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Physical and nutritional impact of fortification of corn starch-based extruded snacks with common bean (*Phaseolus vulgaris* L.) flour: Effects of bean addition and extrusion cooking

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ABSTRACT

Navy and red bean flours (BF) were added to corn starch at levels of 15%, 30%, and 45% and submitted to extrusion cooking to produce fortified puffed snacks. Process variables (screw speed, moisture, and temperature of the final zones) of a twin screw extruder were kept constant (150 rmp, 22% and 160 °C). Corn starch-bean extrudates were denser, less expanded, and harder. However starch fortified with 30% BF produced extrudates with percentage of deformation – an instrumental measurement of crispness- comparable to corn starch alone. At this level, crude protein was increased 12-fold, while total phenols, 2,2-diphenyl-1-picrylhydrazyl radical (DPPH·) and oxygen radical absorbance capacity (ORAC) *in vitro* antioxidant activities (AA) were also increased. Red bean fortification yielded extrudates with higher levels of phenols and both DPPH· and ORAC AA compared to navy beans. In navy and red bean extrudates, total phenols, DPPH·, and ORAC AA were reduced by 10%, 17%, and 10%, and by 70%, 62%, and 17% after extrusion, respectively. Phytic acid and trypsin inhibitors levels were reduced in nearly 50% and 100% in all bean extrudates compared to raw mixtures, indicating that these materials were safe for human consumption.

1. Introduction

Extrusion cooking is an important processing technique in the food industry as it is considered to be an efficient manufacturing process. Food extruders provide thermo-mechanical and mechanical energy (shear) necessary to cause physico-chemical changes of raw materials with an intense mixing for dispersion and homogenization of ingredients (Anton & Luciano, 2007; Linko, Colonna, & Mercier, 1981; Wiedman & Strobel, 1987).

Extruded foods are composed mainly of cereals, starches, and/or vegetable proteins. The major role of these ingredients is to give structure, texture, mouth feel, bulk, and many other characteristics desired for specific finished products (Launay & Lisch, 1983; Tahnoven et al., 1998). Consumer acceptance of extruded foods is mainly due to the convenience, value, attractive appearance and texture found to be particular for these foods, especially when it concerns snack products (Anton & Luciano, 2007; Harper, 1981).

While corn starch provides all the features for production of highly acceptable extruded snack foods, its nutritional value is far from satisfying the needs of health-conscious consumers (Rampersad, Badrie, & Comissiong, 2003). Several attempts to improve the nutritional profile of extruded starch have been reported (Liu, Hsieh, Heymann, & Huff, 2000; Onwulata, Konstance, Smith, & Holsinger, 2001; Rampersad et al., 2003). Among other materials, incorporation of legume flours has been shown to cause a positive impact on levels of proteins and dietary fibre of corn starch-based extruded snacks (Berrios, 2006). On the other hand, addition of high-fibre, high-protein alternate ingredients to starch has been demonstrated to significantly affect the texture, expansion and overall acceptability of extruded snacks (Liu et al., 2000; Veronica, Olusola, & Adebowale, 2006). For the production of nutritious acceptable snacks, rates of starch fortification seem to vary according to the nature of each material. Legumes, for example, have been reported to cause good expansion and are regarded as highly feasible for the development of high-nutritional, low-calorie snacks (Berrios, 2006).

Taking into account the nutritional and economical aspects of common beans (*Phaseolus vulgaris* L.) (Anton, Ross, Beta, Fulcher, & Arntfield, 2008; Tharanathan & Mahadevamma, 2003), fortifying corn starch with flours and fractions of varied bean cultivars for the production of extruded snacks appears to be promising. High in fibre, protein, and low in fat, bean consumption has been inversely associated with reduced risk of coronary diseases and some types of cancer (Azevedo et al., 2003; Winham & Hutchins, 2007). In addition, there is solid scientific evidence that coloured dry beans possess strong *in vitro* antioxidant activity (Anton, Ross, Beta, et al., 2008; Beninger & Hosfield, 2003; Madhujith & Shahidi, 2005),

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which may explain, in part, the protective benefits of bean consumption on development of degenerative diseases.

Antioxidants in beans are related to the presence of phenolic compounds that influence their seed coat colour (Beninger & Hosfield, 2003; Madhujith & Shahidi, 2005). In this regard, coloured dry beans such as red, pinto and black, are expected to possess stronger antioxidant activity than navy beans. Although little is known about the effect of extrusion cooking on phenolic composition and antioxidant activity of dry beans (Korus, Gumul, & Czechowska, 2007; Korus, Gumul, Folta, & Bartoń, 2007), thermal processing of beans has been reported to cause important changes on these parameters (Anton, Ross, Beta, et al., 2008; Rocha-Guzmán, Gonzáles-Laredo, Ibarra-Pérez, Nava-Berúmen, & Gallegos-Infante, 2007).

Additionally, extrusion cooking has been used to partially or totally inactivate several antinutritional compounds that limit the widespread use of beans as a primary staple food (Alonso, Aguirre, & Marzo, 2000; Shimelis & Rakshit, 2007). These compounds, such as phytic acid and trypsin inhibitors, might produce adverse effects for human and animal nutrition (Martin-Cabrejas et al., 2004). Extrusion has also been reported to be the most effective method for improving protein and starch digestibility of kidney beans extrudates (Alonso et al., 2000; Berrios, 2006). Consequently, fortification of corn starch with bean flour is believed to add value to dry beans as well to as result in a product with high-nutritional appeal.

This work aimed to determine the technical feasibility of adding varied levels of navy and red bean flour (15%, 30%, and 45%) to corn starch for production of puffed snack foods through extrusion, as well as to examine the effect of extrusion cooking on levels of nutritional and antinutritional compounds of the various formulations. Parameters such as bulk density, expansion ratio, breaking strength and deformation were used to evaluate the physical properties of extrudates. They were aimed to reflect the technical feasibility of incorporating bean flours into corn-based extruded materials. Additionally, levels of protein, antioxidants, total phenolics, trypsin inhibitors, and phytic acid were measured to determine the nutritional impact of bean fortification and to assess the consequences of the thermal treatment on these parameters.

2. Materials and methods

2.1. Acquisition of samples and preparation of flours

Navy (variety GTS 531) and small red (variety AC Earlired) beans were obtained from the Agriculture and Agrifood Canada Research Station in Morden, MB, Canada. The cultivars were grown and harvested in 2006 and exposed to the same environmental conditions in order to avoid external variation. The weight of 100 seeds was determined gravimetrically and expressed as mean ± SD of three determinations. Crude protein (AOAC, 1990) content of bean samples were: 24.06% for navy, and 21.27% for small red beans.

Whole seeds were ground in a Jacobson pilot scale hammer mill (Model No. 120-B, Minneapolis, MN, USA) to pass a 500 μm sieve (35 mesh US Standard Sieve Series). Ground samples were added at different levels (15%, 30%, and 45%) to regular corn starch (9.8% moisture, 25% amylase and 75% amylopectin – Casco, Etobicoke, ON, Canada) and the composite flours were stored at 5 °C in opaque, closed containers for further use. Composite flours were made in triplicate for each level of substitution for each bean cultivar. The raw composite flours, as well as the extruded products, were analyzed for their moisture content by AOAC (1990) method 925.10.

2.2. Extrusion

A laboratory scale twin screw extruder (MPF 19:25, APV Baker Inc., Grand Rapids, MI, USA) under high shear and high temperature in the final zones was used. The barrel diameter was 19.0 mm and the screw configuration with a length to diameter (*L*/*D*) ratio of 25.0 was as follows: 8 *D* feed screws, 6 × 30° forward kneading paddles, 6 *D* feed screws, 1 × kneading paddle, 1 *D* single lead screw, 2 × 60° forward kneading paddles, 2 × 60° reverse kneading paddles, 1 *D* single lead screw, 3 × 60° forward kneading paddles, 1 *D* single lead screw, 2 × 60° forward kneading paddles, 4 × 60° reverse kneading paddles, 3 *D* single lead screws. Screw diameter was equal to 19.00 mm (1 *D*) and one kneading paddle was equal to 1/4 *D*.

Composite flours were added to the feed hopper and deionized water was injected as the mixture reached the screw zone, allowing a fixed feed moisture of 22%. Based on preliminary experiments, the following conditions were kept constant: 150 rpm screw rotation, 1.8 kg/h feed rate, 4.5 mm die diameter. The barrel consisted of five independent zones, electrically heated and cooled by water. Barrel temperature zones profile was set to 30/80/120/160/160 °C. Extruded products were cooled for 30 min in room temperature and then placed in sealed plastic bags for 24 h in room temperature. Extrudates were analyzed for their physical properties 24 h after production.

2.3. Physical analysis

Expansion ratio was determined as the diameter of extrudates divided by the diameter of the die exit (4.5 mm) (Gujska & Khan, 1991). Diameters at three different locations along the 40 mm strand of an extrudate were measured first and the expansion ratio was calculated by dividing the average diameter of the strand in mm by 4.5. The specific length of extrudates was evaluated as their straight length divided by the equivalent weight of each individual strand (Alvarez-Martinez, Kondury, & Harper, 1988). Density (ρ) was determined following the method of Wang, Klopfenstein, and Ponte (1993) by measuring the diameter (d), length (l) and weight (Pm) of each extrudate. It was calculated as

$$\rho = \frac{\mathrm{Pm}}{\pi(d/2)^2 l}$$

Mechanical properties of extrudates were determined through a three point bending test using a Zwick Z005 materials testing machine (Zwick USA, Kennesaw, GA, USA) equipped with a 1 kN load cell and a Warner-Bratzler shear cell (1 mm thick blade). Tests were controlled and data were compiled using the software TextXpert II (Zwick GmbH, Ulm, Germany). The extrudates were analyzed at a cross head speed of 0.2 mm/s. Breaking strength index (BSI) was calculated using: BSI = peak breaking force (n)/extrudate cross-sectional area (mm^2). dL (F_{max}) was defined as deformation at maximum force, meaning how much the shear cell penetrated the sample until breaking. This information was used to calculate the % deformation, defined as dL (F_{max}) × 100/extrudate diameter. For all physical analysis so far described, at least ten strands of each type of extrudate were assayed for each test. Following the described measurements, extrudates were ground in a coffee grinder (Smart Grind, Black and Decker, Towson, MA, USA) so that the meal passed through a 500 μm sieve (35 mesh US Standard Sieve Series). The ground samples were stored at 5 °C for no more than 3 weeks in opaque, closed containers.

Colour measurements (CIE L^*, a^*, b^* colour space) were performed on ground samples using a Minolta CM-3600d model spectrophotometer (Konica Minolta, Ramsey, NJ, USA). The colour of extrudates was expressed as the average of three L^*, a^*, and b^* readings, where L^* stands for brightness, +a^* redness, $-a^*$ greenness, +b^*