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# Design of a testing machine to determine certain physical and mechanical properties of hard-shelled and hard-pitted fruits, and application of olives in the Edremit Gulf region (Turkey)

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**ABSTRACT:** A multidisciplinary collaboration approach was used to design a computer controlled testing device to determine certain physical and mechanical properties of hard-shelled and hard-pitted fruits under compression force. High-resolution cameras and image processing methods were utilized to determine physical properties such as fruit size and volume. Two different types of load cells were used to measure compression force and fruit weight. A linear variable differential transformer (LVDT) was used to measure the compression distance. During the test period, all data were sent to a computer by using data acquisition system and analyzed using LabView software. In this study, both physical and mechanical tests were conducted on two separate occasions over a period of 82 days for olives in the Edremit region. The results show the rate of increase in certain physical properties of olives such as the weight, length, width, thickness, and volume were 26.86%, 12.42%, 15.90%, 17.58%, and 39.6%, respectively. However, a decrease of 17.49% was found for olive density. The rate of decrease in certain mechanical properties of olives such as crush force, crush energy, and total rigidity were determined as 31.16%, 63%, and 28.22% respectively. Additionally, an increase of 30% was found in specific deformation of the olives. Thus, we conclude that both physical and mechanical properties of olives in the Edremit Gulf region changed during the 82-day experimental period.

***Key Words:*** Hard-pitted fruit; Hard-shelled fruit; Physical and mechanical properties; Olive; Biological testing device

## INTRODUCTION

Analyzing how external forces affect the behavior of agricultural materials can yield useful information that has various potential applications (Şahin 2006). A greater understanding of the physical and mechanical properties of agricultural materials could be useful when designing equipment for harvesting, processing, transporting, storing, and producing food (Bagvand & Lorestani 2013). Presently, agricultural development depends on increasing production per unit area, both quantitatively and qualitatively, and achieving value added production processes. A greater understanding of the properties of biological materials would enable such developments and this information could be used as engineering data in technological processes (Tunalıgil 1993). Furthermore, understanding the biological properties of agricultural products is important in designing, manufacturing, operating, and controlling the appropriate machinery, as well as assessing and analyzing its efficiency. This information could also be used to present new vegetal or animal-based products to consumers and evaluate the quality of the product. Having access to useful data about biological materials serves not only engineers but also food scientists and the food processing industry, as well as other designers and creative experts in horticulture and animal husbandry. For example, knowledge of geometrical properties such as figure, volume, sphericity, shape, and arithmetic and geometric diameter is required to design effective harvesting machinery, cleaning products with the help of mechanical, pneumatic, and electrostatic systems, and in heat transfer processes. Knowledge of the mechanical properties of agricultural products is important in product processing methods such as drying, crushing, grinding, packaging, as well as in storage, transportation, and harvesting processes, along with engineering design.

When the technical properties of biological materials are not accounted for, damage losses occur. Damage loss is evaluated by comparing the cost of damage prevention and the cost of the damage. The amount of damage is a function of the amount of energy consumed. The relationship between damage/loss and energy consumption constitutes a method for damage projection.

Other important damage criteria in fruits and vegetables are mass, breaking strength, fruit and vegetable pulp firmness, and elasticity modulus. Mechanical damage in agricultural products shows variation depending on the physical and biological structure of the product and the nature of the external forces. Agricultural materials are exposed to initial mechanical damages during harvesting and transportation. Generally, damage is incurred as a rupture or breakage due to collisions and excess deformation. Damage scale varies according to the type and ripening phrase of the product, and the temperature of the environment. Damage generally is caused by static and dynamic external forces and varies according to the moisture content of the material (Şahin 2006).

The physical and mechanical properties of agricultural products not belonging to the stone fruit category have been investigated. Examples of research in this area include a study by Altuntaş & Yıldız (2007) who investigated the effect of moisture content of faba beans (*Vicia faba L.)* on their physical and mechanical properties. Another study by Arazuri et al. (2007) investigated the effects of mechanical harvesting on the physical properties of tomatoes (*Lycopersicon esculentum Mili.),* and a study by Ozturk et al. (2009) identified the physico-mechanical properties of Hınıs and İspir varieties of bean seeds known as Turkish beans (*Phaseolus vulgaris L.).* Other investigations include a study by Çalışır et al. (2005) who identified the physical properties of kolza seeds (*Brassica napus oleifera L.),* a study by Kiani Deh Kiani et al. (2011) who evaluated the Young's Modulus and Poisson ratio of red beans, and a study Jafari et al. (2011) who attempted to determine the mechanical properties of sunflower seeds.

In their study investigating the post-harvest physico-mechanical properties of orange fruit and orange peel, Singh & Reddy (2006) were able to identify properties of orange peel such as tensile strength, fruit color, weight loss, bio-yield, hardness, puncture force, and break energy in relation to storage period under environmental temperature and cooling conditions. The results of their study indicated that bio-yield, hardness, puncture force, and fruit cutting decreased by number of days of energy storage.

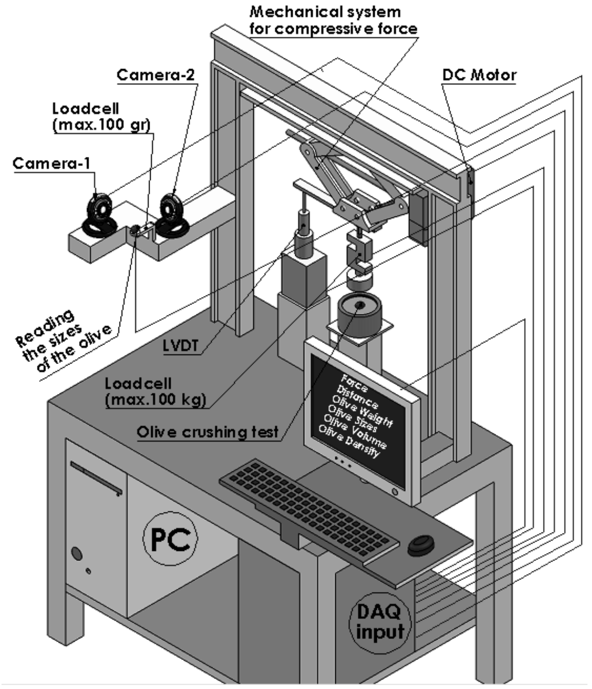
Other studies investigating the mechanical properties of hard-pitted fruits such as apricots and hard-shelled fruits such as peanuts can also be found in the literature. These studies primarily focused on the mechanical behavior of the fruit under compression force (Güner et al. 2003; Vursavuş & Özgüven 2004; Galedar et al. 2009). Ünlü (2009) designed an automatic controlled test device that can be used to determine some of the mechanical properties of general agricultural products. Further, Vursavuş & Özgüven (2004) developed a "Biological Material Test Device" to identify the mechanical behavior of apricot pits under compression force. The device consists of an electrical motor, reduction unit, movable tray, loadcell, signal transducer electronic card, and computer and software. Galedar et al. (2009) examined the mechanical properties of peanut and its kernel under compression force. Kılıçkan & Güner (2008) designed a biological material test device to specifically determine the mechanical properties of olive fruit and its kernel.

The mechanical properties of four varieties of chestnut (Albayrak, Altınay, Ünal and 554-14) were determined in terms of average rupture force, deformation, rupture energy and firmness. Physical characteristics of the chestnut such as dimensions, geometric mean diameter, sphericity, volume and surface area were determined (Yurtlu & Yeşiloğlu 2012). Sabliov et al (2002) applied an image processing algorithm to determine surface area and volume of axi-symmetric agricultural products. Sabzi et al (2015) conducted a study on automatic grading of emperor apples based on Image Processing. Gümüşoğlu (2005) & Gümüşoğlu et al. (2006) investigated certain physical and mechanical properties of selected olive varieties with respect to their ripening periods. The physical properties investigated were moisture, color, size, and total sugar. The mechanical properties that they examined were rupture force from the olive branch and compression force. They showed that the olive rupture force from the olive branch was 5.52 N for the Gemlik variety, 5.50 N for the Domat variety, and 5.48 N for the local variety. Compression force was found to be 47.98 N for Gemlik, 63.62 N for Domat, and 29.46 N for the local variety. The elasticity modulus were 1.68, 2.25, and 0.88 MPa for the fruits. In contrast to the study by their colleagues, Kılıçkan & Güner (2008) studied both the physical and the mechanical behavior of the Gemlik (Turkey) olive variety under compression force. The following values were obtained: 25.25 mm length, 22.00 mm width, 18.06 mm thickness, 14.45 mm average arithmetic diameter, 21.57 mm average geometric diameter, 3.80 $mm^3$ volume, 4.15 g unit mass 556 $kg{\cdot}m^{-3}$ mass density, 1062 $kg{\cdot}m^{-3}$ actual weight, 94.45–98.47 N crush force (based on deformation speed), 0.3156–0.3398 N·m crush energy for olive pulp, 14.00–18.34 N·m crush energy for olive pit, and 20.02–24.25% deformation.

In this study, an automatic controlled test device was specifically designed and manufactured to investigate certain physical and mechanical properties of biological materials. This system will be used to identify certain mechanical properties of agricultural materials. To model the implementation process, two different tests were carried out on September 3 (Test 1) and November 24 (Test 2), 2014, for olives in the Edremit region. The findings showed that the physical and the mechanical properties of the olives changed over a period of 82 days, during the ripening period.

## MATERIALS AND METHODS

The test device (biological material test device) that was developed in this study to identify certain physical and mechanical properties of hard-pitted and hard-shelled fruits consists of ten parts (Figure 1). Basic materials used in the test device and their properties are listed in Table 1. All testing parameters could be controlled (including speed control by PID), and the related data was recorded using a software package that we developed using LabView.



1) Main Frame
2) DC motor
3) Mechanical compression system for olive crushing
4) Loadcell to measure force
5) Moving plate connected to loadcell
6) Sensitive distance measurer (LVDT)
7) Static plate for olive crushing
8) Double camera system for weight and size measurement
9) Data acquisition module (DAQ)
10) PC

Figure 1. Biological material test device

Table 1. Materials and their properties

| Material | Properties |
|---|---|
| Loadcell | Max. 100 kg; 2 mV·V$^{-1}$ |
| Loadcell (mini) | Max. 100 g; 2 mV·V$^{-1}$ |
| Signal amplifier | 0–10 V; 4–20 mA; loadcell amplifier 2 mV·V$^{-1}$ |
| LVDT | ±25 mm stroke , 5 V analog linear out |
| DC Motor and reduction gear | Power: 120 W, 12 V–10 A; stroke: 12–35 cm |
| Mechanical jack | Capacity: 2000 kg |
| Data acquisition card (DAQ) | 8 analog input (12-bit, 10 kS·s$^{-1}$), 2 analog output (12-bit, 150 S·s$^{-1}$), 1 counter (32-bit), 12 digital I/O |
| Power Supply | ±12 V DC, +5 V, +24 V regulated power supply |
| Camera | USB web cam with 6 led adjustable lenses (5 MP) |

### *Measurement of size by image processing and weight by loadcell (physical properties)*

The mini loadcell with a maximum measurement capacity of 100 g and 0.01 g precision (Figure 2) was placed in the section of the device used for measuring size and weight. An elliptical hole, 0.25-mm deep, was bored into a piece of circular polyamide by a CNC milling machine and placed upon the load cell. The olive was placed vertically in this hole and fixed while its size and weight were measured. LED high-resolution CMOS cameras were placed at 10 cm from the olive with the lenses at 90º from each other. The cameras could record views from both the front and side cross-sections of the olive and real-time images were sent to the PC. The visual image and outline of the olive were analyzed using an image processing software. Thereafter, the size variables of the olive (width, length, and thickness) were calculated and recorded.

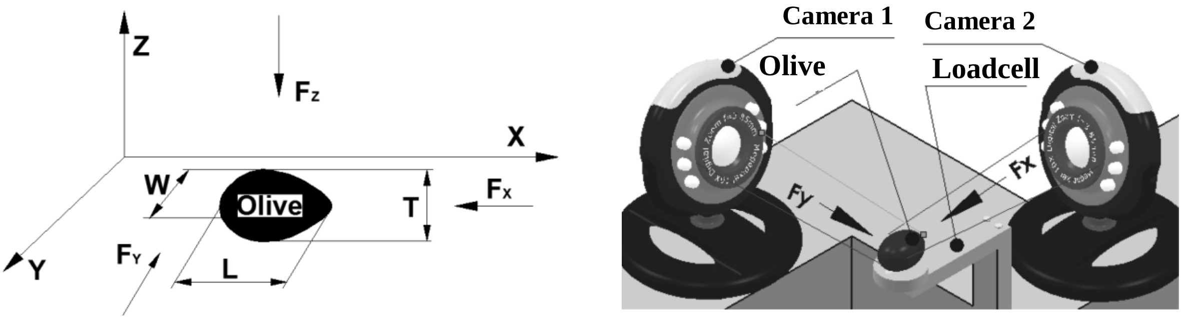
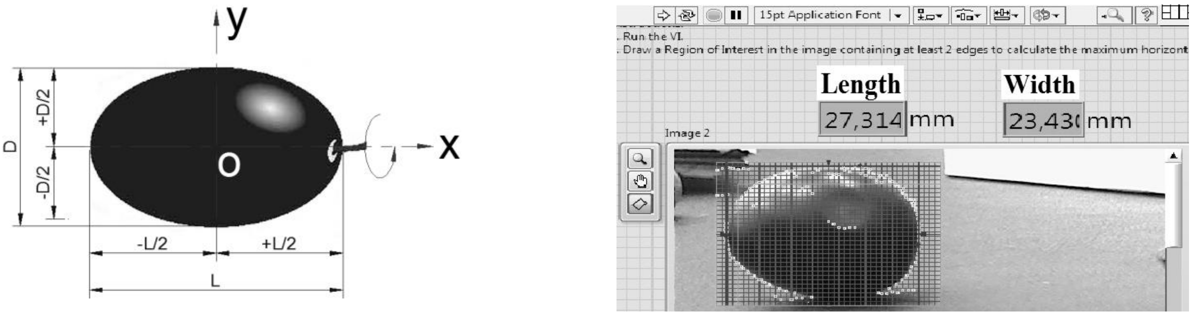


Figure 2. a) Representational image of the three perpendicular dimensions of the olive fruit. b) Olive weight measured by the loadcell and olive size measured by the camera system.

Camera 1 $F_y$ view measures the largest dimension, length (L), and the smallest dimension, thickness (T). Camera 2's $F_x$ view measures the width (W). When calculating the volume, the average of width (W) and thickness (T) is expressed as the average diameter (D) of the olive fruit.

The approximate volume of the olive fruit equates to the volume of the black object rotating around the OX axis in Figure 3.



. Run the VI.
. Draw a Region of Interest in the image containing at least 2 edges to calculate the maximum horizont

Length 27,314 mm

Width 23,43( mm

Figure 3. Olive fruit dimensions: a) schematic diagram and b) image processing technique

The olive volume can be calculated using the below equation:

$$V = \frac{(D/2)^2}{(L/2)^2}\int_{-L/2}^{+L/2}\left[\left(\frac{L}{2}\right)^2 - X^2\right] \qquad (1).$$

If we assume that the right side volume is equal to the left side volume (according to the Y axis), and if we calculate the right half of the integral and multiply the result by two, the volume of the olive can be calculated by the following simplified Equation 3:

$$V = 2\,\frac{(D/2)^2}{(L/2)^2}\int_{0}^{+L/2}\left[\left(\frac{L}{2}\right)^2 - X^2\right] \qquad (2)$$

$$V = \frac{\pi\, D^2 L}{6000} \qquad (3),$$

Where $D$: average diameter (mm); $L$: length (mm); and V: volume (cm$^3$) are given.

Another equation to calculate volume that gives a similar result is as follows (Vursavuş & Özgüven 2004):

$$V = \frac{\pi\, L\, W\, T}{6} \qquad (4),$$

where, $L$: Length (mm); $W$: width (mm); $T$: thickness (mm); and $V$: volume (mm$^3$) is calculated.

The olive density is calculated using the below formula:

$$\rho = \frac{Q}{V} \qquad (5),$$

where $\rho$: density (g.cm$^{-3}$) and $Q$: weight (g).

***Determining some mechanical properties by olive crushing test***

Firstly, size and weight measured olives were placed into the olive crushing chamber. Parameters such as test speed (1–2 mm·s$^{-1}$) and waiting period for a new crush (3–5 s) were set by using a newly developed software. The mechanical press connected to the DC motor gradually moved downward at the test speed (1 mm·s$^{-1}$ in this study). When the crushing head touched the olive, compression force was measured by the loadcell, and compression distance was measured by the LVDT. Compression force was applied using the moving plate until the olive pulp and pit were crushed. Force-deformation curves were plotted in MS Excel from the data obtained during this process.

The olive crushing test under compression is executed in three stages. Stage I: Compression force increases in a linear fashion starting from the first contact with the crushing head (0) as the olive pulp is crushed. Stage II: Compression force increases rapidly generating a steep slope as the olive pit is being smashed. Stage III: The force reaches its maximum point at the moment the pit is crushed. Thereafter, there is a sudden decrease in force, marking the completion of the crushing test. The three stages described and the graph displaying the test data from the two variables on two different days during the ripening season can be viewed in Figure 4.

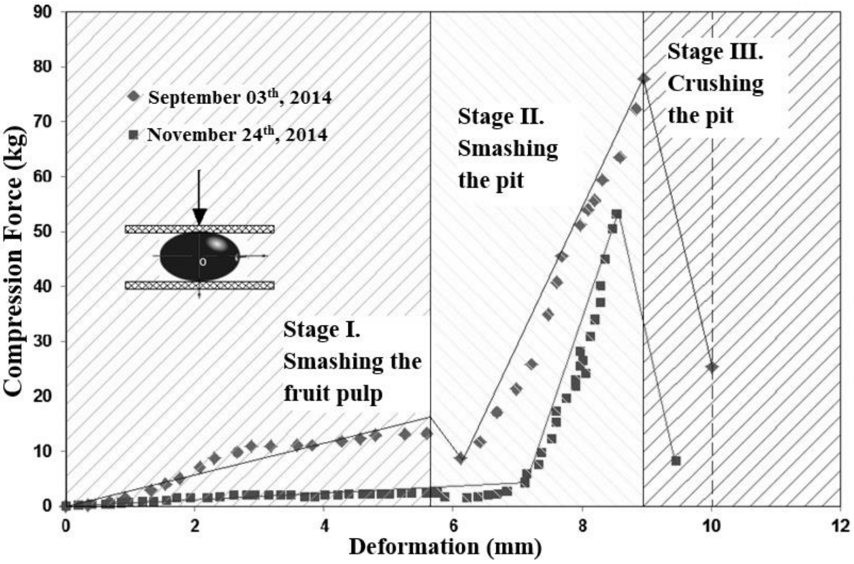


Figure 4. Stages in the olive crushing test and typical force-deformation curves for the olive fruit

Although this study does not include extensive numeric data and analyses, it still allows us to explain the mechanical behavior of olive fruit and pit in terms of crush force, crush energy, rigidity, and specific deformation. It is possible to obtain the specific crush force, crush energy, rigidity, and specific deformation values for olive pulp and pit from each curve.

Specific deformation percentage ($\varepsilon$) can be calculated using the below formulas:

$$\varepsilon\% = \frac{\Delta T}{T_o} 100 \qquad \text{(6) and}$$

$$\varepsilon\% = \frac{T_o - T_f}{T_o} 100 \qquad \text{(7),}$$

where $T_o$: original olive thickness (mm); $T_f$: smashed olive thickness (mm); and $\Delta T$: Maximum distance moved after the crush head touched the olive.

## RESULTS AND DISCUSSION

The sizes were measured as L = 18.12 mm, W = 14.22 mm, and T = 13.45 mm on September 3, but when measured again on November 24, these had increased to 20.69 mm, 16.91 mm, and 16.32 mm, respectively. In the time between tests 1 and 2, the weight of the olive fruit had increased from 2.311 to 3.160 g on average. The olive volume also increased from 1.83 to 3.03 cm$^3$. Based on these values, the olive density was shown to decrease from 1.263 to 1.042 g·cm$^{-3}$. Within the 82-day study period, we observed a 26.86% increase in the weight, 12.42% increase in length, 15.90% increase in width, 17.58% increase in thickness, and

39.60% increase in volume of the olive fruit. Additionally, the observed 17.49% decrease in olive density was directly dependent on the relative increases in the other variables.

The test data from September 3 in Figure 4 shows that Stage I maximum smash force for the olive is 13.29 kg, while at the end of Stage II, the maximum crush force of the pit is 77.82 kg. The test data from November 24 reveals that Stage I maximum smash force for the olive is 2.54 kg, while at the end of Stage II, the maximum crush force of the pit is 53.18 kg. After 82 days, the rate of decrease in olive crush force was 31.16%.

The crush energy graphs (Fig. 4) were transferred to AutoCAD software and the area directly under the force-deformation curve was used as a basis. Crush energy was measured at 165.65 kg·mm$^{-1}$ on September 3, 2014, but it decreased to 61.68 kg·mm$^{-1}$ on November 24, 2014. Crush energy also decreased by 63%. The slopes of the straight lines drawn on these graphs show the rigidity values. The olive pulp rigidity on September 3, 2014, was 2.373 kg·mm$^{-1}$ and the pit rigidity was 27.40 kg·mm$^{-1}$. By November 24, 2014, olive pulp rigidity was calculated to be 0.441 kg·mm$^{-1}$ and pit rigidity was 37.71 kg·mm$^{-1}$. Total rigidity (pulp + pit) of the olive at the end of the final crush decreased from 8.68 to 6.23 kg·mm$^{-1}$. In summary, a decrease of 28.22% in total rigidity and an increase of 30% in deformation were observed.

When we calculate the deformation percentage by using the Equation 7 and after considering the test measurement data from September 3, 2014 (Fig. 4), ε% of 33.38 and 47.73 were obtained, respectively.

## CONCLUSIONS

This test device helps to determine certain mechanical properties such as compression force, crush energy, and rigidity of fruits such as olives, cherries, or almonds, as well as some of their physical properties, including weight, size, volume, and density. Therefore, both physical and mechanical damage that the fruits sustain due to pests, harvesting methods, transportation/storage methods and environmental conditions, which are related to the time of the year and geographical location, can be determined using the described test method.

By using the designed test device, two tests were conducted on September 3 (Test 1) and November 24 (Test 2), 2014, for olives in the Edremit region. Physical (weight and size) and mechanical (crush force, crush energy, rigidity, and specific deformation) properties were investigated. A minimum of 20 olive fruits were used for each test, and the averages were used for data analysis.

To conclude, our findings showed that both the physical and mechanical properties of olives were altered during the 82-day study period. The results can also be interpreted as being an outcome of the olive ripening process rather than external physical processes such as the effects of olive pests, strong winds, and hailstorms. A future study may involve assessment of the periodic damage olive fruit flies inflict on olive fruit and the physical and mechanical properties associated with this damage. We believe that “damaged olive %” could be adopted as a useful measure of the scale of fruit damage.

Table 2

| Abbreviations and Symbols | |
|---|---|
| LVDT | A linear variable differential transformer |
| DAQ | Data acquisition |
| PC | Personal computer |
| L | Length, mm |
| W | Width, mm |
| T | Thickness, mm |
| D | Diameter, mm |
| V | Volume, cm$^3$ |
| ρ | Density, g.cm$^{-3}$ |
| Q | Weight, g |
| ε | Specific deformation percentage, % |
| $T_o$ | Original olive thickness, mm |
| $T_f$ | Smashed olive thickness, mm |
| ΔT | Maximum distance, mm |

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