LWT - Food Science and Technology 62 (2015) 1105–1111

Contents lists available at ScienceDirect

LWT - Food Science and Technology

journal homepage: www.elsevier.com/locate/lwt

Enhanced oxidative stability of extruded product containing polyunsaturated oils

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ARTICLE INFO

Article history:
Received 8 September 2014
Received in revised form
4 December 2014
Accepted 3 February 2015
Available online 11 February 2015

Keywords:
Extrusion
Polyunsaturated oils
Oxidation
Encapsulation
Stability

ABSTRACT

The processing and product characteristics of corn grit based formulations containing 5–15% w/w sunflower oil prepared using twin screw extrusion were compared. The formulations contained (i) corn grit and oil (Control) (ii) corn grit, heated protein-carbohydrate powder and oil (Encapsulant), and (iii) corn grit and microencapsulated oil powder stabilized by the heated protein-carbohydrate (Oil powder). The formulation, the dry feed rate and extrusion parameters affected the processibility and final product properties. Where neat oil was introduced into the barrel (Control and Encapsulant formulations), the surface oil of the extrudates generally increased with increasing oil content. When the microencapsulated oil powder was used, the surface oil was not markedly affected by increasing the oil content. The surface oil content was lowest when microencapsulated oil powder was used at equivalent oil content of extrudates. The oxidative stability of the oil in the extruded products containing corn grit-encapsulant powder or corn grit-microencapsulated oil powder were higher compared to that containing corn grit alone as the dry feed. Overall, the oxidative stability of extruded product containing polyunsaturated oils was enhanced by adding the heated protein-carbohydrate matrix to the formulation, while the highest oxidative stability was achieved using microencapsulated oil powder.

1. Introduction

Extrusion is a technology used to produce human foods, animal feeds and aqua feeds due to its efficiency and versatility (Brennan, Derbyshire, Tiwari, & Brennan, 2013; Kannadhason, Rosentrater, Muthukumarappan, & Brown, 2010). Extrusion cooking affects starch and protein digestibility, vitamin retention, polyphenol degradation, lipid oxidation and physiological properties of dietary fiber (Cheftel, 1986; Singh, Gamlath, & Wakeling, 2007). The retention and degradation of different food ingredients during extrusion are dependent on the inherent characteristics of each ingredient, the formulation, and the heat and pressure-induced effects on food component interactions and degradation during the extrusion cooking process.

Most extruded products are cereal based and they contain <6–7% lipid (Cheftel, 1986). Extrusion were used to deliver 5% sunflower oil within a starch-based matrix and smaller oil droplet size was obtained with increasing hyrophile-lipophile (HLB) value of the added synthetic emulsifiers (Yilmaz, Jongboom, Feil, & Hennink, 2001). However when oil content of the product in the extruder barrel exceeds 7%, the product quality is compromised, and the external surface of the extrudate becomes oily due to smearing out of the oil during extrusion (Ilo, Schoenlechner, & Berghofe, 2000).

In some applications high oil loading in extruded products may be required. For example in aqua feeds, oil loadings of up to 40% are required to provide sufficient energy for fish growth. The oil may be incorporated using vacuum infusion after extrusion (Glencross, Hawkins, Maas, Karopoulos, & Hauler, 2010). The vacuum infusion adds an extra production step. When high levels of unsaturated oil are included in extruded products, attention needs to give to (i) the processibility of the formulation during extrusion, (ii) the physical properties of the extrudate and also (iii) the shelf-stability of the product. Unsaturated oils in extrudates are susceptible to oxidation, because of the porous nature of the extrudates which increases the exposure of the oil at the surface or near the surface to the oxygen in the environment. Oxidation of lipids in the food and feed products can significantly decrease their dietary value. To arrest oxidation of oil in extruded products, antioxidants may be

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http://dx.doi.org/10.1016/j.lwt.2015.02.005
0023-6438/

added, such as phenolics (Viscidi, Dougherty, Briggs, & Camire, 2004), tocopherols (Paradiso, Summo, Trani, & Caponio, 2008) and synthetic antioxidants (e.g. butylated hydroxyanisole and butylated hydroxytoluene) (Butt, Ali, Pasha, Hashmi, & Dogar, 2003). In the feed industry vitamins protected by encapsulation have been included in extruded feeds (Putnam, 1986). It is envisaged that the use of encapsulated oils in extruded products will provide protection to unsaturated oils but this approach appears not to have been reported.

Maillard reaction products formed by heating aqueous mixtures of milk proteins and reducing carbohydrates have been found to protect unsaturated fatty acids against oxidation (McGookin & Augustin, 1991). Heated protein-carbohydrate mixtures containing Maillard reaction products themselves have emulsifying and antioxidant properties and when converted into powder, the heated protein-carbohydrate mixtures may be added as a dry feed. In addition, the Maillard reaction products comprising heated protein-carbohydrate mixtures can be used to emulsify polyunsaturated oils. The emulsions may also be spray dried into microencapsulated powders. Polyunsaturated oil in both the emulsion and powder forms stabilized by Maillard reaction products was protected from oxidation (Sanguansri & Augustin, 2001).

In this study, corn grit based extrudates containing 5–15% w/w sunflower oil were prepared using twin screw extrusion. The processibility and product characteristics of corn grit based formulations containing 5–15% w/w sunflower oil were compared. The formulations contained (i) corn grit and oil (ii) corn grit, heated protein-carbohydrate powder and oil, and (iii) corn grit and microencapsulated oil powder using a heated protein-carbohydrate matrix as the encapsulant. The total oil, surface oil, the pasting properties, the expansion of the extrudates and the oxidative stability of the oil in extruded products were analyzed.

2. Materials and methods

2.1. Materials

The corn grit (Polenta NO 1, containing 76.4% starch, 7.4% protein, 3.1% dietary fiber, 0.7% fat and ~12% moisture) was from Allied Mills, NSW, Australia. Calcium carbonate ($CaCO_3$; from Redox Pty Ltd, Laverton, VIC, Australia) was used to supplement the corn grit to aid expansion. Sunflower oil (Gaganis, Adelaide, Australia) was obtained from a local supermarket. The major fatty acids in sunflower oil, as determined by gas chromatography of methylated fatty acid esters (Shen, Apriani, Weerakkody, Sanguansri, & Augustin, 2011) was as follows: 6.2% palmitic acid, 3.5% stearic acid, 34.3% oleic acid and 56.0% linoleic acid.

The proteins (whey protein isolate (WPI) and sodium caseinate (NaCas), from Fonterra, New Zealand) and carbohydrates (maltodextrin (Fieldose 30) and glucose, from Penford, Lane Cove, NSW, Australia) were used in the preparation of the heated protein-carbohydrate powder (encapsulant) and the microencapsulated oil powder.

2.1.1. Corn grit base

The corn grit base was obtained by premixing 99% (dry basis) of corn grit (Polenta) with 1% w/w of $CaCO_3$.

2.1.2. Heated protein-carbohydrate powder (Encapsulant)

The Encapsulant (3.5% moisture; 1protein:2carbohydrate) was spray dried from a heated aqueous protein-carbohydrate mixture. Briefly, protein dispersion (7WPI:3NaCas, 8.9% total solids) were dispersed in 60 °C water for 30 min. A mixture of carbohydrates (1glucose:1maltodextrin, w/w) was added to the protein solution. The protein: carbohydrate ratio (dry basis) was 1:2 w/w. The aqueous mixture (23% TS, w/w) was adjusted to pH 7.5 using 2 mol/L NaOH, transferred to 3 L cans, sealed and heated at 100 °C for 50 min in a retort. This heat treated protein-carbohydrate mixture was then spray dried in a Niro Production Minor spray dryer (Niro A/S, Søborg, Denmark) using inlet/outlet temperatures of 180/80 °C to obtain the Encapsulant powder.

2.1.3. Microencapsulated oil powder (oil powder)

The sunflower oil was encapsulated within the heated protein-carbohydrate matrix to produce a 50% oil powder (dry basis). Briefly, an aqueous dispersion of heat treated protein-carbohydrate solution was prepared in the retort as outlined above (Section 2.1.2), cooled to 60 °C, and then sunflower oil was added and dispersed using a high shear mixer (Type X50/10, Ystral Gmbh, Ballrechten-Dottingen, Germany) operated at 3000 rpm. The pre-emulsion was homogenized using a Rannie two stage homogenizer (APV Homogenizer, Albertslund, Denmark) at pressures of 35/10 MPa. The final emulsion was spray dried in a Niro Production Minor spray dryer (Niro A/S, Søborg, Denmark) at inlet and outlet temperatures of 180/80 °C to produce microencapsulated oil powder (50% sunflower oil, 16.7% protein, 33.3% carbohydrate, dry basis). The moisture content of the powder was 3.5%.

2.2. Formulation of ingredients in the dry mixtures for extrusion

Three formulations, each at three different oil loadings (5, 10, 15% w/w) were prepared and extruded into total of nine samples (Table 1): (1) Corn grit-oil formulations with 5, 10 or 15% oil loading containing corn grit supplemented with 1% $CaCO_3$, hereafter termed Control 5, Control 10 and Control 15; (2) Corn grit-encapsulant-oil formulations containing 5, 10 or 15% oil loading where there was partial substitution of the corn grit base with the non-oil containing heated protein-carbohydrate powder (encapsulant), hereafter termed Encapsulant 5, Encapsulant 10 and Encapsulant 15; and (3) Corn grit-oil powder formulations containing 5, 10 or 15% oil loading where there was partial substitution of the corn grit base with the microencapsulated oil powder, hereafter termed Oil powder 5, Oil powder 10 and Oil powder 15 (Table 1).

2.3. Extrusion

2.3.1. Extrusion processing

A laboratory scale co-rotating fully intermeshed twin screw extruder with a screw diameter of 15.6 mm (Prism Eurolab 16, Thermo Electron Corporation, Karlsruhe, Germany) was used for the extrusion process. The length to diameter ratio of the screw configuration was 40. The screw has 4 sections of conveying and kneading screws and a metering section before the die (Fig. 1). The barrel has 9 sections, with temperature controlled independently. The oil and water were fed using two independent syringe pumps (Model 500D Syringe Pump, Teledyne Isco, Lincoln, NE 68504, USA) at the same location next to the dry feed, and the dry feed was fed using a volumetric feeder (custom made screw with a geared induction motor, S8126GT-TCE, SPG Co., Ltd., Namdong-gu Incheo, Korea). A single hole die with aperture diameter of 1.25 mm, land length of 5 mm and lead-in angle of 60° was used. During extrusion, the barrel temperatures in each of the sections were sequentially as follows: 80, 90, 90, 90, 100, 100, 120, 120 and 140 °C. The die temperature (180 °C) and screw speed (200 rpm) were kept constant. The volumetric feeder was operated at 80% of the motor capacity and the actual mass feed rate was calibrated for each formulations. The screw torque and die pressure were recorded. The barrel moisture content was controlled at around 26–27%. The samples were dried to 5% moisture at 50 °C oven, then vacuum