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ORIGINAL ARTICLE

Physical and mechanical properties of castor seed

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Keywords
Castor seed; energy; mechanical properties; physical properties; *Ricinus communis*.

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Nomenclature
M = Castor seed mass, g; V = Castor seed volume, cm^3; D_g = geometric mean diameter, mm; D_a = arithmetic mean diameter, mm; S_{MC} = calculated surface area with McCabe formula, mm^2; S_{JB} = calculated surface area with Jean and Ball formula, mm^2; L = length of Castor seed, mm; W = width of Castor seed, mm; T = thickness of Castor seed, mm; PA_1 = first projected area perpendicular to L direction, mm^2; PA_2 = second projected area perpendicular to W direction, mm^2; PA_3 = third projected area perpendicular to T direction, mm^2; CPA = criteria projected area, mm^2; ρ_t = true bulk density, g.cm^{-3}; Φ = sphericity(%); R_a = aspect ratio (%); SD = standard deviation; CV = coefficient of variation(%); Max = maximum; Min = minimum; mean = average value; F_{max} = maximum force that is required for fraction, N; W = required energy for initial fraction, N.mm; E = elasticity modulus, GPa.

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Abstract

Introduction and methods In this paper, the physical properties such as length, width, thickness, geometric mean diameter, arithmetic mean diameter, mass, volume, bulk density, sphericity, projected area and mechanical characteristics, namely Young modulus, maximum force and required energy for initial fracture at yield point for Castor seed (*Ricinus communis*) were determined. *Objectives* These properties are necessary in the design of equipment for harvesting, processing and transportation, separating and packing. *Results* The results showed that the mean values of length, width, thickness, arithmetic mean diameter, geometric mean diameter, mass, volume, projected areas perpendicular to the main diameters and sphericity of Castor seed are 13.52 mm, 13.39 mm, 13.38 mm, 13.43 mm, 13.42 mm, 1.29 g, 0.17 cm^3, 143.8 mm^2, 117.5 mm^2, 143.1 mm^2 and 99.41%, respectively. *Conclusions* The average values of Young modulus, maximum force for initial fracture and required energy at yield point for Castor seed were 0.44 GPa, 198.11 N, and 382.08 N.mm, respectively.

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Introduction

Ricinus communis seed, commonly known as 'higuerilla', 'ricine' or 'mamona', is a member of the Euphorbiaceae family and it is native from tropical climates, although it has been adapted to a wide range of subtropical and temperate climates. The *R. communis* plant has been cultivated since antiquity not only as a garden ornament for its striking foliage and interesting flowers but also because their seeds were used as medicines. The annual world production is around 1 million tons, and nowadays, it is used mainly for the production of non-edible oil. The seeds are poisonous to humans and animals because they contain ricin, a protein with cytotoxic activity, that inhibits protein synthesis at ribosome levels (Perea-Flores *et al.*, 2011).

The physical properties of Castor seed are important in the design of equipment for harvesting, cleaning, sorting, grading, packaging and processing. The physical properties of food materials also affect on handling/conveying characteristics and estimating the cooling and heating loads (Mohsenin, 1986).

Mechanical properties are needed for texture analysis and a better understanding of product quality. For example, firmness of horticulture products, as measured by instrumental methods, is frequently used to determine their maturity and ripeness, which is important in handling, storing and processing procedures. Furthermore, Firmness is a component of texture influencing sensory perception of fruits by consumers. Texture perception and texture acceptability are critical factors in the quality evaluation of fruit and vegetable products offered on market. Although most consumers mention taste as the most important component of fruit quality, tests indicate that consumers are more sensitive to differences in texture than taste (Shewfelt, 1999).

Since currently used systems have been generally designed without taking these criteria into consideration, the resulting design lead to inadequate applications. This results in a reduction in work efficiency and an increase in product losses. Therefore, determination and consideration of these criteria have an important role in designing equipment.

With respect to the economical and processing importance of Castor seed, overcoming the world market and decreasing product losses, investigation and development in the field of selection or design of the most suitable machine is necessary. However, no study concerning the physical and mechanical properties of Castor seed has been performed up to now. The aim of this research was to investigate the physical-mechanical properties of Castor seed in order to achieve a complete profile of these attributes.

Materials and methods

Materials

Mature fresh Castors were used for all experiments. Samples were obtained from the Kermanshah Province, Iran, in July 2011, and kept in a refrigerator until laboratory measurements were performed. Seventy samples were randomly selected for all experiments. All the measurements were carried out at room temperature.

Physical properties determination

Linear dimensions, i.e. length (L), width (W) and thickness (T) were measured using a caliper with an accuracy of 0.01 mm. The arithmetic mean diameter (D_a) and the geometric mean diameter (D_g) were then calculated by the following relationships, respectively (Mohsenin, 1986):

$$D_a = \frac{L + W + T}{3} \tag{1}$$

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

The aspect ratio (R_a) was obtained using following relationship as recommended by Razavi & BahramParvar (2007):

$$R_a\% = \left(\frac{W}{L}\right) * 100 \tag{3}$$

The criteria used to describe the shape of the Castor seed was sphericity. Thus, the sphericity (Φ) of samples was found according to the relationship given by Mohsenin (1986) as

$$\Phi = \frac{(LWT^{1/3})}{L} \tag{4}$$

Surface area is defined as the total area over the outside of the Castor seed. Surface area (S) was theoretically calculated as apparent Surface area using two following equations that given by Razavi & BahramParvar (2007), respectively:

$$S = \frac{\pi B L^2}{2L - B} \tag{5}$$

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

$$S = \pi (D_g)^2 \tag{6}$$

True volume and true density were determined by the liquid displacement method (Mohsenin, 1986). Water was used for this purpose. The true volume (V) calculated by the following equation:

$$V = \frac{(M_a - M_w)}{\rho_w} \quad (7)$$

Where, M_w is mass of sample in water; M_a is mass of sample in air and ρ_w is density of water. Then, the true density of Castor seed obtained by the following relationship:

$$\rho_t = \frac{M_a}{V} \quad (8)$$

Mechanical properties determination

The mechanical properties of Castor seed were expressed in terms of elasticity (Young) modulus, maximum force and required energy for initial fracture at yield point. For determination of mechanical properties a Zowick/Roell Universal Testing Machine (Zwick GmbH & Co. KG, Ulm, Germany) was used, which is a popular destructive test device (Figure 1). This method is based on force–deformation characteristics of the castor seed and evaluation of the rheological properties of Castor seed and is the measure of the maximal force or stress needed to perforate the seed.

In order to do the rheological tests, samples were placed on their natural rest position and the analyses were accomplished in the orientation of thickness. The texture analyzer was fitted with a cylindrical probe (20.17 mm diameter), which was forced into the fruit, at a constant speed (10 mm min^{-1} for Castor seeds) until a deformation equal to 10% of the initial sample length was created. The mechanical parameters of this test, such as Young modulus, maximum force and required energy for initial fracture at yield point for Castor seed (*R. communis*) were determined. These were automatically generated as puncture progress with force–distance and force–time curves being plotted automatically in relation to the response of each sample.

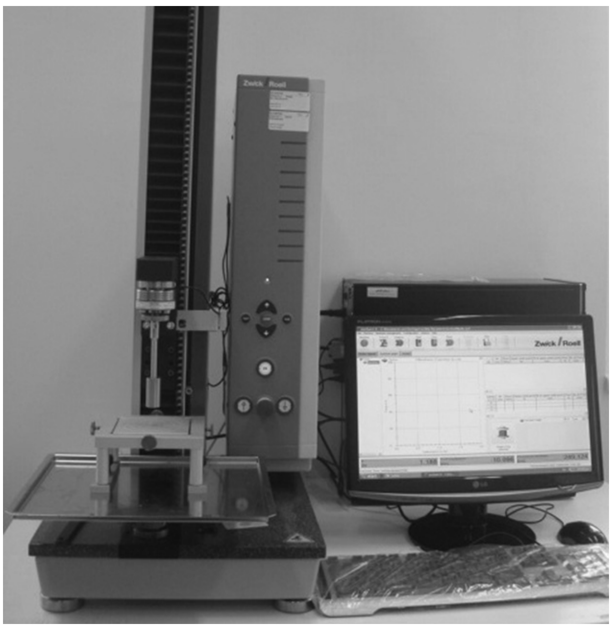

Figure 1 Zowick/Roell Universal Testing Machine.

Table 1 Some physical properties of Castor seeds

Physical properties	Castor seed			Significance level
	Max	Min	Average	
L (mm)	15.01	10.06	13.52	$P < 0.01$
W (mm)	14.26	11.39	13.39	$P < 0.01$
T (mm)	14.89	10.36	13.38	$P < 0.01$
M (g)	1.54	0.89	1.29	$P < 0.01$
V (cm^3)	0.25	0.1195	0.17	$P < 0.01$
ρ_t (g cm^{-3})	11.85	4.50	7.90	$P < 0.01$
D_g (mm)	14.32	11.34	13.42	$P < 0.01$
D_a (mm)	14.34	11.41	13.43	$P < 0.01$
S_{MC} (mm^2)	643.94	404.07	566.62	$P < 0.01$
S_{JB} (mm^2)	626.81	432.93	564.48	$P < 0.01$
Φ (%)	119.21	90.58	99.41	$P < 0.01$
R_a (%)	126.34	79.99	99.31	$P < 0.01$
PA_1 (mm^2)	159.2	123.7	143.8	$P < 0.01$
PA_2 (mm^2)	163.5	102.6	117.5	$P < 0.01$
PA_3 (mm^2)	155.8	127.0	143.1	$P < 0.01$
CPA (mm^2)	145.9	117.8	134.8	$P < 0.01$

Data analysis

All properties were measured with at least in five replications, unless stated otherwise.

Maximum, minimum, range, mean, standard deviation, regression equations and coefficient of determination were obtained using Microsoft Excel (2007).

Results and discussion

Physical characteristics

A summary of the results obtained for the physical properties of Castor seed is shown in Table 1. As it can be seen, the average length, width and thickness were found to be 13.52, 13.39 and 13.38 mm, respectively. The importance of these dimensions in determining the aperture size of machines, particularly for separation of different materials, has been discussed by Mohsenin (1986). The major axis has been found to be indicative of the natural rest position of the material and hence in the application of compressive force to induce mechanical fracture. Also, this dimension will be useful in applying shearing force during slicing (Owolarafe & Shotonde, 2004).

The sphericity and aspect ratio of Castor seeds were found to be 99.41% and 99.31%, respectively. The high sphericity

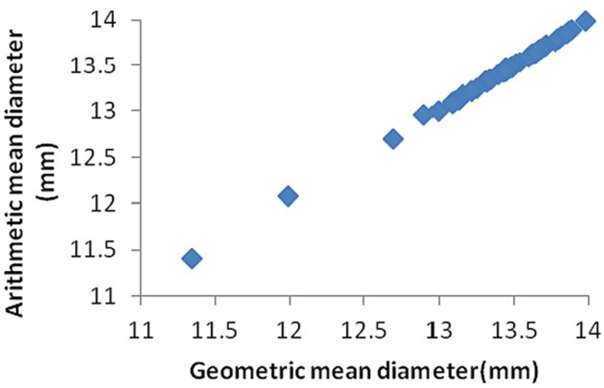

Figure 2 Relationship between arithmetic and geometric mean diameters of Castor seeds.

of Castor seed is indicative of the tendency of the shape towards a sphere. Taken along with the high aspect ratio of 99.31% (which relates the fruit width to length), it may be deduced that Castor seeds will rather roll than slide on their flat surfaces. However, the aspect ratio value being close to the sphericity value may also mean that the Castor seed will undergo a combination of rolling and sliding actions on their flat surfaces.

Figure 2 shows the relationship between geometric and arithmetic mean diameters of Castor seeds. As this figure indicates, the average diameters calculated by the arithmetic mean and the geometric mean formulas (Eqs. 1 and 2) were almost the same. Therefore, either the arithmetic mean or the geometric mean method can be used to calculate the equivalent diameter of Castor seeds. The regression relationship between geometric mean diameter and arithmetic mean diameter was obtained as follows:

$$D_a = 0.975D_g + 0.335\left(R^2 = 0.999\right)$$

The values of surface area of Castor seeds calculated by two used methods are shown in Table 1. The average values of true volume and true density of Castor seeds were 0.17 cm^3 and 7.9 g cm^{-3}, respectively (Table 1). Based on the true density value, there is a tendency for Castor seeds to be partially submerged in water. These properties may be useful in the separation and transportation of the fruit by hydrodynamic means.

Mechanical characteristics

The results for the rheological properties of Castor seeds are presented in Table 2. The elasticity modulus (E), maximum force, which the fruit can support (F_{max}) and the work, which is related to this force, have been determined. These data showed that the castor seed is designated as soft and elastic.

Table 2 Some mechanical properties of Castor seeds

Parameters	CV (%)	SD	Mean	Min	Max
Young modulus (GPa)	68.39	0.43	0.44	0.108	1.35
F_{max} (N)	22.51	44.60	198.11	90.6	247.00
W to F_{max} (N. mm)	39.97	152.71	382.08	137.22	559.57

Conclusion

Castor seed is one of the important seeds that are used to produce oil, etc. Fresh fruits need to be harvested, transported, sorted, graded and packed. As a first step in the design of specific equipment for the above processes, the properties of the fruit need to be known. This study undertook to determine the relevant physical and mechanical properties of the Castor seed, namely mass, size, sphericity, projected area, arithmetic and geometric mean diameters and true densities. The regression relationships between arithmetic and geometric mean diameters were obtained (Lorestani & Tabatabaeefar, 2006; Jaliliantabar *et al.*, 2011; Lorestani & Ghari, 2012). This information will facilitate the design of the machines involved in the processing of Castor seeds.

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