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Microencapsulation of canola oil by lentil protein isolate-based wall materials

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ABSTRACT

The overall goal was to encapsulate canola oil using a mixture of lentil protein isolate and maltodextrin with/without lecithin and/or sodium alginate by spray drying. Initially, emulsion and microcapsule properties as a function of oil (20%–30%), protein (2%–8%) and maltodextrin concentration (9.5%–18%) were characterized by emulsion stability, droplet size, viscosity, surface oil and entrapment efficiency. Microcapsules with 20% oil, 2% protein and 18% maltodextrin were shown to have the highest entrapment efficiency, and selected for further re-design using different preparation conditions and wall ingredients (lentil protein isolate, maltodextrin, lecithin and/or sodium alginate). The combination of the lentil protein, maltodextrin and sodium alginate represented the best wall material to produce microcapsules with the highest entrapment efficiency (~88%). The lentil protein-maltodextrin-alginate microcapsules showed better oxidative stability and had a stronger wall structure than the lentil protein-maltodextrin microcapsules.

1. Introduction

Canola oil is rich in unsaturated fatty acids (e.g., oleic acid, linoleic acid and α-linolenic acid), which provide a variety of health benefits, including the reduction of cardiovascular disease, type 2 diabetes, and osteoporosis risk (Rajaram, 2014). However, the susceptibility of unsaturated fatty acids to oxidation represents a major challenge in its application, since lipid oxidation leads to the formation of free radicals and volatile compounds resulting in undesirable flavor in food products (Pegg, 2005). Microencapsulation is a process that helps circumvent this issue by offering protection to oils during food processing and storage, increasing their shelf-life, and transforming a liquid into a more easily handled and dispersed solid powder (Desai & Park, 2005).

Microencapsulation is defined as a process involving the coating of individual active particles or droplets within an edible wall material comprised of proteins, polysaccharides and/or lipids; to produce capsules in the micron to millimeter size range (Tyagi, Kaushik, Tyagi, & Akiyama, 2011). Among the various microencapsulation techniques (e.g., spray drying, extrusion coating, complex coacervation, and liposome entrapment), the most commonly one applied is spray drying, due to its low cost and wide availability of equipment (Desai & Park, 2005). Wall material formulations and emulsification conditions (e.g., emulsion stability, droplet size, and emulsion viscosity) are the most important factors impacting the quality of spray dried microcapsules in terms of their entrapment efficiency, physicochemical properties and storage stability (Koc et al., 2015). Hogan, McNamee, O'Riordan, and O'Sullivan (2001) found that emulsions prepared by soya oil, sodium caseinate, and corn syrup solids had lower viscosity, which further produced microcapsules with significantly higher entrapment efficiency, in comparison with the microcapsules prepared by maize starch. Can Karaca, Low, and Nickerson (2013) also demonstrated that emulsions prepared by flaxseed oil and legume proteins with larger droplet size resulted in microcapsules with better oxidative stability and lower surface oil.

Wall materials act as barriers to protect the core material and to control diffusion, playing an essential role in producing stable microcapsules with high entrapment efficiency. They require to have good emulsifying properties, solubility, drying properties and proper rheological properties to be easily used in the spray dryer (Gharsallaoui, Roudaut, Chambin, Voilley, & Saurel, 2007). The most commonly studied wall materials for microencapsulation in the food industry are whey proteins, sodium caseinate, soy protein, gelatin, maltodextrin, starches and gum Arabic (Gharsallaoui et al., 2007; Koc et al., 2015). Hogan et al. (2001) stated that it was impossible to produce soya oil microcapsules only using sodium caseinate, and the addition of maize starch ideally increased entrapment efficiency. There is no single material

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providing all properties required for an ideal encapsulating agent, therefore the combination of proteins and polysaccharides as wall materials is commonly studied to offer enhanced entrapment efficiency.

Because of its low cost, good solubility, neutral aroma and taste, low viscosity at high concentrations and poor emulsifying capacity, maltodextrin (a hydrolysed starch) is desirable to be used in combination with other wall materials in the microencapsulation process as a processing aid (Madene, Jacquot, Scher, & Desobry, 2006). The degree of hydrolysis [dextrose equivalent (DE) of 5.0–20.0] of corn starch to produce maltodextrin exhibits significant effects on the microcapsules' characteristics (Dokic, Dokic, Sovilj, & Katona, 2004), in which microcapsules prepared by maltodextrin with lower DE value (e.g., DE of 9.0) had lower surface oil in comparison with microcapsules containing maltodextrin with higher DE value (e.g., DE of 18.0), due to the formation of a more hydrophilic microcapsule surface structure resulting from the higher molecular weight glucose oligomers (Can Karaca, Nickerson, & Low, 2013). Lecithin, an ionic phospholipid, is widely used in the preparation of single-layered and bi-layered microcapsules (Carvalho, Silva, & Hubinger, 2014), because of non-toxicity, good compatibility and nutritional effects (e.g., lowering the cholesterol level in the blood) (Wilson, Meservey, & Nicolosi, 1998). The addition of lecithin in the production of microcapsules has been previously reported to improve microcapsules' properties, such as higher entrapment efficiency, better oxidative stability, and smaller particle size (Carvalho et al., 2014). Sodium alginate, which contains two monomeric units of β-D-mannuronic acid and α-L-guluronic acid, is a natural anionic polysaccharide extracted from brown algae (Liu et al., 2013). It is commonly used in the production of microcapsules to form the rigid wall matrix with multivalent cations to increase oxidative stability of encapsulated oils (e.g., olive oil) (Liu et al., 2013; Sun-Waterhouse, Wadhwa, & Waterhouse, 2013). Very little information is available about the microencapsulation of canola oil using pulse proteins-based wall materials in the literature. Lentil protein isolate (LPI) is considered as a promising emerging protein used by the food industry, due to its nutritional value, low cost and functional properties (e.g., water holding capacity and oil binding capacity) (Boye et al., 2010). Can Karaca, Low, et al. (2013) designed a lentil protein-based wall material in combination with maltodextrin to entrap 10% flaxseed oil which is far too low to be commercially viable.

The objective of this study was to improve the oil concentration by developing a LPI-based wall material which provides the protective nature against oxidation for the delivery of healthy oils (e.g., canola oil), beyond that of what Can Karaca, Low, et al. (2013) could achieve (10% oil concentration).

2. Materials and methods

2.1. Materials

LPI and maltodextrin (MALTRIN M100, dextrose equivalent of 9.0–12.0) were kindly donated by POS Bio-Sciences (Saskatoon, SK, Canada) and Grain Processing Corporation (Muscatine, IA, USA), respectively. The crude protein content of LPI was determined to be 78.97% w.b. (% N × 6.25) as described by the Association of Official Analytical Chemists Method 920.87 (AOAC., 2003). Soy lecithin (L-alpha-Lecithin, from soybean oil), canola oil, SA and all chemicals used in this study were purchased from Fisher Scientific (Ottawa, ON, Canada), a local supermarket, and Sigma-Aldrich (Oakville, ON, Canada), respectively. A Millipore Milli-Q™ water purification system (Millipore Corporation, Milford, MA, USA) was used to produce Milli-Q water.

2.2. Emulsion preparation

2.2.1. Phase one

Initial emulsions were formulated with different oil, LPI and maltodextrin concentrations (Table 1a). LPI was first dispersed in Milli-Q water at the specified concentration (corrected for protein level within the powder) and adjusted to pH 3.0 with 2.0 M HCl or 2.0 M NaOH, followed by stirring at 500 rpm for overnight at 4 °C to ensure complete dispersion. pH of the LPI solutions was re-adjusted to 3.0 prior to sample homogenization. In a preliminary experiment, the LPI concentration in the emulsion was restricted <10% (w/w), since at levels ⩾10% (w/w), LPI solutions were too viscous to be used for pH adjustment and emulsion preparation (data not shown). A pH 3.0 protein solution was used based on work by Chang, Tu, Ghosh, and Nickerson (2015). Maltodextrin was then dissolved into LPI solution at levels outlined in Table 1a and stirred at 500 rpm for 3 h at room temperature (22–23 °C). Oil-in-water emulsions were prepared by homogenizing varying amounts of oil (20% vs 30% oil concentration), maltodextrin, and LPI solutions using a Polytron PT 2100 Homogenizer (Kinematica AG, Lucerne, Switzerland) equipped with a 12 mm PT-DA 2112/2EC generating probe at 15,000 rpm for 5 min at room temperature (Table 1a).

2.2.2. Phase two

Stemming from the results in phase one, a wall formulation of 2% LPI and 18% maltodextrin with 20% oil concentration was selected as the base formulation (*See* Section 3) for further reformulation using different homogenization conditions and additional ingredients (lecithin, and/or sodium alginate] in wall material. LPI solutions were prepared in the same manner as described above. A soy lecithin solution was prepared by dissolving it in Milli-Q water and adjusting to pH 3.0 (at which the lecithin has better dissociation behavior, because the phosphate groups on the lecithin have a pK_a value of ~1.5) (Chuah, Kuroiwa, Ichikawa, Kobayashi, & Nakajima, 2009) with 1.0 M HCl or 1.0 M NaOH, followed by stirring at 500 rpm for overnight at 4 °C. In a preliminary experiment, the soy lecithin concentration in the emulsion was restricted ⩽3.0% (w/w), since at levels >3.0% (w/w), the soy lecithin cannot be completely solubilized after stirring overnight, and the solution was too thick to be used for emulsion preparation. pHs of the LPI and the lecithin solutions were re-adjusted to 3.0 prior to sample homogenization. Sodium alginate and maltodextrin were separately dissolved in Milli-Q water and stirred at 500 rpm for 3 h at room temperature. The initial oil-in-water emulsions with 20% (w/w) oil concentration and different wall material components (Table 1b) were prepared as described in Table 1c using the Polytron PT 2100 Homogenizer.

2.3. Emulsion characteristics

2.3.1. Emulsion stability

Emulsion stability (ES) was measured as described by Liu, Elmer, Low, and Nickerson (2010) with minor modification. In brief, freshly prepared emulsions (10 mL) were filled into a 10 mL sealed graduated glass cylinders (inner diameter = 10.5 mm, height = 160 mm), and then stored for 24 h at room temperature. During storage, the emulsions separated into a cream upper layer and a serum bottom layer. The visual observation was done after 24 h of storage. Emulsion stability was measured as ES (%) and expressed as:

$$ES(\%) = HS/HE \times 100 \quad (1)$$

where HS is the height of the serum layer, and HE is the height of the emulsion, as measured using a digital micrometer (Model 62379-531, Control Company, USA) having a precision of