J Food Sci Technol (January 2014) 51(1):104–110
DOI 10.1007/s13197-011-0469-y

ORIGINAL ARTICLE

Some physical properties of sun-dried Berberis fruit (*Berberis crataegina*)

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Revised: 23 June 2011 / Accepted: 15 July 2011 / Published online: 27 July 2011

Abstract The present study was conducted to evaluate some physical properties of sun dried Berberis fruit as a function of moisture content, varying from 9.59% to 27.90% (w.b.). Dried fruit length, width, thickness, geometric mean diameter and sphericity, increased nonlinearly from 7.19 to 7.53 mm; 3.42 to 4.03 mm; 2.78 to 3.02 mm; 4.05 to 4.51 mm and 0.56 to 0.62, respectively with increased moisture content. When we tested 1000-dried fruits, their mass increased linearly from 3.10 to 4.89 g, the true and bulk density increased nonlinearly from 769 to 845 kg m^{-3} and 389 to 395 kg m^{-3}, respectively; with increased moisture content. Also, porosity values of dried fruits increased nonlinearly from 49.40% to 53.30%. The lowest static coefficient of friction was found on the steel surface. The angle of repose increased nonlinearly from 20.14° to 23.20° with the increasing in the moisture content.

Keywords Dried fruits · *Berberis crategenia* · Physical properties · Moisture content

Introduction

Fruits of Berberis species of wild plants are frequently encountered in the Central Anatolia region of Turkey. Fruits of Berberis species are widely consumed in Turkey since very ancient times, because of their antipyretic and diuretic effects (Baytop 1963).

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Epidemiological studies have shown a negative association between intake of fruit and vegetable containing anthocyanin and certain diseases (Prior and Cao 2000; Kaur and Kapoor 2001). This relationship has increased interest in diets containing fruits and vegetables. The interest in wild fruits used in direct human food, pharmaceutical and cosmetic raw material and alternative medicine has also increased. An in vivo study to evaluate the effect of dried berberry (*Berberis vulgaris*) fruit on some blood parameters of laying hens has shown that dried berberry fruit has significantly ($P<0.05$) changed hematocrit value and HDL-cholesterol and LDL-cholesterol. It was concluded that use of dried berberry fruit as a phytochemical compound may improve some of the blood parameters and possibly egg components that are important for human health (Kermanshahi and Riasi 2006). Fruits of Berberis sp. are edible and rich in vitamin C and contain a large amount anthocyanin (Wallace and Giusti 2008; Akbulut et al. 2009; Parichehr and Golkho 2009). Anthocyanins and other phenolic compounds are potent scavengers of free radicals, although they can also behave as pro-oxidants (Konczak and Zhang 2004).

There are four Berberis sp. in Turkey. *Berbeis crataegina* DC. and its hybrids are widespread (Yeşilada and Küpeli 2002). *Berberis crataegina* belongs to the family Berberidaceae, and grows wild in Asia and Europe; the plant is well known in Turkey. It is a deciduous shrub growing up to 2 m high. The leaves are small, oval in shape and their flowers are yellow. The fruits of the plant vary from dark purple to black in colour, ripening in late summer or autumn (Baytop 1963). *Berberis crataegina* fruits are known by different names in Turkish such as "karamuk" and "kadın tuzluğu" (Baytop 1994). All parts of this plant are used worldwide in traditional medicine for the treatment of various diseases (Baytop 1999).

Berberis (*Berberis crataegina*) fruits are processed as natural juices, marmalades and jellies and they are also dried in sun (Baytop 1994). Sun-dried fruits are very important in a part of daily diet of Anatolian people because of possible health benefits (Baytop 1994) and also because dried fruits are used mainly as snack food. Moisture content of sun-dried fruits depends on the weather, the temperature and relative humidity outside and also manufacturers. Therefore dried Berberis fruits have different moisture contents. After cleaning and separating processes, appropriate packing of dried Berberis fruits will protect the product from external factors and will increase the possibility of entering into the market as a snack food. Therefore, physical properties of dried Berberis fruits are very dependant on the design of equipment and facilities for the drying, preservation and packaging of dried fruits and these parameters are also very important for industrial products such as colored edible powder form dried berberis fruits.

The physical properties of various seeds and fruits as a function of moisture content were studied such as hackberry by Demir et al. (2002), caper seed by Dursun and Dursun (2005), pomegranate seeds by Kingsly et al. (2006), flaxseed by Coşkuner and Karababa (2007a), olive fruits by Kılıçkan and Güner (2008), chickpea seed by Nikoobin et al. (2009), cornelian cherry by Nalbandi et al. (2009), jatropha fruit by Pradhan et al. (2009), locust bean seed by Sobukola and Onwuka (2010) and paddy rice by Adebowale et al. (2010).

In this study, some moisture dependent physical properties of dried Berberis fruits were investigated; namely, linear dimensions, geometric mean diameter, mass of 1,000 dried fruits, true density, bulk density, porosity, angle of repose, and static coefficient of friction against three structural surfaces at different levels of moisture content.

Material and methods

Sample preparation

Mature Berberis (*Berberis crategenia)* fruits were collected from shrubs growing wild in Sivas province of Turkey in September 2009. Berberis fruits were cleaned to remove all foreign material; damaged parts, immature fruits and then fruits were sun-dried. In the sun-drying process, Berberis fruits were placed on a drying tray and covered with netting to keep off dust and insects, and then the tray was placed in direct sunlight on a roof away from animals and traffic exhaust. Drying process of Berberis fruits lasted 7 days. Initial moisture content was determined according to standard AOAC vacuum oven method (AOAC 1984). After drying the fruits, the initial moisture level was 9.59%.

Preliminary experiments done with sun-dried berberis fruits obtained from different manufacturers showed that moisture content varied in the range of 10–20%. Therefore, dried Berberis fruits were moistened near these moisture values and extreme moisture values were also included in the study. Dried Berberis fruits were moistened to obtain desired moisture content by adding the amount of distilled water as calculated from the following formula:

$$Q = \frac{W_i(Mf - Mi)}{(100 - Mf)} \quad (1)$$

Where Q is the mass of water added in kg; Wi is the initial mass of the sample in kg; Mi is the initial moisture content of the sample in %w.b and Mf is the final moisture content of the sample in %w.b.

Dried fruit samples with the desired moisture content were placed in separate polythene bags and the bags were sealed tightly. All of bags were stored in a refrigerator at 5 °C for 1 week, so that the moisture was distributed uniformly throughout the sample. Before each test, the required quantity of dried fruit was taken out of the refrigerator and allowed to warm up to room temperature and moisture content was determined.

All physical properties were determined at the moisture content of 9.59, 13.42, 18.30, 22.80 and 27.90%w.b.

The experiments were replicated three times at each moisture level and the average values were reported. The relationships between all physical properties and moisture content of dried Berberis fruit were evaluated by analysis of regression using SPSS software package for Windows version 11.0 (2008 SPSS Inc.).

Dimensions and sphericity

To determine the dimensions of the dried Berberis fruits, hundred dried fruits were randomly selected at the desired moisture content. Then length (L), width (W) and thickness (T) of the dried fruits were measured using a micrometer with an accuracy of ±0.01 mm.

The geometric mean diameter, Dg, and sphericity, Φ, of the dried fruits were calculated by using the following relationships (Mohsenin 1980),

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

$$\phi = \frac{(LWT)^{1/3}}{L} \quad (3)$$

where L is dried fruit length, W is dried fruit width and T is dried fruit thickness, all in mm.

1000-dried fruit mass

The mass of 1000-dried fruits was determined by counting 100 dried fruits at the desired moisture content and weighing on a digital electronic balance and then multiplying by 10 to give the mass of 1000-dried fruits.

True and bulk density

The dried Berberis fruits' true density (q_t) as a function of moisture content was determined by using the liquid displacement method. Toluene was used instead of water in order to avoid absorption of water during the experiment. Fifty milliliter of toluene was placed in a 100 ml graduated measuring cylinder and 5 g dried fruit was immersed in toluene. The amount of displaced toluene was recorded from the graduated scale of the cylinder. The true density (kg m^{-3}) was found as the ratio of mass of dried fruit to the volume of displaced toluene (Coşkuner and Karababa 2007b; Nikoobin et al. 2009).

To determine the bulk density (q_b), a 100 ml cylindrical glass container was filled completely with dried Berberis fruits. The container was tapped several times and the excess dried fruits were removed without compressing the fruits. Then, its content was weighted by an electronic balance. Bulk density (kg m^{-3}) was calculated by taking the ratio of mass of dried fruit to their bulk volume (Coşkuner and Karababa 2007b; Kahyaoğlu et al. 2010; Karaj and Müler 2010).

Porosity

The porosity of dried berberis fruit at various moisture contents was calculated from its bulk (q_b), and true (q_t) densities using the relationship given by Mohsenin (1980) as follows.

$$\varepsilon = \frac{q_t - q_b}{q_t} \times 100 \tag{4}$$

where q_b and q_t are the bulk density and the fruit density, respectively.

The static coefficient of friction

The static coefficient of friction of dried Berberis fruit was determined on knitted bag, steel and rubber sheets. An open-ended PVC cylinder of 50 mm diameter and 50 mm height was filled with the dried fruit at the desired moisture content and placed on an adjustable tilting table made from steel. When the tilting table was still horizontal, the cylinder was raised slightly to avoid contact between it and the friction surface. The tilting surface was raised gradually with a screw device until the cylinder with dried fruit just began to slide down and the angle of tilt was read with a graduated scale mounted on the tilt table. The tangent of this angle was used as the static coefficient of friction for that surface (Karababa and Coşkuner 2007; Coşkuner and Karababa 2007a; Pradhan et al. 2009; Singh et al. 2010).

Angle of repose

A plywood box 15×15×15 cm^3 with a removable front panel was used to determine the dynamic angle of repose. The box was filled with the dried fruits at the moisture content being investigated, and the front panel was quickly removed allowing the dried fruits to flow to their natural slope. The angle of repose was determined from measurements of height of dried fruits, H, at two points in the sloping dried fruits and the horizontal distance, X, between the two points using the relation

$$\theta = \tan^{-1}\left[\frac{H}{X}\right] \tag{5}$$

This method has been used by other researchers for other grains and seeds (Baryeh and Mangope 2002; Bart-Plange and Baryeh 2003; Nikoobin et al. 2009).

Result and discussion

Dimensions of dried Berberis fruits

The dimensions of dried Berberis fruits at different moisture content are presented in Table 1. Regression analysis of the experimental data showed a polynomial relationship between length, width, thickness and moisture content of dried fruits (Fig. 1). The dimensions of dried Berberis fruits had the following relationship with moisture content.

$$L = -0.0011M^2 + 0.0578M + 6.7338;\ R^2 = 0.999 \tag{6}$$

$$W = -0.0006M^2 + 0.0593M + 2.8822;\ R^2 = 0.981 \tag{7}$$

$$T = -0.0026M^2 + 0.1104M + 1.9536;\ R^2 = 0.982 \tag{8}$$

All the dimensions of dried fruit were significantly correlated to their moisture content ($p<0.01$) and their dimensions increased within the moisture range of 9.59–27.90% (wb). This indicates that, the capillaries and voids in dried fruit were filled with water as a result of the increase in moisture content of the fruit and then the fruits swelled and their axial dimensions increased. However, the increase was not the same in all dimensions. The total average expansion when moisture content was increased from 9.59% to 27.90% was the largest along the fruit width and thickness, respectively and least along its length. Reddy and Chakraverty (2004), have found similar results with raw paddy.

Table 1 Axial dimensions of dried Berberis fruit

Moisture content % (w.b)	Length (L) mm	Width (W) mm	Thickness (T) mm	Geometric mean diameter (Dg) mm
9.59	7.2±0.39	3.4±0.25	2.8±0.18	4.1
13.42	7.3±0.39	3.5±0.27	2.9±0.30	4.3
18.30	7.4±0.29	3.8±0.26	3.1±0.32	4.4
22.80	7.5±0.26	3.9±0.19	3.2±0.21	4.5
27.90	7.5±0.34	4.0±0.20	3.0±0.22	4.5

The geometric mean diameter was larger than the thickness and width. Similar results reported for bambara groundnuts (Baryeh 2001), coriander seed (Coşkuner and Karababa 2007b), jatropha fruit by (Pradhan et al. 2009) and wheat (Nalbandi et al. 2010). Such dimensional changes are important in sizing, sorting, grinding and other separation process

Sphericity

Sphericity of dried fruits was in the range of 57%–60% (Fig. 1). The experimental data showed a nonlinear trend with the moisture content (in % w.b.) in the moisture range evaluated. These results are in agreement with published literature for bambara groundnuts (Baryeh 2001), coriander

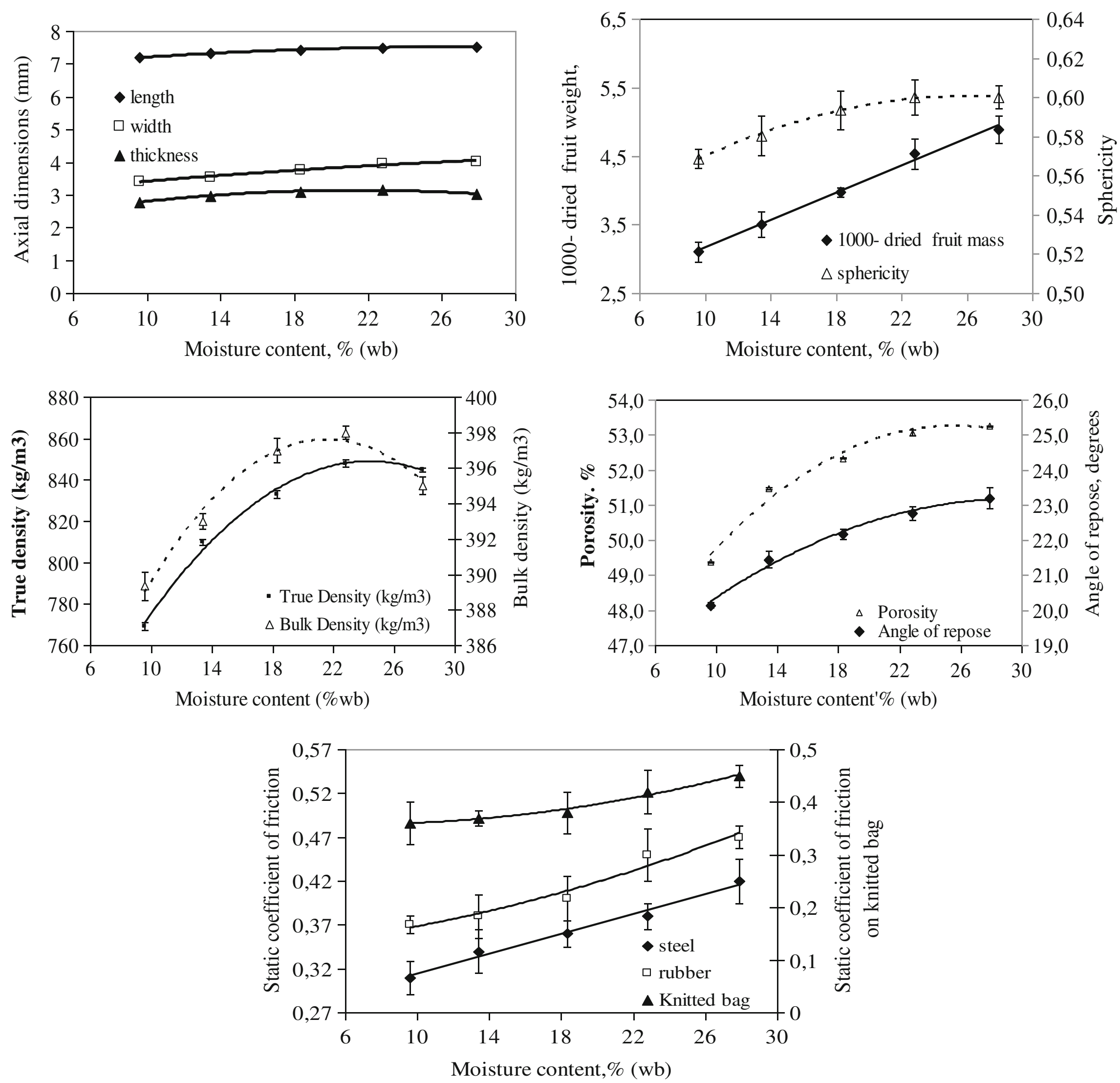

Fig. 1 Effect of moisture content on physical characteristics of friction of dried Berberis fruit (n=100 for axial dimensions and sphericity; n=3 other physical properties at each moisture level)

seeds (Coşkuner and Karababa 2007b), barnyard millet grains and kernels (Singh et al. 2010). The relationship between sphericity and moisture content of dried Berberis fruit was significant ($p<0.01$) and the variation in sphericity with moisture content can be expressed by the following equation.

$$\phi = -0.0001M^2 + 0.0062M + 0.5195; R^2 = 0,997 \quad (9)$$

Sphericity of dried Berberis fruits was found close to safflower seeds (Baümler et al. 2006) and wheat (Nalbandi et al. 2010). However, it was lower than those reported for chickpea seeds (Konak et al. 2002), popcorn (Karababa 2006), caper fruits (Sessiz et al. 2007) and cornelian cherries (Nalbandi et al. 2009). Sphericity value is essential in designing separation and sizing equipment. These low sphericity values shows that dried Berberis fruits tend to slide rather than roll on specific surface.

Thousand fruit mass

The mass of 1,000 dried Berberis fruits, M_{1000}, in g increases linearly from 3.10 to 4.89 g as the moisture content, M, increases from 9.59% to 27.90 w.b. (Fig. 1). This relationship was significant ($p<0.01$) and the linear equation for 1,000 fruit mass can be formulated as

$$M_{1000} = 0.1001M + 2.1581; \; R^2 = 0,994 \quad (10)$$

A similar trend was reported for other fruits and seeds (Dursun and Dursun 2005; Aydın and Özcan 2007; Karababa and Coşkuner 2007; Sessiz et al. 2007; Pradhan et al. 2009; Balasubramanian and Viswanathan 2010).

True and bulk density

The true and bulk density values of dried Berberis fruits increased when the moisture content increased until 22.80% and then density values decreased with increasing moisture content (Fig. 1). Increase in the moisture content between 9.59% and 22.80% leads to increase both weight and volume of dried fruits. However the mass of dried fruit increased more than their volume in this range. The bulk and true density of dried fruits can be represented by following polynomial equations.

$$q_b = -0.0599M^2 + 2.588M + 369.69; \; R^2 = 0.984 \quad (11)$$

$$q_t = -0.3561M^2 + 17.381M + 636.85; \; R^2 = 0.994 \quad (12)$$

The variation in bulk density and true density with moisture content was significant at a significance level of 0.05 and 0.01, respectively. Linear increase of true and bulk density as the moisture content increases was found by Aydın and Özcan (2002) for terebinth fruits and by Kingsly et al. (2006) for pomegranate seeds while the negative linear relationship of bulk and true density with moisture content was also observed by various research workers (Nimkar and Chattopadhyay 2001; Dursun and Dursun 2005; Balasubramanian and Viswanathan 2010). Polynomial relationship was reported between true/bulk density and increasing moisture content for pigeon peas by Baryeh and Mangope (2002), safflower seeds by Baümler et al. (2006) and barnyard millet grains and kernels by Singh et al. (2010). These differences in results could be due to the cell structure, and the volume and mass variation characteristics of grains and seeds as moisture content increases (Baryeh 2002). The true and bulk densities of dried Berberis fruits at 27.90% moisture levels are found to be lower than that of fresh barberries (*Berberis vulgaris* L.) fruits (Akbulut et al. 2009).

Porosity

As shown in Fig. 1 porosity, ε, of dried Berberis fruits increased nonlinearly as the moisture content increased. Porosity of the dried fruits was 49.4% at the moisture content of 9.59% and then increased nonlinearly to 53.3% at 27.90% moisture content. This indicated that less number of dried fruits can be stored at 27.90% moisture content than at 9.59% moisture content. The relationship between porosity and moisture content was significant ($p<0.05$) and the variation in porosity (ε) with moisture content (M) of dried Berberis fruits can be described by the following equation

$$\varepsilon = -0.0147M^2 + 0.7495M + 43.708; \; R^2 = 0.980 \quad (13)$$

A similar porosity variation was found for pigeon peas and millet grains (Baryeh and Mangope 2002; Baryeh 2002). Coşkuner and Karababa (2007b) found that porosity of coriander seeds decrease nonlinearly as the seed moisture content increases from 7% to 12.87%; then it increases nonlinearly as the seed moisture content increases from 12.87% to 18.94%. Variation in porosity depends on the bulk and true densities. The bulk and true density of each seed, fruit or grain definitely vary with increasing moisture content. Therefore porosity values of each seed or fruit are also variable.

The angle of repose

Variations of the angle of repose of dried Berberis fruits, against moisture content in the range of 9.59%–27.90% wb are shown in Fig. 1. The angle of repose increased nonlinearly with increase in moisture content ($p<0.01$).

The moisture dependence of angle of repose is described by a polynomial equation as follows

$$\theta = -0.0074M^2 + 0.4363M + 16.731;\ R^2 = 0.990 \quad (14)$$

The angle of repose is a characteristic of bulk material that indicates the cohesion among the individual fruits and the surface layer of moisture surrounding the individual fruits holding the aggregates together by the surface tension (Pradhan et al. 2009). Previous researches reported linear increasing trends with increasing moisture content in angle of repose for some seeds, grains and fruits (Dursun and Dursun 2005; Coşkuner and Karababa 2007a; Sessiz et al. 2007). Our results are similar to those reported for bambara groundnuts, cocoa beans, coriander seeds and barnyard millet grains and kernels (Baryeh 2001; Bart-Plange and Baryeh 2003; Coşkuner and Karababa 2007b; Singh et al. 2010).

The static coefficients of friction

The static coefficients of friction for dried Berberis fruit on various surfaces at different moisture contents are shown in Fig. 1. Based on the surface used, the static coefficient of friction increased linearly or non-linearly with increase in moisture content for all contact surfaces ($p<0.05$). The relationships between static coefficient of friction, μ, and moisture contents, M, on steel, rubber and knitted bag are described by linear and polynomial equations as follows

$$\mu_{steel} = 0.0057M + 0.258;\ R^2 = 0,984 \quad (15)$$

$$\mu_{knittedbag} = 0.0002M^2 - 0.0025M + 0.3652;\ R^2 = 0,981 \quad (16)$$

$$\mu_{rubber} = 0.0001M^2 + 0.0016M + 0.341;\ R^2 = 0,963 \quad (17)$$

The moisture dependence of the static coefficient of friction may be attributed to the increase in the bulk density and cohesion of dried fruits as well as the increased adhesion between the dried fruits and those surfaces (Nwakonobi and Onwualu 2009; Nalbandi et al. 2010). For the entire moisture content range, the highest friction was observed for rubber, followed by knitted bag and steel surfaces. Static coefficient of friction is the lowest against steel and this may be because of smoother and more polished surface of the steel sheet relative to the other surface materials used. Our results are in good agreement with previous researchers' for stainless steel (Özarslan 2002; Coşkuner and Karababa 2007b; Sobukola and Onwuka 2010).

Conclusions

In this study, some physical properties of dried Berberis fruits were investigated in the range of moisture contents from 9.59% at 27.90% (w.b.). The results show that the average width, thickness, geometric mean diameter, true density, bulk density, porosity, angle of repose, and static coefficient of friction of dried Berberis fruits against three structural surfaces increased polynomially with the increase in moisture content. The knowledge on the physical properties of dried Berberis fruits, like those of other grains and seeds would allow the design of equipment and processes for handling, conveying, separation, drying, packing and storing of dried Berberis fruits and the development of alternative drying and packing processes. Physical properties are affected by numerous factors such as size, form, superficial characteristics and moisture content of the dried fruit. The results of the analysis indicate that moisture content is one of the factors to consider in the design of handling and processing facilities for dried Berberis fruits.

It is recommended that mechanical, thermal, and rheological properties should also be investigated to provide a fairly comprehensive advice on design parameters involved in drying and packing process of Berberis fruits.

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