Study of Structural Changes of Pumpkin Tissue Before and After Mechanical Loading

Maryam Shirmohammadi[1,a], Prasad KDV Yarlagadda[1,b]

[1]CPME, Queensland University of Technology, Brisbane, Australia.

[a]m.shirmohammadi@qut.edu.au, [b] y.prasad@qut.edu.au

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Abstract

The texture of agricultural crops changes during harvesting, post harvesting and processing stages due to different loading processes. There are different source of loading that deform agricultural crop tissues and these include impact, compression, and tension. Scanning Electron Microscope (SEM) method is a common way of analysing cellular changes of materials before and after these loading operations. This paper examines the structural changes of pumpkin peel and flesh tissues under mechanical loading. Compression and indentation tests were performed on peel and flesh samples. Samples structure were then fixed and dehydrated in order to capture the cellular changes under SEM. The results were compared with the images of normal peel and flesh tissues. The findings suggest that normal flesh tissue had bigger size cells, while the cellular arrangement of peel was smaller. Structural damage was clearly observed in tissue structure after compression and indentation. However, the damages that resulted from the flat end indenter was much more severe than that from the spherical end indenter and compression test. An integrated deformed tissue layer was observed in compressed tissue, while the indentation tests shaped a deformed area under the indenter and left the rest of the tissue unharmed. There was an obvious broken layer of cells on the walls of the hole after the flat end indentations, whereas the spherical indenter created a squashed layer all around the hole. Furthermore, the influence of loading was lower on peel samples in comparison with the flesh samples. The experiments have shown that the rate of damage on tissue under constant rate of loading is highly dependent on the shape of equipment. This fact and observed structural changes after loading underline the significance of deigning postharvesting equipments to reduce the rate of damage on agricultural crop tissues.

Introduction

The quality of food products is highly affected by the changes and deformations that occur during post harvesting and industrial food processing stages. Post harvesting operations consist of various operations such as handling, grading, packaging and processing. These stages can create a high rate of damage on agricultural tissues as a result of compression, impact and tensile loading. The rate of post harvesting and processing loss reaches up to 25% [1]. There are several experimental studies that investigate the changes occur during food processing stages. Harket et al. [2] has compared the effects of tensile testing and other instrumental and sensory measurements on banana, watermelon, muskmelon, avocado, carrot and apple tissue in terms of strength and juiciness. Although banana cells detached from the neighbouring cells, no breakage happened in cell structure while in muskmelon samples, some of the cells were broken. Watermelon, carrot, avocado and apple cell structures all failed as a result of tensile loading. Tensile loading test was performed on apple tissues to study the mealiness of apple tissue during the cool storage [3]. The results reported significant changes in cell wall arrangement between cooled stored ripe and unripe apple samples.

Tensile properties of pears and the influence of ripening and turgor pressure [4] showed firmness of 96 and 62 N for the European pear while the value for the Asian pear was 56 and 26N. The low firmness and tensile strength of the pears sample reported a fail as the result of cell to cell debonding. However for the pears of high tensile strength and firmness failure was due to the cell wall failure and cell fracture.

The effects of compression testing on the apple tissues structure [5, 6] indicated that cells undergo the pressure and deformation starts from a certain point. For the larger strain values elastic modulus has also increased, and the resistance of the cell wall against rupture delays the failure of the structure.

Fracture and tensile tests on carrots structural changes [7] illustrated that carrot tissue is brittle in general; however, during the storage life, tissue loses the moisture and this will affect the response of the tissue to loading.

A biphasic stress strain curve was observed for onion epidermal tissue under tensile loading [8] and this has been linked to the composition of the plant cell wall arrangements. The elastic modulus in the second phase was found to be lower than the value in the first zone for all samples. This difference was due to the changes after the yielding of material and the sliding of microfibrils that pass each other in a constant manner.

The mechanical properties and structural changes of pumpkin tissue were studied during the osmotic dehydration by Mayor et al. [9]. The results have been compared with the other vegetables behaviours. The results indicated an elastic behaviour as high elastic modulus in pumpkin tissue that was similar to the apple and higher than the values for kiwi fruit and mango. A study of change in the mechanical properties of water-soaked and dehydrated pumpkin samples showed an elastic, hard and brittle behaviour for the fresh samples, whereas the dehydrated samples lost the elasticity and changed to a more deformable tissue.

Analysis of agricultural crops microstructural changes facilitates modification and optimisation of food processing technologies. This paper investigates structural changes that occur after mechanical loading of pumpkin peel and flesh tissue. The samples cell structure was captured using a Scanning Electron Microscope (SEM) method after compression and indentation using flat and spherical indenters.

Materials and methods

Pumpkin is a member of the Cucurbitaceous [10] of 125 genera and 825 species. Three commercialised varieties of pumpkin are Jarrahdale, Jap, and Butternut [11, 12]. Total pumpkin production in Australia was 150,728 tonnes and Queensland had the highest rate of production among all states in 2007 [13]. Raw pumpkin can be used to produce fresh cut products or used in processed food production lines. Regardless of the type of production, pumpkin tissue, similar to other agricultural crops, pumpkin tissue undergoes different loading stages after harvesting and through processing operations. Mechanical loading including compression and indentation were performed to analyse the behaviours of pumpkin flesh and peel samples. Samples were prepared from ripe and defect free Jap variety pumpkins that were purchased from local shops in Brisbane Australia and kept in laboratory condition. The humidity and temperature were 20-25% and 20-25^{0}C respectively. Flesh samples were cut from the ripe section of the pumpkin underneath of peel the layer of peel with an average thickness of 50mm, while peel samples were cut from the green layer with 5mm thickness. All the samples were cut in cylindrical shapes with a diameter of 40mm. A spherical end indenter with an 8mm diameter and flat end indenter with a 10mm diameter were used for the indentation tests. Samples were cut and kept in fixative liquid for at least 2hours and dehydrated afterwards for SEM imaging of fresh flesh and peel samples.

According the ASABE standard for food materials [14], the tests were carried out at a constant deformation rate of 20 mm/min. An Instron Universal Testing machine was used to apply loads and the results of the load deformation were obtained from the computer attached to the machine. The details of tests were similar with the previous work on tough skinned vegetables [15-18]. Samples were reserved in a fixative solution of Glutaraldehyde 3% for at least 2 hours after the each test.

For the purpose of fixing sample structures without any changes after compressive loading, the sample holders were filled by fixative liquid and left under compressive loading for at least 2 hours. After the fixation process, the loads were removed and samples transferred to containers filled with fixative. Samples were then dehydrated after the completion of the fixation step. The purpose of dehydrating samples was to remove all the moisture from the structure of the tissue in order to capture the images of cell structure under a Scanning Electron Microscopic (SEM) system. The dehydrated samples were cut into small pieces and coated with gold and kept in desiccators until the imaging started. The structural changes in the top and bottom layer tissues structure were captured for the compression test samples, while in the spherical and flat indentation samples, the main focus was on the deformed area punctured under the indenter.

Results and Discussion

The cellular structure of pumpkin flesh and peel samples were captured before and after mechanical loading tests. These tests consisted of indentation using two different types of indenter and compression test. Flat and spherical indenter was used to perform indentation tests and a flat platen used in compression test. Processed and dehydrated samples after loading were compared in terms of structural change using SEM system. The SEM images and results of mechanical loading force deformation curves have been presented in this section and a through comparison has been made between results.

Specimens were cut from fresh peel and flesh layers used to capture the normal structure of cell before loading (Figure1 & 2). Samples were fixed in fixative solutions and dehydrated afterwards and cut into small pieces. Images of normal peel and flesh samples showed similar patterns of cells with images of raw pumpkin tissue presented by de Escalada et al. [19].

As shown in Figure 1& 2, before loading a clear arrangement of cells exist in flesh tissue while a layer of wax has covered peel cells. Flesh cells are visibly bigger than the size of wax arrangements on the peel surface (Figure 1&2). According Mayer et al. [9], different parameters influence mechanical properties of fruit and vegetable materials, density, composition of materials, turgor pressure of cells, and adhesion are some them. Cell wall rupture and cell-cell debonding are two main defined reasons of failure in plant materials [9].

The compression test was performed at the loading rate of 20mm/min on peel and flesh samples of pumpkin tissue using a flat platen to compress the samples. Results obtained from INSTRON (Figure 3) showed elastic behaviours for both flesh and peel samples as first linear part of force-time curve which followed to a force peak value.

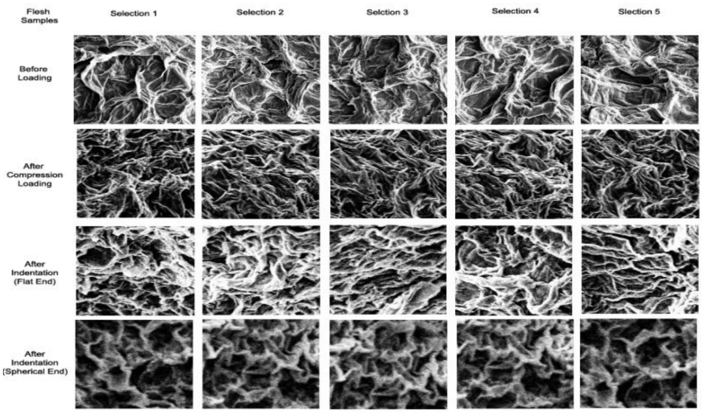

Figure1: SEM images of pumpkin flesh before and after loading.

This maximum compressive load was 300 N for the flesh sample while for peel samples it reached more than 1000N before yielding actually occurred and this was similar to the results from previous studies on flesh samples of pumpkin [16]. Under laboratory condition compressed peel and flesh samples were kept in the fixative liquid to fix the structural changes, the fixed samples were dehydrated and kept in desiccators before SEM imaging started.

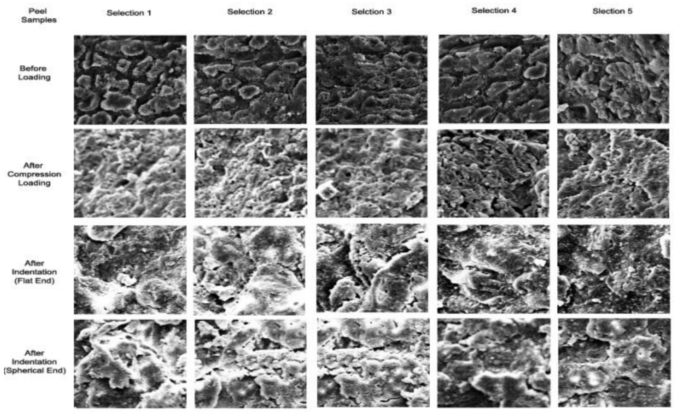

Figure2: SEM images of pumpkin peel before and after loading.

Images of peel samples indicate the rough part of peel and a distortion of wax layer as it shown in Figure 2. In flesh samples, the cellular structure of normal flesh with bigger cell sizes (see Figure1) has deformed to smaller and more compacted layers. The flesh and peel load curves show a higher resistance of peel tissue to compressive loading than the flesh tissue. This could indicate the longer life of unpeeled pieces compared to peeled of crops.

A flat end indenter was used to perform the indentation test, the samples were fixed using a fixative solution before removing the load. After this, the samples were dehydrated and cut into small pieces in laboratory condition. The main stress in imaging samples after indentation was to capture the deformation of cells around the hole that remained on the tissue surface. The diagrams obtained after loading illustrate that the maximum load for the flesh sample was approximately 130 N and for peel was 400N.

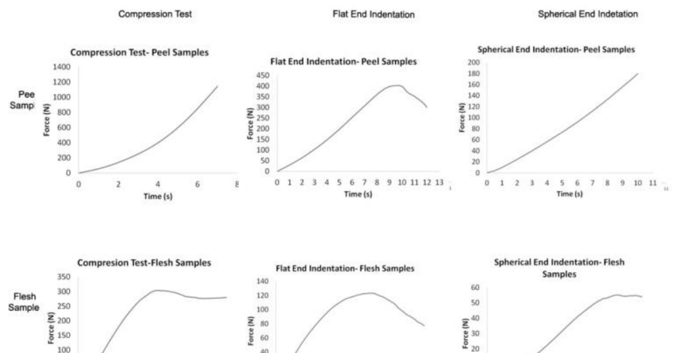

Figure3: Mechanical loading results for compression and indentation tests.

Similar to the results of compression loading, flesh structure was damaged and changed to compressed layers; although it was not possible to see any cellular arrangement, the breakage of the cell was clear around the hole caused by indenter (Figure 4).

Results of spherical indentation on tissue structure also were presented in Figure 1, 2&4. Due to the thickness of the peel sample, it was not possible to reach the yielding point. From the SEM images, the structure of the peel changes to a compact layer of deformed cells, and the flesh cells are also destroyed to a more compressed shape compared with the images from the fresh peel and flesh samples. Comparison between spherical and flat end indenters' results indicates samples under spherical end indenter did not break to pieces and just smashed to a damaged layer in contrast with the results from flat end indenter Figure 4. Images of compression test for both peel and flesh showed damages distributed on entire sample while in indentation tests' results apart from layers around the indenter the other cells left less or unharmed.

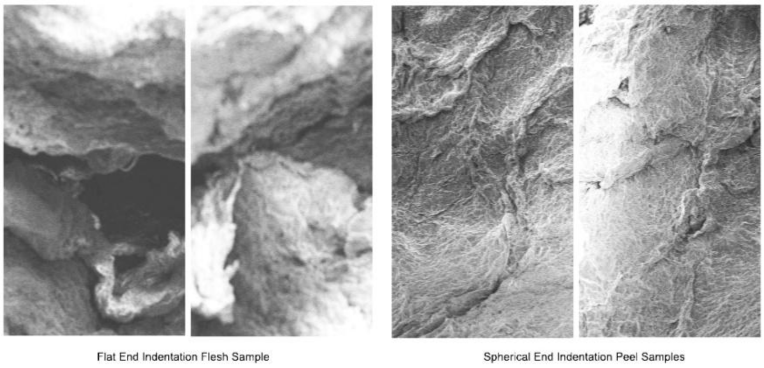

Figure 4: Comparison between Flat and Spherical end indentations.

Conclusion and Future Work

Mechanical loading tests are a common method of analysing agricultural crop responses under processing operations. SEM imaging technology is a novel method of capturing structural changes of tissue after different types of loading. The structural deformations of flesh and peel cells of pumpkin were determined performing compression and indentation tests and compared with the structure of fresh peel and flesh samples. The loading rate details obtained from Instron testing machine demonstrates the high resistance of peel and flesh samples to the compressive loading and the susceptibility of samples to deform under spherical indentation. Mechanically loaded samples dehydrated and used under SEM camera to capture cellular changes of tissue after loading. The results of indentation and compression tests were then compared with the images took from fresh peel and flesh samples. The damages on tissues were different in each test, as the compression results showed a compressed layer of cells while in flat end indentation test, the cells were ruptured around the edges of hole. In spherical end indentation however, the tissue was totally compressed around the hole under the indenter and the rest of tissue was untouched. Comparison between the results of three tests revealed the severity of deformation on samples cellular structure under flat end indentation test.

The effects of compression and indentation loading on cellular structure of pumpkin tissue were studied using SEM imaging technology. This study was a part of a Finite Element Modelling of mechanical peeling of tough skinned vegetables. Although there are studies captured structural changes of food materials under loading, few of them have focused on the distinction between peel and flesh structure under loading. Furthermore, the tissue structural difference under compression and indentation tests have been analysed as a new approach in this paper but more study needs to be done on the mechanical and physical changes of tissue under loading. Calculation of mechanical properties of each test, and analysis of discoloration in combination with the SEM imaging as a future study will indicate the visible damages on peel and flesh tissues. This will be an important part of quality control in post harvesting and packaging lines. Additionally, the effects of loading rate can be studied in order to simulate the structural changes of cell under gradual and rapid loads. Investigation of differences between fresh, loaded and loaded-unloaded agricultural crop samples will enable researchers to classify loading effects in a long term period which might appear later during processing of food particles. Preventing and diminishing rate of damage on tissue will lead to a higher quality of tissues inter to processing stages and will enhance the shelf and storage life of food products.

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