Properties of Tough Skinned Vegetable-Pumpkin Tissue

Shirmohammadi M.* and Yarlagadda P.

Chemistry, Physics and Mechanical engineering- Queensland University of Technology, Australia
**Email Address: m.shirmohammadi@qut.edu.au*

Gudimetla P.

School of Mechanical and Mining Engineering- The University of Queensland, Australia

Abstract

Understanding of mechanical behaviour of food particles will provide researchers and designers essential knowledge to improve and optimise current food industrial technologies. Understanding of tissue behaviours will lead to the reduction of material loss and enhance energy efficiency during processing operations. Although, there are some previous studies on properties of fruits and vegetables however, tissue behaviour under different processing operations will be different. The presented paper is a part of FE modelling and simulation of tissue damage during mechanical peeling of tough skinned vegetables. In this study indentation test was performed on peeled and unpeeled samples at loading rate of 20 mm/min for peel, flesh and unpeeled samples. Consequently, force deformation and stress and strain of samples were calculated. The toughness of the tissue also has been calculated and compared with the previous results.

Keywords*: Mechanical behaviours, FE modelling, Stress, Strain, material loss, energy efficiency.*

1 Introduction

Australian food industrial sector is a sub section of food and beverages industry. It is the largest manufacturing industry in Australia with a turnover of more than $71.4 billion in 2005-6 [1]. The rate of material waste and energy consumption are the major factors are affecting the efficiency of this industrial division.

Regarding the properties of materials and the loading type, the rate of deformations differs in different operations. A loss of 30-50% has been reported in mango production line, as well as 20% and 30-50% waste for banana and orange respectively [2]. Different deformations such as bruise, pressure and dynamic collision are diminishing the quality and quantity of post harvesting and food processing chain. As an example dynamic and static collision can cause 20% loss in potato production lines [3] however the rate of loss will be higher for softer produce such as banana, mango and tomato. Apple loss raise up to 50% [4], it appears as internal discoloration and off flavours in damaged parts because of bruising and pressure [5]. Furthermore, mechanical deformations create up to 25% loss in post harvesting and 50-60% loss in processing period of agricultural produce [6].

Majority of agricultural crops have a skin that needs to be removed in one of the first steps of food processing industry. Regarding the method of peeling and the type of crops this process can create high rate of loss which generally is not desirable in processing industries. Studying the behaviours of agricultural crops under different industrial operations will help researchers and designers to optimise and design new technologies to diminish unwanted deformations and total energy usage [7-11]. The presented work is a part of research on FE analysis and simulation of tissue damage during mechanical peeling of tough skinned vegetables. This study has focused on the response of tough skinned vegetables -pumpkin tissue under compressive loading.

2 Mechanical behaviours of agricultural crops under loading

The typical force deformation curve for agricultural crops under indentations has been presented by Mohsenin (Figure 1) [12].

There is a linear section where material shows the elastic behaviours and deformation and damages disappear after unloading. Although it is essential to consider that agricultural crops are naturally soft and any source of force – even very small amount- can create damage which will diminish the quality and customer acceptability of these crops. In Figure 1, "stiffness or rigidity is indicated by the slope of initial straight line portion of the curve" [12].

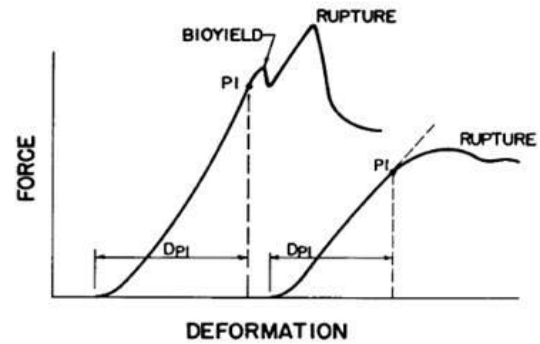
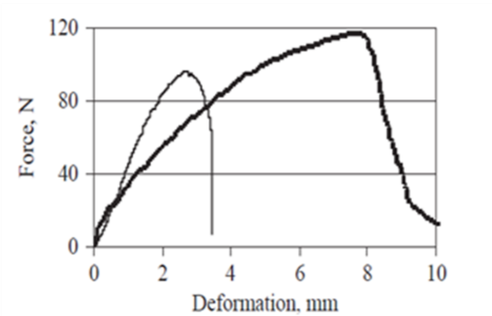
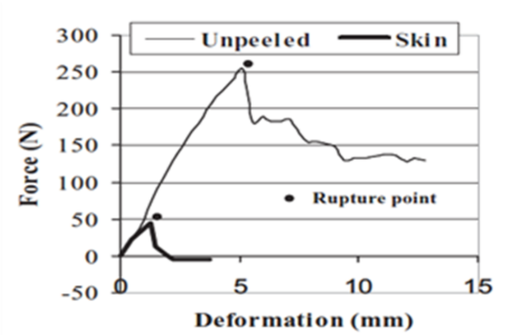


Figure 1: Force deformation curve for agricultural products[13].

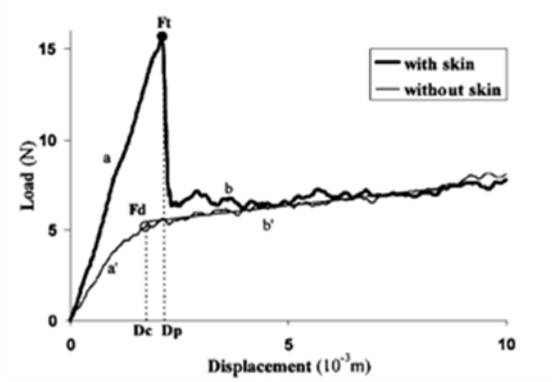
Elastic behaviours continue up to bio yield point (Figure 1) , and afterward, permanent deformation and changes take place [12-14].



(a)



(b)



(c)

Figure 2: Force-deformation curves for (a) cantaloupe melon: ──, peel; ──, unpeeled produce [15] and (b) apple [16] and (c) pumpkin [17].

In a study done by Emadi et al. [15] on peel and unpeeled samples of cantaloupe melon, Honeydew melon and Watermelon, compression test has been done using a 8 mm in diameter cylindrical probe in the speed of 20 mm/min. Additionally, Grotte et al. have been studied mechanical behaviours of different varieties of apple peel and flesh (including Fuji, Golden Delicious, Grammy Smith and Pink Lady apple). A hemispherical tip indenter with diameter of 4mm has been used by Grotte et al. The test performed at a loading speed of 20 cm per minutes. The results (Figure 2) shown that the maximum deformation and rupture force are 31.91 and 72.60 for Granny Smith and Golden Delicious respectively. The force deformation curve for pumpkin samples under indentation test also has been presented in Figure 2 (c) [17] in each study the results of tests have been used to calculate mechanical properties of samples.

3 Material and method

A spherical end indenter was used to compress the samples of Jap variety of pumpkin. This study has been done as a part of FE modelling and simulation of mechanical peels process of tough skinned vegetables. Accordingly, the core objectives of the study were calculating required properties of peel, flesh and unpeeled sample in order to use develop the computer model. The test completed according available standard for compression test of convex shape food materials [18]. The spherical indenter with diameter of 8mm used to compress samples in loading speed of 20 mm/ min. Samples have been prepared using Jap variety of pumpkin purchased from local shops in Brisbane (Queensland Australia). During sampling and test, the temperature and humidity were 20-25^{0}C and 20-55% respectively, and samples were prepared from ripe and defect free pumpkins. Pumpkins kept in laboratory condition 24-48 hours before the test. The average thickness of skin samples was 5 mm and unpeeled and flesh samples have 50mm thickness.

Test has been performed using an Instron Universal testing Machine (IUTM). Consequently, the results of force deformation collected from the computer attached to the machine. Afterward, different mechanical properties of tissue were calculated and compared with previous works. In order to calculate the mechanical properties of pumpkin tissue the following formulas were used [11, 12, 19, 20]:

$$\sigma = \frac{F}{A} \tag{1}$$

$$\varepsilon = \frac{\Delta l}{l} \tag{2}$$

$$T = \frac{1}{2} F_r D_r \tag{3}$$

$$Firmness = \frac{F}{D} \tag{4}$$

In these formulas, σ, ε, F, A, Δl, l, F_r, D_r and T were compressive stress, strain, load, cross sectional area, deformation, initial length, rupture force, deformation in rupture point and toughness.

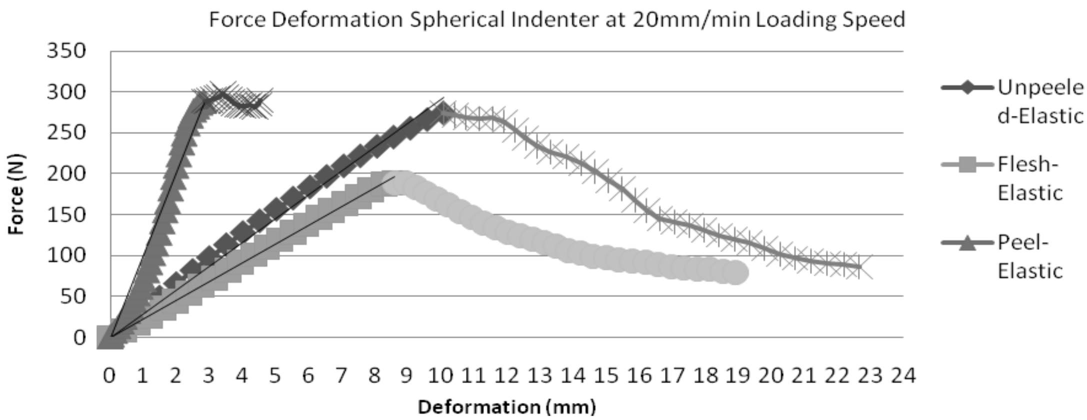


Figure 3: Force deformation curve of peel, flesh and unpeeled samples in indentation test.

4 Result and Discussion

4.1 *Load Deformation Results*

The results of force deformation curve for skin, flesh and unpeeled specimens have been presented in Figure 3.

From the obtained data, the following properties calculated and compared with available literature.

4.2 *Rupture Point*

Rupture in biological materials happens in bio yield point where the initial cell rupture starts taking place [12, 15, 17]. The details of maximum compressive load for skin, flesh and unpeeled samples presented in Figure 3, according to this data rupture point for flesh, unpeeled and skin are 188.5, 274, and 291 respectively. The result of rupture point for unpeeled sample is comparable with results of previous study of Jap variety of pumpkin which reported 250N [17]. The results also were higher than rupture point calculated for watermelon peel and honey melon unpeeled samples, 175 and 183 respectively [15].

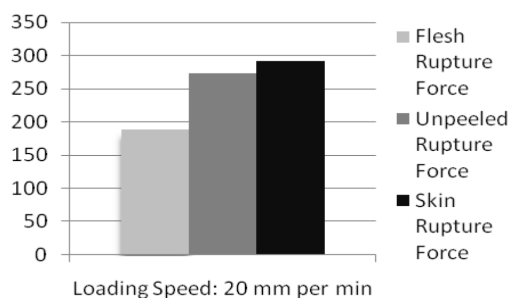


Figure 4: Rupture Force for Skin, Flesh and Unpeeled samples.

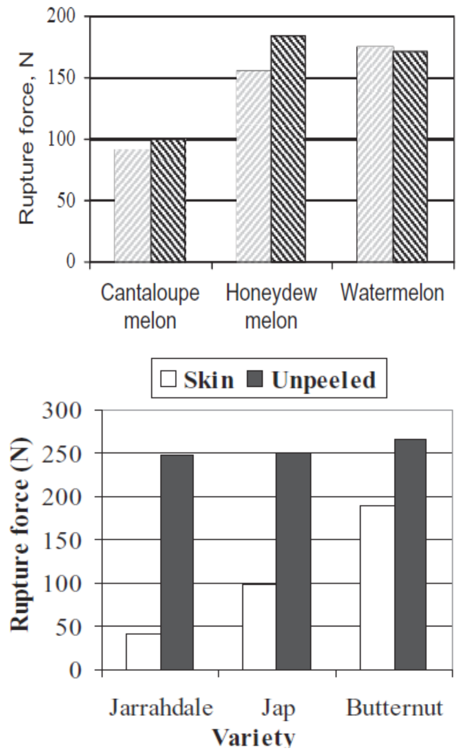


Figure 5: Rupture force for melons: unpeeled and peel (left) [15] and pumpkin (right) [17]

4.3 *Firmness*

The required force to achieve a specified deformation (Bourne 1967 & Schomer et al. 1962 in [19]) defined as firmness, the extension occurs under standard load (Kattan 1957, Parker et al.1966, Whittenberger et al. 1950 & Whittenberger 1951 in [19]), as well as the slope of force deformation curve from zero to the point of rupture and or failure (Ang et al.1960, Burkner et al.1967 in [19] and [16, 19]). Regarding to these definitions, any increase in the ratio of force over deformation will increase the tissue firmness. In the other word, if for a particular crop in a given range of loading the deformation rate is low, the firmness of tissue will be high. The firmness of pumpkin samples calculated using formula (4), results have been presented in Table 1.

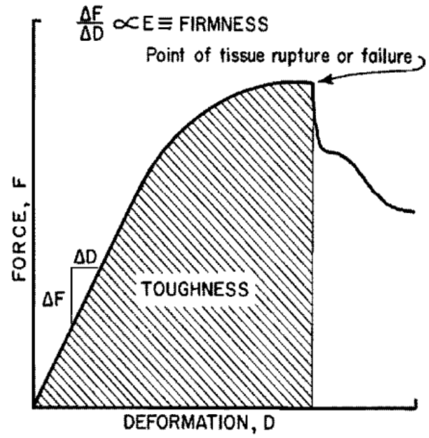


Figure 6: Firmness and toughness from force deformation details of food particles under compressive loading [19].

Consequently, firmness of skin, flesh and unpeeled pumpkin for the results of compressive loading at 20 mm/min calculated as 107.7, 21.42 and 26.6 N/mm.

4.4 *Toughness*

Toughness is the work causes rupture in bio materials [12, 19], it is defined as the area under force deformation curve up to rupture point (formula (3), Figure 6). Calculated toughness for unpeeled and flesh samples of Jap variety of pumpkin have been shown in Figure 7. Toughness of flesh and unpeeled sample were 829.4 and 1411.1 N.mm respectively these results were higher than the results of previous work on cantaloupe melon and watermelon (Figure 8) [15].

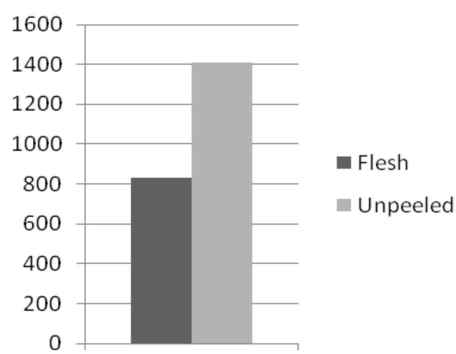


Figure 7: Toughness of flesh and unpeeled samples in 20 mm/min loading rate.

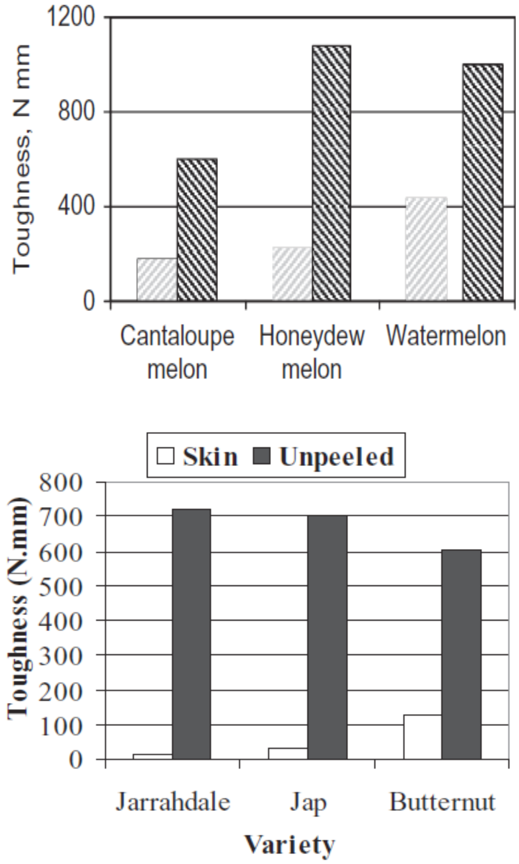


Figure 8: Toughness for melons: unpeeled and peel (left) [15] and pumpkin (right) [17].

Table 1: Mechanical properties of pumpkin peel flesh and unpeeled.

sample	Rupture Force (N)	Firmness ($N.m^{-1}$)	Toughness (N.mm)
Peel	**291**	**107.78**	**392.85**
Flesh	**188.5**	**21.42**	**829.4**
Unpeeled	**274**	**26.60**	**1411.1**

Results of the test have been shown in Table 1. It is clear that the peel firmness were higher than the flesh and unpeeled samples. Additionally, the value of rupture force was higher for peel compare to other samples.

5 Application of Investigated Properties

Application of Finite Element Modelling and simulation method in optimization and design of engineering operations is a novel trend and is getting popular among researchers and of industrial equipments. These models are applicable to study rate of energy consumptions, tool wear and material loss in real world operations[8]. Which will help to achieve understanding of interrelationship of different variable involve the processing in order to advance tool design and select optimum conditions [21]. These models are less costly and time demanding than common experimental methods, however material properties of food particles are essential to establish an appropriate model of food processing or post harvesting operation. Experimental tests were performed on pumpkin tissue to calculate material properties of peel, flesh and unpeeled specimens. The results of this study will be used to develop a FE model of mechanical peeling of tough skinned vegetables. To date this work is the first effort on modelling mechanical peeling of tough skinned vegetable and the authors predict get more details of force-deformation, energy rates, and deformation of tissue after establishing the proposed model. The results of both experiments and models will be helpful to expand available database on rheological behaviours of food particles during different loading stages through food operations.

6 Conclusion and future work

Indentation tests were performed using spherical end indenter to test properties of peel, flesh and unpeeled samples of pumpkin. The result of test which was force and deformation details obtained and mechanical properties of sample computed. Regarding to the calculations, rupture force were 291, 188.5 and 274 N for skin, flesh and unpeeled samples respectively. Toughness of flesh was 829.4 N.mm which was lower that toughness of unpeeled of unpeeled samples (1411.1 N.mm). Firmness also estimated for peel, flesh and unpeeled samples, 107.7, 21.42 and 26.6 N/mm respectively.

7 References

[1] Mellentin, J., *The Key Emerging Functional Food Trends and Technologies in the International Market*, C.f.F.H. Studies, Editor 2006.

[2] Otles, S., *The Waste of Fruit and Vegerable Industry*, F.o.E. Ege University, Food Engineering Department, Editor: Izmir.

[3] Baheri, M., *Development of a method for prediction of potato mechanical damage in the chain of mechanized potato production.* Dissertationes de Agricultura (Belgium); Doctoraatproefschrift aan de Faculteit der Landbouwwetenschappen van de KU Leuven, 1997.

[4] Lewis, R., A. Yoxall, M. Marshall, and L. Canty, *Characterising pressure and bruising in apple fruit.* Wear, 2008. **264**(1-2): p. 37-46.

[5] Simson, S.P. and M.C. Straus, *Post-Harvest Technology of Horticultural Crops*2010: Oxford Book Company

[6] Fontana, A.J., B. Wacker, C.S. Campbell, and G.S. Campbell, *Simultaneous Thermal Conductivity, Thermal Resistivity, and Thermal Diffusivity Measurement of Selected Foods and Soils.* The socienty of engineering in agriculture, food, and biological systems, 2001.

[7] Shirmohammadi, M. and P.K.D.V. Yarlagadda, *Experimental Study on Mechanical Properties of Pumpkin Tissue.* Journal of Achievements in Materials and Manufacturing Engineering, 2012. **54**(1): p. 16-24.

[8] Shirmohammadi, M., P. K. D. V. Yarlagadda, V. Kosse, and Y.T. Gu, *Study of Mechanical Deformations on Tough Skinned Vegetables during mechanical Peeling Process (A Review).* Global Science and Technology Forum, 2012.

[9] Maryam Shirmohammadi and P.K.D.V. YARLAGADDA, *Properties of Tough Skinned Vegetable-Pumpkin Tissue*, in *11th Global Congress on Manufacturing and Management GCMM2012*2012: AUT University Auckland New Zealand.

[10] Shirmohammadi, M., P.K.D.V. Yarlagadda, P. Gudimetla, and V. Kosse, *Mechanical Behaviours of Pumpkin Peel under Compression Test.* Advanced Materials Research. **337**: p. 3-9.

[11] Shirmohammadi, M., P. K. D. V. Yarlagadda, V. Kosse, and Y. Gu. *Study of tissue damage during mechanical peeling of tough skinned vegetables*. Global Science and Technology Forum.

[12] Mohsenin, N., *Physical properties of plant and animal materials: structure, physical characteristics, and mechanical properties*1986: Routledge.

[13] Mohsenin, N.N. and J.P. Mittal, *Use of Rheological Terma and Correlation of Compatible Measurement in Food Texture Research.* Journal of Texture Studies, 1978. **8**: p. 395-408.

[14] Mohsenin, N.N., *Physical properties of plant and animal materials*. New York1986.

[15] Emadi, B., M.H. Abbaspour-Fard, and P.K.D.V. Yarlagadda, *Mechanical properties of melon measured by compression, solar and cutting modes.* . International Journal of Food Properties, 2009. **12**: p. 780-790.

[16] Grotte, M., F. Duprat, D. Loonis, and E. Pietri, *Mechanical properties of the skin and the flesh of apples.* International Journal of Food Properties, 2001. **4**(1): p. 149-161.

[17] Emadi, B., V. Kosse, and P.K.D.V. Yarlagadda, *Mechanical properties of pumpkin.* International Journal of Food Properties, 2005. **8**(2): p. 277-287.

[18] *Compression test of food materials of convex shape.* ASAE, 2008.

[19] Finney, E., *To define texture in fruits and vegetables.* Agrie. Eng, 1969. **50**: p. 462-465.

[20] Vursavu, K. and F. Ozguven, *Mechanical behaviour of apricot pit under compression loading.* Journal of Food Engineering, 2004. **65**(2): p. 255-261.

[21] Özel, T. and T. Altan, *Process simulation using finite element method--prediction of cutting forces, tool stresses and temperatures in high-speed flat end milling.* International Journal of Machine Tools and Manufacture, 2000. **40**(5): p. 713-738.