LWT - Food Science and Technology 84 (2017) 804–814

Contents lists available at ScienceDirect

LWT - Food Science and Technology

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

Physical and hydration properties of expanded extrudates from a blue corn, yellow pea and oat bran blend

Gonzalo Emmanuel Jacques-Fajardo [a], Rogelio Prado-Ramírez [a], Enrique Arriola-Guevara [b], Esther Pérez Carrillo [c], Hugo Espinosa-Andrews [a], Guadalupe María Guatemala Morales [a, *]

[a] CIATEJ, Centro de Investigación y Asistencia en Tecnología y Diseño del Estado de Jalisco, A. C. Avenida Normalistas No. 800, Colinas de la Normal, 44270, Guadalajara, Jalisco, Mexico

[b] UDG, Departamento de Ingeniería Química, Centro Universitario de Ciencias Exactas e Ingenierías, Universidad de Guadalajara, Av. Marcelino García Barragán, Guadalajara, Jalisco, Mexico

[c] ITESM, Departamento de Biotecnología e Ingeniería de Alimentos, Centro de Biotecnología, Tecnológico de Monterrey, Av. Eugenio Garza Sada 2501 Sur, CP 64849, Monterrey, NL, Mexico

A R T I C L E I N F O

Article history:
Received 10 November 2016
Received in revised form
16 June 2017
Accepted 20 June 2017
Available online 21 June 2017

Keywords:
Extrusion-cooking
Functional properties
Physical properties
Principal component analysis
Response surface methodology

A B S T R A C T

Extrudates were prepared from a blue corn, yellow pea and oat bran blend employing a twin-screw extruder. Response surface methodology was used to evaluate the effect of extrusion-cooking process independent variables: screw speed (SS, 300–400 rpm), die temperature (DT, 120–160 °C) and feed moisture content (FMC, 20–25%) on the system parameters (specific mechanical energy and product temperature), physical properties (sectional and specific longitudinal expansion indices, porosity, hardness and color attributes), hydration properties (water absorption and solubility indices, and pasting properties), microstructure and x-ray diffraction. Although, system parameters, physical and hydration properties were affected by SS and DT, the greatest effect was due to the FMC. Indicating this way lubricant effect as the preponderant factor controlling extrusion effects on raw material. Decreased FMC increased specific mechanical energy, expansion, soluble compounds; and decreased hardness, time to raw peak viscosity, raw peak, total setback and final viscosities. Data were also analyzed with a principal component analysis, showing that 74.67% of data variability can be explained defining two components corresponding to the 62.10% that was due to mechanical effect and 12.57% that was related to thermic effect. Conditions obtained for multiple optimization were: 158.64 °C, 371.98 rpm, 18.38% FMC.

1. Introduction

Corn, peas, oats and other dried seeds have been produced, processed and consumed as staple foods for thousands of years. Nowadays large amounts of these staple foods are made commercially instead of being homemade, mainly in industrialized countries. Processing may reduce the health benefits of food by removing bran and germ, what depends mostly on the form in which the products are consumed. Some of these removed components have been found to play important roles beyond satisfying basic nutritional requirements, therefore to receive maximum health benefits, food products made from whole grains and pulses are preferable (Bao et al., 2012). In recent years, consumers become more concerned about eating food with health benefits and reduced energy content (Altan, McCarthy, & Maskan, 2008).

Extrusion cooking offers an excellent alternative to traditional techniques for food processing; extruders can process a great variety of powder ingredients including whole grain flours and are very useful in producing low-fat products with high productivity and significant nutrient retention, reduce microbial contamination, and inactivate some antinutritional factors (trypsin inhibitors, tannins and phytates) (Frame et al., 1994; Guy et al., 2001; Singh, Gamlath, & Wakeling, 2007). Extrusion is widely used for pasta, texturized vegetable protein, modified starch, breakfast cereals, ready to eat snack foods, and other textured foods production (Brennan, Brennan, Derbyshire, & Tiwari, 2011).

Corn flour has been widely used to elaborate expanded extrudates. However, as with other cereals, corn flour's nutritional value

* Corresponding author.
E-mail address: guadisga@msn.com (G.M. Guatemala Morales).

http://dx.doi.org/10.1016/j.lwt.2017.06.046
0023-6438/

does not satisfy the needs of consumer's health (da Silva, Ascheri, Carvalho, Takeiti, & Berrios, 2014). Blue corn composition is similar to white corn, with the advantage of containing anthocyanin and phenolic compounds. Their consumption has been correlated with health benefits, chronic, and degenerative illness prevention, such as cancer, cardiovascular diseases, and cataracts (Camacho-Hernandez et al., 2014). Yellow pea contains high levels of protein, dietary fibers, complex carbohydrates, isoflavones, and folate and is low in fat and sodium. Most of these components are also associated with health benefits such as protein with hypocholesterolemic effects, and isoflavones help in prevention of osteoporosis and certain cancers (Nayak, Berrios, Powers, & Tang, 2011a). Oat bran is the edible outermost layer of the oat kernel and is produced during grinding clean groats or rolled oats for separating the resulting flour by sieving (Bao et al., 2012). It is a fiber-rich byproduct, which contains the fragmented outer coats of the grain together with variable amounts of the starchy endosperm. In contrast to wheat bran, it is rich in water-soluble fiber and poor in cellulose and lignin (Jacobs, 1983).

Raw material composition, processing temperature, feed moisture content, extruder type, screw configuration and rotation, as well as their effect on the rheological properties of food compounds during extrusion make extrusion cooking a very complex process (Ficarella, Milanese, & Laforgia, 2006; Osen, Toelstede, Wild, Eisner, & Schweiggert-Weisz, 2014), what results in non-standardized reporting of extrusion control parameters (Brennan et al., 2011). Over the years, extrusion has been rapidly evolving from an art into a science (Brennan et al., 2011).

The objectives of this study were: (a) to evaluate the effect of extrusion process variables (screw speed, SS; feed moisture content, FMC; and die temperature, DT) on physical and hydration properties of a cereal-pulse extrudates formulated with blue corn, yellow pea and oat bran; (b) to analyze the correlation between physical and hydration properties as well as its relationship with extrusion variables and (c) to find the ideal extrusion conditions to produce expanded extruded snacks.

2. Materials and methods

2.1. Materials

Blue corn var. chalqueño (BC) was purchased from a local producer in Mexico state, yellow pea (YP) was obtained from Saskcan® pulse trading from Canada, and oat bran (OB) was bought from a local distributor of dried fruits and seeds. Before milling, all materials were stored at room temperature. A hammer mill with a 5 mm mesh was employed in flour production. BC seeds were previously broken in a roller mill. YP was directly milled. OB was sieved through a number 20 Tyler mesh, retained particles were milled and mixed with the smaller particles. The BC, YP, and OB flours (80/15/5% wet base) were blended during 10 min prior to extrusion in 6 kg batches to ensure homogeneity. The blended flour composition was 69.33 g/100 g dry base (db) carbohydrates, 13.97 g/100 g db crude fiber, 10.59 g/100 g db protein, 4.33 g/100 g db lipids, and 1.77 g/100 g db ash.

2.2. Extrusion process

Feeding mixture was extruded with a twin-screw co-rotating extruder (BCTM-30, Bühler, Uzwil, Switzerland) with a 600 mm length and L/D = 20 at a feeding rate of 25.7 kg/h (db). Die diameter was 4 mm, and the screw configuration was selected specifically to create high levels of shear stress (Cortes-Ceballos, Perez-Carrillo, & Serna-Saldivar, 2015). The first section contained only conveying elements, with the next containing both conveying and kneading elements. Finally, the high-shear section contained conveying, reverse conveying, and kneading elements. Cutter speed was fixed at 30 rpm for all runs. Temperature was controlled at the final stage of the extruding chamber by using a TT- 137N water heater (Tooltemp, Sulgen, Switzerland). The SS, DT and FMC were established to fulfill the runs of the design of experiments (Table 1). Specific mechanical energy (SME, Wh/kg), and product temperature (PT,°C) were directly obtained for each run from the extruder software (BCTBII, extruder automation control). Prior to analyses, extruded samples were dried during 3 h at 70 °C in a forced-air dryer reaching 5 g/100 g moisture and stored in polyethylene bags at room temperature for further analyses.

2.3. Physical properties

2.3.1. Sectional expansion index (SEI) and specific longitudinal expansion (SLE)

Diameter of each sample was recorded during the hardness test, afterwards mean was calculated. SEI was obtained dividing the cross-sectional mean area of extruded samples by the cross-sectional die area (da Silva et al., 2014). Extrudates length was measured with a caliper on the same samples before hardness testing. SLE was calculated as the extrudates length per density unit, obtained dividing average length of each run by its bulk density. SLE (specific longitudinal expansion) is a specific parameter proposed from the authors to quantify the grade of longitudinal expansion occurred during extrusion. Once the extrudates is released from the extruder, its volume changes in radial and longitudinal ways. The authors are correlating at a constant cutting speed, the grade of longitudinal expansion related to its bulk density. During the tests, was observed that extrudates length was also strongly dependent of bulk density, thus in order to make length measurements comparable among experiments, it was decided to obtain an intensive property to relate length/density, this way SLE allowed to compare lengths of extrudates with those that, have the same density or per unit of density.

Table 1
Experimental design and system parameters.

Run	Extrusion conditions			System parameters	
	DT	SS	FMC	SME[a]	PT[a]
	°C	rpm	%	Wh/kg	°C
1	106.4[b]	350	22.5	95.77	86
2	120	300	20	133	87.5
3	120	400	20	145.56	92
4	120	300	25	86.47	90
5	120	400	25	104.08	73
6	140	350	22.5	94.55	97
7	140	265.9[b]	22.5	61.12	97.5
8	140	350	22.5	59.44	97
9	140	434.1[b]	22.5	118.28	102
10	140	350	18.3	149.82	111
11	140	350	22.5	81.8	116
12	140	350	26.7	73.72	115
13	140	350	22.5	102.83	116
14	160	300	20	116.4	124
15	160	400	20	133.05	124
16	160	300	25	78.31	124
17	160	400	25	82.92	126
18	173.6[b]	350	22.5	108.12	132
19	140	350	22.5	71.04	97

SME: specific mechanical energy. DT: die temperature. SS: screw speed. FMC: feed moisture content. PT: product temperature.
[a] After SME values were got stable (3–5 min) SME and PT were registered (one datum per run).
[b] Values were rounded for setting up extrusion conditions on extruder.