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Investigation the Effect of Skin on Mechanical Behavior of Apple

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Abstract: The usual puncture test was applied to determine some mechanical properties of Golden Delicious and Red Delicious apple and effect of skin on this parameters. The difference between overall puncture load displacement (whole fruit) and that measured without skin provide a satisfactorily precise result related to mechanical behavior of skin itself. This procedure is applied to evaluate the effect of skin on mechanical behavior of apple. Skin has an effective role in most puncture properties of the apple. Skin cause to increase in maximum force of compression, firmness, toughness, lam's coefficient and elastic modulus of the apple. The kind of varieties has a significant effect on force, firmness, lam coefficient (μ) and elastic modulus of apple. For two varieties of apple skin has a high percent of toghness and rupture force but the contribution of skin in Golden Delicious apple is higher than Red Delicious apple. The contribution of skin in deformation for 2 varieties is few.

Key words: Apple, skin, puncture test, mechanical property

INTROUDUCTION

After harvesting fruit and vegetable tissue are submitted to a lot of mechanical strains (shocks, vibrations, compressions) causing tissue damage and quality loss. Studies may be performed with materials in their natural state, or with specimens prepared from them. Since, most agricultural materials are processed in their natural state (e.g., whole fruits with peel), measurements should generally be carried out under circumstances corresponding as closely as possible to this state. Skin has an important role in maintaining overall shape and integrity of many fruit and vegetables. It provides a physical barrier against to microbial invasion. The mechanical behavior of the skin greatly influences firmness and resistance of fruit to splitting (Blahovec *et al*., 1995; Clevenger and Hamann, 1968; Lustig and Bernstein, 1985; Jackman and Stanley, 1994; Grrote *et al*., 2001). A better knowledge of its physical properties is, as a matter of fact, of importance to select new varieties with lower bruise susceptibility. Conventionally, puncture tests are carried out on a peeled area at the equator (ASAE, 1995; Bourne, 1965; Timbers *et al*., 1965; Grrote *et al*., 2001). Various devices are used for this purpose Hand-operated instruments or semiautomatic devices take out only maximal force required for tissue breaking. Supplied results are solely related to the flesh firmness. Automatic apparatus with indenter movement control allow defined and constant speed of penetration (Abbott, 1999; Planton, 1996; Grrote *et al*., 2001). Mostly computerized, these systems have the ability to instantaneously record load displacement curve.

Several researchers (Lustig and Bernstein, 1985; Duprat *et al*., 2000; Jackman and Stanley, 1994; Thompson *et al*., 1992; Voisey *et al*., 1970) had shown the feasibility of usual puncture tests to study mechanical properties of fruit skin (apple, cucumber, grape berry, tomato). With tomato fruit ripening, Jackman and Stanley (1992) had noted an increase in effective area of compression during puncture with skin. From this they conclude nevertheless that the difference between overall puncture load displacement and that measured with the skin removed, can provide a first approximation of the load displacement behavior of the skin itself. Previous results of texture measurements on the Golden Delicious apple (Duprat *et al*., 2000) also suggested that error lies within the accuracy limits of the method and within the inter- and intralot variabilities. Grotte *et al*. (2001) investigated the mechanical properties of the skin of Golden Delicious apples with the puncture test. They showed that apples texture properties of skin are varried during cold storage.

There is a little published information on young's modulus and lam's coefficient of apples and effect of skin on this parameters, in most of investigations the effect of skin is ignored. The objectives of the present work were to calculate young's modulus and lam's coefficient of whole and flesh of apple and show the effect of skin and calculated the texture property (deformation, failure load, firmness and toughness) of flesh and skin of 2 varieties by the use of puncture test and compare them.

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MATERIALS AND METHODS

Apple sample: The apples used in this study were of Golden Delicious and Red Delicious variety, which are 70-80 mm diameter. This variety was selected because they are common variety of apple in Iran. The apples were carefully hand-picked in autumn 2006 from an orchard in Maragheh. This apples were kept in cold storage (0°C, 95% humidity), for 120 day's. For each cultivar 10 apples were analysed. In this study we use the method that applied by Jackman and Stanley (1992) and Grrote *et al.* (2001).

Local puncture test: Firmness measurement was performed using an Instron universal testing machine. After removing from the cool store apples were kept during 24 h at 23°C before testing. A cylindrical indenter, 11 mm in diameter, with a hemispherical tip was used. Penetration speed was set at 22.5 mm min^{-1} and test was stopped after penetration to 10 mm. measurements were taken in the equatorial region of the whole fruit (Fig. 1).

Measurements were taken in the equatorial region of the whole fruit (Fig.1), up to 10 mm flesh depth. Penetration test on each apple was first carried out at three equally distributed locations (a, b, c) on the equator for load displacement curve with skin. Next, the puncture test was performed for load displacement curves at peeled (a', b', c') locations between the measured points.

Load displacement curve: Load displacement curves obtained with and without skin (Fig. 2). The output from a whole apple at constant strain rate presents a linear compression part (a′) with a maximum (F_t). After this, the load falls to a lower level (b′) as the indenter moves through the tissue. The effect of friction on the sides of the indenter may have been the primary cause of the slight rise in force for additional displacement. The first and largest peak (F_t) representing skin bursting occurs when the flesh elasticity limit is reached and then the flesh collapses.

Without skin peak is missing. Maximum level of the linear compression part (a′) represents the flesh elasticity limit. Its value is almost equal to the mean force value of the shear force phase (b′). Thereafter, the loading force increases slightly. Inferred parameters from load displacement curves with skin are bursting skin force F_t and related displacement D_p. Without skin, inferred parameters are maximum load F_d of the linear compression phase (a′) and related displacement Dc. F_d corresponds to the elasticity limit of the flesh.

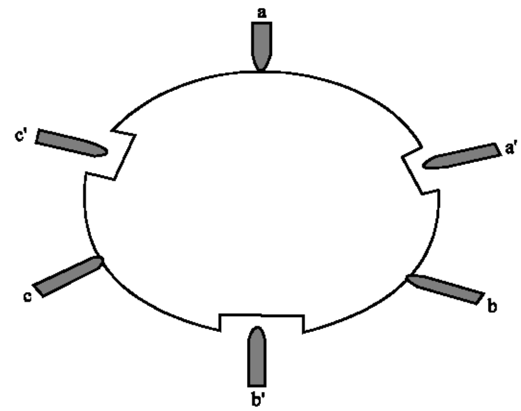

Fig. 1: Puncture locations on apple equator (a, b, c- with skin; a', b', c'- without skin)

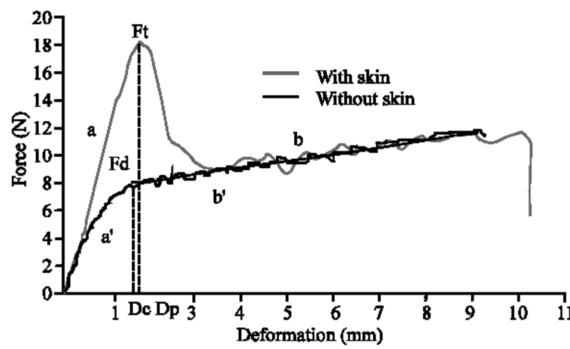

Fig. 2: Load-displacement curve from puncture tests. F_t, bursting skin force; F_d, force corresponding to the elasticity limit of the flesh; D, displacement related to F_t; D_c, displacement related to F_d

Contribution of the skin to firmness values: Curve parts related to puncture shear with whole fruit (b) and with skin removed (b′) are virtually parallel unless superimposed. Therefore, the contribution of the skin (F^s) to the overall bursting force is equal to the difference between the overall rupture force (Ft) and the flesh rupture force (F_d):

$$F_S = F_t - F_d \quad (1)$$

Displacements: On principle, puncture tests supply a pinpoint measure of firmness. So as to limit the effect of the fruit heterogeneity on the data, comparison is made between each displacement value with whole fruit and those measured without skin at one close location:

- a with a' and c'
- b with a' and b'
- c with b' and c'

The 3 pairs of data retained for comparisons are those ones where absolute error on the displacement is lowest: Error = $|D_p - D_c|$. Selected individual measurements taken at three locations with and without skin are averaged to describe firmness properties of individual fruit.

Firmness parameter: Puncture firmness in N m^{-1} is calculated as the average slope of load displacement curve from zero to the point of rupture or failure.

For apples, this curved part is generally straightforward. Therefore, the curve slope will be calculated from both the puncture force (F_t or F_d) and the Displacement (D_p or D_c) induced by this force:

$$\text{Firmness} = \frac{F}{D} \tag{2}$$

Toughness (rigidity), or mechanical energy or work required for skin rupture is calculated from the area under load displacement curves from zero up to the point of rupture or failure. So, toughness will be determined as follow:

$$\text{Toughness} = \frac{1}{2}F.D \tag{3}$$

Elasticity coefficient measurement: The following equations used to estimate the valve of apparent modulus of elasticity. These equations are based on the hertez equation for contact stresses used in solid mechanics (ASAE standard, S368.3):

For whole apple (skin+flesh):

$$E = \frac{0.338k_u^{\frac{3}{2}}F\left(1-\mu^2\right)}{D^{\frac{3}{2}}}\left(\frac{1}{R_U}+\frac{1}{R'_U}+\frac{4}{d}\right)^{\frac{1}{2}} \tag{4}$$

For flesh of apple:

$$E = \frac{0.531F\left(1-\mu^2\right)}{D^{\frac{3}{2}}}\left(\frac{4}{d}\right)^{\frac{1}{2}} \tag{5}$$

Where, E, F, μ and D are, respectively young's modulus, force, poission's ratio and deformation. R_u, R'_u are are maximum and minimum radii of curvature of apple and k_u is constants that's related to the radii of curvature.

Lama's coefficients λ and μ: Lama's coefficients λ and μ are derived from Young's modulus and Poisson's ratio following equations:

$$\lambda = \frac{v.E}{(1-v).(1-2v)} \tag{6}$$

$$\mu = \frac{E}{2(1+v)} \tag{7}$$

The amount of poission ratio is 0.23 for flesh of 2 varieties and 0.18, 0.21 for whole apple, respectively in Red Delicious and Golden Delicious apple (Mohsenin, 1986; Grotte *et al.*, 2002).

RESULTS AND DISCUSSION

Displacement: ANOVA results showed that difference between 2 varieties with and without skin are not statistically significant (Table 1). But contribution of skin's displacment in Golden Delicious apple is higher than Red Delicious apple (Table 2). For 2 varieties D_t is higher than D_f also skin represent very few displacment. It seem's that higher percent of displacment is for flesh deformation (Fig. 3a). This result have shown the same magnitude as those obtained by Grotte *et al.* (2001) from punch test with 4 varieties of apple, that after storage displacement D_t is higher than D_f and skin represent a little percent of displacement.

Maximum force of compression: ANOVA result showed that difference between 2 varieties of apple is statistically significant, also difference between samples with skin and without skin are significant (Table 1). Figure (3b) showed that for Red Delicious apple flesh rupture force (f_d) is higher than skin rupture force (f_t-f_d). Skin represent 44.1% of overall rupture force. For Golden Delicious apple, skin rupture force is higher than flesh rupture force and skin represent 55.2% of overall rupture force. This results are have not the same magnitude as those obtained by Thompson *et al.* (1992), from preliminary punch test with various fruits (avocado, Bartlett pear, McIntosh apple) and vegetables (eggplant, green bell pepper, slicing type cucumber, Zucchini squash): Relative contribution from 58-88% of the overall puncture force. Probably difference between these results is for difference between the kind of varieties and for difference between times of storage. It seam's that for Red Delicious apples after 120 day storage the amount of flesh rupture force is high and it's flesh is very stiff than it's skin, but for Golden Delicious apple is vice versa.

Firmness: For 2 varieties of apple flesh firmness is higher than skin firmness, also amount of firmness for Golden Delicious apple is lower than Red Delicious apple

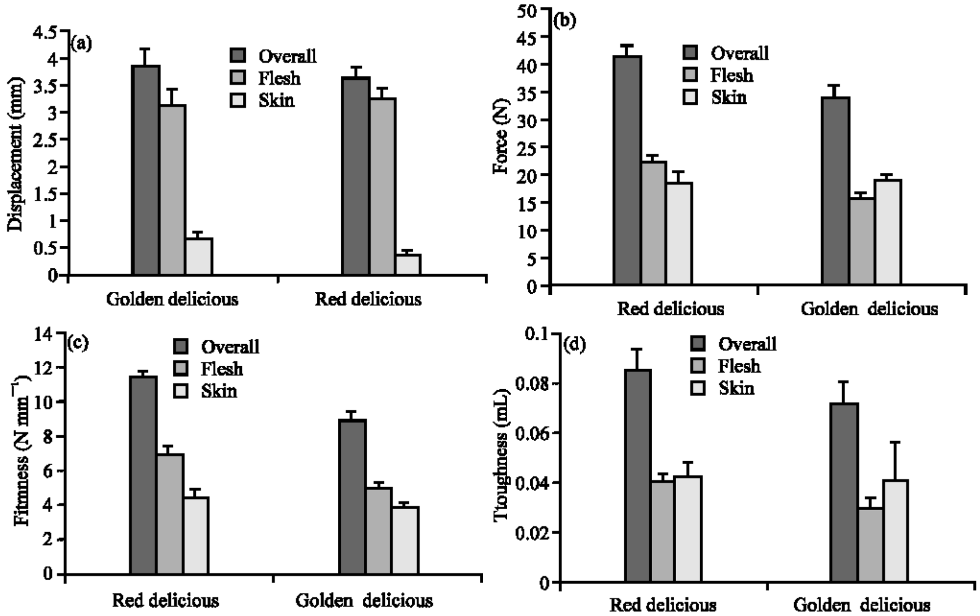

Fig. 3: Firmness properties of two varieties (Golden Delicious, Red Delicious) after 120 day storage period. a) displacement; b) rupture force; c) firmness; d) toughness. Error bar represent standard deviation of means

Table 1: F-values from ANOVA on the main effects and interaction for force, displacement, firmness

SOV	df	Force	Displacement	Firmness
A	1	16.9307**	0.0469^{ns}	43.96**
B	1	116.85**	4.7562*	160.97**
A and B	1	0.0008^{ns}	0.4429^{ns}	0.5195^{ns}
Error	36			

A: variety of apple; B: with skin and without skin; ns = not significant, ** significant at the 0.01 level of significant, *significant at the 0.05 level of significant

Table 2: F-values from ANOVA on the main effects and interaction for toughness, elastic modulus and lam's coefficient

SOV	df	Toughness	Elastic modulus	λ	μ
A	1	2.5654^{ns}	13.3836**	2.8913^{ns}	14.9148**
B	1	47.9985**	59.7033**	11.7939**	62.8561**
A and B	1	0.2149^{ns}	0.477^{ns}	2.7468^{ns}	0.858^{ns}
Error	36				

A: variety of apple; B: with skin and without skin; ns= not significant, ** significant at the 0.01 level of significant, *significant at the 0.05 level of significant

Table 3: Percent contribution of skin on firmness parameters of apple

	Contribution of the skin (%)			
Variety	Deformation	Rupture force	Firmness	Toughness
Red delicious	10.84	44.1	39.8	51.00
Golden delicious	20.8	55.2	43.21	58.34

(Fig. 3c). Skin represents 43.21 and 39.8% of overall firmness, respectively for Golden Delicious and Red Delicious apple (Table 2). ANOVA results showed that kind of varieties and skin have significant effect on firmness of apple (Table 1). It seem's that for 2 varieties of apple skin has a high role in firmness parameters of apple. This results are not agree with those result that obtained by Grotte *et al.* (2001) that skin firmness is higher than flesh firmness. It seem's that this difference is for difference between condition of growers and storage of apple.

Toughness: For 2 varieties skin toughness is higher than flesh toughness. The amount of toughness in Red Delicious apple is higher than Golden Delicious apple (Fig. 3d). Skin has a significant effect on toughness of apple but variety has not shown significant difference (Table 3). Skin represents 51 and 58.3% of overall firmness, respectively for Red Delicious and Golden Delicious apple.

Elastic modulus: For two varieties elastic modulus of whole apple (skin+flesh) is higher than flesh elastic modulus (Fig. 4a). Skin cause to increase of elastic modulus. Statistic analys showed that skin has a significant effect on young's modulus of apple. Also there is significant difference between variety ($p<0.01$). Red Delicious apple's elastic modulus is higher than Golden Delicious apple. The amount of elastic modulus in this study is near to those that obtained by Mohsenin *et al.* (1986) and Grotte *et al.* (2002).

Lam's coefficient (μ, λ): For two varieties lam's coefficient of whole apple is higher than flesh (Fig. 4b and c). Skin has a significant effect on this coefficients, ($p<0.01$). ANOVA results shown significant difference between 2

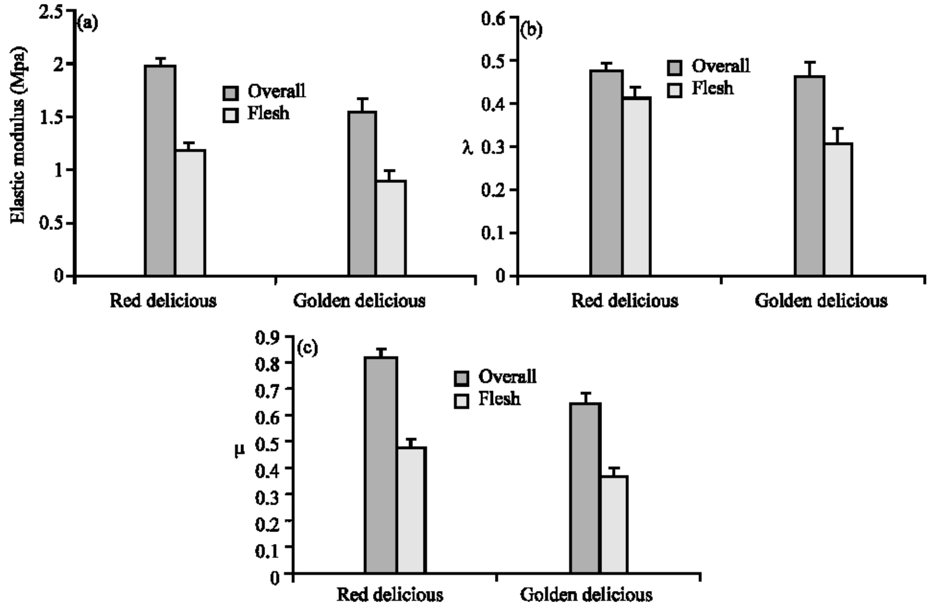

Fig. 4: Elastic modulus, lam's coefficient (μ, λ) of 2 varieties (Golden Delicious, Red Delicious) apple after 120 day storage periode. a) Elastic modulus; b) λ; c) μ. Error bar represent standard deviation of means

varieties for λ. This result are in agreement with those result that obtained by Grotte *et al.* (2002) for Golden Delicious apple.

CONCLUSION

Puncture tests through skin enable simultaneous measurements of fruit flesh and skin firmness. Differences between whole fruit load displacement curve and that measured with the skin removed provide knowledge on the mechanical behavior of the skin itself. Skin has a significant effect on all mechanical parameters of apple. In Golden Delicious apple skin has a high contribution of toughness, firmness, rupture force and deformation. But this contributions for Red Delicious apple is lower than Golden Delicious apple. Difference between two varieties in all parameters except toughness and displacement are significant.

REFERENCES

Anzaldua-Morales, A., M.C. Bourne and I. Shomer, 1992. Cultivar, Specific Gravity and Location In Tuber Affect Puncture Force of Raw Potatoes. J. Food Sci., 57: 1353-1356.

ASAE, 1995. ASAE Standard: ASAE S368.3. Compression Test of Food Materials of Convex Shape. In Standards Engineering Practice and Data Adopted by the ASAE; ASAE: St. Joseph, MI, pp: 466-470.

Abbott, J.A., 1999. Quality Measurement of Fruits and Vegetables. Post Harvest Bio. Tech., 15: 207-225.

Bourne, M.C., 1965. Studies on Punch Testing of Apples. Food Technology, 19: 413-415.

Blahovec, J., J. Jeschke and M. Houska, 1995. Mechanical Properties of the Flesh of Sweet and Sour Cherries. J. Texture Stud., 26: 45-57.

Clevenger, J.T. and D.D. Hamann, 1968. The Behavior of Apple Skin under Tensile Loading. Trans. ASAE., 11: 34-37.

Chen, H., F. Duprat, M. Grotte, D. Loonis and E. Pietri, 1996. Relation of the Impact Transmission Wave to the Apple Texture during Ripening. J. Texture Stud., 27: 123-141.

Duprat, F., F. Roudot, M. Grotte-Nicolas and A.C. Roudot, 1991. De L'h'et'erog'en'eit'e des Fruits. Sci. Aliments, 11: 609-622.

Duprat, F., M. Grotte, D. Loonis and E. Pietri, 2000. Etude de la Possibilit'e de Mesurer Simultan 'ement la Fermet'e de la Chair et de L''epiderme des Pommes. Sci. Aliments, 20: 253-264.

Finney, E.E., 1969. To Define Texture in Fruits and Vegetables. Agric. Eng., 50: 462-465.

Garcia, J.L., M. Ruiz-Altisent and P. Barreiro, 1995. Factors Influencing Mechanical Properties and Bruise Susceptibility of Apples and Pears. J. Agric. Eng. Res., 61: 11-18.

Grrotte, M., D. Loonis and E. Dand Pietri, 2001. Mechanical properties of the skin and the flesh of Apples. Int. J. Food Properties, 4: 149-161.

Grrotte, M. Duprat, F.E. Pietri, D. Loonis and Young's Modulus. 2002. Poisson's ratio and Lam's Coefficients of Golden Delicious apple. Int. J. Food Properties, 5: 333-349.

Jackman, R.L. and D.W. Stanley, 1994. Influence of the Skin on Puncture Properties of Chilled and Nonchilled Tomato Fruit. J. Texture Stud., 25: 221-230.

Lustig, I. and Z. Bernstein, 1985. Determination of the Mechanical Properties of the Grape Berry Skin by Hydraulic Measurements. Sci. Hortic., 25: 279-285.

Mohsenin, N.N., 1986. Physical Properties of Plant and Animal Materials-Second Updated and Revised Edition. New York: Gordon and Breach Science Publishers.

Planton, G., 1996. Mesurer la Qualit´e des Fruits. M´ethodes et Appareils N´ecessaires. Infos CTIFL, 124: 22-26.

Thompson, R.L., H.P. Fleming and D.D. Hamann, 1992. Delineation of Puncture Forces for Exocarp and Mesocarp Tissues in Cucumber Fruit. J. Texture Stud., 23: 169-184.

Timbers, G.E., L.M. Staley and E.L. Watson, 1965. Determining Modulus of Elasticity in Agricultural Products by Loaded Plungers. Agric. Eng., 46: 274-275.

Voisey, P.W. and L.H. Lyall, 1970. Measurement and Relation to C racking. J. Am. Soc. Hortic. Sci., 95: 485-488.