Determination of the mechanical properties of unbroken canola pods

Ehsan Ghajarjazi[1], Mohsen Azadbakht[1*], Farshid Ghaderi-Far[2]

(1. Department of Bio-system Mechanical Engineering, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran; 2. Department of Agronomy, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran.)

Abstract: The mechanical properties for the threshing mechanism design, distance setting and the size of thrasher for better threshing and less damage to the seeds were used. In this study the mechanical properties of unbroken pods of canola were investigated including failure force, failure strain, failure energy, toughness, and modulus of elasticity planted in three canola varieties in the fields of Aliabad city in Iran including Hyola 50,401, and 420 at the three times of sampling in pre-harvest, harvest and post-harvest in two directions of loading (in the direction of small and medium diameter). Canola varieties had different moisture levels at the same time, and this moisture was measured as a sub factor. The results showed that moisture changes were effective at 5% on deformation, failure strain and failure energy and canola variety changes were effective at 1% on deformation, failure strain and modulus of elasticity. Changes of sampling time were effective at 1% on failure strain and 5% on toughness. And also changes of loading direction was 1% effective on failure force, failure strain and failure energy and toughness and it was 5% effective on modulus elasticity. The mutual effect time and variety on deformation, failure strain and modulus of elasticity was significant at 1%, and with 5% significant on failure energy. The mutual effect of variety and direction on modulus of elasticity was 5% effective.

Keywords: Canola pod, mechanical properties, failure, force, deformation, energy, toughness, modulus of elasticity

Citation: Ghajarjazi, E., M. Azadbakht, and F. Ghaderifa. 2015. Determination of the mechanical properties of unbroken canola pods. AgricEngInt: CIGR Journal, 17(3): 392-403.

1 Introduction

Canola is scientifically classified and known as *Brassica napus* L. belonging to Cruciferea family with chromosome number of 38 that generally has the spring, fall and in the middle growth types (Omidvar et al., 2014). There are more than 350 kinds of oilseeds in the world. Grains and oilseeds are the world`s second largest food supply and canola is one of the world`s most important oilseeds (ImanMehr et al., 2007). Canola is grown in most part of the country and its cultivation is possible in every types of soil. The amount of oil in canola are 40% to 45% of the whole seed`s weight (ImanMehr et al., 2007). After soybean and cotton, canola is the world`s third largest source of vegetable oil production. About 17,000 ha are under cultivation of canola, producing 17,000 t, equivalent to 61% of the world`s average production (Hazbavi and Minaie, 2008). Increase in performance of this product is considered. Canola contains 40% of oil and canola varieties often contain less than 2% of uric acid and 30% of glucose molecule in each gram of seeds. Harvesting time affects the performance of the product. Harvest management is an important practice that may result in reducing the loss of canola. According to high temperature of weather in the end of the ripping period, the moisture reduction of the seed was very fast, so, after the moisture had reduced to 10%, the crop must be harvested. Therefore, if the time passes more than 4-5 days, due to excessive dryness of the pod, the losses caused by combine blades will increase (Rajabivandchali and Ghanbarimalidare, 2010). The mechanical properties are important parameters for

Received date: 2015-05-24 **Accepted date:**2015-08-12

***Corresponding author: Mohsen Azadbakht,** Department of Bio-system Mechanical Engineering, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran. Email: azadbakht@gau.ac.ir

the design of threshing tools with its parts and they are also crucial in computer stimulation for analysis, optimization and seed control damage during threshing, storage, transfer and commercialization of seeds (Azadbakht et al., 2013). So, a few studies done on this subject will be addressed:

In a study, the mechanical behavior of canola pod during threshing was measured against the impact and friction forces. In this study the effect of moisture and energy on impact in threshing the canola was investigated. A threshing machine was used based on pendulum mechanism. The experiments were done based on three levels of moisture: 10%, 17% and 24%. The result of the experiment showed that the moisture and energy influenced the threshing percentage significantly. The highest amount of threshing in 10% moisture level and 0.077 J energy will be 88.81% and the least amount of threshing in 24% moisture and 0.069 J energy will be 48.55% (Azadbakht et al., 2013). In the study about the mechanical properties of hazelnut and its seed, it was observed that moisture and loading direction, failure force and special deformation will significantly influence the rupture of hazelnut`s seed with increasing moisture. The failure force will reduce and special deformation of the failure will increase (Kermani, 2008). All researchers measured the failure resistance of sunflower seed and grain based on the average compressive force, deformation and energy absorption in volume unit. Samples at different moisture contents had been loaded vertically and horizontally (Gupta and Das, 2000). Other researchers have examined the rupture force, bio yield force, deformation, modulus of elasticity and failure energy in examination of effects of moisture content and loading on mechanical properties of carob pod (Ekinci et al., 2010). Davison et al. (1975) observed in mechanical properties examination of canola that the maximum compressive force of the healthy canola will reduce due to increase in moisture ratio, in canola with 7.2% moisture (based on wetness) the average amount of 13.73 N and with average moisture of 17%, the mean value of 81.9N was obtained. While it was loaded 0.05 cm/min respectively, average deformation of canola was 20% until the failure of the pod. The apparent elastic modulus of canola decreased with increasing moisture. The energy required to threshing the bean pod was measured in some ways of forcing with pendulum and friction and pressure. Dried beans (13.3% to 15.3% moisture) were fully opened and then it was observed that the shells were broken. Pods with 17.3% moisture content after the seeds had been released, will slowly open up and will never break (De Simon et al., 2000). Sadrnia *et al.* (2009) studied mechanical failure of two types of watermelon in Quasi-Static loading. In each test the variables of the failure force, failure deformation and shell thickness were measured. Their results show that the loading direction will affect the failure force in longitudinal direction significantly less than the transverse direction. Golmohammadi et al. (2013) examined the effects of moisture on mechanical properties of three varieties of Pistachios, including failure force, deformation of failure, failure energy and toughness. They showed that increasing moisture will result in increasing failure force, deformation, failure energy and toughness. Other researchers measured the Ahmad Aghaie`s variety of pistachio and its seed including rupture force, rupture energy in three levels of moisture and observed that rupture force, rupture energy and deformation were significantly affected by moisture (Gholamiparashkouhi et al., 2013). Kermani et al. (2007) studied the mechanical properties of rice and the effect of force pressure and observed that decreasing moisture, the failure force and energy, apparent elastic modulus and deformation of rice, failure strain and stress, apparent compressive modulus of elasticity and toughness will increase. In determining mechanical properties of soybean under quasi-static loading, it was observed that with increasing moisture from 10% to 14%, the failure force and failure energy will increase from 47.5 N and 10 mJ to 82 N and 56 mJ. This different behavior of soybean is justified compared to other grains because of excessive fat in the tissue structure. Elasticity coefficient of seed moisture in 10% moisture was set to 80.95 MPa that with increasing moisture to 14%, this parameter reduces to 25.56 (Alemi et al., 2009). Khazaei et al. (2004) studied required force and energy to failure or break the chickpea in three levels of moisture (7%, 12%, and 16%), two loading directions and three kinds of Iranian chickpea influenced by Quasi-Static forces and observed that moisture, variety and loading direction have significant effect on required force and energy to break or rupture the grain.

The mechanical properties of canola were used for threshing mechanism design, distance setting, and the thrasher size for better threshing and less damaging the grain. Therefore, the purpose of this study is to evaluate the effect of change in sampling time, type and loading direction on the mechanical properties of the Canola Pods. Review of the appropriate variety and harvesting time as well as design of suitable machines to harvest canola is important.

2 Materials and methods

2.1 Sample preparation

At first three varieties of Hyola 50, 401 and 420, canola were chosen from farms of Aliabad city. Sampling was conducted at three times: before harvest, during harvest and after harvest. Each one of the harvest times differs from one another in 4 days. Healthy canola pods were maintained unbroken (with seeds) in plastic bags in refrigerator with 3 ℃ (Azadbakht et al., 2013). The pods filled with grain (and also unbroken) were taken to the laboratory in Gorgan University of Agricultural Sciences and Natural Resources and they were placed into an oven. The pod samples were put into the oven with 103 ℃ for 17±1 h (Azadbakht et al., 2013). Then moisture content of empty and full pods were determined, according to the standard methods based on wetness. At each sampling time, because of different varieties, the moisture content were also different, the amount of moisture were stated in Table 1.

Table 1 Percentage of moisture of different types in sampling time based on wetness

	Post Harvest	Harvest	Before Harvest
Hyola 50	5.63	13.64	32.71
Hyola 401	13.6	18.57	24.41
Hyola 420	6.66	10.41	14.51

2.2 Test method

The mechanical properties of a full canola pod were measured under quasi-static loading and checking of force- deformation curve including toughness, failure force, deformation, failure stress, failure energy, failure strain and modulus of elasticity in three digit levels and three levels of sampling time and two levels of loading in small and middle diameters were done. (Golmohammadi et al., 2013)

The quasi-static loading represents the sample resistance and mechanical properties; therefore, the extracted information is useful to assess the impact of different varieties.

To carry out the mechanical test of canola, the Instron Santam (santam-STM5) with 100 Newton load cells was used. As it can be seen in Figure 1 and Figure 2, the jaw`s level was larger than pod`s level so that it covered the whole pod. Unbroken canola pods were placed in both directions in the system. At first, the pods in small diameter (horizontal) and medium diameter (vertical) with 5 replicates were put under pressure.

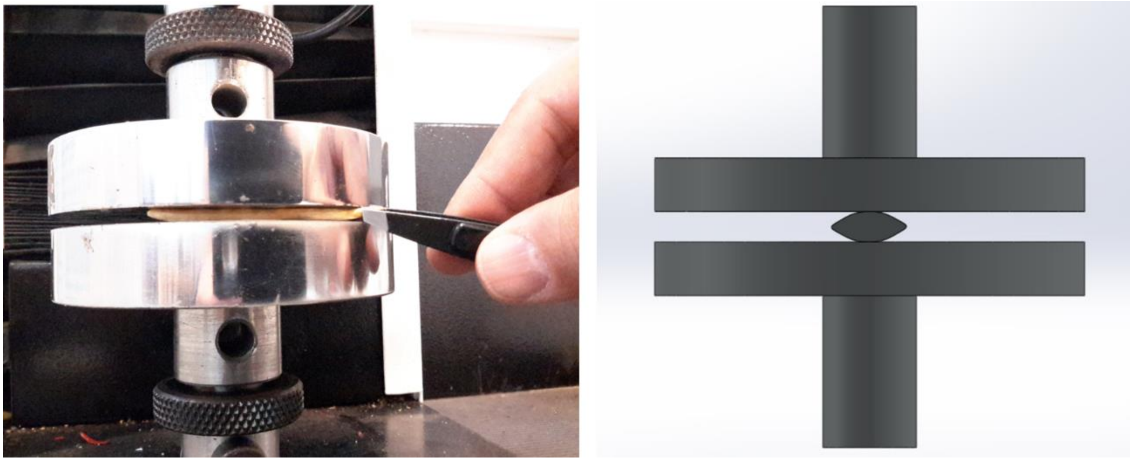

Figure 1 Loading in the small diameter

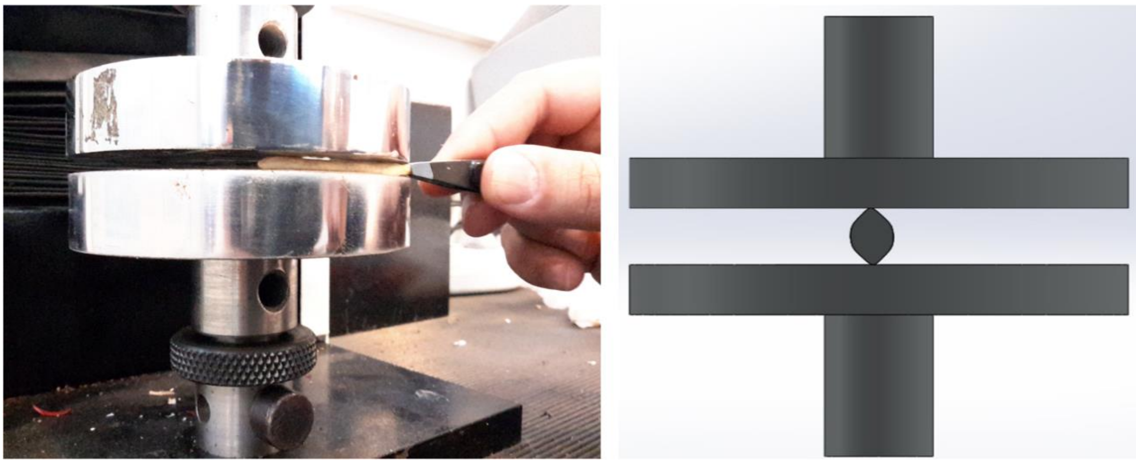

Figure 2 Loading in the medium diameter

Loading continued until the canola failure and then the diagram of force-deformation was plotted by Instron and the data was extracted according to the failure force is like a point on the force-deformation curve. Failure force is the point which with a little increase in deformation the force will drop too much at that point (Golmohammadi et al., 2014). And also due to the corresponding point of the failure force on the deformation axis on the force-deformation graph was the deformation on the deformation point, the deformation in the failure point was calculated. To measure the failure energy, the area under the force-deformation curve was obtained by excel software, from the starting point of loading to the failure point. And since toughness is equal to the amount of work done per unit volume of the object to the point of failure and also given the amount of work done and the area under the curve, thus by dividing the area under the curve from the canola sample volume, the toughness will be obtained (Golmohammadi et al., 2014). To determine the mass, balance scale was used (Razavi and Akbari, 2013) because the density of pods is less than the water, and the pods were immersed to the base with a thin wire in the water. Initial weight of pods was determined as (M_1). Then weight of the beaker and the water inside it were measured as (M_2). Then the weight of beaker, water, and the pods were determined as (M_3). Thus, according to Equation 1 pod`s amount was obtained:

$$V = \frac{(M_3 - M_2)}{\rho_w} \qquad (1)$$

Failure stress was obtained by dividing failure force from surface area of the pod which was under the jaw pressure (Golmohammadi et al., 2013). Determination of the pod`s surface area includes software and hardware.

HP scanner was connected to the computer. First, the pod`s imaging was done in a very high quality and resolution scanner in a way that all the color differences between surface of the pod and the bottom plate was clear. The images were saved in a permanent memory of a pc which had windows 8 and 8GB of RAM. Image J software, is a powerful application to analyze the images. This app is able to statistically calculate the surface area and the chosen pixels of the images by the user (Azadbakht et al., 2014). Failure strain was calculated by dividing the amount of displacement (deformation) in the beginning of loading to the failure point from the early pod length. Modulus of elasticity was calculated by dividing failure stress from the failure strain. The obtained data was used for analysis in a completely randomized design with 20 replications using SAS software.

3 Results and discussions

The mechanical resistance depends on cellulosic compounds of the cell wall and composites that bind the cells together (Khazaie and Razavi, 2005). In Table 2, the results of variance analysis of mechanical properties of unbroken canola pod are observed.

Table 2 Results of variance analysis of mechanical properties of unbroken canola pod

Source of variation	**Failure Force (N)**	**Failure Stress (N/mm^2)**	**Deformation (mm)**	**Failure Strain (mm/mm)**	**Failure Energy (mJ)**	**Elastic Modulus (N/mm^2)**	**Toughness (mJ/mm^3)**
Moisture	0.48^{ns}	$7.1\times10^{-6\,ns}$	0.59^{*}	0.05^{*}	19.92^{*}	$3.78\times10^{-3\,ns}$	$5\times10^{-5\,ns}$
Variety	10.72^{ns}	$4.2\times10^{-4\,ns}$	0.81^{**}	0.10^{**}	0.07^{ns}	$2.63\times10^{-2\,**}$	$7.4\times10^{-6\,ns}$
Sampling Time	2.23^{ns}	$5.1\times10^{-5\,ns}$	0.67^{**}	0.06^{**}	4.5^{ns}	$6.89\times10^{-4\,ns}$	$1.5\times10^{-4\,*}$
Loaded Orientation	341.26^{**}	$2.6\times10^{-3\,**}$	0.003^{ns}	0.19^{**}	74.62^{**}	$1.1\times10^{-1\,**}$	$5.7\times10^{-4\,**}$
Variety × Time	26.21^{ns}	$2.7\times10^{-4\,ns}$	0.54^{**}	0.04^{**}	15.30^{*}	$1\times10^{-2\,**}$	$2.9\times10^{-5\,ns}$
Variety × Orientation	6.45^{ns}	$2.1\times10^{-4\,ns}$	0.05^{ns}	0.007^{ns}	0.41^{ns}	$9.1\times10^{-3\,*}$	$4.1\times10^{-6\,ns}$
Time × Orientation	16.82^{ns}	$2.7\times10^{-5\,ns}$	0.004^{ns}	0.0008^{ns}	5.91^{ns}	$1.7\times10^{-4\,ns}$	$5.2\times10^{-5\,ns}$
Error	17.85	1.3×10^{-4}	0.12	0.01	4.94	2.4×10^{-3}	1.3×10^{-4}

Note:** and * represent significant difference within probability level of 1% and 5% (LSD) ;ns represents the lack of significant difference

3.1 Failure force

As it can be seen in Table 2, changes in loading within probability level of 1% was effective on the failure force. Moisture, variety, and sampling time had no significant effect on failure force. Failure force was 6.11 N in horizontal loading and 10.15 N in vertical loading (Figure3). This might be because of the differences in pod`s tissue; it means that toughness and thickness of connectivity part of two pods are more than center of the pod which result in resistance to compressive forces (Ekinci et al., 2010). In the vertical force the force is inserted in pod`s connection. For this reason much more force is needed to break the pod and bounding and connection between the pods is stronger. In this section there is a layer between two empty pods which increase the strength. And in the horizontal direction the force is applied to the surface of the thin pod, and the failure and breaking happened with less force. This result is similar to the results obtained by Kermani (2009) in determining the physical and mechanical properties of hazelnut and its seed who observed that the failure force in line with the longest diameter is the highest and along the smallest diameter it is the lowest. Also, Gupta and Das (2000) observed in the failure resistance of the sunflower seeds in pressure loading that when the seed is placed under horizontal load, needs less pressure to skin them in the vertical load.

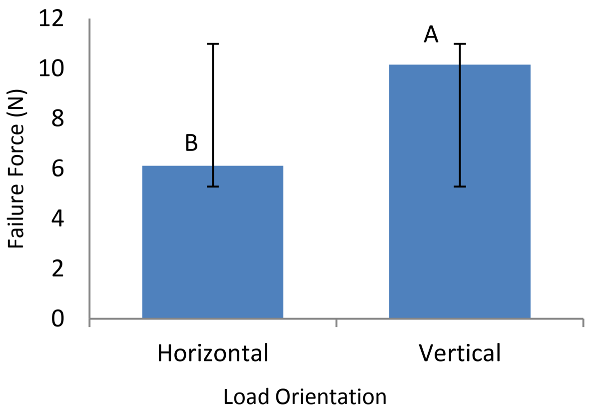

Figure 3Effect of loading on the failure force

3.2 Failure stress

In Table 2 it is shown that changes in loading direction will affect the failure stress at 1% probability level. But the effect of variety, moisture and sampling time were not significant on failure stress. Failure stress in horizontal loading was 0.0103 (N/mm^2) and in vertical loading it was 0.0215 (N/mm^2) (Figure 4). This result was also in vertical direction due to higher failure force and less surface area under the force.

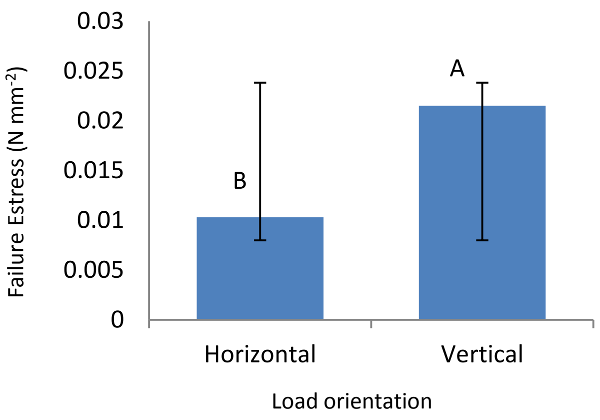

Figure 4 Effect of loading on failure stress

3.3 Deformation

Table 2 shows the change of moisture which is significant at 5% level and change of variety and time at 1% probability level on unbroken deformed pod. Loading direction had a significant effect on deformation. Also, the mutual effect was effective on deformation at 1% probability level. Therefore, comparison of the mean through LSD method and the results are stated in Table 3.

Table 3 Mutual effect of time and variety on deformation (mm) at the failure point

Sampling Time	Variety		
	Hyola 50	Hyola 401	Hyola 420
Before Harvest	0.94 ^{aA}	1.14 ^{aB}	0.95 ^{aA}
Harvest	1.02 ^{bA}	1.66 ^{aA}	0.87 ^{bA}
Post Harvest	0.72 ^{aA}	0.92 ^{aB}	0.94 ^{aA}

Note:Lower case letters in each row and upper case letters in each column represent no significant difference

Gupta and Das (2000) observed in the pressure loading of failure resistance of sunflower seed that with increasing moisture, sunflower skin deformation will increase, but about Hyola 401 as mentioned in Table 3 the most and the least amount of deformation in the failure point was 1.66 and 0.77 respectively in time levels of harvest and post-harvest and in Hyola 401 and Hyola 50.According to Figure 5, Hyola 50 and Hyola 420 had a relative reduction in the amount of deformation with passing sampling time. This result is similar to the one achieved by Kermani (2009) in determining physical and mechanical properties of hazelnut and its seed. He observed that with increasing moisture, deformation increases. The reason is that increased moisture due to skin softening causes increased deformation. Also with moisture reduction, deformation increased firstly and then it decreased. Increase in failure deformation might be because of viscoelastic tendency of the skin which caused the increased deformation under pressure (Fatollahzadeh and Rajabipour, 2008).

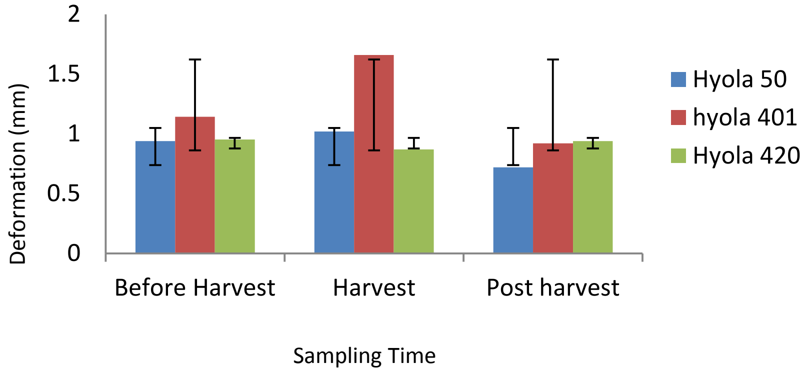

Figure 5 Mutual effects of varieties and sampling time on deformation at failure point

This result corresponds with ideas of Khazaie et al. (2005) which stated that increase in deformation ability of the seed is a key feature which prevents the fragmentation of seeds under loadings that is important regarding early harvest. Golmohammadi et al. (2013) investigated and studied the effect of moisture on some mechanical properties of three varieties of Pistachio; they observed that with decrease in moisture, the deformation increases. Therefore, Hyola 401 at harvest time, Hyola 50 and 420 at pre-harvest time are in good conditions for harvesting.

3.4 Strain at the failure point

As shown in Table 2, changes of moisture at the probability level of 5% were effective on strain at the failure point. Changes of canola varieties and sampling time and loading direction at probability level of 1% are effective on failure strain. Mutual effects of variety and time at probability level of 1% influence the failure strain. So, comparison of the mean was done according to LSD method and the results are stated in Table 4.

Table 4 Mutual effect of time and variety on failure strain (mm/mm)

Sampling Time	Variety		
	Hyola 50	Hyola 401	Hyola 420
Before Harvest	0.24[aA]	0.32[aAB]	0.24[aA]
Harvest	0.26[bA]	0.47[aA]	0.24[bA]
Post Harvest	0.18[aA]	0.26[aB]	0.25[aA]

Note:Lower case letters in each row and upper case letters in each column represent no significant difference

As shown in Table 4, the highest and the lowest amounts of failure strain are 0.47and 0.18 at harvest and post-harvest time in variety levels of Hyola 401 and 50. According to Figure 6, there weren`t any significant changes observed in Hyolavarieties of 50 and 420 in different times. Strain of Hyola 401 increases from pre-harvest to harvesting time and decreases until post-harvest.

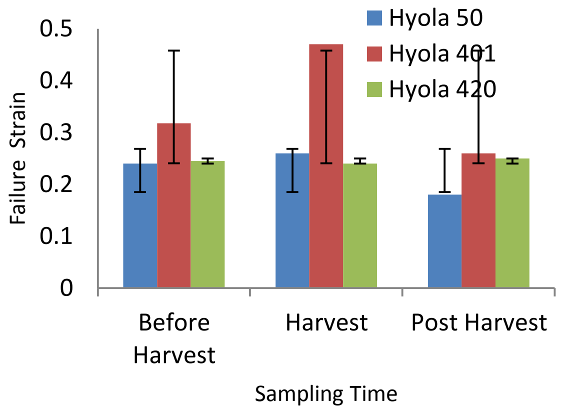

Figure 6 Mutual effects of variety and sampling time on strain at the failure point

According to Figure 7, failure strain was more in horizontal direction than vertical. Strain is defined as the comparison of length to the original length. Changes in length (Figure 7) showed no significant difference in various loadings, but the original length in horizontal loading is less than vertical loading. Then its strain is more and further.

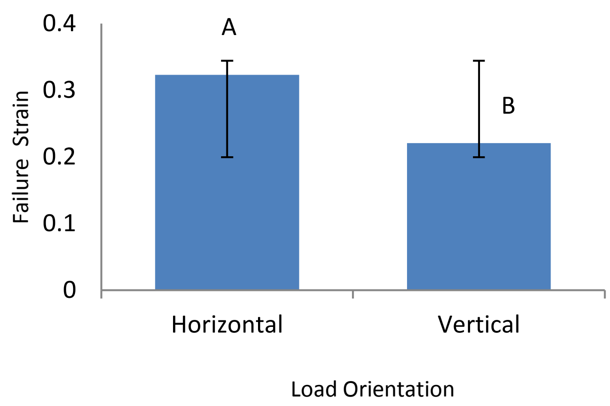

Figure 7 Effect of loading directions on failure strain

3.5 Failure energy

According to Table 2, moisture changes in probability level of 5% are significant on failure energy. Loading direction is effective on failure energy at probability level of 1% and mutual effect of varieties and time in probability level of 5% on failure energy. Therefore, mean comparison according to LSD method was done and the results are stated in Table 5.

Table 5 Mutual effect of time and variety on failure energy (mJ)

Sampling Time	Variety		
	Hyola 50	Hyola 401	Hyola 420
Before Harvest	4.25^{aA}	2.47^{aAB}	3.03^{aA}
Harvest	2.43^{aA}	5.14^{aA}	2.63^{aA}
Post Harvest	2.67^{aA}	1.98^{aB}	2.64^{aA}

Note:Lower case letters in each row and upper case letters in each column represent no significant difference

According to Table 5, the highest and the lowest amounts of failure energy are 1.98 and 5.14 mJ in harvest and post-harvest at variety levels of 401 Hyola. Considering that failure energy is the surface area below the force-deformation curve and it is highly influenced by these two factors and considering that time and variety had no significant effect on failure energy, it can be seen that Figure 8 regarding failure energy is similar to Figure 5 regarding pod deformation. This was similar to the results obtained by Alemi et al. (2010) in determining mechanical properties of soybean in quasi-static loading. They studied how energy increases with increase in moisture. Also Gupta and Das (2000) observed in failure resistance of sun flower seed in pressure loading that absorbed energy per unit volume of sun flower seeds increase with moisture rise. GharibZabedi et al. (2010) observed in investigation of physical, mechanical and nutritional properties of sesame in different moisture levels in order to improve the product process that with moisture increase, failure energy of sesame seed will increase due to higher resistance. The reason of pod`s stiffness increase is the state of lower moisture (Ekinci et al., 2010).

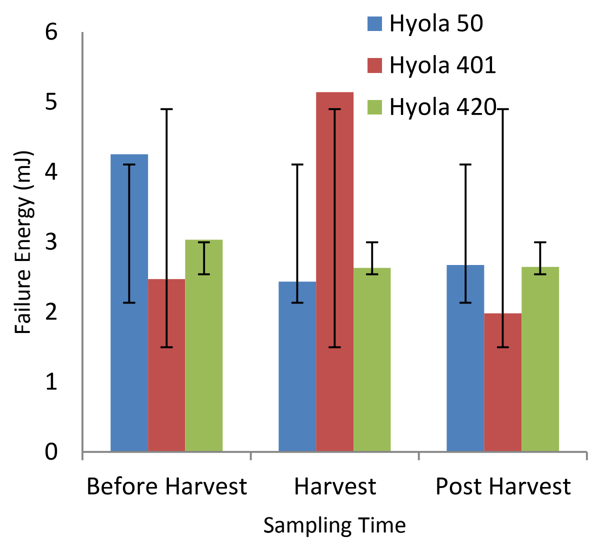

Figure 8 Mutual effects of variety and sampling time on force at failure point

As can be seen in Figure 9, failure energy in vertical direction is more than horizontal direction, failure energy in horizontal loading is 2.13 mJ and in vertical loading it is 3.94 mJ. This is because the failure force in vertical loading is more than horizontal loading.

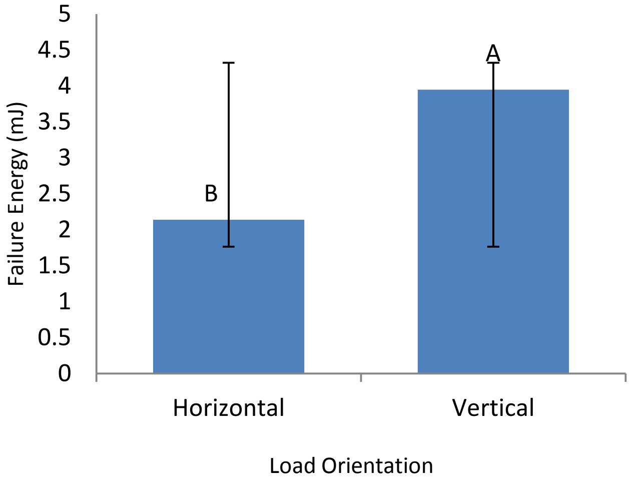

Figure 9 Loading direction on failure force

Gupta and Das (2000) observed in failure resistance of sun flower seed in pressure load that the seed absorb more energy in vertical loading.

3.6 Elasticity modulus

According to Table 2, changes of varieties and load directions in probability level of 1% were significant on elasticity modulus, however, moisture and sampling time were not effective on elasticity modulus, mutual effect of variety and sampling time is effective on elasticity modulus at 1% probability level and mutual effect of variety and loading direction is effective on it at 5% probability level. Therefore, the comparison of means according to LSD method was conducted and the results are shown in Table 6.

Table 6 Mutual effect of time and variety on elasticity modulus (N/mm^2)

Sampling Time	Variety		
	Hyola 50	Hyola 401	Hyola 420
Before Harvest	0.094^{aA}	0.048^{aA}	0.069^{aA}
Harvest	0.073^{aA}	0.032^{aA}	0.097^{aA}
Post Harvest	0.13^{aA}	0.035^{bB}	0.056^{abAB}

Note: Lower case letters in each row and upper case letters in each column represent no significant difference

According to Table 6, the highest and the lowest amounts of elasticity modulus are respectively 0.13 (N/mm^2) and 0.032 (N/mm^2) in time level of post-harvest and harvest and in variety levels of Hyola 50 and 401. The greatest difference in elasticity modulus is at post-harvest time. Alemi et al. (2010) in determining soybean`s mechanical properties and Ekcini et al. (2010) in studying effects of moisture and pressure on the mechanical properties of carob pod observed that with increasing soybean`s elasticity modulus decreases. According to Figure 10, in Hyola 50 and Hyola 401,at first elasticity modulus decreases and after harvest it increases along with decreasing moisture and increasing sampling time which this rise is more in Hyola 50 than 401. However, in Hyola 420, elasticity modulus increases firstly then it decreases with increasing sampling time.

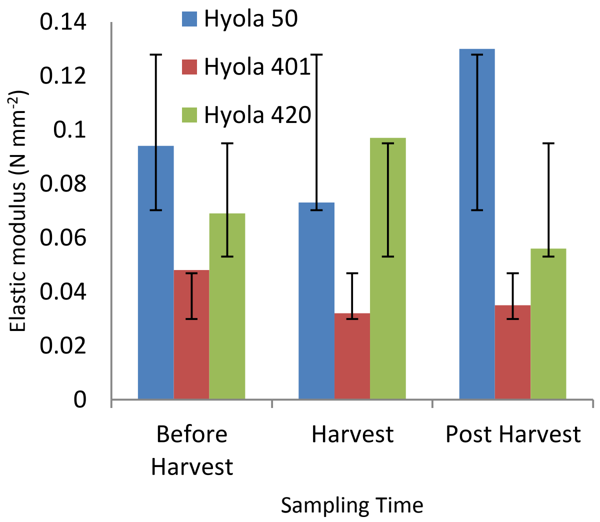

Figure 10 Mutual effects of variety and sampling time on elasticity modulus

According to Table 7, it is observed that the highest and the lowest amount of elasticity modulus respectively are 0.152 (N/mm^2) and 0.022 (N/mm^2) in vertical and horizontal loading direction in 50 and 401 Hyola of surface area. Modulus of elasticity does not have significant difference in small diameter`s direction in various varieties, however there is a significant difference in vertical loading direction in each three varieties or types, loading direction is effective on modulus of elasticity.

Table 7 Mutual effect of loading direction and variety on elasticity modulus (N/mm^2)

Sampling Time	Variety		
	Hyola 50	Hyola 401	Hyola 420
Before Harvest	0.094^{aA}	0.048^{aA}	0.069^{aA}
Harvest	0.073^{aA}	0.032^{aA}	0.097^{aA}
Post Harvest	0.13^{aA}	0.035^{bB}	0.056^{abAB}

Note: Lower case letters in each row and upper case letters in each column represent no significant difference*

In Figure 7 it is shown that with loading direction changes from horizontal to vertical, elasticity modulus increases. Elasticity modulus in Hyola 401 is less than other varieties and in Hyola 50 it is more. See Figure 11 please.

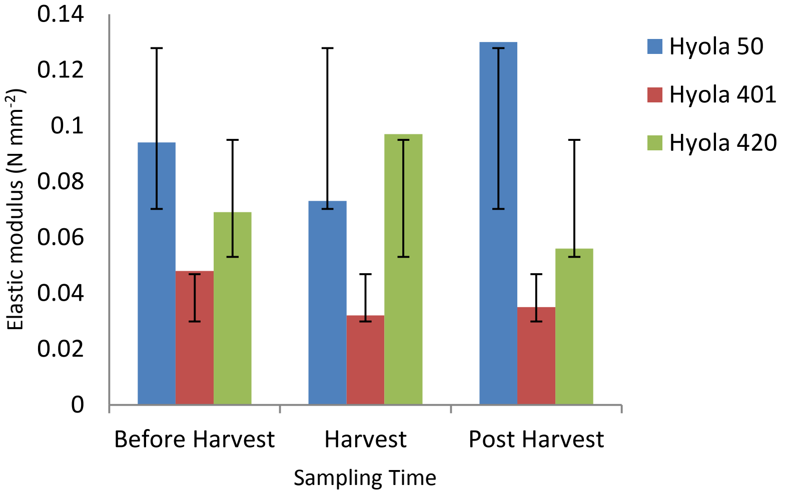

Figure 11 Mutual effects of varieties and loading direction on elasticity modulus

3.7 Toughness

As observed in Table 2, sampling time had significant effect on toughness at 5% probability level and also on one another effective factor was loading direction changes at 1%probability level. Variety and moisture had no significant effect on toughness. As can be seen in Figure 12, increasing the sampling time and reducing moisture at first enhanced the toughness and then after harvesting it highly reduced. Toughness in sampling time of pre-harvest was 0.0065, (mJ/mm^3) during harvesting it was 0.0093 (mJ/mm^3), and after harvesting it was 0.0046 (mJ/mm^3). Williamson and Lucas (1995) also observed in determination of moisture influence on mechanical properties of seed coat that with increased moisture, the toughness of shielding plates or surfaces reduced. Also Golmohammadi et al. (2013) observed in determining the effect of moisture on some mechanical properties of three varieties of Pistachio that decreasing moisture, the toughness increases.

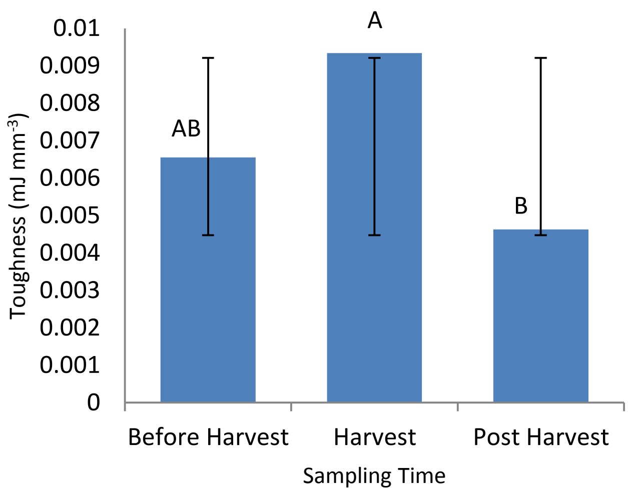

Figure 12 Effect of sampling time on toughness

According to Figure 13, toughness in vertical loading is significantly more effective than horizontal loading. Toughness was 0.0044 (mJ/mm^3) in horizontal loading and 0.0094 (mJ/mm^3) in vertical loading.

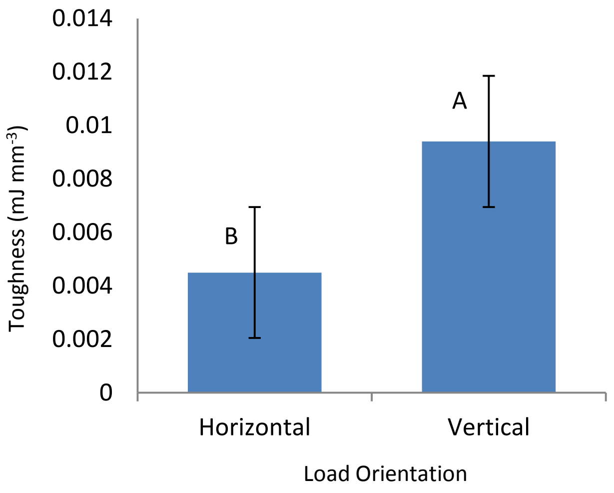

Figure 13 Effect of loading direction of toughness

Because the toughness had direct proportion to failure energy, its changes in loading directions are similar to failure energy and it is directly influenced by failure energy.

4 Conclusions

Failure force, stress, failure energy, and toughness were lower in horizontal loading and they were higher in vertical loading, therefore if the pods are horizontally placed under the force, lower amount of energy and force will be consumed. The highest amount of determination was in Hyola 401 at harvesting time and the lowest amount of it was in Hyola 50 at post-harvesting time when the pod`s deformation for failure is less, the damage to the seeds in the pods will also be less. So Hyola 50 and post-harvesting time is beneficent. The minimum failure strain was in Hyola 50 at post-harvesting time. Failure strain in horizontal loading was higher than vertical loading. Studying the failure energy, it was observed that the highest and the lowest amount of failure energy was in Hyola 401, but it was higher in harvesting time and lower in post-harvesting time. Therefore, postponing Hyola 401`s harvest caused consuming lower amount of energy. The highest amount of elasticity modulus in Hyola 50 was at harvesting time and in vertical direction while the lowest amount of that was in Hyola 401 at harvest time in horizontal loading direction. It can be considered that the mutual effect of variety and time had no significant effect on stress elasticity modulus increases with decreasing strain. The highest amount of toughness was at harvesting time.

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