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Evaluation of orange mechanical damage during packaging by study of changes in firmness

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Abstract

Mechanical damage during packaging can be determined by study of firmness changes of fruit. In this research, to simulate static and dynamic loads, the four deformations (0, 9, 18 and 27% of the major diameter) with the four compression rates (0, 25, 250 and 500 mm/min) were conducted on oranges (*Citrus sinensis* var. Egyptian Valencia). A statistical factorial experiments in the form of completely randomize design (4×4) was applied to show the effects of these treatments on firmness in different regions of orange carpel. It is found that the compression rates did not have a significant effect on the firmness of the orange carpel. Also the oranges firmness for 9% deformation did not indicate significant difference with control samples (zero deformation).

Introduction

Orange is important part of sale in Iran fruit market (Khanali *et al*., 2007; Sharifi *et al*., 2007). Any treatment on a fruit must be compatible with its physical and mechanical properties. Someone studied physical and biochemical properties of some tropical fruits that are essential in design of harvesting and post-harvesting process machines (Ozturk *et al*., 2010; Athmaselvi *et al*., 2014). Mechanical properties of fruit are also essential in study of interaction between fruits and machines. The reaction of a fruit to mechanical damage is important, especially for fresh fruit consumption. Oranges may be more resistant during packaging compared to other fruits; therefore, there is less concern in citrus fruits packaging to avoid mechanical damages (Montero *et al*., 2009). In addition, mechanical damage cause unfavorable changes in color, flavor and shelf life (Durigan *et al*., 2005) and reduction in the vitamin C content of orange (Lee and Kader, 2000). Appearance and firmness are two primary parameters to evaluate the overall orange quality (Fekete, 1994). Unlike fruits with soft peel such as apples, orange does not blurt obvious changes to mechanical damage in appearance. Montero *et al.* (2009) reported that the impact on two varieties of tangerine *(Citrus tangerine)* had no effect on the appearance change yet reduced the ascorbic acid content and increased the sugar content. Therefore desirable mechanical treatment including that does not have harmful effect on the appearance, internal texture, flavor and nutrients of the fruit.

We reviewed studies concerning the mechanical treatment on orange. Moresi *et al.* (2012) used the stress-relaxation test to determine the maximum strain without the permanent deformation in orange fruit (*Citrus sinensis* var. Tarocco). The permanent deformation can decrease the marketability of orange fruit. Also impact has been investigated as an important and abundant event during the packaging process on Valencia oranges and tangerine (*Citrus tangerine* var. Murcott) (Fischer *et al*., 2009). It has also been examined with instrumented sphere to determine the critical point of the packaging line (Garcia−Ramos *et al*., 2004). Impact and shear create more changes in appearance and chemical composition of orange (Durigan *et al*., 2005). According to the reports of many researchers (Garcia−Ramos *et al.*, 2004; Durigan *et al*., 2005; Montero *et al*., 2009), the impact and shear loads were more destructive than the compression load, therefore it is resulted to use more compression treatment in packaging processes without any damage. Compression test was one of methods for testing the quality of fruits (Hebda and Złobecki, 2013) but because of the few number of researches performed in this area, we cannot refer to any appropriate standard for the compression level.

Firmness of fruits is used as a useful indicator of fruit decay (DeLong *et al*., 2000; Dobrzański *et*

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al., 2000; Singh and Reddy, 2006; Pallottino *et al.*, 2011). Much research has been carried out in order to find effect of pre-harvest and postharvest treatments on the firmness of orange (Coggins, 1969; Porat *et al.*, 1999; Fidelibus *et al.*, 2002). Firmness can be measured directly through the Magness–Taylor (MT) test that indicates the peak force at the rupture point or through the elastic modulus as an index of product firmness (Shmulevich *et al.*, 2003; Singh and Reddy, 2006; Pallottino *et al.*, 2011). The firmness of cherry was measured by the portable instrument for the four bruise treatments. The results show the system is capable of distinguishing between bruise treatments (Timm *et al.*, 1996). In this study pre-deformation treatment was considered as an important factor in packaging process that could affect on firmness of fruit. The objectives of this research were to determine the maximum allowable deformation without internal damage during orange packaging. Also we try to find the regions of fruits that more internal damage was occurred.

Materials and Methods

Fruit samples

A number of 36 oranges (*Citrus sinensis* var. Egyptian Valencia) were provided. They had normal appearances and without any defects in different parts of the orange structure. All experiments were performed at room temperature (25°C) within a day. A number of 9 oranges were regarded as the control samples and the other 27 ones were used in the experimental design.

Compression treatments

Deformations and compression rates were selected as the independent variables in a completely randomized design. The deformations were selected as four levels of 0 (control), 9, 18 and 27% of the major diameter perpendicular to the stem axis of orange. The compression rate was applied in four levels of 0 (control), 25, 250 and 500 mm/min. High compression rate can increase the rate of operation during packaging. The compression tests were performed as loading and unloading steps to obtain the difference between the areas under the curves. Two-way analysis of variance (ANOVA) was performed on ranks at the confidence level of 95% ($p < 0.05$). H5K-S UTM Bench top Materials Tester was used and equipped with two circle plates with the diameter of 90 mm which were larger than the major diameter of the tested oranges. The stem axis of the samples was perpendicular to the direction of compression.

Table 1. Variance analysis of energy absorption

Source	Sum of Squares	df	Mean Squares	F
Pre-deformation (A)	4.791	2	2.396	129.191^{*}
Rate (B)	.003	2	.001	$.069^{ns}$
A * B	.044	4	.011	$.599^{ns}$
Error	.334	18	.019	
Total	11.158	26		

*Significant at 5% level of significance

Firmness measurement

Based on the orange anatomy that is comprised of carpel, albedo and flavedo, the damage can occur in any of these parts. Since our goal was to consider the internal changes, our orange samples were peeled so that the probe could directly penetrate to the carpel. The tests were performed by the probe with 8 mm of diameter and 25 mm/min of rate. Two points of each fruit were considered for the penetration test. The first point was exactly under and center of the compression area and the second one was 90 degrees different from the first one so that the orange could deform freely.

Some specific forces corresponding to penetration such as yield and maximum point can be selected as the firmness index. Since the peel tissues are different in various oranges, the puncture force cannot be the index of firmness (Moresi *et al.*, 2012). Researchers selected different depths of probe penetration as the firmness index; for example, 10 mm for Powell Summer Navel variety of orange (Sanchez *et al.*, 2013), 20% deformation for unripe oranges and lemons *(Citrus limon)* (Katsiferis *et al*., 2008), 20 mm for oranges (*Citrus sinensis* var. Tarocco Arcimusa) (Menesattia *et al*., 2009), maximum force without depth consideration for Shamouti oranges (Porat *et al.*, 1999) and 10 mm for Mandarin orange (*Citrus reticulate* var. Nagpur) (Singh and Reddy, 2006). In this study, depths of 3, 6, 9 and 12 mm were selected for the determination of the appropriate depth. Results were analyzed with the IBM SPSS Statistics 20 software.

Results and Discussion

The amount of absorbed energy between the two steps of loading and unloading indicates the plastic work and mechanical damage for an object. Based on the obtained results (Table 1), only the amount of compression affected the absorbed energy. The energy absorption was rapidly increased with respect to the level of compression and it indicates the internal injury because of more energy absorption with increased compression.

Table 2 shows the results of ANOVA for firmness in 3, 6, 9 and 12 mm depths in the compressed and

Table 2. Variance Analysis of firmness in different depths

Source		F value							
		compression area				uncompressed area			
	Df	3	6	9	12	3	6	9	12
Pre-deformation (A)	2	2.508^{ns}	5.609^{*}	4.097^{*}	0.870^{ns}	6.062^{*}	12.270^{*}	14.093^{*}	10.282^{*}
Rate (B)	2	0.206^{ns}	0.685^{ns}	0.517^{ns}	1.114^{ns}	0.679^{ns}	0.575^{ns}	0.340^{ns}	0.409^{ns}
A*B	4	0.566^{ns}	0.653^{ns}	0.354^{ns}	0.548^{ns}	0.575^{ns}	0.734^{ns}	0.382^{ns}	2.050^{ns}
Error	18								
Total	26								

*Significant at 5% level of significance

Table 3. Means comparison by Duncan's multiple range tests (at 5% level)

	Compressed area		Uncompressed area		
	a	b	a	b	c
%27	8.845		6.794		
%18	10.196	10.196		8.926	
%9		11.487			10.600
Control sample		11.413			11.413
Sig.	0.093	.128	1.000	1.000	0.203
Error	2.747		1.765		

uncompressed areas. Compression for the compressed area was significant in 6 and 9 mm depths while the uncompressed area was significant in all depths. Rate and interaction between pre-deformation and rate were not significant in all depths and the two areas. Since depth of 9 mm had significant effect for both areas, it selected for comparison between the two areas.

It can be concluded that the relation between firmness and pre-deformation in the uncompressed area was clearer than the compressed area. This conclusion can also be seen in Table 3. There were significant differences among 9 and 27% in the compressed area and also between all three levels of pre-deformation in the uncompressed area revealed by the multi range Duncan test at 95% confidence level. According to Table 3, there was significant difference neither between the control sample and the first two levels of deformation in the compressed area nor between the control sample and 9% deformation in the uncompressed area. These results indicated that there was no destruction in the orange carpel because of the elastic property of orange in 9% strain throughout the fruit. Moresi *et al.* (2012) reported the viscoelastic response of orange (*Citrus sinensis* var. Tarocco) in strain less than 5%.

Moreover, by comparing three levels of compression, the firmness in both areas of the test reduced compared to the control sample. Also the firmness in the uncompressed area was less than the compressed area showing more tissue change in this area. Reason for this result is that structure of orange fruit particularly orange segments. When orange compressed in perpendicular direction of stem axis, orange segments on the top and the bottom of fruit can transform into central column. Bean-shaped orange segments together create a central column in stem axis of orange that filled with soft material such as albedo or is empty in somewhere of it. Beside, orange segments on the left and the right of fruit pushed toward out but peel of orange resisted against them due to tensile strength of peel. As a result orange segments on the top and the bottom suffered less resistant force than orange segments on the left and the right. These results indicated that the uncompressed area was more important than the compressed area for analyzing the carpel destruction.

According to Table 3, the compression rate had no significant effect on firmness. Since the compression rate represents the viscous properties, so this result indicated viscose property of orange had no effect on internal damage of orange. Rate-independent plasticity is characterized by the irreversible strain that occurs in a material once a certain level of stress is reached. The plastic strains are assumed to be developed instantaneously which are independent of time.

Conclusion

The rise in energy absorption between the two steps of loading and unloading by increasing pre-deformation was due to the plastic deformation of orange which resulted in the firmness reduction. The rate of pre-deformation had no significant effect on the firmness of the orange carpel; the mechanical damage in the orange fruit cannot be related to the compression rate in packaging process. In this study, results showed a rate independent plasticity behavior for oranges. Thereby, for compressing orange in packaging or in other process lines, compression can be performed at high rates to save time.

Plastic deformation is the main cause of texture damage and is difficult to be detected in orange. In this research, Egyptian Valencia orange with minimum energy absorption in 9% strain showed the elastic behavior with certain level of compression without carpel destruction. By comparing the compressed and uncompressed areas, it was found out that more damage occurred in the uncompressed area which was due to the structure of orange segments. This observation is confirmed by the results contained in Table 3. We need more level of compression and other indexes of quality to determine the critical level of compression.

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