Grain hardness index (GHI) was measured using single-kernel characterization system (SKCS). Porosity (P) of grains was determined using the following equation:

$$P(\%) = 1 - (BD / TD) \times 100$$

where BD = Bulk density, TD = True density

The surface area (S) was computed using the following equation:

$$S = \pi L^2 B / (2L - B)$$

where L = Length, B =  $\sqrt{WT}$ ,

The sphericity ( $S_p$ ) was determined using the following formula:

$$S_p = \text{Equivalent diameter} / \text{Length}$$

### Milling of wheat

Wheat grains were cleaned and tempered to set the moisture content at the level of 14% (dwb). Whole wheat flour was prepared from the tempered wheat kernels using a laboratory scale flour mill (Milcent Appliances, Anand, Gujrat), and the whole wheat flour obtained was packed in air-tight packets for further analysis.

### Chemical composition of flour

The whole wheat flour obtained from different varieties was examined for chemical composition i.e., moisture, ash, fibre, fat, protein, wet gluten, and dry gluten according to the standard procedures of AACC (2000). Damaged starch content was determined according to the standard method AACC (1992).

### Physicochemical properties

The method of Sosulski et al. (1976) was employed to determine the water absorption capacity (WAC), oil absorption capacity (OAC), swelling capacity (SC), and solubility index (SI) of the flour. The swelling capacity (SC) and solubility index (SI) of the flour samples were determined at 90 °C, and the values were expressed in g/g. Solvent retention (SRC) capacity was determined using the standard method of AACC (2000) by making the respective suspension of 1.0 g flour in 5 ml water, 5% lactic acid, 5% sodium carbonate, and 50% sucrose. Alkaline water retention capacity (AWRC) was measured using the standard procedure of AACC (2000). Gluten performance index (GPI) was calculated using the equation:

$$\text{GPI} = \text{LASRC} / \text{SCSRC} + \text{SUSRC}$$

where LASRC, SCSRC, and SUSRC are lactic acid, sodium carbonate, and sucrose retention capacity, respectively.

## Color analysis

The color characteristics of all the wheat flour samples were determined using a colorimeter (Color flex EZ, 45/0 USA). The color parameters, such as lightness ( $L^*$ ), yellowness ( $b^*$ ), and redness ( $a^*$ ) were recorded after standardizing the device by using black and white tiles. Chroma, hue value, and total color difference ( $\Delta E$ ) were computed using the following formulas:

$$\text{Chroma} = (a^{*2} + b^{*2})^{0.5}$$

$$\text{Hue} = \tan^{-1} (b^*/a^*)^2$$

$$\Delta E = (dL^*) + (da^*) + (db^*)^{1/2}$$

## Particle size distribution

The particle size distribution of the wheat flour samples was assessed with the help of a particle size analyzer (Malvern Instruments Ltd., Worcestershire, UK) furnished with a hydro-dispersion assembly using the principle of laser light scattering. The particle distribution in the suspension was identified in diameters  $Dv(10)$ ,  $Dv(50)$ , and  $Dv(90)$  which represents 10, 50, and 90% of the total volume of particles, respectively.

## Preparation of cookies

Whole wheat flour cookies were developed according to the method of Yadav et al. (2011). The ingredients were: whole wheat flour (WWF) (100 g), sugar (60 g), butter (40 g), sodium bicarbonate (2.0 g), salt (0.5 g), skim milk powder (SMP) (2 g), and the required amount of water. The dry ingredients (sugar, WWF, sodium bicarbonate, salt, and SMP) were mixed in a dough mixer (INALSA, Kitchen Master 1000) for 1 min, followed by addition of butter (at 40 °C) to the mixture and again mixed for 1 min. The distilled water (at 40 °C) was added and the dough was kneaded again for 4 min using dough mixer. After resting the dough for 10 min, the sheeted dough was cut into circular shapes using a die, and baked in a baking oven (ContiBake CO3/E23S) at 190 °C for 12 min.

## Analysis of whole wheat flour cookies

The diameter of the cookies was measured by arranging six cookies edge to edge, measuring the diameter using a scale and the average value was recorded. Weight was determined using an electronic weighing balance. Thickness was determined by piling six cookies vertically one over each other and calculating the average thickness. The

spread ratio (SR) was computed by dividing the diameter by the thickness of cookies. The chemical composition of cookies was analyzed for moisture, protein, ash, fat, and crude fiber according to the methods of AACC (2000). The color of the cookies was analyzed using the same procedure as discussed in Sect. 2.6. The cookies were analysed for their fracture strength using a texture analyzer (TA-XT2i, Stable Micro system, Haslemere U.K) with the help of a 3-point bending rig. The pre-test, test, and post-test speeds of 1.0, 3.0, and 10.0 mm/s, respectively were used.

## Statistical analysis

The data obtained were analyzed using one-way analysis of variance (ANOVA) followed by a comparison test (Tukey's HSD) at  $p < 0.05$  using SPSS version 25.0 and recorded as mean  $\pm$  SD (standard deviation). Pearson correlation with the help of SPSS version 25.0 and principal component analysis using Minitab version 17 were applied to determine the correlation between different parameters.

## Results

### Grain characteristics

The data related to physical characteristics of wheat kernels of different cultivars is presented in Table 1. TKW of wheat kernels from selected cultivars varied from 31.76 to 51.38 g. HI1620 showed a significantly ( $p < 0.05$ ) highest value and DBW168 showed the lowest value for TKW. The different wheat cultivars showed non-significant differences ( $p < 0.05$ ) for equivalent diameter, and the DBW168 cultivar showed the highest value (3.90 mm) while UAS375 showed the lowest value for equivalent diameter (3.58 mm). There was not any significant difference ( $p < 0.05$ ) in the thickness of grains among the various wheat cultivars. L/B ratio was found in the range of 1.79 to 2.77. Surface area of wheat grains of different cultivars was varied from 37.43 to 44.25 mm<sup>2</sup>. Bulk density (BD) and true density (TD) of different wheat cultivars varied from 0.78 to 0.91 g/ml and 1.15 to 1.30 g/ml, respectively. The BD of DBW168 was significantly ( $p < 0.05$ ) lowest (0.78 g/ml) from other wheat cultivars. Porosity values of wheat grains ranged from 20.87 to 34.62%. The significantly ( $p < 0.05$ ) highest value of porosity was noted for DBW173 (34.62%), while HD 3226 had the lowest value (20.87%). The sphericity of wheat grains ranged from 56.82 to 65.72%. PBW757 had a significant ( $p < 0.05$ ) difference from the UAS375 cultivar. GHI of wheat grains ranged between 62.51 to and 87.26. The significantly ( $p < 0.05$ ) highest value of GHI was recorded for DBW173 (87.26), while HI1612 had the lowest value (62.51).

**Table 1** The physical parameters of grains from different wheat cultivars

Cultivar	TKW (g)	ED* (mm)	L* (mm)	B* (mm)	T* (mm)	L/B ratio	S (mm <sup>2</sup> )	BD (g/ml)	TD* (g/ml)	P (%)	Sphericity (%)	GHI (N)
HI1620	51.38 ± 1.38 <sup>a</sup>	3.72 ± 0.22 <sup>a</sup>	5.70 ± 1.12 <sup>a</sup>	3.06 ± 0.11 <sup>a</sup>	2.96 ± 0.05 <sup>a</sup>	1.86 ± 0.40 <sup>ab</sup>	37.43 ± 4.19 <sup>c</sup>	0.90 ± 0.02 <sup>a</sup>	1.15 ± 0.00 <sup>a</sup>	21.74 ± 1.22 <sup>b</sup>	65.26 ± 8.37 <sup>a</sup>	63.02 ± 2.18 <sup>e</sup>
HI1612	40.52 ± 1.47 <sup>bc</sup>	3.80 ± 0.18 <sup>a</sup>	6.50 ± 0.50 <sup>a</sup>	3.00 ± 0.00 <sup>a</sup>	2.83 ± 0.28 <sup>a</sup>	2.16 ± 0.24 <sup>a</sup>	39.79 ± 2.14 <sup>b</sup>	0.87 ± 0.05 <sup>a</sup>	1.18 ± 0.01 <sup>a</sup>	26.28 ± 1.11 <sup>b</sup>	58.46 ± 4.69 <sup>ab</sup>	62.51 ± 1.24 <sup>e</sup>
PBW 752	38.89 ± 0.30 <sup>c</sup>	3.72 ± 0.11 <sup>a</sup>	6.16 ± 0.28 <sup>a</sup>	3.16 ± 0.28 <sup>a</sup>	2.66 ± 0.28 <sup>a</sup>	1.94 ± 0.08 <sup>a</sup>	41.10 ± 3.16 <sup>b</sup>	0.88 ± 0.00 <sup>a</sup>	1.16 ± 0.15 <sup>a</sup>	24.14 ± 0.55 <sup>b</sup>	60.38 ± 3.39 <sup>a</sup>	80.10 ± 1.08 <sup>b</sup>
PBW 757	33.46 ± 5.00 <sup>c</sup>	3.72 ± 0.32 <sup>a</sup>	5.66 ± 0.57 <sup>a</sup>	3.16 ± 0.28 <sup>a</sup>	2.96 ± 0.05 <sup>a</sup>	1.79 ± 0.18 <sup>b</sup>	40.63 ± 5.11 <sup>b</sup>	0.86 ± 0.00 <sup>a</sup>	1.16 ± 0.00 <sup>a</sup>	25.87 ± 0.25 <sup>b</sup>	65.72 ± 2.12 <sup>a</sup>	87.26 ± 2.41 <sup>a</sup>
DBW187	45.02 ± 2.50 <sup>b</sup>	3.81 ± 0.80 <sup>a</sup>	6.06 ± 0.11 <sup>a</sup>	3.16 ± 0.28 <sup>a</sup>	2.96 ± 0.05 <sup>a</sup>	1.91 ± 0.18 <sup>b</sup>	38.95 ± 4.89 <sup>b</sup>	0.87 ± 0.02 <sup>a</sup>	1.16 ± 0.01 <sup>a</sup>	25.00 ± 2.49 <sup>b</sup>	62.87 ± 2.00 <sup>a</sup>	68.01 ± 2.33 <sup>d</sup>
DBW 173	40.70 ± 0.72 <sup>bc</sup>	3.66 ± 0.09 <sup>a</sup>	6.03 ± 0.55 <sup>a</sup>	3.00 ± 0.00 <sup>a</sup>	2.73 ± 0.20 <sup>a</sup>	2.01 ± 0.17 <sup>a</sup>	37.80 ± 0.23 <sup>bc</sup>	0.85 ± 0.00 <sup>a</sup>	1.30 ± 0.25 <sup>a</sup>	34.62 ± 0.52 <sup>a</sup>	60.69 ± 1.51 <sup>a</sup>	80.08 ± 1.57 <sup>b</sup>
DBW 168	31.76 ± 0.80 <sup>d</sup>	3.90 ± 0.10 <sup>a</sup>	6.53 ± 0.26 <sup>a</sup>	3.23 ± 0.25 <sup>a</sup>	2.83 ± 0.28 <sup>a</sup>	2.02 ± 0.44 <sup>a</sup>	44.25 ± 7.09 <sup>a</sup>	0.78 ± 0.06 <sup>b</sup>	1.15 ± 0.00 <sup>a</sup>	32.62 ± 5.35 <sup>a</sup>	59.72 ± 3.72 <sup>ab</sup>	75.26 ± 0.65 <sup>c</sup>
UAS375	38.88 ± 1.31 <sup>c</sup>	3.58 ± 0.33 <sup>a</sup>	6.30 ± 0.25 <sup>a</sup>	3.20 ± 0.26 <sup>a</sup>	2.76 ± 0.25 <sup>a</sup>	1.96 ± 0.30 <sup>a</sup>	37.82 ± 1.89 <sup>bc</sup>	0.89 ± 0.02 <sup>a</sup>	1.30 ± 0.25 <sup>a</sup>	31.54 ± 1.94 <sup>a</sup>	56.82 ± 2.09 <sup>b</sup>	79.00 ± 1.00 <sup>bc</sup>
HD3226	42.57 ± 0.50 <sup>bc</sup>	3.77 ± 0.18 <sup>a</sup>	6.23 ± 0.40 <sup>a</sup>	3.06 ± 0.11 <sup>a</sup>	2.83 ± 0.28 <sup>a</sup>	2.03 ± 0.26 <sup>a</sup>	39.87 ± 3.09 <sup>b</sup>	0.91 ± 0.00 <sup>a</sup>	1.15 ± 0.01 <sup>a</sup>	20.87 ± 1.09 <sup>b</sup>	60.81 ± 2.51 <sup>a</sup>	77.00 ± 1.00 <sup>bc</sup>
HD 2967	46.62 ± 0.37 <sup>ab</sup>	3.76 ± 0.23 <sup>a</sup>	6.43 ± 0.51 <sup>a</sup>	3.00 ± 0.00 <sup>a</sup>	2.76 ± 0.25 <sup>a</sup>	2.77 ± 0.07 <sup>a</sup>	39.49 ± 1.17 <sup>a</sup>	0.88 ± 0.00 <sup>a</sup>	1.15 ± 0.01 <sup>a</sup>	23.75 ± 1.10 <sup>b</sup>	58.47 ± 1.76 <sup>ab</sup>	74.00 ± 2.00 <sup>c</sup>

The values are expressed as the mean ± SD of three independent determinations. Values in the same column with different superscripts are significantly different ( $p \leq 0.05$ ) \*Denoted superscripts are non-significantly different ( $p > 0.05$ )

TKW Thousand kernel weight, ED Equivalent diameter, L Length, B Breadth, T Thickness, S Surface area, BD Bulk density, TD True density, P Porosity, GHI Grain hardness index

## Flour characteristics

### Chemical composition

The results related to the chemical composition of flour obtained from selected wheat cultivars had significant ( $p < 0.05$ ) differences (Table 2). The moisture content of wheat flour ranged from 8.62 to 11.32%. The ash content of flour of different cultivars varied significantly ( $p < 0.05$ ) and was found in the range of 1.06 to 1.80%. HI1620 had significantly highest ash (1.80%) whereas HD3226 had significantly ( $p < 0.05$ ) lowest ash (1.06%). The fiber content in flour of different wheat cultivars was found in the range of 1.87 to 2.14%. The fiber content was significantly ( $p < 0.05$ ) lowest in DBW187 (1.87%) and HI1612 (2.14%) wheat cultivars. The fat content of different wheat flour was noted from 0.85 to 1.42%. HD2967 had significantly highest fat whereas DBW168 had the lowest fat content. The protein content of wheat flour ranged from 9.87 to 12.15%. The protein was significantly highest in PBW757 (12.15%) and significantly ( $p < 0.05$ ) lowest in HI1612 (9.87%). Damaged starch (DS) was varied from 3.59 to 7.83% and found significantly ( $p < 0.05$ ) highest in PBW757 (7.83%) whereas significantly ( $p < 0.05$ ) lowest in HI1612 and DBW187 (3.59%). WG and dry gluten (DG) content of flour of different cultivars ranged from 26.72 to 37.78% and 8.77 to 13.38%, respectively. HI1612 showed the lowest value, whereas HD2967 showed the highest value for WG. HD3226 had a significantly ( $p < 0.05$ ) highest value (13.38%), whereas DBW168 had a significantly lowest value (8.77%) for DG.

### Physicochemical properties

The results of various physicochemical properties of whole wheat flour obtained from selected cultivars are given in Table 3. WAC of different wheat cultivars ranged from 147.33 to 179.00%. The significantly ( $p < 0.05$ ) highest WAC value (179%) was observed for PBW757, while the significantly ( $p < 0.05$ ) lowest value (147.33%) was noted for HI1612. OAC of wheat flour of different cultivars varied significantly ( $p < 0.05$ ) and ranged from 114 to 142.67%. The SC of wheat flour was recorded from 8.50 to 11.59 g/g. PBW757 had the significantly ( $p < 0.05$ ) highest SC (11.59 g/g). Maximum solubility was observed for HI1620 (0.17 g/g), and minimum solubility was reported for DBW173 (0.12 g/g) at a temperature of 90 °C.

### Flour color

The color parameters ( $L^*$ ,  $a^*$ , and  $b^*$ ) of the whole wheat flour from selected cultivars varied from 83.37 to 87.36, 1.27 to 2.01, and 10.51 to 13.39, respectively (Table 4).  $L^*$  parameter of wheat flours reflected a significant ( $p < 0.05$ )

**Table 2** The chemical composition, wet and dry gluten content of whole wheat flour from different cultivars

Cultivar	Moisture (%)	Ash (%)	Fibre (%)	Fat (%)	Protein (%)	Carbohydrate (%)	DS (%)	WG (%)	DG (%)
HI1620	9.35 ± 0.04 <sup>f</sup>	1.80 ± 0.26 <sup>a</sup>	1.94 ± 0.01 <sup>b</sup>	0.88 ± 0.02 <sup>c</sup>	10.75 ± 0.05 <sup>d</sup>	75.28 ± 0.02 <sup>c</sup>	4.53 ± 0.45 <sup>b</sup>	31.60 ± 1.24 <sup>cd</sup>	12.18 ± 0.27 <sup>b</sup>
HI1612	9.25 ± 0.04 <sup>f</sup>	1.50 ± 0.10 <sup>ab</sup>	2.14 ± 0.02 <sup>a</sup>	1.11 ± 0.07 <sup>b</sup>	9.87 ± 0.04 <sup>e</sup>	76.13 ± 0.03 <sup>b</sup>	3.59 ± 0.36 <sup>b</sup>	26.72 ± 1.07 <sup>f</sup>	9.39 ± 0.54 <sup>c</sup>
PBW 752	11.32 ± 0.02 <sup>a</sup>	1.20 ± 0.34 <sup>b</sup>	1.96 ± 0.01 <sup>b</sup>	1.19 ± 0.04 <sup>b</sup>	12.10 ± 0.02 <sup>a</sup>	72.23 ± 0.02 <sup>i</sup>	6.89 ± 0.44 <sup>ab</sup>	37.88 ± 1.07 <sup>a</sup>	13.11 ± 0.53 <sup>ab</sup>
PBW757	9.67 ± 0.02 <sup>e</sup>	1.50 ± 0.10 <sup>ab</sup>	2.10 ± 0.02 <sup>a</sup>	1.20 ± 0.02 <sup>b</sup>	12.15 ± 0.05 <sup>a</sup>	73.38 ± 0.02 <sup>h</sup>	7.83 ± 0.35 <sup>a</sup>	36.46 ± 0.55 <sup>a</sup>	13.41 ± 0.10 <sup>a</sup>
DBW 187	8.62 ± 0.02 <sup>g</sup>	1.26 ± 0.30 <sup>b</sup>	1.87 ± 0.02 <sup>c</sup>	0.91 ± 0.01 <sup>c</sup>	10.71 ± 0.05 <sup>d</sup>	76.63 ± 0.03 <sup>a</sup>	3.59 ± 0.36 <sup>b</sup>	32.80 ± 0.65 <sup>c</sup>	11.95 ± 0.13 <sup>bc</sup>
DBW 173	10.35 ± 0.06 <sup>e</sup>	1.30 ± 0.26 <sup>b</sup>	1.99 ± 0.02 <sup>b</sup>	0.88 ± 0.03 <sup>c</sup>	11.69 ± 0.04 <sup>b</sup>	73.79 ± 0.01 <sup>f</sup>	7.09 ± 0.25 <sup>ab</sup>	29.32 ± 0.63 <sup>de</sup>	9.09 ± 0.20 <sup>c</sup>
DBW 168	10.26 ± 0.02 <sup>e</sup>	1.60 ± 0.10 <sup>ab</sup>	2.11 ± 0.02 <sup>a</sup>	0.85 ± 0.05 <sup>c</sup>	11.02 ± 0.13 <sup>c</sup>	74.16 ± 0.03 <sup>e</sup>	4.02 ± 0.60 <sup>b</sup>	27.17 ± 0.55 <sup>ef</sup>	8.77 ± 0.25 <sup>c</sup>
UAS375	11.12 ± 0.02 <sup>b</sup>	1.20 ± 0.34 <sup>b</sup>	1.95 ± 0.01 <sup>b</sup>	1.15 ± 0.04 <sup>b</sup>	11.10 ± 0.05 <sup>c</sup>	73.48 ± 0.03 <sup>g</sup>	5.69 ± 0.32 <sup>ab</sup>	33.84 ± 1.06 <sup>bc</sup>	12.51 ± 0.21 <sup>bc</sup>
HD3226	10.10 ± 0.01 <sup>d</sup>	1.06 ± 0.11 <sup>b</sup>	1.89 ± 0.01 <sup>c</sup>	1.35 ± 0.05 <sup>a</sup>	11.14 ± 0.03 <sup>c</sup>	74.46 ± 0.04 <sup>d</sup>	5.53 ± 0.15 <sup>b</sup>	36.22 ± 0.51 <sup>ab</sup>	13.38 ± 0.10 <sup>a</sup>
HD 2967	10.29 ± 0.05 <sup>e</sup>	1.72 ± 0.02 <sup>ab</sup>	2.10 ± 0.02 <sup>a</sup>	1.42 ± 0.02 <sup>a</sup>	11.11 ± 0.03 <sup>c</sup>	73.36 ± 0.02 <sup>h</sup>	5.66 ± 0.14 <sup>b</sup>	37.78 ± 0.67 <sup>a</sup>	13.24 ± 0.17 <sup>ab</sup>

DS Damaged starch, WG Wet gluten, DG Dry gluten, Values in the same column with different superscripts are significantly different ( $p \leq 0.05$ )

difference from each other. DBW 168 flour had the highest (87.36), and DBW 173 had the lowest value (83.37) for  $L^*$ . For a  $a^*$  parameter, HI1612 flour reflected a significantly ( $p < 0.05$ ) higher value than other cultivars, indicating redness in the wheat flour sample. DBW173 wheat showed high yellowness compared to other cultivar flours due to a significantly ( $p < 0.05$ ) highest value of  $b^*$ . The flour of DBW168 showed the lowest value of  $b^*$ .

### Solvent retention capacity (SRC)

The WSRC, SCSRC, LASRC, and SUSRC were reported between 74.33 to 97.66%, 87.33 to 104.66%, 103.66 to 126.66%, and 81.30 to 98.00%, respectively for different wheat flours. WSRC was noted as maximum for UAS375 and minimum for PBW752. SCSRC and SUSRC values were significantly highest for UAS375 and lowest for PBW757. LASRC was observed as maximum for PBW757 (126.66%) and minimum for PBW752 (103.66%).

### Particle size distribution

Particle size is a key indicator influencing wheat flour quality and its end products. A broad range of particle size in wheat flour of different cultivars was observed and it varied between 11 to 150  $\mu\text{m}$  (Table 4). The flours of all the cultivars showed unimodal distribution. The larger particle diameter ranged from 98.43 to 149.66  $\mu\text{m}$ , while, the smaller and medium particle diameter varied from 11.03 to 16.56  $\mu\text{m}$  and 40.43 to 54.20  $\mu\text{m}$ , respectively. PBW757 wheat flour showed the maximum value for Dv (90), Dv (50), and Dv (10). DBW173 showed the lowest value for Dv (90) and Dv (50).

## Analysis of cookies

### Physical properties of cookies

The physical parameters of cookies developed from flour of various wheat cultivars are presented in Table 5. The weight of cookies varied from 10.31 to 12.15 g with the highest value for HI1612 and the minimum value for PBW757. The diameter of the cookies ranged from 53.2 to 66.6 mm. Cookies developed from wheat cultivar DBW 187 had a significantly ( $p < 0.05$ ) highest diameter, while the cookies prepared from HD 2967 had significantly ( $p < 0.05$ ) lowest diameter. The thickness of cookies prepared from different wheat cultivars varied from 5.7 mm to 6.6 mm with DBW168, DBW 187, and PBW 757 showing the higher value (6.6 mm) for thickness. The Fracture strength of cookies varied from 908.33 to 1574.9 g. DBW168 cookies showed a significantly ( $p < 0.05$ ) highest value, whereas HD3226 cookies had a significantly ( $p < 0.05$ ) lowest value for fracture strength. The SR of cookies varied from 10.26 to 8.18.

### Chemical composition of cookies

The moisture content of cookies varied from 2.97 to 4.67% (Table 5). The maximum moisture content was reported for PBW752 cookies and the minimum for HD3226 cookies. The protein content of cookies varied from 7.27 to 10.42%. The HD3226 cookies showed the highest protein (10.42%), while DBW168 showed the lowest protein (7.27%). The fat content of cookies ranged from 15.27% to 21.53%. A significant difference ( $p < 0.05$ ) was noted for fat content among all samples. The fiber content of cookies

**Table 3** The physicochemical parameters and solvent retention capacity of whole wheat flour from different cultivars

Cultivar	WAC (%)	OAC (%)	SC (g/g)	SI (g/g)	LASRC (%)	SCRSC (%)	SUSRC (%)	WSRC (%)	AWRC (%)	GPI (%)
HI1620	152.67 ± 2.51 <sup>de</sup>	114.00 ± 3.60 <sup>d</sup>	8.90 ± 0.02 <sup>f</sup>	0.17 ± 0.00 <sup>a</sup>	116.00 ± 8.54 <sup>ab</sup>	100.33 ± 1.52 <sup>ab</sup>	85.28 ± 3.43 <sup>bc</sup>	85.28 ± 3.43 <sup>bc</sup>	85.44 ± .30 <sup>d</sup>	.62 ± .03 <sup>ab</sup>
HI1612	147.33 ± 2.08 <sup>e</sup>	115.00 ± 1.00 <sup>d</sup>	8.50 ± 0.05 <sup>h</sup>	0.16 ± 0.00 <sup>ab</sup>	109.33 ± 10.01 <sup>ab</sup>	97.00 ± 2.00 <sup>ab</sup>	85.33 ± 1.52 <sup>bc</sup>	85.33 ± 1.52 <sup>bc</sup>	96.27 ± 4.75 <sup>c</sup>	.59 ± .04 <sup>b</sup>
PBW752	169.67 ± 1.52 <sup>b</sup>	137.67 ± 2.51 <sup>ab</sup>	10.97 ± 0.02 <sup>b</sup>	0.16 ± 0.02 <sup>ab</sup>	103.66 ± 5.68 <sup>b</sup>	87.33 ± 2.08 <sup>c</sup>	81.33 ± 1.52 <sup>c</sup>	74.33 ± 2.08 <sup>d</sup>	111.85 ± 3.08 <sup>ab</sup>	.61 ± .03 <sup>ab</sup>
PBW757	179.00 ± 3.60 <sup>a</sup>	139.67 ± 1.52 <sup>ab</sup>	11.59 ± 0.01 <sup>a</sup>	0.14 ± 0.02 <sup>ab</sup>	126.66 ± 4.61 <sup>a</sup>	95.33 ± 3.05 <sup>bc</sup>	92.00 ± 2.00 <sup>ab</sup>	78.00 ± 2.64 <sup>cd</sup>	91.20 ± 1.09 <sup>cd</sup>	.67 ± .01 <sup>a</sup>
DBW187	147.67 ± 2.51 <sup>e</sup>	142.67 ± 2.51 <sup>a</sup>	8.67 ± 0.08 <sup>g</sup>	0.16 ± 0.01 <sup>ab</sup>	125.66 ± 5.13 <sup>ab</sup>	98.33 ± 3.51 <sup>ab</sup>	96.66 ± 4.93 <sup>a</sup>	82.00 ± 5.29 <sup>bcd</sup>	103.84 ± 1.43 <sup>bc</sup>	.64 ± .00 <sup>ab</sup>
DBW173	169.67 ± 1.52 <sup>b</sup>	137.00 ± 2.00 <sup>ab</sup>	10.22 ± 0.02 <sup>c</sup>	0.12 ± 0.01 <sup>b</sup>	105.00 ± 3.00 <sup>b</sup>	102.33 ± 2.51 <sup>ab</sup>	85.33 ± 2.51 <sup>bc</sup>	85.33 ± 2.51 <sup>bc</sup>	85.63 ± 2.15 <sup>b</sup>	.55 ± .00 <sup>b</sup>
DBW168	156.67 ± 1.52 <sup>cd</sup>	133.33 ± 3.05 <sup>bc</sup>	8.98 ± 0.02 <sup>c</sup>	0.15 ± 0.02 <sup>ab</sup>	115.33 ± 4.50 <sup>ab</sup>	102.66 ± 2.08 <sup>ab</sup>	95.66 ± 4.50 <sup>a</sup>	87.33 ± 1.52 <sup>bc</sup>	117.08 ± 2.60 <sup>a</sup>	.57 ± .02 <sup>b</sup>
UAS375	160.67 ± 3.05 <sup>c</sup>	134.00 ± 1.73 <sup>bc</sup>	9.79 ± 0.04 <sup>d</sup>	0.13 ± 0.02 <sup>ab</sup>	116.00 ± 8.54 <sup>ab</sup>	104.66 ± 5.50 <sup>a</sup>	98.00 ± 2.64 <sup>a</sup>	97.66 ± 2.30 <sup>a</sup>	107.08 ± 2.05 <sup>b</sup>	.57 ± .02 <sup>b</sup>
HD 3226	162.44 ± 2.50 <sup>c</sup>	129.00 ± 1.00 <sup>c</sup>	10.22 ± 0.02 <sup>c</sup>	0.14 ± 0.00 <sup>ab</sup>	123.66 ± 6.02 <sup>a</sup>	101.95 ± 2.63 <sup>ab</sup>	84.66 ± 2.51 <sup>bc</sup>	84.66 ± 2.51 <sup>bc</sup>	96.58 ± 3.14 <sup>c</sup>	.65 ± .02 <sup>ab</sup>
HD2967	162.33 ± 2.51 <sup>c</sup>	137.33 ± 2.51 <sup>ab</sup>	8.98 ± 0.02 <sup>e</sup>	0.16 ± 0.02 <sup>ab</sup>	122.33 ± 2.51 <sup>a</sup>	99.66 ± 2.08 <sup>ab</sup>	84.33 ± 4.16 <sup>bc</sup>	84.33 ± 4.16 <sup>bc</sup>	105.11 ± 3.17 <sup>b</sup>	.66 ± .01 <sup>ab</sup>

WAC Water absorption capacity, OAC Oil absorption capacity, SC Swelling capacity, SI Solubility index, LASRC Lactic acid solvent retention capacity, SCRSC Sucrose solvent retention capacity, SUSRC Sucrose solvent retention capacity, WSRC Water solvent retention capacity, AWRC Water solvent retention capacity, GPI Gluten performance index, Values in the same column with different superscripts are significantly different ( $p \leq 0.05$ )

**Table 4** Color and particle size distribution parameters of whole wheat flour from various cultivars

Cultivars	L*	a*	b*	Hue	Chroma	$\Delta E$	D [4,3] ( $\mu\text{m}$ )	D [3,2] ( $\mu\text{m}$ )	D <sub>v</sub> (10) ( $\mu\text{m}$ )	D <sub>v</sub> (50) ( $\mu\text{m}$ )	D <sub>v</sub> (90) ( $\mu\text{m}$ )
HI1620	85.99 ± 0.29 <sup>ab</sup>	1.48 ± 0.05 <sup>c</sup>	11.32 ± 0.19 <sup>c</sup>	89.01 ± 0.3 <sup>b</sup>	11.41 ± .20 <sup>c</sup>	86.74 ± 2.6 <sup>ab</sup>	62.03 ± 1.95 <sup>c</sup>	22.40 ± 0.96 <sup>bc</sup>	11.03 ± 1.00 <sup>c</sup>	45.73 ± 0.64 <sup>c</sup>	130.33 ± 1.52 <sup>c</sup>
HI1612	83.66 ± 1.13 <sup>b</sup>	2.01 ± 0.04 <sup>a</sup>	12.64 ± 0.08 <sup>b</sup>	88.55 ± 0.4 <sup>e</sup>	12.60 ± .32 <sup>b</sup>	84.63 ± 1.1 <sup>b</sup>	67.93 ± 2.61 <sup>ab</sup>	25.36 ± 0.77 <sup>ab</sup>	15.30 ± 0.60 <sup>ab</sup>	54.20 ± 0.72 <sup>b</sup>	146.66 ± 1.52 <sup>a</sup>
PBW752	85.25 ± 0.33 <sup>ab</sup>	1.56 ± 0.03 <sup>c</sup>	11.72 ± 0.11 <sup>c</sup>	88.94 ± .09 <sup>bc</sup>	11.84 ± .08 <sup>c</sup>	86.06 ± .32 <sup>b</sup>	51.73 ± 1.41 <sup>d</sup>	20.23 ± 0.68 <sup>c</sup>	12.00 ± 1.00 <sup>bc</sup>	41.23 ± 0.68 <sup>d</sup>	102.66 ± 2.51 <sup>e</sup>
DBW187	85.69 ± 0.29 <sup>ab</sup>	1.54 ± 0.02 <sup>c</sup>	11.22 ± 0.11 <sup>c</sup>	89.28 ± .04 <sup>a</sup>	11.47 ± .13 <sup>c</sup>	87.28 ± 2.6 <sup>ab</sup>	62.76 ± 2.04 <sup>c</sup>	24.33 ± 0.83 <sup>b</sup>	14.86 ± 1.20 <sup>ab</sup>	51.03 ± 2.60 <sup>b</sup>	130.66 ± 1.15 <sup>c</sup>
DBW173	83.37 ± 0.60 <sup>d</sup>	1.97 ± 0.05 <sup>a</sup>	13.39 ± 0.24 <sup>a</sup>	88.91 ± .02 <sup>cd</sup>	11.32 ± .11 <sup>c</sup>	86.43 ± .29 <sup>ab</sup>	50.30 ± 1.57 <sup>d</sup>	20.46 ± 1.36 <sup>c</sup>	12.1 ± 0.85 <sup>bc</sup>	40.43 ± 1.40 <sup>d</sup>	98.43 ± 1.50 <sup>e</sup>
PBW757	86.53 ± 0.28 <sup>ab</sup>	1.27 ± 0.05 <sup>d</sup>	11.41 ± 0.13 <sup>c</sup>	88.75 ± .02 <sup>cd</sup>	13.53 ± .24 <sup>a</sup>	84.46 ± .55 <sup>b</sup>	72.26 ± 2.05 <sup>a</sup>	27.80 ± 1.92 <sup>a</sup>	16.56 ± 1.25 <sup>a</sup>	62.33 ± 2.51 <sup>a</sup>	149.66 ± 0.57 <sup>a</sup>
DBW168	87.36 ± 0.21 <sup>a</sup>	1.56 ± 0.03 <sup>c</sup>	10.51 ± 0.09 <sup>d</sup>	88.71 ± .02 <sup>d</sup>	10.62 ± .08 <sup>d</sup>	87.98 ± 1.9 <sup>ab</sup>	61.16 ± 0.76 <sup>c</sup>	23.60 ± 1.21 <sup>bc</sup>	14.60 ± 0.52 <sup>ab</sup>	50.10 ± 1.85 <sup>bc</sup>	126.66 ± 3.05 <sup>c</sup>
UAS375	87.26 ± 0.49 <sup>a</sup>	1.27 ± 0.06 <sup>d</sup>	11.54 ± 0.25 <sup>c</sup>	89.28 ± .04 <sup>a</sup>	11.60 ± .26 <sup>c</sup>	88.10 ± 4.5 <sup>a</sup>	58.20 ± 1.70 <sup>c</sup>	22.4 ± 0.96 <sup>bc</sup>	14.00 ± 2.00 <sup>abc</sup>	45.43 ± 2.37 <sup>c</sup>	121.00 ± 1.00 <sup>d</sup>
HD 3226	84.97 ± 1.04 <sup>b</sup>	1.80 ± 0.04 <sup>b</sup>	12.95 ± 0.24 <sup>ab</sup>	88.86 ± .02 <sup>cd</sup>	12.93 ± .21 <sup>ab</sup>	85.95 ± .99 <sup>b</sup>	66.33 ± 1.52 <sup>bc</sup>	24.33 ± 0.98 <sup>b</sup>	13.46 ± 1.36 <sup>abc</sup>	52.16 ± 0.76 <sup>b</sup>	141.00 ± 1.00 <sup>b</sup>
HD2967	83.96 ± 1.43 <sup>b</sup>	1.69 ± 0.04 <sup>bc</sup>	13.03 ± 0.43 <sup>ab</sup>	89.03 ± .02 <sup>b</sup>	13.13 ± .43 <sup>ab</sup>	84.66 ± 1.13 <sup>b</sup>	60.60 ± 1.21 <sup>c</sup>	22.36 ± 1.48 <sup>bc</sup>	13.73 ± 1.41 <sup>abc</sup>	46.06 ± 1.00 <sup>c</sup>	129.00 ± 1.00 <sup>c</sup>

D[4,3] = volume-weighted mean particle diameter, D[3,2] = surface-weighted mean particle diameter, D<sub>v</sub> (10) = Maximum particle diameter below which 10% of the sample volume exist, D<sub>v</sub> (50) = Maximum particle diameter below which 50% of the sample volume exist, D<sub>v</sub> (90) = Maximum particle diameter below which 90% of the sample volume exist, Values in the same column with different superscripts are significantly different ( $p \leq 0.05$ )

**Table 5** The physical parameters, color values, and chemical composition of cookies prepared from different wheat cultivars

Cultivar	Diameter (mm)	Thickness (mm)	Spread ratio	Weight (g)	Fracture strength (g)	L*	a*	b*
HI1620	61.5 ± 0.13 <sup>ab</sup>	6.1 ± 0.01 <sup>c</sup>	10.08 ± 0.22 <sup>a</sup>	10.70 ± 0.71 <sup>b</sup>	1255.76 ± 4.83 <sup>c</sup>	57.33 ± 0.72 <sup>b</sup>	11.34 ± 0.62 <sup>b</sup>	30.41 ± 0.54 <sup>ab</sup>
HI1612	56.5 ± 0.47 <sup>b</sup>	5.7 ± 0.09 <sup>d</sup>	9.91 ± 0.46 <sup>a</sup>	12.15 ± 0.52 <sup>a</sup>	1061.33 ± 3.97 <sup>g</sup>	53.88 ± 3.71 <sup>c</sup>	8.23 ± 0.01 <sup>c</sup>	28.99 ± 0.26 <sup>b</sup>
PBW752	62.6 ± 0.23 <sup>ab</sup>	6.1 ± 0.03 <sup>c</sup>	10.26 ± 0.56 <sup>a</sup>	10.45 ± 0.36 <sup>b</sup>	1078.58 ± 1.63 <sup>f</sup>	53.30 ± 1.91 <sup>c</sup>	8.37 ± 0.45 <sup>c</sup>	29.31 ± 1.10 <sup>b</sup>
PBW757	55.8 ± 0.05 <sup>b</sup>	6.6 ± 0.05 <sup>a</sup>	8.45 ± 1.03 <sup>b</sup>	10.31 ± 1.06 <sup>b</sup>	1093.48 ± 1.60 <sup>e</sup>	56.93 ± 0.19 <sup>b</sup>	9.81 ± 0.45 <sup>bc</sup>	30.45 ± 0.20 <sup>ab</sup>
DBW187	66.6 ± 0.29 <sup>a</sup>	6.6 ± 0.04 <sup>a</sup>	10.09 ± 1.09 <sup>a</sup>	12.10 ± 0.52 <sup>a</sup>	1017.24 ± 11.04 <sup>h</sup>	59.87 ± 0.11 <sup>ab</sup>	9.88 ± 0.98 <sup>bc</sup>	30.01 ± 0.96 <sup>ab</sup>
DBW173	56.4 ± 0.08 <sup>b</sup>	6.4 ± 0.07 <sup>b</sup>	8.81 ± 1.59 <sup>b</sup>	11.45 ± 0.15 <sup>ab</sup>	1107.06 ± 7.53 <sup>e</sup>	57.84 ± 0.34 <sup>b</sup>	9.77 ± 0.50 <sup>bc</sup>	29.10 ± 0.39 <sup>b</sup>
DBW168	59.8 ± 0.57 <sup>b</sup>	6.6 ± 0.05 <sup>a</sup>	9.06 ± 0.89 <sup>ab</sup>	11.32 ± 1.03 <sup>ab</sup>	1574.93 ± 3.96 <sup>a</sup>	55.69 ± 0.50 <sup>b</sup>	11.14 ± 0.42 <sup>b</sup>	31.32 ± 0.92 <sup>a</sup>
UAS375	59.2 ± 0.60 <sup>b</sup>	6.0 ± 0.04 <sup>c</sup>	9.86 ± 0.45 <sup>ab</sup>	11.20 ± 0.63 <sup>ab</sup>	1304.90 ± 3.48 <sup>b</sup>	61.32 ± 0.17 <sup>ab</sup>	13.32 ± 0.85 <sup>a</sup>	31.71 ± 0.48 <sup>a</sup>
HD3226	55.0 ± 0.12 <sup>b</sup>	6.5 ± 0.04 <sup>ab</sup>	8.46 ± 0.58 <sup>b</sup>	10.71 ± 0.46 <sup>ab</sup>	908.33 ± 3.05 <sup>i</sup>	62.18 ± 0.20 <sup>a</sup>	7.42 ± 0.73 <sup>c</sup>	27.92 ± 0.11 <sup>c</sup>
HD2967	53.2 ± 0.02 <sup>c</sup>	6.5 ± 0.04 <sup>ab</sup>	8.18 ± 0.47 <sup>b</sup>	11.26 ± 0.78 <sup>ab</sup>	1136.60 ± 1.63 <sup>d</sup>	63.35 ± 0.40 <sup>a</sup>	10.88 ± 0.35 <sup>b</sup>	31.12 ± 0.30 <sup>a</sup>
Cultivar	Moisture (%)	Protein (%)	Fat (%)	Fiber (%)	Ash (%)	Carbohydrate (%)		
HI1620	4.42 ± 0.02 <sup>b</sup>	7.29 ± 0.05 <sup>h</sup>	15.40 ± 0.01 <sup>g</sup>	1.71 ± 0.10 <sup>c</sup>	1.86 ± 0.06 <sup>a</sup>	69.32 ± 0.02 <sup>ab</sup>		
HI1612	4.38 ± 0.01 <sup>b</sup>	7.62 ± 0.02 <sup>f</sup>	15.43 ± 0.01 <sup>g</sup>	1.92 ± 0.10 <sup>a</sup>	1.48 ± 0.01 <sup>b</sup>	69.17 ± 0.01 <sup>b</sup>		
PBW752	4.67 ± 0.01 <sup>a</sup>	9.45 ± 0.02 <sup>b</sup>	15.67 ± 0.02 <sup>f</sup>	1.73 ± 0.10 <sup>c</sup>	1.44 ± 0.05 <sup>b</sup>	67.04 ± 0.02 <sup>f</sup>		
PBW757	4.15 ± 0.02 <sup>c</sup>	9.51 ± 0.02 <sup>b</sup>	17.56 ± 0.01 <sup>c</sup>	1.82 ± 0.40 <sup>b</sup>	1.89 ± 0.04 <sup>a</sup>	65.07 ± 0.03 <sup>h</sup>		
DBW187	3.02 ± 0.03 <sup>e</sup>	8.72 ± 0.02 <sup>c</sup>	17.12 ± 0.02 <sup>e</sup>	1.53 ± 0.05 <sup>d</sup>	1.46 ± 0.01 <sup>b</sup>	68.15 ± 0.03 <sup>d</sup>		
DBW173	3.55 ± 0.01 <sup>d</sup>	8.36 ± 0.03 <sup>d</sup>	15.27 ± 0.02 <sup>h</sup>	1.75 ± 0.05 <sup>c</sup>	1.49 ± 0.01 <sup>b</sup>	69.58 ± 0.01 <sup>a</sup>		
DBW168	4.60 ± 0.04 <sup>a</sup>	7.27 ± 0.02 <sup>h</sup>	15.67 ± 0.02 <sup>f</sup>	1.83 ± 0.30 <sup>b</sup>	1.93 ± 0.02 <sup>a</sup>	68.70 ± 0.02 <sup>c</sup>		
UAS375	4.17 ± 0.02 <sup>c</sup>	7.42 ± 0.02 <sup>g</sup>	17.45 ± 0.02 <sup>d</sup>	1.74 ± 0.10 <sup>c</sup>	1.41 ± 0.01 <sup>b</sup>	67.81 ± 0.04 <sup>e</sup>		
HD3226	2.97 ± 0.01 <sup>e</sup>	10.42 ± 0.01 <sup>a</sup>	17.78 ± 0.02 <sup>b</sup>	1.55 ± 0.10 <sup>d</sup>	1.42 ± 0.01 <sup>b</sup>	65.86 ± 0.01 <sup>g</sup>		
HD2967	4.07 ± 0.02 <sup>c</sup>	8.07 ± 0.02 <sup>e</sup>	21.53 ± 0.03 <sup>a</sup>	1.81 ± 0.05 <sup>b</sup>	1.50 ± 0.01 <sup>b</sup>	63.02 ± 0.02 <sup>i</sup>		

The values are expressed as the mean ± SD of three independent determinations. Values in the same column with different superscripts are significantly different ( $p \leq 0.05$ )

**Fig. 1** Cookies prepared from different wheat cultivars

varied from 1.53 to 1.92%. The significantly highest value was observed for HI1612 (1.92%) cookies and the lowest for DBW187 (1.53%) cookies.

### Color analysis of cookies

The results of color parameters for cookies are presented in Table 5. The lightness ( $L^*$ ) value of cookies varied from 53.30 to 63.35. HD2967 cookies showed the highest (63.35), and PBW 752 showed the lowest value (53.30) for  $L^*$ ,  $a^*$  and

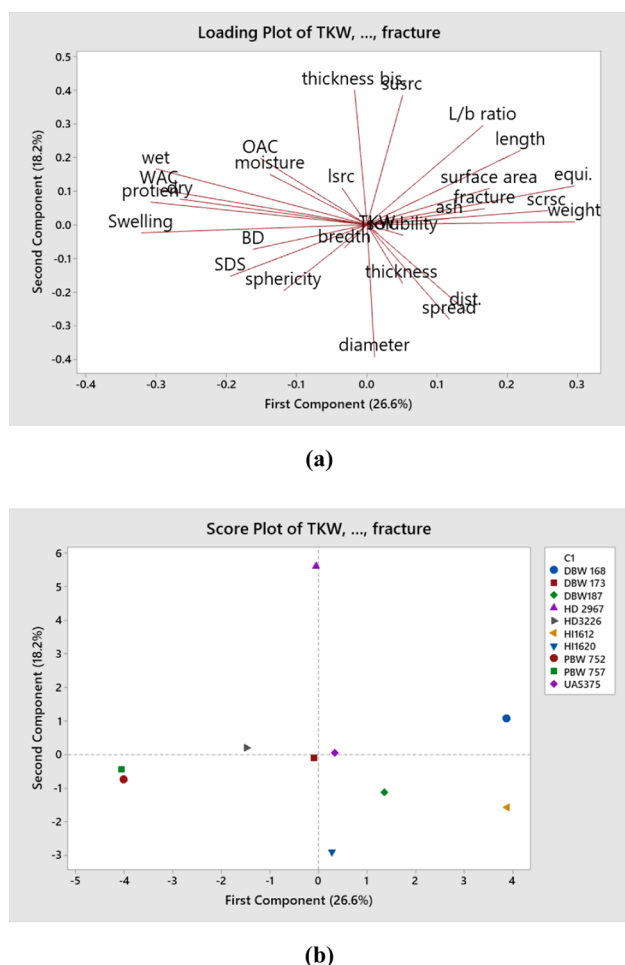
$b^*$  values of the cookies varied from 7.42 to 11.34 and 27.92 to 31.71, respectively (Fig. 1).

### Principal component analysis (PCA)

The grain properties, flour physicochemical properties, and biscuit quality parameters were assessed through principal component analysis. The loading plot reflects the relationship between the grain properties, flour properties, and cookies characteristics (Fig. 2a). The score plots distinctly separated the various wheat cultivars into separate zones (Fig. 2b).

### Discussion

In this research study, we tried to examine the suitability of whole wheat flour of some selected wheat cultivars for the development of cookies with desired traits. The geographical location, processing condition and varietal differences affects the physical properties of wheat grains. TKW of wheat grain indicates the quality of grain, the wide variation in the contents, and their compactness within the grain. The values of TKW (31.76 to 51.38 g) of wheat grains in



**Fig. 2** **a** Loading plot reflecting the relationship of wheat grain and physicochemical properties of different wheat cultivars. **b** Score plot reflecting the variations in the wheat cultivars

this study were similar to as noted by Siddiqui et al. (2020) (33.05 to 47.24 g) and Amir et al. (2020) (36.00 to 49.00 g) for different wheat cultivars. The cultivars of high TKW have been found to provide a high grinding yield (Anjum and Walker, 2000). Equivalent diameter gives information about the flowing characteristics of wheat grain in the air, which helps to remove extraneous materials by pneumatic means (Omobuwajo et al. 1999). The equivalent diameter (3.58 to 3.90 mm) of different wheat cultivars reported in this investigation was comparable to as reported for various wheat cultivars by Baljeet et al. (2017) (3.50–4.00 mm).

Siddiqui et al. (2020) observed the equivalent diameter of 4.01 to 4.29 mm for different wheat cultivars of North India. The L, W, and T of wheat grains of different cultivars varied from 5.66 to 6.50 mm, 3.00 to 3.23 mm, and 2.66 to 2.96 mm, respectively in this study. Iqbal et al. (2015) observed slight variation in the results of length (5.39 to 6.11 mm) width (3.09 to 3.19 mm), thickness (2.57 to 2.74 mm) of wheat grains of different cultivars. These

variations in the physical parameters might be due to varietal differences. L/B ratio could be a very good indicator of plumpness of the wheat kernels which in turn affect the flour yield as more plumpy grains provide better flour yield. The knowledge of L/B ratio is also helpful in the selection and implementation of compressive force to break the covering of the seed with minor damage to the wheat kernel (Omobuwajo et al. 1999). L/B ratio of wheat cultivars (1.78 to 2.15) reported by Siddiqui et al. (2020) was comparable to the values (1.79 to 2.77) observed in our study. Baljeet et al. (2017) reported L/B ratio of 2.02–2.15 for different wheat cultivars. The values of BD, TD, and porosity varied from 0.78 to 0.91 g/ml, 1.15 to 1.30 g/ml, and 20.87 to 34.62%, respectively, in this investigation. The BD, TD, and porosity value noted by Baljeet et al. (2017) for different wheat varieties of *Triticum aestivum* were varied from 0.83 to 0.88 g/ml, 1.25 to 1.38 g/ml, and 33.52 to 39.54%, respectively. The density is the indicator of the compactness and soundness of grains whereas porosity plays an important role during packaging, storage, and the heat transfer process. Information about the compactness of the grains is important for determining the product yield, output, and quality (Omobuwajo et al. 1999). Grain hardness index (GHI) is related to milling properties of wheat and indicates wheat grain's resistance to crack and ability to convert into flour. The GHI value of 62.51 to 87.26 g of wheat grains of different cultivars was found in this study. The outcomes were in agreement with Kaur et al. (2013) who observed the GHI of 66 to 90 g for Indian wheat cultivars.

The chemical composition of wheat flour depends on irrigation practice, soil fertility, climatic variations, genetic makeup of different wheat cultivars and the milling performance of the kernels. The moisture (8.62 to 11.32%), fat (0.85 to 1.42%), protein (9.87 to 12.15%), ash (1.06 to 1.80%), and crude fiber (1.87 to 2.14%) content of flour of different wheat cultivars found in this study were slightly varied to those reported in an earlier study (Menon et al. 2020), which might be due to varietal differences.

Damaged starch content of flour plays an important role in quality of dough and end products. The level of DS in the flour affects its water absorption capacity and thus influences the cookie quality. The DS of the wheat flour found in this investigation (3.59 to 7.83%) was close to as reported in previous researches. Earlier studies reported the DS value of 2.5 to 9.3 (Pauly et al. 2013) and 5.27 to 8.58 (Ali et al. 2014) for different wheat flour samples. The wet gluten content (WG) determines the amount of gluten-forming proteins present in the flour, which plays an important role in baking and rheological properties of the dough (Biesiekierski 2017). The present results of WG (26.72 to 37.78%) and DG (8.77 to 13.38%) were within the range of 23.46–43% (WG) and 8.28–15% (DG) as reported by Siddiqui et al. (2020) for different wheat cultivars. However, Asim et al. (2018) reported



lower values for WG (19.76 to 26.08%) and DG (6.83 to 10.75%) for different wheat varieties.

The knowledge of physico-chemical properties of flour is important for its successful utilization in development of products. WAC reflects the capacity of a sample to absorb water. WAC is useful to enhance the weight and consistency of the product (Osundahunsi et al. 2003). WAC of wheat flours varied from 147.33 to 179.00%. Suresh et al. (2013) reported the WAC of 140% for wheat flour. The highest WAC of PBW757 might be due to a high amount of protein and fiber content. The variations in WAC between different cultivar flours might be due to difference in protein content, their conformational form and their level of interaction with water. OAC indicates the ability of flour to interact with oil. It is an important functional parameter that enhances the mouthfeel and flavour of products. The OAC of the wheat flours varied from 114 to 142.67% and DBW187 showed the highest value. The high value of OAC of the flour indicates its application in fat-containing products such as bakery products. The variations in OAC observed in the wheat flours might be due to the difference in hydrophobic protein content with good oil-binding efficacy (Ye et al. 2016). The SC and solubility value of wheat flours ranged from 8.50 to 11.59 g/g and 0.12 to 0.17 g/g, respectively. Baljeet et al. (2017) reported the SC of 6.07 to 9.26 g/g and solubility of 0.11 to 0.18 g/g for different Indian wheat varieties. The SC and solubility of flour particles reflects the degree of association between the particles. The variations in SC and solubility depend upon the extent of protein, lipids, and amylose content present in the flour (Yadav et al. 2014). The  $L^*$ ,  $a^*$ , and  $b^*$  value of the wheat flours in this study varied from 83.37 to 87.36, 1.27 to 2.01, and 10.51 to 13.39, respectively. However, Katyal et al. (2017) observed slight variation in the value of  $L^*$  (87.91 to 90.92),  $a^*$  (0.47 to 0.60) and  $b^*$  (8.95 to 10.14) for soft Indian varieties. The hue and chroma values differed significantly ( $p \leq 0.05$ ) among the different flours and varied from 88.55 to 89.28 and 10.62 to 13.53, respectively. Wheat cultivars DBW187 and UAS375 exhibited the highest, and HI1612 exhibited the lowest value for the hue. The maximum chroma value was recorded in PBW-757, and the minimum in DBW168. Color difference ( $\Delta E$ ) ranged from 84.46 to 88.10 for wheat flour of the different cultivars. Siddiqi et al. (2020) reported 86.51–88.54, 7.71–10.8, and 91.32–93.29 values for hue, chroma, and  $\Delta E$ , respectively. The variations in flour color of different wheat cultivars might be due to presence of some bran and naturally found pigments such as carotenoids, phenolic compounds, and flavonoids (Martinek et al. 2014). The ash content of flour is also responsible for the color differences in wheat flour of various cultivars.

SRC is defined on the basis of swelling characteristics of various flour components in specific solvents: lactic acid (LASRC), water (WSRC), sucrose (SUSRC), and sodium

carbonate (SCSRC) (Duyvejonck et al. 2012). The proteins, pentosans, glycoproteins, and amount of damaged starch present in the flour are responsible for solvent retention capacity (Yamazaki and Lord 1988). The WSRC is influenced by all flour components (starch, gluten, arabinoxylan, and gliadin), SCSRC by damaged starch, SUSRC by pentosans, and LASRC by glutenin (Kweon et al. 2011). The values of WSRC (74.33 to 97.66%), SCSRC (87.33 to 104.66%), LASRC (103.66 to 126.66%), and SUSRC (81.30 to 98.00%) found in this study were comparable to as observed by Siddiqui et al. (2020), who reported WSRC of 69.70 to 87.53%, LASRC of 80.45 to 110.88%, SCSRC of 81.22 to 91.87%, and SUSRC of 85.37 to 114.61%. Baljeet et al. (2017) reported the WSRC, SCSRC, LASRC, and SUSRC ranging from 59.03 to 80.73%, 55.63 to 112.30%, 80.66 to 128.33%, and 101.5 to 119.43%, respectively. The high values of SRC are generally related with good baking attributes (Baljeet et al. 2017). Hamed et al. (2015) reported high SRC for some hard wheat cultivars as a result of high protein, more gluten, high DS, high WAC, and greater arabinoxylan content. The gluten performance index (GPI) gives information regarding the functionality, baking performance, and gluten strength of flour (Kweon et al. 2011). GPI of flour of different wheat cultivars varied significantly ( $p \leq 0.05$ ) and ranged from 0.57 to 0.67. PBW757 had the highest GPI (0.67), and DBW173 and UAS375 showed the lowest GPI (0.57). Jeon et al. (2019) noted a GPI of 0.52–0.69 for some wheat cultivars. However, lower values of GPI have been observed by Siddiqi et al. (2020) (0.46–0.59) for different wheat cultivars. The GPI is directly linked with LASRC and could be adversely reduced with high SCSRC and SUSRC values.

Particle size is a key indicator influencing wheat flour quality and its end products. The flours of all the cultivars showed unimodal distribution in this study. The results of Dv(10) (11.03 to 16.56  $\mu\text{m}$ ), Dv(50) (40.43 to 54.20  $\mu\text{m}$ ), and Dv(90) (98.43 to 149.66  $\mu\text{m}$ ) of different wheat cultivars in present investigation were agreement to as noted by Sapirstein et al. (2018) for different Canadian wheat cultivars (11.3 to 20.5  $\mu\text{m}$ ), (50.03 to 69.1  $\mu\text{m}$ ), and (113.3 to 136.7  $\mu\text{m}$ ) respectively. The gap between the volume-weighted mean D (4,3) and surface-weighted mean D (3,2) diameter of the surface area steadily decreased with the decrease in Dv (50), and Dv (10). The increase in surface area was observed with a decrease in particle size. The influence of particle size on quality of WWF has been reported in several studies. The reduced particle size of WWF is usually preferable for high quality baked products. Wang et al. (2016) reported that the flour with finer particle size (90–96  $\mu\text{m}$  diameter) resulted in whole-wheat cracker of desirable quality.

The correlation among the physical parameters of grains and physico-chemical properties of flour of different cultivars was determined using Pearson's coefficients. Equivalent

diameter showed a significant positive (+ve) correlation with the surface area ( $r=0.717^*$ ) of wheat grain. L/B ratio had highly significant +ve correlation with grain length ( $r=0.782^*$ ). Thongbam et al. (2010) also observed a +ve correlation between the L/B ratio and length. L/B ratio had a significant negative (-ve) correlation with grain thickness ( $r=-0.575^*$ ). A significant +ve correlation was found between TKW and BD of grain ( $r=0.674^*$ ), however surface area showed a significant -ve correlation ( $r=-0.716^{**}$ ) with BD. The protein content was positively correlated with GHI ( $r=0.889^{**}$ ). This showed that cultivars with higher protein content had high GHI. The results revealed that the GHI decreased with a decrease in protein content. A significant positive correlation was observed between WG and the fat content of flour ( $r=0.742^*$ ). A highly significant positive correlation was found between GHI and damaged starch ( $r=0.860^{**}$ ). The protein content was positively correlated ( $r=0.905^{**}$ ) with DS of flour. WAC reflected significant +ve correlation with GHI, protein, and WG ( $r=0.768^{**}$ ;  $r=0.668^*$ ;  $r=0.665^*$ , respectively). A significant +ve correlation was found between OAC and GHI as well as protein ( $r=0.702^*$ ;  $r=0.648^*$ , respectively). SC had significant +ve correlation with GHI, ash, protein, and DS ( $r=0.877^{**}$ ;  $r=0.782^*$ ;  $r=0.899^{**}$ ;  $r=0.916^{**}$ , respectively). SC had significant positive correlation with GHI, protein, and DS ( $r=0.877^{**}$ ;  $r=0.899^{**}$ ;  $r=0.916^{**}$ , respectively). WSRC had highly significant +ve correlation with protein content, GHI, and WAC ( $r=0.876^{**}$ ;  $r=0.919^{**}$ ;  $r=0.856^{**}$ , respectively). SCSRC showed a highly significant +ve correlation with GHI and DS ( $r=0.767^{**}$ ;  $r=0.801^{**}$ , respectively), which indicated that wheat grains of higher hardness formed flour with high DS. SCSRC had a highly significant +ve correlation with WSRC and LASRC ( $r=0.765^{**}$ ;  $0.827^{**}$ , respectively). LASRC had highly significant +ve correlation with protein content ( $r=0.892^{**}$ ). Xiao et al. (2006) also noted a linear correlation between protein content and LASRC. A significant +ve correlation was observed between GPI and WG ( $r=0.695^*$ ) of flour. A highly significant +ve correlation was observed between D (4,3) and D (3,2) ( $r=0.956^{**}$ ). Dv (90) also showed a +ve correlation with D (4,3) and D (3,2) ( $r=0.915^{**}$ ,  $r=0.990^{**}$ ), respectively.

The cookies developed from flours of various wheat cultivars showed significant variations for physical parameters. The diameter and thickness of cookies varied from 53.2 to 66.6 mm and 5.70 to 6.60 mm, respectively. The correlation studies showed that variation in thickness and diameter of cookies is mainly affected by intrinsic factors (particle size, GPI, & GHI) and physicochemical properties (WAC & OAC) of wheat flour. A highly significant -ve correlation was found between particle size D (90) and the diameter of cookies ( $r=-0.781^{**}$ ). WAC showed a non-significant -ve correlation ( $r=-0.352$ ) whereas OAC showed +ve correlation ( $r=0.12$ ) with diameter. A significant +ve correlation

was observed between OAC and thickness of cookies ( $r=0.675$ ,  $p<0.05$ ) whereas; thickness of cookies was also correlated +vely with GPI and GHI ( $r=0.447$ ,  $r=0.437$ , respectively). The fracture strength is the property related to the hardness of the cookies and used to assess the textural properties of cookies. The fracture strength of cookies varied from 908.33 to 1574.9 g. DBW168 cookies showed a significantly ( $p<0.05$ ) highest value, whereas HD3226 cookies had a significantly ( $p<0.05$ ) lowest value for fracture strength. The variations in fracture strength of cookies might be due to the varietal differences. The spread ratio (SR) is the key factor for determining the quality of cookies. The SR value of cookies varied from 8.18 to 10.26. Cookies developed from PBW752 showed the highest value, while cookies prepared from HD2967 showed the lowest value for SR. Variation in SR is due to the differences in thickness and diameter of cookies, which are influenced by intrinsic factors such as protein content and damaged starch. SR reflected a significant -ve correlation with WAC ( $r=-0.731^*$ ). A -ve correlation was reported between damaged starch and SR ( $r=-0.426$ ). Moiraghi et al. (2011) reported that the higher content of damaged starch causes low spread factor of cookies. This might be because of increased WAC due to presence of high damaged starch, resulting in stiffness of biscuit dough and lower SR. The protein of flour exhibited a -ve correlation with the SR of cookies ( $r=-0.375$ ). Gutierrez et al. (2004) also observed a reduction in spread factor of cookies with the increase in protein content. The SR was negatively (-vely) correlated with LASRC ( $r=-0.396$ ), SCSRC ( $r=-0.302$ ), and WSRC ( $r=-0.520$ ). The results described that the wheat cultivars with low LASRC, SCSRC, and WSRC reflected a higher SR. Moiraghi et al. (2011) also recorded a -ve correlation of SUSRC and WSRC with SR. AWRC is considered as a key factor to check the suitability of wheat flour for the preparation of cookies. Wheat flour with a low AWRC value is generally preferable for cookies as it produces cookies with high SR. The spread ratio of cookies showed a -ve correlation ( $r=-0.553$ ) with AWRC. The present result agrees with an earlier study that also observed a -ve correlation between SR and AWRC (Roccia et al. 2006).

The moisture content of cookies varied might be due to variations in WAC of wheat flour. Protein content of cookies showed a -ve correlation with spread ratio ( $r=-0.331$ ) and diameter ( $r=0.046$ ) of cookies. A significant difference ( $p<0.05$ ) was noted for fat content among all samples. The significantly highest value was observed for HI1612 (1.92%) cookies and the lowest for DBW187 (1.53%) cookies. Fiber content had a -ve correlation with spread ratio and diameter ( $r=-0.116$ ;  $r=-0.452$ , respectively) of cookies. A significant ( $p<0.05$ ) variation in the color of cookies was found. HD2967 cookies showed the highest (63.35), and PBW 752 showed the lowest value (53.30) for L\*. For a\* parameter,

HI1620 cookies showed a significantly highest value than other cultivars, which indicates redness in cookies. UAS375 cookies showed high yellowness compared to other cookies due to a significantly ( $p < 0.05$ ) highest value of  $b^*$ . The decrease in the lightness/yellowness of cookies may be due to the browning reaction which takes place during baking process. The browning process during baking is affected by many factors, such as type and ratio of amino compounds, temperature, sugar, pH, and water activity (Sharma and Gujral 2013).

All the parameters including grain properties, flour physicochemical properties, and biscuit quality parameters were assessed through principal component analysis. PCA analysis showed that PC1, PC2, PC3, and PC4 accounted for 74.4% of cumulative variance. PC1 accounted for 26.6% variance with equivalent diameter, length, protein, WAC, SC, WG, SCSRC, and weight of cookies as the major factors. PC2 contributed for 18.2% variance and had L/B ratio, SUSRC, thickness of cookies, and OAC being the main factors. PC3 was responsible for 17.0% variances with breadth, moisture, ash, protein, WAC, swelling capacity, and fracture strength of cookies being the main contributors. PC4 accounted for 12.6% variances with TKW, BD, SDS, and SR of cookies as the main factors. In the loading plot, SR of cookies was located opposite to WG and protein content of flour, while WG and protein content were located very close to each other and were positively correlated. Results showed that wheat cultivars with higher protein and WG content gave lower SR of cookies. LASRC is located opposite to SR of cookies and same side of protein content of flour. Results revealed a negative correlation of LASRC with SR of cookies and a positive correlation of LASRC with the protein content of flour. L/B ratio, length, equivalent diameter, surface area, and fracture strength were located close to each other on one side but opposite to breadth, BD, SDS, and sphericity. These results reflected a positive relation between L/B ratio, length, equivalent diameter, surface area, and fracture strength and negatively correlated with breadth, SDS, and sphericity. The diameter of cookies was located opposite to the thickness of cookies, indicating a significant negative correlation between diameter and thickness. The wheat cultivars HI 1620, DBW187, and HI1612 with higher SR, thickness, and WSRC values are grouped separately. However, four wheat cultivars i.e., PBW752, PBW757, HD3226, and HD2967 with higher protein, WAC, SC, WG and DG content, SDS, and LASRC value were clustered but parted from one another. In aspect of quality parameters, remaining cultivars were extensively separated. UAS375, DBW168, and DBW173 with high fracture strength of cookies, L/B ratio, length, cookies weight, and equivalent diameter are grouped separately.

The outcomes of the research showed that the analyzed wheat cultivars varied in their physicochemical properties.

The wheat cultivars with higher protein and ash content had high GHI. A highly significant positive correlation was noted between GHI and damaged starch. SC showed a significant positive correlation with GHI, ash, protein, and DS. A linear correlation was observed between protein content and LASRC. The results of the study concluded that the biscuit quality is influenced by various factors like DS, protein content, WAC, and SRC. It was observed that the wheat flours with high SRC (LASRC, SCSRC, WSRC), AWRC, protein content, and DS adversely influenced the biscuit quality. On the basis of spread ratio and fracture strength, PBW752, DBW187, H1620 and H1612 wheat cultivars could be recommended more suitable for the preparation of whole wheat flour cookies. The information could be useful to millers, plant breeders, and baking industries in choosing the wheat cultivars with good quality parameters for end-product use.

**Author contribution** JN conducted the experiments, collected all data, and interpreted the results. Dr. RBY designed and supervised the study and involved in drafting and data interpretation of manuscript. Prof. BSY critically revised and edited the manuscript.

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**Availability of data and material** Not applicable.

**Code availability** Not applicable.

## Declarations

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical approval** This study does not involve any human or animal testing.

**Consent to participate** Not applicable.

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