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Comparative study of physicochemical and functional properties of different buckwheat varieties and their milling fractions

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Abstract

The present work evaluated the physicochemical and functional characteristics of different indigenous buckwheat varieties grown in Gilgit Baltistan, Pakistan, using grains and milled flour (fine flour, coarse flour, bran, and husk). Results showed that the thousand grain weight, length, width, thickness, arithmetic mean diameter, and geometric mean diameter were found to be highest in common buckwheat. In contrast, the highest mean values for sphericity were observed in Tartary buckwheat. The water absorption capacity, oil absorption capacity, swelling capacity, foaming, and foaming stability were high in common buckwheat as compared to Tartary buckwheat. Results regarding chemical properties revealed that common buckwheat contained higher quantity of protein (14.67%), fat (3.86%), fibre (1.38%), ash (2.24%), and total carbohydrate (65.8%); while Tartary buckwheat contained moisture (13.31%), protein (11.9%), fibre (1.38%), fat (3.57%), ash (2.69%), and total carbohydrate (68.8%). Furthermore, during the comparison of milling factions, it was found that buckwheat husk contained the highest quantity of copper (6.78 mg/100 g) and manganese (32.79 mg/100 g), while fine flour proved to be a rich source of magnesium. The present work identified variability among buckwheat varieties and milling fractions for physicochemical and nutritional traits that could be used to supplement various food products as functional ingredients.

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Introduction

Buckwheat, originated from Asia, is a traditional food utilised worldwide for a long time owing to its potential functional ingredients. Several buckwheat species are grown around the world, with nine species having higher nutritional and agricultural importance than others. Common buckwheat (*Fagopyrum esculentum*) and Tartary buckwheat (*F. tataricum*) are two predominant cultivars of buckwheat that have been successfully grown in Northern areas of Pakistan (Unal *et al.,* 2017). The most important benefit of buckwheat as compared to other cereal crops is that it is gluten-free (Bonafaccia *et al*., 2003), and consists of distinctive amino acids that provide higher biological value (Rani and Kulkarni, 2020).

Buckwheat grain has a wide variety of important nutrients like dietary fibres, fats, proteins, vitamins (B and E), minerals (iron, calcium, and magnesium), essential amino acids, and bioactive compounds that play significant influence in the maintenance of human health (Wellytton *et al.*, 2019). Being a good source of proteins with high biological value, it also has anti-cholesterol and anti-hypertension properties, and also improves digestion by reducing constipation (Ahmed *et al*., 2014).

Due to the occurrence of several bioactive components, buckwheat is believed to have functional and therapeutic qualities in addition to its nutritional properties. Buckwheat is famous due to its antioxidants (rutin and quercetin) and other important compounds, such as D-chiro inositol and fagopyrin, identified to play very important role in the control of different diseases such as hyperglycaemia and diabetes mellitus. Rutin is an important antioxidant that is present in concentrations of 3 - 6%; Tartary buckwheat contains 10.21 mg/100 g, while common buckwheat contains 6.35 mg/100 g. Rutin maintains the flexibility of capillaries and arteries, and minimises the incidence of different vascular problems such as retinal haemorrhage, apoplexy, and

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coronary obstructions. Sterols in buckwheat also play key role in preventing hypertension, and increasing cholesterol in the blood serum (Sah *et al*., 2016).

Furthermore, food substitution is one of the most important approaches to reducing and managing nutritional deficiencies and other strategies for addressing malnutrition, including food enrichment and diversification. Buckwheat may be supplemented in cookies, breads, and chapattis to harness its nutritious potentials and reduce malnutrition through widespread intake and usage.

Owing to the significance of buckwheat concerning its high biological, nutritional, and nutraceutical potentials, the present work aimed to evaluate underutilised physicochemical and functional attributes of buckwheat, and its use in cereal-based products to improve the nutritional quality of people's diets and health. The present work also identified potential functional dietary compounds available in locally produced buckwheat that can be successfully utilised to control malnutrition and acute diseases such as diabetes mellitus.

Materials and methods

The present work was carried out at the Institute of Food and Nutritional Sciences (IFNS), PMAS-Arid Agriculture University Rawalpindi, and Grain Quality and Product Development Laboratory, National Agriculture Research Centre (NARC), Islamabad. The buckwheat samples were collected from Skardu Gilgit-Baltistan, with the help of the Agriculture Department, Skardu, and transported to the Postgraduate Research Laboratory for further analyses.

Physical characteristics of different buckwheat varieties

Grain weight

Thousand grain weights of buckwheat grain samples were determined by counting clean and sound grains, and their weight in g/1,000 grains was recorded using an electric balance as described in the standard procedure of AACC (2000).

Grain size

Average size of the buckwheat grain samples was determined by randomly taking 100 grains, and measuring three linear dimensions (length, width, thickness) using digital Vernier calliper with an accuracy of 0.01 mm. The arithmetic means diameter (D_a), geometric mean diameter (D_g), and sphericity (Ø) of the samples were calculated using Eqs. 1 - 3 (Gharibzahedi *et al*., 2011):

$$D_a = (L + W + T)/3 \quad \text{(Eq. 1)}$$

$$D_g = (L \times W \times T)^{(1/3)} \quad \text{(Eq. 2)}$$

$$Ø = (Dg/L)\ 100 \quad \text{(Eq. 3)}$$

Bulk density

Bulk density of buckwheat grain samples was measured using the standard method of Unal *et al*. (2017) by filling a 500 mL container with grain from a height of 150 mm at a constant rate, and weighing the content using Eq. 4:

$$Bulk\ density = \frac{Seed\ weight\ (g)}{Seed\ volume\ (mL)} \quad \text{(Eq. 4)}$$

Tempering of buckwheat

Buckwheat grains were tempered in the clogged container, and water was added to attain 16% moisture by adopting the procedure of Morishita *et al*. (2020).

Milling of buckwheat

To obtain different milling fractions, buckwheat was properly cleaned and subjected to Quadrumate Senior Mill at the National Agriculture Research Centre (NARC), Islamabad. In total, four buckwheat fractions (fine flour, coarse flour, bran, husk) were obtained. Milling of buckwheat samples was carried out by adopting the procedure of Skrabanja *et al*. (2004) using the Quadrumate Senior Mill. The milling fractions were automatically divided on the base of a combination of severing. The chemical and functional characteristics of buckwheat samples were determined after milling.

Proximate analysis

The whole buckwheat and milling fractions of their flours were analysed for total moisture (method no. 44-19), crude protein (method no. 46-10), crude fat (method no. 30-10), total ash (method no. 08-01), and crude fibre (method no. 32-10.01) following the procedure recommended by AACC (2000), while total carbohydrate was determined following the method described by Shimelis and Rakshit (2005).

Total dietary fibres

Buckwheat samples were further analysed for their total dietary fibre contents. Soluble, insoluble, and total dietary fibre contents of buckwheat samples were determined following AACC (2000) method no. 991-43. Buckwheat samples (1 g) were stirred with 40 µL of phosphates at pH 8.2, and then heated at 100°C after which 40 µL of alpha-amylase was added. The samples were cooled till 60°C, followed by their digestion with 100 µL of protease and 200 µL of amyloglucosidase, and stayed at 60°C for 30 min. The samples were filtered, followed by their washing with 95% ethanol and dried. The residues were measured for insoluble dietary fibre (ISDF) and filtrates were precipitated for soluble dietary fibre (SDF) using four-time 95% ethanol. Contents of protein and ash were subtracted from the final weights, and again, the sample for SDF was filtered and weighted. Total dietary fibres were calculated by the sum of IDF and SDF.

Minerals

Mineral contents (calcium, magnesium, iron, copper, manganese, and zinc) in respective buckwheat samples was estimated using atomic absorption UV visible spectrophotometer by the methods outlined in AACC (2000), method no. 40-70. The highlighted minerals were mainly selected for the comparisons of both varieties.

Functional properties of buckwheat

Buckwheat flour was supplemented at 10, 20, 30, 40, and 50% with wheat flour, and the following functional properties of composite flour were evaluated. Buckwheat is a valuable crop, and considered the best choice as potential functional food since it contains numerous nutraceutical compounds, amino acids, proteins of high biological value, vitamins, and antioxidants that are insufficient in wheat flour. Owing to these reasons, it can serve as the best dietary supplement in different baked products to mitigate the issue of malnutrition, specifically protein malnutrition, and combat several nutritional disorders.

Water and oil absorption, and swelling capacity

The water and oil absorption abilities of buckwheat flour samples were analysed using the standard method of Sosulski *et al*. (1976). Briefly, 1 g of sample was mixed with 10 mL of distilled water, and left at room temperature for half-hour, and then centrifuged for 10 min at 2,000 *g*. Water and oil absorption abilities were expressed as percent water or oil bound per gram of the sample.

The buckwheat sample's swelling capacity was determined using Okaka and Potter's (1977) method. The buckwheat sample was filled up to 10 mL mark in a 100 mL cylinder, and then water was added to create 50 mL volume. After then, the graduated cylinder was properly enclosed and mixed by overturning the cylinder. The cylinder was inverted again after 2 min, and kept for 30 min, and the occupied volume was taken.

Foaming capacity and foaming stability

The method of Narayana and Narasinga (1984) was adopted with minor modifications to determine the foaming capacity and stability. At a temperature of 30 ± 20°C, 1 g of sample was put in a graduated cylinder, and then the suspension was inverted properly for 5 min to foam. The volume of foam after whipping for 30 s was taken as foaming capacity (Eq. 5). The foam volume was noted before and after 1 h whipping to measure foaming stability as a percent of the initial foam volume.

$$FC = \frac{Volume\ of\ foam\ (AW) - Volume\ of\ foam\ (BW) \times 100}{Volume\ of\ foam\ (BW)} \quad \text{(Eq. 5)}$$

Statistical analysis

All experiments were performed three times, and the results were reported as means and standard deviation. The data were statistically analysed using Statistix 8.1 and Minitabe-16 software. Means were compared using the LSD (least significant difference) test at a 0.05% level of probability, as described by Steel *et al*. (1997).

Results and discussion

Analysis of chemical composition is a standard to evaluate the chemical and nutritional quality, and appropriateness of food ingredients, in various food applications. In the present work, buckwheat varieties and their milling fractions were physically, chemically, and nutritionally analysed to compare the quantity of minerals and dietary fibres, which can affect their nutritional profile.

Physical characteristics of different buckwheat varieties

Physical characteristics of buckwheat grains were determined and compared in terms of thousand-grain weight, length, width, thickness, arithmetic mean diameter, geometric mean diameter, bulk density, volume, surface area, and sphericity (Table 1a). The thousand-grain weight of buckwheat grains of different varieties ranged from 18.82 to 20.33 g. The significantly (p < 0.05) maximum mean values for 1,000 grain weight were observed in common buckwheat (20.33 g), while significantly minimum mean values were observed in Tartary buckwheat (18.82). Similarly, the significantly highest mean value for the length (5.90 mm), width (3.48 mm), thickness (3.66 mm), arithmetic mean diameter (4.35), and geometric mean diameter (422) were observed in common buckwheat, while the significantly lowest mean values were observed in Tartary buckwheat. Significantly (p < 0.05) higher mean value for bulk density (0.96 w/v) and sphericity (101.69) were observed in Tartary buckwheat, while significantly lower mean values were observed in common buckwheat. These were similar to the findings of Kaliniewicz *et al*. (2015) who reported that the mean length, width, and thickness values were 6.0, 4.2, and 3.5, respectively. The differences in physical characteristics of buckwheat grain may be due to environmental, individual varieties, and growth conditions (Unal *et al*., 2017). The decrease in moisture content during drying causes an increase in bulk density, true density, and porosity of buckwheat grain (Kaliniewicz *et al*., 2015).

Table 1. Mean values **(a)** and Pearson correlation coefficients **(b)** between physical parameters of different buckwheat varieties.

(a)

Physical characteristic	CBW ± SD	TBW ± SD
1000 grain weight (g)	20.33 ± 0.05[a]	18.82 ± 0.02[b]
Length (mm)	5.90 ± 0.01[a]	3.15 ± 0.03b[b]
Width (mm)	3.66 ± 0.02[a]	3.27 ± 0.02[b]
Thickness (mm)	3.48 ± 0.01[a]	3.22 ± 0.01[b]
Sphericity (%)	71.55 ± 0.05[b]	101.69 ± 0.11[a]
Bulk density (w/v)	0.96 ± 0.04[a]	0.91 ± 0.03[b]
Volume (ml)	22.56 ± 0.05[a]	20.14 ± 0.03[b]
Surface area (mm^3)	52.63 ± 0.07[a]	44.27 ± 0.04[b]
Arithmetic mean diameter (mm)	4.35 ± 0.04[a]	3.21 ± 0.01[b]
Geometric mean diameter (mm)	4.22 ± 0.01[a]	3.21 ± 0.02[b]

(b)

AMD	AMD	BD	GMD	L	S	SA	T	TGW	V	W
	1									
BD	0.8640 P-V(0.0002)	1								
GMD	0.7840 (0.0003)	0.5320 (0.0243)	1							
L	0.6547 (0.0032)	0.7820 (0.0002)	0.6547 (0.0041)	1						
S	0.7747 (0.0012)	0.8350 (0.0001)	0.7747 (0.0003)	-0.6852 (0.0031)	1					
SA	0.6926 (0.0031)	0.5000 (0.0210)	0.6527 (0.0021)	0.6547 (0.0054)	-0.5747 (0.0164)	1				
T	0.6206 (0.0035)	0.6608 (0.0034)	0.7206 (0.0012)	0.6959 (0.0051)	0.6967 (0.0043)	0.7206 (0.0004)	1			
TGW	0.8966 (0.0001)	0.4271 (0.0413)	0.6966 (0.0024)	0.5903 (0.0213)	0.7201 (0.0021)	0.6873 (0.0012)	0.6611 (0.0052)	1		
V	0.6453 (0.0035)	0.5450 (0.0231)	0.9320 (0.0001)	0.6547 (0.0032)	-0.5747 (0.0124)	0.5634 (0.0312)	0.7206 (0.0013)	0.5966 (0.0134)	1	
W	0.3273 (0.0512)	0.8220 (0.0001)	0.3273 (0.0572)	0.4286 (0.0410)	0.8511 (0.0002)	0.3175 (0.0512)	0.8910 (0.0001)	0.5673 (0.0234)	0.7634 (0.0022)	1

CBW: common buckwheat; TBW: Tartary buckwheat; SD: standard deviation; BD: bulk density; L: length; S: sphericity; T: thickness; TGW: thousand grain weight; W: width; AMD: arithmetic mean diameter; GMA: geometric mean diameter; V: volume; and SA: surface area.

Pearson correlation coefficients for physical parameters of different buckwheat varieties

The correlation coefficient was to study the relationship between different physical parameters of buckwheat grain, including thousand-grain weight, length, width, thickness, bulk density, sphericity, arithmetic mean diameter, geometric mean diameter, volume, and surface area. The results revealed that most of the correlation coefficient of the physical parameters of buckwheat grain in parameters was significant at 5 and 1% levels. The results also showed positive correlations among thousand-grain weight, width, thickness, arithmetic mean diameter, bulk density, and geometric mean and diameter, while a negative correlation was found for sphericity, length, and surface area. It means there was a significant difference between most physical parameters of buckwheat (Table 1b).

Proximate analysis of different buckwheat varieties and their milling fractions

Milling fractions of buckwheat varieties were analysed for all proximate parameters, including moisture, ash, protein, crude fat, crude fibre, and total carbohydrate. The results revealed that buckwheat varieties and their milling fractions (fine flour, coarse flour, bran flour, and husk) differed significantly ($p < 0.05$) between common and Tartary buckwheat. Interactions between varieties and their milling fractions were also found to be significantly different.

Moisture and ash contents

The mean values for moisture content of buckwheat showed a significant difference between buckwheat varieties ranging from 12.48 - 13.31%, the highest being in V2 (Tartary buckwheat), while the lowest in V1 (common buckwheat) as given in Table 2. Similarly, significant variations in buckwheat milling fractions were found for moisture content (Figure 1). Significantly ($p < 0.05$) highest moisture content was observed in common bran flour (13.18%), while the lowest in fine flour (11.36%). The interaction between the buckwheat variety and milling fractions for moisture contents showed that bran flour had maximum moisture content than the rest of the fractions in both varieties, ranging from 13.18 to 14.30%. The results were aligned with Bhvsar *et al*. (2013) who found similar moisture content (11.31) in common buckwheat flour. Similarly, the highest ash content was observed in common buckwheat bran flour (4.99%), while the lowest was found in coarse flour (1.31%).

Table 2. Physicochemical and mineral analyses of buckwheat varieties.

Parameter	CBW ± SD	TBW ± SD
Moisture (%)	12.48 ± 0.05^b	13.31 ± 0.09^a
Ash (%)	2.24 ± 0.05^b	2.69 ± 0.04^a
Crude protein (%)	14.67 ± 0.03^a	11.9 ± 0.09^b
Crude fat (%)	3.86 ± 0.04^a	3.57 ± 0.02^b
Crude fibre (%)	1.38 ± 0.03^a	1.13 ± 0.02^b
Total carbohydrate (%)	65.89 ± 0.48^b	68.83 ± 0.14^a
Insoluble dietary fibre	2.85 ± 0.08^a	1.79 ± 0.02^b
Soluble dietary fibre	5.43 ± 0.03^a	4.27 ± 0.06^b
Total dietary fibre	8.3 ± 0.11^a	6.24 ± 0.06^b
Zinc (mg/100 g)	17.363 ± 0.88^b	27.700 ± 0.58^a
Copper (mg/100 g)	1.462 ± 0.16^b	2.581 ± 0.16^a
Manganese (mg/100 g)	4.293 ± 0.03^b	5.640 ± 0.26^a
Iron (mg/100 g)	52.57 ± 0.71^b	58.527 ± 0.58^a
Magnesium (mg/100 g)	262.334 ± 0.55^b	354.934 ± 0.67^a
Calcium (mg/100 g)	268.133 ± 0.49^b	275.182 ± 0.28^a

Different lowercase superscripts in the same row indicate significant differences ($p < 0.05$). CBW: common buckwheat; TBW: Tartary buckwheat; and SD: standard deviation.

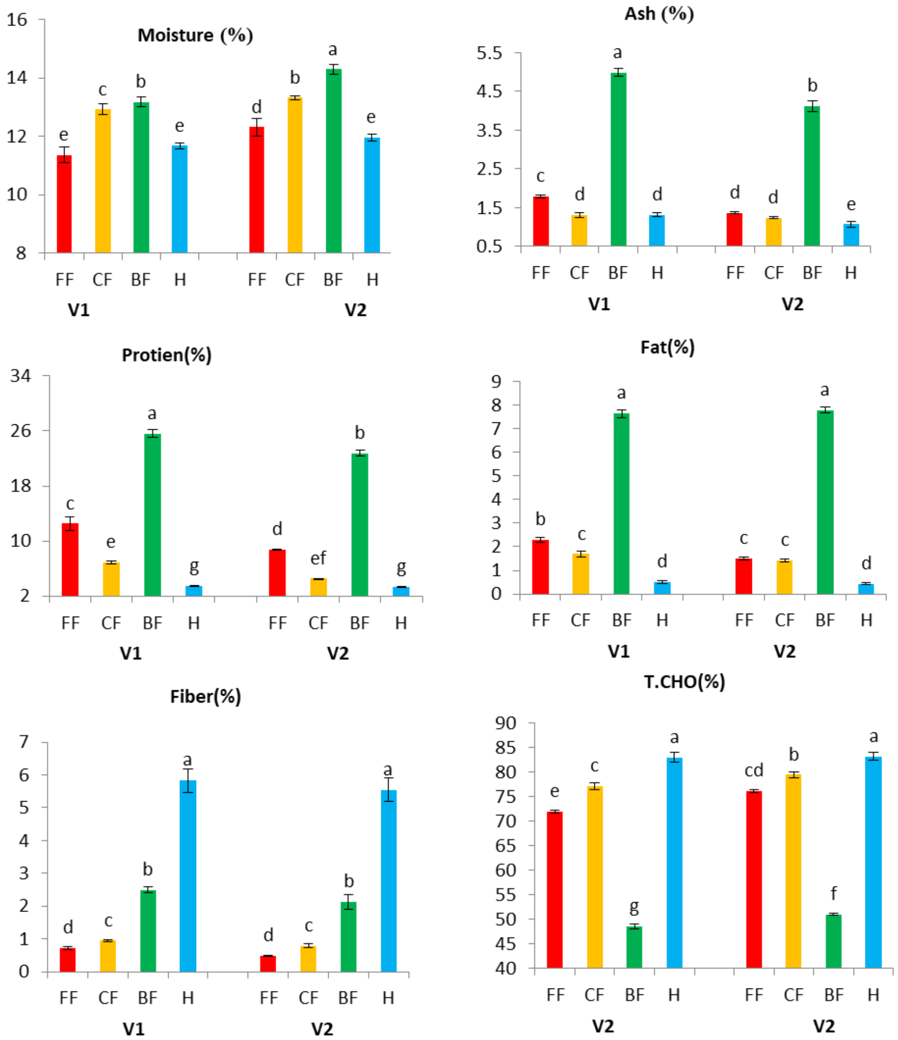

Figure 1. Mean values for milling fractions and varieties interaction for proximate parameters. V1: common buckwheat; V2: Tartary buckwheat; FF: fine flour; CF: coarse flour; BF: bran flour; and H: husk.

The mean values for ash content of buckwheat showed a significant difference between buckwheat varieties. Meanwhile the mean values for the moisture content of buckwheat showed a significant difference between buckwheat varieties (Table 2). The interaction between buckwheat varieties and their milling fractions for the ash contents revealed that the bran flour had maximum ash content than the rest of the fractions in both varieties, ranging from 4.12 to 4.99%, being highest in common buckwheat (CBW) bran flour, and the lowest in Tartary buckwheat (TBW), while in coarse flour, ash contents ranged from 1.24 - 1.31%, being highest in CBW, and lowest in TBW (Figure 1). The results closely conformed to Unal *et al*. (2017) who found similar ash contents (2.5) in buckwheat flour. The ash contents may change with time, as well as due to ecological strain. Tartary buckwheat showed more ash content than common buckwheat (Ahmed *et al*., 2014).

Crude protein, fat, and fibre contents

The mean values for protein content of buckwheat showed a significant difference between buckwheat varieties ranging from 11.9 - 14.67%, being higher in V1 (common buckwheat), while significantly lower in V2 (Tartary buckwheat) (Table 2). The highest crude protein content was significantly recorded in common buckwheat bran flour (25.63%), while the lowest in coarse flour (3.53%) (Figure 1). The results were in accordance with Unal *et al*. (2017) who reported that the protein content in buckwheat flour ranged from 13 - 14%. Furthermore, the results for protein contents were also in agreement with Guo *et al*. (2007) who found 8.81 to 18.71 g/100 g protein in buckwheat flour.

The mean values for the crude fat content of buckwheat showed a significant difference between buckwheat varieties ranging from 3.57 - 3.86%, being higher in common buckwheat, and lower in Tartary buckwheat (Table 2). The interaction between buckwheat varieties and their milling fractions for the fat contents was significantly different (Figure 1). The results were aligned with Bhvsar *et al*. (2013) who found similar crude fat content (1.80 - 2.80%) in buckwheat flour. The results also agreed with Steadman *et al*. (2001).

Results regarding crude fibre content showed that significantly ($p < 0.05$) highest mean values were found in common buckwheat (1.38%), whereas the lowest in Tartary buckwheat (1.13%) (Table 2). Crude fibre content was also significantly affected in all milling fractions, being highest in husk (5.83%), while lowest in fine flour (0.49) (Figure 1). The results were in accordance with Hosaka *et al*. (2014) who reported similar fibre contents in buckwheat flour.

Total carbohydrate and dietary fibre contents of buckwheat

The mean values for total carbohydrate content of buckwheat showed a significant difference between buckwheat varieties ranging from 65.89 - 68.83%, being highest in Tartary buckwheat, and lowest in common buckwheat (Table 2). Interactions between varieties and their milling fractions were also found to be significantly different, with husk having maximum carbohydrates than the rest of the fractions in both varieties, ranging from 82.96 to 83.21%, highest in CBW husk, while lowest in TBW (Figure 1). The results were aligned with Shweta *et al*. (2018) who found similar carbohydrate content (71.23%) in buckwheat flour. The results also agreed with Khan *et al*. (2013).

The mean values for insoluble dietary fibre contents of buckwheat showed a significant difference between buckwheat varieties ranging from 1.79 to 2.85%, being highest in common buckwheat and lowest in Tartary buckwheat (Table 2). The highest insoluble dietary fibre content was observed in common buckwheat bran flour (4.22%), while the lowest in coarse flour (0.91%). The interaction between buckwheat varieties and milling fractions showed that bran flour had maximum moisture content. The fractions in both varieties ranged from 2.25 to 4.22%, highest in CBW bran flour, and lowest in TBW. Similarly, fine flour's insoluble dietary fibre content ranged from 2.74 - 2.76%, highest in TBW, and lowest in CBW (Figure 2).

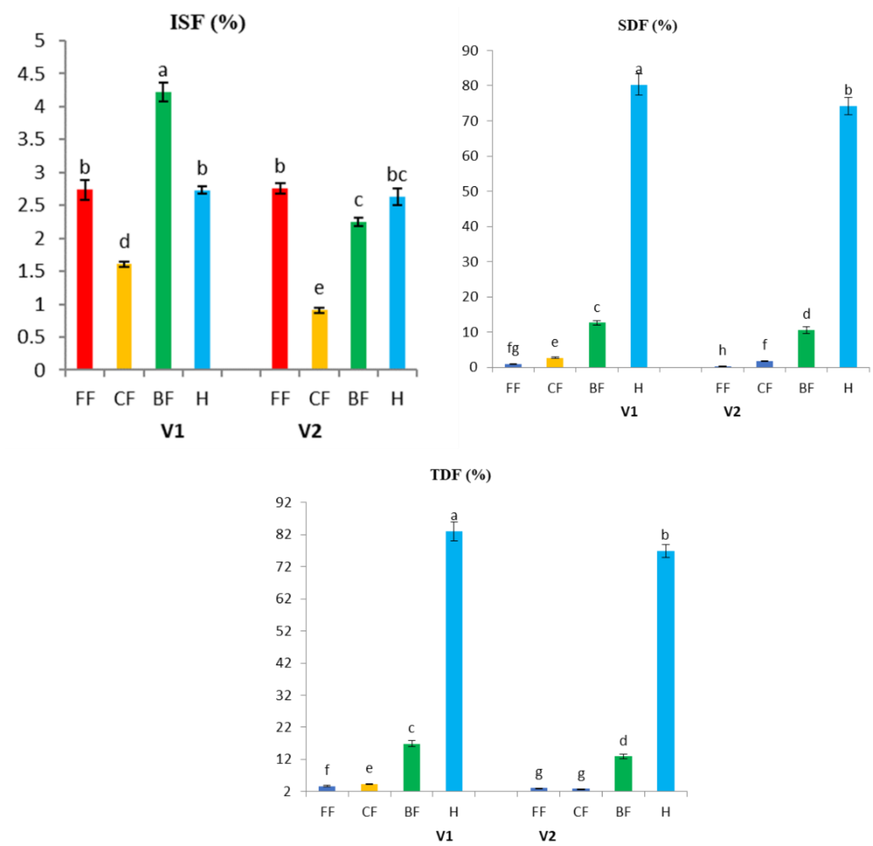

Figure 2. Mean value for varieties and milling fractions interaction for dietary fibre. V1: common buckwheat; V2: Tartary buckwheat; ISF: insoluble dietary fibre; SDF: soluble dietary fibre; TDF: total dietary fibre; FF: fine flour; CF: coarse flour; BF: bran flour; and H: husk.

Furthermore, the main effects for soluble dietary fibre contents revealed variation among buckwheat varieties ranging from 5.43 to 4.27%, higher in common buckwheat, and lower in Tartary buckwheat. The interaction between buckwheat varieties and milling fractions for insoluble dietary fibre contents showed that the soluble dietary fibre content was also affected significantly in all milling fractions, being highest in husk (80.24%) and lowest in fine flour (0.31), whereas in fine flour soluble, dietary fibre content ranged from 0.31 - 0.95%, being highest in V1 (common buckwheat), and lowest in V2 (Tartary buckwheat). Significantly ($p < 0.05$), the highest total dietary fibre content was noticed in common buckwheat (8.30%), whereas the lowest was recorded in Tartary buckwheat (6.24%), as presented in Figure 2. The interaction between the buckwheat varieties and milling fractions revealed that the buckwheat husk had maximum total dietary fibre content than the rest of the fractions in both varieties. The results were aligned with Bhvsar *et al*. (2013) who found similar variations in dietary fibre content in buckwheat flour. In buckwheat milling fractions (except husk), the whole range in total dietary fibre was 2.7 to 21.3% (db), while husk fibre content exceeded 90%, but the proportion of soluble dietary fibre was relatively small (2.9%, db). Flour fractions contained minor amounts of total dietary fibre than semolina or bran fractions (Skrabanja *et al*., 2004).

Mineral profile of buckwheat

Results regarding the minerals profile revealed that both buckwheat varieties were good sources of minerals. However, differences between buckwheat milling fractions were recorded. The mean square values revealed significant differences ($p < 0.05$) between buckwheat varieties, fractions, and their interactions for all estimated minerals. The mean values for zinc of buckwheat showed significant difference between buckwheat varieties ranging from 17.63 - 27.70 mg/100 g, being higher in V2 (Tartary buckwheat), while lower in V1 (common buckwheat), as given in Table 2. Similarly, the main effect of minerals for buckwheat milling fractions, irrespective of buckwheat varieties, showed significantly highest minerals contents in fractions of V2 (Tartary buckwheat) as compared to V1 (common buckwheat), as presented in Figure 3. The highest zinc content was observed in Tartary coarse flour (39.90 mg/100 g), while the lowest in fine flour (4.44 mg/100 g). The interaction between buckwheat variety and milling fractions for zinc contents showed that coarse flour had maximum zinc content. The rest of the fractions in both varieties ranged from 28.68 to 39.90 mg/100 g, highest in Tartary buckwheat coarse flour, and lowest in common buckwheat. Similarly, fine flour zinc contents ranged from 2.79 - 4.44 mg/100 g, highest in TBW, and lowest in CBW. The results were in accordance with previous findings of Unal *et al*. (2017) who observed more zinc in Tartary buckwheat flour (27.34 mg/100 g) as compared to in common wheat flour.

The mean values for copper of buckwheat showed a significant difference between buckwheat varieties. Significantly, the higher copper content was observed in Tartary buckwheat (2.581 mg/100 g), and the lowest mean value was observed in common buckwheat (1.462), as presented in Table 2. The highest copper content was observed in common buckwheat husk (6.781 mg/100 g), while the lowest in fine flour (0.84). The interaction between buckwheat varieties and milling fractions for copper contents revealed that husk had maximum copper content than the rest of the fractions in both varieties, ranging from 5.855 pmm and 6.781 mg/100 g, being highest in CBW husk, and lowest in TBW. In coarse flour, copper contents ranged from 0.68 - 0.90 mg/100 g, highest in TBW, and lowest in CBW. The main effect of minerals for buckwheat milling fractions, irrespective of buckwheat varieties, showed a significantly highest quantity of manganese in husk of both varieties, with the mean value ranging from 25.33 to 32.79 mg/100 g, being the highest in Tartary buckwheat (V2), while lowest in common buckwheat (V1). The higher magnesium content was found in Tartary buckwheat (354.93 mg/100 g), and the lower in common buckwheat (262.33 mg/100 g). The interaction between buckwheat varieties and milling fractions for magnesium content showed that fine flour had maximum magnesium content than the rest of all fractions in both varieties, ranging from 310.14 to 459.16 mg/100 g, being highest in Tartary buckwheat fine flour, and lowest in common buckwheat, as given in Figure 3. Buckwheat varieties also significantly affected iron contents. The results were in accordance with Unal *et al*. (2017) who reported a higher quantity of iron in TBW. Bilgicli (2009) also found higher iron, magnesium, and zinc, and lower contents of manganese and copper in buckwheat as compared to wheat flour.

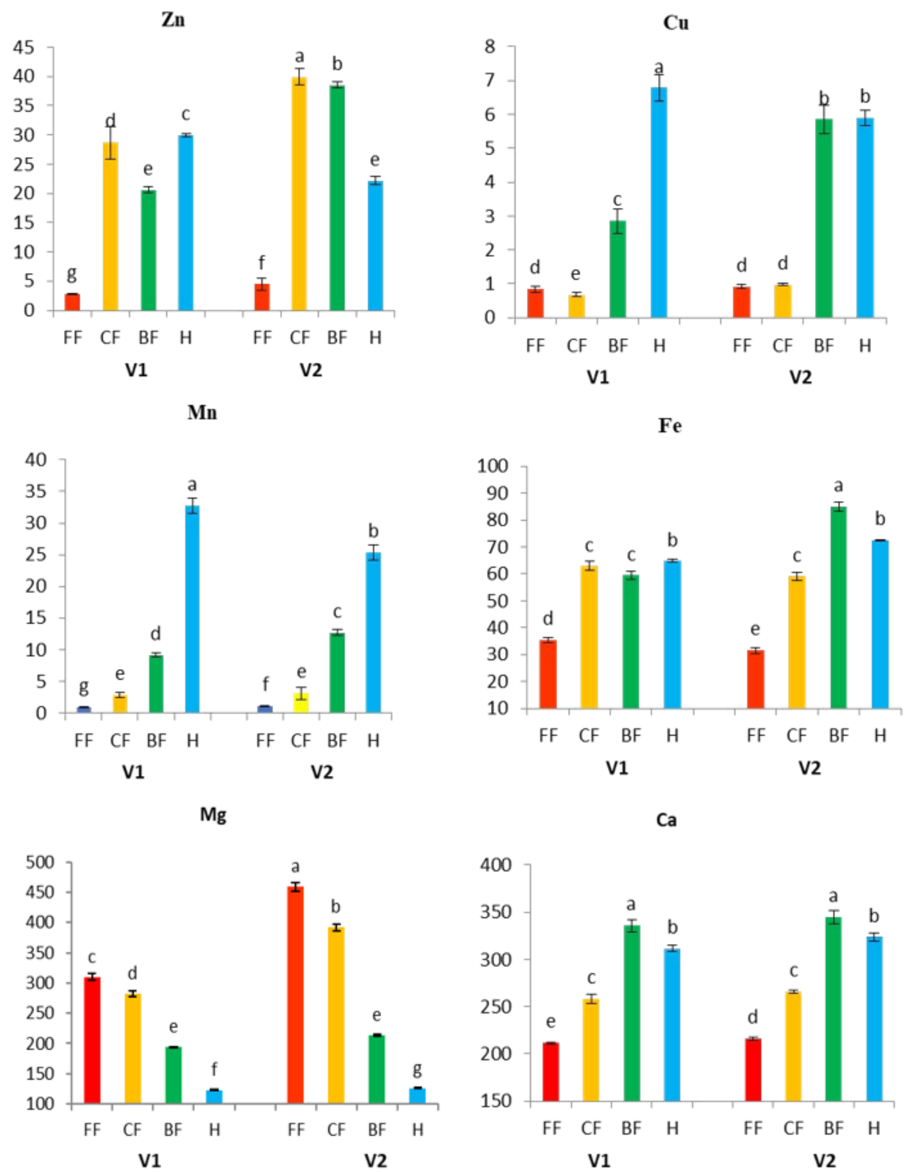

Figure 3. Mean values for varieties and milling fractions interaction for mineral contents (mg/100 g). V1: common buckwheat; V2: Tartary buckwheat; FF: fine flour; CF: coarse flour; BF: bran flour; and H: husk.

PCA analysis of buckwheat milling fractions and functional properties

Principal component analysis was performed to evaluate the relationship between the chemical parameters of different milling fractions of buckwheat varieties. The PCA plots give an overview of the similarities and differences between the samples. The location of milling fractions and varieties is demonstrated in Figure 4A, and the distribution of chemical parameters in space defined by the first and second PCA dimensions is presented in Figure 4B. The sum of PC1 and PC2 explained 81.2% among buckwheat varieties. PC1 demonstrated a variability of 47.5%, and was highly contributed by the variable common buckwheat, while PC2 showed 36.5% variability for the variable Tartary buckwheat. The results showed that the husk and bran were in different quadrant, which means that there was significant difference between husk and bran, while fine and coarse flours were in the same quadrant, which means that there was the least significant difference between fine and coarse flours of buckwheat varieties (Figure 4A).

The functional and chemical properties of different buckwheat varieties were examined and compared in terms of water absorption capacity (WAC), oil absorption capacity (OAC), swelling capacity (SC), foaming, and foaming stability (FS). Significantly, the highest mean values for water holding capacity (2.20 ml/g), oil absorption capacity

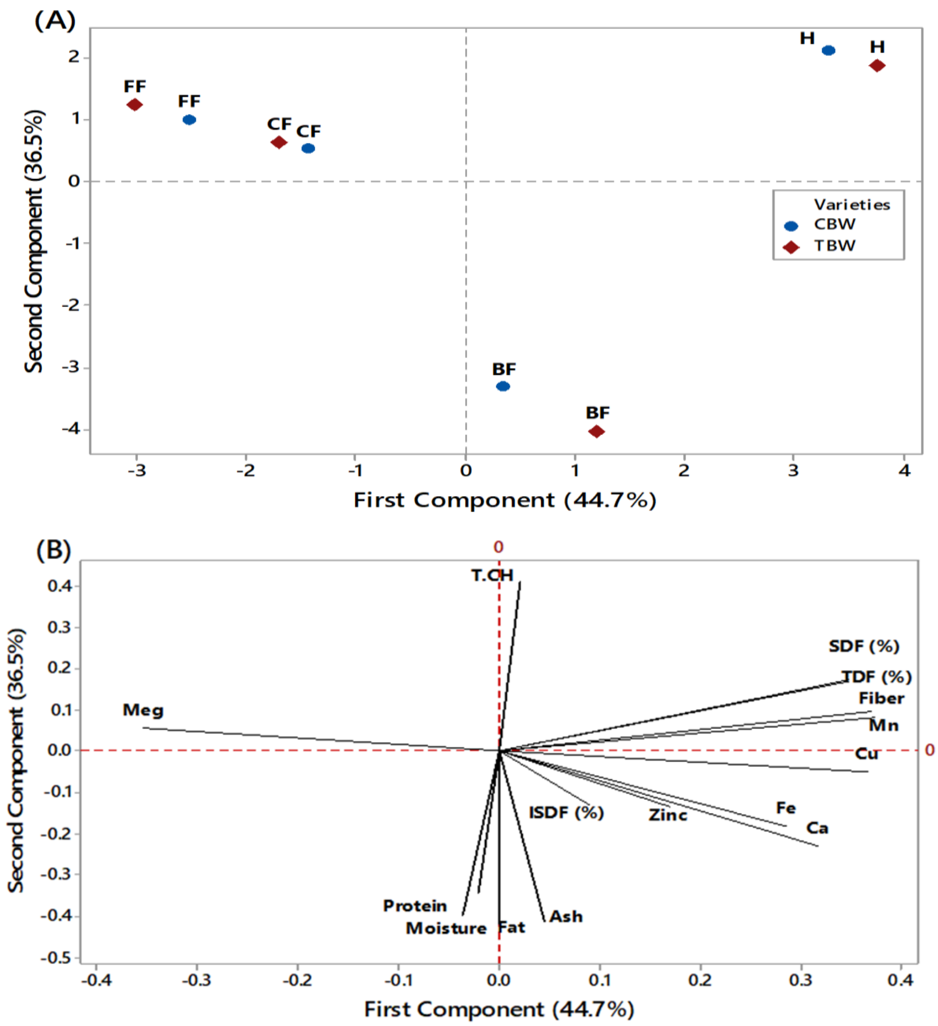

Figure 4. PCA analysis of different buckwheat milling fractions: **(a)** location of varieties and milling fractions, and **(b)** location of chemical parameters.

(1.95 ml/g), swelling capacity (19.27%), foaming capacity (16.52%), and foaming stability (56.37%) were observed, whereas the lowest values were observed in Tartary buckwheat. Similarly, the results also indicated that the highest value for all functional properties was observed in T_5 (50% buckwheat flour), while the lowest was in T_0 (100% wheat flour). Sindhu and Khatkar (2016) reported that buckwheat varieties' functional properties may differ from each other due to variations in their grain size, shape, structure, and genetic makeup (Table 3).

Conclusion

Comparative analysis between buckwheat varieties showed a higher proportion of protein, crude fibre, crude fat, and total dietary fibre in common buckwheat as compared to Tartary buckwheat. Conversely, Tartary buckwheat was found to be a good source of ash, total carbohydrate, and mineral as compared to common buckwheat. All milling fractions of both buckwheat varieties were found to be good sources of dietary fibre and mineral, but Tartary buckwheat milling fractions contained higher number of minerals as compared to common buckwheat. The present work identified variability among buckwheat varieties and milling fractions for physicochemical and nutritional traits that can be used in the supplementation of various food products. The obtained results suggested that higher chemical, nutritional, and functional properties of common buckwheat and their milling fractions emphasise their use in food products as functional ingredients.

Table 3. Comparison of functional properties of two buckwheat varieties.

Treatment	WHC (mL/g)		OAC (mL/g)		FC (%)		FS (%)		SC (mL)	
	CBW	**TBW**	**CBW**	**TBW**	**CBW**	**TBW**	**CBW**	**TBW**	**CBW**	**TBW**
T_0	2.40 ± 0.04[a]	2.22 ± 0.05[b]	1.95 ± 005[a]	1.72 ± 0.01[b]	16.52 ± 0.21[a]	14.77 ± 0.09[b]	56.34 ± 0.12[a]	51.74 ± 0.09[b]	19.27 ± 0.06[a]	17.38 ± 0.02[b]
T_1	2.67 ± 0.02[a]	2.45 ± 0.3[b]	2.26 ± 0.04[a]	1.98 ± 0.02[b]	16.78 ± 0.07[a]	14.92 ± 0.05[b]	56.68 ± 0.32[a]	51.97 ± 0.14[b]	19.46 ± 0.03[a]	17.56 ± 0.10[b]
T_2	2.95 ± 0.06[a]	2.78 ± 0.11[b]	2.67 ± 0.02[a]	2.34 ± 0.12[b]	16.98 ± 0.04[a]	15.1 ± 0.02[b]	56.95 ± 0.08[a]	52.23 ± 0.11[b]	19.78 ± 0.05[a]	17.93 ± 0.08[b]
T_3	3.25 ± 0.12[a]	3.04 ± 0.04[b]	2.85 ± 0.01[a]	2.72 ± 0.06[b]	17.33 ± 0.08[a]	15.44 ± 0.06[b]	57.26 ± 0.06[a]	52.68 ± 0.07[b]	19.97 ± 0.08[a]	18.12 ± 0.05[b]
T_4	3.68 ± 0.22[a]	3.33 ± 0.06[b]	3.12 ± 0.03[a]	2.94 ± 0.05[b]	17.56 ± 0.23[a]	15.87 ± 0.01[b]	57.58 ± 0.04[a]	52.94 ± 0.31[b]	20.28 ± 0.04[a]	18.42 ± 0.07[b]

Different lowercase superscripts in the same row of each parameter indicate significant differences ($p < 0.05$). WHC: water holding capacity; OAC: oil absorption capacity; FC: foaming capacity; FS: foaming stability; and SC: swelling capacity.

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