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Lentil flour formulations to develop new snack-type products by extrusion processing: Phytochemicals and antioxidant capacity

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The effects of extrusion processing on fibre (soluble and insoluble), total available carbohydrates, tocopherols, organic acids, total phenolics, flavonols, hydroxycinnamic and hydroxybenzoic acids, as well as on the antioxidant capacity of different fibre-enriched lentil flours, were evaluated before and after extrusion process. Total dietary fibre was partially decreased after extrusion, which correlated with a significant increase in the soluble fibre fraction. γ-tocopherol was the major isoform, before and after extrusion. Additionally, a marked decrease of 83–94% in total tocopherols content after extrusion was observed. Conversely, an increase in most polyphenolic fractions was found, probably due to the effect of extrusion in the hydrolysis of polyphenols bound to fibre and proteins, with an increase in antioxidant activity. Only flavonols presented an extensive decrease (62–82%) after treatment. The novel pulse-based flours, enriched with gluten-free soluble and insoluble fibres, provide snack-type products with a balanced nutritional and antioxidants composition.

1. Introduction

Extrusion of foods is a growing technology for the food industries that process and market a large number of products, like pasta, breakfast cereals, biscuits, crackers, baby foods, snack foods, confectionery items, chewing gum, texturised vegetable protein (TVP), pet foods, dried soups, and dry beverage mixes, among others. This technology is a high-temperature, short-time process in which food materials are plasticised and cooked by the combination of temperature under pressure and mechanical shear, resulting in molecular transformation and chemical reactions that modified food functional properties and could affect their nutrient and phytochemical composition (Ainsworth, 2011; Alam, Kaur, Khaira, & Gupta, 2015). In general, extrusion cooking can influence polyphenols content in food products (Nayak, Berrios, Powers, & Tang, 2011) but does not affect the total dietary fibre (TDF), and it is

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highly conditioned to the food matrix (Berrios, Camara, Torija, & Alonso, 2002). Furthermore, the oil-soluble vitamins, such as tocopherols, are not as severely affected by processing as water-soluble vitamins. Among the biologically active forms of Vitamin E, α-tocopherol is less resistant to temperature compared to other forms (Riaz, Asif, & Ali, 2009).

Extrusion cooking has been extensively used in the processing of cereal-based flours for the fabrication ready-to-eat snack products. In recent years, different studies were performed in order to evaluate the suitability of other promising food ingredients to snacks production, such as different fruits and vegetables, namely apple, beetroot, carrot, cranberry, blueberry, cactus fruits, etc. (Camire, Dougherty, & Briggs, 2007; Moussa-Ayoub, Youssef, El-Samahy, Kroh, & Rohn, 2015; Potter, Stojceska, & Plunkett, 2013; Stojceska, Ainsworth, Plunkett, & Ibanoglu, 2010), as well as pulses (lentil, chickpea, dry, carioca and green beans), with very few studies focusing on the incorporation of pulse flours to develop snack-type foods rich in bioactive compounds and with acceptable quality (Berrios, 2006; Berrios et al., 2002; Berrios, Morales, Cámara, & Sánchez Mata, 2010; da Silva, Ascheri, de Carvalho, Takeiti, & Berrios, 2014; Flores-Silva, Berrios, Pan, Osorio-Díaz, & Bello-Pérez, 2014; Morales et al., 2015; Nayak et al., 2011; Simons et al., 2014). Pulses are currently considered as functional gluten-free foods, since they encourage different metabolic functions, including glycaemic and cholesterol indices stabilisations, reduction of body lipids accumulation, promotion of intestinal transit, and may act in the prevention of some cancers, osteoporosis, heart disease or diabetes (Asif, Rooney, Ali, & Riaz, 2013). In this way, pulses could be included as vegetable protein sources with high-content dietary fibres and complex carbohydrates, leading to low glycaemic index in extrusion formulations, for making functional and convenient products with high nutritional value, and could be included in the daily diet, being a good alternative to cereal-based snacks.

Based on the literature reviewed, there is limited information on the effect of extrusion processing on some phytochemicals in pulses' extruded products. Therefore, the aim of this study is to evaluate the changes induced by extrusion cooking on phytochemicals and antioxidant activity in functional novel formulations fortified with fibre-rich, gluten-free or gluten-containing ingredients, in order to establish suitable formulations for the development of gluten-free snack-type products.

2. Materials and methods

2.1. *Standards and reagents*

Methanol was of analytical grade purity and supplied by Pronalab (Lisbon, Portugal). Formic and acetic acids were purchased from Prolabo (VWR International, France). Tocopherol standards (α, β, γ and δ-isoforms), glucose, fructose, sucrose, and organic acid standards (L (+)-ascorbic, oxalic, malic, citric and succinic acids), glucose standards and fibre enzymatic kit (TDF-100A) were purchased from Sigma (St. Louis, MO, USA). Glutamic acid, HPLC-grade acetonitrile, *n*-Hexane and ethyl acetate were purchased from Merck (Darmstadt, Germany). The 2,2-diphenyl-1-picrylhydrazyl (DPPH), β-carotene, ascorbic acid, iron chloride, and potassium ferricyanide were obtained from Alfa Aesar (Ward Hill, MA, USA). Folin–Ciocalteu's reagent, iron sulphate, methanol, phosphate buffer, sodium carbonate, thiobarbituric acid, trichloroacetic acid and Tween 80 were acquired from Fisher Scientific (Waltham, MA, USA). Sulphuric acid, perchloric acid, hydrochloric acid, sodium hydroxide and anthrone reagent were obtained from Panreac Quimica S.L.U. (Barcelona, Spain). Water was treated in a Milli-Q water purification system (TGI Pure Water Systems, Greenville, SC, USA).

2.2. *Lentil flour and formulated flours*

Decorticated red chief lentils (*Lens culinaris* L.) were purchased from a local wholesale distributor in California (USA). Different fibre-rich samples, based on lentil flour, were formulated. The samples with at least 68% of lentil flour were used for extrusion processing by blending the lentil flours with specific food ingredients, such as starch, soluble fibre as Nutriose®, and/or insoluble fibre from wheat bran, corn and apple, and flavouring agents (patent pending) (Berrios, Tang, & Swanson, 2008), as shown in Table 1. The pulse flours and formulated pulse flours, before and after extrusion cooking, were reduced to uniform powders using a Cyclone mill (Udy Corp., Fort Collins, CO, USA) fitted with a 0.5-mm screen, and then stored in airtight glass jars at room temperature until analysed.

2.3. *Extrusion process*

A Clextral EVOL HT32-H twin-screw extruder (Clextral, Inc., Tampa, FL, USA) with co-rotating and closely intermeshing screws and capacity to run at about 50 kg feed/h was used. The extruder was equipped with six barrel sections, each 128 mm in length. The temperature of the last barrel section and the die was maintained at 160 ± 1 °C. The screw diameter (D) was 32 mm and the total configured screw length (L) was 768 mm, which gave an overall L/D ratio of 24. Screws were driven by a 74.8 kW variable speed drive, Model ACS600 (ABB Automation, Inc., New Berlin, WI, USA). The screw speed was maintained constant at 500 rpm. A combination of feeding, transporting, compression and kneading elements was used to provide a moderate-shear screw configuration (patent pending) (Berrios et al., 2008).

Table 1 – Lentil flour formulations analysed.

Sample		Characteristics
CR	Control raw flour	Raw lentil flour (*Lens culinaris* L.)
CE	Control extruded flour	Extruded CR
CF#1	Control formulated 1	Raw lentil flour + wheat bran + apple fibre
EF#1	Extruded formulated 1	Extruded CF1
CF#2	Control formulated 2	Raw lentil flour + wheat bran + Nutriose®
EF#2	Extruded formulated 2	Extruded CF2
CF#3	Control formulated 3	Raw lentil flour + apple fibre + Nutriose®
EF#3	Extruded formulated 3	Extruded CF3
CF#4	Control formulated 4	Raw lentil flour + apple fibre + corn fibre
EF#4	Extruded formulated 4	Extruded CF4