Comparison of some physical and chemical characteristics of buckwheat (*Fagopyrum esculentum* Moench) grains

Halil Unal, Gokcen Izli, Nazmi Izli & Baris Bulent Asik

Published online: 08 Dec 2016.

Submit your article to this journal

Article views: 3320

View related articles

View Crossmark data

Citing articles: 11 View citing articles

Taylor & Francis
Taylor & Francis Group

Comparison of some physical and chemical characteristics of buckwheat (*Fagopyrum esculentum* Moench) grains

Halil Unal[a], Gokcen Izli[b], Nazmi Izli[a] and Baris Bulent Asik[c]

[a]Department of Biosystems Engineering, Faculty of Agriculture, Uludag University, Bursa, Turkey; [b]Department of Food Engineering, Faculty of Natural Sciences, Architecture and Engineering, Bursa Technical University, Bursa, Turkey; [c]Department of Soil Science and Plant Nutrition, Faculty of Agriculture, Uludag University, Bursa, Turkey

ABSTRACT

Several physical and chemical characteristics of two buckwheat varieties (commercial buckwheat and the Güneş variety) were determined and compared in terms of linear dimensions, length, width, thickness, arithmetic and geometric mean diameters, sphericity, surface area, aspect ratio, volume, weight of thousand grains, bulk and densities, porosity, terminal velocity, angle of repose, coefficient of static friction, rupture strength, apparent colour of buckwheat varieties, ash, protein, antioxidant capacity, total phenolic content and minerals (P, K, Mg, Na, Ca, Fe, Zn, Cu, B Cr and Pb) content. Multilinear models for two buckwheat varieties were developed and presented to predict the grain volume. All properties of the varieties that provide useful data to engineers in equipment design and post-harvest technology for the buckwheat grains were statistically different. These differences could be due to the individual characteristics of the varieties, environmental and growth conditions.

Comparación de algunas características físicas y químicas de los granos de trigo sarraceno (*Fagopyrum esculentum* Moench)

RESUMEN

Se determinaron diversas características físicas y químicas de dos variedades de trigo sarraceno (variedad comercial de trigo sarraceno y Güneş), además se compararon en términos de dimensión linear, alargada, anchura, espesor, promedio de diámetro aritmético y geométrico, esfericidad, área de superficie, relación de aspecto, volumen, peso de mil granos, grueso y densidad, porosidad, velocidad terminal, ángulo de caída, coeficiente de fricción estática, fuerza de ruptura, color aparente de las variedades de trigo sarraceno, ceniza, proteína, capacidad antioxidante, contenido total fenólico y minerales (P, K, Mg, Na, Ca, Fe, Zn, Cu, B Cr y Pb). Se desarrollaron modelos multilineares de las dos variedades de trigo sarraceno y se presentaron para predecir el volumen del grano. Todas las propiedades de las dos variedades, que produjeron datos útiles a los ingenieros en el diseño de equipos y tecnologías postcosecha para los granos de trigo sarraceno, fueron diferentes. Estas diferencias podrían ser debido a las características individuales de estas variedades, además de sus condiciones ambientales y de crecimiento.

Introduction

Buckwheat is a dicotyledonous plant belonging to the genus *Fagopyrum* of the family *Polygonaceae*. Although not a cereal grain, buckwheat is usually handled and classed with other cereals because of the similarity in cultivation and utilization. Buckwheat originates from Asia and today is widely planted worldwide. Two main buckwheat species have been commonly produced and consumed: common buckwheat (*Fagopyrum esculentum* Moench) and tartary buckwheat (*Fagopyrum tataricum* Gaertn). The high nutritional value of this important alternative crop is mainly due to its balanced amino acid composition (rich in lysine and arginine), the high biological quality of its protein, and its high content of minerals (P, Fe, Zn, K and Mg) and biologically active compounds (Wijngaard & Arendt, 2006). Furthermore, buckwheat can be safely consumed by people with coeliac disease because it contains no gluten (Bonafaccia, Marocchini, & Kreft, 2003; Christa & Soral-Smietana, 2008; Li & Zhang, 2001; Mazza & Oomah, 2005). According to 2014 data, the world cultivation area of buckwheat is 2,008,694 ha and its production quantity is 2,056,607 tonnes (FAO, 2014).

The most serious problem in buckwheat production is damage by birds at maturity and after harvest when the crop is left to dry in the field. Rats are also sometimes destructive of buckwheat crops. When most (at least 75%) of the seed is mature and most of the leaves have yellowed and dropped, the crop is harvested by mowing; the stems are then bundled and placed in heaps to dry. If the leaves are not dried sufficiently, they may stick together, causing problems for threshing. Combine harvesting is practised in more industrialized countries. Seed yields normally vary from 0.6–2.5 t/ha, but 3 t/ha are occasionally obtained. Research has not succeeded in increasing the yields of buckwheat; they remain approximately the same as they were a century ago. Thorough drying to moisture content below 16% facilitates the removal of straw fragments and immature seed. Small farmers usually thresh manually. Mechanical threshing requires careful regulation of the threshing cylinder to avoid

damaging the seed (Brink & Belay, 2006). Processing, which was formerly done by individual households or in small village workshops, begins with hulling and separation of the hulls from the groats, followed by milling. At present, most buckwheat is processed in factories that apply advanced food technology to make specific foodstuffs (Campbell, 1997; Grubben & Siemonsma, 1996).

Because buckwheat undergoes a series of unit operations before reaching the final step of processing, the value-added products development designs and fabrication of particular equipment and structures used in unit operations such as handling, transport, processing and storage and assessing product quality require knowledge of its physical, chemical and nutritional properties (Patel, Pradhan, & Naik, 2011). Knowledge of the physical, chemical and nutritional properties of buckwheat grain are essential for the design of equipment for drying, cleaning, grading, storage and for the creation of value-added products. The importance of physical properties for designing post-harvest processing equipment has been emphasized earlier (Pradhan, Naik, Bhatnagar, & Vijay, 2009; Unal, Isık, Izli, & Tekin, 2008). In recent years, the physical, chemical and nutritional characteristics of various seeds such as buckwheat (Inglett, Rose, Chen, Stevenson, & Biswas, 2010; Kaliniewicz, Markowski, Anders, & Jadwisienczak, 2015; Kan, 2011; Parde, Johal, Jayas, & White, 2003; Steadman, Burgoon, Lewis, Edwardson, & Obendorf, 2001), flaxseed Coskuner & Karababa, 2007), vetch (Yalçın & Özarslan, 2004), lentil (Amin, Hossain, & Roy, 2004; Gharibzahedi, Ghasemlou, Razavi, Jafarii, & Faraji, 2011), sainfoin (Altuntas & Karadag, 2006), cowpea (Kabas, Yilmaz, Ozmerzi, & Akinci, 2007), wheat (Al-Mahasneh, Taha, & Rababah, 2007; Kalkan & Kara, 2011), chia (Ixtaina, Nolasco, & Tomás, 2008), mung bean (Unal et al., 2008), sorghum (Mwithiga & Sifuna, 2006), rapeseed (Unal, Sincik, & Izli, 2009) and sunflower (Ilori, Oradugba, & Raji, 2011) have been studied. As far as we know, there is no detailed study available regarding to the physical, chemical and mineral content characteristics of buckwheat grown in Turkey. In this respect, the aim of this study was to compare the physical as well as the chemical characteristics of Güneş variety that grown in Turkey with commercial buckwheat grown in Kazakhstan that important producer and exporter of buckwheat which could be of great interest for nutritional quality and food processing.

Materials and methods

Raw materials

Two different common buckwheat (*Fagopyrum esculentum* Moench) grain samples were used in this study. The Güneş variety was produced by the Bahri Dagdas International Agricultural Research Institute, Konya, Turkey. The seeds were harvested in 2014 from experimental plots. Samples of commercial buckwheat seed produced in Kazakhstan were used for comparison. The seeds were cleaned manually to remove all extraneous materials and broken seeds.

Determination of size properties

To determine the average size of the buckwheat seeds, 100 grains were randomly chosen and their three linear dimensions, namely, length (L), width (W) and thickness (T), were measured using a digital vernier calliper (Mitutoyo, CD-15CP,

England) with an accuracy of 0.01 mm. The arithmetic mean diameter (D_a), geometric mean diameter (D_g) and sphericity (ϕ) of the samples were calculated using the following equations (Gharibzahedi et al., 2011; Mohsenin, 1986):

$$D_a = (L + W + T)/3 \tag{1}$$

$$D_g = (LWT)^{(1/3)} \tag{2}$$

$$\emptyset = (D_g/L)100. \tag{3}$$

The surface area A_s of the seed was found by analogy with a sphere of the same geometric mean diameter using the following relationship:

$$A_s = \pi D_g^2. \tag{4}$$

The aspect ratio R_a of the grain was calculated using the following formula (Ixtaina et al., 2008):

$$R_a = W/L. \tag{5}$$

The volume of the individual buckwheat seeds was calculated from the principal dimensions measured earlier. For ellipsoidal-shaped materials such as buckwheat grains, the volume (V) is given (Mohsenin, 1986) by the following equation:

$$V = \frac{\pi}{6}(LWT), \tag{6}$$

where D_a is the arithmetic mean diameter (mm), D_g is the geometric mean diameter (mm), L is the length (mm), W is the width (mm), T is the thickness (mm), ϕ is the sphericity (%), A_s is the surface area (mm^2), R_a is the aspect ratio (%) and V is the seed volume (mm^3).

Determination of gravimetrical and aerodynamic properties

The weight of thousand buckwheat seeds was determined using an electronic balance weighing to 0.001 g accuracy (Chyo, MP-300, Kyoto, Japan).

The average bulk density of the buckwheat seed was determined using the standard test weight procedure. This involved filling a 500 ml container with seed from a height of 150 mm at a constant rate and weighing the content. The average true density was determined using the toluene displacement method. The volume of toluene displaced was found by immersing a weighed quantity of buckwheat seed in toluene (Mohsenin, 1986; Unal et al., 2008).

The porosity of the grain depends on its bulk and true densities. The method of Mohsenin (1986) was used to calculate the grain porosity (ε):

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right)x100, \tag{7}$$

where ε is the porosity (%) and ρ_b and ρ_t are the bulk and true densities, respectively, in kg/m^3.

The terminal velocity of the buckwheat samples was measured using an air column. For each test, a sample was dropped into the airstream from the top of the air column, and air was blown up the column to suspend the material in the airstream. The minimum air velocity that kept the grain in suspension was recorded using a digital anemometer (Thies Clima, Göttingen, Germany) with a sensitivity of

0.1 m/s (Mohsenin, 1986; Unal et al., 2009). Twenty determinations were made for each sample.

Determination of repose angle and frictional properties

The angle of repose (θ) was determined using a hollow cylindrical mould 100 mm in diameter and 150 mm in height. The cylinder was placed on a wooden table, filled with buckwheat grains and raised slowly until a cone of grains was formed. The diameter (D) and height (H) of the cone were recorded. The reported value is the mean of 20 replications. The angle of repose was calculated from the following relationship (Amin et al., 2004; Unal et al., 2008):

$$\theta = \tan^{-1}\left(\frac{2H}{D}\right). \tag{8}$$

The coefficient of static friction was measured using a friction device with aluminium, rubber and stainless steel surfaces. For this measurement, the material was placed on the surface and then gradually raised by the screw. The vertical and horizontal height values were read from the ruler when the material began to roll over the surface and the nursing the tangent value of the angle so that the coefficient of friction was found (Pradhan et al., 2009; Unal et al., 2009). Twenty replications were made for each sample.

Determination of rupture strength properties

The rupture force of the buckwheat samples was tested to determine the magnitude of the force required to break the seed when the grains are arranged in a layer, the thickness of which is one axial dimension. Rupture forces were measured using a dynamometer (Sundoo, 50 SH, accuracy 0.01 N, China) with 50 N capacity. The loading velocity of the dynamometer was constant at 35 mm/min during the measurements. For each test, a single grain was placed on its thickness axes on a flat steel washer and compressed with a 12 mm diameter probe.

Determination of colour properties

The colour of the buckwheat samples was determined by measuring the L^* (lightness: 100, white; 0, black), a^* (+, red; −, green) and b^* (+, yellow; −, blue) values of the samples using a HunterLab Color Analyzer (HunterLab MSEZ-4500 L, Virginia, USA). The instrument was calibrated using standard black and white surface plates, and five measurements were performed on each sample. The Chroma (C) (Equation (9)) and Hue angle (α) (Equation (10)) values were calculated and used to describe the visual colour appearance of the sample (Bernalte, Sabio, Hernández, & Gervasini, 2003) according to the following equations:

$$C = \sqrt{(a^*)^2 + (b^*)^2} \tag{9}$$

$$\alpha = \tan^{-1}(b^*/a^*). \tag{10}$$

Chemical analysis

The content of total solids of the buckwheat samples was determined by oven (ED115 Binder, Tuttlingen, Germany) drying at 130 ± 5°C until a constant weight was achieved (AACC method 44–19). Ash content was determined by AACC method 08–01 in a muffle furnace (MF100 Nüve, Ankara, Turkey) at 550°C to complete burning of all organic matter. Grain protein content was determined by the Kjeldahl method (AACC method 46–12) and calculated using the conversion factor 6.25 (AACC, 2000).

One gram of each buckwheat sample was extracted with 4.5 ml methanol/water (80/20 v/v) using a mechanical shaker (Biosan OS-20, Latvia) at 140 rpm for 2 h at room temperature. The mixture was then centrifuged at 10,000 rpm for 15 min (Sigma 3K30, UK). After the clear supernatant was removed, the residue was re-extracted with an additional 4.5 ml solvent, and the supernatants were combined. Sample extracts used for measurement of antioxidant capacity and total phenolic content were obtained by filtering the supernatants through 0.45-μm PTFE syringe filters.

The antioxidant capacity of the buckwheat extracts was determined using the DPPH (2.2-diphenyl-1-picrylhydrazyl) free radical scavenging method as described by Vollmannova et al. (2013) with a minor modification. An aliquot (0.1 ml) of the sample extract (or pure methanol as blank) was mixed with 3.9 ml of 25 mM methanolic solution of the DPPH radical and vortexed (WiseMix VM-10, Daihan, Korea) for 15–30 s. The reaction was allowed to proceed in the dark at room temperature for 30 min, and the absorbance at 515 nm was then measured with a UV/VIS spectrophotometer (Shimadzu 1800, Kyoto, Japan). Trolox was used as a reference standard, and antioxidant capacity was expressed as μmol Trolox equivalents (TE) per g dry weight of sample according to the calibration curve ($y = 116.5x + 10.508$, $R^2 = 0.9917$).

The total phenolic content of the extracts was determined using the Folin–Ciocalteu method as described by Vollmannova et al. (2013) with a minor modification. Diluted buckwheat extracts (1 ml) were mixed with 2.5 ml Folin–Ciocalteu reagent and 5 ml deionized H_2O in 50-ml volumetric flasks and vortexed (WiseMix VM-10, Daihan, Korea) for 15 s. After the 3-min incubation, 7.5 ml of 20% Na_2CO_3 was added and the mixture was diluted to 50 ml with deionized H_2O. The sample was then incubated in the dark for 2 h at room temperature, and its absorbance at 765 nm was determined using a spectrophotometer (Shimadzu UV/VIS 1800, Kyoto, Japan). Methanol was used as the blank. The results are expressed as mg gallic acid equivalent (GAE) per 100 g dry weight of sample ($y = 0.0793x + 0.0243$, $R^2 = 0.999$).

The mineral contents of the samples were analysed as described by Kacar (2014). The samples (0.20 g) were digested with a mixture of HNO_3/H_2O_2 (3:4 v/v) using a microwave oven (Berghof MWS 2 DAP 60 K) in a tree-step digestion programme at 180ºC over 20 min. The final volume was adjusted to 50 ml. The P content of the samples was determined colorimetrically using the metavanadate method, which is based on the formation of a yellow vanadomolybdophosphoric complex using a PG Instruments T60 Split Beam UV/VIS model spectrophotometer. Na, K and Ca were determined with an Eppendorf Elex 6361 model flame photometer. Fe, Cu, Zn, Mn and B in the extracts were analysed using inductively coupled plasma optical emission spectrometry (ICP-OES) (Perkin Elmer OPTIMA 2100 DV). The samples were analysed in three replications.

Statistical analysis

Descriptive statistics were obtained on the two buckwheat samples. The differences between the mean values were analysed using the JMP (Version 7.0, SAS Institute Inc., Cary, NC, USA) software program. The means were compared using the least significant difference (LSD) test at 5% and 1% levels of significance. Mean values and standard deviations are reported.

Results and discussion

Size distribution and geometrical properties of buckwheat samples

The buckwheat grains presented three unequal semi-axes; they may, therefore, be described as triangular in shape. Table 1 shows the size distribution of the buckwheat samples. The longitudinal dimension (L) of the grains ranged from 3.11 to 7.33 mm. The majority of buckwheat grains (approximately 57% by number of both varieties) were medium-sized (3.60 < L < 6.52 mm). The frequency distribution curves of length (L), width (W) and thickness (T) values of the Güneş variety and of commercial buckwheat grains both showed a trend towards a normal distribution (Figure 1). The average grain widths (W) were 2.20–4.90 mm and 2.73–4.22 mm for the Güneş variety and for commercial buckwheat, respectively. The average grain thicknesses (T) were 2.87–4.52 mm and 2.43–3.82 mm for the Güneş variety and for commercial buckwheat, respectively (Table 1). In general, grains of the Güneş variety were longer, wider and thicker than the commercial buckwheat grains. A similar trend was reported by Kaliniewicz et al. (2015) for buckwheat of the Panda variety. Sieves can now be designed within a range for separation of the seeds from the chaff. Kaliniewicz et al. (2015) reported that grains of buckwheat are oval in shape and that the mean grain L, W and T values are 6.0, 4.1 and 3.6 mm (at 12.5% moisture content d.b.), respectively. The mean grain dimensions of commercial buckwheat determined in this study are lower than the dimensions reported by Kaliniewicz et al. (2015).

The dimensions of buckwheat grains were observed to fall within the same range as the dimensions of vetch and green wheat seeds (Al-Mahasneh et al., 2007; Yalçın & Özarslan, 2004) and to be greater than those of red lentil seeds (Gharibzahedi et al., 2011) and smaller than those of buckwheat grains (Kaliniewicz et al., 2015).
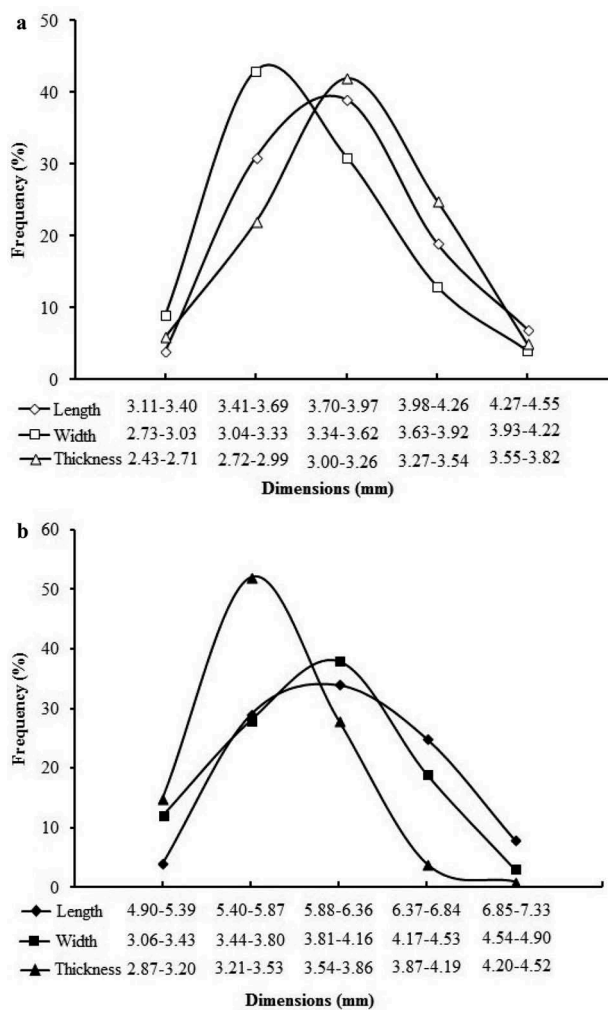

Figure 1. Frequency distribution curves of buckwheat grain dimensions: (a) commercial buckwheat; (b) Güneş variety.

Figura 1. Curvas de distribución de frecuencia de las dimensiones de las dimensiones de los granos de trigo sarraceno: (a) trigo sarraceno comercial; (b) variedad Güneş.

The physical characteristics of the two buckwheat samples are presented in Table 2. Most of the physical characteristics of the two samples, with the exception of the thousand grain weight and the terminal velocity, were statistically significantly different at the probability level $P < 0.05$. These results can be attributed to the individual properties of the buckwheat species and the environmental

Table 1. Size distribution of buckwheat grains based on length (L), width (W) and thickness (T).

Tabla 1. Distribución del tamaño de los granos de trigo sarraceno en base a la alargada (L), la anchura (W) y el espesor (T).

Samples	Size category			
	Ungraded	Small	Medium	Large
Length (L)				
Commercial buckwheat	3.11–4.55 (100)	3.11–3.59 (26)	3.60–4.07 (57)	4.08–4.55 (17)
Güneş variety	4.90–7.33 (100)	4.90–5.71 (21)	5.72–6.52 (57)	6.53–7.33 (22)
Width (W)				
Commercial buckwheat	2.73–4.22 (100)	2.73–3.23 (30)	3.24–3.74 (63)	3.75–4.22 (7)
Güneş variety	2.20–4.90 (100)	2.20–3.67 (31)	3.68–4.28 (58)	4.29–4.90 (11)
Thickness (T)				
Commercial buckwheat	2.43–3.82 (100)	2.43–2.89 (12)	2.90–3.35 (71)	3.36–3.82 (17)
Güneş variety	2.87–4.52 (100)	2.87–3.42 (49)	3.43–3.97 (51)	3.98–4.52 (3)

Range and frequency (%) in parenthesis.

Rango y frecuencia (%) en paréntesis.

Table 2. Physical and mechanical characteristics of buckwheat grains.

Tabla 2. Características físicas y mecánicas de los granos de trigo sarraceno.

Characteristics	Number of replications	Commercial buckwheat	Güneş variety
Moisture (d.b.)	3	6.46 ± 0.26 b	9.46 ± 0.36 a
Length (mm)	100	3.80 ± 0.28 b	6.14 ± 0.49 a
Width (mm)	100	3.36 ± 0.27 b	3.87 ± 0.35 a
Thickness (mm)	100	3.14 ± 0.26 b	3.46 ± 0.26 a
Arithmetic mean diameter (mm)	100	3.43 ± 0.22 b	4.49 ± 0.29 a
Geometric mean diameter (mm)	100	3.41 ± 0.23 b	4.34 ± 0.28 a
Sphericity (%)	100	89.94 ± 4.98 a	70.79 ± 4.46 b
Aspect ratio (%)	100	88.50 ± 7.02 a	63.25 ± 6.44 b
Seed volume (mm^3)	100	21.19 ± 4.29 b	43.44 ± 8.48 a
Surface area (cm^2)	100	36.78 ± 4.91 b	59.33 ± 7.70 a
1000-grain weight (g)	20	19.98 ± 1.21 Ns	21.74 ± 0.81 Ns
Bulk density (kg/m^3)	20	833.7 ± 48.4 a	598.6 ± 27.5 b
True density (kg/m^3)	20	1269.3 ± 138.5 a	1077.1 ± 94.2 b
Porosity (%)	20	33.9 ± 3.9 b	44.2 ± 3.3 a
Rupture force (N)	20	27.59 ± 1.33 a	18.72 ± 1.84 b
Angle of repose (°)	20	22.03 ± 1.85 b	25.47 ± 1.51 a
Terminal velocity (m/s)	20	2.98 ± 0.48 Ns	3.11 ± 0.45 Ns
Coefficient of static friction on			
Rubber	20	0.462 ± 0.022 A	0.474 ± 0.022 A
Aluminium	20	0.431 ± 0.023 B	0.442 ± 0.031 B
Stainless steel	20	0.396 ± 0.023 Cb	0.438 ± 0.035 Ba

Different letter in the same line indicate significant differences ($P < 0.05$).
Letters a and b indicate the statistical difference in rows.
Letters A–C indicate the statistical difference in columns for coefficient of static friction.
Ns: Not significant

Las distintas letras en la misma línea indican diferencias significativas ($P < 0,05$).

Las letras a y b indican diferencias estadísticas en las filas.

Las letras A–C indican diferencias estadísticas en las columnas para el coeficiente de fricción estática.

Ns: No es significativo

and growing conditions. For the Güneş variety, the mean grain L, W and T values were 6.14, 3.87 and 3.46 mm, respectively, whereas the corresponding values for commercial buckwheat grains were 3.80, 3.36 and 3.14 mm. The Güneş variety grains were significantly ($P < 0.05$) longer, broader and thicker than commercial buckwheat. The dimensional properties (length, width, thickness and arithmetic and geometric mean diameters) and shapes (sphericity and aspect ratio) of the two buckwheat samples differed significantly ($P < 0.05$). The arithmetic (D_a) and geometric mean diameters (D_g) of grains of the Güneş variety were 4.49 and 4.34 mm, respectively; these values were 3.43 and 3.41 mm, respectively, for commercial buckwheat grains. The arithmetic and geometric diameters were smaller than the length and greater than the width and thickness. Baümler, Cuniberti, Nolasco, and Riccobene (2006), Unal et al. (2008), Ashtiani Araghi, Sadeghi, and Hemmat (2010), Gharibzahedi et al. (2011), Ilori et al. (2011) and Kaliniewicz et al. (2015) found similar results for safflower, mung bean, rough rice, red lentil, Mexican sunflower and buckwheat seeds, respectively. The importance of these and other characteristic axial dimensions for determining aperture size and other parameters in machine design have been discussed by Mohsenin (1986).

The sphericities of the Güneş variety and of commercial buckwheat were found to be 70.79% and 89.94%, respectively, whereas the aspect ratios of the buckwheat grains were 63.3% and 88.5%, respectively (Table 2); these parameters were significantly different ($P < 0.05$) in the two types

of grains. The commercial sample showed more sphericity than the Güneş variety. The values of the dimensions and shape parameters indicate that the Güneş variety produces larger-sized grains than commercial buckwheat. However, the commercial grain was more spherical in shape. The calculated sphericity value of the Güneş variety was closer to the reported average sphericity value of 74.7% for buckwheat Panda variety reported by Kaliniewicz et al. (2015). Considering the low aspect ratio (which relates the grain's width to its length) and sphericity values, it may be deduced that Güneş variety grains would tend to slide on their flat surfaces rather than roll. The tendency to roll or slide is very important in the design of hoppers because most flat grains slide more easily than spherical grains, which roll on structural surfaces. Furthermore, the shape indices obtained in this study indicate that the buckwheat grain may be treated as a scalene ellipsoid for analytical prediction of its drying behaviour.

The volume and surface area of the buckwheat samples were found to differ significantly ($P < 0.05$). The volume of a single grain (V) was calculated by Equation (6) and ranged from 21.2 to 43.4 mm^3. The mean volume of Güneş variety grains (43.4 mm^3) was significantly ($P < 0.05$) greater than that of commercial buckwheat grains. A similar trend was observed for the surface area of the grains; the surface area of the Güneş variety (59.3 mm^2) was significantly ($P < 0.05$) greater than that of commercial buckwheat (36.8 mm^2).The importance of these and characteristic axial dimensions for determining aperture size and other parameters in machine design have been discussed by Mohsenin (1986).

Gravimetric and aerodynamic properties of buckwheat grains

The thousand seed weight values obtained for Güneş variety (21.74 g) were greater than those of commercial buckwheat (19.98 g) (Table 2), but the difference was not statistically significant ($P > 0.05$). When the seed weight in this study was compared with previous studies, the mean weight of the buckwheat was within normal limits (Campbell, 1997).

The bulk density of the buckwheat seeds ranged from 598.6 to 833.7 kg/m^3 (Table 2); the bulk density of the Güneş variety was significantly lower ($P < 0.05$) than that of the commercial buckwheat. The lower bulk density of the Güneş variety (598.6 kg/m^3) may be attributed to its larger grain size. This parameter is important because it determines the capacity of storage and transport systems. A decrease in bulk density is an indication of reduced overall quality of the grain. Factors that commonly affect bulk density are insect infestation, the presence of excessive foreign matter and high moisture content (WFP, 2006). The bulk density results obtained here are similar to those reported by Parde et al. (2003) for the Koto, Koban and Manisoba buckwheat varieties and by Agri-Facts (2001) for the Mancan and Manor varieties. The true densities of the Güneş variety and of commercial buckwheat varied from 1077.1 to 1269.3 kg/m^3, and the two samples differed significantly ($P < 0.05$) in true density. The true density indicates that the grains are heavier than water, and this characteristic can be used to design separation and cleaning processes. The porosity of the grains ranged from 33.9% (commercial buckwheat) to 44.2% (Güneş variety); the Güneş variety was significantly higher in porosity ($P < 0.05$). The average porosity of the

buckwheat samples was lower than that of vetch seed (Yalçın & Özarslan, 2004), green wheat (Al-Mahasneh et al., 2007) and Mexican sunflower (Ilori et al., 2011) and higher than that of lentil (Amin et al., 2004) and chia seed (Ixtaina et al., 2008); however, it fell within the same range of porosity as three rapeseed cultivars (Unal et al., 2009), two rice cultivars (Ashtiani Araghi et al., 2010) and wheat varieties (Kalkan & Kara, 2011). Porosity depends on the geometry and surface properties of the material. Knowledge of the per cent voids of an unconsolidated weight of material such as grain, hay and other porous materials is often needed in airflow and heat flow studies (Mohsenin, 1986). This property allows fluid to pass through the bulk, and it is useful in the calculation of rates of aeration, cooling, drying and heating and in the design of heat exchangers and similar equipment (Asoegwu, Ohanyere, Kanu, & Iwueke, 2006).

There was no significant difference between the two samples in terminal velocity ($P > 0.05$). Terminal velocity values ranged from 2.98 to 3.11 m/s, and the highest terminal velocity value was found for the Güneş variety. At any moisture level, the terminal velocity of the buckwheat sample was lower than that of vetch seed (Yalçın & Özarslan, 2004) but almost the same as those of cowpea (Kabas et al., 2007), rapeseed (Unal et al., 2009) and Mexican sunflower seed (Ilori et al., 2011). The differences in the results could be due to the increase in mass of the individual seed per unit when their frontal areas were presented to the airstream to suspend the grain.

Rupture strength properties of buckwheat grains

The rupture strengths of the samples were investigated and are given in Table 2. The rupture properties of the buckwheat samples showed statistically significant differences ($P < 0.05$), with commercial buckwheat proving to be harder than the Güneş variety. The mean values of the rupture force for the commercial and Güneş variety were 27.6 N and 18.7 N, respectively. This difference may be attributed to the physical properties of the buckwheat grains. The results are similar to those reported by Altuntas and Karadag (2006)

for sainfoin seed, by Kalkan and Kara (2011) for wheat seed, by Mwithiga and Sifuna (2006) for sorghum seed and by Baümler et al. (2006) for safflower seed.

Correlation relationship of buckwheat grains

As seen in Table 3, most of the correlation coefficients of the measured parameters of the buckwheat grains, including sizes (L, W, T, D_a and D_g), sphericity (ϕ), surface area (A_s), aspect ratio (R_a) and volume (V), were significant at the 5% and 1% levels. Grain volume was closely related to grain arithmetic (D_a) and geometric mean diameter (D_g) but was less associated with grain sphericity. Thus, the best dimensions by means of which to estimate the volume of the buckwheat grain are the arithmetic and geometric mean diameters. Furthermore, the best dimensions by means of which to estimate grain volume for the Güneş variety and commercial buckwheat were found to be surface area, aspect ratio and the arithmetic–geometric mean diameters of the grains, respectively.

To investigate the relationship between grain volume (V) and dimensional properties such as length (L), width (W), thickness (T), arithmetic mean diameter (D_a), geometric mean diameter (D_g), sphericity (ϕ), surface area (A_s) and grain aspect ratio (R_a) a multiple linear regression model was fitted to the experimental data. Based on the results of stepwise regression analysis, the best-fit model yielded the following equations:

$$\text{(Commercial buckwheat)} V = 24.3 - 3.00L - 5.08W$$
$$- 2.10T + 0.64D_a - 7.94D_g$$
$$- 0.176\emptyset + 1.68A_s + 0.123R_a$$
$$- 7.94D_g - 0.176\emptyset + 1.68A_s$$
$$+ 0.123R_a \rightarrow \left(R^2 = 1\right) \quad (11)$$

$$\text{(Güneş variety)} V = 53.1 - 4.05L - 9.55W - 3.64T + 2.36D_a$$
$$- 15.1D_g - 0.486\emptyset + 2.19A_s + 0.382R_a$$
$$- 0.486\emptyset + 2.19A_s + 0.382R_a \rightarrow \left(R^2 = 1\right) \quad (12)$$

Table 3. Correlation coefficients among seed dimensions (L, W and T), sphericity (ϕ), surface area (A_s), aspect ratio (R_a) and seed volume (V) of buckwheat grains.

Tabla 3. Coeficientes de correlación entre las dimensiones de las semillas (L, W y T), la esfericidad (ϕ), el área de superficie (A_s), la relación de aspecto (R_a) y el volumen de la semilla (V) de los granos de trigo sarraceno.

Species		W	T	D_a	D_g	ϕ	A_s	R_a	V
Commercial buckwheat[a]									
	L	0.436**	0.327*	0.713**	0.676**	−0.503**	0.674**	−0.469**	0.672**
	W	1	0.899**	0.924**	0.937**	0.528**	0.939**	0.588**	0.938**
	T		1	0.877**	0.899**	0.633**	0.897**	0.592**	0.891**
	D_a			1	0.998**	0.245[Ns]	0.997**	0.268*	0.993**
	D_g				1	0.294*	0.999**	0.314*	0.995**
	ϕ					1	0.294*	0.975**	0.291*
	A_s						1	0.315*	0.999**
	R_a							1	0.315*
Güneş variety[a]									
	L	0.275*	0.257[Ns]	0.758**	0.631**	−0.603**	0.629**	−0.531**	0.625**
	W	1	0.825**	0.813**	0.889**	0.569**	0.887**	0.666**	0.882**
	T		1	0.785**	0.869**	0.567**	0.872**	0.526**	0.875**
	D_a			1	0.984**	0.061[Ns]	0.983**	0.129[Ns]	0.979**
	D_g				1	0.235[Ns]	0.999**	0.293**	0.996**
	ϕ					1	0.236*	0.970**	0.237[Ns]
	A_s						1	0.292*	0.999**
	R_a							1	0.289*

[Ns]: not significant; [a] 98 degrees of freedom; * Significant level at 5%; ** Significant level at 1%.
[Ns]: No es significativo; [a] 98 grados de libertad; * nivel de significancia a 5%; ** nivel de significancia a 1%.

These models have been analysed and show that the parameters *L*, *W*, *T*, *D_a*, *D_g*, *ϕ*, *A_s* and *R_a* in the both samples explain 100% of the total variation in the grain volume.

Angle of repose and frictional properties of buckwheat grains

The angle of repose (*θ*) of the buckwheat samples ranged from 22.0° (commercial grain) to 25.5° (Güneş variety) (Table 2). Significant differences (*P* < 0.05) existed in the angle of repose for the two varieties of grains. The commercial buckwheat had a higher angle of repose than the Güneş variety. This confirms the fact that the seeds are spherical or oval in shape, enabling the grains to roll. The measured angle of repose was considerably lower than that reported for rough rice (Ashtiani Araghi et al., 2010), mung bean (Unal et al., 2008) and lentil (Amin et al., 2004) and similar to that reported for buckwheat grain (Parde et al., 2003) and sorghum seed (Mwithiga & Sifuna, 2006). This may be due to the smoother surface or shape factor of buckwheat that imposes resistance to the seeds in sliding on one another. The surfaces of rough rice, mung bean and lentil seed may be comparatively rougher or have lower sphericity, thus enabling them to slide against one another more readily, resulting in a greater angle of repose.

The coefficient of static friction for the buckwheat grain on rubber, aluminium and stainless steel surfaces was determined (Table 2). The highest coefficient of static friction (0.474 for Güneş and 0.462 for commercial buckwheat) was obtained on rubber, followed by aluminium (0.442 and 0.431, respectively) and stainless steel surfaces (0.438 and 0.396, respectively). The Güneş variety had the highest coefficient of friction for all surfaces, but the differences between the samples on the rubber and aluminium surfaces were not significant (*P* > 0.05). However, there were highly significant differences on the stainless steel surface (*P* < 0.05). The static frictions of buckwheat grains were observed to lie within the same range as those of lentil, green wheat and cowpea seeds (Al-Mahasneh et al., 2007; Amin et al., 2004; Kabas et al., 2007); they were higher than those of mung bean (Unal et al., 2008) and buckwheat cultivars (Parde et al., 2003) and lower than that of flaxseed (Coskuner & Karababa 2007). Knowledge of the static coefficient of friction is important for designing storage bins, hoppers, pneumatic conveying systems, threshers, forage harvesters and similar containers (Mohsenin, 1986). For this reason, the static coefficient of friction, which affects the design of the processing machine, was measured on three different contacting materials (rubber, aluminium and stainless steel).

Colour characteristics of buckwheat grains

The colour parameters *L**, *a**, *b**, *C* and *α* of the buckwheat samples are shown in Table 4. Significant differences (*P* < 0.05) in the overall colour values of the two buckwheat seeds were observed. The commercial buckwheat sample showed higher values of *L**, *a**, *b** and *C* and a lower value of *α* compared to the Güneş variety. The *L** value (42.41) determined for commercial buckwheat indicated that it was lighter in colour than the Güneş variety. The *a** and *b** values were positive for both samples, indicating that they were more red than green and more yellow than blue. The colour

Table 4. Colour parameters of buckwheat grains[a].

Tabla 4. Parámetros de color de los granos de trigo sarraceno[1].

Parameter	Commercial buckwheat	Güneş variety
*L**	42.41 ± 0.95 a	36.08 ± 1.83 b
*a**	11.45 ± 0.23 a	7.35 ± 0.12 b
*b**	21.10 ± 0.44 a	14.66 ± 0.37 b
C	24.01 ± 0.49 a	16.40 ± 0.38 b
α	61.53 ± 0.13 b	63.40 ± 0.23 a

[a]Different letter in the same line indicate significant differences (*P* < 0.05).
[1]Las distintas letras en la misma línea indican diferencias significativas (*P* < 0,05).

values of the studied buckwheat samples were in agreement with the *L**, *a** and *b** values determined by Ikeda, Yamashita, Kusumoto and Kreft (2005); these values ranged from 39.0 to 59.2, 10.6 to 11.2 and 12.7 to 24.0, respectively, for buckwheat seeds obtained from Japan, Europe and Canada.

Chemical characteristics of buckwheat grains

As shown in Table 5, commercial buckwheat was rich in total solid and protein and possessed lower ash content than the Güneş variety (*P* < 0.05). The ash content ranged from 2.56 g/100 g in commercial buckwheat to 4.89 g/100 g in the Güneş variety. Buckwheat grain is a rich source of protein with high biological value (Bonafaccia et al., 2003). A significant difference (*P* < 0.05) in protein content was found between commercial buckwheat (14.62 g/100 g) and the Güneş variety (13.75 g/100 g). Steadman et al. (2001) reported the total solid, ash and total protein content of commercial buckwheat grains as 88.2 g/100 g, 2.4 g/100 g

Table 5. Chemical properties of buckwheat grains[a,b].

Tabla 5. Propiedades químicas de los granos de trigo sarraceno[1,2].

Property	Commercial buckwheat	Güneş variety
Total solids (g/100 g)	93.54 ± 0.26 a	90.54 ± 0.36 b
Ash (g/100 g)	2.56 ± 0.14 b	4.89 ± 0.86 a
Protein (g/100 g)	14.62 ± 0.41 a	13.75 ± 0.29 b
Antioxidant capacity (μmol TE/g)	1.41 ± 0.14 b	2.86 ± 0.16 a
Total phenolic content (mg GAE/100 g)	207.12 ± 2.67 b	329.83 ± 3.88 a
P (mg/kg)	3451.34 ± 62.39 Ns	3643.47 ± 101.85 Ns
K (mg/kg)	3900.00 ± 50.00 b	5458.33 ± 38.19 a
Mg (mg/kg)	1890.40 ± 12.06 b	2083.83 ± 21.03 a
Na (mg/kg)	741.67 ± 14.43 b	933.33 ± 14.43 a
Ca (mg/kg)	133.33 ± 14.43 b	916.67 ± 14.43 a
Fe (mg/kg)	44.01 ± 1.82 b	170.50 ± 4.20 a
Zn (mg/kg)	30.00 ± 1.36 a	24.29 ± 0.94 b
Mn (mg/kg)	13.88 ± 0.86 Ns	14.91 ± 0.41 Ns
Cu (mg/kg)	7.86 ± 0.46 Ns	8.26 ± 0.02 Ns
B (mg/kg)	0.49 ± 0.01 b	19.25 ± 0.25 a
Ni (mg/kg)	4.24 ± 0.47 a	2.85 ± 0.09 b
Cr (mg/kg)	0.66 ± 0.10 b	1.10 ± 0.07 a
Pb (mg/kg)	0.19 ± 0.01 b	0.24 ± 0.01 a
Cd (mg/kg)	–	–

[a]Different letter in the same line indicates significant differences (*P* < 0.05).
[b]Based on dry matter.
a and b letters indicate the statistical difference in rows.
Ns: Not significant
[1]Las distintas letras en la misma línea indican diferencias significativas (*P* < 0,05).
[2]En base a la materia seca.
Las letras a y b indican diferencias significativas en las filas.
Ns: No es significativo

and 12.3 g/100 g, respectively. The protein content of the buckwheat samples used in the current study are higher than the corresponding values of 6.0–13.6 g/100 g reported for buckwheat grains produced in Japan, Europe and Canada (Ikeda et al., 2005). Moreover, the results obtained in this study for protein content are in agreement with the range of 8.81 to 18.71 g/100 g reported for buckwheat by Guo, Chen, Yang, and Huang (2007). The observed differences in total solid, ash and protein content of the samples can be explained by differences in the variety and in the environment in which the buckwheat is grown.

The antioxidant capacity and total phenolic content of the buckwheat samples are given in Table 5. There were significant differences ($P < 0.05$) between the studied samples. The antioxidant capacity of the Güneş variety was 2.86 µmol TE/g, whereas that of commercial buckwheat was 1.41 µmol TE/g. The Güneş variety also showed a higher total phenolic content (329.83 mg GAE/100 g) than commercial buckwheat (207.12 mg GAE/100 g). It is well known that buckwheat is an important source of antioxidants. The main antioxidants in buckwheat are rutin, quercetin, hyperin and catechins (Morishita, Yamaguchi, & Degi, 2007; Quettier-Deleu et al., 2000). Vollmannova et al. (2013) reported the total phenolic content and antioxidant capacity of five varieties of buckwheat as 138.10–286.99 mg GAE/100 g and 2.32–4.64 µmol TE/g, respectively. Inglett et al. (2010) investigated the effect of using different extraction methods and showed that the total phenolic content and the antioxidant capacity of buckwheat were 143–1845 mg GAE/100 g and 3.72–5.73 µmol TE/g, respectively. Other researchers found that the total phenolic content of buckwheat grains grown in Serbia and in the Czech Republic were 187 mg GAE/100 g and 390.3 mg GAE/100 g, respectively (Holasova et al., 2002; Sedej et al., 2012). The differences in the total phenolic content and antioxidant capacity measured in this study compared with the values reported in other studies may be related to the different buckwheat varieties and sample extraction methods used in the experiments.

The concentrations of the 14 elements measured in the buckwheat samples are shown in Table 5. There were significant differences ($P < 0.05$) in the K, Ca, Mg, Na, Fe, Zn, B, Ni, Cr and Pb content of the buckwheat samples. Of the measured minerals, K was the most abundant macroelement in the buckwheat grains, as shown in previous studies (Ikeda et al., 2005; Mann, Gupta, & Gupta, 2012; Steadman et al., 2001). The content of macroelements followed the order K > P > Mg > Na > Ca. The high P content of buckwheat grain can be attributed to its high phytic acid content (11700 mg/kg) (Steadman et al., 2001). The K, Ca, Mg and Na contents of the Güneş variety were found to be higher than those of the commercial buckwheat sample ($P < 0.05$). The Güneş variety was characterized by high Fe, B and Cr concentrations, and the commercial buckwheat sample was characterized by high Ni concentration ($P < 0.05$). In earlier studies, the P, K, Mg, Na, Ca, Fe, Zn, Mn, Cu, B, Ni, Cr, Pb and Cd contents of various common buckwheat varieties were found to be between 1675–4900, 911–5650, 632–2676, 11–126, 67–748, 2.2–92.5, 12.9–48.7, 8.9–22.7, 3.1–7.1, 6.7–8.1, 0.7–3.9, 0.0–0.5, 0.0–4.8 and 0.0–0.1 mg/kg, respectively (Ikeda et al., 2005; Kan, 2011; Lian-Xin et al., 2014; Mann et al., 2012; Steadman et al., 2001). Compared to the previous studies, differences were observed in the concentration of minerals in the buckwheat samples in the current study. Many factors, including both environmental and genetic influences, can affect the mineral composition of agricultural crops (Bonafaccia et al., 2003; Huang, Zeller, Huang, Shi, & Chen, 2014; Lian-Xin et al., 2014; Prado, Fernández-Turiel, Tsarouchi, Psaras, & González, 2014).

Conclusion

The tested two different buckwheat grain were found to be quite different on the basis of variation in most of the important physical and chemical characteristics. Grains of Güneş variety were larger in length, width and thickness than commercial buckwheat. The Güneş variety has a significantly ($P < 0.05$) higher geometric and arithmetic mean diameter, volume and surface area than commercial buckwheat grain. The commercial buckwheat grains had higher sphericity than the Güneş variety. The Güneş variety was slightly heavier than commercial buckwheat, whereas the latter was significantly ($P < 0.05$) lower in porosity. However, the commercial grain was significantly ($P < 0.05$) higher in bulk and in true density. The terminal velocity, rupture force and angle of repose were 2.98 m/s, 27.6 N and 22.0°, respectively, for commercial grain and 3.11 m/s, 18.7 N and 25.5° for the Güneş variety. For both buckwheat samples, the static friction coefficient was the highest for rubber, followed by aluminium and stainless steel. The Güneş variety showed a darker colour compared to the commercial buckwheat sample. The total phenolic content and antioxidant capacity of grains were higher in the Güneş variety. K was the most abundant mineral, followed by P and Mg. This new buckwheat variety is a rich source of nutrients and it can be processed into different kind of buckwheat products. In summary, this report describes the physical and chemical characteristics of buckwheat, enlarging the knowledge and providing useful data for its industrial processing. Further studies should be conducted to investigate the moisture-dependent characteristics of buckwheat varieties.

Disclosure statement

References

AACC. (2000). *Approved methods of American association of cereal chemists*. St. Paul, MN: The American Association of Cereal Chemists.

Agri-Facts. (2001). *Common buckwheat*. Agri-Fact, Practical Information for Alberta's Agriculture Industry, pp. 6. Retreived from http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex103.

Al-Mahasneh, M.A., Taha, M., & Rababah, A. (2007). Effect of moisture content on some physical properties of green wheat. *Journal of Food Engineering*, 79, 1467–1473. doi:10.1016/j.jfoodeng.2006.04.045

Altuntas, E., & Karadag, Y. (2006). Some physical and mechanical properties of sainfoin (*Onobrychis sativa* Lam.), grasspea (*Lathyrus sativus* L.) and bitter vetch (*Vicia ervilia* (L.) Willd.) seeds. *Journal of Applied Sciences*, 6(6), 1373–1379. doi:10.3923/jas.2006.1373.1379

Amin, M.N., Hossain, M.A., & Roy, K.C. (2004). Effects of moisture content on some physical properties of lentil seeds. *Journal of Food Engineering*, 65, 83–87. doi:10.1016/j.jfoodeng.2003.12.006

Ashtiani Araghi, H., Sadeghi, M., & Hemmat, A. (2010). Physical properties of two rough rice varieties affected by moisture content. *International Agrophysics*, 24, 205–207.

Asoegwu, S.N., Ohanyere, S.O., Kanu, O.P., & Iwueke, C.N. (2006). Physical properties of African oilbean seed (*Pentaclethra macrophylla*). *Agric*

Eng Int Cıgr E-Journal Vııı (Manuscript FP 05 006), 15. http://core.ac.uk/download/pdf/4909030.pdf

Baümler, E., Cuniberti, A., Nolasco, S.M., & Riccobene, I.C. (2006). Moisture dependent physical and compression properties of safflower seed. *Journal of Food Engineering*, 72, 134–140. doi:10.1016/j.jfoodeng.2004.11.029

Bernalte, M.J., Sabio, E., Hernández, M.T., & Gervasini, C. (2003). Influence of storage delay on quality of 'Van' sweet cherry. *Postharvest Biology and Technology*, 28, 303–312. doi:10.1016/S0925-5214(02)00194-1

Bonafaccia, G., Marocchini, M., & Kreft, I. (2003). Composition and technological properties of the flour and bran from common and tartary buckwheat. *Food Chemistry*, 80, 9–15. doi:10.1016/S0308-8146(02)00228-5

Brink, M., & Belay, G. (2006). *Plant Resources of Tropical Africa 1 -Cereals and Pulses*. Wageningen: Backhuys Publishers.

Campbell, C.G. (1997). *Buckwheat. Fagopyrum esculentum Moench. Promoting the conservation and use of underutilized and neglected crops. 19. Institute of Plant Genetics and Crop Plant Research, Gatersleben* (pp. 94). Rome: Germany/International Plant Genetic Resources Institute.

Christa, K., & Soral-Smietana, M. (2008). Buckwheat grains and buckwheat products – nutritional and prophylactic value of their components – a review. *Czech Journal of Food Sciences*, 26, 153–162.

Coşkuner, Y., & Karababa, E. (2007). Physical properties of coriander seeds (*Coriandrum sativum* L.). *Journal of Food Engineering*, 80, 408–416. doi:10.1016/j.jfoodeng.2006.02.042

FAO. (2014). *Production, yield, harvested area values of buckwheat*. Retrieved from http://faostat.fao.org

Gharibzahedi, S.M.T., Ghasemlou, M., Razavi, S.H., Jafarii, S.M., & Faraji, K. (2011). Moisture-dependent physical properties and biochemical composition of red lentil seeds. *International Agrophysics*, 25, 343–347.

Grubben, G.J.H., & Siemonsma, J.S. (1996). Fagopyrum esculentum Moench. In G.J.H. Grubben & S. Partohardjono (Eds.), *Plant resources of South-East Asia No 10. Cereals* (pp. 95–99). Leiden: Backhuys Publishers.

Guo, Y.-Z., Chen, Q.-F., Yang, L.-Y., & Huang, Y.-H. (2007). Analyses of the seed protein contents on the cultivated and wild buckwheat *Fagopyrum esculentum* resources. *Genetic Resources and Crop Evolution*, 54, 1465–1472. doi:10.1007/s10722-006-9135-z

Holasova, M., Fiedlerova, V., Smrcinova, H., Orsak, M., Lachman, J., & Vavreinova, S. (2002). Buckwheat-the source of antioxidant activity in functional foods. *Food Research International*, 35, 207–211. doi:10.1016/S0963-9969(01)00185-5

Huang, X., Zeller, F.J., Huang, K., Shi, T., & Chen, Q. (2014). Variation of major minerals and trace elements in seeds of tartary buckwheat (*Fagopyrum tataricum* Gaertn.). *Genetic Resources and Crop Evolution*, 61, 567–577. doi:10.1007/s10722-013-0057-2

Ikeda, S., Yamashita, Y., Kusumoto, K., & Kreft, I. (2005). Nutritional characteristics of minerals in various buckwheat groats. *Fagopyrum*, 22, 71–75.

Ilori, T.A., Oradugba, O.B., & Raji, A.O. (2011). Physical properties of Mexican sunflower seed. *International Agrophysics*, 25, 299–302.

Inglett, G.E., Rose, D.J., Chen, D., Stevenson, D.G., & Biswas, A. (2010). Phenolic content and antioxidant activity of extracts from whole buckwheat (*Fagopyrum esculentum* Möench) with or without microwave irradiation. *Food Chemistry*, 119(3), 1216–1219. doi:10.1016/j.foodchem.2009.07.041

Ixtaina, V.Y., Nolasco, S.M., & Tomás, M.C. (2008). Physical properties of chia (*Salvia hispanica* L.) seeds. *Industrial Crops and Products*, 28, 286–293. doi:10.1016/j.indcrop.2008.03.009

Kabas, O., Yilmaz, E., Ozmerzi, A., & Akinci, İ. (2007). Some physical and nutritional properties of cowpea seed (Vigna sinensis L.). *Journal of Food Engineering*, 79, 1405–1409. doi:10.1016/j.jfoodeng.2006.04.022

Kacar, B. (2014). *Easy Applicable Plant Analysis – Plant, Soil and Fertilizer Analysis: 2* (in Turkish). (pp. 423)., Ankara: Nobel Publishing, ISBN: 978-605-133-812-5, Publish No: 910, Food, Agriculture and Livestock No: 4.

Kaliniewicz, Z., Markowski, P., Anders, A., & Jadwisienczak, K. (2015). Frictional properties of selected seeds. *Technical Sciences*, 18(2), 85–101.

Kalkan, F., & Kara, M. (2011). Handling, frictional and technological properties of wheat as affected by moisture content and cultivar. *Powder Technology*, 213, 116–122. doi:10.1016/j.powtec.2011.07.015

Kan, A. (2011). Investigation of some characteristic of buckwheat (*Fagopyrum esculentum* Moench) growing in Konya ecological conditions. (in Turkish). *Selcuk Journal of Agriculture and Food Sciences*, 25 (4), 67–71.

Li, S., & Zhang, Q.H. (2001). Advances in the development of functional foods from buckwheat. *Critical Reviews İn Food Science and Nutrition*, 41, 451–464. doi:10.1080/20014091091887

Lian-Xin, P., Yan-Fei, H., Yuan, L., Zhi-Feng, Z., Lu-Yang, L., & Gang, Z. (2014). Evaluation of essential and toxic element concentrations in buckwheat by experimental and chemometric approaches. *Journal of Integrative Agriculture*, 13(8), 1691–1698. doi:10.1016/S2095-3119(13)60724-8

Mann, S., Gupta, D., & Gupta, K.R. (2012). Evaluation of nutritional and antioxidant potential of Indian buckwheat grains. *Indian Journal of Traditional Knowledge*, 11(1), 40–44.

Mazza, G., & Oomah, B.D. (2005). Buckwheat as a food and feed. In E. Abdel-Aal & P. Wood (Eds.), *Speciality Grains for food and Feed* (pp. 375–393). St Paul, MN: American Association of Cereal Chemists.

Mohsenin, N.N. (1986). *Physical properties of plant and animal materials* (2nd ed.). New York: Gordon and Breach Science Publishers.

Morishita, T., Yamaguchi, H., & Degi, K. (2007). The contribution of polyphenols to antioxidative activity in common buckwheat and tartary buckwheat grain. *Plant Production Science*, 10, 99–104. doi:10.1626/pps.10.99

Mwithiga, G., & Sifuna, M.M. (2006). Effect of moisture content on the physical properties of three varieties of sorghum seeds. *Journal of Food Engineering*, 75, 480–486. doi:10.1016/j.jfoodeng.2005.04.053

Parde, S.R., Johal, A., Jayas, D.S., & White, N.D.G. (2003). Physical properties of buckwheat cultivars. *Canadian Biosystems Engineering*, 45, 3.19–3.22.

Patel, M., Pradhan, R.C., & Naik, S.N. (2011). Physical properties of fresh mahua. *International Agrophysics*, 25, 303–306.

Pradhan, R.C., Naik, S.N., Bhatnagar, N., & Vijay, V.K. (2009). Moisture-dependent physical properties of jatropha fruit. *Industrial Crops and Products*, 29, 341–347. doi:10.1016/j.indcrop.2008.07.002

Prado, F.E., Fernández-Turiel, J.L., Tsarouchi, M., Psaras, G.K., & González, J.A. (2014). Variation of seed mineral concentrations in seven quinoa cultivars grown in two agroecological sites. *Cereal Chemistry Journal*, 91(5), 453–459. doi:10.1094/CCHEM-08-13-0157-R

Quettier-Deleu, C., Gressier, B., Vasseur, J., Dine, T., Brunet, C., Luyckx, M. … Trotin, F. (2000). Phenolic compounds and antioxidant activities of buckwheat (*Fagopyrum esculentum* Moench) hulls and flour. *Journal of Ethnopharmacology*, 72, 35–42. doi:10.1016/S0378-8741(00)00196-3

Sedej, I., Sakač, M., Mandić, A., Mišan, A., Tumbas, V., & Čanadanović-Brunet, J. (2012). Buckwheat (*Fagopyrum esculentum* Moench) grain and fractions: Antioxidant compounds and activities. *Journal of Food Science*, 77(9), C954–959. doi:10.1111/j.1750-3841.2012.02867.x

Steadman, K.J., Burgoon, M.S., Lewis, B.A., Edwardson, S.E., & Obendorf, R.L. (2001). Minerals, phytic acid, tannin and rutin in buckwheat seed milling fractions. *Journal of the Science of Food and Agriculture*, 81, 1094–1100. doi:10.1002/(ISSN)1097-0010

Unal, H., Isık, E., Izli, N., & Tekin, Y. (2008). Geometric and mechanical properties of mung bean (*Vigna Radiata* L.) grain: Effect of moisture. *International Journal of Food Properties*, 11, 585–599. doi:10.1080/10942910701573024

Unal, H., Sincik, M., & Izli, N. (2009). Comparison of some engineering properties of rapeseed cultivars. *Industrial Crops and Products*, 30, 131–136. doi:10.1016/j.indcrop.2009.02.011

Vollmannova, A., Margitanova, E., Toth, T., Timoracka, M., Urminska, D., Bojnanska, T., & Cicova, I. (2013). Cultivar influence on total polyphenol and rutin contents and total antioxidant capacity in buckwheat, amaranth, and quinoa seeds. *Czech Journal of Food Sciences*, 31, 589–595.

WFP. (2006). *United nations world food programme*. Food quality control. Retreived from http://foodquality.wfp.org/FoodSpecifications/Grains/tabid/102/Default.aspx#109.

Wijngaard, H.H., & Arendt, E.K. (2006). Buckwheat. *Cereal Chemistry*, 83 (4), 391–401. doi:10.1094/CC-83-0391

Yalçın, I., & Özarslan, C. (2004). Physical properties of vetch seed. *Biosystems Engineering*, 88, 507–512. doi:10.1016/j.biosystemseng.2004.04.011