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Physical and Thermal Properties of Chia, Kañiwa, Triticale and Farro as a Function of Moisture Content

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Abstract

The knowledge of physical and thermal properties in cereals, grains and oilseeds establishes an essential engineering tool for the design of equipment, storage structures, and processes. The physical properties and thermal properties for Chia, Kañiwa, Farro and Triticale grains were investigated at three levels of moisture content: 10 %, 15 % and 20 % (d.b). Physical properties determined where 1000 seed weight, seed dimensions, arithmetic and geometric mean diameter, surface area, volume sphericity and aspect ratio. The result shows 1000 seed weight increased linearly with moisture content from 2.0 to 3.5 g for chai, 2.5 to 4.0 g for Kañiwa, 42.7 to 48.3 g for Farro and 51.0 to 53.7 g for Triticale. Likewise, the bulk and true density decreased as moisture content increased. The porosity for Farro and Triticale increased from 38.71% to 44.17 %, 40.37 % to 44.65 % respectively as moisture increased from 10 to 20 %. The angle of repose for Chia, Kañiwa, Farro and Triticale all increased as moisture content increased. In general, the values of L, a* and b* increased with moisture content. Thermal properties showed a very good correlation to moisture content. The negative relationship was observed for the specific heat capacity and thermal conductivity while the thermal diffusivity had a positive linear increase trend with moisture content. This study showed that physical and thermal properties varied from grain to grain as a function of moisture content. The findings of this study will broaden the knowledge of physical properties of Chia, Kañiwa, Triticale and Farro and provide useful data for industries and researchers.

Keywords

Chia, Kañiwa, Triticale, Farro, physical properties, moisture content

Disciplines

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Comments

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PHYSICAL AND THERMAL PROPERTIES OF CHIA, KAÑIWA, TRITICALE AND FARRO AS A FUNCTION OF MOISTURE CONTENT

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Abstract.

The knowledge of physical and thermal properties in cereals, grains and oilseeds establishes an essential engineering tool for the design of equipment, storage structures, and processes. The physical properties and thermal properties for Chia, Kañiwa, Farro and Triticale grains were investigated at three levels of moisture content: 10 %, 15 % and 20 % (d.b). Physical properties determined where 1000 seed weight, seed dimensions, arithmetic and geometric mean diameter, surface area, volume sphericity and aspect ratio. The result shows 1000 seed weight increased linearly with moisture content from 2.0 to 3.5 g for chai, 2.5 to 4.0 g for Kañiwa, 42.7 to 48.3 g for Farro and 51.0 to 53.7 g for Triticale. Likewise, the bulk and true density decreased as moisture content increased. The porosity for Farro and Triticale increased from 38.71% to 44.17 %, 40.37 % to 44.65 % respectively as moisture increased from 10 to 20 %. The angle of repose for Chia, Kañiwa, Farro and Triticale all increased as moisture content increased. In general, the values of *L*, *a** and *b** increased with moisture content. Thermal properties showed a very good correlation to moisture content. The negative relationship was observed for the specific heat capacity and thermal conductivity while the thermal diffusivity had a positive linear increase trend with moisture content. This study showed that physical and thermal properties varied from grain to grain as a function of moisture content. The findings of this study will broaden the knowledge of physical properties of Chia, Kañiwa, Triticale and Farro and provide useful data for industries and researchers.

Keywords. Chia; Kañiwa; Triticale; Farro; physical properties; moisture content.

Introduction

The information of engineering properties, especially physical and thermal properties of grains, legumes and oilseeds are very crucial for engineers to understand. Physical and thermal characteristics are important in analyzing the behavior of grains in handling operation (Mohsenin, 1986). Data on physical properties of Chia, Kañiwa, Triticale and Farro are essential for the design of equipment and facilities for harvesting, handling, conveying, grading and separation, drying, and aeration, storing and processing of seeds and grains (Sacilik et al., 2003). To our knowledge, this will be the first research to look physical properties of Kañiwa, Farro and Triticale.

Chia (*Salvia hispanica* L.), is a summer annual herbaceous plant belongs to the *Lamiaceae* family (Ixtaina et al., 2008), which is native to the mountainous regions of southern Mexico and northern Guatemala (Ayerza and Coates, 1999). It is a multiple purpose grain crop used as food, traditional medicines and paints by an Aztec Indian for several centuries (Ixtaina et al., 2008; Ayerza, 1995). The grain contains about 19-23 % protein, 25-38 % oil and 26-41 % carbohydrates (Ayerza and Coates, 1999; Ixtaina et al., 2008). According to Ayerza (1995) and Ayerza and Coates (1999), Chia seeds (Figure 1) are an excellent source of omega three fatty which contains high polyunsaturated fatty acid (60 % linolenic acid) and can be used as functional and bioactive ingredients in food products (Rosell et al., 2009).

Kañiwa or Kalliwa (*Chenopodium pallidicaule*) is a native food plant of the Andean region of South America (Repo-Carrasco et al., 2003). Kañiwa is actually a seed and not a grain. Botanically, Kañiwa (Figure 2) belongs to the *Poaceae* or *Gramineae* family, and is classified as “pseudo-cereals” or “pseudo-grains” instead of cereals (Sanchez, 2012; Cook and Aramouni, 2014). It is a major source of calories (65 %), good quality edible oil (6.96 %) and excellent source of proteins (15-17 %), dietary fiber and micronutrients (Repo-Carrasco-Valencia, 2010; Repo-Carrasco-Valencia, 2009) in the Andrean region. Moreover, the seeds are a rich source of α- and γ- tocopherol and phenolic compounds (Diaz, 2012). Nutritionally, Kañiwa is excellent food: it is gluten free, provides balanced amino acid profile equivalent to that of milk protein and offers high lysine content (Repo-Carrasco-Valencia, 2010; Sanchez, 2012; White et al., 1995). It is considered a lenticular form in shape with a diameter between 1 and 1.2 mm (Diaz, 2012).

Triticale (*Triticosecale wittmack*), is an artificial cereal crop and the first man-made cereal (Hawthorn, 1976). It is a cross between the female parent wheat and the male parent rye (Doxastakis et al., 2002). The name Triticale is derived from the respective generic names of the parent plants *Triticum* (wheat)-*“Triti”* and from *Secale* (rye)-*“Cale”* (Wu et al., 1978; Hawthorn, 1976). According to Mergoum and Macpherson (2004), Triticale resembles wheat more than rye in terms of grain size, shape and color. However, Triticale grain is a relatively soft grain and usually larger and longer than wheat grain (Mergoum and Macpherson, 2004). Triticale (Figure 3) grain is a good source of vitamins, mineral nutrients, and protein (Wu et al., 1978).

Farro also refers to hulled wheat or emmer wheat (*Triticum dicoccon*), and it is one among the diverse strains of the wheat plant, and ancient crops of the Mediterranean region (Brown, 2012; van Slageren and Payne, 2013). According to Buerli (2006), the term Farro is an Italian name and reserves for three species of hulled wheat, Einkorn (*Triticum monococcum*), Emmer (*T. dicoccon*) and Spelt (*T. spelta*). In Italy they are commonly known as “Farro piccolo”, “Farro medio” and “Farro grande”, respectively (Buerli, 2006). Figure 4 show pictures of Farro.

The most important physical and thermal properties of the grain, oilseed and others agricultural commodities are seed dimensions (length, width and thickness), arithmetic and geometric mean diameter, surface area, volume, sphericity and aspect ratio. Other includes 1000 grain weight, bulk and kernel density, fractional porosity, static and dynamic coefficient of friction against different materials and the angle of repose, heat capacity, thermal conductivity and diffusivity, and latent heat of vaporization (Dutta et al., 1988; Mohsenin, 1986). These properties vary widely, depending on moisture content and temperature of the grains, oilseeds or legumes (Chakraverty, 2003). The objective of this study was to determine the physical and thermal properties of Chia, Kañiwa, Triticale and Farro at three different levels of moisture content.

Materials and Methods

Sample preparation

The seeds used in this experiment were Farro (village harvest), Triticale (Handy Pantry Sprouting), Chia (Healthworks) and Kañiwa (Angelina's Gourmet, G47C63). All seeds were purchased online and cleaned manually to remove any foreign matter, stones and broken seeds. Seeds were mixed well and about 1000 g of each seed was sampled for this study. The initial moisture content of each seed was determined with samples of 30 g within three replications at 103 ºC for 72 h (ASAE, 2001). The samples were cooled, weighed, and then the moisture content of each seed was calculated. To obtain desired moisture content seeds were either rewetted by adding the amount of distilled water as calculated by the equation 1 (Sacilik et al., 2003). Mixed thoroughly and then hermetical sealed in polythene bags and stored at 10 ºC in the refrigerator for 24 h to allow uniformity of moisture sample distribution or dried in a convection air oven at 103 ºC for 15 to 20 minutes. The physical properties of seeds were investigated at three moisture contents: 10, 15 and 20 % dry basis (d.b.) within ± 0.5 % (d.b.) margin of error.

$$Q = \frac{W_i(M_f - M_i)}{(100 - M_f)} \quad (1)$$

Where W_i is the initial weight of seeds, M_i is the initial moisture content of seeds and M_f is the final moisture content of seeds.

Seed dimensions, arithmetic and geometric mean diameter, surface area, volume, sphericity and aspect ratio

To determine the seed dimensions (length *L*, width *W* and thickness *T*), 100 seeds were randomly picked for Chia and Kañiwa while 60 seeds were randomly selected for Farro and Triticale. ImageJ software (version, 1.49p, 2015) was used to determine seeds dimensions. The arithmetic mean diameter, D_a, and geometric mean diameter, D_e, of all samples were calculated by using relationships developed by (Mohsenin, 1986).

$$D_a = \frac{L + W + T}{3} \quad (2)$$

$$D^3{}_e = LWT \quad (3)$$

The seed surface area (S) and volume (V) were calculated using the following relationship (Jain and Bal, 1997), equation 4 and 5 respectively.

$$S = \frac{\pi B^2 L^2}{2L - B} \quad (4)$$

$$V = \frac{\pi B^2 L^2}{6(2L - B)} \quad (5)$$

Where $B = (WT)^{0.5}$

The sphericity (ϕ) is defined as the ratio or the surface area of a sphere having the same volume as that of the seed to the surface area of the seed. In this experiment, the sphericity (ϕ) of the seeds was calculated by using formula stated by Mohsenin (1986).

$$\emptyset = \frac{(LWT)^{1/3}}{L} \tag{6}$$

To determine seed shape, aspect ratio (R) was calculated according to equation given by Maduako and Faborode (1990).

$$R = \frac{W}{L} * 100 \tag{7}$$

One thousand seed weight

To determine one thousand grain weight, 100 kernel of each seed or grain were picked at random from the bulk seeds and weighed on an electronic balance (Denver Instrument, DI-4K, Bohemia, NY, USA) with 0.01 g graduations. The measurement was repeated three times and the average of three measurements were then multiplied by 10 to give the weight of 1000 seeds (Ixtaina et al., 2008; Tunde-Akintunde et al., 2004).

Density and porosity

The average bulk density of the seeds was determined by using the standard test weight procedure reported by (Singh and Goswami, 1996; Cetin, 2007; Paksoy and Aydin, 2004) by filling a glass jar of 500 ml with the seed from a height of 150 mm at a constant rate and then its mass determined using an electronic balance (Denver Instrument, DI-4K, Bohemia, NY, USA). The trial was repeated five times and the average mass was calculated. The bulk density was then calculated from the mass of seeds and the volume of the container. The true density of seed is defined as the ratio of the mass of a grain sample to the solid volume occupied by the sample (Dutta et al., 1988). True density was determined by micrometritics AccuPyc 1330 (Norcross, GA 30093, USA) using nitrogen gas as compressed gas for Farro and Triticale. Due to equipment limitation true density for Chia and Kañiwa were not determined. The porosity is described as the fraction of the space in the bulk seeds which is not occupied by the seeds (Thompson and Issac, 1967). The porosity (ε) of the seed was calculated from the relationship:

$$\varepsilon = \left(1 - \frac{\rho_g}{\rho_b}\right) \times 100 \tag{8}$$

Where ρ_g is the bulk density, ρ_b is the true density.

Angle of repose

The angle of repose (θ) is defined as the angle with the horizontal at which the material will stand when piled (Altuntas and Yildiz, 2007). In this study, the angle of repose was determined by using a topless plywood box with small opening at the bottom, and with dimensions of 140 mm by 140 mm by 30 mm. The box was filled with the seeds at desired moisture content, and the hole was unplugged to allow the seeds to flow out and form a natural heap. Then pictures were taken and the angle of repose was calculated by using ImageJ software (version, 1.49p, 2015).

Color

Color is an important attribute of grains and seeds in grading and inspection. A machine can provide a quick and objective measure of color in contrast to traditional visual inspection and other subjective methods (Shahin and Symons, 2003). In this study, the seed color was measured using a Chroma meter CR-410 (Konica Minolta Optics, Japan). Three color values were recorded, including L, which is the indicator for brightness; a*, which is the indicator for the change from green to red; and b*, which is the indicator for the change from yellow to blue (Mavi, 2010).

Thermal conductivity, diffusivity and specific heat capacity

Thermal conductivity, diffusivity and heat capacity of the seeds under various moisture content were determined by a thermal properties meter (KD2, Decagon Devices, Pullman, Wash).

Analysis of statistic

The experiments were carried out with three replications for each moisture levels unless stated otherwise, and the average values with their standard deviations were reported. The data were statistically analyzed for various parameters at the 5 % level of confidence. The analysis of regression and all figures were plotted using Microsoft Office Excel®.

Results and Discussion

Seed dimensions, arithmetic and geometric mean diameter, surface area, volume, sphericity and aspect ratio

The average seed dimensions (length, width and thickness) for Chia, Kañiwa, Farro and Triticale were shown in Table 1. The average seed length, width and thickness for Chia were 1.99 ± 0.38 mm, 1.21 ± 0.22 mm and 1.01 ± 0.18 mm. These values were in the same range with those reported by Ixtaina et al. (2008) for Chia seeds. However, were lower than those of amaranth seeds (Abalone et al., 2004) and higher than those of quinoa (Vilche et al., 2003). For Kañiwa, the mean values of length, width and thickness were 1.14 ± 0.20 mm, 0.92 ± 0.18 mm, and 0.78 ± 0.16 mm respectively. The values were lower than Chia seeds determined in this experiment, higher than Sesame seeds (Tunde-Akintunde and Akintude, 2004) and quinoa seed (Vilche et al., 2003).

In addition, the average dimension (length, width and thickness) for Farro were 7.69 ± 0.07 mm, 3.39 ± 0.59 mm, and 3.11 ± 0.58 mm, the measurement was within range with those reported by Tabatabaeefar (2003) for wheat. However, were lower than those reported by

Sologubik et al. (2013) for barley and higher than those reported by (Al-Mahasneh and Rababah (2007) for green wheat. Likewise, the average length, width and thickness for Triticale were 7.52 ±1.19 mm, 3.32 ± 0.57 mm and 3.06 ± 0.55 mm respectively. The values were slightly lower than dimensions of Farro and significant higher than the dimensions of wheat (Tabatabaeefar, 2003) and green wheat (Al-Mahasneh and Rababah, 2007).

The mean of arithmetic and geometric mean diameter for Chia seeds were 1.40 ± 0.26 mm, 0.81 ± 0.00 mm, respectively, the values were lower than those reported by (Ixtaina et al., 2008) for Chia seeds. For Kañiwa, the values for mean arithmetic was 0.95 ± 0.20 mm, and 0.27 ± 0.00 mm for geometric mean diameter. The values were lower than those of quinoa seeds (Vilche et al., 2003) and amaranth seeds (Abalone et al., 2004). Furthermore, for Farro, the values of the average arithmetic mean diameter ranged from 5.57 to 0.47 mm with a standard deviation of 0.41 while the geometric mean diameter was 26.98 ± 0.01 mm. For Triticale, arithmetic means diameter was 4.63 ± 0.77 mm and the geometric mean was 25.45 ± 0.12 mm, the values were similar to wheat (Tabatabaeefar, 2003).

The surface area and volume for Chia, Kañiwa, Farro and Triticale seeds were shown in Table 1. On the other hand, the mean value of sphericity and the aspect ratio for Chia seeds were 0.41 ± 0.01 and 60.56 % respectively. The values of sphericity obtained in this study were lower than those reported by (Ixtaina et al., 2008) for Chia seeds, but the aspect ratio were within the range of results of Ixtaina et al. (2008). For Kañiwa, the sphericity were 0.24 ± 0.01, and the values were lower than *Amaranthus* (Abalone et al., 2004), quinoa seed (Vilche et al., 2003), and sesame seeds (Tunde-Akintunde, 2004), therefore, Chia seeds cannot be expressed as spherical in shape for analytical calculations because of their low sphericity value (Hauhouot-O'Hara et al., 2000).

The aspect ratio for Kañiwa seeds was 80.79 %, and the value was higher than those cited by Ixtaina et al. (2008) for dark and white Chia seeds but similar to amaranth seeds (Abalone et al., 2004). The high sphericity value means that the Kañiwa seeds tend towards a spherical shape (Omobuwajo et al., 2000). Furthermore, for Farro and Triticale the sphericity values were 3.5 and 3.39 respectively, while the mean aspect ratio was 44.11 % for Farro and 44.20 % for Triticale. The value was similar to those reported by Tabatabaeefar (2003) for wheat.

One thousand seed weight

The one thousand seed weight (W_{1000}) for Chia seeds increased linearly from 2.00 to 3.50 g as the moisture content increased from 10 % to 20 % d.b. (Fig. 5). The relationship between one thousand seed weight and moisture content of Chia seeds could be expressed by the following equation.

$$W_{1000} = 1.083 + 0.15\mathrm{M} \qquad (\mathrm{R}^2 = 0.96) \qquad (9)$$

It was shown Fig. 5 that the 1000 seed weight of Kañiwa increased with the increase in moisture content and a linear relationship between W_{1000} and M was obtained as follows:

$$\mathrm{W}_{1000} = 0.417 + 0.15\mathrm{M} \qquad (\mathrm{R}^2 = 0.96) \qquad (10)$$

Furthermore, for 1000 seed weight, for Farro and Triticale, increased linearly as moisture content increased from 10 % to 20 % dry basis (Fig. 6). The equation 11 and 12 showed the relationship between thousand seed weight and moisture content for Farro and Triticale respectively.

$$\mathrm{W}_{1000} = 37.267 + 0.56\mathrm{M} \qquad (\mathrm{R}^2 = 0.98) \qquad (11)$$

A Similar trend was observed for gram (Dutta et al., 1988), coriander seed (Coşkuner and Karababa, 2007a), guna seeds (Aviara, et al., 1999), Cumin seed (Singh and Goswami, 1996), rapeseed (Çalışır, et al., 2005), caper seed (Dursun and Dursun, 2005), flaxseed (Coşkuner and Karababa, 2007b), wheat (Tabatabaeefar, 2003), green wheat (Al-Mahasneh, and Rababah, 2007) and barley (Sologubik et al., 2013).

$$W_{1000} = 48.283 + 0.27M \qquad (R^2 = 0.99) \tag{12}$$

Bulk and true density

The results of the bulk density for Chia and Kañiwa seed at three moisture levels were presented in Fig. 7 and Fig. 8. The bulk density was found to decrease from 729 to 458 kg/m^3 for Chia and 958 to 904 kg/m^3 for Kañiwa as moisture content increased from 10 to 20 % d.b. Similar results was observed for caper seed (Dursun and Dursun, 2005), *Amaranthus* seed (Abalone et al., 2004), Chia seeds (Ixtaina et al., 2008), Sunflower seeds (Gupta and Das, 1997), Quinoa seeds (Vilche et al., 2003) and rapeseed (Çalışır et al., 2005). However, the bulk density of Chia seed was lower than those reported by Ixtaina et al. (2008). The linear relationship between the bulk density of Chia and Kañiwa seed and moisture content could be represented by the equation (13) and (14) respectively. The values for the coefficient of determination were, R^2 of 0.81 for Chia and 1 for Kañiwa respectively.

$$\rho_b = 0.47 - 1.3 \times 10^{-2} M \tag{13}$$

$$\rho_b = 0.50 - 2 \times 10^{-3} M \tag{14}$$

The bulk density for Farro and Triticale showed similar trends, bulk density decreased as moisture content increased (Fig. 9 and 10) respectively. Our results were concurred with those obtained by (Tabatabaeefar, 2003) for wheat and (Al-Mahasneh and Rababah, 2007) for green wheat.

The variations in true density of Farro and Triticale with moisture content were shown in Fig.11 and 12. It revealed that the true density decreased from 1396 to 1337 kg/m^3 as moisture content increased. A similar decrease trend was observed for Triticale from 1393 to 1326 kg/m^3, when the moisture level increased from 10 to 20 % d.b. The trends in results were similar to true Caper seed (Dursun and Dursun, 2005), wheat (Tabatabaeefar, 2003), Moth gram (Nimkar et al., 2005), Guna seeds (Aviara et al., 1999) and hemp seed (Sacilik, et al., 2003). The true density and moisture content for Farro (eqn.15) and Triticale (eqn.16) can be correlated as follows:

$$\rho_t = 1453.5 - 5.93M \qquad (R^2 = 0.98) \qquad (15)$$

$$\rho_t = 1465.3 - 6.71M \qquad (R^2 = 0.92) \qquad (16)$$

Porosity

The porosity of the Farro and Kañiwa seed was found to increase linearly from 38.7 to 44.10 % for Farro and from 40.30 % to 44.60 % for Triticale when the moisture content changed from 10 % to 20 % (Fig. 13). Similar trends were reported by (Joshi et al., 1993) for pumpkin seed, (Vilche et al., 2003) for Quinoa seeds, (Dutta et al., 1988) for gram, (Ixtaina et al., 2008) for Chia seeds and (Abalone et al., 2004) for Amaranth seeds.

The linear relationship between the porosity and moisture content of the Farro (eqn.17) and Triticale (eqn.18) was obtained as

$$\varepsilon = 35.68 + 0.4282M \qquad (R^2 = 0.62) \qquad (17)$$

$$\varepsilon = 32.02 + 0.5461M \qquad (R^2 = 0.90) \qquad (18)$$

Angle of repose

The angle of repose for Chia, Kañiwa, Farro and Triticale at different moisture content were shown in Fig. 14. It was observed that the angle of repose increase with increase moisture content. The results indicated that the increase in angle of repose for Chia was 32.84 to 39.86 º as moisture content from 10 to 20 %, for Kañiwa the result show decrease at 15 % and increase again at 20 %. The angle of repose of Farro and Triticale increases linearly from 45 to 52.81 º and 38.59 to 46.86 º respectively. A linear increase in angle of repose when the seed moisture content increases have also been noted by Singh and Goswami (1996) for cumin seeds, Gupta and Das (1997) for sunflower seeds, Vilche et al. (2003) for quinoa seeds.

The relationship can be expressed in equation 19, 20, 21, 22 for Chia, Kañiwa, Farro and Triticale respectively.

$$\theta = 37.49 + 0.781M \qquad (R^2 = 0.98) \qquad (19)$$

$$\theta = 29.23 + 0.827M \qquad (R^2 = 0.83) \qquad (20)$$

$$\theta = 31.44 + 0.327M \qquad (R^2 = 0.51) \qquad (21)$$

$$\theta = 25.05 + 0.702M \qquad (R^2 = 0.87) \qquad (22)$$

The value of the angle of repose for Chia seeds obtained in this study was higher than those reported by Ixtaina et al. (2008).

Color

The value of color for Chia, Kañiwa, Triticale and Farro are shown in Table 2. For Chia seeds "*L*" varied between 42.00, 41.89 and 41.30 for corresponding moisture content of 10 %, 15 % and 20 %. *L* is the degree of lightness range from 0 for black and 100 for white, this means the color of Chia seeds is little bit dark in color and darkness increased as moisture content increased. Linear increased in "*a**" was observed in Chia from 3.19, 3.76, to 3.81 as moisture content increased from 10 % to 20 %. Likewise, the value of "*b**" increases as moisture content increases from 7.43, 8.55 to 8.61 as moisture content increased from 10 %, 15 % to 20 %. Mixed results for "*L*" and "*a**" was obtained for Kañiwa as indicated in Table 1. However, positive increases were observed for value of "*b**".

Moreover, for Farro, the value of "*L*" decreases as moisture content increases varied from 62.21 for 10 % to 56.43 for 20 % dry basis. On the other hand, the value of "*a**" increased from 8.09, 8.51, to 8.92 as moisture content increased from 10 %, 15 % to 20 % respectively. The mixed result was obtained for "*b**" value (Table 2). The "*L*" values of Triticale were 57.44 for 10 %, 58.13 for 15 % and 56.89 for 20 % dry basis; "*a**" varied between 9.13 for 10 %, to

15 % and 9.51 for 20 %. Likewise, the value of "*b**" increased as moisture content increased from 25.04, 25.31 and 26.57 for 10 %, 15 % and 20 % dry basis respectively.

Thermal conductivity, diffusivity and specific heat capacity

The variation of thermal conductivity for Chia, Kañiwa, Farro and Triticale with three levels of moisture contents is presented in Fig. 11. As the moisture contents increased from 10 to 20 % (d.b) thermal conductivity increased from 0.129 to 0.139 $Wm^{-1}K^{-1}$ for Chia, 0.138 to 0.164 $Wm^{-1}K^{-1}$ for Kañiwa, 0.137 to 0.220 $Wm^{-1}K^{-1}$ for Farro and 0.170 to 0.291 $Wm^{-1}K^{-1}$ for Triticale. The effect of moisture on the thermal conductivity was lower for Chia seeds and higher for Triticale. The positive linear relationship of thermal conductivity on moisture content was also observed for minor millet grains and flours (Subramanian and Viswanathan, 2003). The relationship between thermal diffusivity for Chia, Kañiwa, Farro and Triticale and moisture content is shown in eq. 23, 24, 25, and 26 respectively.

$$k_b = 0.123 + 0.001M \qquad (R^2 = 0.38) \qquad (23)$$

$$k_b = 0.113 + 0.0083M \qquad (R^2 = 0.97) \qquad (24)$$

$$k_b = 0.056 + 0.0083M \qquad (R^2 = 0.99) \qquad (25)$$

$$k_b = 0.074 + 0.0091M \qquad (R^2 = 0.96) \qquad (26)$$

The relationship between thermal diffusivity and different moisture contents are shown in Table 3. The uneven trend was observed for thermal diffusivity. For Chia, thermal diffusivity were 0.093 mm^2/s at 10 %, increased to 0.105 mm^2/s at 15 % and decreases to 0.093 mm^2/s at 20 %. Thermal diffusivity for Kañiwa were 0.092 mm^2/s at 10 % decrease to 0.091 mm^2/s for 15 % and 20 % moisture contents. The results concurred with the finding of (Kazarian and Hall, 1965; Dutta et al., 1988) for grain. For Farro, thermal diffusivity were 0.098 mm^2/s at 10 % and 15 % dry basis and increases to 0.103 mm^2/s at 20 % (d.b.). Likewise, a steady increase in thermal diffusivity with moisture contents was observed for Triticale from 0.102 mm^2/s, 0.105

mm^2/s and 0.115 mm^2/s at 10 %, 15 % and 20 % respectively. A similar linear trend was observed for gram (Dutta et al., 1988).

The variation of specific heat capacity for Chia, Kañiwa, Farro and Triticale with moisture content are shown in Fig. 12. It was observed that the specific heat of all samples increased linearly as moisture content increased from 10 % to 20 %, dry basis. The same trend was reported by Muir and Viravanichai (1972) for wheat, Cao et al. (2010) for wheat, Dutta et al. (1988) for gram, Bamgboye and Adejumo (2010) for roselle seeds Subramanian and Viswanathan (2003) for minor millet grains and flours and Hsu et al. (1991) for pistachios. The regression equation determined for predicting the specific heat of Chia, Kañiwa, Farro, and Triticale is indicated in eq. 27, 28, 29 and 30 respectively.

$$C_p = 1.274 + 0.0101M \qquad (R^2 = 0.63) \tag{27}$$

$$C_p = 1.196 + 0.0317M \qquad (R^2 = 0.97) \tag{28}$$

$$C_p = 0.676 + 0.0752M \qquad (R^2 = 0.97) \tag{29}$$

$$C_p = 2.265 + 0.0608M \qquad (R^2 = 0.99) \tag{30}$$

Conclusions

The following conclusions were drawn from the investigation of some physical and thermal properties for Chia, Kañiwa, Farro and Triticale at three levels moisture content (10 %, 15 % and 20 %). The average of length, width, thickness, arithmetic and geometric mean diameter, surface area, volume, sphericity and aspect ratio for Chia seed were 1.99 mm, 1.21 mm, 1.01 mm, 1.40 mm, 0.81 mm, 5.29 mm^2, 0.88 mm^3, 0.41 and 60.56 % respectively. For Kañiwa, the mean values were 1.14 mm, 0.92 mm, and 0.78 mm, 0.95 mm, 0.27 mm, 2.05 mm^2, 0.18 mm^3, 0.24, and 80.79 % respectively. Likewise, the average values for Farro were 7.69 mm, 3.39 mm, 3.11 mm, and 4.73 mm, 29.98 mm, 161.07 mm^2, 26.84 mm^3, 3.51 and 44.11 %

respectively. For Triticale, the average values were 7.52 mm, 3.32 mm, 3.06mm, 4.63mm, 25.45 mm, 0.20 mm^2, 20.71 mm^3, 3.39 and 44.20 % respectively.

One thousand seed weight increased linearly with a increase of moisture content. The bulk density decreased as moisture content increases from 729 to 458 kg/m^3 for Chia and 958 to 904 kg/m^3. The true density decreased with moisture content from 1396 and 1337 kg/m^3 for Farro and 1393 to 1326 kg/m^3 for Triticale as increased moisture content from 10 % to 20 %. Farro and Triticale porosity increased with moisture content in the range of 38.71 to 44.17 % and 40.37 to 44.65 % respectively. The angle of repose for Chia, Kañiwa, Farro and Triticale increased as moisture content increased from 10 to 20 % dry basis. In general, the values of L, a* and b* increased with moisture content. Thermal properties showed a very good correlation to moisture content. The linear decrease relationship was observed for the specific heat capacity and thermal conductivity while the thermal diffusivity had a linear increases trend to moisture content. From the experimental data, all physical and thermal properties evaluated showed simple linear moisture dependence relationships with good correlation coefficients.

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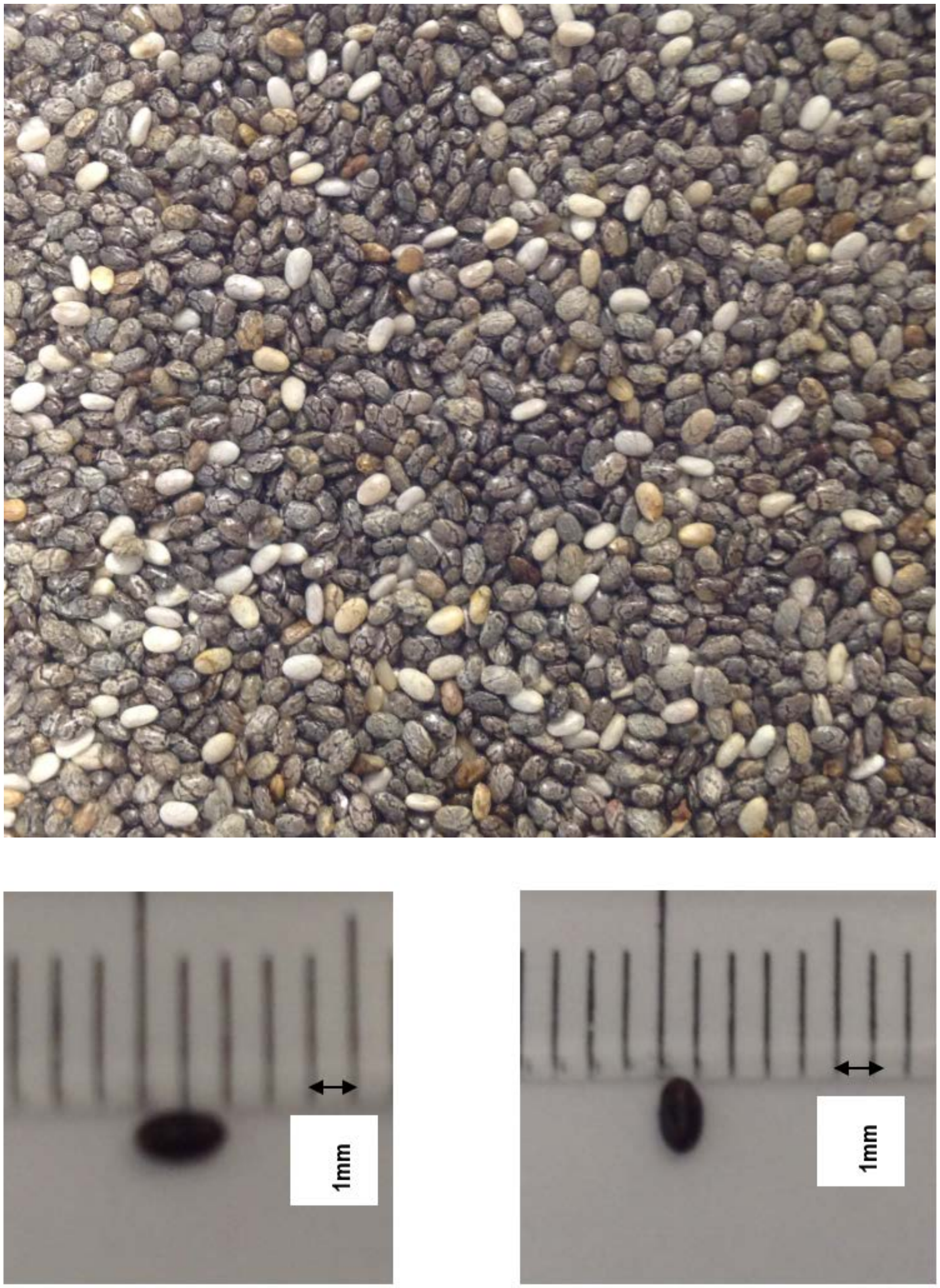

Figure 1. Chia seeds

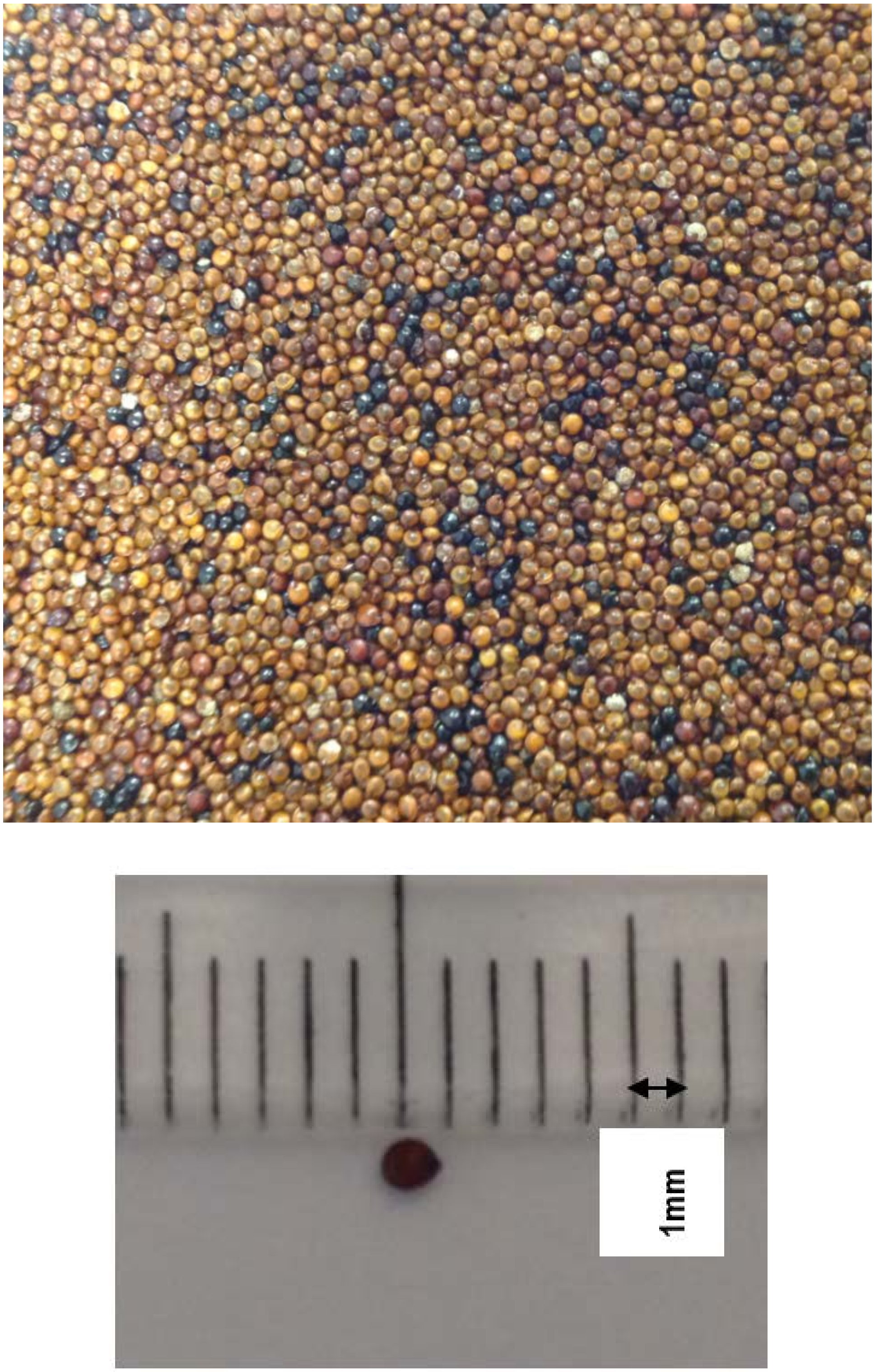

Figure 2. Kañiwa

Figure 3. Triticale

Figure 4. Farro

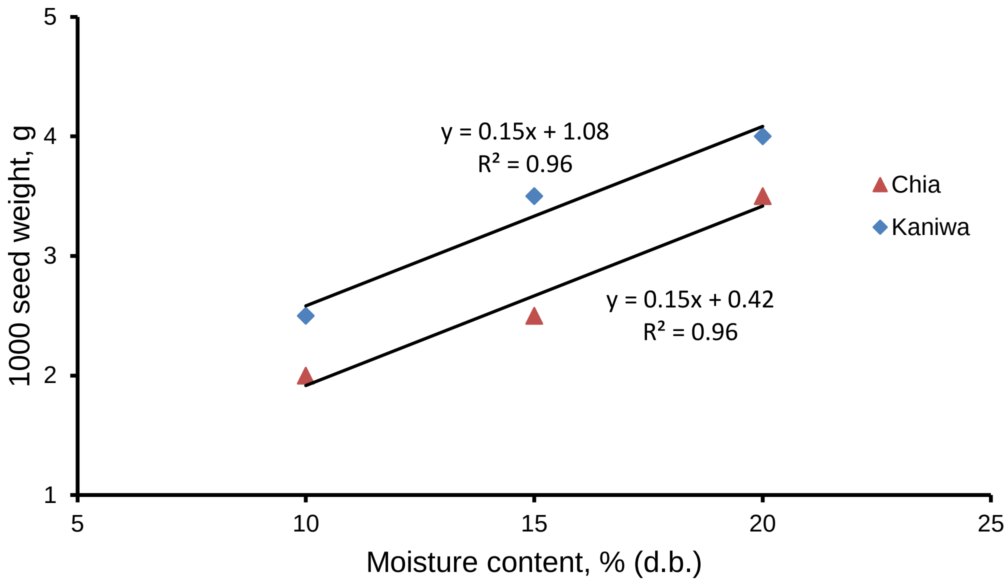

Figure 5. Effect of moisture content on 1000 seed weight for Chia and Kañiwa seed.

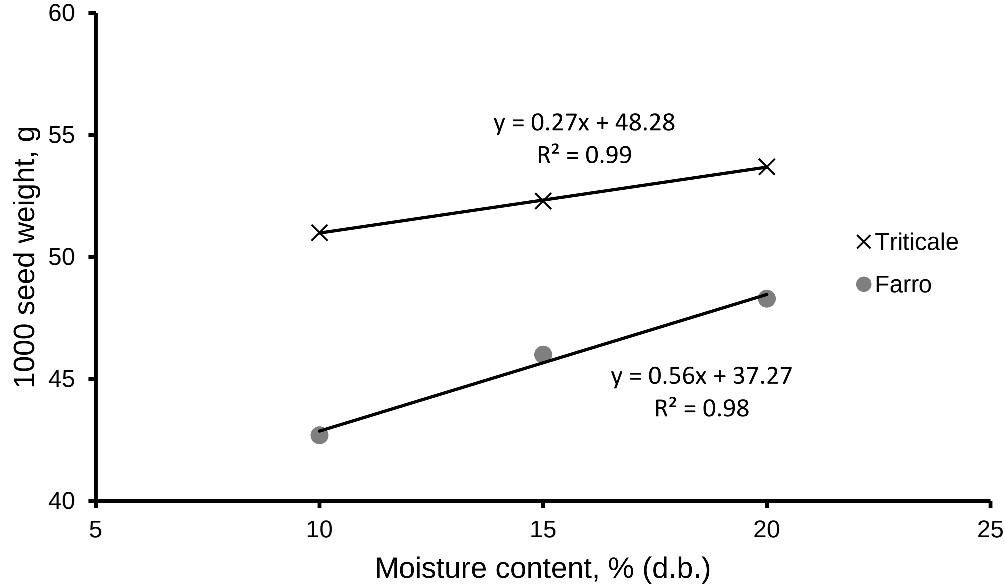

Figure 6. Effect of moisture content on 1000 seed weight for Triticale and Farro seed.

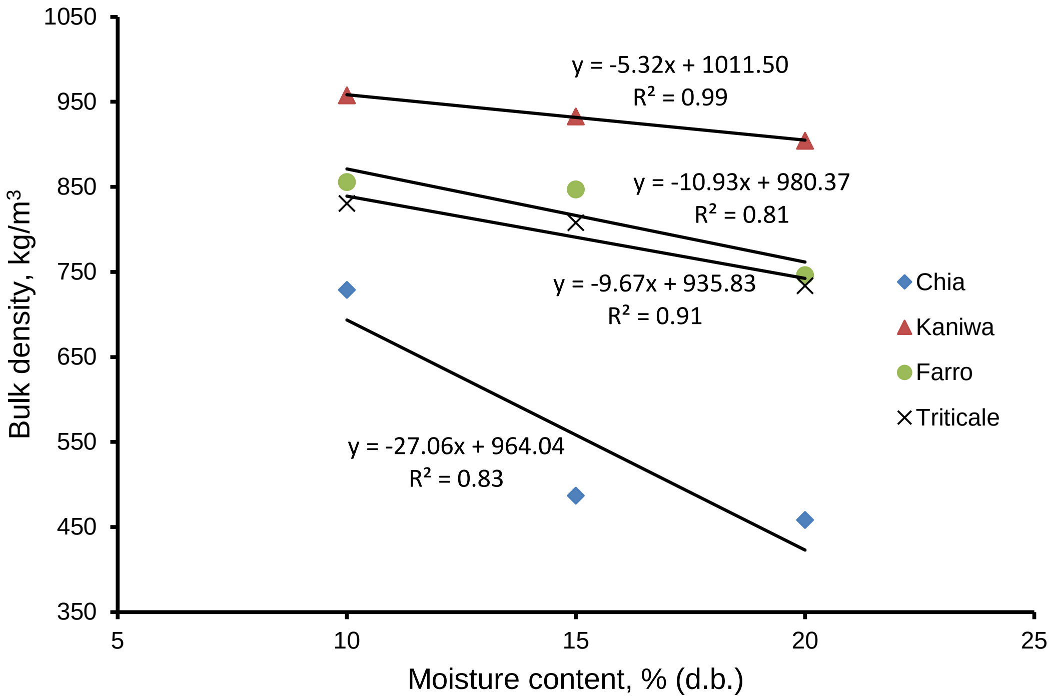

Figure 7. Effect of moisture content on bulk density for Chia seed, Kañiwa, Farro and Triticale.

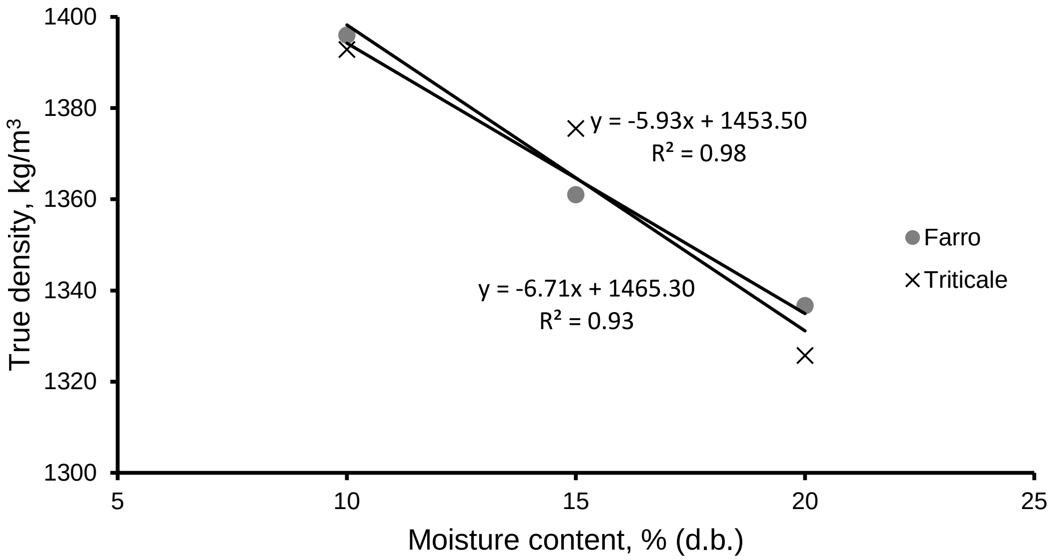

Figure 8. Effect of moisture content on true density for Farro and Triticale seed.

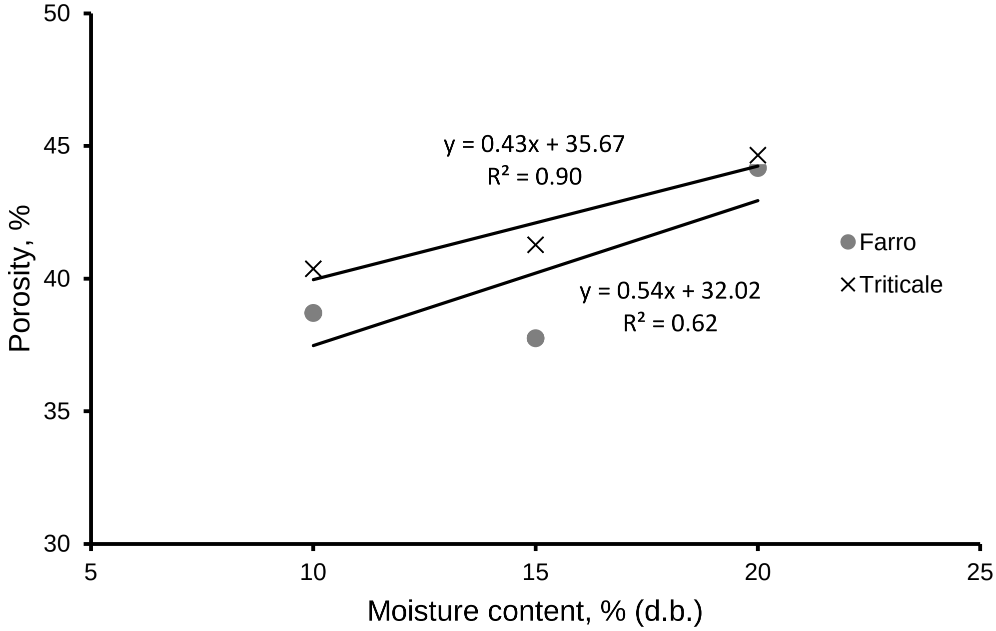

Figure 9. Effect of moisture content on porosity for Farro and Triticale seed.

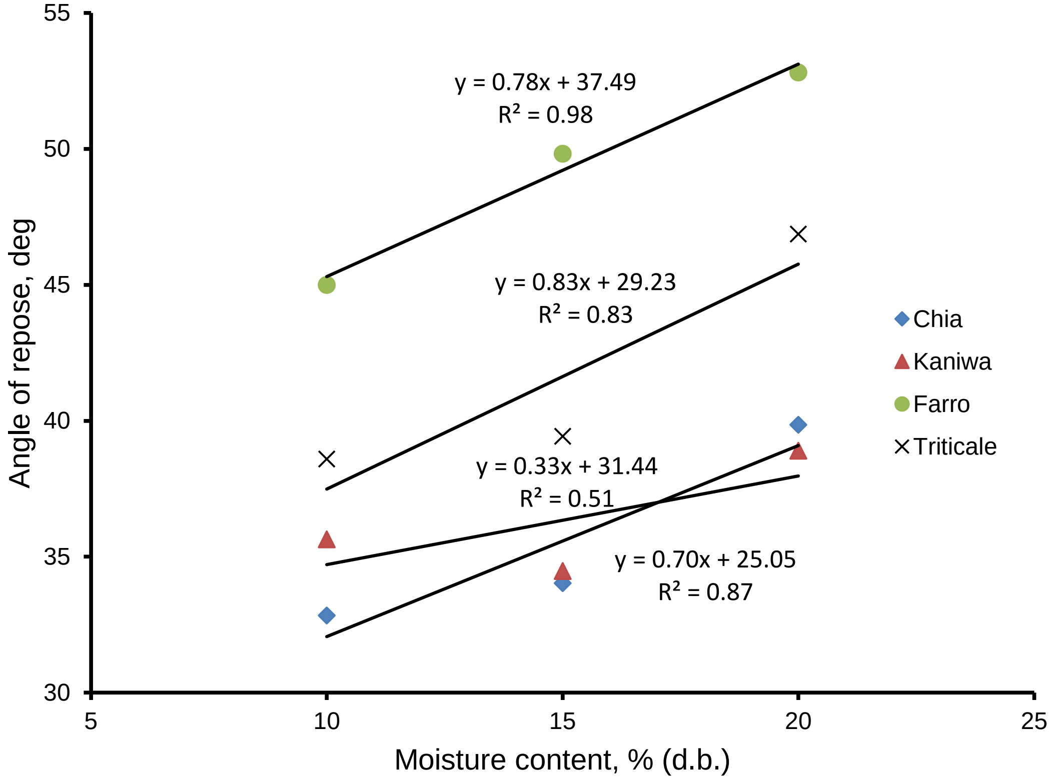

Figure 10. Effect of moisture content on angle of repose for Chia, Kañiwa, Farro and Triticale seed.

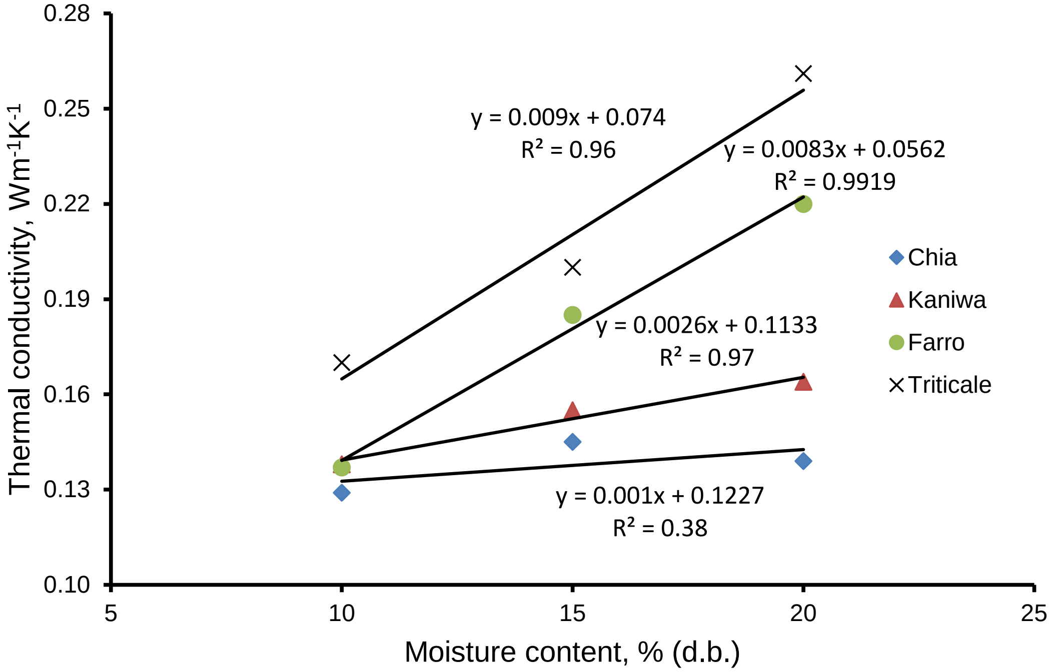

Figure 11. Effect of moisture content on thermal conductivity for Chia, kañiwa, Farro and Triticale seed.

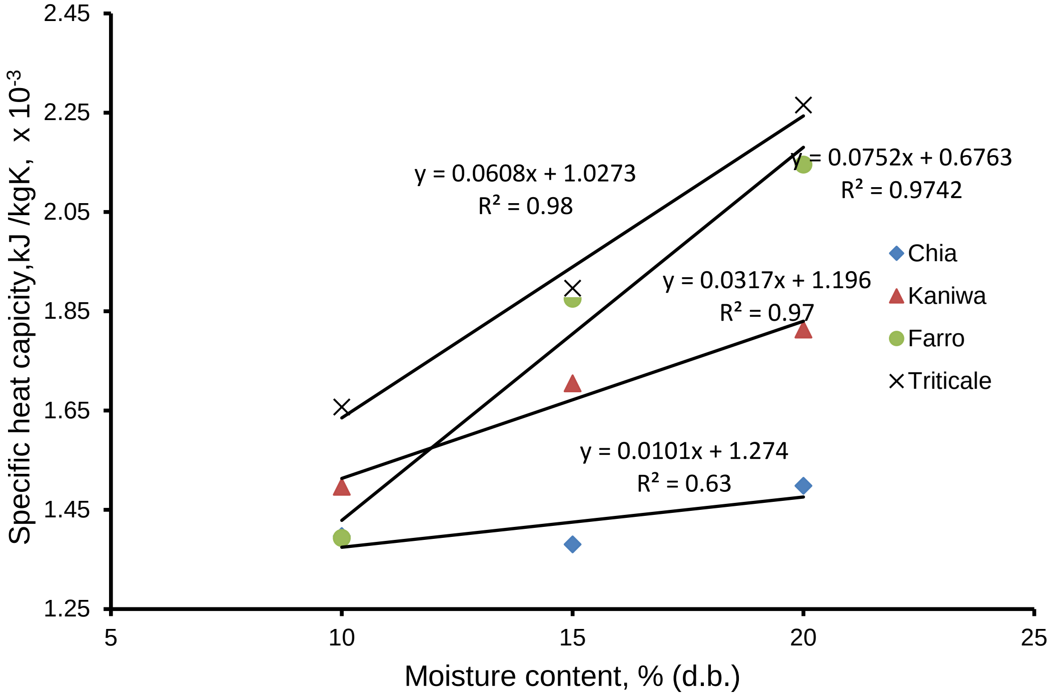

Figure 12. Effect of moisture content on heat capacity for Chia, Kañiwa, Farro and Triticale seed.

Table 1.

Physical properties of Chia, Kañiwa, Farro and Triticale.

	Parameter	*N*	*Mean value*	*Max value*	*Min value*	*SD*
Chia	Length *L*, mm	40	1.99	2.49	0.26	0.38
	Width *W*, mm	40	1.21	1.68	0.14	0.22
	Thickness *T*, mm	40	1.01	1.25	0.12	0.18
	Arithmetic mean dia, mm	40	1.40	1.81	0.17	0.26
	Geometric mean dia, mm	40	0.81	1.74	0.00	0.00
	Surface area *S*, mm^2	40	5.29	6.14	0.00	0.00
	Volume *V*, mm^3	40	0.88	0.83	0.13	0.00
	Sphericity ∅	40	0.41	0.70	0.01	0.01
	Aspect ratio *R*, %	40	60.56	67.23	55.29	0.59
Kañiwa	Length *L*, mm	40	1.14	1.45	0.13	0.20
	Width *W*, mm	40	0.92	0.12	0.13	0.18
	Thickness *T*, mm	40	0.78	1.08	0.12	0.16
	Arithmetic mean dia, mm	40	0.95	0.88	0.13	0.18
	Geometric mean dia, mm	40	0.27	0.06	0.00	0.00
	Surface area *S*, mm^2	40	2.05	2.31	0.07	0.00
	Volume *V*, mm^3	40	0.18	0.29	0.70	0.25
	Sphericity ∅	40	0.24	0.04	0.00	0.01
	Aspect ratio *R*, %	40	80.79	8.27	94.78	0.88
Farro	Length *L*, mm	40	7.69	8.83	0.68	0.07
	Width *W*, mm	40	3.39	4.03	0.33	0.59
	Thickness *T*, mm	40	3.11	3.85	0.38	0.58
	Arithmetic mean dia, mm	40	4.73	5.57	0.47	0.41
	Geometric mean dia, mm	40	26.98	45.75	0.03	0.01
	Surface area *S*, mm^2	40	161.07	178.88	8.06	0.00
	Volume *V*, mm^3	40	26.84	29.81	3.12	0.00
	Sphericity ∅	40	3.51	5.18	0.04	0.11
	Aspect ratio *R*, %	40	44.11	45.66	48.25	8.96
Triticale	Length *L*, mm	40	7.52	8.62	0.48	1.19
	Width *W*, mm	40	3.32	4.09	0.32	0.57
	Thickness *T*, mm	40	3.06	4.20	0.32	0.55
	Arithmetic mean dia, mm	40	4.63	5.64	0.37	0.77
	Geometric mean dia, mm	40	25.45	49.39	0.02	0.12

Parameter	*N*	*Mean value*	*Max value*	*Min value*	*SD*
Surface area *S*, mm^2	40	0.20	0.23	0.00	0.00
Volume *V*, mm^3	40	20.71	23.63	2.85	0.00
Sphericity ø	40	3.39	5.73	0.03	0.01
Aspect ratio *R*,%	40	44.20	47.46	66.05	0.48

N= number of observations, SD = standard deviation

Table 2.

Color characteristics for Chia, Kañiwa, Farro and Triticale at different moisture content

Moisture content, % d.b.	Constituent	*L*		*a**		*b**	
		Mean value	SD	Mean value	SD	Mean value	SD
10	Chia	42.00	0.29	3.19	0.08	7.43	0.19
	Kañiwa	29.80	0.54	11.31	0.31	12.98	0.66
	Farro	62.21	0.81	8.09	0.26	24.45	0.22
	Triticale	57.44	0.27	9.13	0.06	25.04	0.28
15	Chia	41.89	0.75	3.76	0.05	8.55	0.18
	Kañiwa	30.47	0.30	11.07	0.17	14.13	0.23
	Farro	60.20	0.24	8.51	0.23	25.85	0.97
	Triticale	58.13	0.94	9.13	0.31	25.31	0.67
20	Chia	41.30	0.15	3.81	0.03	8.61	0.26
	Kañiwa	29.84	0.28	11.92	0.15	14.82	0.27
	Farro	56.43	0.60	8.92	0.19	24.00	0.31
	Triticale	56.89	0.70	9.51	0.37	26.57	0.10

L= degree of brightness (0=black & 100=white), a = change from green to red, b* = change from yellow to blue, SD = standard deviation*

Table 3.

Thermal diffusivity for Chia, Kañiwa, Farro and Triticale at different moisture contents

Moisture content, % d.b.	Constituent	Thermal diffusivity, x 10^{-3} mm^2/s	
		Mean value	SD
10	Chia	93.00	2.00
	Kañiwa	92.00	2.00
	Farro	98.00	2.00
	Triticale	10.20	3.00
15	Chia	10.50	3.00
	Kañiwa	91.00	1.00
	Farro	98.00	2.00
	Triticale	10.50	3.00
20	Chia	93.00	0.00
	Kañiwa	91.00	1.00
	Farro	10.30	2.00
	Triticale	11.50	6.00

SD = standard deviation