J. Agr. Sci. Tech. (2012) Vol. 14: 1219-1227

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

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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, Dezfoul, 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 Dezfoul 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.

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[DOR: 20.1001.1.16807073.2012.14.6.3.3]

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, Dezfoul 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 twoparallel plates, and force-deformation curves were obtained. The

Figure 1. Castor seeds.

Table 1. Annual climatic data of different regions (Anonymous, 2005).

Region	Annual rainfall (mm)	Maximum relative Humidity (%)	Temperature (Average high °C)
Urmia	304.5	81	18.4
Shoshtar	299.1	58	33
Izeh	791.5	65	28.9
Dezfoul	337.6	51	24.4
Baghmalek	463.5	61	29.2

[DOR: 20.1001.1.16807073.2012.14.6.3.3]

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:

$$E_a = \left[\frac{F_r D_r}{2} \right] \quad (1)$$

Where E_a is the rupture energy in mJ, F_r 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.

Figure 2. Materials testing machine

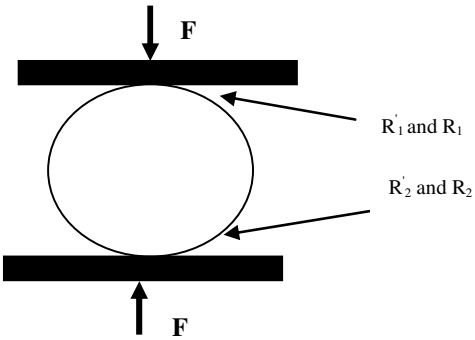

Figure 3. Loading geometry.

The sphericity relates to the overall shape of a feature irrespective of the sharpness of its edges and is a measure of the degree of its conformity to a sphere. This measurement was determined using the following equation (Mohsenin, 1978):

$$\Phi = \frac{(LWT)^{\frac{1}{3}}}{L} \quad (2)$$

Where Φ 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:

$$E = \frac{0.338 k^{\frac{3}{2}} F (1-\mu^2)}{D^{\frac{3}{2}}} \left[\left(\frac{1}{R_{\min 1}} + \frac{1}{R_{\max 1}}\right)^{\frac{1}{3}} + \left(\frac{1}{R_{\min 2}} + \frac{1}{R_{\max 2}}\right)^{\frac{1}{3}} \right]^{\frac{3}{2}} \quad (3)$$

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, $R_{\min 1}$ and $R_{\max 1}$ are radii of curvature of the convex surface of the sample at the point of contact with the upper plate respectively. $R_{\min 2}$ and $R_{\max 2}$ 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 μ 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

[DOR: 20.1001.1.16807073.2012.14.6.3.3]

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 rapture 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.

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

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

Table 3. Physical properties of castor seeds.

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

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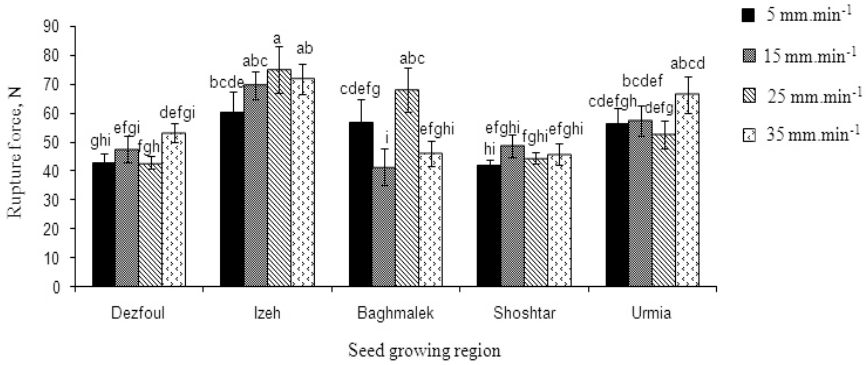

Figure 4. The effect of seed growing region on the rupture force of castor seed (different letters are significantly different at 1% level by LSD).

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).

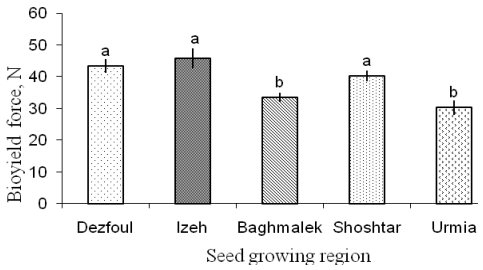

Figure 5. The effect of seed growing region on the bio-yield force of castor seed (different letters are significantly different at 5% level by LSD).

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

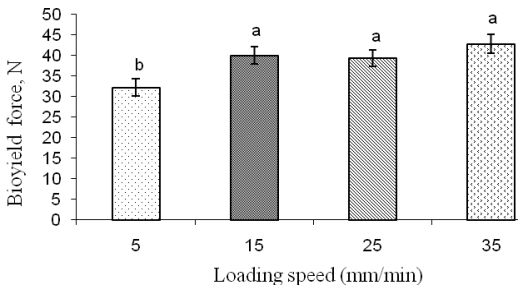

Figure 6. The effect of loading speed on the bio-yield force of castor seed (different letters are significantly different at 5% level by LSD).

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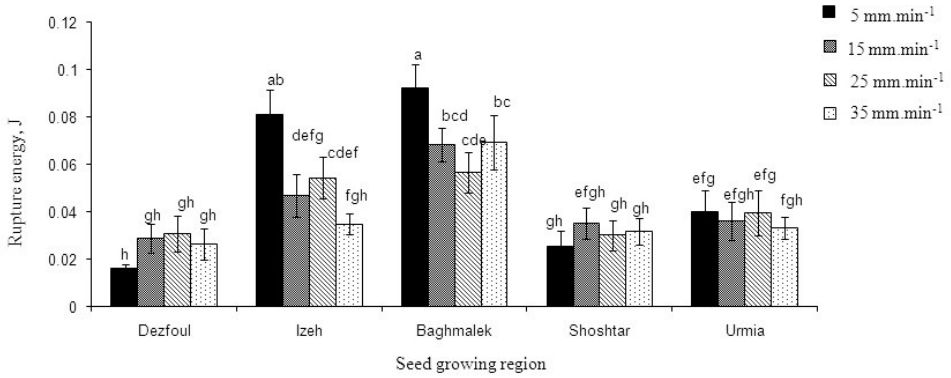

Figure 7. The effect of seed growing region on the rupture energy of castor seed (different letters are significantly different at 1% level by LSD).

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

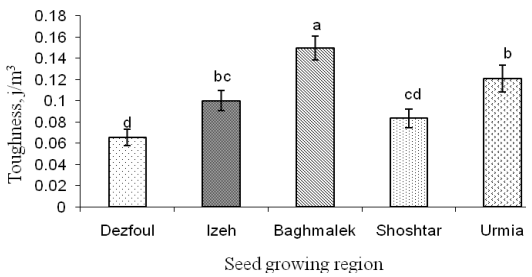

Figure 8. The effect of seed growing region on the toughness of castor seed (different letters are significantly different at 1% level by LSD).

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

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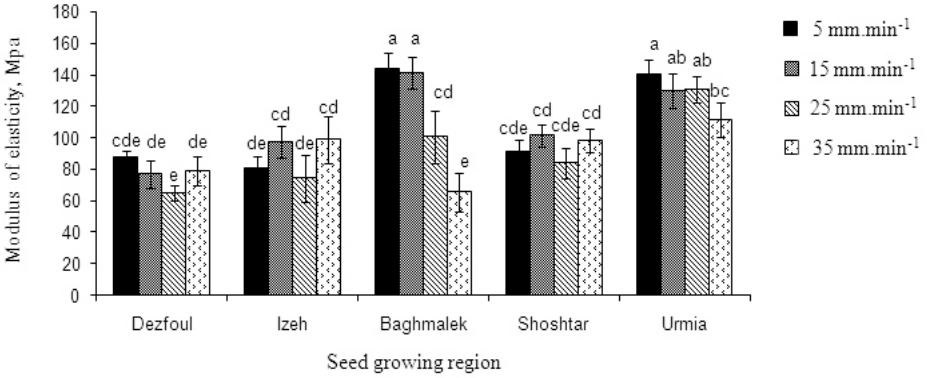

Figure 9. Interaction effect of seed growing region and modulus of elasticity for castor seed (different letters are significantly different at 1% level by LSD).

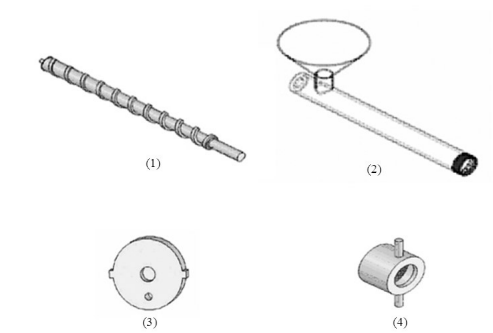

Figure 10. 1. Screw, 2. Barrel, 3. Die, 4. Cap.

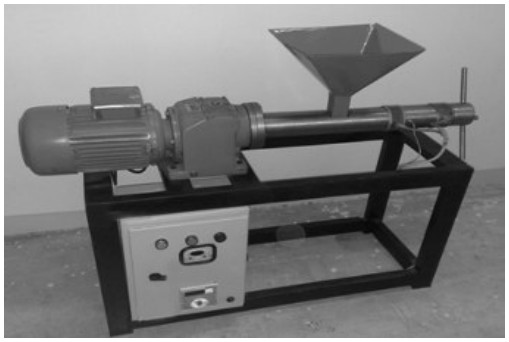

Figure 11. Side view of the oil extraction machine.

machine is portability to use in fields and small-size workplaces.

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.

ACKNOWLEDGEMENTS

The authors would like to thank Tarbiat Modares University for providing the laboratory facilities and financial support for this project. The authors wish to thank the National Iranian Oil Refining and Distribution Company (NIORDC) for the research grant provided to complete this project.

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تعیین خواص مکانیکی دانه کرچک (*Ricinus communis* L.) به منظور طراحی و ساخت دستگاه روغن‌کشی

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چکیده

در این تحقیق به بررسی برخی از خواص مکانیکی دانه کرچک از واریته‌های مختلف که در مناطق مختلفی رشد می‌کنند، پرداخته شده است. از این خواص مکانیکی برای طراحی و بهبود ماشین‌های برداشت و ماشین‌های استخراج روغن دانه کرچک استفاده می‌شود. خواص مکانیکی دانه کرچک عبارتند از نیرو و انرژی لازم برای گسیختگی محصول، مدول الاستیسیته و چقرمگی مواد که معمولا با استفاده از دستگاه آزمون مواد قابل اندازه‌گیری هستند. از روش آماری آزمون فاکتوریل با طرح بلوک تصادفی به منظور بررسی اثر سرعت بارگذاری (۴ سطح ۵، ۱۵، ۲۵ و ۳۵ میلی‌متر بر دقیقه) بر روی پنج واریته مختلف از کرچک (ایذه، دزفول، باغملک، شوشتر و ارومیه) استفاده گردید. نتایج حاصل از این تحقیق نشان دادند که نوع واریته کرچک بر روی نیرو و انرژی گسیختگی و مدول الاستیسیته اثر معنی داری داشته به طوری که بیشترین نیروی گسیختگی متعلق به واریته ایذه بوده (۷۵/۱۱ نیوتن) و واریته-های دزفول و شوشتر کمترین نیروی گسیختگی را داشتند (تقریبا ۴۲ نیوتن). آزمایش‌ها نشان دادند که سرعت بارگذاری تاثیر معنی داری بر روی مدول الاستیسیته و انرژی گسیختگی داشته به طوری که به عنوان مثال با افزایش سرعت بارگذاری، مدول الاستیسیته رقم باغملک از ۱۴۴ مگاپاسکال به ۶۵/۵ مگاپاسکال کاهش یافت. اثر متقابل نوع رقم محصول و سرعت بارگذاری نیز برای مشخصات ذکر شده معنی دار بود. در این تحقیق یک دستگاه روغن‌کشی به روش اکستروژن سرد برای استحصال روغن از کرچک طراحی و ساخته شد. برای طراحی دستگاه روغن‌کشی کرچک از اطلاعات به‌دست آمده در زمینه خواص فیزیکی و مکانیکی دانه کرچک استفاده گردید.

[DOR: 20.1001.1.16807073.2012.14.6.3.3]