Determining dimensional, gravimetrical and frictional properties of red radish seeds (Raphanus Sativus L.) as a function of moisture content

Amir Hossein Mirzabe[1*], Mojtaba Taheri[1], Habil Asaei[2], Mohammad Hossein Kianmehr[1]

(1.Department of Mechanical Engineering of Biosystems, Aboureihan College, University of Tehran, Tehran, Iran; 2. Biosystem Engineering Department, Faculty of Agriculture, Shiraz University, Shiraz, Iran.)

Abstract: To design the planting, separating, threshing, sizing and packing machines for agricultural products, physical and mechanical properties of the products should be known. In this paper, some physical properties of red radish seeds were studied. Dimensional parameters, when moisture content equals to 5.65% based on dry bases (d.b), were measured using image processing technique. Effects of moisture content on gravimetrical and frictional properties of the seeds, including mass of single seed, 1000-unit seed, bulk density, true density, porosity, static coefficient of friction on various surfaces, and angle of repose based on pouring, Hele-Shaw, empting and filling methods were studied. Effects of volume of the container (150, 350, 550 and 750 mL) and height of fall on bulk density and porosity of the radish seeds when moisture content equals to 5.65% (d.b) were studied. Also length, width, thickness and mass distributions of radish seeds were modeled using Gamma, Generalized Extreme Value and Weibull distributions. Results showed that length, width and thickness of the seeds ranged from 0.660 to 0.900 mm, 0.524 to 0.763 mm and 0.490 to 0.759 mm, respectively. With increasing volume of the container from 150 to 550 mL, bulk density of the seeds increased; but with increasing volume of the container from 550 to 750 mL, bulk density of the seeds decreased. With increasing volume of the container from 150 to 550 mL, bulk density of the seeds increased; but with increasing volume of the container from 550 to 750 mL, bulk density of the seeds decreased. With increasing moisture content from 5.65 to 21.71% (d.b) , bulk and true density of the seeds decreased from 694.807 to 654.889 kg/m3 and 1141.810 to 1057.795 kg/m3; but with increasing moisture content from 5.65% to 21.71% (d.b) , 1000-unit mass increased from 6.98 to 7.17 g.

Keywords: image processing technique, dimensional properties, modeling, moisture content, gravimetrical properties, frictional properties.

Citation: Mirzabe, A. H., M. Taheri, H. Asaei, and M. H.Kianmehr. 2015. Determining dimensional, gravimetrical and frictional properties of red radish seeds (Raphanus Sativus L.) as a function of moisture content. Agric Eng Int: CIGR Journal, 17(4): 288-310.

1 Introduction

Radish (Raphanus sativus) is an edible root vegetable of the Brassicaceae family that was domesticated in Europe in pre-Roman times (Lewis-Jones et al. 1982). Radish seeds are grown and consumed throughout the world. Radish has numerous varieties, varying in size, color and duration of required cultivation time. There are some radishes that are grown for their seeds; oilseed radish is grown, as the name implies, for oil production.

Almost all parts of the plant including leaves, seeds and roots are utilizable in medicine (Alqasoumi et al. 2008). The fresh juice obtained from leaves are diuretic and laxative, roots are used for urinary complaints, haemorrhoids, gastrodynic pains and several gastric ailments. Seeds are expectorant, digestive, diuretic, laxative and carminative and the root extract has been reported to have antiurolithiatic properties (Alqasoumi et al. 2008; Vargas S et al. 1999).

Received date: 2015-07-02 **Accepted date: 2015-08-16**

***Corresponding author: Amir Hossein Mirzabe,** Department of Mechanical Engineering of Biosystems, Aboureihan College, University of Tehran, Tehran, Iran. Email: a_h_mirzabe@alumni.ut.ac.ir

Black radish *(Raphanus sativus* L. var. *niger)* root has been used in folk medicine since antiquity as a natural drug for the stimulation of bile function. According to in vitro studies, the squeezed juice from black radish root exhibits significant antioxidant properties (Lugasi et al. 2005). Lugasi et al. (2005) reported that although the exact mechanism of the biologically active compounds in black radish on the lipid metabolism and lipid peroxidation is not clear yet, a beneficial effect of the drug was evident in alimentary hyperlipidemia.

White radish has an abundance of health benefits, not only because it belongs to the crucifer family of flowering plants highly efficacious in fighting cancer, but also because it packs 10 times as much vitamin C as apples or pears. White radishes have also been found to contain a wide variety of isothiocyanates, which have anti-carcinogenic properties. The large white radish has long been called "little ginseng" in China. The old saying goes that "when radishes come onto the market, nobody will go to the pharmacies".

Radish is considered to be a model crop and is widely used for studies related to heavy metal pollution (Khan and Frankland 1983; Kostka-Rick and Manning 1993). The advantage of using radish and other members of cabbage family for heavy metal studies are well described in Mathe-Gaspar and Anton (2002). The influence of brassinosteroids on seed germination and seedling growth under Cd toxicity in Raphanus sativus seedlings were examined by Anuradha and Rao (2007).

It was reported that radish roots could accumulate large amounts of lead (Pb), which could cause a potential health risk in polluted conditions (Lane and Martin 1977; He et al. 2008). Considerable efforts have been invested into investigating Pb stress in radishes, especially its accumulation, translocation, physiological and metabolic variations, and cell deposition (Inoue et al. 2013). However, little is known about the mechanism of radish plant responses to Pb stress at the molecular level, i.e. gene expression variations under Pb stress (Wang et al. 2013).

The proper design of process equipment depends essentially on the physical and mechanical properties of agricultural crops and products. Different researchers report the use of characteristic dimensions to determine the size of seeds (Aviara et al. 2013; Garnayak et al. 2008). Size and shape are of importance for separator and sorter and can be used to determine the lower size limits of conveyors. Furthermore, the characteristic dimensions allow a calculation of the surface area and volume of grains, important aspects for the modeling of drying and ventilation. Porosity affects the bulk density which is also necessary factor in the design of dryer, storage and conveyer capacity while the true density is useful to design separation equipment (Sologubik et al. 2013). The angle of repose and coefficient of friction are considered by engineers as important properties for the design of seed containers and other storage structures and accessories. The static coefficient of friction limits the maximum inclination angle of conveyor and storage bin. The amount of power requirement for conveyor depends on the magnitude of frictional force. Angle of repose is a useful parameter for calculation of belt conveyor width and for designing the shape of storage.

There are many published literature on radish (Moreland et al. 1974; Sekimata et al. 1989; Terras et al. 1992; Hwang 2009); numerous studies have been conducted on physical and mechanical properties of agricultural seeds, grains, fruits, nuts and kernels. Sometimes many similar studies have been conducted on one and same product; both similar and different results have been obtained.

Literature review showed that there is one published work on physical properties of radish seeds. The length, width and thickness of radish seeds, 1000-seed mass, projected area, sphericity, terminal velocity, bulk density, true density, porosity and static coefficient of friction of radish seed against surfaces of four structural materials, namely, rubber, aluminum, stainless steel and galvanized iron were measured as a function of moisture content in the range of 6.95–19.08% dry basis (d.b) by Cetin et al.

(2010). There are some dimensional parameters that were not measured by Çetin et al. (2010) such as geometric mean diameter, arithmetic mean diameter, equivalent diameter, surface area, volume, flakiness ratio and elongation ratio. On the other hand, for a single seed, dimensions and mass can be determined; however, values of these properties differ for each individual seed to other. Normally, we are not interested to know the properties of each individual seed, but description of the frequency distributions of the dimensions of the whole sets of the seeds is needed for designing agricultural equipment (Mirzabe et al. 2012).

Although angle of repose is a very important parameter for granular materials and agricultural seeds, Cetin et al. (2010) did not investigate the effect of moisture content on angle of repose. Although measuring bulk density of the agricultural seeds has a standard method (height of fall equal to 150 mm, volume of the container equal to 500 mL), in practice, when filling large reservoirs and silos, we do not normally use standard parameters, so the effect of height of fall and volume of the container are of importance parameters on bulk density. Cetin et al. (2010) did not investigate these effects. The aim of this study was to investigate dimensional properties, gravimetrical properties and frictional properties of red radish seeds. The dimensional parameters investigated include three principle dimensions (length, width, and thickness), geometric mean diameter, equivalent diameter, arithmetic mean diameter, sphericity, volume, surface area, projected area, flakiness ratio, elongation ratio, aspect ratio, and modeling of dimensions by statistical functions. The effects of the moisture content on mass of single seed, 1000-unit seed, bulk density, true density, porosity, static angle of friction on various surfaces, and angle of repose based on pouring, Hele-Shaw, empting and filling methods were investigated. Also effects of the volume of the container and height of fall on bulk density and porosity were investigated.

2 Materials and methods

2.1 Sample preparation

Three kilograms of the red radish seeds were bought from a local market in Varamin, Tehran province, Iran in 2013. The seeds were cleaned manually to remove all foreign materials. The moisture content of each sample was determined using the standard hot air oven method at 105±1 °C for 24 hours (Gupta and Das 1997; Altuntaş et al. 2005), and using Equation 1, moisture content of the seeds based on dry bases (d.b) were calculated:

$$M = \frac{M_w - M_d}{M_d} \times 100 \qquad (1)$$

Where, M is moisture content of the sample, % (d.b) ; M_w is the initial mass of the sample or wet mass, g; M_i is the initial moisture content of the sample, % (d.b) ; and M_d is the final mass of the sample or dry mass, % (d.b) .

The average values of three replications were reported as moisture content for the seeds. Initial value of the moisture content of the radish seeds was equal to 5.65% (d.b). The tests which investigated dimensional properties and the effects of the volume container and height of fall on bulk density and porosity were conducted in this moisture content level.

In order to study effects of moisture content on gravimetrical and frictional properties, the seeds were divided into three portions labeled A, B, C and D. The sample A was left at the market storage moisture content (5.65 % (d.b)), while a different distillated water was added to samples B, C, and D at room temperature in order to raise their moisture content to the desired different levels, based on the following formula (Garnayak et al. 2008):

$$M_{water} = \frac{W_i(M_f - M_i)}{100 - M_f} \qquad (2)$$

Where, M_{water} is the mass of water added, kg; W_i is the initial mass of the sample, kg; M_i is the initial moisture content of the sample, % (d.b); and M_f is the final moisture content of the sample, % (d.b) .

The sample was packed in sealed polyethylene bags and kept in a refrigerator for 72 hours to enable the moisture to distribute uniformly throughout the samples.

The moisture content of each sample was determined using the standard hot air oven method at 105±1°C for 24 h (Gupta and Das 1997; Altuntaş et al. 2005; Özarslan 2002). The average values of three replications were reported as moisture content for each sample. The samples with different moisture content were stored in refrigerator until the test.

2.2 Dimensional properties

2.2.1 Calculate parameters

The three major perpendicular dimensions of each radish seed were measured by image processing technique. The average diameter of each seed was calculated using the geometric mean and arithmetic mean of the three axial dimensions. The geometric mean diameter, D_G, arithmetic mean diameter, D_A and equivalent diameter, D_E of the seed were calculated using the following Equations (Garnayak et al. 2008; Milani et al. 2007; Heidarbeigi et al. 2009):

$$D_G = \sqrt[3]{LWT} \tag{3}$$

$$D_A = \frac{L+W+T}{3} \tag{4}$$

$$D_E = \left[\frac{(T+W)^2}{4} L\right]^{\frac{1}{3}} \tag{5}$$

Where, L is the length, W the width and T is the thickness, all in mm.

The sphericity (φ) of the grains, seeds, nuts, kernels or fruits is an index of its roundness. Sphericity is defined as the ratio of the surface area of a sphere having the same volume as the seed to the surface area of the seed. The sphericity of radish seed was calculated using the following Equation (Sirisomboon et al. 2007):

$$\varphi = \left(\frac{\sqrt[3]{LWT}}{L}\right) \times 100 = \frac{D_G}{L} \times 100 \tag{6}$$

Where, L is the length, W the width and T is the thickness, all in mm.

The surface area of seed (S) was found by analogy with a sphere of the same geometric mean diameter, using the following Equation (McGahon et al. 2007; Xu et al. 2009; Ersoy 2010):

$$S = 4\pi \left[\frac{(LW)^P + (LT)^P + (WT)^P}{3}\right]^{\frac{1}{P}} \tag{7}$$

Where, L is the length, W the width and T is the thickness, all in mm and P is a constant. P approximation has the least relative error (±1.061% in the worst case) when P≈1.6075.

The volume of seed (V) was found by analogy with a sphere of the same geometric mean diameter, using the following Equation (Perez et al. 2007; Burubai et al. 2007):

$$V = \frac{\pi (D_G)^3}{6} \tag{8}$$

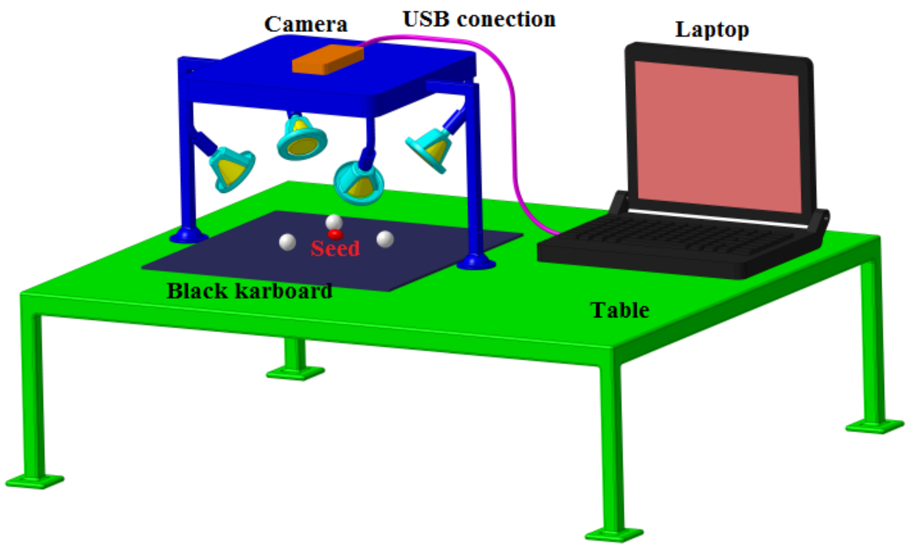


Figure 1 Experimental set up was used to image processing

The projected area (A_P), one of the most important parameters for determining aerodynamic properties, of the seeds was determined using Equation 9 (Kabas et al. 2007):

$$A_p = \left(\frac{\pi W L}{4} \right) \quad (9)$$

The flakiness ratio, F_r, and elongation ratio, E_r for each seed were calculated using the Equation 10 and 11 respectively (Mora and Kwan 2000):

$$F_r = \frac{T}{w} \quad (10)$$

$$E_r = \frac{L}{W} \quad (11)$$

2.2.2 Image processing set up

The image processing system consisted of a camera (Canon, IXY 600F, 12.1 megapixels, USB connection, Japan), and four white-colored fluorescent lamps (32 W) and a laptop computer (Dell, 1558, China) equipped with Matlab R2012a software package (Figure 1). A white paper was placed on the floor of the box to provide a white background. Tow RGB color images were captured from up and front views of seed. The contrast between the seeds and the background was improved by several functions of MATLAB. Pixels above a certain threshold value, 52, were converted into white, pixels below this threshold to black, resulting in a binary image (Koc 2007). A group of black pixels adjacent to each other represented a seed. The pixels must be converted to millimeter, hence some circulars and squares with identified dimensions were depicted on the paper and then a relation between pixel and length in millimeter was obtained.

2.2.3 Modeling of dimensions

Distributions of the length, width and thickness of radish seeds were modeled with three probability density functions. These functions were: Gamma, Weibull and Generalized Extreme Value (G. E. V). The probability density function and cumulative frequency for Gamma distribution are described in Equation 12 and 13, respectively (Bhunya et al. 2007):

$$f(x) = \frac{(x-\delta)^{\varepsilon-1}}{\sigma^{\varepsilon}\Gamma(\varepsilon)} \exp(-\frac{x-\delta}{\sigma}) \quad (12)$$

$$F(x) = \frac{\Gamma_{(x-\delta)/\sigma}(\varepsilon)}{\Gamma(\varepsilon)} \quad (13)$$

where, x is variable; δ is location parameter; σ is scale parameter; ε is shape parameter; Γ is the Gamma function and Γ_z is the incomplete Gamma function:

$$\Gamma(\varepsilon) = \int_0^{\infty} x^{\varepsilon-1} e^x dx \quad , \quad \varepsilon > 0 \quad (14)$$

$$\Gamma_z(\varepsilon) = \int_0^{z} x^{\varepsilon-1} e^x dx \quad , \quad \varepsilon > 0 \quad (15)$$

If δ equals to zero, the Gamma distribution would be a two-parameter distribution; otherwise, that would be named a three-parameter distribution. In the present work, for modeling the data, three-parameter Gamma distribution was used. The probability density function and cumulative frequency for Weibull distribution are described in Equations 16 and 17, respectively (Mirzabe et al. 2012):

$$f(x) = \frac{\gamma}{\beta}\left(\frac{x-\alpha}{\beta}\right)^{\alpha-1} exp\left(-\left(\frac{x-\alpha}{\beta}\right)^{\gamma}\right) \quad (16)$$

$$F(x) = 1 - exp\left(-\left(\frac{x-\alpha}{\beta}\right)^{\gamma}\right) \quad (17)$$

where, x is variable; α is location parameter; β is scale parameter; γ is shape parameter. If α equals to zero, the Weibull distribution would be a two-parameter distribution; otherwise, that would be named a three-parameter distribution. In the present work, for modeling the data, three-parameter Weibull distribution was used. The probability density function and cumulative frequency for Generalized Extreme Value (G. E. V) distribution are described in Equations 18 and 19 respectively (Mirzabe et al. 2012):

$$f(x) = \frac{1}{\psi}\left[1 + \xi\left(\frac{x-\lambda}{\psi}\right)\right]^{(-1/\xi)-1} exp\left\{-\left[1 + \xi\left(\frac{x-\lambda}{\psi}\right)\right]^{-1/\xi}\right\} \quad (18)$$

$$F(x) = exp\left\{-\left[1 + \xi\left(\frac{x-\lambda}{\psi}\right)\right]^{-1/\xi}\right\} \quad (19)$$

Where, x is variable; ψ is scale parameter; λ is location parameter; ξ is shape parameter.

The adjustable parameters for each probability density function were calculated using the commercial spreadsheet package of Easy Fit 5.5. Kolomogrov-Smirnov methods were used for comparison of all probability densities. Kolmogorov-Smirnov goodness of fit test was used to test how well different prediction techniques work for prediction of diameter, thickness and height distributions (Gorgoso et al. 2007). The test is based on the vertical deviation between the observed cumulative density function and estimated cumulative density function based on the Equation 20. In this equation, small values of the test statistics K_s index indicate a better fit.

$$K_s = max[s(x) - f(x)] \qquad (20)$$

where, $S(x)$ is the cumulative frequency distribution observed and $F(x)$ is the probability of the theoretical cumulative frequency distribution. Also the Kolmogorov-Smirnov index for each probability density function was calculated using the commercial spreadsheet package of Easy Fit 5.5.

2.3 Gravimetric properties

To measure mass of each radish seed, 100 seeds were randomly selected from the bulk sample; then the mass of the seeds were measured by a digital balance (Kern, Japan, accuracy of ±0.001 g) one by one. To evaluate the 1000-unit mass, 100 seeds were randomly selected from the bulk sample; the 100-unit mass was measured by the same digital balance. 1000-unit mass was calculated by multiplying the 100-unit mass by 10.

Four containers with known volumes, 150, 350, 550 and 750 cm^3, were used to measure the bulk density of radish seeds and investigate the effects of volume of the container. The seeds were poured into the containers at the height of 50, 100, 150, 200 and 250 mm (Gupta and Das 1997; Mirzabe et al. 2013a). The bulk density (ρ_b) is equal to the mass of bulk material divided by volume containing the mass. To study the effects of the moisture content on bulk density, bulk of seeds was obtained using a container with 550 cm^3 volume and seeds were poured into the containers at the height of 150 mm.

The true density (ρ_t) is defined as the mass of sample (M_s) divided by the volume of the sample (V_s). It was determined using the water displacement method. Toluene (C_7H_8) was used instead of water because it is absorbed by seeds to a lesser extent, density of toluene is less than the water and its surface tension is low, so it even fills shallow dips in a seed and its dissolution power is low (Milani et al. 2007; Garnayak et al. 2008). The volume of each sample was determined by weighing displacement volume of toluene:

$$V_s = \frac{M_{TD}}{\rho_t} = \frac{(M_T - M_P) - (M_{PTS} - M_{PS})}{\rho_t} \qquad (21)$$

$$\rho_s = \frac{M_s}{V_s} \qquad (22)$$

where, M_{TD} is the mass of displacement volume of toluene in kg, ρ_t is the density of toluene (870 kg m^{-3}), M_T is the mass of filled pycnometer with toluene in kg, M_P is the mass of pycnometer kg, M_{PTS} is the mass of pycnometer with toluene and the seeds in kg, and M_{PS} is the mass of pycnometer and seeds in kg.

Porosity defined as the ratio of the volume of pores to the total volume. Porosity or void fraction is a measure of the void spaces or empty spaces in a material, expressed in number between 0 to1, or in a percentage. The porosity of bulk seeds was calculated from bulk and true densities using the Equation 23 (Sharma et al. 2011):

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \qquad (23)$$

2.4 Frictional properties

2.4.1 Coefficients of static friction

The effects of the moisture content on coefficients of external static friction of the radish seeds were examined using sloped plane method on surfaces of galvanized, iron, plywood and rubber. A topless and bottomless cylinder of 100 mm diameter and 50 mm height was filled with the sample of seeds. The cylinder was raised slightly so as not to touch the surfaces (Figure 2). The structural surface with the cylinder resting on it was inclined gradually with a screw device until the cylinder just started to slide down over the surface. The angle of tilt at this juncture was photographed by a camera (Canon, IXY 600F, 12.1

megapixels, USB connection, Japan) and photos were transferred to a laptop computer (Dell, 1558, China) equipped with Auto Cad 2007 software. The angle of tilt or angle of static friction, C_f, was read by the software. The coefficient of static friction, μ_s, was calculated from the following formula (Mirzabe et al. 2013b).

$$\mu_s = \tan(C_f) \quad (24)$$

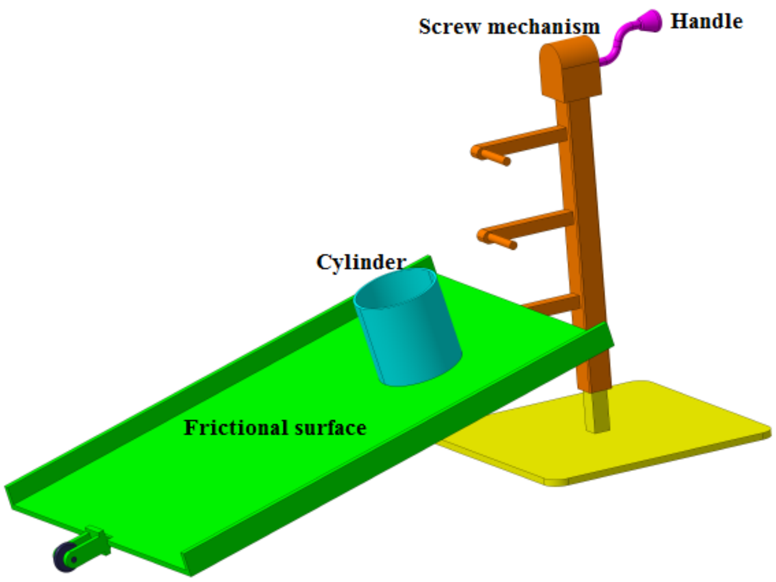


Figure 2 Experimental set up used to measure coefficient of external static friction

2.4.2 Angle of repose

When bulk granular materials are poured onto a horizontal surface, a conical pile will form. The internal angle between the surface of the pile and the horizontal surface is known as the angle of repose. Materials with a low angle of repose form flatter piles than materials with a high angle of repose. Angle of repose of the agricultural materials is dependent on the density, surface area and shape of the particles (seeds, grains, nuts, kernels, fruits, etc.), the coefficient of friction of the material and gravity-dependence (Kleinhans et al. 2011). There are different methods of measuring the angle of repose, including pouring, filling (charging), empting (discharging), Hele-Shaw, submerging, and rotating drums. In the present study, to study the effects of the moisture content on angle of repose of the radish seeds, pouring, filling, empting and Hele-Shaw methods were used.

2.4.2.1 Pouring angle of repose

Static angle of repose was measured using pouring method. The angle of repose of seeds sample was determined using a topless and bottomless metallic cylinder of 200 mm height and 150 mm diameter (Mirzabe et al. 2013b). The cylinder was placed on horizontal surface and was filled with seeds (seeds were poured into the cylinder at the height of 150 mm), then, the cylinder was raised very slowly (rotational velocity of electromotor was equal 1400 rpm and linear velocity of chord was equal to 5 mm/sec, Figure 3). The camera (Canon, IXY 600F, 12.1 megapixels, USB connection, Japan) was placed at the opposite of the front view of the bulk seeds. The bulk seeds were photographed. The pouring angle of repose was calculated using image processing technique by Auto Cad 2007 software package. In order to study the effects of the material of the contact surface, galvanized, iron, plywood and rubber plates were placed on the frame of the set up (beneath of the cylinder) and pouring angle of repose was measured on these surfaces.

Although measuring pouring of the agricultural seeds has a standard method (height of fall equal to 150 mm), in practice, when filling large reservoirs and silos, we do not normally use standard parameters, so the effect of height fall is of importance parameters on pouring angle of repose. Therefore the effects of the height of fall (50, 100, 150, 200 and 250 mm) on pouring angle of repose, when the moisture content was equal to 5.65 % (d.b), were investigated.

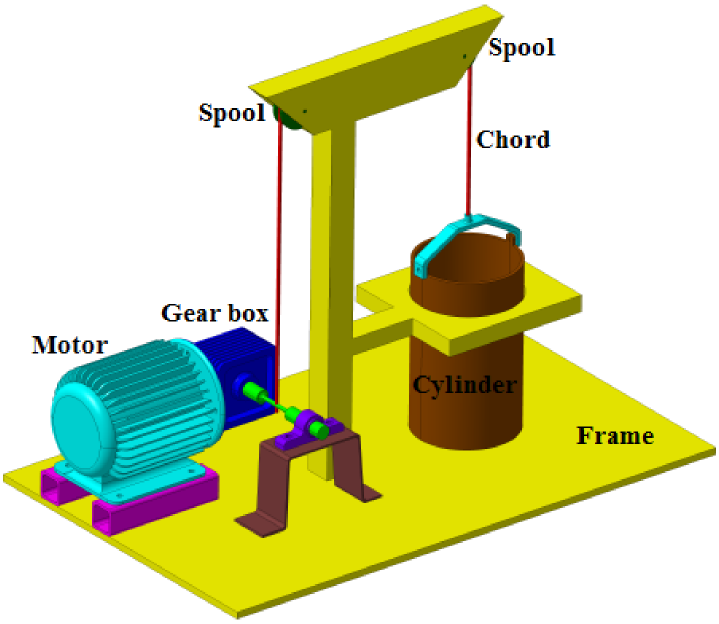


Figure 3 Experimental set up used to measure pouring angle of repose of red radish seeds

2.4.2.2 Filling and empting angle of repose

The filling and empting angle of repose of the seeds were measured. The device used in this study was a box made from two smaller, upper and lower boxes. The dimensions of the box were 120 mm length, 120 mm height, and 60 mm width (Figure 4). The upper box was filled with the sample seeds. The material of upper box could flow down through a removable port. The filling or static angle of repose is the angle of surface with the horizon at which the seeds will stand when piled on the ground. The empting or dynamic angle of repose is the angle of surface of residual with horizon in the upper box. The filling and empting angle of repose were calculated using the same technique mentioned for pouring angle of repose.

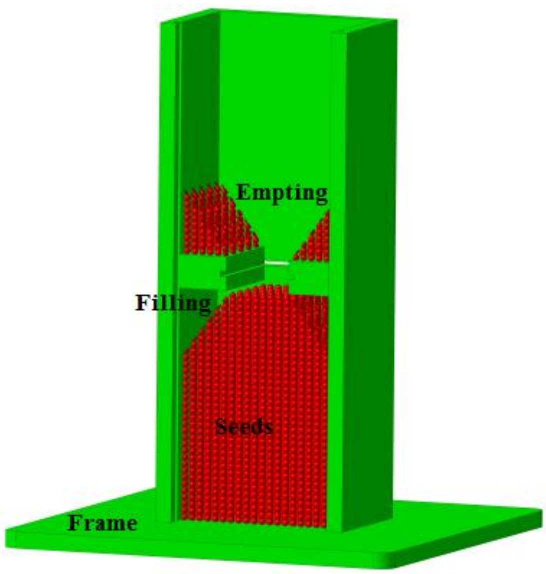
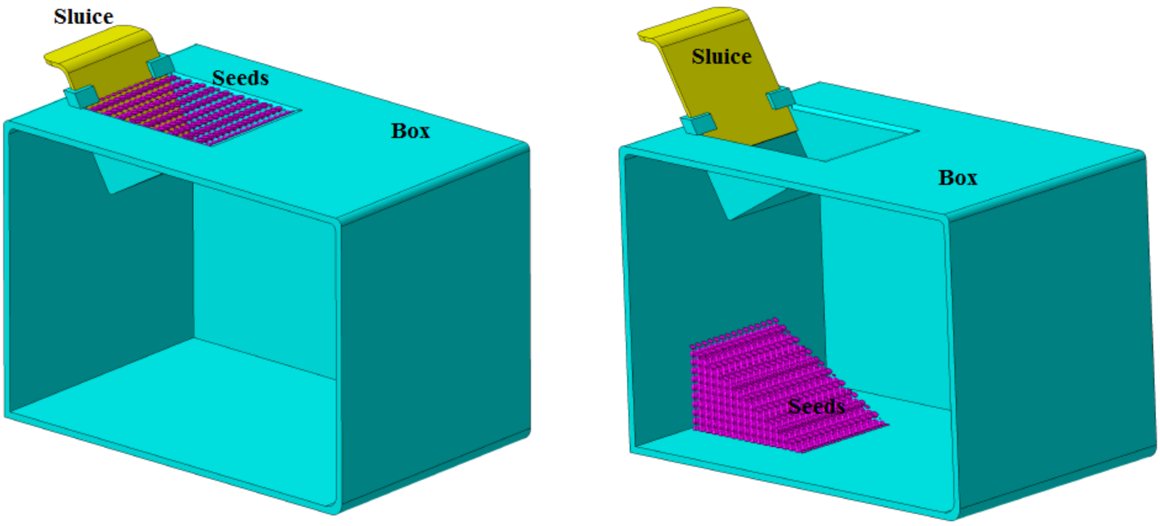


Figure 4 Experimental set up used to measure filling and empting angle of repose of red radish seeds

2.4.2.2 Hele-Shaw angle of repose

The Hele-Shaw angle of repose of the radish seeds was measured. The device used in this study was a box of dimensions of 300 mm length, 200 mm height, and 200 mm width (Figure 5). There was a small box above the main box. Bottom surface of the small box was sloped. The small box was filled with the sample seeds. The material of upper box can flow down through a removable port. The Hele-Shaw is the angle of surface with the horizon at which the seeds will stand when piled on the bottom of the main box. The camera was placed at the opposite of the front view of the box, then the bulk seeds were photographed (the front side of the main box was made of glass). The Hele-Shaw angle of repose was calculated using image processing technique by Auto Cad 2007 software package. In order to study the effects of the material of the contact surface, galvanized, iron, plywood and rubber plates were placed at the bottom of the main box and the Hele-Shaw angle of repose was measured on these surfaces.



(A) (B)

Figure 5 Experimental set up used to measure Hele-Shaw angle of repose of radish seeds. (A) is the experimental set up before seeds falling and (B) is the experimental set up after seeds falling

2.6 Data analysis

Based on the measurements and calculations made above, for calculating statistical indices including maximum, minimum, average, standard deviation, skewness, and kurtosis for measured and calculated dimensions and dimensional properties, Microsoft Office Excel 2010 was used. Also in order to calculating the average of the repetitions of all gravimetrical properties and frictional properties, Microsoft Office Excel 2010 was used. Numbers of repetitions of the tests are shown in Table 1.

Table 1 Number of repetitions of the all tests including dimensions, dimensional, gravimetrical and frictional properties of red radish seeds

Property	Measured or calculated parameter	Number of repetitions
Dimensions	Length	100
	Width	100
	Thickness	100
Dimensional properties	Diameters, Sphericity, Surface area, Volume, Projected area, Flakiness ratio, Elongation ratio	100
Gravimetrical properties	Mass of single seed	100
	1000-unit mass	5
	Bulk density	5
	True density	3
	porosity	5
Frictional properties	Coefficient of friction	5
	Pouring angle of repose	5
	Hele-Shaw angle of repose	5
	Filling and empting angle of repose	5

3 Results and discussion

3.1 Dimensional properties

Length, width, thickness and dimensional properties of the radish seeds are shown in Table 2. The length, width, and thickness of the seeds ranged from 0.660 mm to 0.990 mm, 0.524 mm to 0.763 mm and 0.490 mm to 0.759 mm, respectively. Average of the geometric mean diameter, arithmetic mean diameter, equivalent diameter, sphericity, surface area, volume, projected area, flakiness ratio and elongation ratio of the seeds were found to be 0.656 mm, 0.660 mm, 0.613 mm, 87.987%, 1.372 mm^2, 0.150 mm^3, 0.377 mm^2, 0.932 and 1.169, respectively (Table 2).

Table 2 Calculated statistical indices of three principle dimensions and dimensional parameters of red radish seeds when moisture content equals to 5.65 % (d.b)

Parameter	Units	Max	Min	Mean	Standard Deviation	Skewness	Kurtosis
Length	mm	0.900	0.660	0.746	0.049	0.871	0.772
Width	mm	0.763	0.524	0.641	0.057	0.237	-0.840
Thickness	mm	0.759	0.490	0.594	0.057	0.579	0.120
D_g	mm	0.770	0.572	0.656	0.044	0.423	-0.251
D_A	mm	0.775	0.575	0.660	0.044	0.432	-0.223
D_E	mm	0.684	0.560	0.613	0.027	0.461	-0.073
Sphericity	%	93.650	83.448	87.987	2.534	0.309	-0.694
Surface area	mm^2	1.879	1.038	1.372	0.185	0.581	-0.040
Volume	mm^3	0.239	0.098	0.150	0.031	0.732	0.193
Projected area	mm^2	0.520	0.271	0.377	0.055	0.686	-0.056
Flakiness ratio	-	1.199	0.748	0.932	0.108	0.641	0.110
Elongation ratio	-	1.377	1.021	1.169	0.072	0.356	0.358

Skewness and kurtosis are two statistical indices calculated so that the reader would better understand the probability density distribution data. The first thing usually noticed about a distribution’s shape is whether it has one mode (peak) or more than one. If it is unimodal (has just one peak), like most data sets, the next thing noticed is whether it is symmetric or skewed to one side.

Kurtosis is a measure of whether the data are peaked or flat relative to a normal distribution, that is data sets with high kurtosis tend to have a distinct peak near the mean, decline rather rapidly, and have heavy tails. Data sets with low kurtosis tend to have a flat top near the mean rather than a sharp peak. A uniform distribution would be the extreme case. Results of statistical analysis of dimensional properties of the radish seeds indicated that values of the skewness in all cases were positive and values of the kurtosis in most cases were negative.

3.2 Gravimetrical properties

3.2.1 Mass and 1000-unit mass

Statistical indices including maximum, minimum, average, standard deviation, skewness, and kurtosis for single mass of seed in 5.65 % (d.b) moisture content were found to be 0.015 g, 0.002 g, 0.0069 g, 0.003, 0.679 and 0.056, respectively. The 1000-unit mass of the radish seeds was measured at different moisture levels. The Figure 6 indicates that the 1000-unit mass increases linear with increase in seed moisture content. It varies from 6.98 to 7.17 g when the moisture content increased from 5.65 to 21.71 % (d.b). There are many published literatures on moisture dependency of 1000-unit mass; results indicated that in most cases, with increasing moisture content, 1000-unit mass increased (Sacilik et al. 2003; Özarslan 2002).

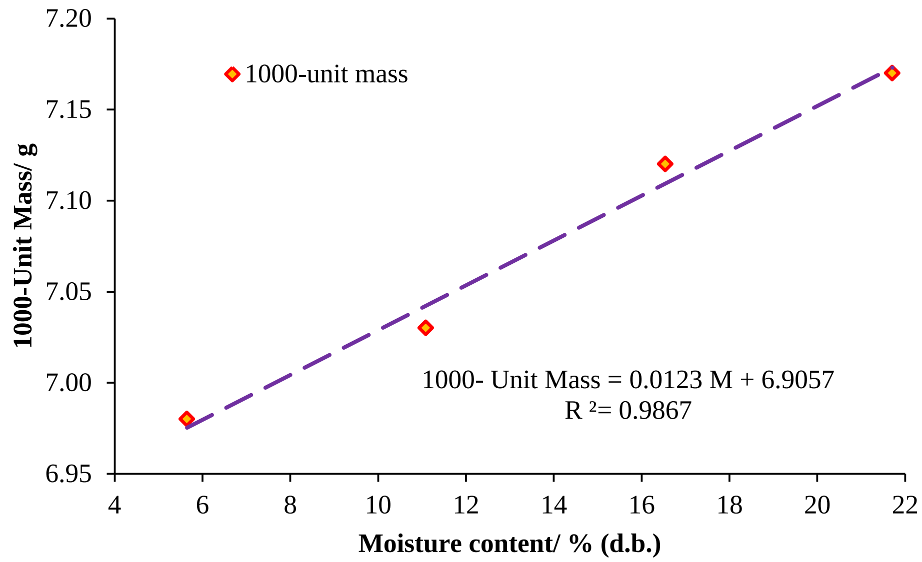


Figure 6 Variation of 1000-unit mass of red radish seeds with moisture content

Cetin et al. (2010) reported that when the moisture content increased from 6.95 to 19.08 % (d.b), the 1000-unit mass of the radish seeds decreased from 11.9 to 13.85 g. A comparison between obtained results from the present study and reported results by Cetin et al. (2010) shows in all moisture levels values of the 1000-unit mass of the radish seeds are less than the value of the 1000-unit mass reported by Cetin et al. (2010).

3.2.2 Effect of volume of the container and height of fall on bulk density and porosity

Results of the effects of volume of the container and height of fall on bulk density of the seeds are illustrated in Figures 7. Results showed that with increasing volume of container from 150 mL to 550 mL, bulk density of the seeds increased. But with increasing volume of container from 550 mL to 750 mL, bulk density of the seeds decreased. In all cases, with increasing height of fall of the seeds to the container from 50 mm to 250 mm, value of bulk density of the seeds increased.

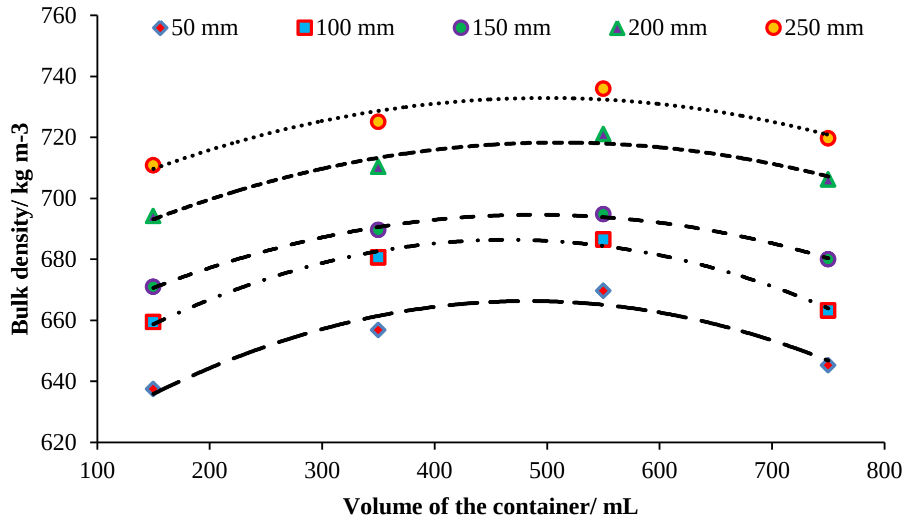


Figure 7 Effects of volume of the container and height of fall on bulk density of red radish seeds when the moisture content equals 5.65% (d.b)

Using the value of true density, values of bulk density in different heights of fall, and volume of the container, and Equation 23, values of porosity of the radish seeds were calculated when moisture content was equal to 5.65% (d.b) . Results of porosity of the seeds are illustrated in Figure 8. Results showed that with increasing volume of container from 150 mL to 550 mL, bulk density of the seeds decreased. But with increasing volume of container from 550 mL to 750 mL, bulk density of the seeds increased. In all cases, with increasing height of fall of the seeds to the container from 50 mm to 250 mm, value of the porosity of the seeds decreased.

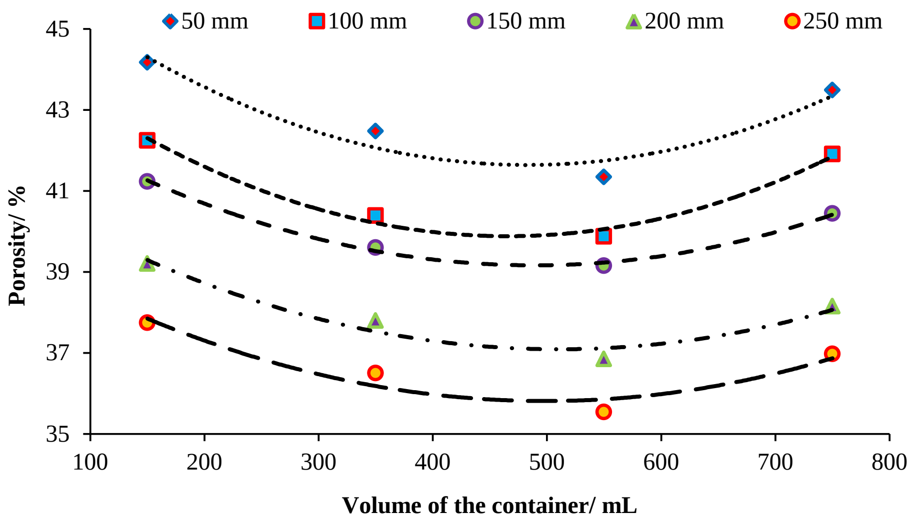


Figure 8 Effects of volume of the container and height of fall on porosity of red radish seeds when the moisture content equals to 5.65 % (d.b)

When the moisture content equals to 5.65% (d.b) , the results of bulk density in different levels of volume of container and different heights of fall of seeds to the container indicated that value of bulk density of radish seeds ranged from 637.460 kg/m^3 (when volume of the container was equal to 150 mL and height of fall was equal to 50 mm) to 735.987 kg/m^3 (when volume of the container was equal to 550 mL and height of fall was equal to 250 mm). The corresponding values for porosity were equal to 35.542% (when volume of the container was equal to 550 mL and height of fall was equal to 250 mm) to 44.171% (when volume of the container was equal to 150 mL and height of fall was equal to 50 mm), respectively.

Results of quadratic regression analysis of bulk density and porosity of radish seeds related to the volume of the container and height of fall are shown in Table 3. Results showed that in all cases, r-square value was more than 0.90; it means that the quadratic regression has a good performance in modeling the relationship between bulk density and volume of the container and also relationship between porosity and volume of the container.

Table 3 Constant coefficients of quadratic regression of bulk density and porosity of radish seeds related to volume of the container, in different levels of height of fall of seeds to the containers (moisture content equal to 5.65 % (d.b))

Parameter	Height of fall	$y = \alpha (x)^2 + \beta (x) + \gamma$			
		α	β	γ	R^2*(r-square)*
Bulk density (Kg m^{-3})	50 mm	-0.0003	0.2649	602.3600	0.9202
	100 mm	-0.0003	0.2586	626.2300	0.9819
	150 mm	-0.0002	0.2042	644.7500	0.9938
	200 mm	-0.0002	0.9440	667.8700	0.9440
	250 mm	-0.0002	0.1907	685.3700	0.9137
Porosity (%)	50 mm	0.00002	-0.0232	47.2450	0.9202
	100 mm	0.00002	-0.0226	45.1540	0.9820
	150 mm	0.00002	-0.0179	43.5320	0.9938
	200 mm	0.00002	-0.0173	41.5080	0.9440
	250 mm	0.00002	-0.0167	39.9670	0.9138

Where: y is bulk density or porosity and x is volume of the container

3.2.1 Effects of moisture content on bulk and true density and porosity

The bulk density of radish seeds decreased linearly with moisture content from 694.807 to 654.889 kg/m^3 in the moisture ranges of 5.65% to 21.71% dry basis (Figure 9). The bulk density of seeds was significantly affected by moisture content at 5% level of significance; a relationship exists between bulk density and moisture content. The negative relationship of bulk density with moisture content is also observed by other researchers (Garnayak et al. 2008; Pradhan et al. 2009; Sánchez-Mendoza et al. 2008; Zewdu and Solomon 2007)

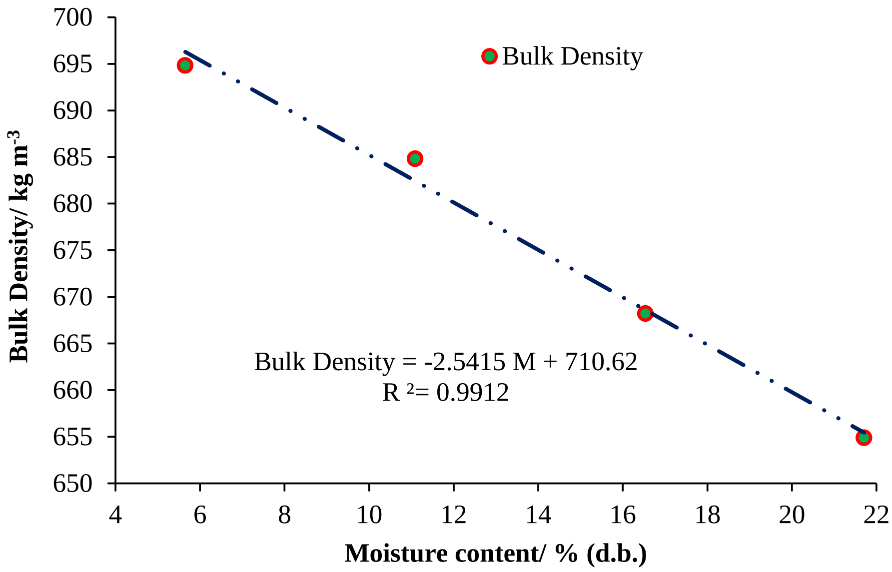


Figure 9 Variation of bulk density of red radish seeds with moisture content

Cetin et al. (2010) reported that when the moisture content increased from 6.95% to 19.08% (d.b), the bulk density of the radish seeds decreased from 698.6 to 652.3 kg/m^3. A comparison between obtained results from the present study and reported results by Cetin et al. (2010) shows in all moisture levels values of the bulk density of the radish seeds are less than the value of the bulk density reported by Cetin et al. (2010).

The true density of radish seeds decreased linearly with moisture content from 1141.810 to 1057.79 6 kg/m^3 in the moisture ranges of 5.65% to 21.71% dry basis (Figure 10). The reported results of the relationship between the true density and moisture content were often contradictory; the results sometimes indicated an increase of the true density with increase in moisture content (Bart-Plange and Baryeh 2003; Aydin 2003; Garnayak et al. 2008; Milani et al. 2007; Mirzabe et al. 2013b), but in some cases with increasing moisture content, the true density decreased (Deshpande et al. 1993; Sologubik et al. 2013; Zewdu and Solomon 2007; Pradhan et al. 2009).

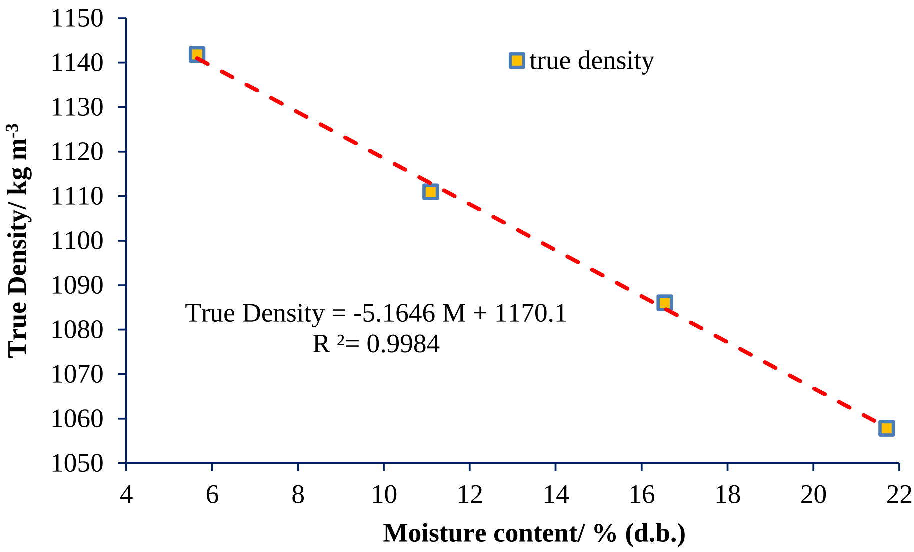


Figure 10 Variation of true density of red radish seeds with moisture content

Cetin et al. (2010) reported that when the moisture content increased from 6.95% to 19.08% (d.b), the true density of the radish seeds decreased from 1000.41 to 974.66 kg/m^3. A comparison between obtained results from the present study and reported results by Cetin et al. (2010) shows in all moisture levels values of the true density of the seeds are more than the value of the true density reported by Cetin et al. (2010).

The porosity was calculated using the average values of bulk density and true density of each batch by Equation 23. It was observed that when the moisture content increased from 5.65% to 11.09% (d.b), the porosity decreased from 39.149% to 38.358%. Also it was observed that when moisture content increased from 11.09% to 16.54% (d.b), porosity increased from 38.358% to 38.470%, while when moisture content increased from 16.54% to 21.71% (d.b), porosity decreased from 38.470% to 38.089% as shown in Figure 11. For a given mass of seeds, an increase in the moisture content leads to higher bulk volume and the addition of water to the seeds structure affects principle dimensions of seed differently, altering mainly the thickness and width, it influences are more on the bulk density than on the true density of seeds, resulting in a rise in porosity (Sologubik et al. 2013). Pradhan et al. (2009) for jatropha fruit and Mwithiga and Sifuna (2006) for sorghum seeds reported a decreasing trend of porosity with increasing moisture content.

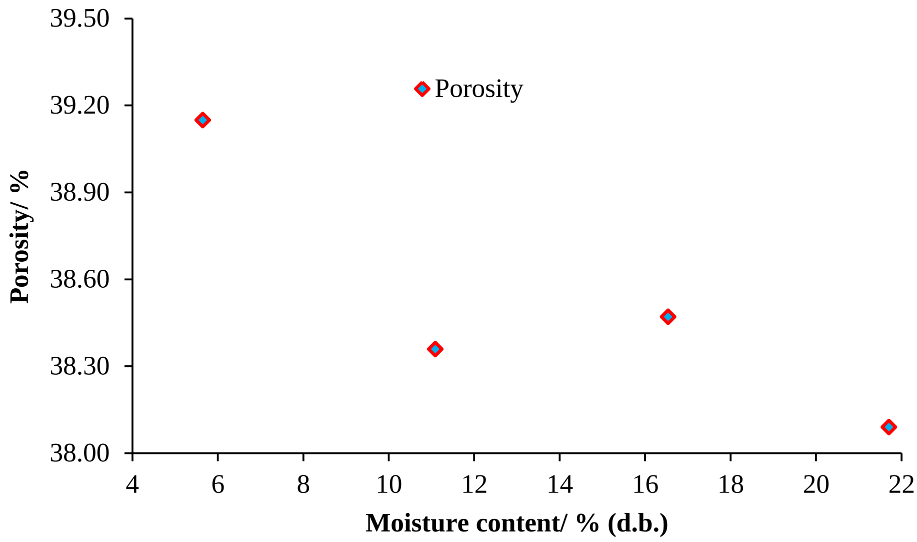


Figure 11 Variation of porosity of red radish seeds with moisture content

Cetin et al. (2010) reported that when the moisture content increased from 6.95% to 19.08% (d.b), the porosity of the radish seeds increased from 30.17% to 33.07%; while results of present study showed that porosity of the seeds decreased from 38.470% to 38.089%, when the moisture content increased from 5.65% to 21.71% (d.b). A comparison between obtained results from the present study and reported results by Cetin et al. (2010) shows in all moisture levels, values of the porosity of the radish seeds are more than the values of the porosity reported by Cetin et al. (2010).

3.3 Frictional properties

3.3.1 Angle of friction

The static angle of friction of radish seeds on galvanized, iron, plywood and rubber surfaces when moisture content increased from 5.65% to 21.71% (d.b) was measured. It is observed that the static coefficient of friction of the radish seeds increased linearly with increase in moisture content for all contact surfaces as shown in Figure 12. When moisture content equals to 5.65% and 11.09% (d.b) the maximum and minimum friction is offered by rubber and galvanized surfaces, respectively, while when moisture content equals to 16.54% and 21.7% (d.b) the maximum and minimum friction is offered by plywood and galvanized surfaces, respectively. The least static coefficient of friction may be owing to the smoother and more polished surface of the galvanized sheet than the other materials used. Wood also offered the maximum friction for tef seed (Zewdu and Solomon 2007), jatrofa fruit (Pradhan et al. 2009) and for almond (Mirzabe et al. 2013b), but the galvanized iron had higher coefficient of friction than plywood for Roselle seeds (Sánchez-Mendoza et al. 2008) and lentil seeds (Amin et al. 2004).

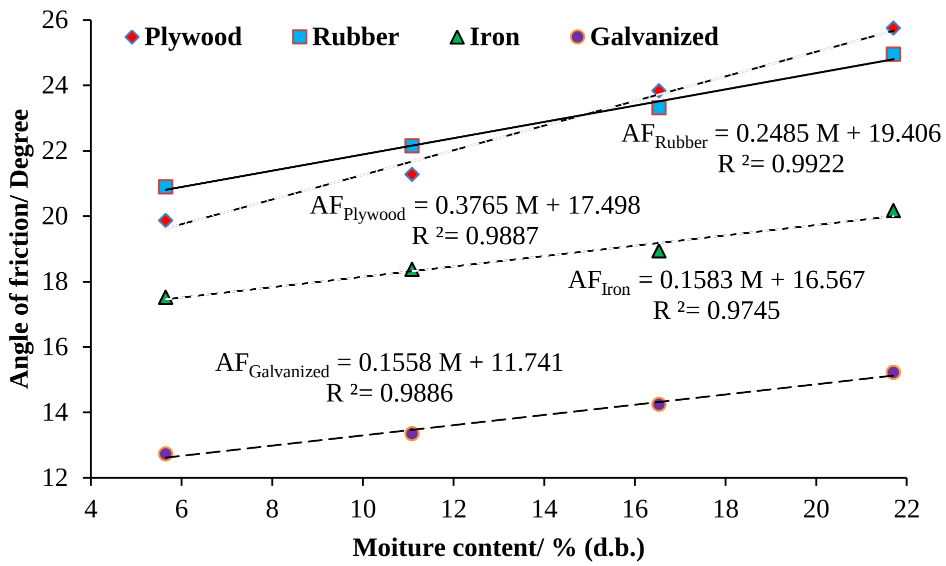


Figure 12 Variation of static angle of friction of red radish seeds with moisture content

Cetin et al. (2010) reported that when the moisture content increased from 6.95% to 19.08 % (d.b), the static coefficient of friction of radish seed increased linearly against surfaces of four structural materials, namely, rubber (0.354–0.410), aluminum (0.295–0.346), stainless steel (0.245–0.306) and galvanized iron (0.308–0.368). A comparison between obtained results from the present study and reported results by Cetin et al. (2010) shows in all moisture levels, values of the static coefficient of the seeds on rubber and galvanized iron surface are more and less than the results of the Cetin et al. (2010), respectively.

3.3.2 Angle of repose

The angle of repose is sometimes used in the design of equipment for the processing of particulate solids. For example, it may be used to design an appropriate hopper or silo to store the material, or to size a conveyor belt for transporting the material. It can also be used in determining whether or not a slope will likely collapse; the talus slope is derived from angle of repose and represents the steepest slope a pile of granular material will take. Also the angle of repose is an indicator of the product’s flow ability. The effect of moisture content on pouring angle of repose (PAR) on galvanized, iron, plywood and rubber surface are shown in Figure 13. It is observed that the pouring angle of repose of the radish seeds increased linearly with increase in moisture content for all contact surfaces. The maximum and minimum pouring angle of repose (PAR) is offered by rubber and galvanized surfaces, respectively.

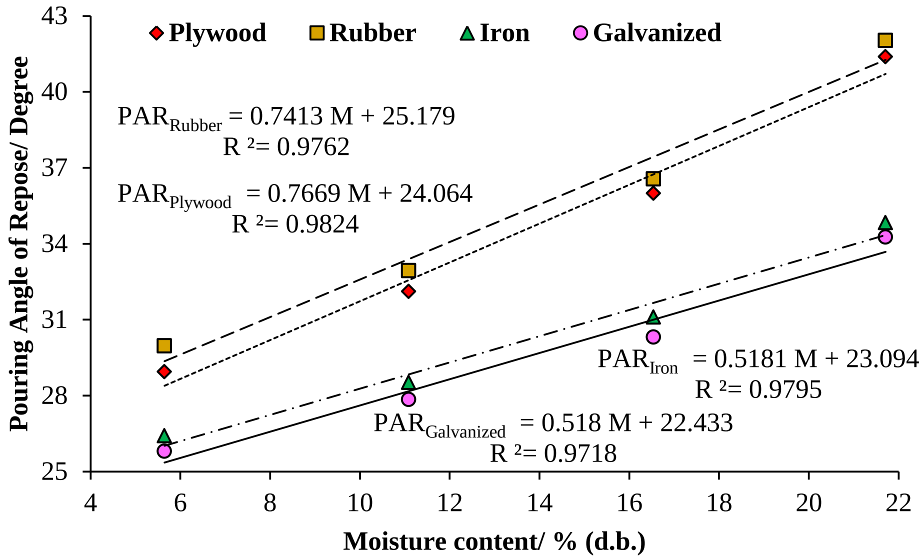


Figure 13 Variation of pouring angle of repose of red radish seeds with moisture content

The effect of height of fall on pouring angle of repose on galvanized, iron, plywood and rubber surface are shown in Figure 14. It is observed that, for all contact surfaces, the pouring angle of repose of the radish seeds increased linearly with increase in height of fall from 50 to 150 mm. Also, on the rubber and plywood surfaces with increasing height of fall from 150 mm to 250 mm, pouring angle of repose of the radish seeds increased. But, on the iron and galvanized surfaces with increasing height of fall from 150 mm to 250 mm, pouring angle of repose of the radish seeds decreased.

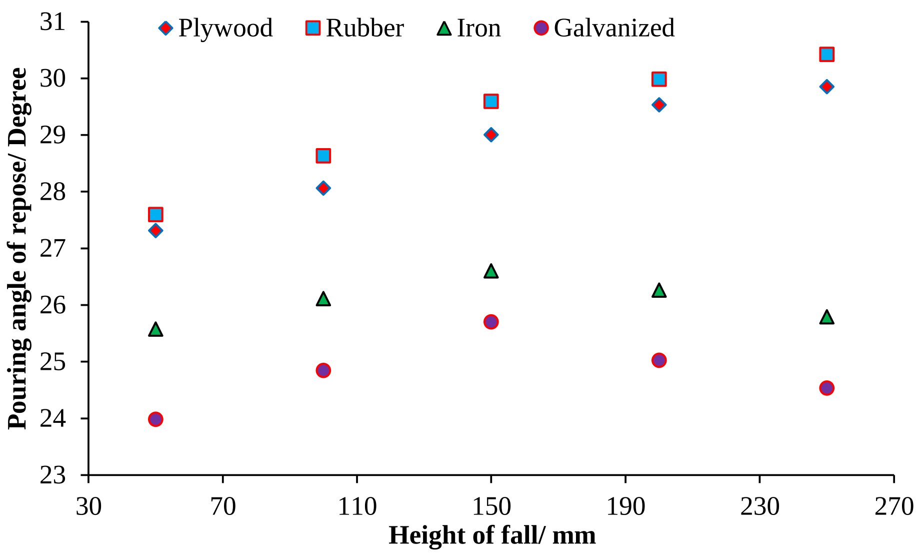


Figure 14 Variation of pouring angle of repose of red radish seeds with height of fall when the moisture content equals to 5.65% (d.b)

The effect of moisture content on filling and empting angle of repose are shown in Figure 15. It is observed that the filling and empting angle of repose of the radish seeds increased linearly with increase in moisture content; also, in all moisture content levels, empting angle of repose was more than the filling angle of repose. Different behaviors for empting and filling angle of repose have been reported for other agricultural materials, the angle of repose was obtained from empting method was greater than that of filling method for wild pistachio (Fadavi et al. 2013), but the reverse results were shown for jatropha (Sirisomboon et al. 2007).

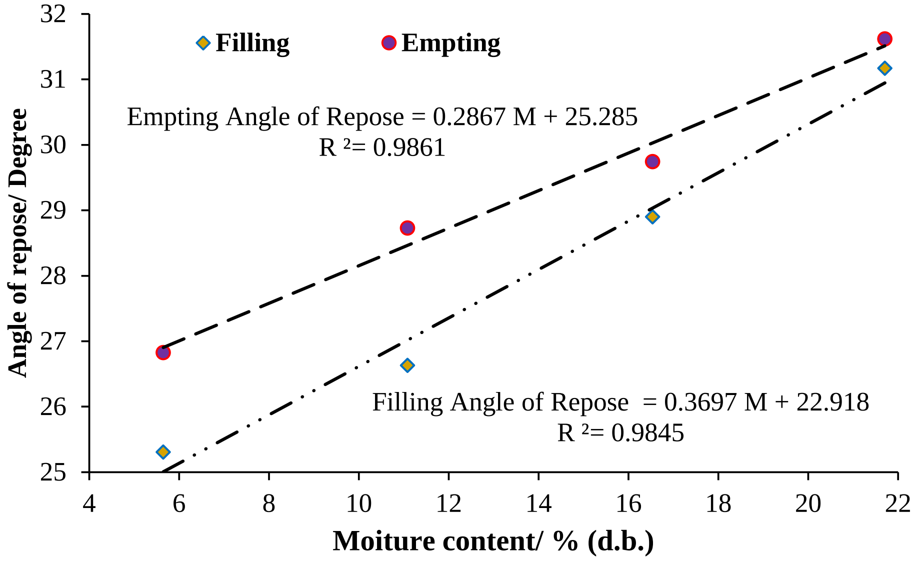


Figure 15 Variation of filling and empting angle of repose of red radish seeds with moisture content

The effect of moisture content on Hele-Shaw angle of repose (HAR) is shown in Figure 16. It is observed that the Hele-Shaw angle of repose (HAR) of the radish seeds increased linearly with increase in moisture content in all surfaces. The maximum and minimum Hele-Shaw angle of repose is offered by rubber and galvanized surfaces, respectively. The least angle of repose may be owing to the smoother and more polished surface of the galvanized sheet than the other materials used.

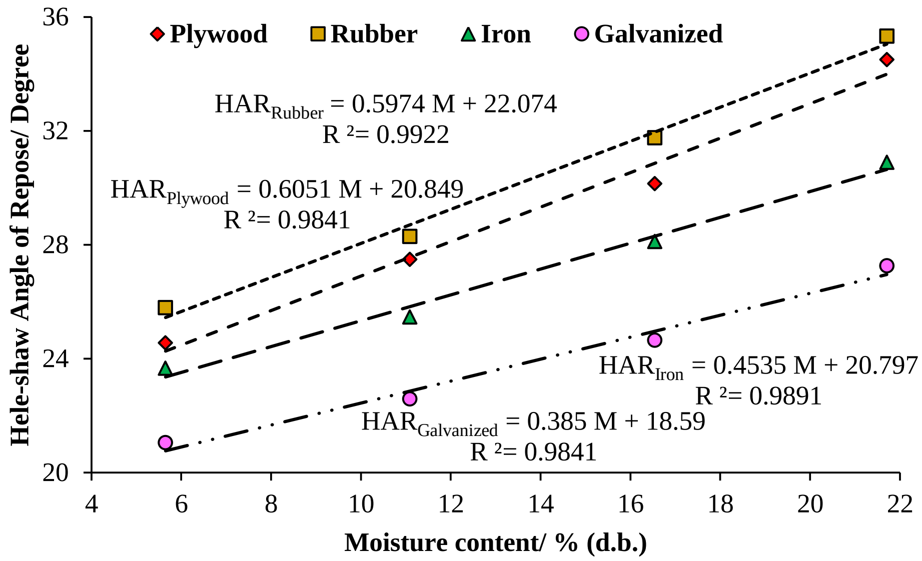


Figure 16 Variation of Hele-shaw angle of repose of red radish seeds with moisture content

A comparison between different methods used to measure angle of repose of radish seeds showed that when the Hele-Shaw methods was used to measure angle of repose, minimum values were found, while pouring method had maximum values.

3.4 Modeling of dimensions and mass

Distributions of the length, width, thickness and single mass of the radish seeds were modeled using the tree-parameter Gamma, Generalized Extreme Value (G. E. V) and three-parameter Weibull probability density functions (PDF) distribution; the results of modeling are shown in Table 3. Results showed that to model length, thickness and mass of the seeds, G. E. V distribution had the best performance, while Weibull distribution had the worst performance. Also to model the width of the seeds, G. E. V distribution had the best performance, while Gamma distribution had the worst performance (Table 4).

Table 4 Calculated parameter values of the Gamma, Generalized Extreme Value (G. E. V) and Weibull probability density function for length, width, thickness and mass of radish seeds

Parameter	Distribution name	Shape parameter	Scale parameter	Location parameter	Kolmogorov-Smirnov index	Rank
	Gamma	4.778	0.022	0.639	0.0381	2
Length	G. E. V	-0.018	0.040	0.724	0.0340	1
	Weibull	1.931	0.102	0.656	0.0534	3
	Gamma	16.305	0.014	0.411	0.0804	3
Width	G. E. V	-0.155	0.053	0.617	0.0741	1
	Weibull	2.538	0.150	0.508	0.0768	2
	Gamma	6.080	0.023	0.451	0.0876	2
Thickness	G. E. V	-0.099	0.050	0.569	0.0864	1
	Weibull	2.052	0.125	0.482	0.0943	3
	Gamma	5.351	0.001	0.000	0.1055	2
Mass	G. E. V	-0.029	0.002	0.006	0.1021	1
	Weibull	2.092	0.006	0.002	0.1065	3

Results of modeling showed that whenever skewness and kurtosis had positive values, Generalized Extreme Value distribution had good performance, while Weibull distribution had poor performance for modeling the data. Also whenever skewness had positive value and kurtosis a negative value, G.E.V distribution showed good performance, while Gamma distribution had poor performance for modeling the data.

Khazaei et al. (2008) modeled mass and size distributions of two varieties of sunflower seeds and kernels using the Log-normal, normal and Weibull distributions. They cited that when skewness had a positive value, Log-normal distribution was the best and normal distribution was the worst model for data prediction. Mirzabe et al. (2012) modeled distance between adjacent sunflower seeds on sunflower head of three varieties using the Log-normal, normal and Weibull distributions. They cited that whenever skewness and kurtosis had negative value, Weibull distribution was the best fit.

For an easy comparison between dimensions of radish seeds together, probability density functions (PDF) are shown in Figure 16. For all modeling in Figure 16, Generalized Extreme Value was used, because it had the best prediction of probability density functions (PDF) of length, width and thickness of seeds. For length and thickness of seeds, skewness and kurtosis had positive value and for width, skewness had positive value and kurtosis had negative value; which is shown in Figure 16. This figure shows that there is little overlap between the PDF of length and width, and even less overlap between the PDF of length and thickness. There is no overlap between length and thickness. It means that the greatest measured thickness of seeds is more than the lowest measured length. Also there is great overlap between the PDF of width and thickness; it means that the difference between measured thickness of the seeds and measured width of seeds is very low; also in several cases value of thickness of seeds is more than the value of width of the seeds.

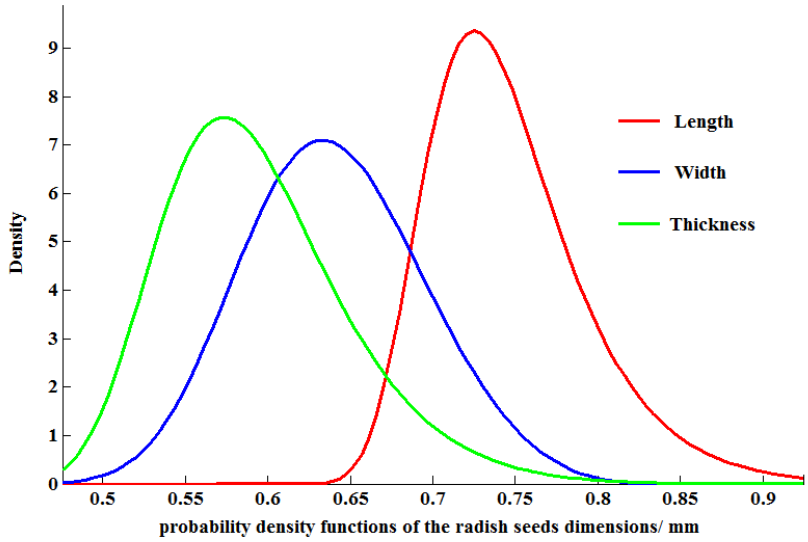


Figure 17 Probability density functions of length, width and thickness distribution of red radish seeds

4 Conclusions

Dimensional properties of radish seeds were measured using image processing technique and length, width, thickness and mass distributions of radish seeds were modeled using Gamma, Generalized Extreme Value and Weibull distributions. Also effects of the moisture content on mass of single seed, 1000-unit seed, bulk density, true density, porosity, static angle of friction and angle of repose were studied. Effects of volume of the container and height of fall on bulk density and porosity when the moisture content equaled to 5.65% (d.b) were studied. Also pouring angle of repose and Hele-Shaw angle of repose on galvanized, iron, plywood and rubber surfaces were measured.

Results showed that with increasing volume of the container from 150 mL to 550 mL, bulk density of the seeds increased; but with increasing volume of the container from 550 mL to 750 mL, bulk density of the seeds decreased. In all cases with increasing height of fall of the seeds to the container from 50 mm to 250 mm, value of the porosity of the seeds decreased. The results of bulk density in different levels of volume of container and different heights of fall of seeds to the container indicated that value of bulk density of radish seeds ranged from 637.460 kg/m^3 (when volume of the container was equal to 150 mL and height of fall was equal to 50 mm) to 735.987 kg m^{-3} (when volume of the container was equal to 550 mL and height of fall was equal to 250 mm).

Results of the effect of the moisture content on gravimetrical properties showed that the bulk density of radish seeds decreased linearly with moisture content from 694.807 to 654.889 kg/m^3 and the true density of radish seeds decreased linearly with moisture content from 1141.810 to 1057.796 kg/m^3 in the moisture ranges of 5.65% to 21.71% (d.b); while, 1000-unit mass increases linear with increase in seed moisture content.

Results of the effect of the moisture content on frictional properties showed that with increasing moisture content, angle of friction (on all surfaces) and angle of repose based on different methods and different surfaces decreased. A comparison between different methods used to measure angle of repose of radish seeds shows when the Hele-Shaw methods was used to measure angle of repose, minimum values were found, while pouring method had maximum values. So, when it is necessary for seeds to move (in planter machines, for instance), the designation of the machines and silos has to be based on the pouring angle of repose. But when seeds do not need to move (transfer conveyors, for instance), Hele-Shaw angle of repose needs to be considered.

Although the seed dimensions and seeds mass measured by Cetin et al. (2010) were greater than those obtained in the present study, the bulk density of both samples was in the same range. More interesting, the true density of our sample was more than theirs. So, this claim can be made that in general, the differences between Cetin et al. (2010) and our results can be due to the difference in the variety of the plant and also in the conditions in which the plants are cultivated. In cases where the values do not show considerable differences, these results can be of a great help to those agricultural equipment producers who need to use these results in designing their machines. Take, for example, a person who aims to design a planter machine for radish seeds. Similar results obtained in different studies can ensure the designer that his machine can be used for different varieties grown in different places.

Acknowledgement

The authors would like to thank the University of Tehran for providing technical support for this work. The authors would also like to thank Mr. Mohammad Hassan Torabi for his support in editing the language of the paper.

References

Alqasoumi, S., M. Al-Yahya, T. Al-Howiriny, and S. Rafatullah. 2008. Gastroprotective effect of radish “Raphanus sativus” L. on experimental gastric ulcer models in rats. *Farmacia* Lvi (2): 204-214.

Altuntaş, E., E. Özgöz, and Ö. F. Taşer. 2005. Some physical properties of fenugreek (Trigonella foenum-graceum L.) seeds. *Journal of Food Engineering* 71 (1):37-43.

Amin, M., M. Hossain, and K. Roy. 2004. Effects of moisture content on some physical properties of lentil seeds. *Journal of Food Engineering* 65 (1):83-87.

Anuradha, S., and S. Rao. 2007. The effect of brassinosteroids on radish (Raphanus sativus L.) seedlings growing under cadmium stress. *Plant Soil and Environment* 53 (11):465.

Aviara, N. A., P. P. Power, and T. Abbas. 2013. Moisture-dependent physical properties of moringa oleifera seed relevant in bulk handling and mechanical processing. *Industrial Crops and Products* 42(1):96-104.

Aydin, C. 2003. Physical properties of almond nut and kernel. *Journal of Food Engineering* 60 (3):315-320.

Bart-Plange, A., and E. A. Baryeh. 2003. The physical properties of Category B cocoa beans. *Journal of Food Engineering* 60 (3):219-227.

Bhunya, P., R. Berndtsson, C. Ojha, and S. Mishra. 2007. Suitability of Gamma, Chi-square, Weibull, and Beta distributions as synthetic unit hydrographs. *Journal of Hydrology* 334 (1):28-38.

Burubai, W., A. Akor, A. Igoni, and Y. Puyate. 2007. Some physical properties of African nutmeg (Monodora myristica). *International Agrophysics* 21 (2):123.

Cetin, M., E. Şimşek, T. Akbaş, and C. Özarslan. 2010. Physical Properties of Radish (Raphanus sativus L.) Seed as a Function of Moisture Content. *The Philippine Agricultural Scientist* 93 (3): 1.

Deshpande, S., S. Bal, and T. Ojha. 1993. Physical properties of soybean. *Journal of Agricultural Engineering Research* 56 (2):89-98.

Ersoy, O. 2010. Surface area and volume measurements of volcanic ash particles by SEM stereoscopic imaging. *Journal of Volcanology and Geothermal Research* 190 (3):290-296.

Fadavi, A., S. R. Hassan-Beygi, and F. Karimi. 2013. Moisture dependent physical and mechanical properties of Syrjan region wild pistachio nut. *Agricultural Engineering International: CIGR Journal* 15 (2):221-230.

Garnayak, D., R. Pradhan, S. Naik, and N. Bhatnagar. 2008. Moisture-dependent physical properties of jatropha seed (Jatropha curcas L.). *Industrial Crops and Products* 27 (1):123-129.

Gorgoso, J., J. Á. González, A. Rojo, and J. Grandas-Arias. 2007. Modelling diameter distributions of Betula alba L. stands in northwest Spain with the two-parameter Weibull function. *Forest Systems* 16 (2):113-123.

Gupta, R., and S. Das. 1997. Physical properties of sunflower seeds. *Journal of Agricultural Engineering Research* 66 (1):1-8.

He, L.-L., L.-W. Liu, Y.-Q. Gong, X.-L. Hou, X.-W. Zhu, J.-L. Yang, and B. Wu. 2008. Physiological responses of radish (Raphanus Sativus L.) to lead stress. Paper read at Bioinformatics and Biomedical Engineering, 2008. ICBBE 2008. The 2nd International Conference on.

Heidarbeigi, K., H. Ahmadi, K. Khaeiralipour, and A. Tabatabaeefar. 2009. Some physical and mechanical properties of khinjuk. *Pakistan Journal of Nutrition* 8 (1):74-77.

Hwang, C. W. 2009. Antifungal and Plant Growth Promotion Activities of Recombinant Defensin Proteins from the Seed of Korean Radish (Raphanus sativus L.). *한국환경농학회지* 28 (4):435-441.

Inoue, H., D. Fukuoka, Y. Tatai, H. Kamachi, M. Hayatsu, M. Ono, and S. Suzuki. 2013. Properties of lead deposits in cell walls of radish (Raphanus sativus) roots. *Journal of plant research* 126 (1):51-61.

Kabas, O., E. Yilmaz, A. Ozmerzi, and İ. Akinci. 2007. Some physical and nutritional properties of cowpea seed (Vigna sinensis L.). *Journal of Food Engineering* 79 (4):1405-1409.

Khan, D., and B. Frankland. 1983. Effects of cadmium and lead on radish plants with particular reference to movement of metals through soil profile and plant. *Plant and soil* 70 (3):335-345.

Khazaei, J., S. Jafari, and S. Noorolah. 2008. Lognormal vs. Normal and Weibull distributions for modeling the mass and size distributions of sunflower seeds and kernels. Paper read at World conference on agricultural information and IT.

Kleinhans, M., H. Markies, S. De Vet, and F. Postema. 2011. Static and dynamic angles of repose in loose granular materials under reduced gravity. *Journal of Geophysical Research: Planets (1991–2012)* 116 (E11).

Koc, A. B. 2007. Determination of watermelon volume using ellipsoid approximation and image processing. *Postharvest Biology and Technology* 45 (3):366-371.

Kostka-Rick, R., and W. J. Manning. 1993. Radish (Raphanus sativus L.): a model for studying plant responses to air pollutants and other environmental stresses. *Environmental pollution* 82 (2):107-138.

Lane, S., and E. Martin. 1977. A histochemical investigation of lead uptake in Raphanus sativus. *New Phytologist* 79 (2):281-286.

Lewis-Jones, L., J. Thorpe, and G. Wallis. 1982. Genetic divergence in four species of the genus Raphanus: implications for the ancestry of the domestic radish R. sativus. *Biological Journal of the Linnean Society* 18 (1):35-48.

Lugasi, A., A. Blázovics, K. Hagymási, I. Kocsis, and Á. Kéry. 2005. Antioxidant effect of squeezed juice from black radish (Raphanus sativus L. var niger) in alimentary hyperlipidaemia in rats. *Phytotherapy research* 19 (7):587-591.

Mathe-Gaspar, G., and A. Anton. 2002. Heavy metal uptake by two radish varieties. *Acta Biologica Szegediensis* 46 (3-4):113-114.

McGahon, M. K., J. M. Dawicki, A. Arora, D. A. Simpson, T. A. Gardiner, A. Stitt, C. N. Scholfield, J. G. McGeown, and T. M. Curtis. 2007. Kv1. 5 is a major component underlying the A-type potassium current in retinal arteriolar smooth muscle. *American Journal of Physiology-Heart and Circulatory Physiology* 292 (2):H1001-H1008.

Milani, E., M. Seyed, A. Razavi, A. Koocheki, V. Nikzadeh, N. Vahedi, M. MoeinFard, and A. GholamhosseinPour. 2007. Moisture dependent physical properties of cucurbit seeds. *International Agrophysics* 21 (2):157.

Mirzabe, A. H., J. Khazaei, and G. R. Chegini. 2012. Physical properties and modeling for sunflower seeds. *Agricultural Engineering International: CIGR Journal* 14 (3):190-202.

Mirzabe, A. H., J. Khazaei, G. R. Chegini, and M. H. Amir Pour Rostami Nejad. 2013a. Determination of some physical properties of virgin olive fruits. *Agricultural Engineering International: CIGR Journal* 15 (1):201-210.

Mirzabe, A. H., J. Khazaei, G. R. Chegini, and O. Gholami. 2013b. Some physical properties of almond nut and kernel and modeling dimensional properties. *Agricultural Engineering International: CIGR Journal* 15 (2):256-265.

Mora, C., and A. Kwan. 2000. Sphericity, shape factor, and convexity measurement of coarse aggregate for concrete using digital image processing. *Cement and concrete research* 30 (3):351-358.

Moreland, D. E., G. G. Hussey, C. R. Shriner, and F. S. Farmer. 1974. Adenosine phosphates in germinating radish (Raphanus sativus L.) seeds. *Plant physiology* 54 (4):560-563.

Mwithiga, G., and M. M. Sifuna. 2006. Effect of moisture content on the physical properties of three varieties of sorghum seeds. *Journal of Food Engineering* 75 (4):480-486.

Özarslan, C. 2002. PH—postharvest technology: physical properties of cotton seed. *Biosystems engineering* 83 (2):169-174.

Perez, E., G. Crapiste, and A. Carelli. 2007. Some physical and morphological properties of wild sunflower seeds. *Biosystems engineering* 96 (1):41-45.

Pradhan, R., S. Naik, N. Bhatnagar, and V. Vijay. 2009. Moisture-dependent physical properties of jatropha fruit. *Industrial Crops and Products* 29 (2):341-347.

Sacilik, K., R. Öztürk, and R. Keskin. 2003. Some physical properties of hemp seed. *Biosystems engineering* 86 (2):191-198.

Sánchez-Mendoza, J., A. Domínguez-López, S. Navarro-Galindo, and J. A. López-Sandoval. 2008. Some physical properties of Roselle (Hibiscus sabdariffa L.) seeds as a function of moisture content. *Journal of Food Engineering* 87 (3):391-397.

Sekimata, M., K. Ogura, Y. Tsumuraya, Y. Hashimoto, and S. Yamamoto. 1989. A β-galactosidase from radish (Raphanus sativus L.) seeds. *Plant physiology* 90 (2):567-574.

Sharma, V., L. Das, R. Pradhan, S. Naik, N. Bhatnagar, and R. Kureel. 2011. Physical properties of tung seed: An industrial oil yielding crop. *Industrial Crops and Products* 33 (2):440-444.

Sirisomboon, P., P. Kitchaiya, T. Pholpho, and W. Mahuttanyavanitch. 2007. Physical and mechanical properties of Jatropha curcas L. fruits, nuts and kernels. *Biosystems engineering* 97 (2):201-207.

Sologubik, C., L. Campañone, A. Pagano, and M. Gely. 2013. Effect of moisture content on some physical properties of barley. *Industrial Crops and Products* 43(1):762-767.

Terras, F. R., I. J. Goderis, F. Van Leuven, J. Vanderleyden, B. P. Cammue, and W. F. Broekaert. 1992. In vitro antifungal activity of a radish (Raphanus sativus L.) seed protein homologous to nonspecific lipid transfer proteins. *Plant physiology* 100 (2):1055-1058.

Vargas S, R., R. Perez G, S. Perez G, M. Zavala S, and C. Perez G. 1999. Antiurolithiatic activity of Raphanus sativus aqueous extract on rats. *Journal of Ethnopharmacology* 68 (1-3):335-338.

Wang, Y., L. Xu, Y. Chen, H. Shen, Y. Gong, C. Limera, and L. Liu. 2013. Transcriptome profiling of radish (Raphanus sativus L.) root and identification of genes involved in response to lead (Pb) stress with next generation sequencing.

Xu, D., J. Cui, R. Bansal, X. Hao, J. Liu, W. Chen, and B. S. Peterson. 2009. The ellipsoidal area ratio: an alternative anisotropy index for diffusion tensor imaging. *Magnetic resonance imaging* 27 (3):311-323.

Zewdu, A., and W. Solomon. 2007. Moisture-dependent physical properties of tef seed. *Biosystems engineering* 96 (1):57-63.