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Development of whole grain wheat flour extruded cereal and process impacts on color, expansion, and dry and bowl-life texture

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A B S T R A C T

The use of whole grains in extruded products is of great interest for obtaining healthy breakfast cereals (BC). The objective of the study was to investigate the effects of feed moisture and temperature of 3rd and 4th barrel zones, and whole grain wheat flour (WGWF):corn flour (CF) ratio on development of ready-to-eat expanded BC. Response Surface Methodology tool was used to set formulation and process conditions to optimize product characteristics. Sectional expansion index (SEI), bulk density (BD), instrumental color, and dry and bowl-life texture were evaluated. SEI and BD responses were fixed by moisture variable rather than WGWF content. As WGWF is incorporated, darker products were produced. Nevertheless, high WGWF together with higher temperature and lower moisture levels produces better color appearance. At high WGWF:CF ratio desirable low hardness and crispy expanded extrudates can be generated as long as moisture is lower than about 22%. The bowl-life texture results showed a decrease in hardness and crispness after immersion in milk compared to dry one. However, WGWF ratio in formulation did not change the textural properties of milk soaked BC. Optimum characteristics for BC were set at 80% WGWF, 16% of moisture and temperature in the range of 90–110 °C.

1. Introduction

Extrusion cooking is food processing technology that combines several unit operations including mixing, cooking, kneading, shearing, shaping, and forming (Steel, Schmiele, Leoro, Ferreira, & Chang, 2012). This technology utilizes high temperature, pressure and shear force to produce highly expanded and low density products with unique texture properties (i.e. crispness, crunchiness). It has been increasingly used for generating a wide range of food products such as snack foods and breakfast cereals (Stojceska, Ainsworth, Plunkett, & İbanoğlu, 2009).

Among extruded products, ready-to-eat (RTE) breakfast cereals have gained space because of the convenience and practicality claims associated to these products (Albertson, Franko, Thompson, Tuttle, & Holschuh, 2013). These products commonly consumed with milk in the first meal of the day are considered a source of micronutrients through the fortification with vitamins and minerals, being a healthy choice when containing whole cereals due to the dietary fiber levels (Oliveira, Rosell, & Steel, 2015).

Despite the well-known health benefits, recommendations, labeling, and communication campaigns, the majority of cereal foods is made from refined flour, and contains less dietary fiber and other health-promoting compounds when compared to the whole grain raw material. Health and nutrition policies (Food and Agriculture Organization of the United Nations, Food and Drug Administration and Whole Grains Council in the United States of America) have encouraged the increase of dietary fiber in foods, mainly grain-based products such as expanded ready-to-eat (RTE) breakfast cereals. In this context, the use of whole grains, such as whole grain wheat flour in extruded products can be an effective alternative for obtaining healthier breakfast cereals (Oliveira et al., 2015).

However, when refined flours are replaced by whole grain flours in extruded products, the cereal microstructure and texture is negatively affected, which needs to be overcome by adjusting the extrusion parameters and the composition of the raw material blend (Brennan, Monro, & Brennan, 2008; Rzedzicki & Blaszczak, 2005). Therefore, the food industry has faced challenges to adjust processes that result in products with good taste and texture.

The incorporation of fiber into extrudates in the form of bran, and the expansion and texture properties have been studied by several authors (Brennan, Merts, Monro, Woolnough, & Brennan,

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2008; Brennan, Monro, & Brennan, 2008; Robin, Dubois, Curti, Schuchmann, & Palzer, 2011). Dietary fiber most often leads to lower expansion volumes, higher density, harder texture, less crispness, and thus less preferred products (Brennan, Monro, & Brennan, 2008; Chanvrier et al., 2013; Chassagne-Berces et al., 2011). The effects of temperature and moisture on the texture properties have also been reported (Robin et al., 2011; Robin et al., 2012). However, studies on the texture quality of extrudates containing whole grain wheat flour are recent and scarce (Chanvrier et al., 2013; Chassagne-Berces et al., 2011; Robin et al., 2012).

Breakfast cereals are commonly consumed by soaking in milk (Sacchetti, Pittia, & Pinnavaia, 2005; Sacchetti, Pittia, Biserni, Pinnavaia, & Rosa, 2003), readily absorbing moisture, thus leading to undesirable textural changes such as loss of crispness, brittleness, and crunchiness, due to the plasticization effect of water (Gondek & Lewicki, 2006; Lewicki, 2004; Sacchetti et al., 2003). Although the hydration characteristics of breakfast cereals are recognized as an important quality attribute, few studies have investigated the changes on physical properties of the extrudates after rehydration in milk (Sacchetti et al., 2005; Sacchetti et al., 2003; Takeuchi, Sabadini, & Cunha, 2005). Furthermore, only few researchers have studied the Kramer Shear Compression Test Cell (KSC) accessory for texture analysis of expanded cereals (Agbisit, Alavi, Cheng, Herald, & Trater, 2007; Meng, Threinen, Hansen, & Driedger, 2010; Peressini, Foschia, Tubaro, & Sensidoni, 2015). Color is another important quality attribute of extruded products, once many reactions during extrusion can affect color, together with the effect of the inclusion of new raw materials (Ilo, Liu, & Berghofer, 1999).

Response surface methodology (RSM) is recommended for extrusion processing studies since it enables exploring the relationships between the responses and the experimental levels of each factor and deducing the optimum conditions (Triveni, Shamala, & Rastogi, 2001). The objective of this study was to investigate the effects of the replacement of whole grain wheat flour by corn flour and extrusion conditions, feed moisture, and 3rd and 4th cooking zones on the quality parameters (sectional expansion, density, texture, color, and water activity) on expanded breakfast cereals development, including texture after soaking in milk, using the Response Surface Methodology.

2. Material and methods

2.1. Raw material

Corn flour (CF) and whole grain wheat flour (WGWF) used in this study were provided by Milhão Alimentos (Inhumas, GO, Brazil) and Moinho Anaconda (São Paulo, SP, Brazil), respectively. The CF was stored in plastic barrels and the WGWF was vacuum packed in plastic bags and stored at −21 °C until use.

The proximate composition of the flours was determined in our previous studies (Oliveira et al., 2015). The moisture content was 10.80 and 11.40% for WGWF and CF, respectively. WGWF contained higher protein, fat, ash, and dietary fiber (12.80%), mainly insoluble fiber (10.50%) when compared to corn flour. The total fiber in corn flour was 2.90%, of which 2.09% was insoluble fiber.

2.2. Sample preparation and extrusion cooking

The RTE breakfast cereals were elaborated in a co-rotating ZSK 30 twin-screw extruder (Werner Pfleiderer Corporation, Ramsey, USA), following a 2^3 central composite rotatable design (CCRD), with WGWF (0–100%), feed moisture (13.96–24.04%), and temperature of 3rd and 4th barrel zones (76.40–143.60 °C) as independent variables. Results from preliminary trials were used to select suitable extruder operating conditions and raw material levels. The experimental design with the coded and real values of the independent variables is presented in Table 1. The screw configuration is shown in Fig. 1, with L/D = 29. The sample preparation was as described by Oliveira et al. (2015).

2.3. Sectional expansion index (SEI)

Fourteen pieces from each trial run were randomly sampled and the diameter was measured in two different parts of the extrudate with a universal Craftsman caliper. The SEI was calculated as the ratio between the diameter of the extruded product and the diameter of the die (Brennan, Monro, & Brennan, 2008), as shown in Equation (1).

$$SEI = \frac{Dc}{Dm} \quad (1)$$

where *Dc* is the medium cereal diameter (mm) and *Dm* is the die diameter (mm).

2.4. Bulk density (BD)

The BD (g/L) was determined by a volumetric displacement procedure, as described by Meng et al. (2010) and Chiu, Peng, Tsai, Tsay, and Lui (2013), with modifications. Extrudates were weighed (g) and put in a 1 L beaker, and then millet seeds were added to fill up the beaker. The extrudates were taken out, and the volume of millet seeds was measured (L). The BD was calculated according to Equation (2).

$$BD(g/L) = \frac{p}{v} \times 100 \quad (2)$$

where *p* is the sample weight (g) and *v* is the excess millet seed volume (L). Five measurements were made for each trial run.

2.5. Instrumental color

Raw materials (CF and WGWF) and the whole cereals (not ground) were analyzed with a HunterLab UltraScan PRO colorimeter (Hunter Associate Laboratory Inc., Reston, USA). The flours and the whole expanded cereals were set in optical glass cells with a fixed path length of 50 mm and the reflectance measurement area adjusted to 25 mm aperture (Large Area View – LAV). The measurements were the average of five readings. The apparatus UltraScan PRO can easily measure the reflected color of food products represented by CIELab values ($L^*a^*b^*$ color space – rectangular coordinates).

2.6. Instrumental texture of dry breakfast cereals

Hardness (N) and crispness of the dry breakfast cereals were investigated using a TA-XT2i Plus texture analyzer (Stable Micro Systems Ltd., Godalming, UK) equipped with a 5-blade Kramer shear cell (Chassagne-Berces et al., 2011), with a 50 kg charge cell, adjusted in mode ‘measure force in compression’. The samples were arranged in a one-layer bed and the test was carried out according to the following operation conditions: probe distance of 48 mm, pre-test speed of 1 mm/s, test speed of 2 mm/s and pos-test speed of 10 mm/s. Hardness was defined as the peak force (N) of the first compression required for the sample to rupture (Anton & Luciano, 2007), while crispness was the total number of measured force peaks (Dogan & Kokini, 2007) along the curve. The results represented the average of ten measurements.