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Indian wheat (*Triticum aestivum* L.) cultivars: physical characteristics, micronutrients and heavy metal content

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RESEARCH ARTICLE

Abstract

Six (C-306, PBW-373, WH-147, WH-1025, PBW-343 and PBW-502) Indian wheat cultivars were evaluated for their physical, milling and colour characteristics. The micronutrients and heavy metals were detected using an atomic absorption spectrophotometer. The physical parameters of grains revealed that WH-1025 had the smallest whereas WH-147 had the biggest grain size. Cultivar's C-306 and WH-147 showed significantly ($P \leq 0.05$) higher (58.828 and 58.805%, respectively) grain sphericity, so grains from these cultivars were more spherical in shape compared to other cultivars under study. The grains of studied cultivars were mealy and intermediate vitreous as reflected from their bulk and true density values. Cultivar WH-147 was the heaviest (4.313 g/100 grains) and also showed more volume (3.9 ml/100 grains) as compared to others, which reflected its importance for higher flour yield. Grains from cultivar WH-147 also showed the highest hunter L* and b* values, whereas grains from C-306 had the lowest hunter L*, a* and b* values as compared to other cultivars. Heavy metals and micronutrients concentration was higher in bran fraction of grain. The lowest chromium was detected in whole grain and bran (5.78 and 12.74 mg/kg, respectively) of C-306 cultivar. Zinc which is a very important micronutrient was found in the highest amount in whole grain as well as in bran fraction (43.62 and 83.88 mg/kg, respectively) of PBW-373 cultivar. WH-147 showed the highest manganese concentration for whole grain as well as bran fraction (35.79 and 93.30 mg/kg, respectively). The flour and bran yields ranged from 58.66-67.97 and 29.86-39.00%, respectively, with cultivar WH-147 having the highest flour and the lowest bran yield.

Keywords: kernel characteristics, nutrients, colour characteristics, milling yields

1. Introduction

Wheat is the second most produced food crop amongst the cereal crops in the world after rice (FAO, 2014). Wheat ranked as first staple food amongst cereals (Kalkan and Kara, 2011). The mechanical properties are very strongly heritable in wheat kernel. The wheat quality is affected by numerous parameters like milling, chemical, baking and rheological dough properties. The wheat quality is overall contribution of climate, effects of soil, kernel composition, and seed stock (Pasha *et al.*, 2010). Different qualities like cleaning, conveying, storing and milling properties of wheat grains at different moisture contents are helpful in designing machines for handling (Tabatabaeefar, 2003). The physical, mechanical and aerodynamic properties of kernels are important in proper designing and development of harvest machines, post-harvest processing equipment, and storage structures. The size and mass related properties of cereal grains proved useful during grain spreading process in fields by spreaders. In the designing of silos, bins, hoppers, and storage structures the bulk density, true density, porosity, and angle of repose are important parameters. Projected area and volume values of the grains are important parameters in cooking, aeration and artificial drying processes (Kheiralipour *et al.*, 2008). Frictional properties of cereal grains are important parameters and help in the designing of hoppers, handling equipments and all machine components in which friction of grains against component surface occurs (Kalkan and Kara, 2011). Bulk density and porosity affect the horizontal and vertical loads in silos during storage (Tipples *et al.*, 1994). The kernel degree of filling during growth and therefore hardness and breakage susceptibility, milling and baking qualities are indicated by bulk density (Chang, 1988). Bulk density data have been used in research for determining the dielectric properties of cereal grains (Nelson and You, 1989) and volume fractions to use in the dielectric mixture equations (Nelson, 1992). On the other hand, porosity allows gases, such as air and liquids to flow through a mass of particles in aeration, drying, heating, cooling and distillation operations. Bulk density, true density, porosity and surface area are helpful in determining the capacity of the dryer, storage and transportation appliances, and airflow resistance during aeration (Babic and Babic, 2000; Mohsenin, 1980).

The heavy metals enter into plants through soil. The metals do not biodegrade, unlike organic pollutants, and have thousands of year's residence time because these are usually immobile (Adriano, 2001), subsequently can cause serious health problems in humans and animals (Kabata-Pendias and Pendias, 1992). The mechanism of heavy metal uptake by cereal crops from contaminated soil is very important from study point of view because accumulation of heavy metal in crops or plants may adversely affect the animal or human physiological functions through the food chain (Gupta and Shukla, 1995; Silbergeld *et al.*, 2000).

The aim of the present study was to evaluate physical, colour and milling properties of grains from different Indian wheat cultivars. Heavy metal and micronutrient contents of whole wheat flour and bran fraction were also determined.

2. Materials and methods

Materials

Six conventional wheat cultivars, PBW-502 and PBW-343 from District Mansa (Punjab) India and PBW-373, C-306, WH-147, and WH-1025 from District Hisar (Haryana) India were procured. The physical properties of wheat kernels were determined at 13% moisture content.

Geometrical properties

Length, width and thickness of seeds

Ten randomly selected seeds were used to measure length (L), width (W) and thickness (T) using a vernier calliper reading up to 0.01 mm. These three principal dimensions are directed into three mutually perpendicular directions.

Equivalent diameter (geometric mean diameter)

The geometric mean diameter (D_m) was calculated using the following relationship (Mohsenin, 1970):

$$D_m = (LWT)^{1/3}$$

Sphericity

The sphericity (ϕ) was calculated as a function of the three principal dimensions as shown below (Mohsenin, 1970).

$$\phi = [(LWT)^{1/3}/L] \times 100$$

Aspect ratio

The aspect ratio (R_a) was calculated using the following equation. (Hauhouot-O'Hara *et al.*, 2000; Omobuwajo *et al.*, 1999):

$$R_a = W/L$$

Seed volume

The volume (V) was calculated using the relationship (Mohsenin, 1970):

$$V = 0.25\ [(\pi/6)L(W + T)^2]$$

Seed surface area

The surface area(A) was calculated using the relationship (Mohsenin, 1970):

$$A = \pi BL^2 / 2L - B$$

Where $B = \sqrt{W} \times T$, and B is the diameter of the spherical part of the kernel.

Gravimetrical properties

100 seed mass and 100 seed volume

One hundred seeds were manually counted and then weighed on a digital weighing balance (Citizen Scale (I) Pvt. Ltd., Maharashtra, India) with accuracy up to 0.001 mg. Seed volume was determined by counting one hundred seeds manually and putting them in 50 ml graduated cylinder. 20 ml of double distilled water was added to it seed volume (ml) was determined as:

$$100 \text{ seed volume} = \text{total volume} - 20 \text{ ml}$$

Bulk density

For the determination of bulk density, a 50 ml graduated cylinder was previously tarred and gently filled up to the mark with seeds. The sample was then packed by gently tapping the cylinder on bench top from a height of five cm until there was no further diminution of the sample level after filling up to the 50 ml mark. Weight of the filled cylinder was taken and the bulk density calculated as the weight of sample per unit volume of sample (g/ml).

True density

True density is weight per unit volume of individual seed. True density was determined using liquid displacement method. Toluene (C_7H_8) was used instead of water because it is absorbed by seeds to a lesser extent. Besides it has low surface tension, so that it fills even shallow dips in a seed and its dissolution is low (Mohsenin, 1980).

Porosity

The porosity (ε) is described as the ratio of free spaces between grains to total bulk of grains. It was computed as:

$$\varepsilon = 100\,[1 - (P_b / P_k)]$$

Where ε is the porosity in percentage, P_b is the bulk density in g/ml and P_k is the true or seed density in g/ml (Mohsenin, 1970; Nimkar and Chattopadhyay, 2001).

Colour measurement

Visual colour was measured using a Hunter colorimeter (Ultra Scan, VIS-1084; Hunter Associates Laboratory, Reston, VA, USA). Colorimeter was standardised with standard tile. The sample cup was filled with grains, kept in sample platform and its colour was recorded in terms of L*, a* and b* values. The L* values indicates whiteness to darkness. Chromatic portion is defined by a*(+) redness and a*(-) greenness, b*(+) yellowness and b*(-) blueness. The values were also used to compute $\Delta E = \sqrt{L^{*2} + a^{*2} + b^{*2}}$.

Heavy metals and micronutrients detection

Dried sample (0.5 g) was taken in a 250 ml digestion flask and 15 ml of diacid mixture (nitric acid and perchloric acid in ratio 4:1) was added to it. The mix was digested in a digestion chamber until it becomes colourless. Then the content was diluted up to 30 ml with distilled water, filtered through Whatman filter paper no. 1 (Whatman, Maidstone, UK) and transferred to a 50 ml volumetric flask. Final volume was made up to 50 ml with distilled water and was analysed under an atomic absorption spectrophotometer (240FS-AA; Agilent, Santa Clara, CA, USA) for the different heavy metal and micronutrient contents.

Milling of wheat

The moisture content of wheat samples was determined using MG-53 Halogen Moisture Analyser (Mettler Toledo, Greifensee, Switzerland). Wheat was conditioned up to 13% moisture level by adding required amount of water and conditioned in a refrigerator for 24 h to equilibrate moisture content. Then milling was done in a Brabender Quadrametric Junior Mill (Duisburg, Germany) and sieved through 60-mesh screen and stored in airtight containers at refrigerated temperature until used. The yield of flour and bran was calculated.

Statistical analysis

The data reported in all tables regarding physical parameters of grains is an average of ten observations with standard deviation. The rest of the data is an average of triplicate observations. Averages, one-way ANOVA and LSD were computed to measure variations in the observations with the help of MS-Excel (Microsoft, Redmond, WA, USA). Principal component analysis was computed using Minitab statistical software version 17 (Minitab Inc., State College, PA, USA).

3. Results and discussion

Geometrical properties

Length, width, thickness and length/width ratio of seeds

Size is an important physical attribute of seeds used in screening solids to separate foreign materials, and heat and mass transfer calculations. The size of a food material is usually expressed in terms of length, width and thickness. Length, width, thickness and length/width ratio for ten grains of different wheat cultivars ranged from 66.55 to 69.34 mm, 29.65 to 33.57 mm, 24.6 to 28.9 mm and 2.03 to 2.26, respectively (Table 1). Similar results for length, width and thickness were also reported by Baslar *et al.* (2012).

Geometric mean diameter (equivalent diameter), seed volumes and seed surface area

The physical parameters including geometric mean diameter, seed volume and seed surface area are based on length, width and thickness. Geometric mean diameter of wheat grains varied from 3.65 to 4.02 mm (Table 1). WH-147 showed the highest whereas WH-1025 showed the lowest geometric mean diameter values. Baslar *et al.* (2012) observed similar results for geometric mean diameter and seed surface area. Kalkan and Kara (2011) also reported the results for geometric mean diameter values of some wheat cultivars in line with our study. The seed volume ranged from 25.84 to 34.10 mm^3. WH-147 showed the highest whereas WH-1025 showed the lowest value for

Table 1. Physical properties of different wheat cultivar grains.[1]

Parameter	Cultivar					
	C-306	PBW-373	WH-147	WH-1025	PBW-343	PBW-502
Length (mm)[2]	66.55^{a}±1.56	68.15^{a}±1.66	68.32^{a}±1.82	66.87^{a}±1.23	69.34^{a}±0.98	68.3^{a}±1.23
Width (mm)[2]	32.44^{c}±0.55	33.57^{c}±1.98	32.83^{c}±0.95	29.65^{a}±1.14	32.08^{c}±0.96	30.86^{b}±0.98
Thickness (mm)[2]	27.8^{b}±0.15	27.0^{b}±0.18	28.9^{b}±0.13	24.6^{a}±0.21	26.5^{b}±0.22	26.7^{b}±0.18
Length/width ratio	2.05^{a}±0.06	2.03^{a}±0.08	2.08^{a}±0.06	2.26^{b}±0.05	2.16^{b}±0.04	2.21^{b}±0.06
Equivalent diameter (mm)[3]	3.91^{b}±0.08	3.95^{b}±0.18	4.02^{b}±0.08	3.65^{a}±0.14	3.89^{b}±0.09	3.83^{b}±0.09
Sphericity (%)	58.83^{c}±1.12	57.94^{c}±1.52	58.81^{c}±1.40	54.59^{a}±1.64	56.09^{b}±1.76	56.13^{b}±1.33
Aspect ratio	0.488^{b}±0.01	0.492^{b}±0.02	0.481^{b}±0.01	0.443^{a}±0.01	0.463^{a}±0.01	0.453^{a}±0.01
Seed volume (mm^3)[3]	31.63^{b}±1.77	32.90^{b}±4.53	34.10^{b}±1.96	25.84^{a}±2.88	31.16^{b}±1.75	29.59^{b}±2.05
Seed surface area (mm^2)[3]	40.61^{c}±1.67	41.42^{c}±3.74	42.69^{d}±1.67	35.55^{a}±2.64	40.16^{c}±1.62	38.92^{b}±1.84
Bulk density (g/ml)	0.831^{d}±0.01	0.809^{c}±0.002	0.778^{a}±0.01	0.783^{a}±0.003	0.818^{c}±0.01	0.798^{b}±0.01
True density (g/ml)	1.37^{c}±0.01	1.40^{d}±0.01	1.27^{a}±0.01	1.36^{c}±0.01	1.34^{b}±0.01	1.38^{c}±0.01
Porosity (%)	39.19^{a}±0.25	42.21^{b}±0.41	38.90^{a}±0.28	42.43^{b}±0.43	39.15^{a}±0.77	42.17^{b}±0.42
Hundred seed volume (ml)	3.82^{c}±0.08	3.24^{b}±0.05	3.90^{c}±0.07	2.98^{a}±0.04	3.16^{b}±0.05	3.26^{b}±0.11
Hundred seed mass (g)	4.28^{e}±0.11	3.72^{b}±0.05	4.31^{e}±0.11	3.35^{a}±0.03	4.04^{d}±0.06	3.89^{c}±0.11

[1] Values expressed are average of duplicate (n=10) ± standard deviation. Averages in the row with different superscript letters are significantly different at $P\leq0.05$.

[2] For 10 grains.

[3] For one grain.

seed volume. Seed surface area for different cultivars varied from 35.55 to 42.69 mm^2. The highest seed surface area was observed for WH-147, and the lowest for WH-1025 wheat cultivars (Table 1).

Sphericity and aspect ratio

Shape is also an important parameter in heat and mass transfer calculations, screening solids to separate foreign materials, and food material quality evaluations. The shape of a food material is usually expressed in terms of its sphericity and aspect ratio. Sphericity of different wheat cultivars ranged from 54.59 to 58.83%. C-306 and WH-147 cultivars had the highest grain sphericity, i.e. 58.83 and 58.81%, respectively (Table 1) with non-significant difference among them. Similar sphericity values of five wheat cultivars were reported by Baslar *et al.* (2012). Tabatabaeefar (2003) reported the sphericity for wheat cultivars in the range from 0.48 to 0.65 at 7.4% moisture content. The aspect ratio varied from 0.443 to 0.492 (Table 1) with wheat PBW-373 cultivar exhibiting the highest and WH-1025 the lowest values.

Gravimetrical properties

100 seed mass and 100 seed volume

The hundred seed mass and hundred seed volume of different wheat cultivars ranged between 3.35 to 4.31 g and 2.98 to 3.90 ml, respectively (Table 1). WH-147 showed the highest whereas WH-1025 had the lowest seed mass and seed volume values. Kalkan and Kara (2011) reported similar values for wheat cultivars. Schuler *et al.* (1994) reported that kernel length, width and length/width ratio were negatively but non-significantly associated with kernel test weight.

Bulk density, true density and porosity

The density of food materials is helpful in mathematical conversion of mass to volume. The quality of food materials can be assessed by measuring their densities. Density data of foods are required in pneumatic and hydraulic transport. The bulk density of different wheat cultivars ranged from 0.778 to 0.831 g/ml (Table 1); C-306 and WH-147 showed the highest and lowest values. Kalkan and Kara (2011) also reported the bulk densities of some wheat cultivar grains in the range from 770.16 to 807.37 kg/m^3. Grains below 1,360 kg/m^3 density (calculated by British Standard method) were completely mealy in appearance, whilst grains above 1,400 kg/m^3 density (calculated by British Standard method) were completely vitreous. Those in between were of intermediate appearance, containing varying proportions of vitreous and mealy endosperm (Dobraszczyk *et al.*, 2002). Thus, the wheat cultivar grains chosen in our study were mealy in appearance. Stenvert and Kinswood (1977) reported that degree of compactness of protein matrix could be responsible for observed difference in density and hardness of wheat kernels, which is strongly influenced by genetic and environmental factors during growth and development.

True density varied from 1.27 to 1.40 g/ml (Table 1). WH-147 cultivar showed the lowest whereas PBW-373 had the highest true density values. The true densities examined by us, were found close to those examined by Kheiralipour *et al.* (2008) and Kalkan and Kara (2011) for wheat. Porosity is an important physical property useful in material packaging, modelling, and designing of heat and mass transfer processes. The porosity was calculated from bulk and true densities of grains. Porosity of different cultivars ranged between 38.90 to 42.43%. Wheat cultivar WH-147 showed the lowest, whereas WH-1025 had the highest porosity. Porosity values of grains from some wheat cultivars in the range from 39.58 to 42.23% have been observed earlier by Kalkan and Kara (2011).

Colour measurement

The L*, a* and b* values of different wheat cultivars were studied. The L* value of grains from different cultivars ranged from 49.55 to 56.94 (Table 2). C-306 showed the lowest, whereas WH-147 had the highest L* values. High value of WH-147 indicates its lighter colour than grains from other cultivars. The a* value of grains from different cultivars varied from 5.04 (for C-306) to 5.89 (for PBW-373). The lowest a* values of C-306 indicates its lowest redness. The b* values were the lowest for C-306 (11.50) and the highest (15.89) for WH-147 cultivar. The total colour difference (ΔE) values of wheat cultivar grains were calculated from L*, a* and b* values. WH-147 cultivar grains had the highest (59.40) whereas C-306 had the lowest (51.12) values for ΔE (Table 2). So grains from PBW-373 cultivar were the most red whereas those from WH-147 were the most light or white and yellow in colour.

Heavy metals and micronutrients

Heavy metals and micronutrients were detected both in whole grain and bran fractions. Bran contains higher amounts of heavy metals and micronutrients as compared to endosperm part and this may be attributed to the appreciable amount of minerals deposition in bran. The heavy metals which are very harmful and micronutrients which are beneficial for human beings both were found in reasonable amounts in different wheat cultivars. The whole grain from PBW-502 contained the largest (10.26 mg/kg) amount of chromium (Cr), nearly double than C-306 (5.78 mg/kg) (Table 3). The Cr concentration in bran fraction was nearly three times higher than whole grains of C-306 cultivar, except for bran fraction of C-306 and PBW-373 cultivar. Cadmium (Cd) was found in low concentrations and ranged between 0.20-0.60 mg/kg in whole grain and bran portions. But Cd is toxic even at very low concentrations (Jarup *et al.*, 1998). The genetic variation of Cd accumulation in wheat is not only due to difference of its uptake by roots but also due to difference in the internal Cd translocation (Hart *et al.*, 1998). Micronutrients such as zinc (Zn) and manganese (Mn) were also found in appreciable amounts. Micronutrients copper (Cu), Mn and Zn were found in the range 1.50-3.50, 26.02-35.79 and 21.11-43.62 mg/kg in whole grain and 5.30-8.90, 60.80-93.30 and 46.47-83.88 mg/kg in bran, respectively. Lavado *et al.* (2001) also reported Cu and Zn from wheat grains at zero tillage (11.00 and 36.87 mg/kg, respectively) and conventional tillage (5.80 and 37.65 mg/kg, respectively). Zn is very important micronutrient and was found in the highest amounts in whole grain as well as bran fraction of PBW-373 among the cultivars under study. WH-147 showed the highest Mn concentration for whole grain as well as bran fractions (35.79 and 93.30 mg/kg, respectively). The concentration of Zn was found double in bran fractions than whole grain. Similarly, in case of Mn the concentration was more than double in bran fractions than whole grain.

Table 2. Colour values of different wheat cultivar grains.[1,2]

Colour parameters	Cultivar					
	C-306	PBW-373	WH-147	WH-1025	PBW-343	PBW-502
L*	49.55^a±0.73	50.82^a±1.43	56.94^b±1.01	50.31^a±0.80	51.86^a±1.17	50.02^a±1.04
a*	5.04^a±0.29	5.89^b±0.13	5.80^b±0.22	5.72^b±0.03	5.82^b±0.26	5.83^b±0.13
b*	11.50^a±0.39	13.64^c±0.33	15.89^d±0.74	12.64^b±0.23	14.30^c±0.45	13.44^c±0.56
ΔE	51.12^a±0.77	52.94^a±1.45	59.40^b±1.14	52.19^a±0.82	54.11^a±1.26	52.12^a±1.14

[1] Values expressed are average of n=3 ± standard deviation. Averages in the row with different superscript letters are significantly different at P≤0.05.
[2] L* = lightness; a* = redness-greenness; b* = blueness-yellowness; ΔE = total colour difference.

Table 3. Heavy metal and micronutrient concentrations (mg/kg) of different wheat cultivar whole grains and bran fractions.[1]

Cultivar	Heavy metals		Micronutrients		
	Cr	Cd	Cu	Mn	Zn
Whole grain					
C-306	5.78^{a}±0.10	0.30^{b}±0.01	3.00^{c}±0.05	32.08^{d}±0.35	39.32^{e}±0.55
PBW-373	6.10^{b}±0.13	0.30^{b}±0.02	3.50^{e}±0.05	30.58^{c}±0.26	43.62^{f}±0.39
WH-147	6.03^{b}±0.08	0.30^{b}±0.01	1.50^{a}±0.03	35.79^{e}±0.41	21.11^{a}±0.40
WH-1025	8.58^{c}±0.07	0.20^{a}±0.01	3.30^{d}±0.06	29.21^{b}±0.42	26.12^{c}±0.25
PBW-343	8.66^{c}±0.04	0.20^{a}±0.01	1.50^{a}±0.02	26.70^{a}±0.41	25.03^{b}±0.18
PBW-502	10.26^{d}±0.07	0.40^{c}±0.003	2.10^{b}±0.07	26.02^{a}±0.45	31.03^{d}±0.28
Bran					
C-306	12.74^{a}±0.10	0.40^{a}±0.004	7.50^{e}±0.11	83.40^{d}±0.51	80.56^{d}±0.61
PBW-373	13.23^{b}±0.12	0.50^{b}±0.004	8.90^{f}±0.11	85.30^{e}±0.59	83.88^{e}±0.36
WH-147	14.74^{c}±0.07	0.50^{b}±0.01	6.50^{d}±0.07	93.30^{f}±0.57	46.47^{a}±0.65
WH-1025	15.24^{d}±0.12	0.60^{c}±0.004	5.30^{a}±0.08	65.71^{b}±0.55	46.54^{a}±0.54
PBW-343	16.28^{e}±0.09	0.50^{b}±0.01	6.00^{c}±0.09	70.60^{c}±0.49	54.18^{b}±0.54
PBW-502	17.39^{f}±0.15	0.60^{c}±0.01	5.70^{b}±0.09	60.80^{a}±0.45	66.58^{c}±0.53

[1] Values expressed are average of n=3 ± standard deviation. Averages in the columns with different superscript letters are significantly different at P≤0.05.

PBW-373 also revealed the highest amount of Cu for whole grain and bran (3.50 and 8.90 mg/kg, respectively).

Milling of wheat

The milling yield of flour and bran from different wheat cultivars (Table 4) varied from 58.66-67.97%, and 29.86-39.00%, respectively. The losses during milling for different cultivars varied between 1.81-2.34% (Table 4). Wheat cultivar WH-147 showed the highest and WH-1025 had the lowest flour yield. The bran yield was the highest for WH-1025 and the lowest for WH-147 cultivar. The flour and bran yields were significantly (P≤0.05) different from each other for different wheat cultivars. As reported by Marshall *et al.* (1986) the test weight and high flour yield depended on kernel size heterogeneity, density and packing factors, and highly correlated with thousand kernel weight in soft wheat (*Triticum aestivum* L.) and oats. Our results also showed the same trends for the studied cultivars.

Vitreous kernels are somewhat translucent, whereas mealy kernels are opaque and floury (Greffeuille *et al.*, 2007), subsequently flour yield for WH-147 (mealy) and WH-1025 (intermediate vitreous) were found the highest and the lowest, respectively. The degree of compactness of the endosperm is generally related to its vitreousness. A discontinuous protein matrix with numerous air spaces can be seen in electron micrographs of mealy endosperms (Dexter *et al.*, 1989; Sadowska *et al.*, 1999). Samson *et al.* (2005) reported different density and number of air vacuoles in vitreous and mealy grains of durum wheat. Environmental conditions like water and nitrogen availability, temperature, etc., during growth and maturation play a major role in vitreous texture development. However, its origin has still

Table 4. Milling properties of different wheat cultivar grains.[1]

Parameter (%)	Cultivar					
	C-306	PBW-373	WH-147	WH-1025	PBW-343	PBW-502
Flour	66.80^{b}±0.41	66.64^{b}±0.28	67.97^{b}±0.57	58.66^{a}±0.43	67.43^{b}±0.43	66.72^{b}±0.28
Bran	31.27^{b}±0.31	31.38^{b}±0.24	29.86^{a}±0.33	39.00^{c}±0.31	30.76^{b}±0.32	31.35^{b}±0.27
Milling losses	1.93^{a}±0.09	1.98^{a}±0.09	2.17^{a}±0.09	2.34^{a}±0.12	1.81^{a}±0.09	1.93^{a}±0.11

[1] Values expressed are average of n=3 ± standard deviation. Averages in the row with different superscript letters are significantly different at P≤0.05.

unidentified, but is often associated with protein content in a particular cultivar (Pomeranz and Williams, 1990). Some previous studies also revealed that an increase in vitreousness level that could be linked with increase in the gliadin/glutenin ratio in durum wheat kernels (Dexter *et al.*, 1989; Samson *et al.*, 2005).

Principal component analysis

Principal component analysis of different physical and milling properties of wheat grains and their colour values was carried out (Figure 1). Loading plot showed that the physical properties of grains like equivalent diameter, seed surface area, seed volume, seed thickness, hundred seed mass and hundred seed volume were located close to each other. Flour yield, sphericity, seed width and seed aspect ratio indicated the dependence of these properties on each other and they were found to be positively correlated. Bran yield was negatively correlated with equivalent diameter (r=-0.911, $P\leq0.05$), seed surface area (r=-0.908, $P\leq0.05$), seed volume (r=-0.894, $P\leq0.05$), seed thickness (r=-0.853, $P\leq0.05$), hundred seed mass (r=-0.838, $P\leq0.05$) and flour yield (r=-0.999, $P\leq0.01$). Length/width ratio was negatively correlated with seed aspect ratio (r=-0.9999, $P\leq0.01$). Grain colour values were close to each other and showed dependence on each other. Porosity was negatively correlated with hundred seed mass (r=-0.866, $P\leq0.05$). The true density of grains also showed negative correlations with colour value '*L*' and ΔE (r=-0.905 and -0.888, respectively, $P\leq0.05$).

4. Conclusions

The results from grain's physical size parameters revealed that WH-1025 was the smallest, whereas WH-147 had the largest sized kernel amongst the wheat cultivars. C-306 and WH-147 cultivar grains had nearly equal and the highest grain sphericity than others. Subsequently both were more spherical in shape as compared to grains from other cultivars. The seed mass and seed volume values revealed that WH-147 was the heaviest and had more volume, whereas WH-1025 was the lightest and had lower volume than all other cultivars. Grains from WH-147 cultivar showed the lowest, whereas PBW-373 had the highest true density. WH-147 showed the lowest and WH-1025 the highest porosity and this might be due to their highest and the lowest length, width, thickness, equivalent diameter, seed volume and seed surface area values, respectively. The Hunter colour parameters showed that grains from WH-147 were the lightest and more yellow, whereas those from C-306 were the darkest, least red and least yellow in colour. Heavy metals and micronutrients concentration were higher in bran portion of grain. The amount of Zn and Mn micronutrients was significantly higher. The heavy metal Cd was found in least amounts, even then it may be harmful. Cr was detected the lowest in C-306 cultivar for both whole grain and bran fractions. WH-147 and PBW-373 had the highest Mn and Zn concentrations for whole grain as well as bran portions. So from the heavy metals and micronutrient aspects C-306, PBW-373 and WH-147 proved better for human food uses among studied

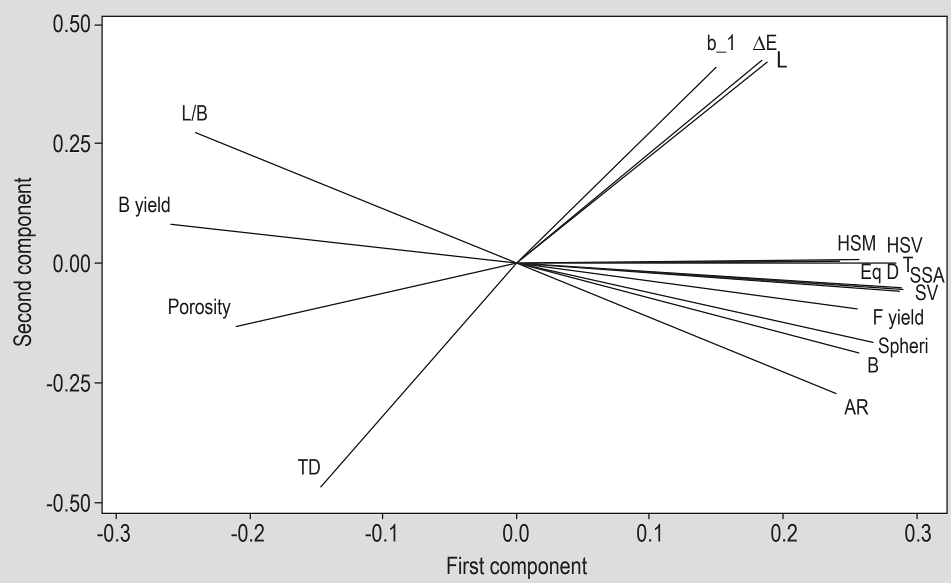

Figure 1. Loading plot of physical and milling properties wheat grain and their colour values (B = width; T = thickness; L/B = length/breadth ratio; Eq D = equivalent diameter; Spheri = sphericity; AR = aspect ratio; SV = seed volume; SSA = seed surface area; TD = true density; Poro = porosity; HSV = hundred seed volume; HSM = hundred seed mass; FY = flour yield; BY = bran yield; L = colour value; b_1 = colour value; ΔE = total colour difference).

wheat cultivars. WH-147 cultivar showed the highest and WH-1025 the lowest flour yield, whereas bran yield was the highest for WH-1025 and the lowest for WH-147 cultivar and this may be attributed to their size parameters. The principal component analysis showed that different physical, colour and milling properties were interrelated and showed significant dependence on each other.

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