Moisture content on some engineering properties of celery (Apium Graveolens L) seeds

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Abstract: The study was conducted to investigate some physical properties of celery seed at various moisture levels. The average length, width, thickness and 1000-seeds mass were 0.571, 0.429, 0.295 mm and 0.792 g, respectively, at moisture content of 5.24% (d.b). Length, width and thickness distributions of the seeds were modeled using Generalized Extreme Value, lognormal and Weibull distributions. Results showed that to model length of the seeds, lognormal distribution had the best performance while to model the width of the seeds Weibull distribution had the best performance. True density has increase from 892.02 to 931.42 kg/m3 when the moisture content increased from 5.24% to 20.25% (d.b). The angle of static friction increased from 28.45 to 39.66 °, 25.15 to 34.84 °, 19.57 to 27.07 ° and 16.72 to 19.720 ° for plywood, rubber, iron and galvanized metal, respectively, as the moisture content increases from 5.24% to 20.25% (d.b). The pouring angle of repose increased from 34.70 to 39.12 °, 33.37 to 36.37 °, 30.59 to 33.33 ° and 27.16 to 29.45 ° for plywood, rubber, iron and galvanized metal , respectively, as the moisture content increases from 5.24% to 20.25% (d.b). The Hele-Shaw angle of repose increased from 32.65 to 35.25 °, 30.35 to 32.77 °, 27.81 to 30.03 ° and 24.72 to 26.61 ° for plywood, rubber, iron and galvanized metal , respectively, as the moisture content increases from 5.24% to 20.25% (d.b).

Keywords: Image processing technique; dimensional properties; modeling; gravimetrical properties; -; medicinal plant-.

Citation: Mirzabe, A. H., M. Taheri, A. Pouyesh, and N. B. Bavani. 2016. Moisture content on some engineering properties of celery (Apium Graveolens L) seeds. Agricultural Engineering International: CIGR Journal, 18 (2):243-259.

1 Introduction

Celery (*Apium graveolens* L.) is a plant variety in the family Apiaceae, commonly used as a vegetable. Celery is a biennial species of the Umbelliferae which probably arose in Eurasia and grows to 1 m tall (Orton and Arus 1984). The leaves are pinnate to bipinnate with rhombic leaflets 30 to 60 mm long and 20 to 40 mm broad. The flowers are creamy-white, 2 to 3 mm in diameter, and are produced in dense compound umbels. The seeds are broad ovoid to globose, 1.5 to 2 mm long and wide.

Celery is important plants in some countries, where they have been used to flavor various foods and also for medicinal purposes (Daukšas et al., 2002). The leaves are strongly flavored and are used less often, either as a flavoring in soups and stews or as a dried herb. In temperate countries, celery is also grown for its seeds. Actually very small fruit, these "seeds" yield a valuable volatile oil used in the perfume and pharmaceutical industries. They also contain an organic compound called apiol. Celery seeds can be used as flavoring or spice, either as whole seeds or ground and mixed with salt, as celery salt. Celery salt can also be made from an extract of the roots, or using dried leaves.

Recent research has greatly bolstered our knowledge about celery's anti-inflammatory health benefits, including its protection against inflammation in the digestive tract itself. Some of the unique non-starch polysaccharides in

Received date: 2015-10-31 **Accepted date:** 2016-02-16
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celery including apiuman appear especially important in producing these anti-inflammatory benefits. In addition to well-known antioxidants like vitamin C and flavonoids, scientists have now identified at least a dozen other types of antioxidant nutrients in celery. These antioxidants include dihydrostilbenoids like lunularin as well as furanocoumarins like bergapten and psoralen.

Medicinal and aromatic substances are present in the roots, stem and leaves of celery. The healing properties of celery are due to the essential oils and flavonoids, mostly apiin and apigenin. Essential oils are present in all parts of the plant: in leaves and roots up to 1%, while their content in the seed can amount even to 7%. Essential oils from celery exhibit antifungal and antibacterial actions on Staphylococcus aureus, Staphylococcus albus, Shigella dysenteriae, Salmonella typhi, Streptococcus faecalis, Streptococcus pyogenes and Pseudomonas solanacearum. Apigenin does not act on Escherichia coli and Pseudomonas aeruginosa (Lewis et al. 1985; Atta and Alkofahi 1998; Popović et al. 2006).

Celery can lower blood pressure, regulate heart function, as well as the blood glucose level by stimulating the pancreas to insulin secretion, so that it can be used to slow down and treat complications caused by diabetes. From old times celery has been known as an aphrodisiac and the investigations showed that celery contains the male sex hormone and rosterone (Teng et al., 1988).

It is known that celery can cause photodermatitis and contact dermatitis. Larger amounts of essential oils can cause sedation and irritation and be responsible for spasmolytic action. A number of chemical compounds present in celery seeds show anti-inflammatory and analgesic actions (Atta and Alkofahi, 1998; Lewis et al., 1985). Apigenin from celery seed exhibits an antiaggregation effect in vitro (Teng et al., 1988). It also inhibits contractions of the isolated smooth muscle of the thoracic aorta (Ko et al., 1991). Active components of celery seed (senkyunolide-N and senkyunolide-J) obtained by methanol extraction exhibit nematicidal, antifungal and mosquitocidal actions (Atta and Alkofahi, 1998; Momin and Nair, 2001).

The proper design of process equipment depends essentially on the physical and mechanical properties of agricultural products. Nowadays, engineers greatly complicated systems in the design of storage structures of crops and in the selection of storage equipment. Both structural properties and features of the stored material are important in the design of storage equipment and facilities (Kibar and Öztürk, 2008; Kibar et al., 2014). Different researchers report the use of characteristic dimensions to determine the size of seeds (Aviara et al., 2013; Garnayak et al., 2008; Sologubik et al., 2013). Size and shape are important 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 friction coefficient 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. Moisture content is useful information in the drying process (Sirisomboon et al., 2007).

A lot of researches have been conducted on physical and mechanical properties of agricultural seeds, grains, fruits, nuts and kernels (Gupta and Das, 2000; Milani et al., 2007; Altuntaş et al., 2005; Aydin, 2003; Varnamkhasti et al., 2008; Tabarsa et al., 2011). While a lot of researchers have conducted studies on physical and mechanical properties of agricultural crops and products, literature review showed that there is no published literature on physical and mechanical celery seed. Dimensions, mass and other physical properties can be determined for a single seed; 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 (Khazaei et al., 2008). There are many reports on modeling the properties of agricultural products based on continues statistical distributions such as normal, lognormal, Weibull, gamma and Generalized Extreme Value and etc. (Gorgoso et al., 2007; Mirzabe et al., 2012; Khazaei et al., 2008; Nanang, 1998).

The aim of this study was to determine the physical properties of celery seeds as a function of moisture content. The parameters investigated namely: dimensions (length, width and thickness), geometric mean diameter, arithmetic mean diameter, equivalent diameter, sphericity, volume, surface area, projected area, flakiness ratio, elongation ratio, mass of single seed, 1000-seed mass, bulk density, true density and porosity, static coefficient of friction on various surfaces, pouring angle of repose, Hele-Shaw angle of repose, emptying and filling angle of repose. This knowledge is important to minimize the effect of an inadequate use of equipment that could affect the quality of the seed and its distillate, and/or leading to high operation/processing costs.

2 Materials and methods

2.1 Sample preparation

Four kilograms of the dried celery seeds were obtained from a local market in Amol, a city of Mazandaran province in the country of Iran in 2013 year. The seeds were cleaned manually to remove all foreign materials. The seeds were divided into four portions labeled A, B, C and D. The sample A was left at the market storage moisture content, while a different distillated water was added to B, C and D parts at room temperature in order to raise their moisture content to the desired four different levels, based on Equation 1 (Garnayak et al., 2008):

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

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°C±1°C for 24 h (Gupta and Das, 1997; Altuntaş et al., 2005; Özarslan, 2002) and using Equation 2 moisture content of the seeds based on dry bases (d.b) were calculated:

$$M = \frac{M_w - M_d}{M_d} \times 100 \quad (2)$$

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 repetitions were reported as moisture content for each sample. The samples with different moisture content were stored in refrigerator until to test.

2.2 Dimensional properties

2.2.1 Calculate parameters

The three major perpendicular dimensions of the each seeds were measured by image processing technique. The geometric mean diameter, D_G, arithmetic mean diameter, D_A, equivalent diameter, D_E, sphericity (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), φ, surface area of seed, S, volume, V, projected area (projected area is one of the most important parameters for determining aerodynamic properties), A_P, flakiness ratio, F_r, and elongation ratio, E_r of celery seed was calculated using the mentioned equations in Table 1.

Table 1 List of physical properties equations

Formula	Description	Reference
$D_G = \sqrt[3]{LWT}$	*L:* length, *W:* width, *T:* thickness, mm	(Heidarbeigi et al., 2009; Garnayak et al., 2008)
$D_A = \frac{L+W+T}{3}$	*L:* length, *W:* width, *T:* thickness, mm	(Garnayak et al., 2008; Milani et al., 2007)
$D_E = \left[\frac{(T+W)^2}{4} L\right]^{\frac{1}{3}}$	*L:* length, *W:* width, *T:* thickness, mm	(Milani et al., 2007; Heidarbeigi et al., 2009)
$\varphi = \left(\frac{\sqrt[3]{LWT}}{L}\right) \times 100$	*L:* length, *W:* width, *T:* thickness, mm	(Aydin, 2003; Sirisomboon et al., 2007; Hazbavi et al., 2013)
$S = 4\pi\left[\frac{(LW)^P + (LT)^P + (WT)^P}{3}\right]^{\frac{1}{P}}$,$P \approx 1.6075$	*L:* length, *W:* width, *T:* thickness, mm	(McGahon et al., 2007; Xu et al., 2009; Ersoy, 2010)
$V = \frac{\pi\,(D_G)^3}{6}$	D_G : Geometric mean diameter, mm	(Perez et al., 2007)
$A_p = \left(\frac{\pi WL}{4}\right)$	*W:* width, *T:* thickness, mm	(Kabas et al., 2007)
$F_r = \frac{T}{w}$	*W:* width, *T:* thickness, mm	(Mora and Kwan, 2000)
$E_r = \frac{L}{W}$	*L:* length, *W:* width, mm	(Mora and Kwan, 2000)

2.2.2 Image processing set up

The image processing system consisted of a camera (Canon, IXY 600F, Japan) with 3X IS lens capable of filming up to 120 frames per second (fps) and 12.1 megapixels, USB connection, four white-colored fluorescent lamps (32 W) and a laptop computer (VAIO, VPCEG34FX, Japan) equipped with Matlab R2012a software package. A white cardboard was placed on a table to provide a white background. The camera was placed at the center of the lamps. The distance between the white cardboard surface and the camera was set at 15 cm. Each celery seed was placed at the center of the camera's field of view and three metal spheres with same and identified diameters were placed at the side (three different positions) of the seed; then tow RGB color images were captured from up view and front view of the celery seed and kernel. The number of pixels representing the length, width and thickness of the celery seeds were also measured on the captured images using Matlab R2012a software package.

2.2.3 Statistical analysis for dimensional properties

Statistical indices including maximum, minimum, mean and standard deviation (STD) for three principal dimensions and dimensional properties were calculated using Microsoft Office Excel 2010. Skewness and kurtosis are two statistical indices which were calculated so that the reader would better understand the probability density distribution data (Mirzabe et al., 2013). The skewness and kurtosis were calculated using Equation 3 and Equation 4, respectively (Khazaei et al., 2008):

$$Skewness = \frac{n}{(n-1)(n-2)} \sum_{i=1}^{n} \left(\frac{x_i - x_{avg}}{STD}\right)^3 \quad (3)$$

$$Kurtosis = \left\{\frac{n(n-1)}{(n-1)(n-2)(n-3)} \sum_{i=1}^{n} \left(\frac{x_i - x_{avg}}{STD}\right)^4\right\} - \frac{3(n-1)^2}{(n-2)(n-3)} \quad (4)$$

where, n is number of occurrence; *STD* is standard deviation; x_{avg} is the mean of seeds dimension (length, width, thickness and dimensional properties); x_i is midpoint of each class interval in metric.

Length, width and thickness of the celery seeds distribution were modeled using three probability density functions. These functions were: 3-parameter lognormal distribution, 3-parameter Weibull distribution, and Generalized Extreme Value distribution. The probability density functions for three distributions are showed in Table 2 (Khazaei et al., 2008; Mirzabe et al., 2012; Gorgoso et al., 2007; Nanang, 1998; Mirzabe et al., 2013)

Table 2 The Log normal, Weibull and Generalized Extreme Value probability density function

Distribution name	Probability density function
Lognormal	$f(x)=\left(\frac{1}{(x-\alpha)\gamma\sqrt{2\pi}}\right)exp\left(-\frac{1}{2}\left(\frac{\ln(x-\alpha)-\beta}{\gamma}\right)^2\right)$
Weibull	$f(x)=\frac{\gamma}{\beta}\left(\frac{x-\alpha}{\beta}\right)^{\alpha-1}exp\left(-\left(\frac{x-\alpha}{\beta}\right)^{\gamma}\right)$
Generalized Extreme Value	$f(x)=\frac{1}{\beta}\left[1+\gamma\left(\frac{x-\alpha}{\beta}\right)\right]^{(-1/\gamma)-1}exp\left\{-\left[1+\gamma\left(\frac{x-\alpha}{\beta}\right)\right]^{-1/\gamma}\right\}$

α, β, and γ are location (shift parameter), scale parameter, and shape parameter, respectively.

Then, the three probability density functions were fitted to the empirical probability density, in order to estimate the parameter values. The adjustable parameters for each probability density function were estimated using the Easy Fit 5.5. There are several competing models for the same data set such as likelihood, Kolmogorov-Smirnov, Chi-squar and Anderson Darling. In this study, Kolmogorov-Smirnov was selected to comparison between models. The Kolmogorov-Smirnov test is based on the vertical deviation between the observed cumulative density function and estimated cumulative density function using the Equation 5 (Mirzabe et al., 2012):

$$K_S = \text{Max } |(S(x) - F(x))| \quad (5)$$

where, $S(x)$ is the observed cumulative frequency distribution and $f(x)$ is the estimated cumulative frequency distribution. Based on the Equation 5, smaller values of the test statistics K_s indicate a better fit.

2.3 Gravimetric properties

To evaluate the single seed mass and 1000-seeds mass, 100 seeds selected from the bulk sample, randomly; the 100-seeds mass was measured by a digital balance (Kern, Japan, accuracy of ±0.001 g). Single seed mass was calculated by dividing the 100-seeds mass to 100 and 1000-seeds mass was calculated by multiplying the 100-seeds mass by 10. The average values of five repetitions were reported as single seed mass and 1000-seeds mass.

The bulk material of seeds was obtained by containers with known volume (500 cm^3). The seeds were poured into the containers at a height of 100, 150 and 200 mm (Gupta and Das, 1997; Mirzabe et al., 2013). The bulk density (ρ_b) is equal to mass of bulk material divided by volume containing the mass. The average values of three repetitions were reported as bulk density.

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 in place 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 that it fills even shallow dips in a seed and its dissolution power is low (Milani et al., 2007; Garnayak et al., 2008). The volume of the individual sample was determined by weighing displacement volume of toluene:

$$V_s = \frac{M_{TD}}{\rho_t} = \frac{(M_T - M_P) - (M_{PTS} - M_{PS})}{\rho_t} \quad (6)$$

$$\rho_S = \frac{M_s}{V_s} \quad (7)$$

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 a nut in kg, and M_{PS} is the mass of pycnometer and seeds in kg. The average values of three repetitions were reported as true density.

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, which is between 0 to one, or as a percentage between 0 to100%. The porosity of bulk seed was calculated from bulk and true densities using the Equation 8 (Sharma et al., 2011; Hazbavi et al., 2013):

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

Where, is porosity in percentage, ρ_b is bulk density and ρ_t is true density. The average values of three repetitions were reported as porosity.

2.4 Frictional properties

2.4.1 Angle of static friction

The coefficients of external static friction of the celery seeds were determined using sloped plane method on surfaces of galvanized, iron, plywood and robber. A topless and bottomless cylinder of 100 mm diameter and 50 mm height was filled with the samples. The cylinder was raised slightly so as not to touch the surfaces. 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 and the angle of tilt at this juncture, the angle of tilt, in degree was read by Auto Cad 2007 software package. The average values of five repetitions were reported as angle of external static friction of the celery seeds.

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. Material with a low angle of repose forms flatter piles than material with a high angle of repose. Angle of repose is related to the density, surface area and shapes of the particles, the coefficient of friction of the material and gravity-dependent (Kleinhans et al., 2011). There are different methods to measure the angle of repose including pouring, filling (charging), emptying (discharging), Hele-Shaw, submerging and rotating drums methods. In present study, to measure angle of repose of the celery seeds pouring, filling, emptying 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 the celery seeds sample was determined using a top and bottomless metallic cylinder of 200 mm height and 150 mm diameter (Mirzabe et al., 2013). The cylinder was placed on horizontal surface and was filled with the seeds; then, the cylinder was raised very slowly. The camera was placed at opposite of the front view of the bulk seeds then photographed from the bulk seeds; then pouring angle of repose calculated using image processing technique and Auto Cad 2007 software package. In order to study the effect of the material of the contact surface, galvanized, iron, plywood and robber plates placed on the frame of the set up (beneath of the cylinder) and pouring angle of repose was measured on these surfaces. The average values of five repetitions were reported as pouring angle of repose (A_{RP}).

2.4.2.2 Filling and emptying angle of repose

The filling and emptying angle of repose of the seeds were measured. The device used in this study consists of two boxes, upper and down box, of dimensions 120 mm length, 120 mm height, and 60 mm width. The upper box was filled with the sample seeds. The material of upper box can flow to down through a removable port, the filling or static angle of repose is the angle of surface with the horizontal at which the seeds will stand when piled on the ground. The emptying or dynamic angle of repose is the angle of surface of residual with horizontal in the upper box. The height of the seeds was measured and the filling angle of repose (A_{RF}) and emptying angle of repose (A_{RE}) were calculated by the following relationships (Sirisomboon et al., 2007):

$$A_{RE} = tan^{-1}\left(\frac{H}{XL}\right) \tag{9}$$

$$A_{RF} = tan^{-1}\left(\frac{h}{xl}\right) \tag{10}$$

where, H and h are the height (mm), and XL and xl (mm) are horizontal distance. The average values of five repetitions were reported as filling and emptying angle of repose of the celery seeds.

2.4.2.3 Hele-Shaw angle of repose

The Hele-Shaw angle of repose (A_{RH}) of the celery seeds was measured. The device used in this study consists of a box of dimensions 300 mm length, 200 mm height, and 200 mm width. There was 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 main box can flow to down through a removable port, the Hele-Shaw is the angle of surface with the horizontal at which the seeds will stand when piled on the bottom of the main box. The camera was placed at opposite of the front view of the box then photographed from bulk seeds (front of the main box was made of the glass); then Hele-Shaw angle of repose calculated using image processing technique and Auto Cad 2007 software package. In order to study the effect of the material of the contact surface, galvanized, iron, plywood and robber plates placed into the main box (beneath of the main box) and Hele-Shaw angle of repose was measured on these surfaces. The average values of five repetitions were reported as Hele-Shaw angle of repose of the celery seeds.

3 Results and discussion

3.1 Dimensional properties

The average value of three principle dimensions and three diameters of the celery seeds, namely length, width, thickness, geometric mean diameter, arithmetic mean diameter and equivalent diameter at different moisture content are given in Table 3. With increasing moisture content from 5.24 to 20.25 % (d.b), the length (L), width (W), thickness (T), the arithmetic mean diameter (D_g), the geometric mean diameter (D_a) and equivalent diameter (D_E) of the seeds increased significantly from 0.571 to 0.597 mm, 0.429 to 0.449 mm, 0.295 to 0.308 mm, 0.414 to 0.433 mm, 0.432 to 0.451 mm and 0.468 to 0.482 mm, respectively. The principle dimensions increased between 4.41% to 4.66%, while the width of seeds had the largest percentage increase with increase in moisture content, the same results was reported for sorghum seed (Mwithiga and Sifuna, 2006) and rice seed (Kibar et al., 2010). The increase in dimensions could be attributed to the expansion of the seeds as a result of moisture absorption in the intracellular spaces inside the seeds (Sologubik et al., 2013).

Table 3 Effect of the moisture content on length (L), width (W), thickness (T) and diameters of celery seeds

Moisture content, % (d.b)	Properties	Number of seeds	Mean*	Skewness*	Kurtosis*
5.24	L	100	0.571 ±0.071	0.532	0.613
	W		0.429 ±0.077	0.316	-0.897
	T		0.295 ±0.036	0.135	-0.323
	D_g		0.414 ±0.040	0.437	-0.099
	D_A		0.432 ±0.043	0.342	-0.140
	D_E		0.468 ±0.031	0.236	-0.032
10.11	L	100	0.580 ±0.072	0.537	0.619
	W		0.436 ±0.079	0.315	-0.899
	T		0.299 ±0.037	0.134	-0.331
	D_g		0.421 ±0.040	0.433	-0.101
	D_A		0.438 ±0.044	0.340	-0.143
	D_E		0.473 ±0.031	0.235	-0.035
15.17	L	100	0.588 ±0.074	0.468	0.393
	W		0.442 ±0.080	0.262	-0.992
	T		0.303 ±0.036	0.129	0.178
	D_g		0.426 ±0.041	0.337	-0.231
	D_A		0.444 ±0.044	0.256	-0.281
	D_E		0.477 ±0.032	0.159	-0.151
20.25	L	100	0.597 ±0.076	0.583	0.835
	W		0.449 ±0.082	0.319	-0.822
	T		0.308 ±0.040	0.470	0.640
	D_g		0.433 ±0.044	0.398	-0.097
	D_A		0.451 ±0.047	0.287	-0.217
	D_E		0.482 ±0.033	0.179	-0.103

*Unit of all parameters is mm.

The average value of sphericity, surface area, volume, project area, flakiness ratio and elongation ratio of celery seeds, at different moisture content are shown in Table 4. With increasing moisture content from 5.24% to 20.25% (d.b), the surface area (S), volume (V) and project area (A_P) of the celery seeds increased significantly from 0.582 to 0.636 mm^2, 0.038 to 0.044 mm^3 and 0.193 to 0.211 mm^2, respectively. The increase in surface area, volume and project area could be attributed to the expansion of the seeds as a result increase in dimensions. Results showed that the moisture content had no significant effect on sphericity (φ), flakiness ratio (F_R) and elongation ratio (E_R).

Table 4 Effect of the moisture content on dimensional parameters of celery seeds namely, sphericity (φ), surface area (S), volume (V), projected area (A_p), flakiness ratio (F_r) and elongation ratio (E_r)

Moisture content, % (d.b)	Dimensional parameter	Units	Number of seeds	Mean*	Skewness*	Kurtosis*
5.24	φ	%	100	72.906 ±5.383	-0.164	-0.926
	S	mm^2		0.582 ±0.117	0.605	0.004
	V	mm^3		0.038 ±0.011	0.895	0.444
	A_p	mm^2		0.193 ±0.047	0.541	-0.249
	F_r	-		0.712 ±0.169	0.551	-0.606
	E_r	-		1.368 ±0.267	0.450	-1.043
10.11	φ	%	100	72.895 ±5.370	-0.172	-0.932
	S	mm^2		0.601 ±0.121	0.603	-0.001
	V	mm^3		0.040 ±0.012	0.893	0.442
	A_p	mm^2		0.200 ±0.048	0.539	-0.258
	F_r	-		0.712 ±0.169	0.553	-0.604
	E_r	-		1.368 ±0.267	0.450	-1.042
15.17	φ	%	100	72.858 ±5.488	-0.169	-0.914
	S	mm^2		0.617 ±0.124	0.506	-0.224
	V	mm^3		0.042 ±0.012	0.779	0.157
	A_p	mm^2		0.205 ±0.050	0.476	-0.478
	F_r	-		0.710 ±0.167	0.585	-0.504
	E_r	-		1.368 ±0.268	0.455	-1.062
20.25	φ	%	100	72.954 ±5.863	0.095	-0.066
	S	mm^2		0.636 ±0.133	0.551	-0.100
	V	mm^3		0.044 ±0.014	0.901	0.623
	A_p	mm^2		0.211 ±0.052	0.484	-0.412
	F_r	-		0.710 ±0.165	0.566	-0.444
	E_r	-		1.367 ±0.272	0.451	-0.957

Hence, in the present study, celery seed is treated as an equivalent to sphere. Considering the high aspect ratio (which relates the seeds width to length) and sphericity, it may be deduced that celery seeds would roll on flat surfaces. This tendency to either roll or slide is very important in the design of hoppers, dehulling and thresher equipment for the seed because most flat seeds slide easier than spherical seeds, which roll on structural surfaces (Sharma et al., 2011). Furthermore, the shape indices indicated that the celery seed may be treated as a sphere for an analytical prediction of its drying behavior. The surface area is a relevant tool in determining the shape of the seeds. This will actually be an indication of the way the seeds will behave on oscillating surfaces during processing (Alonge and Adigun, 1999).

Skewness and kurtosis are two statistical indices calculated so that the reader would better understand the probability density distribution data. The first usually noticed about a distribution's shape is whether it has one mode (peak) or more than one. If it's unimodal (has just one peak), like most data sets, the next thing noticed is whether it is symmetric or skewed to one side. If the bulk of the data is at the left and the right tail is longer, the distribution is skewed right or positively skewed; if the peak is toward the right and the left tail is longer, the distribution is skewed left or negatively skewed.

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 dimensions and diameters of the celery seeds indicated that values of the skewness in all cases were positive and values of the kurtosis in most cases were negative (Table 3). Also results of statistical analysis of dimensional parameters of the celery seeds indicated that values of the skewness in most cases were positive and values of the kurtosis in most cases were negative (Table 4).

3.2 Modeling of dimensions

Length, width and thickness of the celery seeds distributions were modeled using the, Generalized Extreme Value (G. E. V), three-parameter lognormal and three-parameter Weibull probability density functions distribution; the results of modeling are shown in Table 5. Results showed that in all moisture content levels, to model length of the seeds, lognormal distribution had the best performance, while Weibull distribution had the worst performance. In all moisture content levels, to model the width of the seeds, Weibull distribution had the best performance, while lognormal distribution had the worst performance (Table 5). Also in all moisture content levels, to model the thickness of the seeds, G. E. V distribution had the best performance.

Table 5 Calculated parameter values of the Generalized Extreme Value (G. E. V), lognormal and Weibull probability density function for length, width and thickness of the celery seeds

Moisture content, % (d.b)	Properties	Distribution name	Shape parameter	Scale parameter	Location parameter	Kolmogorov-Smirnov index	Rank
		G. E. V	0.142	0.063	0.542	0.0713	2
	L	Lognormal	0.152	0.787	0.110	0.0639	1
		Weibull	2.619	0.196	0.396	0.0774	3
		G. E. V	-0.141	0.072	0.396	0.0993	2
5.24	W	Lognormal	0.295	1.366	0.162	0.1087	3
		Weibull	1.711	0.146	0.298	0.0859	1
		G. E. V	-0.277	0.036	0.281	0.0919	1
	T	Lognormal	0.064	0599	-0.255	0.1128	3
		Weibull	2.633	0.098	0.207	0.1080	2
		G. E. V	-0.141	0.064	0.551	0.0678	2
	L	Lognormal	0.153	0.780	0.116	0.0647	1
		Weibull	2.607	0.198	0.403	0.0743	3
		G. E. V	-0.141	0.073	0.403	0.0994	2
10.11	W	Lognormal	0.295	1.350	0.165	0.1006	3
		Weibull	1.721	0.149	0.302	0.0865	1
		G. E. V	-0.276	0.038	0.286	0.0914	1
	T	Lognormal	0.063	-0.550	-0.279	0.1072	3
		Weibull	2.635	0.100	0.216	0.1000	2
		G. E. V	-0.143	0.066	0.558	0.0809	2
	L	Lognormal	0.141	0.670	0.071	0.0765	1
		Weibull	2.665	0.207	0.403	0.0859	3
		G. E. V	-0.160	0.075	0.409	0.0995	2
15.17	W	Lognormal	0.263	-1.217	0.135	0.1032	3
		Weibull	1.760	0.154	0.304	0.0893	1
		G. E. V	-0.281	0.036	0.290	0.0927	1
	T	Lognormal	0.053	-0.391	-0.375	0.0999	2
		Weibull	2.796	0.103	0.210	0.1054	3
		G. E. V	-0.135	0.067	0.566	0.0641	2
	L	Lognormal	0.157	-0.757	0.121	0.0615	1
		Weibull	2.602	0.209	0.410	0.0741	3
		G. E. V	-0.147	0.076	0.414	0.0957	2
20.24	W	Lognormal	0.272	-1.226	0.144	0.1000	3
		Weibull	1.803	0.161	0.304	0.0878	1
		G. E. V	-0.194	0.038	0.292	0.0859	1
	T	Lognormal	0.148	-1.316	0.037	0.0917	2
		Weibull	2.313	0.100	0.219	0.0995	3

For an easy comparison between dimensions of celery seeds together, probability density functions (PDFs) of dimensions are shown in Figure 1. For all modeling in Figure 1, Generalized Extreme Value was used, because it had good prediction of probability density functions (PDFs) of length, width and thickness of seeds. This figure shows that there is little overlap between the PDF of length and width, and even lesser overlap between the PDF of width and thickness. It means that the greatest measured width of seeds is more than the lowest measured length; also the greatest measured thickness of seeds is more than the lowest measured width.

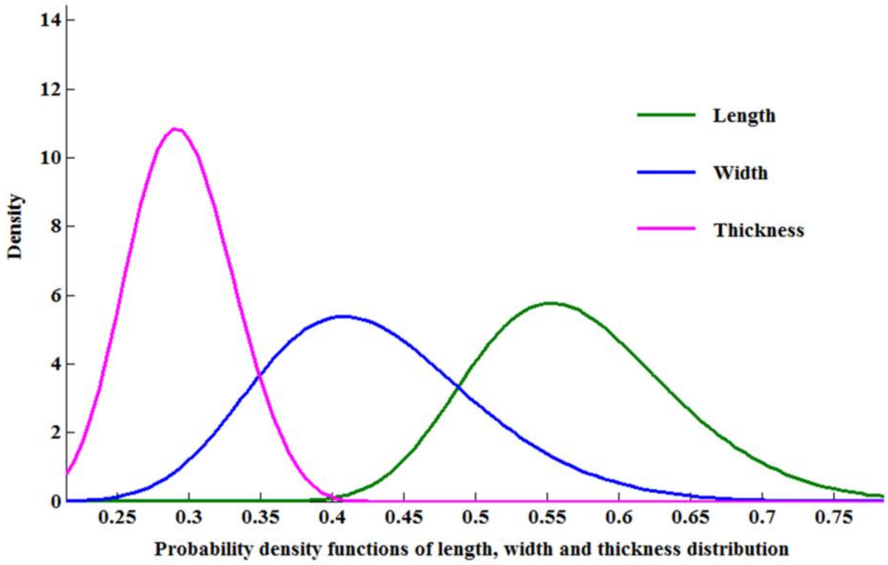


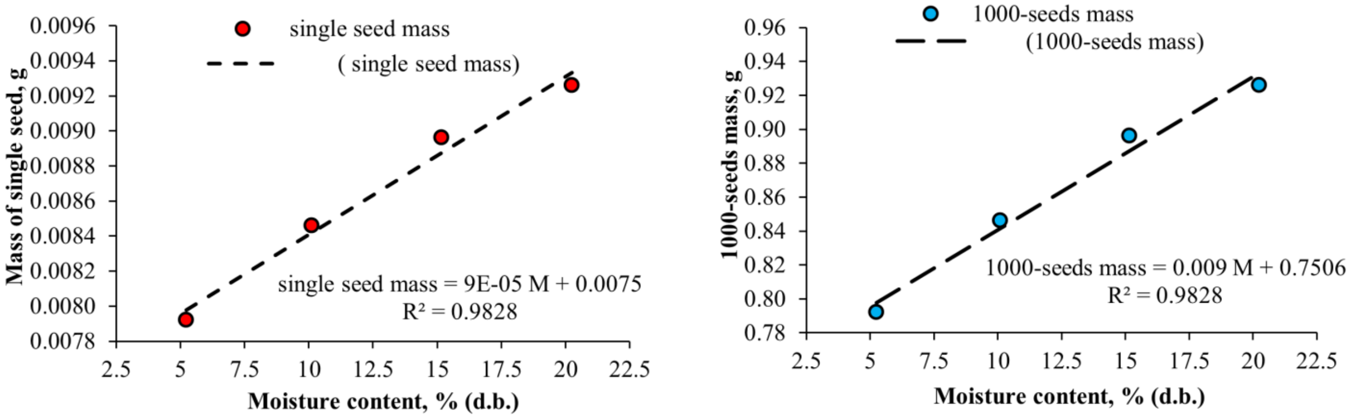
Figure 1 Probability density functions of length, width and thickness distribution of the celery seeds in 5.24% (d.b) moisture content

Results of modeling showed that whenever skewness and kurtosis had positive values, lognormal and Generalized Extreme Value distribution had good performance, while Weibull distribution had poor performance to model the data. Also whenever skewness had positive value and kurtosis a negative value, Weibull and Generalized Extreme Value distribution showed good performance, while lognormal distribution had poor performance to model 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 as 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 kurtosis had negative value, Weibull distribution was the best function to model the data.

3.3 Gravimetrical properties

The single seed mass and 1000-unit mass of the celery seeds was measured at different moisture levels. Figure 2 shows the single seed mass and 1000-seed mass variation with moisture content. The Figure 2 indicates that the seed mass increases linearly with increase in seed moisture content. There are many literatures on moisture dependent on seeds mass of agricultural crops; results indicated that in most cases with increasing moisture content, 1000-unit mass will increased (Visvanathan et al., 1996; Özarslan, 2002; Sacilik et al., 2003).



(A) **(B)**

Figure 2 Variation of single seed mass and 1000-seeds mass of celery seeds with moisture content. (A) is mass of the single seed and (B) is 1000-seeds mass

Effect of moisture content in the ranges of 5.24% to 20.25% (d.b) and height of fall (height of fall of the seeds to the container) content in the ranges of 100 to 200 mm, on bulk density are shown in Figure 3. The bulk density of the celery seeds increased linearly with moisture content (Figure 3). The reason of this increase can be explained as follows: while the seeds absorb moisture, their individual volume and mass increases; consequently, the shape of the seed changes, and their bulk volume. This behavior causes the number of seeds occupying a fixed volume to decrease, but mass of seeds increased. The negative and positive relationship of bulk density with moisture content is also observed by other researchers (Gezer et al., 2003; Akar and Aydin, 2005; Kingsly et al., 2006; Garnayak et al., 2008; Pradhan et al., 2009; Sánchez-Mendoza et al., 2008).

Also the bulk density of the seeds increased linearly with height of fall. The reason of this increase can be explained as follows: when the height of fall of seeds increases the impact velocities of the seeds in the container increases; therefore porosity of seeds decreases and the bulk density increases.

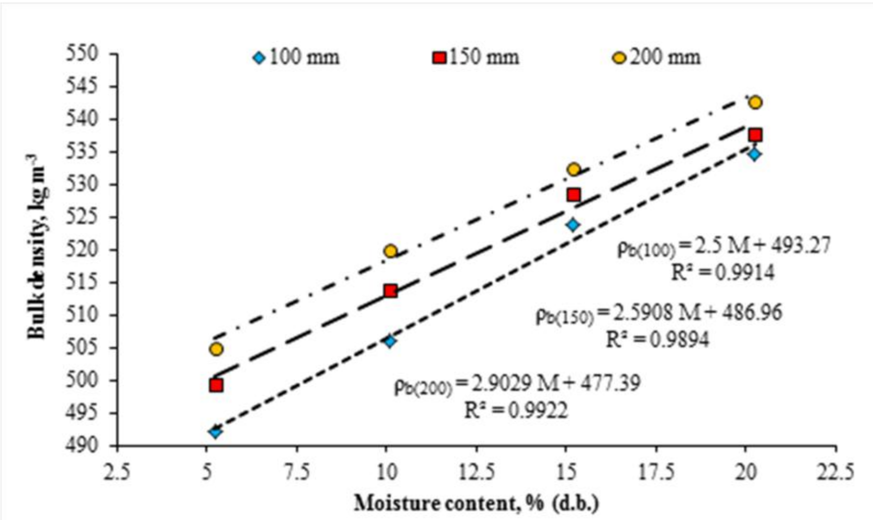


Figure 3 Variations of bulk density of celery seeds with moisture content and height of fall

The true density of the celery seeds was measured at different moisture levels and results are shown in Figure 4. It has increase from 892.018 to 931.419 kg/m^3 when the moisture content increased from 5.24% to 20.25% (d.b). This shows that the celery seed are lighter than water and will float in the water. This characteristic can be used to separate the seeds from other heavier foreign materials.

The observed increase of true density could be explained due to the fact that the increment of seed weight caused by the moisture seed resulted more than the volume expansion experimented by seeds. There are many literatures on moisture dependent of true density for different agricultural crops; the results indicated that in some cases with increasing moisture content, the true density increased (Aydin, 2003; Bart-Plange and Baryeh, 2003; Garnayak et al., 2008; Milani et al., 2007), but in some cases with increasing moisture content, the true density decreased (Dutta et al., 1988; Deshpande et al., 1993; Zewdu and Solomon, 2007; Sologubik et al., 2013; Pradhan et al., 2009)

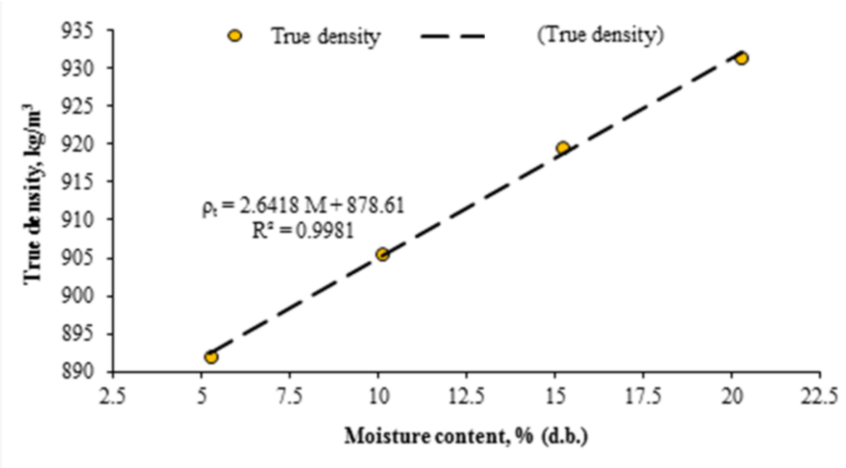


Figure 4 Variation of true density of celery seeds with moisture content.

The porosity was calculated by means of Equation 8, using the average values of bulk density and true density of each batch. Effect of moisture content in the ranges of 5.24% to 20.25% (d.b) and height of fall content in the ranges of 100 to 200 mm, on bulk density are shown in Figure 5. Aviara et al. (2013) for Moringa oleifera seed and Sologubik et al. (2013) for bareley, Zewdu and Solomon for tef seed, and Sánchez-Mendoza et al. (2008) for Roselle seeds stated that as the moisture content increased, the porosity value increased but Pradhan et al. (2009) for jatropha fruit and Mwithiga and Sifuna for sorghum seeds reported a decreasing trend of porosity with moisture content. It must be noted that porosity of the mass of seeds determines the resistance to airflow during aeration and drying process.

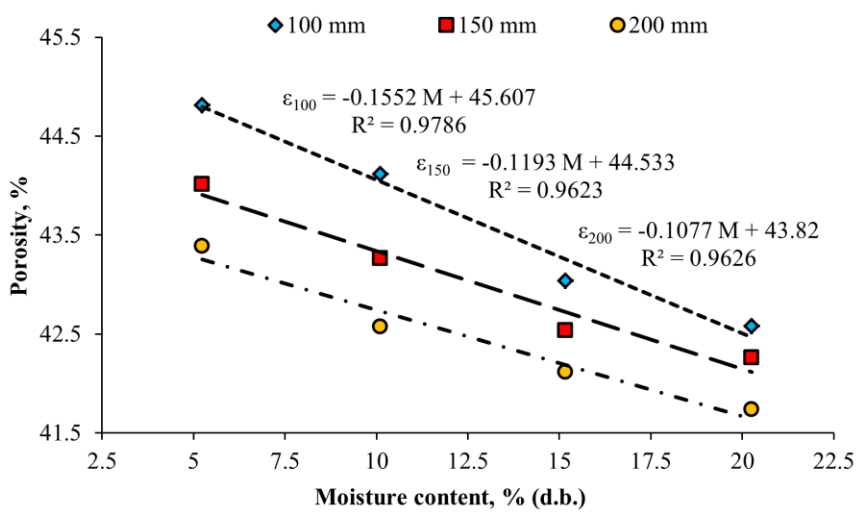


Figure 5 Variations of porosity of celery seeds with moisture content and height of fall

3.4 Static coefficient of external friction

The static angle of friction, which affects the design of the processing machine, was determined on four different contacting materials (plywood sheet, robber sheet, iron sheet, and galvanized sheet). These are common materials used for transportation, storage and handling operations of grains, pulses and seeds and construction of storage and drying bins. The results of static angle of friction are shown in Figure 6. It is observed that the static angle of friction of the seeds increased linearly with increase in moisture content for all contact surfaces. The reason for the increased of friction coefficient at higher moisture content may be owing to the water present in the seed offering an adhesive force on the surface of contact (Pradhan et al., 2009). The angle of static friction increased from 28.446 to 39.664°, 25.146 to 34.842°, 19.574 to 27.074° and 16.716 to 19.720° for plywood, robber, iron and galvanized, respectively, as the moisture content increases from 5.24% to 20.25% (d.b). At all moisture contents, the maximum frictions are offered by plywood, followed by the robber, iron and galvanized surfaces. The least static angle 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., 2013), 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). It must be noted that the static angle of external friction is important for designing of storage bins, hoppers, pneumatic conveying system, screw conveyors, forage harvesters, threshers, etc. (Sahay and Singh, 2004; Sharma et al., 2011).

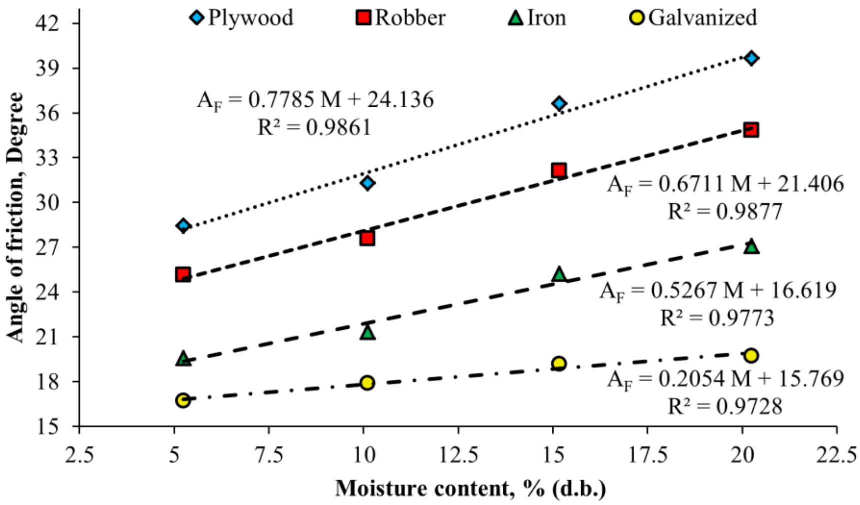


Figure 6 Variation of angle of friction of celery seeds with moisture content

3.5 Angle of repose

The angle of repose is an indicator of the product's flow ability. The results for the pouring angle of repose with respect to moisture content are shown in Figure 7. Pouring angle of repose of the celery seeds was determined on four different contacting materials (plywood sheet, robber sheet, iron sheet, and galvanized sheet). It is observed that the static pouring angle of repose of the seeds increased linearly with increase in moisture content for all contact surfaces. The pouring angle of repose increased from 34.698 to 39.122°, 33.366 to 36.368°, 30.592 to 33.334° and 27.156 to 29.446° for plywood, robber, iron and galvanized, respectively, as the moisture content increases from 5.24% - to 20.25% (d.b). At all moisture contents, the maximum pouring angle of repose are offered by plywood, followed by the robber, iron and galvanized surfaces. The least static pouring angle of repose may be owing to the smoother and more polished surface of the galvanized sheet than the other materials used.

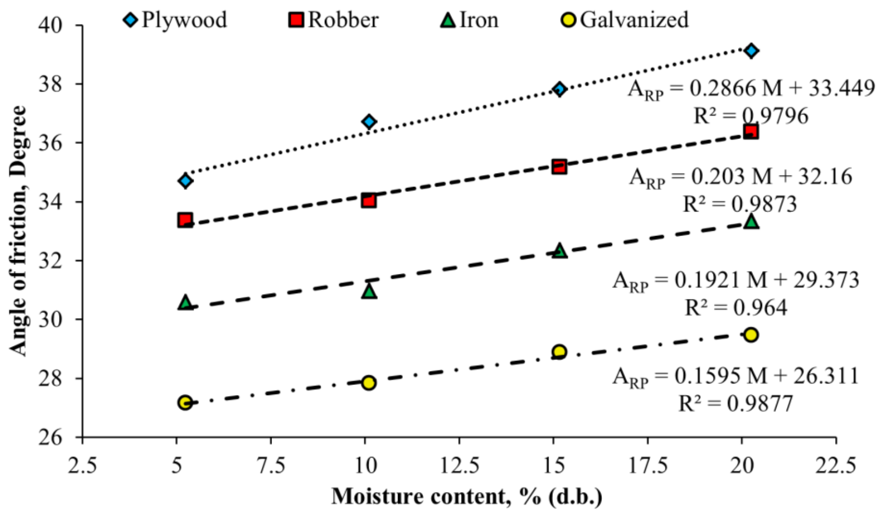


Figure 7 Variation of pouring angle of repose of celery seeds with moisture content

Effect of the moisture content on filling and emptying angle of repose are shown in Figure 8. The value of filling angle of repose is found to increase from 31.450 to 34.406 ° in the moisture range of 5.24% to 20.25% (d.b); the corresponding values for the emptying angle of repose was found to be 36.598 and 39.280 °, respectively. The angle of repose was obtained from emptying 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; Karaj et al., 2008).

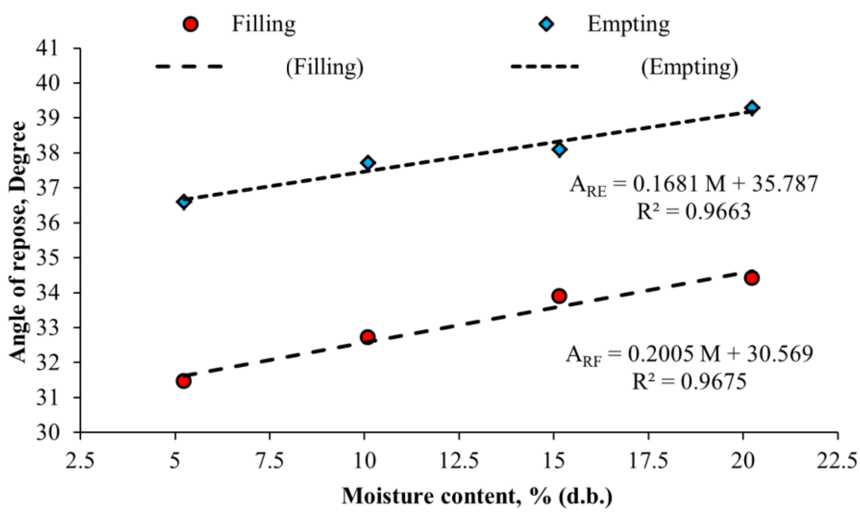


Figure 8 Variation of filling and emptying angle of repose of celery seeds with moisture content

Hele-Shaw angle of repose of the celery seeds was determined on plywood sheet, robber sheet, iron sheet, and galvanized sheet. It is observed that the Hele-Shaw angle of repose of the celery seeds increased linearly with increase in moisture content for all contact surfaces (Figure 9). The Hele-Shaw angle of repose increased from 32.646 to 35.250 °, 30.346 to 32.770 °, 27.814 to 30.034 ° and 24.716 to 26.606 ° for plywood, robber, iron and galvanized, respectively, as the moisture content increases from 5.24% to 20.25% (d.b).

At all moisture contents, the maximum Hele-Shaw angle of repose are offered by plywood, followed by the robber, iron and galvanized surfaces. The least static Hele-Shaw angle of repose may be owing to the smoother and more polished surface of the galvanized sheet than the other materials used.

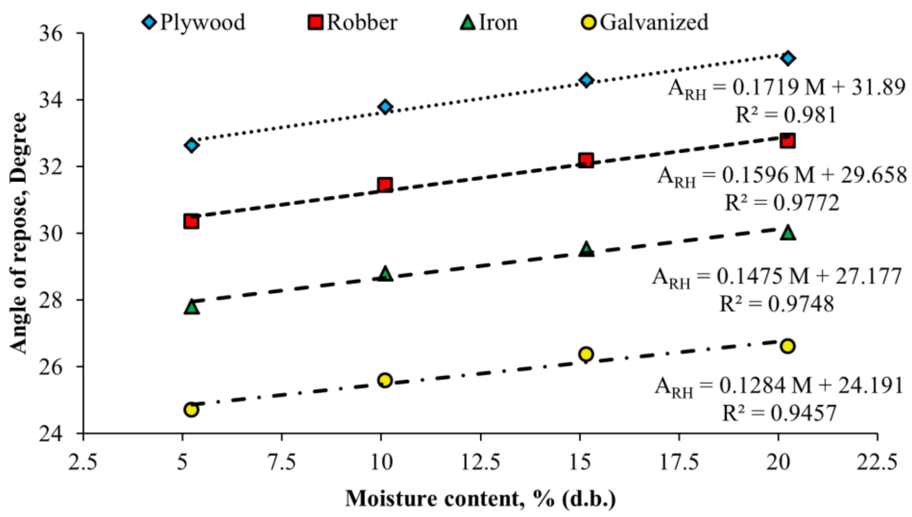


Figure 9 Variation of Hele-Shaw angle of repose of celery seeds with moisture content

This variation of angle of repose with moisture content occurs because the surface layer of moisture surrounding the particle holds the aggregate of seeds together by the surface tension. These results are similar to those reported for other agricultural crops (Visvanathan et al., 1996; Sacilik et al., 2003; Pradhan et al., 2009; Bart-Plange and Baryeh, 2003).

4 Conclusions

The following conclusions are drawn from the investigation on moisture-dependent physical properties of celery seed with moisture contents ranging from 5.24% to 20.25% (d.b). As moisture content increases from 5.24% to 20.25% (d.b), the average length, width, and thickness of celery seed changes from 0.571 to 0.597 mm, 0.429 to 0.449 mm and 0.295 to 0.308 mm, respectively. One thousand seeds mass and true density of celery seed varied from 0.792 to 0.926 g and 892.018 to 931.419 kg/m^3, respectively, with moisture contents ranging from 5.24% to 20.25% (d.b). The bulk density of the celery seeds increased linearly with moisture content and height of fall.

The static angle of friction was determined on four different contacting materials, plywood sheet, robber sheet, iron sheet, and galvanized sheet with moisture contents ranging from 5.24% to 20.25% (d.b). At all moisture contents, the maximum frictions are offered by plywood, followed by the robber, iron and galvanized surfaces. The pouring and Hele-Shaw angle of repose were determined on four different contacting materials, plywood sheet, robber sheet, iron sheet, and galvanized sheet as moisture contents ranging from 5.24% to 20.25% (d.b). At all moisture contents, the maximum pouring and Hele-Shaw angle of repose are offered by plywood, followed by the robber, iron and galvanized surfaces. Also the value of filling and emptying angle of repose are found to increase from 31.450° to 34.406° and 36.598 and 39.280 °in the moisture range of 5.24% to 20.25% (d.b), respectively.

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 their support in editing the language of the paper.

References

Akar, R., and C. Aydin. 2005. Some physical properties of gumbo fruit varieties. *Journal of Food Engineering*, 66(3): 387-393.

Alonge, A., and Y. Adigun. 1999. Some physical and aerodynamic properties of sorghum as related to cleaning. Paper read at 21st annual conference of the Nigerian society of agricultural engineers (NSAE). Federal Polytechnic Bauchi, Nigeria.

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.

Atta, A., and A. Alkofahi. 1998. Anti-nociceptive and anti-inflammatory effects of some Jordanian medicinal plant extracts. *Journal of Ethnopharmacology*, 60(2): 117-124.

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.

Daukšas, E., P. R. Venskutonis, B. Sivik, and T. Nillson. 2002. Effect of fast CO 2 pressure changes on the yield of lovage (Levisticum officinale Koch.) and celery (Apium graveolens L.) extracts. *The Journal of supercritical fluids*, 22(3): 201-210.

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

Dutta, S., V. K. Nema, and R. Bhardwaj. 1988. Physical properties of gram. *Journal of Agricultural Engineering Research*, 39(4): 259-268.

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.

Gezer, I., H. Haciseferoğulları, and F. Demir. 2003. Some physical properties of Hacıhaliloğlu apricot pit and its kernel. *Journal of Food Engineering*, 56(1): 49-57.

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.

Gupta, R., and S. Das. 2000. Fracture resistance of sunflower seed and kernel to compressive loading. *Journal of Food Engineering*, 46(1): 1-8.

Hazbavi, E., M. H. Khoshtaghaza, A. Mostaan, and A. Banakar. 2013. Effect of storage duration on some physical properties of date palm (cv. Stamaran). *Journal of the Saudi Society of Agricultural Sciences*.

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.

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.

Karaj, S., R. M. Huaitalla, and J. Müller. 2008. Physical, mechanical and chemical properties of Jatropha curcas L. seeds and kernels. Paper read at Proceedings of the Conference on International Agricultural Research for Development. Stuttgrant, Germany.

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.

Kibar, H., and T. Öztürk. 2008. Physical and mechanical properties of soybean. International Agrophysics, 22(3): 239-244.

Kibar, H., Öztürk, T., and B. Esen. 2010. The effect of moisture content on physical and mechanical properties of rice (Oryza sativa L.). *Spanish Journal of Agricultural Research*, 8(3): 741-749.

Kibar, H., Öztürk, T., and K. E.Temizel. 2014. Effective engineering properties in the design of storage structures of postharvest dry bean grain. *Acta Scientiarum-Agronomy*, 36(2): 147-158.

Kingsly, A., D. Singh, M. Manikantan, and R. Jain. 2006. Moisture dependent physical properties of dried pomegranate seeds (Anardana). *Journal of Food Engineering*, 75(4): 492-496.

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).

Ko, F.-N., T.-F. Huang, and C.-M. Teng. 1991. Vasodilatory action mechanisms of apigenin isolated from Apium graveolens in rat thoracic aorta. *Biochimica et Biophysica Acta (BBA)-General Subjects*, 1115(1): 69-74.

Lewis, D. A., S. M. Tharib, and G. B. A. Veitch. 1985. The anti-inflammatory activity of celery Apium graveolens L.(Fam. Umbelliferae). *Pharmaceutical Biology*, 23(1): 27-32.

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: the CIGR Journal*, 14(3): 190-202.

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

Momin, R. A., and M. G. Nair. 2001. Mosquitocidal, nematicidal, and antifungal compounds from Apium graveolens L. seeds. *Journal of Agricultural and Food Chemistry*, 49(1): 142-145.

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.

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.

Nanang, D. M. 1998. Suitability of the Normal, Log-normal and Weibull distributions for fitting diameter distributions of neem plantations in Northern Ghana. *Forest Ecology and Management*, 103(1): 1-7.

Orton, T., and P. Arus. 1984. Outcrossing in celery (Apium graveolens). *Euphytica*, 33(2): 471-480.

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.

Popović, M., B. Kaurinović, S. Trivić, N. Mimica-Dukić, and M. Bursać. 2006. Effect of celery (Apium graveolens) extracts on some biochemical parameters of oxidative stress in mice treated with carbon tetrachloride. *Phytotherapy Research*, 20(7): 531-537.

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.

Sahay, K., and K. Singh. 2004. *Unit operations of agricultural processing*: Vikas Publishing House PVT LTD.

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.

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.

Tabarsa, T., S. Jahanshahi, and A. Ashori. 2011. Mechanical and physical properties of wheat straw boards bonded with a tannin modified phenol–formaldehyde adhesive. *Composites Part B: Engineering*, 42(2): 176-180.

Teng, C., L. Lee, F. KO, and T. Huang. 1988. Inhibition of platelet-aggregation by apigenin from apium-graveolens. *Asia Pacific Journal of Pharmacology*, 3(2): 85-89.

Varnamkhasti, M. G., H. Mobli, A. Jafari, A. Keyhani, M. H. Soltanabadi, S. Rafiee, and K. Kheiralipour. 2008. Some physical properties of rough rice (Oryza Sativa L.) grain. *Journal of Cereal Science*, 47(3): 496-501.

Visvanathan, R., P. Palanisamy, L. Gothandapani, and V. Sreenarayanan. 1996. Physical properties of neem nut. *Journal of Agricultural Engineering Research*, 63(1): 19-25.

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.