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Heating and megasonic interventions for improvement of aqueous-based oil extraction from fresh and cold stored coconut meat

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The efficiency of oil recovery is essential for the economics of the coconut oil extraction process. This study evaluated the application of increased heat and/or megasonic steps for enhancing aqueous-based oil separation from coconut meat. Combinations of heating temperature (60 or 70 °C) and time (30 or 50 min) were studied in freshly prepared, or in 20 and 44 h cold stored (5 °C) coconut-water mixtures (1 L). The megasonic effect after heating (60 °C, 30 min) was evaluated at 2 MHz frequency and energy densities of 44–349 kJ/kg. Oil extraction from fresh coconut meat was higher when increasing heating temperature (10–13%). Net ultrasound yield in cold stored coconut meat was improved from 1.1 to 3.2% with increased sonication time from 2.5 to 20 min. Megasonic effects on mixtures heated (60 °C, 30 min) were corroborated in fresh coconut meat at a larger scale, which demonstrates the potential for megasonic to enhance aqueous-based coconut oil extraction processes.

1. Introduction

Coconut (*Cocos nucifera L.*) is an important international commodity. Mature coconuts contain a hard-thick flesh layer, or kernel, which is utilised as the raw material of many products such as copra or dried coconut, coconut oil and coconut milk. Refined and virgin coconut oil (VCO) are two goods easily commercialised as edible oils. Refined coconut oil (RCO) is obtained from copra and is also utilised for the production of soap or cleansing agents. VCO is produced from fresh coconut meat either from expeller or aqueous based processes without the need of further refining, or with the use of solvents for extraction (Liu, 2016; Pham, 2016; Siriphanich et al., 2011; Tan et al., 2014).

RCO occupies larger volumes of production and is mainly manufactured in the Philippines, Indonesia and India. Thirty seven percent of RCO is produced in the Philippines (1.1 million tonnes, in 2014) (FAOSTAT, 2017) and is exported to Europe and America (Pham, 2016; Villarino et al., 2007). Recently, demand for VCO has increased due to its recognition as a healthy ingredient which provides a higher antioxidant content compared to RCO. Moreover, VCO contains lauric acid, a medium-chain fatty acid, and short-chain fatty acids such as capric, caproic and caprylic which have antiviral and antibacterial activities (DebMandal and Mandal, 2011; Marina et al., 2009; Pham, 2016; Siriphanich et al., 2011; Villarino et al., 2007).

Despite the potential health benefits of VCO, little has been reported concerning its industrial production. In 1973 the first pilot plant process proposed using aqueous extraction, where application of hot water at 60 °C was utilised to facilitate the release of oil followed by centrifugation for oil recovery (Hagenmaier et al., 1973). In modern processes, coconut crushed endosperm (approximately millimetric particle size) can be heated in water to obtain coconut milk or dried before it is fed through an oil expeller (Berma Procesys Corp, 2017; Liu, 2016). Alfa-Laval plants are capable of processing up to 600,000 coconuts per day to produce coconut milk (Seow and Gwee, 1997). Coconut milk is a natural oil-in-water emulsion that can contain from 5 to 29% fat. In commercial coconut preparations such as light, milk, cream or concentrated products (Liu, 2016), the globulins and albumins from coconut

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meat, are responsible for emulsion stability (Patil and Benjakul, 2017; Raghavendra and Raghavarao, 2010). For aqueous based extraction of VCO, emulsion breakage in coconut milk is achieved through a series of centrifugation stages that separate clean virgin oil and skim milk. However, up to 24% of the total oil content can be found in the solid coconut waste produced after the aqueous based coconut milk extraction process (Sulaiman et al., 2013).

A number of processing aids have been suggested to increase yields in coconut oil extraction processes, including chilling and thawing, fermentation or enzymatic treatments (Che Man, Suhardiyono, Asbi, Azudin, & Wei, 1996; Mansor et al., 2012; Raghavendra and Raghavarao, 2010). Novel technologies such as high frequency ultrasound treatment named currently megasonic treatment, consisting of sound irradiation of the oily biomass with high frequency standing waves (0.4–4 MHz). It has been successfully applied in aqueous-based oil extraction of olives (Juliano et al., 2017a,b), palm nuts (Juliano et al., 2013a,b), and in avocado fruits (Martínez-Padilla et al., 2018).

In the case of coconut oil extraction, preliminary results showed that treatment of a coconut-water mixtures with megasonic standing waves improved the process (Juliano et al., 2017a,b). Megasonic treatment caused a denser cream layer after centrifugation when compared to the non-treated control. Application of high frequency ultrasound, above 400 kHz, is milder treatment than the traditional high intensity low frequency ultrasound (18–24 kHz) and does not form imploding bubbles from unstable cavitation and hence does not cause cell breakage (Leong et al., 2015). The positive effects of megasonic treatment on oil separation are either due to standing wave particle-droplet separation or microstreaming effects caused by stable cavitating bubbles (Juliano et al., 2017a,b). Conversely, low frequency ultrasound has been applied as an emulsification step for production of nanoemulsions (Kentish et al., 2008; Ramisetty et al., 2015).

$$\text{Oil yield } [\%] = \frac{\text{Oil extracted from gravity} - \text{separated cream layer } [g]}{\text{Mass of coconut meat } [g]} \times 100 \qquad (1)$$

$$\text{Oil extractability } [\%] = \frac{\text{Oil extracted from gravity} - \text{separated cream layer } [g]}{\text{Mass of oil in coconut meat } [g]} \times 100 \qquad (2)$$

The purpose of this study was to firstly investigate the effect of cold storage of coconut meat and heating of coconut-water mixtures for improved VCO aqueous-based separation and secondly to investigate the effect of megasonic treatment time on oil extraction in both fresh and cold stored coconut meat. The megasonic VCO extraction was then scaled-up and evaluated at selected process conditions.

2. Materials and methods

2.1. Sample preparation

Coconuts were purchased from a local fruit market (Hoppers Crossing, Victoria, Australia). Coconuts were stored at 5 °C for less than 2 months. For each treatment, a batch of 8 coconuts was selected. Mature undamaged coconuts were dewatered and deshelled and the separated endosperms were utilised as samples for the trials. Particle size was reduced by shredding the coconut endosperms (coarse particles near 1–3 mm) using a commercial blender (PB9800 Café Series Blender, Sunbeam, Australia) at speed 3 (~2500 rpm) for 2 min. Some of the separated coconut meat or shredded endosperm samples were stored at 5 °C for 20 or 44 h, as shown in the experimental design in Table 1.

2.2. Wet extraction

A heating step was implemented at lab-scale to study the aqueous coconut extraction process and the effect of coconut meat cold storage time simultaneously. A 1 L coconut-meat water mixture was prepared by mixing coconut meat with demineralised water (22 ± 2 °C) manually at 1:4 ratio. Samples of the mixture were heated in a water bath in a circular stainless-steel vessel (12.5 × 16 cm). Extraction variables were explored by conducting a factorial design in duplicate, with three levels of cold storage at 5± 1 °C (0, 20 and 44 h), two heating temperatures (60 and 70± 2 °C) and two heating times (30 and 50 min) (Table 1, Experiment 1).

A schematic diagram of the experimental process for aqueous based oil recovery is shown in Fig. 1. After heating the 1:4 coconut meat-water mixture, a visible and defined coconut cream layer was separated by gravity (approximately in 2 min). The gravity-separated cream layer was then removed with a spoon from the skim milk. All gravity-separated cream layers were centrifuged at 5020 g (4200 rpm) (Beckman Coulter J6-MI, rotor JS-4.2, USA) for 30 min and 40 °C to obtain a centrifuged-cream layer and a skim milk residue. Oil content in the centrifuged-cream layer was measured as described in Section 2.4. Each trial was carried out at least in triplicate. The oil yield and oil extractability were calculated as:

2.3. Megasonic treatment

The high frequency ultrasound system, or megasonic reactor, consisted of a rectangular stainless-steel vessel of 18.2 × 22.5 × 6.2 cm containing the 2 MHz transducer plate (16 × 16 × 3.2 cm) (Sonosys, Germany) (Fig. 2a). The distance between transducer and vessel wall was 3 cm. Compressed air was circulated through the transducer plates to cool the transducer during sonication. Electrical power draw during sonication was measured with a power meter (Belkin, F7C005AU, China).

Megasonic trials were carried out with 1 L coconut meat-water mixture (200 g coconut meat: 8000 g water) at 60 °C for 30 min, which is the temperature applied in traditional aqueous-based virgin coconut oil industrial processes (Berma Procesys Corp, 2017). Fresh meat samples (2 L) were divided into two portions, one treated using the traditional process and the other was used for