Determination of Some Mechanical Properties of Castor Seed (Ricinus communis L.) to Design and Fabricate an Oil Extraction Machine

M. Safieddin Ardebili¹, G. Najafi¹*, B. Ghobadian¹, and T. Tavakkoli Hashjin¹

ABSTRACT

This study was carried out to determine the effect of seed growing regions and loading speed on some mechanical properties of castor seed. These properties are used to design and improve related machines such as expeller that are used for extraction of oil from castor seed. Mechanical properties of castor seed were expressed in terms of rupture force and energy, bio-yield force, apparent modulus of elasticity and toughness using material testing machine. Factorial test with Completely Randomized Design (CRD) was used to study the effect of velocity (4 levels: 5, 15, 25, 35 mm min⁻¹) and seed growing regions (Izeh, Dezful, Baghmalek, Shoushtar and Urmia). The results showed that the effect of seed growing region on force, modulus of elasticity, bio-yield force and rupture energy was significant. Izeh seed had the maximum rupture force (75.11 N) whereas Dezful and Shoushtar seed had the minimum amount of rupture force (approximately 42 N). Also, loading speed had a significant effect on modulus of elasticity and rupture energy. With the increase of loading speed modulus of elasticity of Baghmalek seed decreased significantly from 144 to 65.5 MPa. Finally, interaction effect of seed growing region and loading speed was significant for most properties. In this research work, an extrusion system was designed and fabricated for the extraction of castor oil.

Keywords: Bio-yield point, Castor seed, Modulus of elasticity, Rupture force and energy, Toughness.

INTRODUCTION

Castor (Ricinus communis L.) is a non-edible oilseed, belonging to the Euphorbiaceae family (Kirk-Othmer, 1979). Relative to other vegetable oils, it has a good shelf life and it does not turn rancid unless subjected to excessive heat. India is the world’s largest exporter of castor oil; other major producers being China and Brazil (Ogunniyi, 2006). The bean-shaped seeds of the castor oil usually contain 40–55% oil. It may be possible to obtain a maximum of 2,000 kg ha⁻¹ oil (Volkhard et al., 2008). The high content of ricinoleic acid in the oil (higher than 85%) indicates that it is not suitable for human consumption. Due to its physical and chemical properties, the oil is used as raw material for several industrial applications and for the production of biofuels (Gely and Santalla, 2009). The resistance of the culture to drought conditions gives an additional opportunity to increase its exploitation in marginal regions, promoting also the developing of regional economies without competition with traditional oilseeds (Falasca et al., 2006).

Lack of basic engineering properties of plant material is an identified problem in the development of new equipment for processing and method of sowing the crop.

¹ Department of Agricultural Machinery, Faculty of Agriculture, Tarbiat Modares University, Tehran, Islamic Republic of Iran.
* Corresponding author; e-mail: g.najafi@modares.ac.ir
Knowledge of physical and mechanical properties constitutes important and essential engineering data in the design of machine, storage structures, processing and quality control. This basic information is not only important to engineers but it is also useful to those who may exploit these properties and find new uses for the plant material (Mohsenin, 1978; Ayuga et al., 2005). Biological materials are composed primarily of polymeric substances, and have viscoelastic behavior. This unique behavior has rendered biomaterials loading speed sensitive (Burubai et al., 2007).

Many researchers have worked on the physical and mechanical properties of oil seeds (Makanjuola, 1972; Frazer et al., 1978; Alcali and Guven, 1990; Oje and Ugbor, 1991; Olaoye, 2000; Baumler et al., 2006; Coskuner and Karababa, 2007; Garnayak et al., 2008; Perez et al., 2007; Gharibzahedi et al., 2011). Since quasi-static loading is usually representative of resistance and mechanical behavior of samples that are tested by this method, it can be used in the design and optimization of producing machines such as those used in the extraction of oil from castor seeds. Physical and mechanical properties of seed are important for the design of processing equipment such as husker oil extraction machine. The objective of this study was therefore to investigate the effect of seeds growing region and loading speed on some mechanical properties of castor seed namely rupture energy and force, bio-yield force, modulus of elasticity and toughness to design and fabricate an oil extraction machine.

### MATERIALS AND METHODS

#### Sample Preparation

Castor seeds (Figure 1) used in this study were collected from five different regions in Iran: Urmia, Shoshtar, Izeh, Dezful and Baghmalek cities. Annual climatic data of the different regions in this study are shown in Table 1.

The samples were cleaned and stored manually to get rid of all foreign matters, broken and immature seeds. Initial moisture was measured by oven drying at 103°C for 72 hours (ASAE, 2001).

#### Testing Method

A material testing machine (H50k-S, Hounsfield, England) was used for mechanical properties measurement (Figure 2). For the investigation of the effect of loading speed on rupture force, castor seeds were loaded in constant speeds of 5, 15, 25, 35 mm min$^{-1}$ (ASAE, 2004). A Sample of ten seeds was randomly selected for each test. The sample was located between two parallel plates, and force-deformation curves were obtained. The

![Figure 1. Castor seeds.](image)

<table>
<thead>
<tr>
<th>Region</th>
<th>Annual rainfall (mm)</th>
<th>Maximum relative Humidity (%)</th>
<th>Temperature (Average high °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urmia</td>
<td>304.5</td>
<td>81</td>
<td>18.4</td>
</tr>
<tr>
<td>Shoshtar</td>
<td>299.1</td>
<td>58</td>
<td>33</td>
</tr>
<tr>
<td>Izeh</td>
<td>791.5</td>
<td>65</td>
<td>28.9</td>
</tr>
<tr>
<td>Dezful</td>
<td>337.6</td>
<td>51</td>
<td>24.4</td>
</tr>
<tr>
<td>Baghmalek</td>
<td>463.5</td>
<td>61</td>
<td>29.2</td>
</tr>
</tbody>
</table>
loading geometry is shown in Figure 3 (ASAE, 2004). The amount of force and deformation at rupture point for castor seed were directly obtained from these curves. Absorbed energy by the sample at rupture point was determined by calculating the area under the force-deformation curve from the following equation:

$$E_a = \left(\frac{F \cdot D_r}{2}\right)$$  \hspace{1cm} (1)

Where $E_a$ is the rupture energy in mJ, $F$ is the rupture force in N and $D_r$ is the deformation at rupture point in mm (Braga et al., 1999). There was a decrease in the force after rupture occurred in the specimen and this point was denoted as the bio-yield point (Gupta and Das, 2000).

Toughness is work per unit volume needed to rupture the material, since the area under force-deformation curve is representative of the work that is done for failing the sample. The amount of toughness was estimated by calculating seed volume, considering the assumption that the seed is spherical in shape.

$$\Phi = \left(\frac{LWT}{L}\right)^{\frac{1}{3}}$$  \hspace{1cm} (2)

Where $\Phi$ is the sphericity; $L$ is the length in mm; $W$ is the width in mm; and $T$ is the thickness in mm. Apparent modulus of elasticity was estimated from the following relationship:

$$E = \frac{0.3388\sqrt{\frac{F(1-\mu^2)}{D^2}}}{\left[\frac{\frac{1}{R_{\text{min1}}} + \frac{1}{R_{\text{max1}}} + \frac{1}{R_{\text{min2}}} + \frac{1}{R_{\text{max2}}}}{\frac{1}{R_{\text{min1}}}}\right]}$$  \hspace{1cm} (3)

Equation (3) is based on Hertz equations for constant stresses. In which, $E$ is modulus of elasticity in MPa, $F$ is compression force in N, $D$ is deformation in mm, $R_{\text{min1}}$ and $R_{\text{max1}}$ are radii of curvature of the convex surface of the sample at the point of contact with the upper plate respectively. $R_{\text{min2}}$ and $R_{\text{max2}}$ are radii of curvature of convex surface of samples at the point of contact with lower plate. The value of $k$ is calculated from radii of curvature of the surface in contact (Misra et al., 1981). The $\mu$ is Poisson’s ratio equal to 0.4 (ASAE, 2001).

Data were analyzed using statistical software SPSS16 (SPSS Inc., USA), while the means were compared by LSD model by using MSTATC.

RESULTS AND DISCUSSION

Variance analysis of the mechanical properties of castor is shown in Table 2. Mechanical properties of castor seed were expressed in terms of rupture force and energy, bio-yield force, modulus of elasticity and toughness.

Rupture Force

The results regarding the comparison of means for different seeds showed that Izeh
seed possesses the maximum amount of rupture force (75.11 N) at 35 mm min$^{-1}$ of loading speed; the Baghmalek seeds with 68.21 N of rupture force had the second value of means. At the loading speed of 25 mm min$^{-1}$, Baghmalek, Dezfoul and Shoshtar seeds had the lowest rupture forces. As mentioned earlier, Izeh seeds possess the maximum rupture force, probably, because of differences among surface areas of seeds. Some physical properties of the seeds are shown in Table (3). Several studies have been carried out to determine the rupture force of different crops including Gupta and Das (2000) for sunflower, Ozarslan (2002) for cotton seed, Baumler et al. (2006) for safflower seed, and Stasiak et al. (2007) for rapeseed.

At 25 mm min$^{-1}$ loading speed, the amount of rupture force for Dezfoul, Baghmalek and Shoshtar seeds were lower than those for Izeh and Urmia seeds. Baghmalek seeds had the lowest rupture force at this loading speed. The ANOVA results showed that the amount of rupture force for seeds at different loading speeds was not significantly different (Figure 4).

**Bio-yield Force**

The ANOVA results showed that seed growing region and loading speed exhibit significant effects on maximum bio-yield force at 5% probability level. Izeh, Shoshtar and Dezfoul seeds had the highest bio-yield force, respectively whereas Urmia and Baghmalek had the lowest (Figures 5 and 6). The amount of bio-yield force at the loading speed of 5 mm min$^{-1}$ was the lowest because of the decrease in quasi-static loading state and approaching the dynamic state.

### Table 2. Variance analysis of the mechanical properties of castor.

<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>Rupture force (N)</th>
<th>Bio-yield force (N)</th>
<th>Rupture energy (J)</th>
<th>Toughness (J m$^{-3}$)</th>
<th>Apparent modulus of elasticity (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed growing region</td>
<td>4</td>
<td>3807.4$^*$</td>
<td>1740.9$^*$</td>
<td>0.0014$^*$</td>
<td>0.043$^*$</td>
<td>16664$^{**}$</td>
</tr>
<tr>
<td>Loading speed</td>
<td>13</td>
<td>337.6$^*$</td>
<td>1007.8$^*$</td>
<td>0.0012$^*$</td>
<td>0.005$^*$</td>
<td>5575$^*$</td>
</tr>
<tr>
<td>Seed Growing Region × Loading speed</td>
<td>12</td>
<td>539.4$^*$</td>
<td>113.3$^*$</td>
<td>0.0013$^*$</td>
<td>0.057$^*$</td>
<td>3163$^*$</td>
</tr>
<tr>
<td>Error</td>
<td>180</td>
<td>267.5</td>
<td>194.7</td>
<td>0.0006</td>
<td>0.0038</td>
<td>1032</td>
</tr>
<tr>
<td>CV</td>
<td></td>
<td>15.6585</td>
<td>18.5833</td>
<td>2.24894</td>
<td>4.98622</td>
<td>19.7673</td>
</tr>
</tbody>
</table>

*Significant at 0.05 level; ** Significant at 0.01 level, ns: Not significant.

### Table 3. Physical properties of castor seeds.

<table>
<thead>
<tr>
<th>Seed growing region</th>
<th>Density (gr mm$^{-3}$)</th>
<th>Surface area (mm$^2$)</th>
<th>Length (mm)</th>
<th>Width (mm)</th>
<th>Thickness (mm)</th>
<th>Geometric mean diameter (mm)</th>
<th>Sphericity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dezfoul</td>
<td>0.71d</td>
<td>293.47b</td>
<td>12.22b</td>
<td>8.46b</td>
<td>6.48b</td>
<td>8.69b</td>
<td>0.73a</td>
</tr>
<tr>
<td>Izeh</td>
<td>0.87bc</td>
<td>304.03a</td>
<td>14.71a</td>
<td>9.56a</td>
<td>6.77a</td>
<td>9.83a</td>
<td>0.67b</td>
</tr>
<tr>
<td>Baghmalek</td>
<td>1.01a</td>
<td>300.51a</td>
<td>14.56a</td>
<td>9.61a</td>
<td>6.7a</td>
<td>9.76a</td>
<td>0.67b</td>
</tr>
<tr>
<td>Shoshtar</td>
<td>0.78cd</td>
<td>237.85b</td>
<td>12.22b</td>
<td>8.52b</td>
<td>6.32c</td>
<td>8.7b</td>
<td>0.71a</td>
</tr>
<tr>
<td>Urmia</td>
<td>0.92ab</td>
<td>219.64c</td>
<td>12.01b</td>
<td>8.39b</td>
<td>5.79d</td>
<td>8.35c</td>
<td>0.69a</td>
</tr>
</tbody>
</table>
Rupture Energy

The results of the rupture energy are presented in Figure 7. The ANOVA results showed that the interaction effect of seed growing region and loading speed for rupture energy is significant at 5% probability level. The effect of loading speed on Dezfoul, Shoshtar and Urmia seeds was not significant while it was significant for Izeh and Baghmalek seeds. Baghmalek seeds had the highest rupture energy (0.09 J), while Dezfoul seeds had the lowest value of rupture energy (0.01 J). At all loading speeds the effect of seed growing region on energy was significant. Energy was calculated from the area under force-deformation curve, Izeh seeds had maximum rupture force; because of minimum deformation in rupture point (Figure 7). The rupture energy value ranged from 0.059 to 0.135 J for corn seed (Tarighi et al., 2011) sunflower (Gupta and Das, 2000) hazelnut (Güner et al. 2003) and faba bean grains (Altuntas and Yildiz 2007).

Toughness

The effect of seed growing region on toughness was significant at 5% probability level (Figure 8). The results for comparison of means showed that Baghmalek seeds possessed the highest amount of toughness (0.15 J m$^{-3}$) while those for Dezfoul and Shoshtar were lower than the others.

Apparent Modulus of Elasticity

ANOVA results revealed that the
interaction effect of seed growing region and loading speed for modulus of elasticity was significant at 5% probability level. The Urmia seeds had the maximum value of modulus of elasticity (14.4 MPa), while the increase in loading speed decreased the modulus of elasticity. Urmia seeds modulus of elasticity decreased from 140.4 to 111.3 MPa with the increase of loading speed (Figure 9). The modulus of elasticity for Baghmalek seeds was decreased significantly from 144 to 65.5 MPa. The range of 230 to 4,100 MPa has been reported for the modulus of elasticity (Mohsenin, 1978; Arnold and Robert, 1969; Bargale, et al., 1995; Afkari Sayah and Minaei, 2004) for plants, wheat grains, canola and wheat, respectively.

**Design and Fabrication of Oil Extraction Machine**

In this research work, an extrusion system was designed and fabricated for castor oil extraction. Experiments were carried out to find the effect of parameters on the final oil extraction performance. The various parts designed consist of: barrel, screw, the optimum shaft length for a given screw pitch, die and cap (Figure 10). The castor seeds that were to be pressed were placed inside the hopper. As the oil-seed was fed into the machine, the screw conveyed the seed forward towards the tapering end of the shaft with the increasingly small clearance between the tapered screw shaft and the barrel. The side view of the oil extraction machine is shown in Figure 11.

The machine was tested at auger speeds of 40, 60, 80 and 100 rpm respectively and four die diameters (6, 8, 10 and 12 mm). The result showed that, maximum oil extraction of 74% was possible using the die with 12 mm diameter and the speed of 80 rpm which is an acceptable amount. Also, the result showed that decrease in die diameter and increase in screw rpm increased the amount of extracted oil. The optimum parameters to attain the maximum oil extraction were obtained. A shaft speed of not more than 80 rpm and 6 mm diameter of die was found to be suitable for using the screw press. The manufactured extrusion machine can be also used for the extraction of other grains such as soybean, canola and jatropha due to its flexibility to adjust its processing and design parameters. Moreover, the advantage of this
mechanical properties of Castor Seed  ___________________________________________

Figure 9. Interaction effect of seed growing region and modulus of elasticity for castor seed (different letters are significantly different at 1% level by LSD).

Figure 10. 1. Screw, 2. Barrel, 3. Die, 4. Cap.

Figure 11. Side view of the oil extraction machine.

CONCLUSIONS

Seed growing region has significant effects on mechanical properties of castor seeds, and interaction effect of loading speed and seed growing regions for most properties was significant. Differences between all values were statistically significant at \( P < 0.05 \).

At high loading speeds, modulus of elasticity decreased for all seeds varieties, and bio-yield force increased in some cases. Urmia seeds had the highest value of modulus of elasticity (14.4 MPa).

Baghmalek seeds had the highest rupture energy (0.09 J), while Dezfoul seeds had the lowest amount of rupture energy (0.01 J). Izeh seeds possessed the highest amount of rupture force (75.11 N) at 35 mm min\(^{-1}\) of loading speed with the Baghmalek seeds with 68.21 N of rupture force having the second value of means.

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Mechanical properties of Castor Seed ___________________________________________


Tayān khwās makanikī dānā kārkhi, (Ricinus communis L.)

Sāxāt dastgāh roğān kī

M. صفی الدین ارديبیلی, غ. نجفی, ب. فارابیان, و. ت. توکی هنجهین

چکیده

در این تحقیق به بررسی برخی از خواص مکانیکی دانه کارچک از واریته‌های مختلف که در مناطق مختلفی شرکت کرده‌اند، برداشت و شده است. از این خواص مکانیکی برای طراحی و بهره‌مندی‌های بروخور و مشابهانه نشانه‌گذاری کارچک استفاده می‌شود. خواص مکانیکی دانه کارچک از این نظر واریتی بهترین نشان داده گزارش شده است. در این تحقیق نشان داده شد که نوع واریتی کارچک بر روی تیزی و انرژی غشاینی و مواد استوانه‌ای اثر معنی داری داشته باشد. بدین ترتیب که برای دانه کارچک به طوری که بر روی تیزی و انرژی غشاینی و مواد استوانه‌ای داشته باشند، باید سرعت بارگذاری تأثیر معنی دارد بر روی مواد استوانه‌ای اثر معنی داشته باشد.

References: