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QUALITY PARAMETER OF STORAGE APPLE AS A FIRMNESS

B. Dobrzański, jr.[1], R. Rybczyński[1], K. Gołacki[2]

[1]Institute of Agrophysics, Polish Academy of Sciences, Doświadczalna 4, P.O. Box 201, 20-290 Lublin 27, Poland
[2]Institute of Technical Sciences, University of Agriculture, Doświadczalna 50a, 20-280 Lublin, Poland

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A b s t r a c t. Different physical parameters related to firmness were studied for apple fruit. Fruit were kept in different conditions up to 30 weeks to show a wide range of mechanical behaviour. Refrigerated storage, regular storage frequently applied in small farm in Poland, and storage with artificial high temperature were used in this study to ensure different softness of fruit. Water potential of apple flesh was measured using the HR-33T microvoltmeter equipped with the C-52 sample chamber. The most important mechanical factors related to fruit firmness were determined in different way using Instron machine equipped in each case with special adapters. Application of simple devices designed by the authors for the estimation of the slight changes in fruit firmness during storage is presented.

K e y w o r d s: apple, firmness, physical properties, water potential, quality

INTRODUCTION

In recent years, many studies on quality detection in horticultural commodities and different factors related to the physical properties of these products have been carried out and can be included in the discussion on quality [1,5,10,18,30]. Quality evaluation of horticultural products has been the subject of interest for many researchers for a long time. However, there is no clear definition of quality for agricultural products. Quality of agricultural products is an important factor for both the producer and consumer. In this context, consumer is the person or organization receiving the product at every point of the production chain. This remark is important since quality is perceived differently according to the needs of a particular consumer: a packing shed operator has a very different idea of quality to the ultimate eater of the fruit [30]. Firstly, quality standards are affected by international and cultural preferences [1]. Secondly, standards can be affected by cultural changes or by strong marketing in the media.

Numerous quality factors for fresh fruit and vegetables were listed by Kader [18], and for each factor an objective measuring technique is required. The challenge is to make this technique affordable for the market and what is even more important, to relate the measuring parameters to a very subjective, sensory evaluation of quality by the consumers. Several non-destructive techniques for quality evaluation based on the detection of various physical properties of horticultural products have been developed. As each of these methods is based on measuring a given physical property, the effectiveness of the method depends on the correlation between the measured physical property and the quality factor of interest. Although researchers developed relationships between physical properties and quality factors for a number of horticultural products, firmness is the property that is often used for evaluating fruit quality.

Firmness is related to maturity and it is well known, that fruit firmness decreases gradually during maturation and decreases rapidly during ripening [10,14,22,26,32]. Overripe and damaged fruit become relatively soft. Fekete and Felföldi [16] reckoned firmness to be the principal characteristics of fruit, important for quality, harvest, maturity, storage, and shelf-life. Using penetrometer and impact tests, Yuwana and Duprat [35,36] measured bruise volume of apple to predict mechanical resistance of fruit to damage. Duprat *et al*. [13] used a multi-purpose penetrometer based on a high accuracy measurement of deformation and force to estimate fruit firmness. Thus firmness can be used as a criterion for sorting agricultural products into different maturity groups or for separating overripe and damaged fruit from the good ones. Takao and Ohmori [33] developed a force-deformation type of a firmness tester called HIT (hardness, immaturity, and texture) that can measure nondestructively fruit firmness. Armstrong *et al.* [2] developed an automatic instrument to nondestructively determine firmness of small fruit, such as blue berries or cherries. Fekete and Felföldi [16] reported four rapid penetration methods where the values of force or deformation were measured. Fekete [15] designed a device equipped with a force sensor and Bellon *et al*. [4], reported a rapid method where deformation was measured at constant force. Firmness is related to the quality factors, however, through the use of simple penetrometers, only the maximum squeezing force was frequently correlated with numerous quality factors. Together with external and internal fruit properties, firmness depends on the shape and size of fruit; size and contact area of the plunger; rate of deformation; method of fruit fixing, and the measurement technique applied related to the final accuracy.

Looking for a simple test for firmness estimation, various mechanical properties were studied on an apple fruit and specimens of apple flesh and skin.

Objectives of this study were:

- to determine some mechanical properties related to fruit firmness,
- to evaluate slight changes in fruit firmness and water potential of tissue during storage and shelf-life.

MATERIALS AND METHODS

Cortland, Gala, Gloster, Holyday, Jonagold, Idared, McIntosh, Melrose, Priam, Red Elstar, Spartan, and Šampion apples after harvest were sorted and high quality fruit (the same size for each variety) were cold stored. Firmness was determined twice; at harvest and after storage, using an Instron machine at 10 mm min^{-1} rate of crosshead move. Various pieces of equipment and sample preparation method were applied for the following tests:

- compression of cylindrical flesh sample,
- tension of skin belt,
- penetration into fruit,
- bending of the flesh beam.

For the compression test cylindrical flesh samples were cut out perpendicularly to the stem calyx axis of the fruit. The samples with 13 mm diameter and length were compressed between parallel plates. Deformations at damage of the apple flesh, force and deformation work were observed. Modulus of elasticity was determined from the elastic range of force -deformation curve.

For the tension test skin belts with a cross section area of 2 x 0.3 mm were cut out; five from each apple. The skin belts were placed in a special holder fixed to the cross-head of the Instron apparatus. Ten millimetres middle part of the belt between the holders was used for the calculation as an initial size of the sample. The maximum force, deformation and deformation work were also observed. Modulus of elasticity was determined from the simple equation according to the Hook's law.

The penetration test was also performed at the same speed rate of the cross-head move. All the values such as: force, deformation and deformation work related to fruit firmness were recorded at the point when the penetrometer squeezed into the flesh after skin rupture. The values corresponding to the modulus of elasticity were determined from the elastic range of deformation, before skin rupture.

For the bending test only 8 mm of the superficial layer of apple was used. A beam of the apple flesh, a beam of the flesh with skin over was loaded into the bending test. The cross-section of the beam was 3x3 mm. The distance between cylindrical supports was 10 mm. The force causing deformations at the elastic range was used to calculate the modulus of elasticity. Thirty, not more than five samples from each fruit were cut out and all the routine calculations (average value, standard deviation and coefficient of variance) were done for each test.

Refrigerated storage at 0-2 ^{o}C, regular storage (commonly used in small farms in Poland) at 6-8 ^{o}C and storage with high temperature (14-16 ^{o}C) were used to obtain various degrees of fruit softness. However, only Gloster, Jonagold, Idared and Šampion apples were kept in different conditions up to 30 weeks to obtain a wide range of mechanical behaviour of fruit. Firmness was determined with the Instron apparatus and Elasticity Meter. In both cases the modulus of elasticity was determined at small deformation. All these tests were performed on apple with skin and apple after skin removal, according to the Magnes-Taylor method [20] to establish the measuring range of deformation independent of the skin absence. The previous study concerning compression tests and measurements of fruit strain under the break point, gave the basis for the development of a device for the estimation of fruit firmness and some of the results obtained with this meter for various pins were presented by the authors [11].

The Elasticity Meter used for fruit firmness estimation was described in previous paper [10]. This meter allows for the measurement of fruit elasticity at the limit force corresponding to finger touch.

The results obtained by Gołacki [17] showed that water potential of apple tissue is mostly related to fruit firmness and indicates the physical state of fruit during storage [17,23,24,28]. Water potential of apple flesh was measured using the HR-33T dew point micro-voltmeter equipped with the C-52 sample chamber, according to the method elaborated by Wescor, Inc.

The dew-point temperature, and hence, the relative humidity of the air is strongly connected with water potential, according to the following formula:

$$\psi = \frac{\mathrm{R}T}{\mathrm{V_W}} \ln \frac{p}{p_o}$$

where: $\mathrm{V_W}$ - molar volume of water (1.8 10^{-5} $\mathrm{m^3 mol^{-1}}$), R - gaseous constant (8.31 J $\mathrm{mol^{-1}}$ $\mathrm{^oK^{-1}}$), p - vapour pressure above the solution, p_o - vapour pressure above pure solvent, T - absolute temperature (^{o}K).

After 3, 4 and 5 month of storage the apples were analysed. Water potential of apple tissue was determined after 5 h, four and eight days of storage at 20 ^{o}C to cover the time necessary for handling operations.

RESULTS

Figure 1 shows the modulus of elasticity of apple skin at harvest maturity and after storage. Modulus of elasticity of apple skin reached the values in the 8.10÷16.94 MPa range. The values obtained for Cortland, Holyday, Spartan, Melrose and Šampion cultivar showed more distinctly the effect of storage on the skin strength. The highest values (16.94 MPa - Melrose variety, 14.84 MPa - Šampion cultivar and 14.80 MPa - Idared cultivar) were obtained for the skin at harvest maturity of apples. After storage the highest values were noticed for the Idared (13.71 MPa) and Melrose (13.55 MPa) cultivars. The modulus of elasticity determined

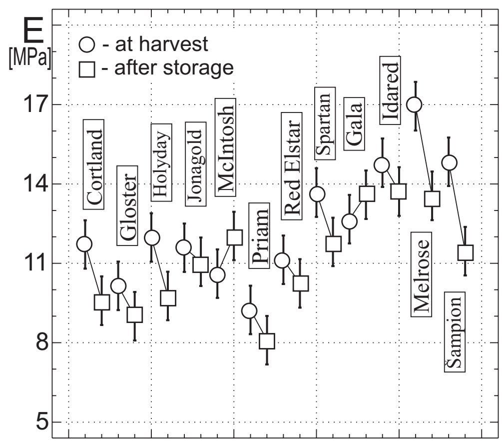

Fig. 1. Modulus of elasticity of apple skin at tension of the belt sample.

for the apple skin showed the weakest mechanical properties in the case of the Priam cultivar.

Modulus of elasticity (*E*) of flesh for all the studied cultivars determined during compression tests is present in Fig. 2. Slight decrease of elasticity during storage was noticed. However, only for the Gloster and Red Elstar cultivars significant (p=5%) differences were observed. The highest value of the modulus of elasticity (2.76 MPa) was obtained for the Gloster cultivar at harvest maturity. The mean values obtained in the compression test for the other studied cultivars reached the range from 1.26 MPa to 2.40 MPa. However, a decreasing tendency of flesh firmness after storage was observed for the modulus of elasticity of cylindrical flesh compressed between parallel plates.

The values related to elasticity determined with the penetration test for the Cortland, Gala, Gloster, Holyday, Jonagold, Idared, McIntosh, Melrose, Priam, Red Elstar, Spartan, Šampion cultivars (Fig. 3) decreased after storage. Mostly, the storage had highest statistically significant effect (p=5%) on the decrease of the calculated values related to the modulus of elasticity. The highest elasticity of apple at harvest maturity was observed for the Holyday (5.96 MPa) and Melrose (5.65 MPa) cultivars. The lowest values at consumption maturity after storage obtained in the penetration test for the apple of the Red Elstar cultivar (0.34 MPa) was close to ten times lower than for the Gala (3.29 MPa), Melrose (3.22 MPa), Holyday (3.13 MPa) or Idared (2.75 MPa) cultivars.

The modulus of elasticity obtained for the flesh beam at the bending test for apple fruit is shown in Fig. 4. Modulus of elasticity reached the values in the 1.04÷2.45 MPa range. Storage had a significant influence on the decrease of the value related to the modulus of elasticity for the most varieties used in this study. Only the Cortland variety reached mean values at the similar level (1.41 MPa at harvest and 1.49 MPa after storage) and no significant differences were noted.

The values of elasticity modulus (Fig. 5) obtained during the bending test of the flesh beam with skin over showed the effect of

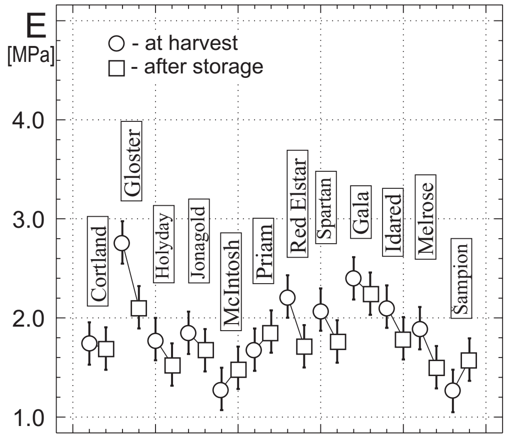

Fig. 2. Modulus of elasticity of apple tissue at compression of the cylindrical flesh sample.

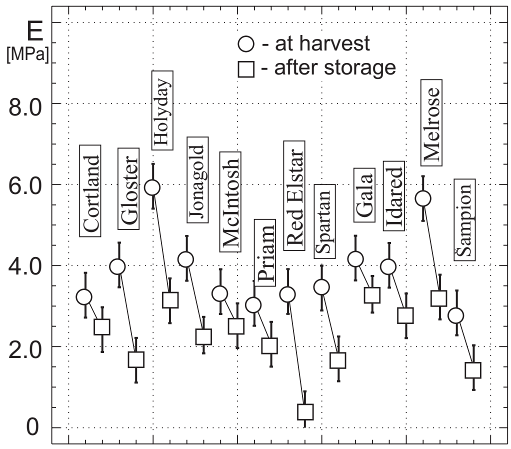

Fig. 3. Elasticity of apple flesh at the penetration test.

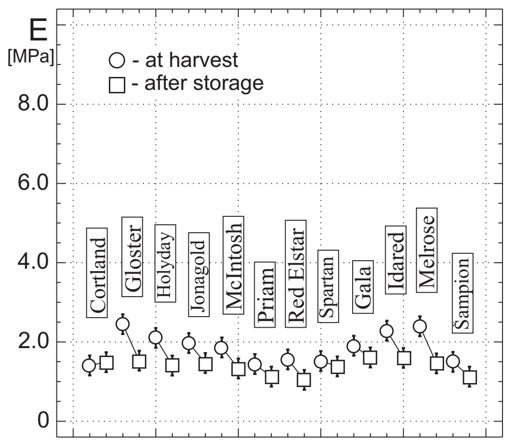

Fig. 4. Modulus of elasticity at bending of the flesh beam.

storage on fruit firmness more distinctly and it allows to distinguish most of the cultivars. The values noticed after harvest ranged from 2.90 MPa for the Red Elstar variety to 6.50 MPa for the Gloster cultivar and were about two times higher than after storage. The highest differences in the elasticity of apple at different stages of maturity were noticed with the bending test of flesh beam with skin. It shows that fruit firmness was strongly related to the modulus of elasticity of apple flesh as well as to the modulus of elasticity of apple skin. The strength of the superficial layer of the apple flesh determined in the bending test reflects the influence of mechanical resistance of apple skin on the fruit firmness more accurately. However, this test needs lots of experience with flesh preparation as the most complicated to perform. Thus differentiation in fruit firmness observed in the previous paper [12], as well as the results obtained in this study for the penetration test allowed to use this method to compare apples during storage.

The maximum values of the squeezing force for the Idared cultivar received in the penetration test with the 6 mm plunger are presented in Fig. 6. There were no significant (p=5%) differences between the studied temperatures of storage for this cultivar. For all the studied cultivars a similar tendency was observed. It was also noticed that the Idared apples were firmer, however, significant differences were observed for the apple with skin only.

The results obtained from the penetration test allowed to compare the cultivars according to the fruit hardness, however, firmness of the flesh was similar and frequently there was no significant differences in fruit, stored at different conditions. It showed that using a simple penetration test, slight changes in fruit firmness were not observed for the apple storage at different conditions.

More distinct differences were observed for the apples kept in different conditions, when observing deformation at the peak of the squeezing force. However, only the apple stored in unsuitable condition showed more significant

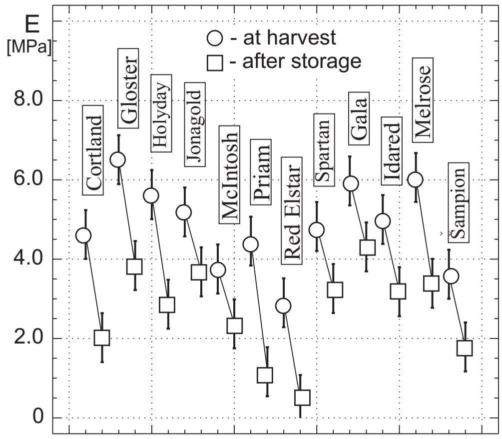

Fig. 5. Modulus of elasticity at bending of the flesh beam with skin.

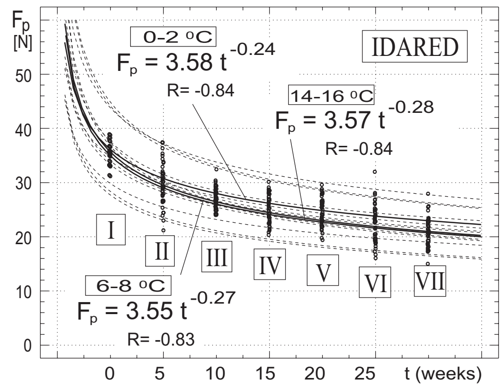

Fig. 6. Squeezing force for the Idared cultivar at penetration with the 6 mm plunger.

soft and large deformations. The influence of temperature on the flesh deformation of the Idared apple is presented in Fig. 7. Big deformation of the apple flesh was observed in the stored fruit, particularly apples kept for more than 10 weeks at 14-16 ^{o}C. A significantly higher flesh deformation was observed at the peak of the force in the case of stored apples and, weak reaction of fruit to the squeezing force. On the other hand, no significant differences of force at the peak proved that the penetration test performed according to the Magness-Tylor's method presented the behaviour of apple flesh in accurately. The results obtained for the four

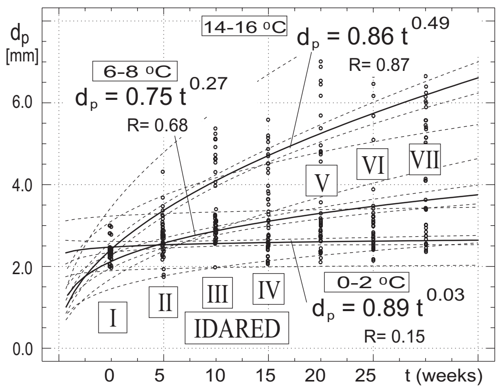

Fig. 7. Flesh deformation of the Idared apple at the peak of force.

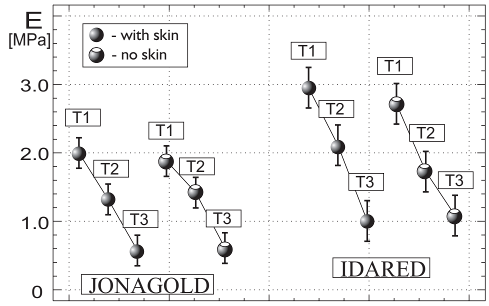

Fig. 8. Modulus of elasticity of apple flesh determined using the Elasticity Meter.

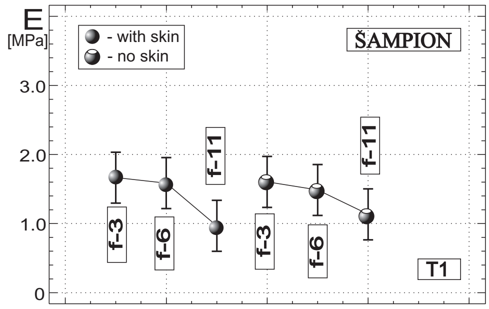

Fig. 9. Modulus of elasticity of apple flesh for the 3, 6 and 11 mm plungers.

apple varieties by Dobrzański, jr. *et al.* [12] by means of penetration, compression and tension tests suggest that the values related to the elasticity limits determined in the penetration test at small deformation allow to compare time and temperature of storage.

According to the results of the previous study, the modulus of elasticity was determined using the Elasticity Meter. It showed the highest firmness of the apple stored at 0-2 ^{o}C for the Idared cultivar. The modulus of elasticity reached the values of: 2.94 MPa for the apple with skin and 2.70 MPa for the apple flesh (Fig. 8). Elasticity related to fruit firmness decreased in all the studied cultivars at the temperature of 6-8 ^{o}C (T2) and 14-16 ^{o}C (T3). For the Jonagold cultivar, the mean values of the modulus of elasticity decreased from 2.0 MPa (0-2 ^{o}C) to 0.57 MPa (14-16 ^{o}C). Modulus of elasticity allowed to compare the influence of storage conditions on fruit firmness.

The lowest elasticity was observed for the Šampion cultivar (Fig. 9). The modulus of elasticity reached the following values: 1.81, 1.58, and 1.04 MPa for the apple with skin and 1.74, 1.49, and 1.23 MPa for apple flesh, respectively for the plungers: 3, 6 and 11 mm. The low value of elasticity for the 11 mm plunger was connected with the convex shape of the fruit and a small contact area with the plunger. It caused low stress of the initial deformation and consequently, large strain up to the full contact of the plunger's surface with the apple. However, there were no significant differences between the diameter of plungers used in this study. Similar values determined in both cases: for fruit with skin and for apple flesh prove that the Elasticity Meter allowed for measuring fruit firmness adequately to the mechanical properties of flesh; independent of the skin strength.

According to the method elaborated by Gołacki [17] water potential was determined for the Golster, Jonagold and Idared apples during storage and shelf life. A negative tendency of water potential decrease was observed (Fig. 10). It shows viscoelasticity of apple flesh (specially for the slightly dehydrated apples with the water potential under 1.2 MPa). After harvest water potential ranged from 0.7 MPa for the Jonagold

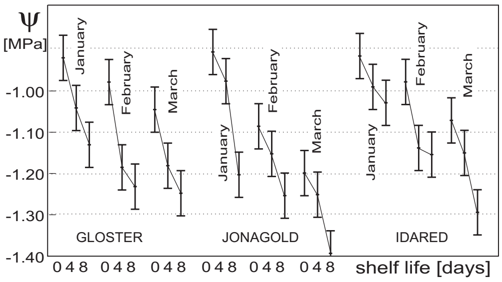

Fig. 10. Water potential for the Golster, Jonagold and Idared apples during storage and shelf life.

cultivar to 0.9 MPa for the Gloster and after storage increased to 1.1 MPa for the Gloster and to 1.2 MPa for the Jonagold. The most distinct increase of water potential was observed for the Jonagold cultivar. For the Gloster and Idared varieties only slight changes in water potential were observed.

DISCUSSION

Measurements of fruit firmness have been used for many years as a guide line to the quality of the product and are often the main test to establish acceptability of the product for a particular market or storage condition. However, the penetration test is still a destructive technique and firmness determined with many simple devices does not correctly reflect the mechanical state of fruit tissue.

Fekete and Felföldi [16] used a hand-held device equipped with a force sensor for the determination of the coefficient of elasticity as a ratio of compressive stress to the constant deformation (0.3 mm). The constant deformation in relation to the unknown size of fruit gives the incomparable values of strain. On the other hand, in the previous paper the authors presented differentiation of fruit size. It is easy to conclude, that the influence of fruit size on the coefficient of elasticity determined in this way, was more significant than differentiation in fruit firmness.

It was also noticed that various squeezing forces are commonly understood as fruit firmness and frequently result in the same deformation. On the other hand the same force is observed at for various deformations. Hence only the modulus of elasticity covers the following parameters: force, stress, deformation and strain; a new device was elaborated for the elasticity estimation.

The elasticity meter was applied for apple (with skin) and apple flesh (skin off) and no significant differences were observed for both methods. The results are almost the same for the 3 and 6 mm pin for the apple with skin and without skin. This proved that the modulus of elasticity was determined at small deformation under the break point; and the Elasticity Meter was successfully used, as a quasi non-destructive device.

Some methods are at a more advanced stage of development than others, however, many researchers [29,31] are not satisfied with several techniques of quality estimation and their poor correlation with fruit firmness. Probably, the methods of fruit firmness estimation based on the measurement of the squeezing force, gave low correlation with many quality factors.

Effects of storage and maturity on bruise susceptibility of apples discussed in literature appears to be contradictory. Diener *et al*. [8], reported that at harvest, more mature apples were less easily bruised, whereas Dobrzański, jr. and Rybczyński [9] and Tsukamoto [34] found exactly the opposite. They also noted a decrease in damage after longer storage periods following harvest. However, Schoorl and Holt [27], found increased bruise susceptibility with increasing storage time.

Some of the results obtained using the Elasticity Meter presented in this paper give hope that the modulus of elasticity shows slight changes in the apple firmness during storage and shelf life more distinctly. The Elasticity Meter should be useful for the system of fruit quality estimation on the basis of firmness of fresh and stored apple evaluation. However, further work is needed to study correlation between many quality factors and fruit firmness.

CONCLUSIONS

Mechanical tests performed on apple flesh and skin showed different behaviour of apple firmness. In most cases, storage had a significance influence on the mechanical properties estimated by different tests used in this study. The elastic behaviour of fruit showed that fruit firmness decreased unequally in the studied cultivars after storage.

The bending technique (flesh beam and flesh beam with skin) allowed to evaluate flesh firmness of the apple in the under-skin layer. Estimations of the mechanical resistance of apple using bending tests evaluated susceptibility to bruising and skin damage. According to this method the values related to the modulus of elasticity showed changes in the apple firmness after storage more distinctly.

The results obtained in this experiment show that the water potential of apple tissue is mostly related to fruit firmness and determines the physical state of apple during storage. The results obtained showed that water potential allows to determine the quality of apple during storage and shelf life, however it is a difficult method to adapt and develop in practice.

Although, these mechanical tests remain destructive, they are very useful as a source of basic information and comparison for the tests that will be developed in the future as non-destructive.

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