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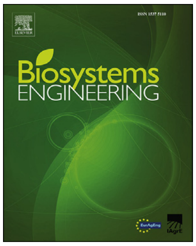

Research Paper

Characterisation of the viscoelastic properties of avocado puree for process design applications

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ARTICLE INFO

Article history:
Received 28 February 2017
Received in revised form
20 June 2017
Accepted 20 June 2017

Keywords:
Rheology
Viscoelastic moduli
Avocado puree
Ultrasound
Malaxation
Oil extraction process

Avocado is increasingly utilised for the manufacture of products including purees, concentrates, powders and avocado oil. The design of such processes requires understanding of the rheology, particularly during the puree's transformation. This study characterised the viscoelastic properties at 25 °C of fresh avocado puree resulting from various processing operations including mixing, water dilution, and after sonication treatment. The storage (G') and loss (G'') moduli of avocado puree demonstrated a solid-like behaviour irrespective of treatment or dilution, contrary to other food matrices. Avocado puree produced with manual-shearing showed greater G' and G'' than when obtained with a food-processor. Extended shearing through the malaxation operation (mixing and kneading at 49 rpm and 45 °C); or water dilution to 72–94% moisture, diminished both moduli, with an exponential decrease observed in the latter. However, sonication for 5 min with high-power-ultrasound (18 kHz and 40 kHz) or megasonics (MS) (2 MHz) (80–90 kJ kg^{-1}) increased G' and G''. The net change in viscoelastic properties due to puree low frequency sonication correlated linearly with moisture content. The influence of processing interventions in avocado puree was demonstrated through rheological methods applicable for avocado process optimisation and product development.

1. Introduction

Avocado (*Persea americana* Mill.) is considered today among the most economically important subtropical/tropical fruit crop in the world. Annual production of avocado fruit now exceeds 3.5 Mt, of which about 20% is traded among countries (Bost, Smith, & Crane, 2013; Schaffer, Wolstenholme, & Whiley, 2013, pp. 1–9). Recently, the consumption of fresh avocado has been associated with improved overall diet quality as a good source of fibre (~1.28 insoluble/soluble), nutrient intake (minerals, vitamins, fatty acids), and reduced risk of metabolic syndrome from health-related phytochemicals (protection from coronary heart disease) (Cowan & Wolstenholme, 2016; Meyer, Landahl, Donetti, & Terry, 2011).

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http://dx.doi.org/10.1016/j.biosystemseng.2017.06.016

The avocado's average composition is 73–74% moisture, 15–17% lipids, 5–8.5% total carbohydrates (including soluble fibre like pectin), 1.5–6.7% total dietary fibre, 2–2.2% protein, counting all the essential amino acids, and 1–1.6% minerals (Bost et al., 2013; Cowan & Wolstenholme, 2016; Eaks & Sinclair, 1978; Meyer et al., 2011; Paull & Duarte, 2011). The triacylglycerol and health-promoting fatty acid composition (high oleic acid) content is comparable with those for olive oil, with high concentrations of β-sitosterol, chlorophyll and carotenoids (particularly lutein) (Cowan & Wolstenholme, 2016; Meyer et al., 2011; Yahia & Woolf, 2011).

For bulk production, the preferred cultivar is 'Hass' due to its superior flavour, higher resistance to enzymatic browning, and year-round availability. Fruits with a 25% dry matter content or 13% oil are recommended for industrial processing (Cowan & Wolstenholme, 2016). Avocado pulp is separated from the rest of the fruit and transformed into a puree through mashing for stabilisation into high-value added products. Avocado puree is sold directly without additives in frozen state or with added ingredients to transform it into avocado-based sauces (Bost et al., 2013; Purroy-Balda, Tonello, Peregrina, & de Celis, 2011; Yahia & Woolf, 2011).

Preservation processes are required in order to obtain a puree of a certain uniformity and able to be pumped into other unit operations. Water addition is used to disperse the mash components and reduce the viscosity before pumping or dehydration into a powder.

During the avocado oil extraction process, water is also added to the puree to prevent blockages in the centrifuges used to separate the oil from water and solid phases (Bost et al., 2013; Costagli & Betti, 2015; Cowan & Wolstenholme, 2016; Flottweg, 2016; Yahia & Woolf, 2011). Oil extraction initially requires a malaxation process consisting of mixing and kneading the puree at a temperature below 50 °C (Wong et al., 2011). Low frequency ultrasound (18–100 kHz) can potentially increase the efficiencies of homogenisation and extraction unit operations by exposing the food material to unstable cavitation where bubbles exist for a very short period and collapse violently (Chemat, Zill-e-Huma, & Khan, 2011; Tiwari, 2015; Vilkhu, Mawson, Simons, & Bates, 2008). Treatment of high frequency ultrasound on pre-macerated olive and palm fruits (400–2000 kHz) has also been demonstrated to increase oil recovery, therefore providing improvements in process efficiency (Jimenez, Beltran, & Uceda, 2007; Juliano, Augustin, Xu, Mawson, & Knoerzer, 2017).

Heating and mechanical treatment received by traditional or novel technologies like ultrasound can modify physical properties of avocado puree. Moreover, rheology in avocado puree is complex due to its semisolid characteristics because it is a multiphase system where an oil-in-water emulsion and a particle-in-water suspension coexist (~20–30% of solid and oil particles dispersed in an aqueous phase). Physicochemical properties, including rheology, depend on pH, oil and non-soluble particle concentrations, sizes and shapes (Martínez-Padilla, 2005). A characteristic, predominantly elastic, behaviour can be observed in avocado puree at rest (viscoelastic properties), and its structure must be destroyed before flow can occur, as a consequence of macrostructural breakdown (aggregates, hydrogen bonds, networks).

Very few studies on the rheology of avocado puree have been reported in the literature and those found have inconsistent approaches for characterisation. The first study carried out in avocado puree and dilutions was performed in flow condition in concentric cylinders (>1 mm gap, T 40 °C). Shear-thinning behaviour of avocado puree has been described by Freitas, Da Silva, Lago, and Qassim (1996). Shear rate and shear stress data were adjusted to a power function and the respective parameters showed a reduction in the consistency index (K) and an increase in the flow behaviour index (n) with a rise in water content. In another study, dynamic-oscillatory testing (cone and plate, 0.8 mm gap, T 20 °C), was performed on high-pressure treated avocado puree with pH adjustment to 4.1. The magnitudes of storage modulus (G′) and complex viscosity (η^*) augmented with increased intensity of high hydrostatic pressure treatments. These samples in flow conditions exhibited shear-thinning behaviour with yield stress (Herschel–Bulkley model) and shear time dependency; however, good determination coefficient of adjusted curves was not observed at shear rates greater than 20 s^{-1} (Tabilo-Munizaga, Moyano, Simpson, Barbosa-Canovas, & Swanson, 2005). A third study of diluted "defatted" avocado puree evaluated the effect of low frequency ultrasound treatment on the viscosity at 100 s^{-1} (parallel plates, 1 mm gap, 25 °C). Ultrasound treatment on the "defatted" puree increased viscosity (Bi, Hemar, Balaban, & Liao, 2015).

Avocado rheological properties can be very useful for the design of many processes that apply shear forces, so the purpose of this study was to characterise the viscoelastic properties of fresh avocado puree, following malaxation at several dilutions and treated by low and high frequency ultrasound. The implications of property variations upon shearing, water addition and sonication will be discussed.

2. Materials and methods

2.1. *Sample preparation*

Avocados of Hass variety obtained from local markets were purchased (Australia or New Zealand supplier) during the Southern spring season between the months of November and January. Mature fruits ready to eat were selected according to their colour, as high degree of blackened skin and soft texture, checked manually and verified according to the moisture content of the puree as suggested by Osuna-García, Doyon, Salazar-García, Goenaga, and González-Durán (2010). Fruits were stored at 4 °C, and conditioned by placing them at room temperature 1 h before tests to reach an initial puree temperature of 20–22 °C.

Fruits were washed, peeled, halved lengthwise, and pitted to obtain the flesh. The pulp was crushed manually with a stainless steel masher to obtain a homogeneous puree (MaP), or using mechanical shear with a food processor (Russell Hobbs 300W Stick Mixer, China) (MeP) during 1 min (six avocados maximum). Diluted samples were prepared at ambient temperature (20 °C) by addition of one, two or three parts of tap water per avocado pulp, and mixing with the food processor for 1 min. Some samples were submitted to a slight mixing with a Scrapemaster spatula (MX7900W Planetary