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Textural, flow and viscoelastic properties of Hass avocado (*Persea americana* Mill.) during ripening under refrigeration conditions

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ABSTRACT

Microstructural and rheological changes in whole and ground (purée) mesocarp of Hass avocado (*Persea americana Mill.*) were studied under storage conditions (40 days at 10 °C). The maximum stress (σ_{max}), relaxation test and microstructural changes were applied to mesocarp chunks. The shear stress (τ), apparent viscosity (η) and complex modulus of viscoelasticity (G^*) were analyzed in the mesocarp purée. The ripening produced a decrease in σ_{max} in both harvest, observing microstructural damage of the plant tissue over 30 days. The values of τ and η decreased, adjusting well to the Cross - Willianson ($R^2 = 0.95$ −0.94) and Herschel - Bulkley ($r2 = 0.91$−0.98) models. G^* has an elastic tendency (G') with a decrease in hysteresis. The results corroborate the impact of ripening on the rheological properties of the fruit.

1. Introduction

Avocado (*Persea Americana* Mill.) is a highly caloric fruit that is rich in vitamins, minerals, folates, potassium and fiber, with a unique composition of lipids (Slater et al., 1975). In addition, it contains high levels of bioactive phytochemicals of lipophilic character such as tocopherols, carotenoids and sterols that possess antioxidant and free radical scavenging activities (Lee et al., 2004). Avocado contains approximately 2% protein and various sugars (mainly glucose, fructose, sucrose, and heptulose). In addition, in its pulp, it has vitamins, tannins and free amino acids. It has the highest level of β-sitosterol that has been shown in clinical trials, which helps reduce the levels of low-density lipoprotein (LDL) cholesterol by blocking cholesterol absorption in the intestine (Heinemann et al., 1993). This fruit may be round and have the shape of a pear, and the skin may vary in texture and color (Yahia, 2011). In addition, both the skin and seeds have antioxidant properties that can be exploited for the development of novel preservative and antimicrobial food ingredients (Rodríguez-Carpena et al., 2011; Calderon-Oliver et al., 2016; Saavedra et al., 2017).

Avocado in the immature state that has been freshly harvested is characterized by having an extremely firm texture. Several biochemical analyses have shown a large increase in the activities of cell wall hydrolytic enzymes of avocado mesocarp during ripening (Awad and Young, 1979; Prasanna et al., 2007; Li et al., 2010). At the beginning of ripening, the fruit begins to have changes in its cellular microstructure generating mesocarp softening, which clearly influences its textural and rheological conditions. Avocado is characterized by ripening when harvested, and this process can be considerably slowed by storage at low temperature (2–5 °C) at the industrial level. However, there is research that indicates that cold storage damages fruits and manifests as a discoloration of the mesocarp, undue softening and bad taste (Couey, 1982; Hopkirk et al., 1994). In addition, the cell membrane displays separations between the phospholipids and bilayer proteins due to cold storage (Platt and Thomson, 1992). However, this damage is more accelerated under storage conditions that are used by small producers who do not have refrigeration and who store the product under domestic conditions (8–10 °C).

The provision of information relating the maturation phenomenon to the microstructural changes, texture, flow properties and

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viscoelasticity of avocado is of significant importance for the food industry, where the fruit is kept refrigerated for later use as a raw material or as an ingredient for various food products such as salads, fast food (guacamole), preserves, sauces and dressings, etc., and also for the emerging avocado oil industry. From this point of view, it is not clear how the rheological properties of flow and viscoelasticity of avocado and its derivatives are affected during the different stages of the climatic maturation process.

However, a number of studies have been reported on the changes in pallet texture due to accelerated ripening using ethylene and a modified atmosphere (Hopkirk et al., 1994; Landahl et al., 2009; Blakey et al., 2014). Studies have been performed on the rheological behavior of avocado during the climacteric state. Other studies have rheologically characterized avocado oil and its emulsions (Logaraj et al., 2008; Souza et al., 2015). Recently, rheological characterization has been reported in model systems of oil avocado oleogels (Pérez-Monterroza et al., 2014). However, Tabilo-Munizaga et al. (2005) analyzed the rheological changes in avocado puree in a state of consumption (mature) treated by high pressure. However, no studies on rheological variations of avocado in the “immature-mature” transition state have been reported. The characterization of rheological behavior associated with post-harvest maturation of the fruit is important for predicting its quality and is the fundamental basis for the design and adjustment of parameters of operation of equipment involved in its industrial processing such as mills, extractors, expellers, centrifuges, pumps and pipes, among others.

As the rheological behavior of the fruit and its purée during the ripening process has only been studied under refrigeration conditions around 5 °C, the objective of this work was to investigate the variations of the flow and viscoelasticity properties of Hass avocado under a storage temperature of 10 °C, to accelerate the ripening process of the fruit and at the same time, obtain the most evident approximation of the phenomena of ripening on the microstructural and physical properties of the fruit.

2. Materials and methods

2.1. Raw material

The Hass avocado fruit (*Persea americana* Mill.) from the Quillota area (V region, Chile) was collected in two periods. The first harvest was carried out in September, and the second harvest was performed in November 2016, with a fat content of the fruit of 15 and 22% dry basis and a humidity of 55 and 57%, respectively. The fruits were stored on the same day of harvest in the dark and at a temperature of 10 ± 1 °C. Physical analysis was performed by sampling on days 0, 20, 30 and 40.

2.2. Microstructural analysis of avocado tissue

2.2.1. Optical microscopy

The Sudan IV staining technique (Kiernan, 2008) with minor modification, which differentiates between lipids and cell walls in oranges, was applied. The samples were cut to approximately 2-nm thickness using a cryo-microtome and were washed with cyto-fixing in the portal object. Subsequently, the sample was washed by dipping in 50% (w/w) alcohol for 2 min and then in 70% (w/w) alcohol for 4 min. The Sudan IV dye was applied for 4 min after applying the dye-mounting medium hematoxylin for 10 s, and the sample was washed with distilled water. Groups of images of the mesocarp tissue microstructure were obtained via light microscopy with a 40× magnification.

2.2.2. SEM analysis

The microstructure of the avocado puree was analyzed using scanning electron microscopy (SEM) according to the Platt and Thomson (1992) methods. The samples for SEM were fixed in 1% glutaraldehyde in 50 mM cacodylate buffer, pH 7.0, at room temperature for 2–4 h followed by rinsing in the buffer. The samples were post-fixed overnight in cacodylate-buffered 1% OsO4, dehydrated in acetone, and embedded in Spurr's resin.

2.3. Rheological analysis

2.3.1. Texture analysis

To determine the texture changes in the fruit, the resistance to penetration at different maturation stages was measured at the mesocarp level. A uniaxial penetration test was used according to the method of Landahl et al. (2009). The maximum fracture stress (σ) of the sample was determined in the pieces of avocado mesocarp, which were cut in the form of a cylinder with a 3.0-cm height and 1.2-cm diameter, and calculated based on

$$\sigma = F/\pi r^2 \tag{1}$$

where F is the force in KPa to obtain the fracture of the cylinder.

On each day of the planned sampling, the fruit cylinders were compressed to 70% of the height of the cuts at a deformation rate of 0.8 mm/s. For this test, an 8-mm-diameter stainless steel rod connected to a Lloyd-type texturometer (model LR-5K, Hampshire, UK) was used.

To perform the relaxation test, cylindrical mesocarp samples were performed to determine the viscoelastic behavior of the mesocarp. For this, the compression force (F_o) was applied to obtain an arbitrary deformation of 10% of the initial cylinder height. Immediately after the applied compression, the 10% deformation was maintained, which initiated the relaxation (Fig. 1). During this stage, the decrease in Fo to a final force (Ft) was measured for an arbitrary relaxation time of 1200 s. The value of the compression speed was 0.8 mm/s (Torres et al., 2012).

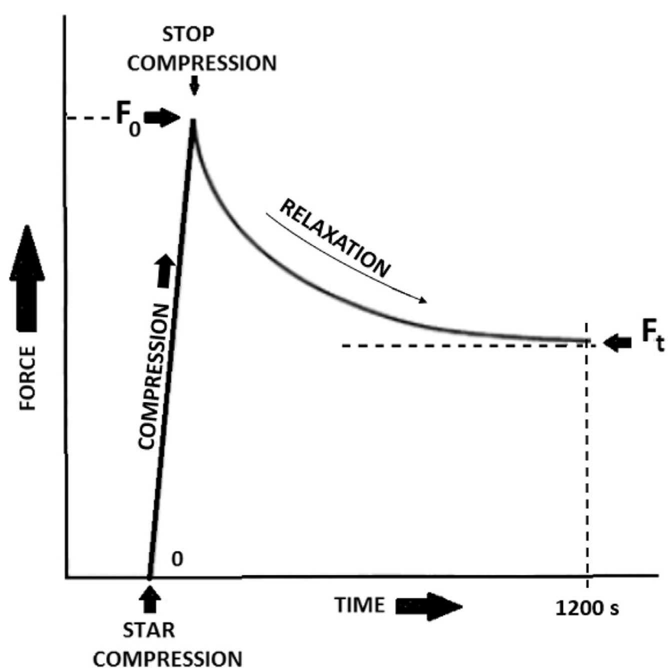

Fig. 1. Force-time relation for the viscoelastic sample under constant strain (Peleg and Calzada, 1976).

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