RESEARCH ARTICLE

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Some physical properties of bitter gourd (*Momordica charantia* L.) seeds and kernels

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Abstract

A noteworthy member of the *Cucurbitaceae* family, the bitter gourd (*Momordica charantia* L.) is a slender, vine-like annual summer vegetable. Despite the health promoting features, it is among the neglected vegetables in terms of both production values and scientific studies. The current study was aimed to assess some physico-mechanical properties of bitter gourd seeds and kernels viz., sizes, geometric shapes, angle of repose, densities, 1000-seed and kernel weight and, coefficient of friction on several surfaces (aluminum, chrome, iron, plastic, rubber, cardboard, glass and MDF wooden panel) in order to determine to important parameters to design seed sowing machines the materials to be used in storage and their design, the screening/separation/classification processes and the processing of bitter gourd into a commercial product. It has been observed that the seeds of bitter gourd have similar geometrical properties with the seeds of melon, watermelon, squash and cucumber from the *Cucurbitaceae* family. While closer values were observed in terms of length and width, it was determined that the seeds of bitter gourd were thicker. The lengths, widths, and thicknesses of these seeds/kernels with a moisture content of 16% (w.b.) according to the wet base were found to be 14.176/11.517, 7.562/5.922, and 4.076/2.815 mm, respectively. The angle of repose, thousand grain weight and true density of seeds/kernels were found 28.467/26.982°, 202.931/118.359 g and 0.919/1.659 g/cm^3 respectively. Obtained results most likely can serve bitter gourd to be grown in large amounts in different part of the world where the climate is suitable for growing.

Keywords: Bitter melon, Cucurbitaceae, Physical properties, Vegetable seed

INTRODUCTION

The bitter gourd (*Momordica charantia* L.) is a thin vine-like annual summer vegetable and is one of the worthy members of the *Cucurbitaceae* family (Grover and Yadav, 2004; Yan et al., 2019). It is well-known for different kinds of names in the world, such as bitter melon, balsam pear or karela, kugua, and kudret nari. It is commonly grown in tropical parts of the world and is popular due to its medicinal value. Although the demand for this vegetable has increased in recent years, only production data for the years 2021 (66 tons), and 2022 (84 tons) are given by the Turkish Statistical Institute (TUIK) (TUIK, 2023). These values show the potency of bitter gourd, which has many benefits, but yet to get enough attention as plant. There is no doubt that importance given to these neglected crops will increase in next coming years.

The fruits of the bitter gourds have a rough texture with a pointy apex and are 8-15 centimeters in length and 4-10 centimeters in breadth. The fruit, which starts off green in color and grows to yellow and golden yellow, has approximately 25 dark red, bean-like seed within. Seeds or seedlings are used to cultivate bitter gourds, but cultivating with seedlings is advisable because the germination rate is not 100% (Baryeh, 2002; Ünal et al., 2013).

In agricultural processes sowing, caring for, harvesting, and handling activities for the crop are key factors, and research on developing tools and equipment and conducting modeling studies associated with these processes is equally important. It has been observed that the basic physical properties of seeds and kernels of various vegetables have a very important role in the design, use and control of processing equipment (Amin et al., 2004). Understanding the characteristics of biological materials such as seeds are vital for engineers as well as food technologists, processors, breeders, and experts from other domains who could find novel applications for it (Mohsenin, 1986; Pradhan et al., 2013).

The physical characteristics of the seeds or kernels provide the basis for the design of various kinds of cleaning, classifying, separating, and oil extraction equipment. When developing machines for separating, sorting, grinding, and flow ability characteristics the size and form of the seeds are crucial. On the other hand, moisture content is required to predict the drying period of seeds.. For the designing of aeration, drying, preservation, and transport-related machinery, an understanding of gravimetric qualities such as bulk and true density, 1000-seed mass, and porosity are crucial considerations because these have an effect on the resistance of mass to airflow (Amin et al., 2004; Dash et al., 2008; Ekinci et al., 2010; Pradhan et al., 2013). When designing a pneumatic conveyor, the terminal velocity is crucial (Vilche et al., 2003; Dursun and Dursun, 2005; Pradhan et al., 2013). The angles of repose, friction coefficient as well as other frictional qualities are essential when creating transportation equipment, grain containers, and some other storage facilities (Pradhan et al., 2013). Typically, threshing is done with handmade threshing equipment on a firm floor. Thus, its physical characteristics must be well understood in order to maximize the bitter gourd's threshing efficiency, pneumatic transportation, and preservation (Unal et al., 2013; Yilmaz and Altuntas, 2020).

The bitter gourd has so many significant therapeutical and health-promoting properties for good wellness. Despite having several beneficial qualities, the bitter gourd is hardly seldom planted and unfortunately one of the neglected vegetables in the world. For widespread cultivation of the bitter gourd all over the world, it is necessary to steer with some agricultural processes. Similar to other crops, the physical characteristics of bitter gourd seed are crucial for the design of machinery for handling, selecting and collecting, processing, as well as preserving kernels.

In recent years, some research has been conducted on various crops such as chickpea seed (Konak et al., 2002), faba bean (Haciseferogullari et al., 2003), watermelon seed (Koocheki et al., 2007), and bottle gourd seed (Pradhan et al. 2013) for the purpose of studying the physical characteristics of seeds in order to similar aims (Aghkhani et al., 2012; Ünal et al., 2013; Pradhan et al., 2013). However, there were limited studies carried out concerning the physical properties of bitter gourd seed.

Thus, in the present study, the physico-mechanical properties of bitter gourd seeds and kernels were characterized in order to determine their potential. The current study documents a number of physical characteristics of bitter gourd seeds and kernels, including their principal dimensions, geometric shapes mean diameter, sphericity, 1000 seed and kernel weight, porosity, angle of repose, as well as coefficient of friction when placed on a variety of surfaces, such as aluminum, 304 stainless steel (chrome), ST-37 black sheet (iron), plastic, rubber, cardboard, glass and MDF wooden panel. The current study aims to find the results to be used in the cleaning, separation, transportation, storage, drying and sowing of bitter gourd seeds and kernels.

MATERIALS AND METHODS

Plant material

Bitter gourd fruits were obtained at approximately similar size, appearance and ripeness from center of Antalya province (36°53′10.1″ N 30°45′23.4″E) in Türkiye. Fruits were washed of under running tap water to remove dust, dirt, stones, and chaff matter. The seeds were manually separated from cleaned fruits and experiments were carried out by removing damaged, broken, and hollow seeds in order to perform uniform operations with a standard measurement system (Figure 1).

Figure 1. Bitter gourd seeds, kernel and shells

Method

Digital calipers were used with 0.01 precision (Mitutoyo, 150x0.01) for determining the dimensional properties of bitter gourd seeds (length (L_s), width (W_s) and thickness (T_s)) and kernels (length (L_k), width (W_k) and thickness (T_k)). In addition, the shells of the seeds were opened and their shell thickness T_{ss} (mm) was measured. In the abbreviations of the measured parameters, the subscript "s" for seeds and "k" for kernels are used. Experiments were carried out with 100 randomly selected seeds. By using these measurements, the geometric mean diameter (D_{gs}/D_{gk}) (mm), sphericity (S_{ps}/S_{pk}) (%), aspect ratio (R_{as}/R_{ak}) and seed surface areas (S_s/S_k) (mm^2) of the seeds/kernels, calculated using Equation 1, 2, 3 and 4 (Mohsenin, 1986; Omobuwajo et al., 1999; Sacilik et al., 2003; Oyelade et al., 2005; Kabas et al., 2006; Saracoglu et al., 2010; Altuntas and Naneli, 2017; Kobuk et al., 2019).

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

$$S_p = \frac{D_g}{H} \quad (2)$$

$$R_a = \frac{W}{H} \quad (3)$$

$$S = \pi D_g^2 \quad (4)$$

D_g : Geometric mean diameter (mm),
L : Length (mm),
W : Width (mm),
T : Thickness (mm),
S_p : Sphericity (%),
R_a : Aspect ratio,
S : Surface area (mm^2).

A pipe with a diameter of 63 mm and a length of 90 mm was used for the angle of repose measurement. This pipe was placed in the middle of a 50x50 cm cardboard plate and filled with bitter gourd seeds and kernels. Afterwards, this piece of pipe was slowly lifted, allowing the spilled seeds and kernels to form a conical structure on the cardboard plate (Cekim and Ozarslan, 2020). The height of the cone formed as a result of the process and the diameter of the circular area formed at the base were measured with 30 repetitions. In order to facilitate diameter measurements, circles were drawn with 0.5 cm radius differences starting from the center of the cardboard plate with the help of a compass, and diameter readings were made using these circles. After the measurements, the angle of repose was calculated with Equation 5 (Kaleemullah and Gunasekar, 2002; Ozguven and Vursavus, 2005; Yilar and Altuntas, 2017).

$$\gamma = tan^{-1}\left(\frac{2h}{d}\right) \quad (5)$$

γ: Angle of repose (°),
h: Cone height (mm),
d: Cone diameter (mm).

A plate mechanism was used to determine the static coefficient of friction. This plate measures 30x45x1.8 cm and has a movable system that is fixed on one side and can be lifted from the other side. Due to a mechanical protractor located on the fixed side, the angle value of the raised plate with the horizontal can be read. In order to determine the static coefficient of friction on different surfaces, experiments were carried out by fixing different materials such as aluminum, 304 stainless steel (chrome), ST-37 black sheet (iron), plastic, rubber, cardboard, glass and MDF wooden panel on the plate. A tube with a diameter of 63 mm and a length of 90 mm, open on both sides, was placed on the different friction surfaces and filled with bitter gourd seeds and kernels. Then, the screw plate system was lifted up on one side, when the pipe started to slide, the system was stopped and the angle value with the horizontal was read, the tangent of this value was taken and the measurements were carried out with 10 repetitions (Suthar and Das, 1996; Ozarslan, 2002; Ertekin et al., 2006; Celik et al., 2007; Yilar and Altuntas, 2017). After the measurements, the static coefficient of friction was calculated with Equation 6.

$$\mu_s = \tan\alpha \quad (6)$$

μ_s: Static coefficient of friction,
α: Angle of gradient (°).

The results of the static coefficient of friction determination experiments on different friction surfaces were compared with the SPSS (Version17; Chicago, IL, USA) statistical data analysis program and groupings were formed.

Single (W_s/W_k) and 1000 grain (W_{ts}/W_{tk}) weights of bitter gourd seeds/kernels were determined by measuring 100 repetitions with a balance which is the sensitivity of 0.001 g (AND, GF-600). In order to determine the 1000 grain weight of the seeds, 100 seeds were randomly selected and their masses were weighed and the measurements were carried out by multiplying the found value by 10.

A cylindrical scale measuring 250 ml was used to determine the bulk density (P_b) of the seeds and kernels. Bitter gourd seeds and kernels, whose mass were determined, were poured into this container from a height of 150 mm and their volume was determined. Bulk density was found by dividing the mass of the bitter gourd seeds by the volume. For the true density (P_t), the liquid displacement method was used and toluene, which has a lower density than water, was preferred as the liquid (Cekim and Ozarslan, 2020). True density was calculated using Equation 7 and all measurements were made in 10 repetitions (Alayunt, 2000).

$$P_t = \frac{mxd_t}{m_t} \quad (7)$$

P_t: True density (g/cm^3),
m: Measured weight of grain (g),
d_t: Toluen density (g/cm^3),
m_t: Weight of toluene displaced with grains (g).

After determining the true density of the seeds and kernels, the porosity was calculated using Equations 8 (Suthar and Das, 1996; Ozarslan, 2002; Akbolat et al., 2008a; Cekim and Ozarslan, 2020; Ertugrul et al., 2022).

$$\varepsilon = \left(1 - \frac{P_b}{P_t}\right) x100 \qquad (8)$$

ε: Porosity (%)

Color measurements of bitter gourd seeds and kernels were measured with a PCE brand CSM3 color measuring device. The L* value represents the degree of lightness, darkness, brightness, or black/white from 0-100. Pure white indicates 100L*, while pure black indicates 0L*. The a* value represents the redness-greenness of the color and the b* value represents the yellowness-blueness ratio. Positive a* and b* values indicate red and yellow, and negative a* and b* values indicate green and blue, respectively. In addition, chrome (C*) and hue angle (°) values were also measured (Akbolat et al., 2008b; Akman, 2022). Measurements were made with 100 repetitions.

In order to determine the moisture content of the seeds and kernels of bitter gourd according to the wet basis, 12 samples were kept at 105°C for 24 hours and the masses of the samples were measured before/after and calculated with the help of Equation 9 (Yagcioglu, 1999).

$$\%N_y = \frac{W_s}{W_s + W_k} x100 \qquad (9)$$

N_y: Moisture content wet basis (%) (w.b.),
W_s: Water weight in the grain (g),
W_k: Dry matter weight (g)

RESULTS AND DISCUSSION

Geometric Properties

It can be said that the lengths of seeds and kernels are about twice their width. The average values of the length, width, thickness, geometric mean diameter, sphericity, aspect ratio and surface area of the seeds/kernels were 14.176/11.517 mm, 7.562/5.922 mm, 4.076/2.815 mm, 7.579/5.759 mm, 53.5/50.1 (%), 1.863/2.111, and 180.765/104.457 mm^2, respectively. In addition, the average value of the shell thickness of the seeds was found to be 0.85 mm (Table 1).

In a study on the physical properties of karingda seeds, the length, width and thickness values were found to be 10.60, 6.18 and 2.37 mm, respectively. Approximately 55% of these seeds are between 9.5-11.5 mm in length (Suthar and Das, 1996). In a study to determine the physical properties of pumpkin seeds at 6.46% dry basis (d.b.) moisture content, the length, width, thickness, geometric mean diameter and sphericity values were found respectively 18.16±1.40 mm, 9.80±0.24 mm, 2.67±0.38 mm, 7.72±0.75 mm and % 43.00±0.42 (Paksoy and Aydın, 2004).

Length of 3 different watermelon seeds in Sarakhsy, Kolaleh and Red varieties, 15.597, 13.455 and 18.972 mm; widths, 9.190, 8.401, 10.720 mm; thicknesses, 3.107, 2.912, 2.988 mm; geometric mean diameters, 7.620, 6.893, 8.456 mm; sphericity, 0.490, 0.513, 0.446%, surface area, 182.963, 149.684, 225.031 mm^2 (Seyed and Elnaz, 2006). Results from their study clearly show that watermelon seeds are similar in shape (length and width) to the seeds of bitter gourd, but thinner. In particular, the sphericity values of bitter gourd and watermelon seeds were highly similar.

In a study of the physical properties of watermelon seeds with 6% dry base moisture content, the average length was found to be 10.8, width 6.8, thickness 2.3, geometric mean diameter 5.5 mm. Sphericity and thousand grain weight were determined as 51.5% and 94.10 g, respectively (Paksoy et.al., 2010). Compared to the seeds of bitter gourd, it was observed that the length, thickness, geometric mean diameter and weight of one thousand seeds of watermelon seeds were less, but their widths and sphericities were close to each other.

In a study on melon seeds with different moisture content, the lowest (2.8%) and highest (25%) moisture content (d.b.) values were found to be length, width, thickness, geometric mean diameter, sphericity, surface area and aspect ratio, respectively; 13.91/14.37 mm, 8.49/8.88 mm, 1.71/2.16 mm, 5.81/.6.44 mm, 0.42/0.45%, 106.87/132.09 mm^2 and 61.15/61.94%. At the lowest (1.1%) and highest (23%) moisture content (d.b.) values in the kernel of the melon seed, the same parameters were respectively; 13.24/14.08 mm, 7.71/8.21 mm, 1.47/1.92 mm, 5.30/6.01 mm, 0.40/0.43%, 88.53/.114.40 mm^2 and 58.35/58.56% (Obi and Offorha, 2015). According to the potency bitter gourd study, while the length and width values were similar, it was seen that these seeds were thicker than melon seeds. This situation caused the geometric mean diameter, sphericity and seed surface area values of bitter gourd seeds and seeds to be larger.

The fact that the results obtained from present study clearly indicated that the physical properties of the bitter gourd vegetable are similar to the seeds of other vegetables in the *Cucurbitaceae* family, such as pumpkin, melon, and watermelon, and assumed that results of present study will guide the design of sowing machines, seed screening systems and systems used for the transportation/storage of these seeds and similar machines for bitter gourd.

Gravimetric Properties

The averages of angle of repose, single grain weight, one thousand grain weight, bulk density, true density and porosity values of seeds/kernels were 28.467/26.982°, 0.192/0.116 g, 202.931/118.359 g, 0.456/0.540 g/cm^3, 0.919/1.659 g/cm^3, 5.526/2.642 cm^3 and 49.788/67.107%, respectively (Table 2). As a result of the examinations, it was observed that a large part of the seed weight was formed by the kernel.

Table 1. Geometric Properties of Bitter Gourd Seeds and Kernels.

Bitter Gourd	Geometric Properties	Maximum	Minimum	Average ± Standard Deviation
Seed	Length (L_s) (mm)	15.400	12.670	14.176 ± 0.679
	Width (W_s) (mm)	9.060	6.290	7.562 ± 0.503
	Thickness (T_s) (mm)	5.770	3.290	4.076 ± 0.340
	Geometric mean diameter (D_{gs}) (mm)	8.585	6.417	7.579 ± 0.348
	Sphericity (S_{ps}) (%)	62.4	47.3	53.5 ± 2.700
	Aspect ratio (R_{as})	2.145	1.282	1.863 ± 0.141
	Surface area (S_s) (mm²)	231.402	129.287	180.765 ± 16.543
	Shell thickness (mm)	1.270	0.650	0.850 ± 0.096
Kernel	Length (L_k) (mm)	12.870	9.870	11.517 ± 0.661
	Width (W_k) (mm)	8.840	4.250	5.922 ± 0.595
	Thickness (T_k) (mm)	3.330	2.310	2.815 ± 0.195
	Geometric mean diameter (D_{gk}) (mm)	6.692	4.740	5.759 ± 0.291
	Sphericity (S_{pk}) (%)	60.0	44.1	50.1 ± 2.600
	Aspect ratio (R_{ak})	2.908	1.518	2.111 ± 0.236
	Surface area (S_k) (mm²)	140.675	70.573	104.457 ± 10.374

Table 2. Gravimetric Properties of Bitter Gourd Seeds and Kernels.

Bitter Gourd	Geometric Properties	Maximum	Minimum	Average ± Standard Deviation
Seed	Angle of repose ((°)	35.700	21.301	28.467 ± 3.670
	Single grain weight (W_s) (g)	0.251	0.116	0.192 ± 0.025
	One thousand grain weight (W_{ts}) (g)	206.570	201.390	202.931 ± 1.624
	Bulk density (P_{bs}) (g/cm³)	0.468	0.442	0.456 ± 0.010
	True density (P_{ts}) (g/cm³)	1.052	0.777	0.919 ± 0.110
	Porosity () (%)	57.361	40.158	49.788 ± 6.175
Kernel	Angle of repose ((°)	34.026	19.871	26.982 ± 2.950
	Single grain weight (W_k) (g)	0.152	0.066	0.116 ± 0.016
	One thousand grain weight (W_{tk}) (g)	121.345	112.873	118.359 ± 1.783
	Bulk density (P_{bk}) (g/cm³)	0.580	0.511	0.540 ± 0.019
	True density (P_{tk}) (g/cm³)	1.933	1.338	1.659 ± 0.303
	Porosity () (%)	73.123	59.668	67.104 ± 6.265

In one of the previous study conducted by Western Mediterranean Agricultural Research Institute (BATEM) clearly showed that some physical and fatty acid properties of bitter gourd seeds were determined by the and 1000 seed weight of bitter gourd seeds was found to be 183.20 ± 6.56 g (Golukcu et al., 2014). In current study, it was seen that the 1000 seed weight of the seeds was close, but 20 grams heavier and on average 202.931 g. In a study on pumpkin seeds, which have similar geometric properties with the seeds of bitter gourd, the weight of thousand seeds was found in the range of 144-295 g (Durgut, 2008). It has been observed that the thousand seed weights of the seeds of the bitter gourd showed similar characteristics.

Single grain and kernel weights of karingda seeds were found to be 0.099 and 0.062 g, respectively (Suthar and Das, 1996). Grain bulk densities of pumpkin seeds at different moisture levels were found to be between 450 and 625 kg/m³ (Paksoy and Aydin, 2004), in another study, it was observed that the grain density of terebinth fruits increased depending on the increase in moisture content (Aydin and Ozcan, 2002).

In a study of three different watermelon seeds (Sarakhsy, Kolaleh and Red), the true density, bulk density and porosity were found as 861.754/866.669/863.036 kg/m³, 416.333/527.265/451.616 kg/m³ and 51.681/39.143/47.604%, respectively (Seyed and Elnaz, 2006). It was observed that the porosity values of bitter gourd seeds and the prosthesis values of watermelon seeds were very close to each other, and this situation is thought to be since the two seeds are similar in shape.

In a study on melon seeds with different moisture content, the lowest (2.8%) and highest (25%) moisture content (d.b.) values were found to have bulk density, true density, 1000 seed weight and porosity values, respectively; 408.04/500.50 kg/m^3, 820.00/1189.00 kg/m^3, 43.60/168.43 g and 45.27/57.52%. At the lowest (1.1%) and highest (23%) moisture content (d.b.) values in the kernel of the melon seed, the same parameters were respectively; 474.80/539.00 kg/m^3, 1039.40/1229.50 kg/m^3, 87.33/105.33 g and 54.33/56.12% were found (Obi and Offorha, 2015). It was observed that 1000 seed weights of bitter gourd seeds and kernels were approximately 1.5 times higher than melon seeds and 1.08 times more than kernels.

In a study on the determination of gravimetric properties of pumpkin seeds, the surface area, sphericity, bulk density, true density and porosity values of these seeds were found to be 533.38 mm^2, 0.47, 0.94 kg/m^3, 1.15 kg/m^3 and 17.55%, respectively (Aremu et al., 2016). The surface area of squash seeds is 2.95 times larger than that of bitter gourd seeds. The porosity value of bitter gourd seeds was 2.83 times greater than that of pumpkin seeds.

The gravimetric properties of bitter gourd seeds and the similarities with other vegetables in the *Cucurbitaceae* family show that the height of the piles to be formed in the storage of seeds gives important values about the circular area they will cover and the equipment to be used in their transportation.

Color Properties

The results for some color values such as L*, a*, b*, C* and h° of bitter gourd seeds and kernels are given in Table 3. Since the L* value is seen as + and is closer to the value of 100, it can be said that these seeds have a shiny surface. The a* value is on the red side, with it being closer to 0. In b* value, it can be said that these seeds are yellow/orange as they are closer to yellow. While the brightness values of the seeds and kernels are close to each other, it can be said that the color of the kernels is closer to yellow, although it is seen that there is a decrease in a*, b* and C* values.

Table 3. Color Parameters of Bitter Gourd Seeds and Kernels.

Bitter Gourd	Color Parameters	Maximum	Minimum	Average ± Standard Deviation
Seed	L*	71.180	49.710	58.843 ± 4.946
	a*	17.010	6.870	11.873 ± 2.203
	b*	29.410	21.730	26.594 ± 1.717
	C*	33.660	23.380	29.172 ± 2.053
	h°	73.810	57.440	66.048 ± 3.801
Kernel	L*	77.370	67.010	72.903 ± 2.271
	a*	7.860	5.460	6.946 ± 0.591
	b*	25.180	15.630	20.587 ± 2.295
	C*	26.380	16.560	21.730 ± 2.352
	h°	72.660	69.700	71.327 ± 0.766

Aydos (2022), examined the color properties of the bitter gourd fruits by drying in microwave, tray dryer and vacuum dryer. L*, a* and b* values were 57.85, 7.03 and 38.53 in microwave, 64.71, 6.30 and 42.24 in tray dryer and 61.36, 12.27 and 37.60 in vacuum dryer. The color of the seed and the bitter gourd fruits themselves are seen to be close to each other in a visual examination.

Frictional Properties

The static coefficient of friction occurring on different friction surfaces of bitter gourd seeds and kernels are given in Table 4. The static friction coefficients of these seeds/kernels on different surfaces such as aluminum, 304 stainless steel (chrome), ST-37 black sheet (iron), plastic, rubber, cardboard, glass and MDF wooden panel surfaces are average, 0.569/0.339, 0.467/0.324, 0.504/0.337, 0.342/0.321, 0.590/0.284, 0.522/0.314, 0.341/0.227, and 0.411/0.289, respectively. In the statistical analysis, when going from low static coefficient of friction to high, plastic and glass are in the first group, MDF wood panel is in the second, 304 stainless steel is in the third, ST-37 black sheet and cardboard is in the fourth, aluminum and rubber are in the fifth group. When the static coefficient of friction for the kernels is evaluated, it is seen that the lowest friction is seen in glass, the highest is seen in aluminum, 304 stainless steel, ST-37 black steel, plastic, and cardboard.

The static coefficient of friction calculations of pumpkin seeds on plywood and galvanized sheet surfaces varied between 0.18 and 0.64 (Paksoy and Aydin, 2004). In a study on watermelon seeds of Sarakhsy, Kolaleh and Red varieties, plywood, galvanized sheet, glass, rubber and fiberglass materials were used as friction surfaces to determine the static coefficient of friction. The static coefficient of friction of these three seeds was found

Table 4. Static Coefficient of Friction of Bitter Gourd Seeds According to Different Materials.

	Materials	Static Coefficient of Friction ±Standard Deviation
Seed	Aluminum	0.569e±0.067
	304 Stainless Steel (Chrome)	0.467c±0.025
	ST-37 Black Sheet (Iron)	0.504d±0.018
	Plastic	0.342a±0.032
	Rubber	0.590e±0.074
	Cardboard	0.522d±0.026
	Glass	0.341a±0.023
	MDF Wooden Panel	0.411b±0.022
Kernel	Aluminum	0.339d±0.034
	304 Stainless Steel (Chrome)	0.324cd*±0.051
	ST-37 Black Sheet (Iron)	0.337d±0.039
	Plastic	0.321cd±0.043
	Rubber	0.284b±0.044
	Cardboard	0.314bcd*±0.040
	Glass	0.227a±0.014
	MDF Wooden Panel	0.289bc*±0.016

* According to the Duncan multiple comparison results, the difference between the means with the same letter is insignificant.

in plywood, 0.56, 0.48, 0.61, galvanized sheet, 0.38, 0.40, 0.43, glass, 0.26, 0.31, 0.26, rubber, 0.66, 0.56, 0.68, fiberglass, 0.30, 0.36, 0.34, respectively (Seyed and Elnaz, 2006). In plywood, glass and rubber materials, bitter gourd seeds showed similar static friction coefficient values with watermelon seeds.

In a study on melon seeds, it was observed that the increase in moisture content of melon seeds and kernels increased the mean values of the geometric, gravimetric and frictional properties studied. Plywood showed the highest coefficient in all of the static coefficient of friction experiments performed at different moisture contents. According to the angle of inclination obtained on different structural materials results on pumpkin seeds, galvanized steel, mild steel, stainless steel, plywood and glass were used. Inclination angles (friction coefficients) on these surfaces were found to be 29.24° (0.559), 27.04° (0.510), 29.04° (0.555), 30.00° (0.577) and 25.52° (0.477), respectively (Aremu et al., 2016).

The frictional properties of bitter gourd seeds and the similarities with other vegetables in the *Cucurbitaceae* family include important details for designers in the selection of materials used in seed storages and in sowing machines.

Moisture Content

The moisture content of bitter gourd seeds was 16.212 ± 2.376% (w.b.), and 11.50 ± 0.316% (w.b.) of kernels. In a study on karingda seeds, it was stated that the moisture content of seeds has an important effect on their physical properties (Suthar and Das, 1996). As the moisture content of edible pumpkin seeds increased, the bulk density, true density, % porosity, surface area and final velocity values increased (Paksoy and Aydın, 2004). This shows that the specified values have increased due to the water absorption ability of the seeds. The average moisture contents of watermelon seeds in Sarakhsy, Kolaleh and red cultivars were found to be 4.55, 5.02 and 4.75% (w.b.), respectively (Seyed and Elnaz, 2006). In another study on watermelon seeds, bulk density, true density, porosity, surface area and sphericity decreased with increasing moisture content of the seed (Paksoy et. Al., 2010). A study was conducted on the physicomechanical properties of melon seeds at different moisture contents. This study was carried out with moisture content values of 2.8%, 7, 12, 17 and 25 in seeds, and 1.1%, 6, 11, 16 and 23 in kernels (Obi and Oforha, 2015).

CONCLUSION

In this study, some physical properties of bitter gourd seeds and kernels such as linear dimensions, geometric mean diameter, shell thickness, sphericity, surface area, true and bulk densities, porosity, static coefficient of friction, color and moisture content were determined. These properties are necessary for cleaning, separating, transporting, storing and drying the seeds and kernels of bitter gourd. The developments of a sowing machine for this seed and the features that must be known in the design of any machine equipment for this seed have been obtained in this study. It has been observed that the physical properties of pumpkin, cucumber, watermelon and melon seeds and the seeds of bitter gourd are similar. Since these vegetables are from the same family, it is normal for them to exhibit similar properties in terms of seed physical properties. On average, the length of the bitter gourd seeds/kernels was 14.176/11.517 mm, their width was 7.562/5.922 mm, and their thickness was 4.076/2.815 mm. The angle of repose, which is an extremely important criterion in the storage of bitter gourd seeds, was found to be 28.467° on average. The static coefficient of friction tests performed on glass and plastic surfaces were lower than the other surfaces. The highest friction occurred in aluminum and rubber materials. It is an undeniable fact that the commercial demand of the bitter gourd vegetable, which is added to its beneficial properties day by day, will increase. Since the demand for this vegetable assumed to be getting increased in next coming years, the physical properties of seeds and kernels revealed in the present study have a high potential to be used in the stages of cultivation, transportation, storage and product processing. But it must be also emphasis that further work should be conducted on this important crop to get complete profile of the physical properties of bitter gourd seeds.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest

The authors declared that for this research article, they have no actual, potential or perceived conflict of interest.

Author contribution

The contribution of the authors to the present study is equal. All the authors read and approved the final manuscript. All the authors verify that the Text, Figures, and Tables are original and that they have not been published before.

Ethical approval

Ethics committee approval is not required.

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Data availability

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Consent for publication

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