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# Determining the Strength Properties of the *Dixired* Peach Variety

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**Abstract:** Peaches, like other fruits, are susceptible to different kinds of damage during and after harvest. Such damage is a major cause of quality loss in fruit. In order to reduce these losses, it is necessary to know the strength properties of fruit. Some strength properties of "Dixred" peaches are investigated in this paper. Peaches were stored at 0 °C and 90% relative humidity for specified lengths of time. Impact treatment was applied by a pendulum impactor at four energy levels. Bruise volume was measured in the bruised peaches after impact, and bruise susceptibility was calculated from the linear regression line for bruise volume vs. absorbed energy. Strength properties (bio-rupture force, apparent modulus of elasticity and rupture stress) were determined by using a biological material test device. It was found that the peaches exhibited superior strength properties immediately after harvest, and that after 14 days in storage they softened rapidly. At harvest, it was calculated that peaches could be packed in corrugated boxes up to about 13 layers deep in a triangular arrangement and 16 layers deep in a rectangular arrangement without damage, while 28 days after storage they could be packed only 4 to 6 layers deep in the boxes. According to impact treatment, the fruit softened and became very susceptible to impact damage during periods exceeding 14 days.

**Key Words:** Peach, strength properties, duration of storage, critical number of layers

## *Dixired* Şeftali Çeşidinin Dayanım Özelliklerinin Belirlenmesi

**Özet:** Diğer meyveler gibi şeftalide hasat ve hasat sonrasında oluşabilecek farklı tip zedelenmelere hassas meyvelerdendir. Bu tür zedelenmeler şeftalide kalite kaybına neden olmaktadır. Bu kayıpları azaltmak için, meyvenin dayanım özelliklerinin bilinmesi gerekmektedir. Bu çalışmada, Dixired çeşidi şeftalinin bazı dayanım özellikleri araştırılmıştır. Şeftaliler, farklı depolama süreleri için 0 °C depolama sıcaklığı ve %90 nem düzeyinde depolanmıştır. Çarpma denemeleri dört farklı çarpma enerji seviyesinde pendulum çarpma test düzeneği kullanılarak gerçekleştirilmiştir. Zedelenme hacimleri çarpma sonrası zedelenmiş şeftali meyveleri üzerinden ölçülmüş ve zedelenme hassasiyeti de zedelenme hacmi ve absorbe edilen enerji arasındaki orandan hesaplanmıştır. Dayanım özellikleri (kabuk yırtılma kuvveti, elastisite modülü ve kabuk yırtılma gerilimi) biyolojik malzeme test cihazı kullanılarak belirlenmiştir. Ölçümler sonucunda, hasattan hemen sonra şeftalilerin yüksek dayanım özellikleri sergilediği ve 14 günlük depolama sonrasında hızla yumuşadığı belirlenmiştir. Hasat gününde, şeftalilerin zedelenmeksizin oluklu mukavva paketlerde, üç köşeli paketleme düzeni için 13 tabaka, dikdörtgen biçimindeki paketleme düzeni için 16 tabaka ve 28 günlük depolama sonunda da sadece 4 ve 6 tabakada paketlenebileceği gözlemlenmiştir. Çarpma denemelerine göre ise, 14 günlük depolama sonrasında şeftalilerin yumuşadığı ve çarpma zedelenmesine karşı çok hassas olduğu belirlenmiştir.

**Anahtar Sözcükler:** Şeftali, dayanım özellikleri, depolama süresi, kritik tabaka sayısı

## Introduction

Fruits are damaged when they impact against each other or when they impact against a hard surface during picking, packing, transporting and retailing at stores and other handling stages. Damage of this nature would be reduced if the fruit were handled more carefully. Since the physical characteristics of fruit change during storage, and also due to differences between varieties, the impact or static response and corresponding bruise susceptibility of fruit also vary with post-harvest time.

Most of the research on strength properties and fruit bruising has focused on apples (Hyde and Ingle, 1968; McLaughlin, 1982; Holt and Schoorl, 1984; Brusewitz and Bartsch, 1989), pears (Chen et al., 1987; Garcia et al., 1995) and peaches (Hung and Prussia, 1989; Brusewitz et al., 1991). Hyde and Ingle (1968) noted that the size of apple bruises tended to increase with advancing pre-harvest maturity but to decrease with longer post-harvest storage time prior to bruising. Holt and Schoorl (1984) found that bruise resistance (bruise

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volume per unit energy absorbed) remained fairly constant during 18 weeks of storage at 2 ºC. For Asian pears, Chen et al. (1987) reported that these did not change texture after picking and could be stored at 0 ºC various periods. For peaches, Hung and Prussia (1989) found that bruise susceptibility remained constant for 14 days after harvest and then increased with the duration of storage. After 21 days, lower impact levels caused similar bruising. Countries such as the USA have a rich and varied scientific literature on this topic. Several types of test equipment to assess the effect of static, quasi-static and dynamic stress on fruit have been developed. As mentioned above, several studies have discussed stress in the damage to fruit. Turkish scientific literature has made few contributions to the assessment of the damage to fruit due to static and dynamic loads in storage.

The aims of the present work were (1) to evaluate the effect of duration of storage on bruise susceptibility of peaches on impact and, (2) to evaluate the effect of duration of storage on selected strength properties used in the packing arrangement of peaches.

## Materials and Methods

### Materials

Fruits used for the investigations was picked by hand on 31 May 2002 from Çukurova University, Faculty of Agriculture Experimental Station orchard in Pozantı, located in the Çukurova region. The peaches were stored at 0 ºC and 90% relative humidity for 0, 7, 14, 21 and 28 days before being evaluated for strength properties such as apparent modulus of elasticity, bio-rupture force and rupture stress, as well as bruise volume due to impact damage. Before testing, the peaches were brought up to 21 ºC for 1 h. The average weight and diameter of Dixred peaches were 102.87 g and 58.41 mm for 40 peaches.

### Methods

To determine the strength properties of peaches in compressive tests, a biological material test device was used. The device was similar to that developed by Aydın and Özcan (2002), and had three main components: a stable forced and moving platform, a driving unit (AC electric motor and electronic variator) and a data acquisition (load cell, PC card and software) system (Figure 1). Halved sections of fruit were placed on the moving lower platform at a speed of 0.00086 m.s$^{-1}$ and pressed with a spherical indenter fixed on the load cell. Force-deformation curves were recorded by the data acquisition system and the strength properties were measured by these curves.

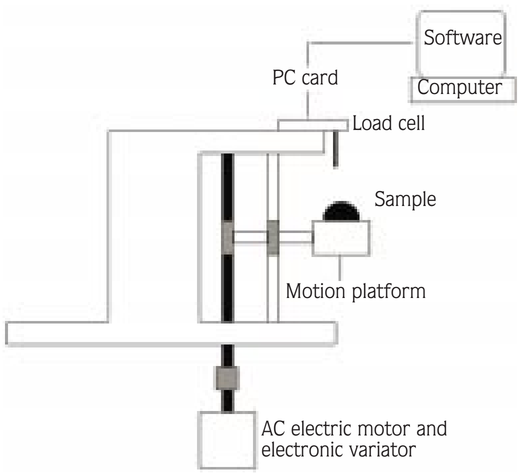

Figure 1. Biological material test unit.

Compression tests were performed on the halved sections of fruit as described above. Tests were conducted in conformity with ASAE testing standards (No. S368.4) (ASAE, 2001). An 8 mm diameter spherical indenter was used in the compression test. The radius of curvature was measured using a radius of curvature meter (ASAE, 2001). According to ASAE standards (No. S368.4) for compression tests of food materials of convex shape (ASAE, 2001), the apparent modulus of elasticity was evaluated as the tangent elastic modulus mid-way along the force deformation curve between the origin and the yield point from the following equation:

$$E = \frac{0.338 K_u^{3/2} F(1-\mu^2)}{D^{3/2}} \left(\frac{1}{R_u}+\frac{1}{R_u'}+\frac{4}{d}\right)^{1/2} \qquad (1)$$

when a halved section of fruit is compressed with a spherical indenter (Figure 2), where E is the apparent modulus of elasticity in Pa, F is the applied compressive force in N, μ is Poisson's ratio (dimensionless), $D$ is the deformation under compression in m, $K_u$ is the constant for the upper convex surface, $R_u$ is the minimum radius of curvature of the sample at the point of contact in m,$R_u'$ is the maximum radius of curvature in m and $d$ is the diameter of curvature of the spherical indenter in m.

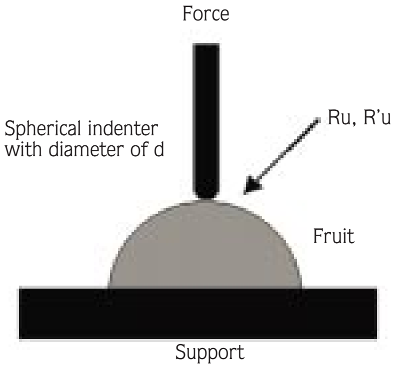

Figure 2. Peach loaded using spherical indenter (ASAE, 2001).

Working with yam tubers, Nwandikom (1990) determined the critical number of layers, $n_{cr,tr}$ for triangular arrangement and $n_{cr,sq}$ for rectangular arrangement, that will just avoid damage. In this research, the critical number of layers was determined for both triangular and rectangular arrangements depending on the duration of storage of peaches from the following equations (Nwandikom, 1990):

$$n_{cr,\ tr} = \left(\frac{\sigma^2}{1.73\rho gE}\right)^{0.5}\left(\frac{1}{d^{0.5}}\right) \quad (2)$$

$$n_{cr,\ sq} = \left(\frac{\sigma^2}{\rho gE}\right)^{0.5}\left(\frac{1}{d^{0.5}}\right) \quad (3)$$

where $\sigma$ is the limiting stress in kPa, $\rho$ is the density of produce in g.mm$^{-3}$, g is the gravitational constant, 9.81 in m.s$^{-2}$, E is the modulus of elasticity in kPa and d is the diameter of produce in mm. Limiting stress in equations 2 and 3 was referred to as the bio-yield point on the force-deformation curve. These equations are based on the maximum distortion energy theory of failure (Benham et al., 1996) and may also be used for peaches when fruits are assumed to be of the same size. Fruits were also packed in both rectangular and triangular forms in corrugated boxes, and the critical layers were noted when the bottom fruit showed signs of damage.

Poisson's ratio, which is used in equation 1, was taken to be 0.49, values used by Fridley et al. (1968) for the plunger tests. Density of produce and volume of fruit were calculated from the following equations:

$$\rho = \frac{m}{V} \quad (4)$$

$$V = \frac{\pi abc}{6} \quad (5)$$

where m is the mass of the fruit in g, V is the volume of fruit in mm$^3$, a is the major diameter in mm, b is the intermediate diameter in mm and c is the minor diameter in mm. Whole fruits were weighed before cutting and dimensions a, b and c were measured with a digital caliper.

A pendulum impactor similar to that developed by Hung and Prussia (1989) was used to apply a presellected amount of energy to the fruit during impact (Figure 3). Modeling clay was used to hold the halved fruit to the sample holder and energy was then applied along the stalk-flower axis for each fruit. The amount energy absorbed by the fruit during impact was calculated from the difference between the energy levels on impact and rebound. Rebound height was directly read from the calibrated scale of the pendulum impactor.

$$E_a = mg(h_1 - h_2) \quad (6)$$

where $E_a$ is the energy absorbed by the fruit in J, m is the mass of the wooden sphere used to impact the halved fruit in kg, g is the gravitational constant, 9.81 in m.s$^{-2}$, $h_1$ is the drop height of the wooden sphere in m and $h_2$ is the rebound height of the wooden sphere in m.

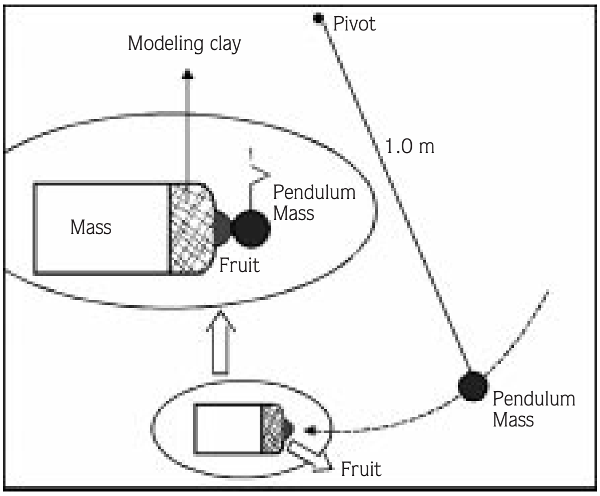

Figure 3. A systematic diagram of the pendulum impactor used to impact peaches.

The energy levels used in this study were 0.1, 0.2, 0.3 and 0.4 J. Six replicates were each given the impact treatment and averaged for 0, 7, 14, 21 and 28 days. A total of 120 peaches were used. Before the impact treatment, each was cut in half with a sharp knife, and was used for determining the strength properties. The other half of the fruit was used for impact treatment.

After impact test treatment with different energy levels, the bruise diameter, depth and width were measured 24 h later when the bruise had turned brown. Total bruise volume was represented by an ellipsoidal shape and was calculated from the following equation used by Hung and Prussia (1989):

$$V_T = 1.33\pi DPW / 8 \tag{7}$$

where $V_T$ is the total bruise volume in $mm^3$, D is the bruise diameter in mm, P is the bruise depth of the browned area in mm and W is the bruise width in mm.

The bruise susceptibility of peaches was assumed to be the slope ($mm^3J^{-1}$) of the linear regression line for the bruise volume vs. absorbed energy (Hung and Prussia, 1989).

In the experimental procedure relating to the strength properties of peaches, a t-test procedure was performed to determine the effect of the five durations of storage on the bio-rupture force, the apparent modulus of elasticity and rupture stress. Furthermore, a two- factor randomized complete block design was used to study the effects of the five durations of storage and four impact energies on the bruise volume and bruise susceptibility of peaches at impact treatment. Duncan's multiple range test was performed to determine the effects on the strength properties and bruise susceptibility of peaches.

## Results and Discussion

The critical packing level shown by the variation in the maximum number of layers of undamaged fruit and the duration of storage for square and triangular packing is displayed in Figure 4. The critical packing level decreased as the duration of storage increased for modes of packing. As seen in Figure 4, the shape of the curves is quite similar to the variation of the firmness ratio by days obtained by Galili et al. (1998) for avocado fruit. At harvest time, when fruit is stronger or firmer, peaches can be packed between 14 and 17 layers deep without damage, depending on packing type. Square packing has a higher critical number of layers than triangular packing. This could be due to the fact that for a given total packing height, rectangular packing contains less fruit and can therefore support more layers. This means that square packing can take more layers than triangular packing before fruit damage occurs. The calculated curve determined for each from equations 2 and 3 is higher than the experimental curve.

The force-deformation curves determined by the compression test are shown in Figure 5 for peaches at

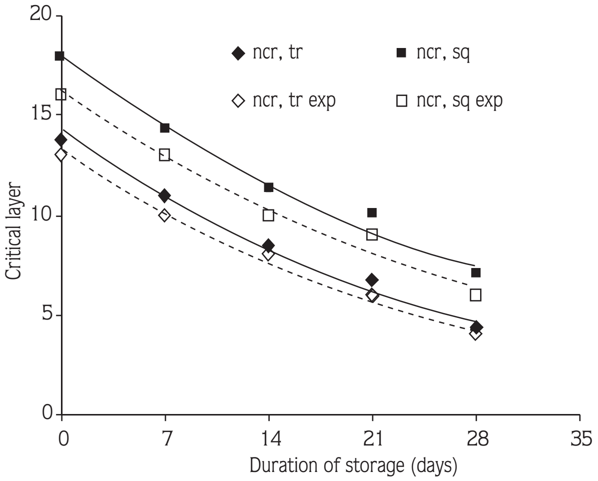

Figure 4. Critical packing layer variation with increasing duration of storage.

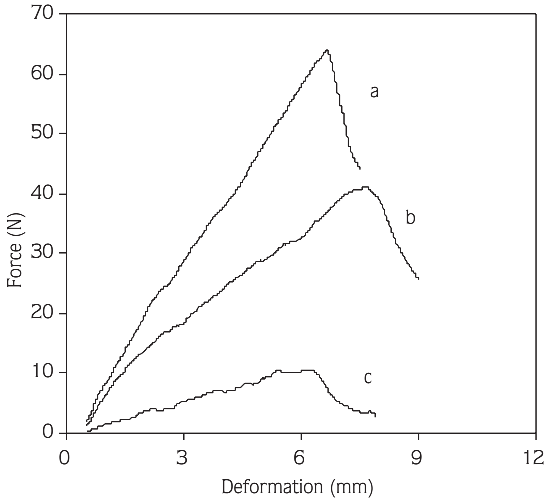

Figure 5. Force-deformation curves for three different times, (a): at harvest, (b): 14 days in storage, (c) 28 days in storage.

harvest and 14 days and 28 days later in storage length. The concavity of the curve was influenced by the length of storage. The increase in the duration of storage resulted in a greater bulge in the curve. Nwandikom (1990) reported the opposite in terms of the moisture content of yam tuber. This could be due to the fact that yam tuber has different strength properties and that the moisture content of fruit is a very important parameter influencing the textural structure. The results presented in Figure 5 confirm that the fruit can withstand more force immediately after harvest. Its strength deteriorates with the increase in the duration of storage.

Apparent modulus of elasticity, bio-rupture force and rupture stress were all found to decrease as the duration of storage increased, as seen in Table 1. The decrease in strength properties is gentle up to about 14 days in storage and then the decrease is rapid as the duration of storage increases. This further supports the findings peaches were able to withstand more force and that they lose some strength after storage. Hung and Prussia (1989) reported that the mechanical properties of peaches generally remained constant in the early stages of storage and then decreased as the length of storage increased. Our results also supported the findings relating to mechanical properties determined by Hung and Prussia (1989).

Table 1. Apparent modulus of elasticity, rupture force and rupture stress.

| Duration of storage, day | Bio-rupture force, N | Apparent modulus of elasticity, kPa | Rupture stress, kPa |
|---|---|---|---|
| 0 | 59.597a* | 887.703a | 173.102a |
| 7 | 52.017a | 849.876a | 154.413b |
| 14 | 46.763b | 805.361b | 130.634c |
| 21 | 39.867c | 630.051c | 122.561c |
| 28 | 19.402d | 293.606d | 62.329d |

* Values in a column with the same letter do not differ at P = 0.05 by Duncan's multiple range test.

The F-values of bruise volume and bruise susceptibility obtained from the experimental procedure are shown in Table 2. The analysis of variance revealed that both factors were significant at a 0.01 level of significance and that their interaction was not significant.

Table 2. F-values from ANOVA on the main effects and interaction for Dixred peaches.

| Source of variation | Degrees of freedom | Bruise volume | Bruise susceptibility |
|---|---|---|---|
| DS | 4 | 48.81** | 40.47** |
| IE | 3 | 34.39** | 33.85** |
| DSxIE | 12 | 0.74$^{ns}$ | 0.60$^{ns}$ |

** : Significant at the probability P < 0.01 level, ns: Not significant.

Impact test results are shown in Figures 6 and 7 for the pendulum tests. In general, fruit bruise susceptibility increased linearly with the increase in impact energy for each of the durations of storage (Figure 6). However, the bruise susceptibility of peaches at impact increased non-linearly with duration of storage considered (Figure 7). The highest level of impact energy damaged almost all of the peaches, whereas the lowest level caused much less bruising. Based upon the bruise volume shown in Figure 6, bruising increased with impact energy and a duration of storage exceeding 14 days.

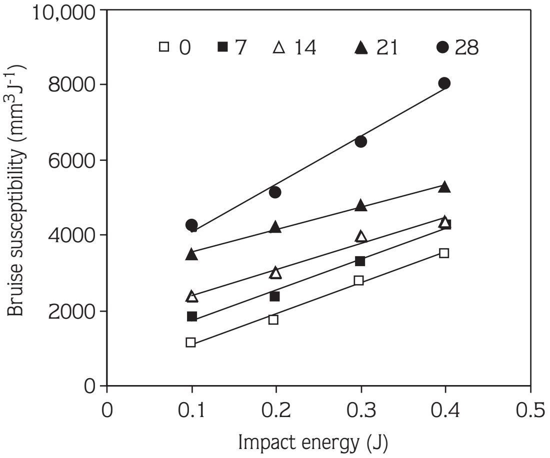

Figure 6. Fruit bruise susceptibility versus impact energy for various duration of storage.

In durations exceeding 14 days, fruit firmness decreased and fruit softened rapidly and was very susceptible to impact damage. Impact damage to fruits is related to impact approach velocity (impact energy), commodity temperature, physical properties of the fruit, specimen mass and the radius of curvature of the specimen and impact surface (Ragni and Berardinelli,

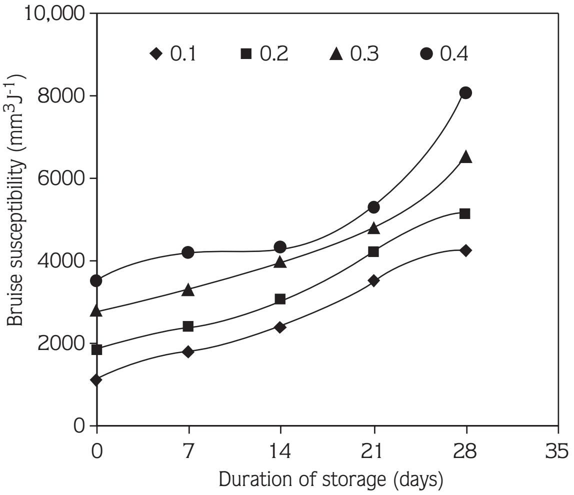

Figure 7. Fruit bruise susceptibility versus duration of storage for impact energy levels.

2000). Hung and Prussia (1989) mentioned that bruise susceptibility and bruise volume increased with duration of storage. The results concerning impact treatment are similar to those reported by Hung and Prussia (1989).

## Conclusion

This study has shown that Dixred peaches exhibit superior strength properties at harvest. Strength properties such as bio-rupture force, apparent modulus of elasticity and rupture stress did not change much over 14 days of storage, but then decreased rapidly, due to the softness of the peaches as the length of storage increased. Therefore, strength properties play a major role in predicting physical damage to peaches. Fruits can be packed to higher levels and withstand higher impact and static loads at harvest. Therefore, it is advisable to do most handling, such as packing and transportation, within 14 days of storage. This study was conducted on only one cultivar during one season, but similar experiments should be applied to other cultivars and horticultural crops.

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