LWT - Food Science and Technology 56 (2014) 414–420

Contents lists available at ScienceDirect

LWT - Food Science and Technology

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

Characterization of supercritical fluid extrusion processed rice–soy crisps fortified with micronutrients and soy protein

Mian Kamran Sharif[a,b,*], Syed S.H. Rizvi[a], Ilankovan Paraman[a]

[a] Institute of Food Science, Stocking Hall, College of Agriculture and Life Sciences, Cornell University, Ithaca, NY 14853-7201, United States
[b] National Institute of Food Science and Technology, University of Agriculture, Faisalabad 38040, Pakistan

ARTICLE INFO

Article history:
Received 24 May 2013
Received in revised form
18 October 2013
Accepted 28 October 2013

Keywords:
Supercritical fluid extrusion
Nutrient fortification
Cereal grain products
Value-added products
Expanded crisps

ABSTRACT

Protein and micro-nutrients enriched rice–soy crisps (RSC) were prepared using supercritical fluid extrusion and their impact on quality attributes was determined. A low-shear, twin screw, co-rotating extruder was used to produce puffed RSC using supercritical CO_2 (SC-CO_2), which served as an expansion agent during the process carried out at lower temperatures (~100 °C) compared to conventional steam based extrusion (~130–180 °C). The fortified RSC contained 25–40 g/100 g soy protein and four micronutrients (iron, zinc, vitamin A and C) at the recommended daily values in 100 g product. The RSC were analyzed for physical characteristics and nutrient composition. The increasing soy protein fortification from 25 to 40 g/100 g reduced the crisps expansion ratio (4.27–2.95), crispiness (15.0–9.5), and increased piece density (0.21–0.27 g/cm^3), bulk density (0.17–0.22 g/cm^3) and hardness (76.39–129.05 N). The nutrient fortification improved protein (334–568%) and dietary fiber (571–901%) and the extrusion process retained all of the added minerals and about 50% retention of vitamin A and C in the final products. The SC-CO_2 assisted extrusion is an effective process-based approach to produce low-moisture, fortified crispy products. These products are appropriate for consumption as nutribars especially for school lunch programs in developing countries to reduce malnutrition through process based nutrient fortification approaches.

1. Introduction

Micronutrient malnutrition is one of the leading causes of serious health and economic problems (Mehansho, Mellican, Hughes, Compton, & Walter, 2003). Micronutrient deficiencies exist when too little of a vitamin or mineral is available to the human body to enable normal physical and/or mental functioning (Bowman & Russell, 2006). Billions of people in the world suffer from micronutrient malnutrition contributing to the global burden of diseases. Iron deficiency is the most common nutritional disorder in the developing countries as well as in affluent societies. Each year, iron deficiency saps the energy and learning capacity of nearly two billion people, vitamin A and zinc deficiencies contribute to one million deaths in children. Blindness due to vitamin A deficiency affects 2.8 million children under 5 years of age (Long, Rosado, & Fawzi, 2007).

Fortification of commonly eaten foods with micronutrients is a cost-effective, flexible, and generally acceptable approach to improve the nutrients intake in the vulnerable segments. Processed foods are often fortified with certain micronutrients accessible to large number of peoples thus playing pivotal role in prevention of deficiencies and disorders (Fiedler, Sanghvi, & Saunders, 2008; Mannar & Ameringen, 2003). Soybean has great potential as human food because of high levels of good quality protein. It contains all the macro nutrients required for good nutrition, complete protein (40 g/100 g), soluble carbohydrate (18 g/100 g), dietary fiber (15 g/100 g) and fat (18 g/100 g) as well as vitamins and minerals (Liu, 1997; Singh, Kadam, Saxena, & Singh, 2009). Soybeans supply all nine essential amino acids and have cholesterol reducing and anti-carcinogenic properties (Riaz, 1999). Since rice, being staple food of half of the world's population, it can be as an excellent vehicle to deliver nutrients in malnourished segment of the population globally.

Extrusion technology has been commercially stable in food industry for a long time mainly for production of expanded snacks and instant flours. Extruded snacks are important part of many consumers' daily nutrient and calories intake (Teltweiler, 1999). Starch-based food materials are ideal for extrusion processing

* Corresponding author. Present address: National Institute of Food Science and Technology, University of Agriculture, Faisalabad 38040, Pakistan. Tel.: +92 333 8608341; fax: +92 41 9201439.
E-mail addresses: mks_ft@yahoo.com, mks@uaf.edu.pk, mks_ft@hotmail.com (M.K. Sharif).

0023-6438/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.lwt.2013.10.042

(Chinnaswamy & Hanna, 1988; Yu, Ramaswamy, & Boye, 2012). Fortified extruded products can be consumed as such or incorporated in other foodstuff for addressing nutritional deficiencies in vulnerable groups. Moreover, being low in moisture, these can be stored at room temperature, which is advantageous, especially in developing countries with poor storage infrastructures. Additionally, extrusion can utilize cereal grain co-products such as broken rice kernels, flour, or bran to produce products enriched with required nutrients (Liu, Miller, & Rizvi, 2008; Mishra, Mishra, & Srinivava Rao, 2012). Extrusion can also increase the bioavailability of some nutrients, such as iron and protein, through the inactivation of anti-nutritional factors (Cheftel, 1986).

Supercritical fluid extrusion (SCFX) has been developed by Rizvi and Mulvaney (1992). The technology involves reactive extrusion of starch-based matrices and injection of supercritical carbon dioxide (SC-CO_2) as a viscosity lowering plasticizer and blowing agent to produce microcellular extrudates (Paraman, Wagner, & Rizvi, 2012; Rizvi, Mulvaney, & Sokhey, 1995; Sokhey, Rizvi, & Mulvaney, 1996). The use of low-temperature and low-shear process conditions offers minimum processing losses to heat-labile nutrients. Moreover, it produces products with less explosive puffing, resulting in a smoother surface and more uniform internal cell structure (Alavi, Gogoi, Khan, Bowman, & Rizvi, 1999; Alavi & Rizvi, 2009). The objectives of the present study were to produce rice–soy based expanded crisps fortified with micronutrients and protein by using SCFX and develop a process based nutrient fortification approach to deliver protein and micronutrients commonly deficient in community to alleviate malnutrition.

2. Materials and methods

2.1. Raw materials

Waxy rice flour (RF-W01080-12) was procured from Sage-V Foods (Los Angeles, CA). Defatted toasted soy flour, soy protein concentrate and lecithin were obtained from ADM Specialty Products (Decatur, IL). Distilled mono-glyceride was provided by Danisco ingredients (Kansas, MO). Vitamin/mineral pre-mix comprised of 4 micronutrients used for fortification (Fe as NaFeEDTA, Zn as zinc oxide, vitamin A as retinyl palmitate, and vitamin C as ascorbic acid were provided by Fortitech (Schenectady, NY)).

2.2. Extrusion formulations

Four formulations were prepared by supplementing two levels (25 and 40 g/100 g) of soy protein concentrate and soy flour in rice flour. The ingredient composition of each formulation is given in Table 1. Feed formulations used in the production of rice–soy crisps were comprised of waxy rice flour (56.5–71.5 g/100 g) and soy flour/soy protein concentrate (25–40 g/100 g) as main ingredients contributing starch and protein. Distilled mono-glycerides (dough conditioner, anti-sticking and stabilizing agent), table salt (flavor enhancer), lecithin (emulsifier, ensure even mixing, improve texture and mouth feel) and SC-CO_2 (blowing and expansion agent, plasticizer) were used as minor ingredients 1 g/100 g each for specific functions. Micronutrient premix was added in a ratio of 325 mg premix/100 g formulation according to percent daily value. All the ingredients were mixed for 9 min in 0.14 m^3 ribbon blender (Littleford Day Inc., Florence, KY).

Table 1
Formulations used for the production of micronutrient fortified rice–soy crisps.

Ingredients	Contribution (g/100 g)			
	RS-SPC 25	RS-SPC 40	RS-SF 25	RS-SF 40
Waxy rice flour (WRF)	71.5	56.5	71.5	56.5
Soy protein concentrate (SPC)	25	40	–	–
Toasted defatted soy flour (SF)	–	–	25	40
Distilled monoglyceride	1	1	1	1
Lecithin	1.5	1.5	1.5	1.5
Table salt	1	1	1	1
Total	100	100	100	100

RSC-SPC 25 (rice–soy crisp with 25 g/100 g soy protein concentrate); RSC-SPC 40 (rice–soy crisp with 40 g/100 g soy protein concentrate); RSC-SF 25 (rice–soy crisp with 25 g/100 g toasted defatted soy flour); RSC-SF 40 (rice–soy crisp with 40 g/100 g toasted defatted soy flour).

2.3. Supercritical CO_2 extrusion

A pilot-scale Wenger TX-57 Magnum co-rotating, self-wiping, low shear, twin-screw extruder with a barrel diameter of 52 mm and length to diameter ratio (L/D) of 28.5:1 (Wenger Manufacturing, Sabetha, KS) was used for the preparation of rice–soy based puffed crisps enriched with four micronutrients (Fig. 1). The operating conditions (screw speed, barrel temperature profile, feed rate, shear rate, SC-CO_2 pressure and injection rate) were standardized based on preliminary trials and the extrusion system was configured to operate at a feed rate of 35 kg/h and screw speed of 120 rpm. The barrel temperature in the first three barrel zones was maintained at ~80 °C by circulating steam through barrel jackets to gelatinize starch. The fourth and fifth barrel zones were cooled rapidly by circulating chilled brine (−10 °C). A flow restrictor was used to maintain the die pressure at ~10 MPa. A pilot-scale supercritical fluid system was used to generate and inject SC-CO_2 at a constant flow rate ($7.6 \times 10{-}5$ kg/s) into the barrel through four valves located at L/D of 24. The SC-CO_2 was injected at a pressure of 8.3 MPa to maintain a continuous flow of SC-CO_2 into the product melt (Rizvi et al., 1995). The water was injected at a flow rate of 14% of the feed flow rate. The extrudates emerging from specially designed lentil shape die were cut by a pair of rotating knives and collected on metal trays (Fig. 2). Rice–soy crisps were dried in an oven at a temperature of 90 °C for 40 min and then kept in proofing cabinet at 40–45 °C for 3 h for uniform drying. Final moisture content of all extrudates was ~3–6%. The samples were then packed in ziploc bags and stored at 25 °C for further analysis.

2.4. Physical characterization

The expansion ratio, piece and bulk densities, color and textural properties of rice–soy crisps were determined using respective method. The expansion ratio (ER) was calculated as the cross-sectional thickness of the extrudate divided by the cross-sectional thickness of the die orifice (Alavi et al., 1999). An average diameter of 15 samples was used to determine the expansion for each set of samples. Piece density (g/cm^3) was measured using the sand displacement method and the bulk density was determined by the ratio of the mass to a given volume (Park, 1976). The procedure was repeated five times for each set of samples. Color analysis was carried out using Konica Minolta's Chroma Meter (Model CR-400, Minolta Co. Ltd., Osoka, Japan). The color readings of the four samples were repeated four times and the average values were recorded. The L-value in color system represented lightness with 0 for darkness and 100 for lightness; a-value represented the extent of green color in the range from −100 to 0 and red in the range from 0 to 100; b-value quantifies blue in the range from −100 to 0 and yellow in the range from 0 to 100.

The textural properties of the extruded products were measured by using a texture analyzer (TA-XT2, Stable Microsystems, Texture Technologies Corp., Scarsdale, NY) equipped with Texture Expert Version 1.22. A group of 5 samples were compressed to 80% of their