*J. Appl. Environ. Biol. Sci.*, 7(11)157-164, 2017
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ISSN: 2090-4274
Journal of Applied Environmental and Biological Sciences
*www.textroad.com*

# Some Physical and Mechanical Properties of Bergamot (*Citrusaurantium*)

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*Received: March 23, 2017*
*Accepted: August 23, 2017*

**ABSTRACT**

By measuring the fruit physical and mechanical properties in both penetrate and compression tests, we can estimate the fruit ripeness and also study the fruit arrangement in ambient boxes to reduce the mechanical damages. In this study the effects of fruit size and load direction were investigated on some bergamot physical andmechanical properties. Strength properties of fruit were obtained by puncture and uni-xialcomperessiontest, with constant loading speed of 10mm/min. The experiment was performed as a factorial test based on completely randomized design. The results of analysis showed that the increasing in fruit size, was led to increase in fruit rind ratiowhile the moisture content was decreased. The fruit density was not affected by fruit size. In addition, according to the results, the fruit size effected on puncture energy, puncture force, rupture deformation and rupture hardness, significantly. The effect of load direction was significant on all mechanical properties except rupture force and rupture hardness. Themean values of puncture force for small, medium and large sizesof bergamot fruits were equal to 27.24N, 35.13N and 43.04N, respectively.
**KEYWORDS**: bergamot, physical and mechanical properties, fruit size, load direction, constant loading speed.

## 1. INTRODUCTION

Fresh fruits and vegetablesinclude citruses are part of human food diet from beginning of history, so they are very important parts ofagricultural products and also they are the important sources for the producing country economically. The reduce of fruits losses need to correct the producing and transportation systems, from garden to markets in order to deliver to the consumer with less losses in harvesting and after harvesting processes, finally. Fruits damages during harvesting and after harvesting operations specially, can increase the fruit losses and decrease fruit quality, which is not desirable economically. Bergamot (*Citrus×aurantium*) is produced plentiful in Iran andmany other outturns.

Iran bergamot production was reduced from 53026 tons to 52312 tonsduring 2008 to 2014 [1].Despite existing advanced packing installation in 5 cities in north of Iran including Ramsar, Shahsavar, Noshahr, Chalus and Amol for production and packing citruses, but unfortunately due to lack in physical and mechanical properties information of bergamot and also its producing processes in harvesting and after harvesting times, there is no progress in industrial production or fruit export and packaging yet. Due to these shortcomings, apparently favorable quality of fruit which is desirable in the market, has not been provided.

There are some researches in physical and mechanical properties of citruses and also bergamot that some of themare mentioned as bellow. Rafiee et al (2007) investigated and reported some physical parameters of three bergamot sizes which are used in fruit postharvest and storage systems designing. Their report includedsome bergamot physical properties such as fruit dimensions, volume, projected areas, density, rind ratio, geometrical mean diameter, sphericity, surface area, bulk density, porosity and packing coefficient. Their research results showed that the density of small, medium and big bergamot fruit sizes were 0.74, 0.66 and 0.62 $g.cm^{-3}$ respectively. In another research, Sharifi et al (2007), compared some physical properties of three orange sizes, they concluded that the fruit true density was decreased with increasing the fruit size. Also Topuz et al (2005) investigated the physical properties of four orange varieties. They reported the dimensions, volume, geometrical mean diameter, projected area, true density, bulk density, porosity, packing factor and friction coefficient of fruits. In their research Navel variety of oranges had the lowest rind ratio with the value of 22.95%. Tabatabaeefar et al (2000) investigated the physical properties of ten orange varieties and also they modeled the fruits mass based on dimenssions.

The most common practice to determine the fruit ripeness in field situation is pressing with ball of the thumb[13]. Respect to this traditional method, researchers have used the rigid cylindrical probe to determine the

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fruit firmness by investigating the fruits and vegetables force-deformation curve [3]. Thethree tests of Magness-Taylor, Unconfind Compression (UC)and Instron Universal Testing Machinewere used for agricultural product compression test Generally. The agricultural productsdeformation under comperession load, is useful for product desteructive process and the fruit firmness is a proper indicatorto estimate the fruit ripeness at harvesting time.

Singh and Reddy (2006) studied some orange Nagpur Mandarin variety physical and mechanical properties such as firmness and puncture force related to design and apply the handling, packaging, storage and transport systems. These properties have been studied during storage period in both refrigerator and ambient conditions. They also reported that orange peel tensile strength, moduls of elasticity and cutting energy decreased during the storage period and their observations also showed that the orange fruit firmness in stem-calyx axis was significantly higher than this parameter in inverse direction and puncture force decreased with increasing the storage time. The force-deformation curve behavior has been studied by Guzel and Sinn (1990). They found out that the relationship between force and deformation affected by the speed of loading. Floodetal (2006) tested the Valencia orange variety by Instron universal testing machine, they also found a correlation model of punch diameter and punch force. In their study, the conditions went to the plate condition when the punch diameter had increased. Also Pallottinoetal (2011) studied some mechanical properties of Tarocco orange variety in the condition of static loading with parallel plate (compression test). They also found that the rupture deformation increased by increasing the fruit size.

Dadvar, etal (2015) investigated the effects of fruit size, load direction and storage time on some physical and mechanical properties of orange (Var. Valencia). They found that the rupture force and deformation increased with increasing the fruit size and they also found out that the effect of load direction on rupture force was significant and the rind ratio and moisture content increased with increasing the fruit size but the true density decreased.

Literature review indicates thatthe most of researches on citrus fruits relate to oranges and hitherto there is no much researches on physical and spatially mechanical bergamot properties (*Citrus×aurantium*). This shows the lack of information in physical and mechanical properties of complete bergamot fruit. So the aim of present research is investigating some physical and mechanical properties of complete bergamot fruit which are used in increasing the fruit acceptability, also designing and optimizing the storage and transportation systems due to reducethe losses. To reach this aim, in this present paper the effect of fruit size on bergamot physical properties (mass, volume, true density, rind ratio and moisture content) was investigated. In addition to the above factor, the effect of load direction on complete bergamot fruit mechanical properties (puncture force, puncture deformation, puncture energy, puncture hardness, rupture force, rupture deformation, rupture energy, rupture hardness and toughness) in quasi static penetrate and compression test were investigated.

## 2. MATERIALS AND METHODS

After preparing the unscathed samples from Shahsavar city in north of Iran in three sizes (small, medium and big) with the average mass of 79.05g, 104g and 139.5g respectively, the sampleswere transfered to arefrigerator at 5°C tempreture and 85%-90% humidity immediately and then they also were tested in a labratoar with the 20°C tempreture condition after 2 days remaining in the mentioned refrigerator.

### *2.1. Physical properties:*

Fruits mass has been measured by a blanace with 0.1gram accuracy and also their volume has been measured by this balance using the water displacement method. The weight of displaced water expresses the fruit volume [8].

$$V = \frac{M_d}{\rho_w} \tag{1}$$

Where V is bergamot fruit volume ($cm^3$), $M_d$ is displacement water mass (g) which is measured by the balance after fruit submerging in water and $\rho_w$ is water density ($g.cm^{-3}$) which may change with changing in water temperature.

Bergamot fruit true density was obtained from the below equation [8]:

$$\rho = \frac{M}{V} \tag{2}$$

In this equation ρ, M and V are fruit true density($g/cm^3$), mass(g) and volume($cm^3$) respectively.

Rind ratio is calculated from the below equation [12]:

$$R_s = \frac{M_s}{M_f} \times 100 \tag{3}$$

Where: $R_s$ is rind ratio (%), $M_s$ is fruit rind mass(g) (every albedo and flavedo parts of fruit rind) and $M_f$ is complete fruit mass (g) [16].

Moisture content is obtained from the following equation:

$$\mathrm{M.C.} = \frac{\mathrm{M} - \mathrm{M_d}}{\mathrm{M}} \times 100 \quad (4)$$

Where: M.C. is fruit moisture content(%), M is the fruit mass(g) and $M_d$ is the dried fruit mass(g) [8]. For drying the bergamot fruits the Shimifan drier which was made in Iran, was used. Thefruits were dried in this drier for 48 hours remaining in, with the 60 °C tempreture degree [14].

*1.1. Mechanical properties:*

Penetrate andcompression tests were done by the cylindrical probe and with tabulate parallel plates respectively. For all tests the tension-pressure machine, Z250 model, made in Germany were used which had the 2500N load cell and 0.00001 N accuracy. All mechanical tests were done under pressure load of 10 $mm.min^{-1}$ speed, according to American Society of Agricultural Engineering Standards [2].

In every two mechanical tests the tension-pressure machine's upper arm motion to below for apply the pressure force on complete bergamot fruit with cylindrical prob in penetrate tests (Figure1) and parallel plates in compression tests, continued up to make the first split in fruit rind. Note that: the machinefelt the loss in pressure force after fruit rind split, automatically and mentioned upper arm went back up inversely then the destructivefruit sample has been replaced with the new sample to begin the new test. In all tests the force-deformation curve data could be observed on the computer manitor of test machine and the machine computer gave us these data in the form ofExcel files for analyzing. The values of energy and maximum force in each test has been shown in the top of these files and force-deformation diagram could be drawn by the excel software as shown in figure 1. In this diagram the maximum force indicats the rupture force or puncture force and the equivalent deformation to this maximum force indicats the rupture deformation or puncture deformation respectively. The areaunder this diagram up to maximum force indicats the rupture energy or puncture energy.
Rupture hardness or puncture hardness (N/m) were calculated from equation 5 [8].

$$H = \frac{F_u}{D_u} \quad (5)$$

Where $F_u$ is rupture force or puncture force (N) and $D_u$ is rupture deformation or puncture deformation (mm)
Fruit toughness (in compression test) was obtained from equation 6 [8].

$$T = \frac{W_u}{V} \quad (6)$$

Where $W_u$(N.m) is rupture energy which was obtained from compression test with parallel plate, V ($m^3$) is complete fruit volume which was measured before mechanical tests by equation 1.

Mechanical tests were done in longitude and transvers loading directions. Longitude load direction test was done when the force vector was parallel to the stem to blossom direction. inverse loadwas performed in perpendicular direction to longitudinal loading.

For penetrate test the 8 mm diameter cylindrical prob with 25 mm curvature radios at the end was used [2]but in compression tests two parallel palates were used to apply the compress force. The lower plate was a 30 cm diameter flat circular fixed plate of the device and upper grip was a similar plate with a diameter of 10 cm, parallel and movable.

*2.2. Statistical analysis:*

To provide information on the physical and mechanical properties of whole bergamot fruits, the factorial experiments in the form of randomized design with 20 replications for determining mass, volume and true density, and 5 replications for determining rind ratio and moisture content and mechanical properties (puncture force, puncture deformation, puncture energy, puncture hardness, rupture force, rupture deformation, rupture energy, rupture hardness and rupture toughness)were used and the effects of size in three levels (small, medium and large) on physical parameters and above that factor the load direction in two levels(longitude and transverse direction) on the mechanical properties of bergamot were studied. All calculations, data analysis and Duncan test comparisons were performed with MSTATC software.

## 3. RESULTS AND DISCUSSION

*3.1. The results of bergamout physical properties:*

The results of bergamot physical properties analysis of variance presented in table 1 and the avrages comparing results of significant factors is shown in table 2. The results of variance analysis showed that the fruit size factor on mass, volume and moisture content values was significant at 1% level and also the effect of this factor also was significant on rind ratio at 5% level but it was not significant on fruit true density. So as shown in table 2, we can conclude that bergamot true density does not change with changing in fruit size but fruit rind ratio increases and fruit moisture content decreases with increasing the bergamot fruit sizes. The rind ratio averages for small, medium and big sizes of bergamot fruits were 32.58%, 35.67% and 38.56% respectively, which are much less than the research results of Rafieeetal (2007) who obtained the average of 62% for this physical parameter. This difference in two groups values may be because of the type of this agricultural product, which exist much dispersion in its physical properties even grown in one place. This result is in disagreement with the research result of Sharifietal (2007) and Dadvaretal (2015) about orange true density too, wihch may because of difference between orange fruit and bergamot fuits.They found out that the orange true density decreased with increasing the fruit size and the rind ratio increased. Therefor the bergamot true density is not changed by changing in this fruit size. The result of the present paper is in agreement with the above mentioned researches about rind ratio.

To discuss this result we should express that according to table 1 and table 2, it can be seen that there is no difference between three fruit sizes in order to true density, whereas the rind ratio increases and moisture content decreases with increasing fruit size. It can be concluded that the ratio of fruit mass to fruit volume in every size is constant, concerning equation 2, therefor in bigger volume size the mass is bigger proportional to fruit volume too. Considering that in bigger size of fruits the rind ratio is bigger and the moisture content is smaller proportional to the fruit mass, so can be concluded that with regard to decreas in fruit moisture content and increase in rind ratio by increasing the fruit size, the rind mass is more increased comparing with decresing in fruit moisture concerning equations 3 and 4. In other word the difference in mass of two different bergamot fruit sizes is more than the difference in moisture of these two bergamot groups. This concolusion may be very important in extraction of some useful materials from bergamot rind.

It is observed in tables 1 and 2 that the true density does not change by increasing the fruit size but the rind ratio and moisture content decreased. According to the equation 2 can be concluded that the ratio of fruit mass to its volume in each fruit size is constant, therefore by increasing volume in bigger sizes of fruits the mass of fruit is also increasing. In the other hand, regarding to increases in rind ratio and decreases in moisture content in bigger mass and volume proportional to it in bigger sizes, can be concluded that although we observe a decrease in moisture content, but an increase in rind ratio. In the other word according to equations 3 and 4, by increasing in fruit size, the rate of increasing in rind ratio is more than the rate of decreasing in fruit moisture content. It means that the rind mass differences in different sizes is bigger than the moisture differences in these fruits. This result is very important in extracting the bergamote rind materials.

With respect to significant effect of fruit size on bergamot moisture content at level 1%, and by comparing the averages of this physical parameter in all three fruit sizes we can conclude that the bergamot moisture content decreased with increasing the fruit size (table 2). The moisture content averages values for small, medium and big sizes ofbergamot fruit were 83.25%, 81.03% and 79.93% respectively. This paper result is in agreement with the result of bergamot fruit result in Rafieeetal (2007) research.

***Table 1.* Analysis of variance results of fruit size effect on bergamot physical properties.**

| Sources | Degrees of freedom | Mean Square | | | | |
|---|---|---|---|---|---|---|
| | | Mass | Volume | True Density | Rind Ratio | Moisture Content |
| **Fruit size A** | 2 | 339.862$^{**}$ | 27679.670$^{**}$ | 0.006$^{ns}$ | 44.741$^{*}$ | 14.372$^{**}$ |
| **Coefficient of Variation (%)** | | 17.15 | 13.79 | 14.70 | 6.94 | 1.44 |
| ***significant difference at level 5%, **significant difference at level 1% , ns means no significant.** | | | | | | |

***Table2.* Results of size effect on bergamot physical properties**

| Physical Properties | Bergamot fruit sizes | | | |
|---|---|---|---|---|
| | Small | Medium | Big | LSD Values |
| **Mass (g)** | 79.05 a | 104.00 b | 139.50 c | 15.81 |
| **Volume ($cm^3$)** | 92.80 a | 126.9 b | 167.1 c | 15.25 |
| **Rind Ratio (%)** | 32.58 b | 35.67 ab | 38.56 a | 3.603 |
| **Moisture content (%)** | 83.25 a | 81.03 ab | 79.93 b | 2.488 |

According to Table 2, the mass and volume of larger fruit sizes are differently biger than those in smaller sizes of fruits. This conclusion is very obvious and also is agree with many researches [4, 12]. Rindratio in bigerfruit sizes is higher than this parameter in smaller ones and moisture content is increased with decreasing the fruit size (see table 2), which is agree with the study results of Dadvar et al, 2015 and Sharifi et al, 2007 in order to rind ratio but is in disagree with those study in order to moisture content. They found out that the moisture content in Valencia variety of oranges were increased with increasing the fruit size. This result disagreement may be because of the difference between orange fruit and bergamote fruit.

Aslso according to table1 there is no difference between fruit true density in all sizes which is in disagreement with many reaserches results which state that the fruit true density is decreased with increasing the fruit size [5,12,10]. This cocluded that the bergamot fruit dispersion in properties is so high and because of this, it is definitely different from other citruse fruits.

*3.2. The results of bergamout mechanical properties:*

Studying the force-deformation diagram procedure narrate the approximate linear curves as shown in Figure1 which was confirmed by the test observations. This shows that the bergamot fruit is elastic under quasi static load.

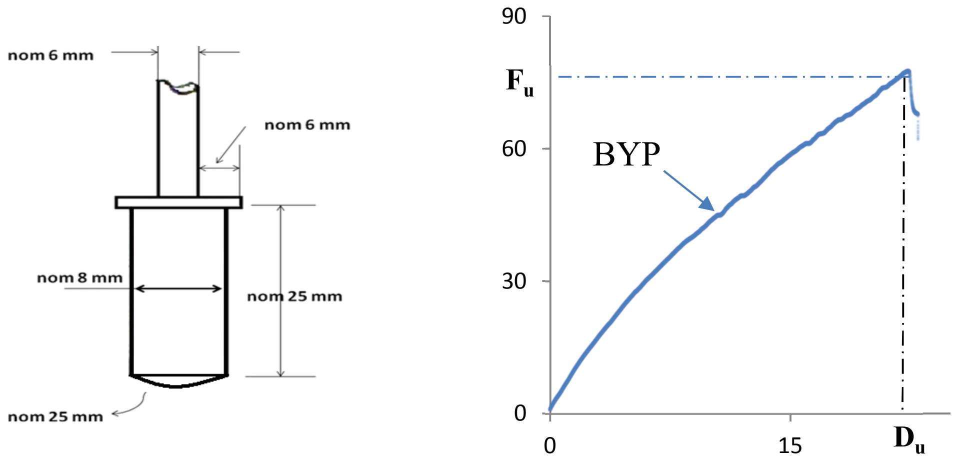


***Fig 1.* Complete bergamot Force-Deformation diagram in quasi static load (Right) and chematic cylindrical probe for penetrat test (Left)**

*3.2.1 Comperession test results with parallel plats*

To study the effects of fruit size, load direction and also these factors interactiveon bergamot fruit mechanical rupture parameters (rupture force, rupture energy, toughness and hardness), the tests data analysis of variance was determined and reported in table 3. Also the results of bergamot mechanical propertiesaverages comparisonwere presented in table 4.

***Table3*. Analysis of variance results of fruit size and load direction effects on bergamot mechanical properties in compression test with parallel palats.**

| Sources | Degrees Of freedom | Mean Square | | | | |
|---|---|---|---|---|---|---|
| | | Rupture Hardness (N/m) | Toughness (N/m$^2$) | Rupture Energy (N.m) | Rupture Deformation (mm) | Rupture Force (N) |
| Fruit size (A) | 2 | 900161.483 $^{*}$ | 0.042 $^{ns}$ | 0.073 $^{ns}$ | 130.675 $^{**}$ | 211.446 $^{ns}$ |
| Load Direction (B) | 1 | 410670.571 $^{ns}$ | 0.183 $^{*}$ | 0.365 $^{**}$ | 248.564 $^{**}$ | 256.747 $^{ns}$ |
| A×B | 2 | 271898.665 $^{ns}$ | 0.095 $^{*}$ | 0.098 $^{ns}$ | 54.704 $^{ns}$ | 293.655 $^{ns}$ |
| Coefficient ofVariation (%) | _ | 23.96 | 29.76 | 27.41 | 16.98 | 20.52 |

*significant difference at level 5%, **significant difference at level 1%, ns means no significant.

Analysis of variance results of data were showed that none of size and load direction factors on bergamot rupture force was significant. Because of nonsignificant interaction effects on bergamot rupture force, we can conclude that there is no difference between three fruit sizes with respect to rupture force.

***Table4*. Results of bergamot fruit mechanical properties averages in compression test with parallel plates**

| | Bergamot size | | | LSD Value | Load Direction | |
|---|---|---|---|---|---|---|
| | Small | Mediume | Big | | Longitude | Transvers |
| **Rupture Deformation (mm)** | 20.39 b | 24.80 ab | 27.56 a | 5.150 | 21.37 b | 27.13 a |
| **Rupture Energy (N.m)** | | | | | 0.552 b | 0.772 a |
| **Rupture Hardness (N/m)** | 2255.66 a | 2164.61 a | 1696.49 b | 491.0 | | |

Also table 3 shows that the effects of main factors of fruit size and load direction on rupture deformation is significant at level 1%, but the intraction effect of fruit size and load direction doesn't show significant difference on this bergamot mechanical parameter. So it can be concluded that the effect of fruit size is significant on rupture deformation in every two load directions similarly, and according to table 4 the rupture deformation increases with increasing the fruit sizesignificantly. This bergamot mechanical property is significantly higher in transvers load direction than the other one. This Significanteffect of fruit size on bergamot rupture deformation in all two load directions, is in agreement with many researchs result on agricultural products. [4,9, 11]. Dadvaretal (2015) expressed that the reason of this result in order to orange rupture deformation may be because of orange issue prosity. Also this direct relationship between fruit size and its rupture deformation is in agreement with Hertz theory [11].

According to table 3, only the effect of load direction was significant on rupture energy at level 1%. Table4 shows that, the rupture energy in transvers load direction issignificantly higher than this mechanical parameter in longititud load direction in all three bergamot fruit sizes. This point can be useful for estimating the consumed energy or minimizing it in extracting fruit juice.

The results of toughness averages comparing the bergamot fruit size and load direction interaction effect were presented in table 5.

***Table5*. Results of size and load direction interactive effect averages comparing on bergamot Toughness (LSD=0.2145)**

| | Bergamot size | Small | Medium | Big |
|---|---|---|---|---|
| **Load Direction** | | | | |
| **Longititude** | | 0.4238 b | 0.6203 ab | 0.3915 b |
| **Inverse** | | 0.7613 a | 0.5711 ab | 0.5720 ab |

As the table 3 shows the effect of bergamot fruit size is not significant on this fruit toughness but the load direction effect and also the interaction of fruit size and load direction is significant on this mechanical parameterat level 1%. So by comparing the toughness average in each fruit size we can conclude that the effect of load direction in small size of bergamot shows the larger difference on bergamot fruit toughness (table 5). In other word, the energy for different fruit sizes can be estimated by volume value information and considering the fruit size in each load direction and also considering the equation 6. This point is useful for estimating the energy value for every fruit size and in every load direction. Also it can be observed frome table 5 that there is no difference between toughness of small and big fruit sizes in longititude load direction, but in inverse load direction medium and big fruit sizes are not significantly different from each other in order to fruit toughness.

Also we can find out from table 3 that only the bergamot size factor on rupture hardness is significant at level 5%. By referring to the table 4 it is indicated that the bergamot rupture hardness is significantly decreased by increasing the fruit size.Note that: fruit hardness decreased with increasing the fruit size and it is significantly higher in fruit big size than those two other sizes which are not significantly different in order to this mechanical parameter.This result can be explained by looking at equation 5 and also the significant bergamot size effect on rupture deformation and nonsignificant effect of this factor on rupture force. This result is in agreement with the result of Pallottinoetal (2011) and also Dadvaretal (2015) about orange fruit. They also found out that the rupture deformation was increased with increasing the fruit size.

### *3.2.2. Penetrate test results with cylindrical probe*

Analysis of variance results for bergamot mechanical properties in penetrate test with cylindrical probe are presented in table 6.

***Table 6*. Analysis of variance results of bergamot mechanical properties in penetrate test**

| Source | Degrees of freedom | Mean Square | | | |
|---|---|---|---|---|---|
| | | Puncture Force | Puncture Deformation | Puncture Energy | Puncture Hardness |
| Bergamot size | 2 | 623.395 * | 18.898 $^{ns}$ | 0.156** | 998100.078$^{ns}$ |
| Load Direction | 1 | 8596.560** | 226.544** | 1.178** | 16332881.692** |
| Size × Direction | 2 | 619.520* | 21.370 $^{ns}$ | 0.138** | 979150.578$^{ns}$ |
| Coefficient of Variation (%) | | 31.71 | 20.60 | 44.29 | 28.27 |
| ***significant difference at level 5%, **significant difference at level 1% , ns means no significant.** | | | | | |

It is found from table6 that only the effect of load direction main factor on all mechanical properties inpenetrate test include: bergamot puncture force, puncture deformation, puncture energy and puncture hardness was significant at 1% level. With respect to the nonsignificantly effects of fruit size factor and also intraction of factors on puncture deformation and puncture hardness, soby comparing the average values of bergamot puncture deformation and puncture hardness, we can conclude that the values of the mentioned mechanical parameters in longitude direction is bigger than these values in transvers direction (table7).

***Table 7.*** **Puncture deformation and hardness averages comparision in penetration test with cylindrical probe**

| Load Direction | Puncture Deformation (mm) | Puncture Hardness (N/m) |
|---|---|---|
| **Longitud** | 14.20 a | 3628.07 a |
| **Transvers** | 8.71 b | 2152.36 b |

This result is in agreement with the result of Singh and Reddy research (2006). This result may be due to thickness of the rind in orange and bergamot blossom (the connecting point of bergamot fruit and the branch on the tree) in compare with the other part of fruit. So for harvesting this hortical product by robot fingers or human hand, it is beter to apply fingers force in longitude direction.

Also it is clear from table 6 that the effects of main factors of fruit size and load direction and these factorsintractive on puncture force and puncture energy are significant at level 5% and 1% respectively. In figure 2 the interaction effect of fruit size and load direction on puncture force and energy is shown. We can conclude from figure 2 that puncture force and puncture energy are increased with increasing fruit size and the magnitudes of these two mechanical parameters are significantly higher in axial loading than those inthe inverse direction. in addition, it seems that loading direction has differenteffects in different fruit size in order to these mechanical parameters, therefore the interacting effect of loading direction and fruit size should be considered in the analysis.

Also it is observed in figure 2 that puncture energy and puncture force changes for big sizes of fruitsin all two load directions, are higher than this changes in small and medium fruit sizes. With respect to the puncture force and puncture energy higer magnitudes in longitude direction than the inverse, it is better to design the bergamot harvest machinewhich apply fruit forces in longitude direction to reduce fruit rind interruption and final product wastage.

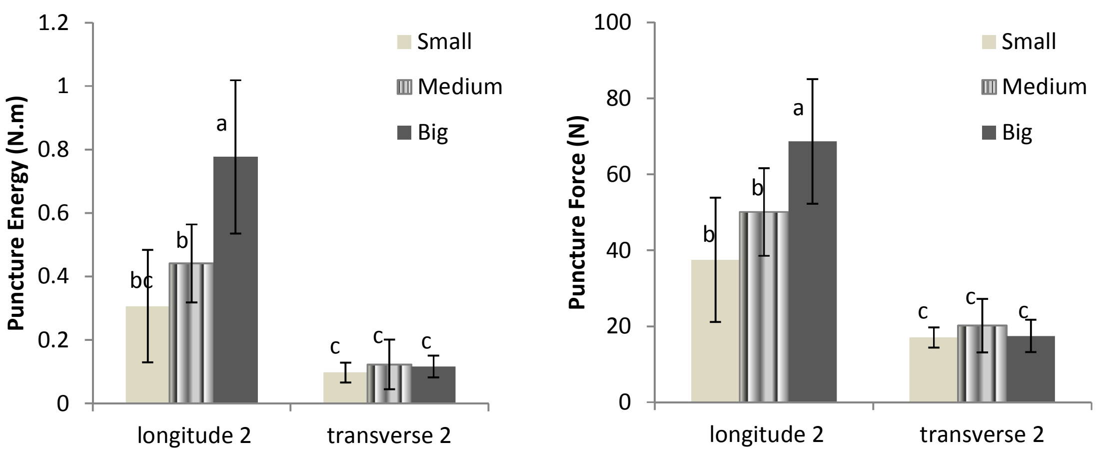


***Fig 2.*** **Results of size and load direction interactive effects averages comparing on bergamot puncture force (Duncan at level 5%, LSD=14.54 Right) and puncture energy (Duncan at level 1%, LSD=0.2438 Left)**

It is also observed in figure 2 that there is no difference between three bergamot fruit sizes in puncture force and puncture energy in inverse load direction. In longitude direction for puncture force and energy there is no difference between small and medium sizes of bergamot fruits but these mechanical parameters in big fruit sizes are significantly higher than these parameters in two other sizes in longitude load direction (significant level are 1% and 5% for puncture energy and force respectively).

## 4. CONCLUSION

Results of thisresearch shown that bergamot rind ratio increased with fruit size increasing but the moisture content decreased and there is no difference between every three bergamot sizes in true densitywhich is cocluded that the bergamot fruit dispersion in properties is so high and because of this, is definitely different from other citruse fruits as bergamot fruits which are grown in different area and trees.Also Studying the force-deformation diagram procedure as shown in Figure1 narrates approximate linear curve which was confirmed by the test observations. This phenomenon shows that the bergamot fruit is elastic under quasi static load. On the other hand, the curves nonlinearity is because of fruit geometric deformation during loading. Also the effects of fruit size and load direction on its puncture force, puncture deformation, puncture energy, puncture hardness, rupture force, rupture deformation, rupture energy, rupture hardness and rupture toughness in quasi static load were investigated. The results showed that the effect of bergamot size on puncture energy, puncture force, rupture deformation and rupture hardness was significant. Meanwhile the effect of load direction on all mechanical properties in every two tests except rupture force and rupture hardness was significant. Itis finally found that fordecreasing the fruit losses during bergamot harvesting with robot fingers, we suggeste that the finger forces should be applied in longitude direction, and in order to decrease the consumed energy in process of taking fruit juice, it is better to apply compression force by the plate in transvers direction.

## 5. Acknowledgment

Authors would like to express their sincere gratitude for tremendous help of Mr. YaghoubMohammadalian, head of the Khoramabad Citrus Reasearch Station of Shahsavar city in the north of Iran, for preparation of bergamots for this research.

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