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Changes in apple tissue with storage time: Rheological, textural and microstructural analyses

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Abstract

In this study, two varieties of apples with different textural characteristics—"Granny Smith" and "Golden Delicious"—were chosen to evaluate the efficacy of rheological and textural analyses. Dynamic rheological measurements (using a controlled stress rheometer), large deformation texture analysis (uniaxial compression and penetration, using a TAXTplus) and cryo-scanning electron microscopy were used to study the macro- and microscopic changes in apple tissue structure during 14 days of storage at 20 °C. The results obtained showed that both dynamic small deformation and static large deformation tests may be used to monitor mechanical changes in apple tissues. Observation of apple flesh microstructure revealed many changes that could be related to macroscopic changes in texture and rheology. All samples with low storage modulus and Young's modulus values had microstructural characteristics with some component of the textural unity (middle lamella, cell wall or cell membrane) affected, resulting in effects such as exudation, loss of cell material and cell separation.
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Keywords: Apples; Dynamic rheology; Texture; Young's modulus; Microstructure; Cryo-scanning electron microscopy (Cryo-SEM)

1. Introduction

Texture is a quality attribute that is critical in determining the acceptability of fresh fruits. The handling and processing of fruits and vegetables involves special problems since the consumer has well-formed opinions and expectations regarding the proper texture of these products. Successful delivery of acceptable products requires care regarding texture changes, and this is most effectively applied when it is based on an understanding of the factors that influence texture. The mechanical properties of biological tissues depend on contributions from the different levels of their structure: the molecular, cellular and organ levels. Softening of apples as they ripen has long been ascribed to changes in the quantity and nature of the cell wall middle lamella polysaccharides. Along with tissue softening and loss of cohesiveness, a decrease in the extent of intermolecular bonding between cell wall polymers takes place, owing to an increase in the solubility of the wall constituents, particularly pectin. Thus, the strength, stiffness, size and shape of cell walls, middle lamella and fibrous tissues and the turgor pressure of living cells contribute greatly to firmness or rigidity. Nowadays, the desire for unadulterated foods forces the industry to apply minimal gentle processing in the case of fruit products. However, fruits undergo material changes, including alterations of the tissue and cell wall structure, even during these processes (Gerschenson, Rojas, & Marangoni, 2001; Kunzek, Kabbert, & Gloyna, 1999; Martínez, Nieto, Viollaz, & Alzamora, 2005; Ramana & Taylor, 1992).

The main textural characteristics that consumers value in fresh apples are crispness and firmness. The quality of apples, as in the majority of fruits, depends on several factors such as variety, climate conditions during growth, stage of maturity at harvest and storage conditions. During these processes texture can deteriorate, resulting in a soft

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and mealy fruit that is less desirable for consumers (Gómez, Fiorenza, Izquierdo, & Costell, 1998).

A variety of chemical and physical quality indicators have been developed to monitor fruit quality and physiology: fruit weight, soluble and total solids, total acidity, external or internal color, firmness with penetrometer, etc. A better understanding of fruit texture and rheology and their relation to microscopic changes may lead to improvements in quality control and process design in the food industry and the marketplace. The rheological properties of foods are affected by their chemical composition which, in turn, affects the structural changes during handling and processing. Three types of deformation that may be used to study the rheology of viscoelastic solids are uniaxial compression, shear and bulk compression. Uniaxial compression is the simplest and most popular test and is often used to analyze apple fruit texture by means of a texture analyzer or a universal testing machine. Bulk compression tests are more complex and seldom used (Bu-Contreras & Rao, 2002). Since the second half of the last century some scientists have suggested that the modulus of elasticity is related to the 'firmness' attribute of texture and this is closely allied with those characteristics of materials which physicists call "stiffness" or "rigidity". However, shearing is the most indicative parameter for judging the textural attributes of vegetables (Ramana, Wright, & Taylor, 1992). Dynamic mechanical analysis is an effective method because it applies very small strains on the samples (less than 0.1%) over a very short time; as a result, the properties of solid foods can be studied with minimal physical changes. In addition, dynamic tests can be used to study the rheological properties of materials at different frequencies, providing more information for discrimination between samples, with the advantage that the instruments are highly sensitive (Bu-Contreras & Rao, 2002). In 1992, Ramana and Taylor established the feasibility of applying an oscillatory shear method to monitor structural changes in small discs of vegetable tissue. However, since then, little research has been carried out in the field of dynamic rheological measurements in fruits. Tregunno and Goff (1996) used that technique to study the effect of osmodehydrofreezing apples, Gerschenson et al. (2001) applied it to kiwifruit to monitor the changes produced by blanching and dehydration and in 2005 Martínez et al. used it to study osmotic dehydration in melons.

To evaluate the applicability of rheological and textural methods, two varieties of apples with different textural characteristics were chosen for this study. Granny Smith is a crisp to crunchy and juicy apple and stores well, although it is susceptible to superficial scald. Golden Delicious is firm at harvest but has a tendency to soften in storage (Abbot, Saftner, Gross, Vinyard, & Janick, 2004).

The aims of this work were: (a) to study the changes in the apple tissue structure of the two varieties during 14 days' storage at 20 °C, using dynamic rheological tests and large deformation texture analyses: penetration and compression, and (b) to relate these changes to those taking place in the tissue structure at cellular level, by means of cryo-scanning electron microscopy (Cryo-SEM).

2. Materials and methods

2.1. Plant material and storage conditions

Granny Smith and Golden Delicious apples at commercial maturity were purchased at a local retailer. They were selected for uniformity and absence of defects and placed in cold storage at 4 °C. Sub-batches were subsequently transferred to storage at 20 °C without atmosphere control, where they remained for 0, 7, and 14 days to attain the different storage times.

2.2. Rheological measurements

Dynamic rheological behavior at 20 °C was characterized using a controlled stress rheometer (Rheostress RS100) equipped with a Phoenix II P1 C2 5-P circulation bath (Haake, Karlsruhe, Germany), using plate and plate geometry, 35 mm in diameter, serrated plates to prevent slippage, with a 9.9 mm gap between plates. Using a cork borer, disks of 35 mm in diameter and 10 mm in height were removed from an apple slice immediately before measuring. It was endeavored to lower the cork borer at a consistent rate, to avoid vascular tissue and to take the disc from the center of the slice and special care was taken to obtain discs with parallel bases and tops. The upper plate was lowered until it touched the sample and 1% compression was applied to ensure adequate contact with the apple (Tregunno & Goff, 1996). Before any measurements were taken, samples were allowed to rest for 5 min in the measuring position as equilibration time. All experiments were conducted at 20 °C and on apple cylinders with the same orientation (top–bottom) because of the fibrous non-isotropic properties of apple flesh. The linear viscoelastic range (LVR) was determined through stress sweeps from 1 to 1000 Pa. A constant stress of 10 Pa was then chosen (common to the LVR of all samples) to obtain the mechanical spectra as frequency sweeps from 0.01 to 10 Hz. The storage modulus (G') and loss modulus (G'') were plotted to characterize the viscoelastic behavior. Four discs were measured for each sample. The replicates of each curve were run with good reproducibility since the differences between them were less than 5%.

2.3. Texture analysis

Immediately before measuring, the samples for texture analysis were peeled and cut into 1.5 cm sided cubes with a sharp cutter, avoiding vascular tissue. All tests on the cubes were performed with the same orientation because of the fibrous non-isotropic properties of apple flesh.

A TA-XTplus Texture Analiser (Stable Micro Systems, Godalming, UK) was used to evaluate the texture of the apple cubes. Four replicates (four cubes) were used in each

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