Relationship between mechanical properties of pumpkin and skin thickness

Bagher Emadi*[1], Vladis Kosse[2], Prasad Yarlagadda[3]

[1, 2, 3] School of MMME, Queensland University of Technology (QUT)

2,George Street, P.O.Box 2434, Brisbane, QLD 4001, Australia

Fax: +617 3864 1469

Bagher_Emadi@yahoo.com

V.Kosse@qut.edu.au

P.Yarlagadda@qut.edu.au

Abstract

Reducing the mechanical damage and losses in pumpkin processing is a matter of interest for manufacturer and consumers of pumpkin processing equipment such as peeler. Knowing the effective mechanical properties in design and application of that equipment and the range of changes because of different thicknesses can be helpful to approach to the ideal design and application. The existence of any relationship and its application between mechanical properties of pumpkin and skin thickness was the main aim of this research. The increase of skin thickness caused increasing of toughness and rupture force in both cases of skin and unpeeled pumpkin. The rate of increase of skin toughness was significantly lower as the reason of low deformability of skin. While the unpeeled cutting force was relatively constant, the cutting force of skin was higher for higher thickness. Applying higher cutting force for thicker skin product will increase the risk of damage and losses. While the shear strength force of skin was higher for thicker skin products, it was lower for unpeeled case. Shear strength was decreasing for both cases. It showed softness of tissues in thicker skin areas of pumpkin and high risk of mechanical damage and losses in these areas.

Introduction

Mechanisation of agriculture particularly after harvest has been produced big demand on the knowledge of physical and mechanical properties of products. Knowing those properties will be useful for both manufacturers and consumers of food processing equipment. To determine the resistance border of product to unwanted mechanical loads will help consumers to save the products from mechanical damage such as bruise (Brusewitz et al., 1991). On the other hand food processors need to apply wanted loads for work to be done. For example applying the minimum force to cut the peel in peeling stage of food processing is a matter of importance. To specify the minimum amount of wanted loads helps producers to save energy and optimise equipment design.

Compression test has been extensively applied in the study of mechanical properties of fruits and vegetables (Jackman, R.L., & Stanley, D.W., 1994, Voisey, P.W., & Lyall, L.H., 1965a, Voisey, P.W., & Lyall, L.H., 1965b, Grotte et al., 2001, Holt, C.B., 1970, Voisey et al., 1970, Behnasawy et al., 2004). Firmness, toughness, and rupture force are some examples of mechanical properties that can be investigated by compression test. It can be used to determine the mechanical properties of product in different cases involving flesh, skin, and unpeeled product. Compression test on skin is conducted in two different forms. The properties of skin can be investigated by applying directly compression test on skin or by calculating the difference between the values of mechanical properties of flesh and unpeeled product (Grotte et al., 2001, Jackman et al., 1994, and Voisey et al., 1970).The first method is preferred because in the case of thick-skinned product there are no limitations such as difficulty in holding of skin specimens during the test (Su & Humphries, 1972) and creation of premature tensile failure during specimen preparation (Clevenger & Hamann, 1968; Thompson, Fleming, & Hamann, 1992).

The mechanical properties of skin can be affected by the thickness of skin. As the thickness of skin changes in different places of product (Ohwovoriole et al., 1988), different values of mechanical properties are expected in different places (Rybczynski, R. and Dobrzanski, B., 1994). Knowing the range of changes in mechanical properties of pumpkin which exist because of different skin thickness will be useful for pumpkin processing industry. Investigation of any relationship between mechanical properties of pumpkin and skin thickness and their preliminary application in pumpkin processing was the main purpose of this study.

Materials and methods

Jarrahdale variety of pumpkins (*Cucurbitaceae family*) was randomly chosen from different local farms around Brisbane (Queensland, Australia). The vegetables were ripe, defect-free, and in different sizes. They were prepared for tests by keeping them under controlled laboratory conditions at least 24 hours prior to tests on the basis of ASAE standard (2001). The temperature of 20-25°C and relative humidity of 50-55% were maintained as main environmental parameters. Because conducting the test on the whole vegetable was impossible, the circular shape specimens of 80 mm in diameter and 10 mm thick (flesh depth) were prepared from unpeeled product by using a special cutter device. Skin specimens were prepared with diameter of about 30 mm and flesh removed by means of scraping to avoid any ambient effects on test results. The specimens were prepared from equatorial region of the whole vegetable as well as from top and bottom regions of whole vegetable. The specimens on each diametrical circle were taken from convex and concave areas of the vegetable. Different holders were designed and fabricated for unpeeled specimens and skin specimens (Figs. 1 and 2). The averaging of results for different skin thickness and for each case were applied for assessment.

Fig.1. The unpeeled specimen holder

Fig. 2. The skin holder

The compression tests were performed under ASAE standard conditions (S368.4, 2001) using an Instron machine (Hounsfield H5000M) controlled by a PC. A cylindrical indentor, 8 mm in diameter, with a hemispherical end was applied. The ratio of diameter of indentor to the diameter of specimen was 1/10 to close the obtained results of investigation on specimen to whole vegetable. The penetration speed of the indentor was chosen 20 mm·min^{-1}. Every experiment was repeated 20 times.
Force-deformation curves for skin and unpeeled cases were obtained directly from compression test for each case. Rupture force was measured at rupture point as the pick point of curve (Fig. 3). The area under force-deformation curve from the initial up to rupture point was calculated as toughness. It was actually the mechanical energy required to break the tissues of pumpkin.

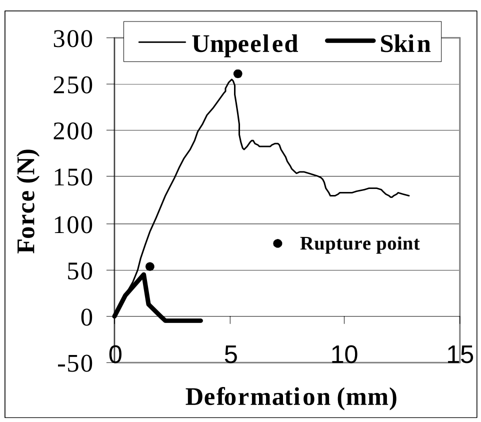


Fig.3. Force-deformation curves of pumpkin (Jarrahdale) for skin and unpeeled cases

In addition to compression test, the shear strength test was carried out on each case of skin and unpeeled product. The shearing strength of the product indicates the degree to which the cells are held together. Shearing strength of a product was investigated by shearing a plug from a slice of the product. Knowing shearing force, **F**, the diameter of the solid cylindrical die with flat end, **d**, and the thickness of the slice, **t**, shearing strength, **S**, was determined from (Mohsenin, N.N., 1980):

$$\mathbf{S} = \mathbf{F} / (\pi \cdot \mathbf{d} \cdot \mathbf{t}) \quad (1)$$

A flat end indentor with diameter 8 mm was used to shear the skin forcing by Instron machine with the speed of 20 $mm \cdot min^{-1}$. The maximum shearing force was recorded and shear strength was calculated for different thickness of skin in each case of specimens. The tests were repeated at least 10 times for every case and the mean in each skin thickness was considered to assess.

The cutting test was carried out to determine the necessary cutting force of a product in two different cases involving skin and unpeeled cases. A stainless steel cutting indentor with sharpened edges of 30° included angle, 1.5 mm thick (Ohwovoriole, 1988) was used on the Instron machine. The speed of loading was 20 $mm \cdot min^{-1}$. The test was repeated 10 times in different skin thickness and averaged results were calculated.

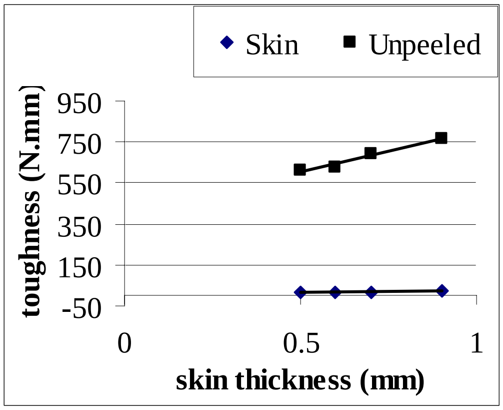
Results and discussion

The results were fit to the first-order regression models (Table 1) which can show the behaviour of investigated properties for different skin thickness within the range of experiments. The increasing of skin thickness showed the increase in skin and unpeeled

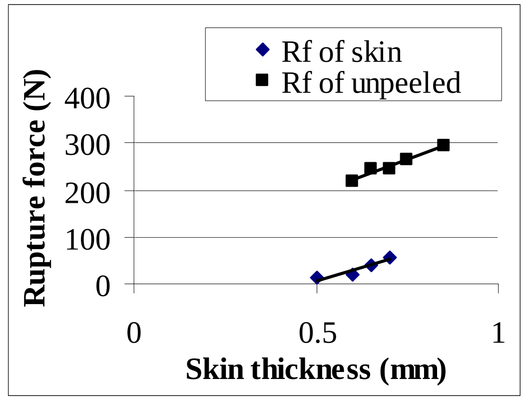
Table1. The regression models of investigated mechanical properties for different skin thickness

Property		Regression model	R^2
Rupture force	Skin	Y=222.27x-104.08	0.87
	Unpeeled	Y=284.29x+51.791	0.97
Toughness	Skin	Y=24.55x+2.1	0.89
	Unpeeled	Y=409.3x+397.79	0.91
Cutting force	Skin	Y=2.5x+1.25	0.97
	Unpeeled	Y=4.98	------
Max. force of shear strength	Skin	Y=23.49x+31.78	0.98
	Unpeeled	Y=-74.75x+232.61	0.87
Shear strength	Skin	Y=-2.68x+4.90	0.99
	Unpeeled	Y=-2.45x+3.18	0.98

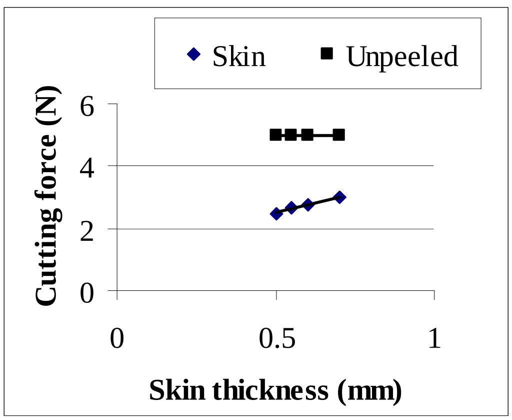
toughness but the rate of increasing of toughness was significantly higher than skin toughness (Fig.4a). It was proved that the toughness of unpeeled pumpkin is strongly related to the skin thickness while the toughness of skin is not significantly affected by skin thickness. Rupture force was also increasing with increase of skin thickness for both cases involving skin and unpeeled pumpkin. The increasing rate was nearly similar as it can be seen in Fig.4b. The comparison of the behaviour of skin and unpeeled pumpkin in toughness and rupture point for different skin thickness on figures 4a and 4b according to the toughness definition shows low deformation of skin compared to



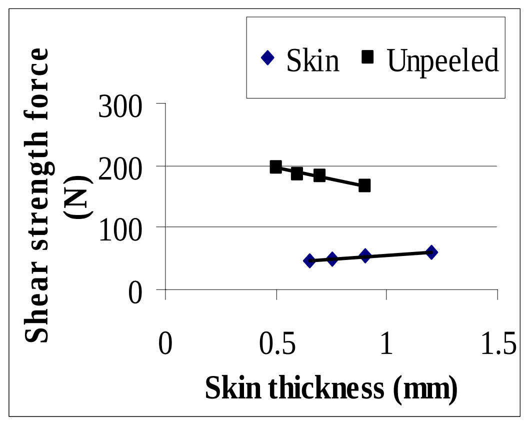
(a)



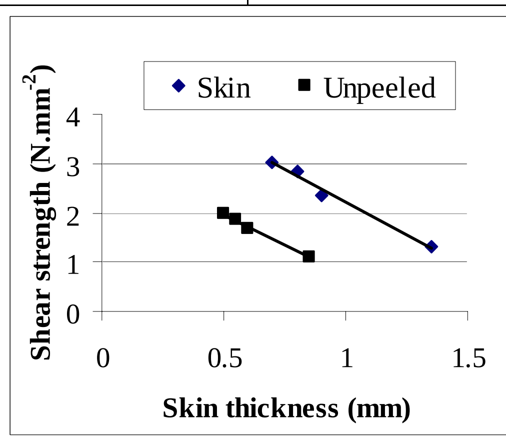
(b)



(c)



(d)



(e)

Fig.4. The relationship between investigated mechanical properties with skin thickness of pumpkin

unpeeled product. While the cutting force of skin increases as the result of higher skin thickness, the necessary force of cutting of unpeeled pumpkin was remained fixed for different skin thickness (Fig.4c). It means the value of cutting force for skin and unpeeled pumpkin will get closer for thicker skins. This point should be considered in the processing equipment of pumpkin such as peeler where applying higher cutting forces to pumpkin with thicker skin may causes damage to the rest of the product. Comparison of obtained results so far suggests applying mechanical peeling methods that work mostly on the basis of rupture and not cutting because to apply higher rupture forces for thicker skins will not injure the rest of products (Fig.4b). With increasing skin thickness the force needed for the shear strength of skin was increasing (Fig.4d) and shear strength of skin was decreasing (Fig.4e). Insufficient increasing rate of shear strength force lead to decreasing of shear strength for higher skin thickness. It means that shear strength of skin in unripened pumpkin is significantly larger (the layers of skin are still incomplete and growing). In other word young cells of peel have higher strength to shear. This result also can be extended to the thin-skinned areas of ripened product. The decreasing trend was found for the shear strength and maximum force of that in unpeeled case of pumpkin. It proves the higher softness of tissues in thick-skinned areas that causes the reduction of both properties in unpeeled case even with increasing the maximum force of shear strength of individual skin. This result confirms the higher risk of bruise and other mechanical damage to the thick-skinned areas of one product and whole thick-skinned pumpkin.

References

American Society of Agricultural engineers (2001). Compression test of food materials of convex shape. *ASAE S368.4* DEC00. USA.

Behnasawy, A.H., El-Haddad, Z.A., El-Ansary, M.Y., & Sorour, H.M. (2004). Physical and mechanical properties of some Egyptian onion Cultivars. *Journal of Food Engineering*, 62, 255-261.

Brusewitz, G.H., McCollum, T.G.; & Zhang, X. (1991). Impact bruise resistance of peaches. *Transactions of the ASAE*, 34 (3), 962-965

Clevenger, J.T., & Hamann, D.D. (1968). The behaviour of apple skin under tensile loading. Transactions of the ASAE, 11, 34-37.

Grotte, M., Duprat, F., & Loonis, D. (2001). Mechanical properties of the skin and the flesh of apples. *International journal of food properties*, 4 (1), 149-161.

Holt, C.B. (1970). The measurement of tomato firmness with a Universal Testing Machine. *J. Texture Studies*, 1, 491-501.

Jackman, R.L., & Stanley, D.W. (1994). Influence of the skin on puncture properties of chilled and nonchilled tomato fruit. *Journal of Texture Studies*, 25, 221-230.

Mohsenin, N.N. (1980). *Physical properties of plant and animal materials* (2nd ed., pp.238-241).New York: Gordon and Breach Science Publishers.

Ohwovoriole, E.N., Oboli, S., & Mgbeke, A.C.C. (1988). Studies and preliminary design for a cassava tuber peeling machine. *Transaction of the ASAE*, 380-385

Rybczynski, R. and Dobrzanski, B. (1994). Mechanical resistance of apple in different place of fruit. *Int. agrophysic*, 8, 455-459.

Su, C.S., & Humphries, E.G. (1972). Rupture properties of cucumber skin. Pickle Pak Sci., 2, 1-10.

Thompson, R.L., Fleming, H.P., & Hamann, D.D. (1992). Delineation of puncture forces for exocarp and mesocarp tissues in cucumber fruit. Journal of Texture Studies, 23, 169-184.

Voisey, P.W., Lyall, L.H., & Kloek, M. (1970). Tomato skin strength-its measurement and relation to cracking. *J. Amer. Soc. Hort. Sci*., 95, 485-488.

Voisey, P.W., & Lyall, L.H. (1965a). Methods of determining the strength of tomato skin in relation to fruit cracking. Proc. *J. Amer. Soc. Hort. Sci*., 86, 597-609.

Voisey, P.W., & Lyall, L.H. (1965b). Puncture resistance in relation to tomato fruit cracking. *Can. J. Plant Sci*., 45, 602-603.