ARTICLE IN PRESS

Journal of Food Engineering xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Journal of Food Engineering

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

Physical and mechanical properties of maize extrudates as affected by the addition of chia and quinoa seeds and antioxidants

Mario Cueto [a,*], Josefina Porras-Saavedra [e], Abel Farroni [b], Liliana Alamilla-Beltrán [e], Regine Schöenlechner [d], Gerhard Schleining [d], Pilar Buera [a,c]

[a] Industry Department, Faculty of Natural and Exact Sciences, University of Buenos Aires, Argentina
[b] Quality of Food, Soil and Water Laboratory, INTA Pergamino, Argentina
[c] Organic Chemistry Department, Faculty of Natural and Exact Sciences, University of Buenos Aires, Argentina
[d] Department of Food Sciences and Technology, BOKU-University of Natural Resources and Life Sciences, Vienna, Austria
[e] Department for Graduates and Research in Food, National School for Biological Sciences, Instituto Politécnico Nacional, Carpio y Plan de Ayala, Mexico

ARTICLE INFO

Article history:
Received 19 November 2014
Received in revised form 13 February 2015
Accepted 19 July 2015
Available online xxxx

Keywords:
Extrudate
Chia
Quinoa
Bioactives
AFM
Sound emission

ABSTRACT

The physical and mechanical properties of maize extrudates have been analyzed in relation to the addition of quinoa flour and two novel ingredients, chia and powder extract of purple corn with antioxidant properties. Maize flour and mixtures with 20% quinoa or 5% chia or 2% antioxidant powder were extruded with a double screw extruder. Physical properties like expansion rate, density, humidity, and mechanical and acoustic properties using a cutting test were measured. Mixtures with chia showed a lower expansion rate, probably related to the higher lipid content of the final mixture. On the other side, quinoa favored the expansion rate compared to maize flour. This was in correlation with the density results, being the quinoa extrudates the ones with the smallest density values. Extrudates with quinoa resulted in a smoother structure while chia addition tended to generate a rougher surface. Also, the addition of antioxidant powder decreased the surface roughness.

1. Introduction

Extrusion cooking is an ideal method for manufacturing a great number of food products as ready to eat cereals, salty and sweet snacks, texture–meat like materials and precooked food mixtures for infants. Beneficial nutritional effects range from increased protein and starch digestibility to the preparation of low cost, protein enriched or nutritionally balanced foods and feeds (Singh et al., 2007).

Nutritional concern about extrusion cooking is reached at its highest level when extrusion is used specifically to produce nutritionally balanced or enriched foods, like weaning foods, dietetic foods, and meat replacers (Cheftel, 1986; Plahar et al., 2003; Singh et al., 2007). However, one of the advantages of extrusion cooking is the destruction of antinutritional factors, especially trypsin inhibitors, haemagglutinins, tannins and phytates, all of which inhibit protein digestibility (Alonso et al., 2000; Armour et al., 1998; Bookwalter et al., 1971; Lorenz and Jansen, 1980).

The most widely used cereals for producing extrudates are maize and wheat. However, blends of these cereals with other seeds have been assayed. There are several studies on the use of quinoa–maize blends in the development of extrudates (Coulter and Lorenz, 1991; De Graaf et al., 2003; Ramos Diaz et al., 2013; Repo-Carrasco et al., 2003). Quinoa (*Chenopodium quinoa*) is a pseudocereal that has been cultivated in South America for more than 5000 years. The studies concerning quinoa proteins revealed that it contains a balanced amino acid composition, with a high content of essential amino acids, and is thus superior to that of common cereals (Drzewiecki et al., 2003). Lipid content of quinoa is also higher (2 or 3-fold) than in common cereals and rich in unsaturated fatty acids, which are desirable from a nutritional point of view (Alvarez-Jubete et al., 2010). Carbohydrates are the major component and their content varies from 67% to 74% of the dry matter (Jancurová et al., 2009). Starch is the only carbohydrate reported and its content varies from 51% to 61%. Cordeiro et al. (2012) showed a potential gastroprotective activity of quinoa polysaccharides.

Chia seeds (*Salvia hispanica L.*), which contain between 25% and 40% fats and up to 68% omega-3 alpha-linolenic acid, are among the plant sources with the highest contents of alpha-linolenic acid (Antruejo et al., 2011). Their protein content is high (19–23%), with

* Corresponding author at: Industry Department, Faculty of Natural and Exact Sciences, University of Buenos Aires, Intendente Güiraldes 2160, Ciudad Universitaria, C1428EGA, Buenos Aires, Argentina.
E-mail address: mariocueto@gmail.com (M. Cueto).

http://dx.doi.org/10.1016/j.jfoodeng.2015.07.027
0260-8774/

Please cite this article in press as: Cueto, M., et al. Physical and mechanical properties of maize extrudates as affected by the addition of chia and quinoa seeds and antioxidants. Journal of Food Engineering (2015), http://dx.doi.org/10.1016/j.jfoodeng.2015.07.027

the whole profile of essential amino acids, in particular leucine, lysine, valine, and iso-leucine (Sandoval-Oliveros and Paredes-López, 2012). However, there is a lack of studies on the use of chia–maize blends to prepare extrudates. Thus, specific studies on its effects on physical performance of extrudates are necessary before it can be incorporated as a novel ingredient to enhance the nutritional value of cereal foods.

Purple corn is known as a good source of natural antioxidants (Pascual-Teresa et al., 2002) and its benefic effects on health are under active study (Finkel et al., 2013; Hosoda et al., 2012; Huang et al., 2015). It can also be considered as an interesting natural alternative for mitigating the oxidation of essential fatty acids during extrusion (Camire et al., 2007).

Many processing variables as well as the blend composition affect the characteristics of the final obtained product. The addition of ingredients such as quinoa, chia or purple corn affect the physical characteristics of the extruded products (density and expansion index), as well as their mechanical properties (that correlate with sensory acceptance). Most textural attributes of foods are perceived through chewing, a process by which a solid food is torn, ripped, crushed, ground and mixed with saliva. Among the most important organoleptic attributes of cereal foods, crispness is characterized by brittle fracture at a low fracture force and distinguishable fracture events, and the emission of sound is an important aspect for the perception of crispness and crunchiness (Drake, 1963; Luyten et al., 2004; Van Vliet et al., 2007; Vickers and Bourne, 1976).

According to Bourne (2002) the texture of foods is derived from their structure. Microscopy techniques are successfully employed to obtain information about the microstructure and morphology (Aguilera, 2005). Atomic force microscopy may allow to obtain quantitative information such as (Arzate-Vázquez et al., 2012; Osés et al., 2009; Villalobos et al., 2005). Therefore, the aim of this work was to characterize physical and mechanical properties of extrudate blends of maize with quinoa, chia, with or without purple corn, and to evaluate their microstructure by means of microscopy techniques (SEM, AFM).

2. Materials and methods

2.1. Antioxidant powder

Purple corn was obtained from a local market. The corn cobs were cut and mixed with water in a proportion 1:1. An ultrasonic aqueous extraction of purple corn was performed in a Hielscher UP100H equipment, using a Probe 7S, an amplitude of 100%, and a pulse 0.5 s. Extraction was performed for 5 min. The aqueous extract was filtered through a filter paper (0.45 μm). Maltodextrin (MD) DE15 was added to the aqueous purple solution to obtain final MD concentration of 20%. Spray Drying was performed in a laboratory-scale, Mini Spray Dryer Büchi B290 (Flawil, Switzerland). The operational conditions of the drying process were inlet air temperature 175 ± 3 °C, outlet air temperature 83 ± 3 °C, flow rate 8 ml min^{-1}, air pressure 3.2 bar and nozzle diameter 1.5 mm.

2.2. Samples

Five blends were prepared, containing maize flour either alone or its mixtures with Quinoa, Chia, or antioxidant powder, in the proportions indicated in Table 1. The blending was done at room temperature in a mechanical mixer for one hour. Water content of the raw mixtures was 14% and 8% for the extrudates.

As fat content of the flour mix is an important factor in extrusion process the amount of fat contributed by the components and the percent of fat in the blend was calculated, and is described in Table 2.

Table 1
Composition of the blends used in the extrusion process.

Sample	Maize (%)	Quinoa	Chia	Anti-oxidant (MD)
C1	100			
C2	98			2%
B1	80	20%		
A1	95		5%	
A2	93		5%	2%

The extruder used was a conical, counter-rotating, twin-screw extruder model CM45-F (Cincinnati Milacron, Austria). The general screw geometry was length 1000 mm, diameter from 90 to 45 mm, channel depth 8.5 mm, calender gap 0.5 mm, and flight gap 0.2 mm. A screw configuration with five conveying sections and three drossel zones was employed. A 4.5 mm circular die was fitted in the die plate. The barrel had four heating sections (50, 80, 100, 150 °C). Operating torque was set to 80%. Samples were then collected, cooled to room temperature under natural convection conditions and stored for further analyses in sealed polyethylene bags.

2.3. Water content

Humidity was measured gravimetrically by drying the milled samples (passing 0.420 μm mesh) for 4 h at 130 °C under forced air current until constant weight (±0.0002 g), all samples were run in triplicate.

2.4. Physical properties

Extrudates diameter was measured with a digital caliper in five samples. The relationship between this average value and the die diameter (4.5 mm) was used to calculate an expansion rate (ER) (Alvarez-Martinez et al., 1988). Bulk density (ρ_{ap}) was calculated using a 5 L graduated cylinder filled to the top and weighted. Five replicates were measured for each formulation and results averaged. Real density (ρ_t) was measured after grinding the samples using the volume displacement method (Yan et al., 2008) using toluene as solvent. All values were made in triplicates.

Porosity (ε) was estimated using the relation between both densities (Bisharat et al., 2013) according to Eq. (1).

$$\varepsilon = 1 - (\rho_{ap}/\rho_t) \tag{1}$$

Table 2
Calculated fat content of the blends.

		Total batch (kg)	% fat in each component[a]	Total fat (kg)	% fat over total blend
C1	Maize	10	2	0.2	2
C2	Maize	9.8	2	0.196	1.96
	Antioxidant	0.2			
B1	Maize	8	2	0.16	
	Quinoa	2	6	0.12	
	Blend			0.28	2.8
A1	Maize	9.5	2	0.19	
	Chia	0.5	30	0.15	
	Blend			0.34	3.4
A2	Maize	9.3	2	0.186	
	Chia	0.5	30	0.15	
	Antioxidant	0.2			
	Blend			0.336	3.36

[a] This data was extracted from United States Department of Agriculture, National Nutrient Database for Standard Reference and was used as an estimated quantity for preparing the blends.

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