Carbohydrate composition of raw and extruded pulse flours

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A B S T R A C T

Extrusion cooking technology is commercially used in the fabrication of a variety of snack-type and ready-to-eat foods made from cereal grains. However, with the exception of soybean, pulses such as lentil, dry pea and chickpea have not been used for the development of extruded food products. In this study, total carbohydrates, mono-, di- and oligosaccharides, and soluble and insoluble dietary fiber were determined before and after extrusion cooking under specific processing conditions. Concentrations of total available carbohydrates (TAC) in lentil, chickpea and dry pea flours ranged from 625 g/kg to 657 g/kg dry matter. Dry pea showed the highest concentration of TAC, followed by chickpea and lentil. Extrusion processing did not significantly (p < 0.05) affect the TAC content of dry pea and lentil flours. However, extrusion processing decreased the concentration of the raffinose family of oligosaccharides (raffinose and stachyose) in pulse extrudates. Formulated pulse flours demonstrated a beneficial increase in dietary fiber. This research indicates that value-added, nutritious snacks with reduced levels of flatulence factors and higher contents of dietary fiber can be fabricated successfully by extrusion processing of formulations based on lentil, dry pea or chickpea, and represent good alternatives to traditional cereal-based snacks. Also, the commercialization of value-added, pulse-based snacks would increase pulse consumption.

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1. Introduction

Dry leguminous seeds, also known as pulses, represent important sources of plant protein and carbohydrates in the human diet. Lentil, dry pea, chickpea and dry bean are widely cultivated and consumed worldwide, and are considered foods with great nutritional value. In addition to their nutritional value, pulses are also important sources of dietary fiber which is an essential part of a healthy diet. Dietary fiber not only naturally promotes bowel health, but also helps lower cholesterol, balances blood glucose, and promotes healthy physiology and well-being (Schofield, 2008). Unlike other food components such as protein, carbohydrate or fat, which the body breaks down and absorbs, fiber is not digested by the body. Therefore, fiber passes almost unchanged through the stomach and small intestine into the colon. Marlett, MCBurney, and Slavin (2002) considered the term dietary fiber to encompass a number of different substances and categories of substances such as non-starch polysaccharides and oligosaccharides, among others.

The carbohydrate–oligosaccharide fraction of pulses includes starch, soluble sugars and dietary fiber. Many health benefits are attributed to these components of pulse seeds. Pulse starch contributes to slow glucose release, inducing a low glycemic index (Rizkalla, Bellisle, & Slama, 2002; Winham, Hutchins, & Melde, 2007), whereas dietary fiber is involved in gastrointestinal health (Marlett et al., 2002).

The soluble sugar fraction of pulses includes monosaccharides (ribose, glucose, galactose and fructose) and disaccharides (sucrose and maltose). The major oligosaccharides of pulses belong to the α-galactosides group where galactose is present in a α-1,6-linkage. Galactosides derived from sucrose, such as raffinose, stachyose and verbascose, represent the most studied sugars in pulses. Another group of α-galactosides in pulses is the glucose galactosides (melibiose and manninotriose) and inositol galactosides (galactinol, galactopinitol and ciceritol). Ciceritol is a trisaccharide (α-galactopyranosyl-6-α-α-galactopyranosyl-2-(1D)-4-O-methyl-chiro-inositol) and has been reported to be the most abundant sugar in chickpea (Bernabe et al., 1993; Sanchez-Mata, Penuela-Teruel, Cámara-Hurtado, Diez-Marques, & Torija-Isasa, 1998; Quemener & Brillonet, 1983). Raffinose and stachyose, in particular, have been shown to have beneficial physiological effects, such as those of dietary fiber. These compounds tend to normalize bowel function, increase lactobacilli and bifidobacteria and decrease enterobacteria in the intestinal microflora, and reduce potentially carcinogenic N-nitroso compounds levels in the gut (Van Loo, 1998). On the other hand, the human digestive system lacks the enzyme α-galactosidase and cannot hydrolyze α-galactosides. Therefore, these oligosaccharides accumulate in the lower intestine and undergo anaerobic fermentation by bacteria with the production of H2,
CO₂ and traces of CH₄, causing the flatus effect and sometimes diarrhea and abdominal pain (Fleming, 1981; Reddy, Salunkhe, & Sharma, 1980). This phenomenon is not a toxic effect of pulses, but is undesirable for people with intestinal problems. Moreover, Fleming (1981) found that consumption of ciceritol in addition to the sugars of the raffinose family did not increase hydrogen production in rats, which indicates that ciceritol is not a flatulence-promoting sugar.

The effect of processing on the α-galactoside content of pulses has been reported by a number of researchers. Soaking pulse seed in tap water or sodium bicarbonate solution resulted in decreased concentrations of sucrose and the raffinose family of sugars (Abdel-Gawad, 1993; Díaz-Pollán, 1994; Sánchez-Mata, Câmara Hurtado, & Díez-Márquez, 1999). Cooking of an soaked or soaked pulse seed led to a decrease in α-galactoside content (Abdel-Gawad, 1993; Reddy et al., 1980). A further reduction in α-galactoside levels was obtained when the cooking process was done under pressure or by autoclaving (Abdel-Gawad, 1993; Díaz-Pollán, 1994).

Extrusion cooking technology is a high-temperature, short-time, versatile, and modern food operation that converts agricultural commodities, usually in a granular or powdered form, into fully cooked, shelf-stable food products with enhanced textural attributes and flavor. Due to the processing flexibility offered by extrusion cooking technology, it has become a cornerstone of the food industry, primarily in the cereal, dairy, bakery, confectionery and pet food industries. Most recently, extrusion technology has been used in the development of expanded, novel, value-added pulse-based foods (Berrios, Camara, Torija, & Alonso, 2002; Berrios, Tang, & Swanson, 2008; Patil, Berrios, Tang, & Swanson, 2007). The present study was conducted to determine the effect of extrusion cooking on the soluble sugars and the dietary fiber components of lentil, dry pea and chickpea (garbanzo) flours. A reduction in the levels of flatulence-promoting compounds would aid the development of value-added, nutritious, extruded foods from pulses.

2. Materials and methods

2.1. Pulse flours and formulated flours

Pulse flours from lentil (Lens culinaris L.), dry pea (Pisum sativum L.) and chickpea (Cicer arietinum L.) were purchased from a local wholesale distributor. The flours were formulated for extrusion processing by blending the flours with specific food ingredients such as specialty starch, fiber, and flavoring agents (patent pending) (Berrios et al., 2008). To obtain representative samples, 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 air-tight glass jars at room temperature until analyzed.

2.2. Extrusion conditions

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/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).

The mixture was metered into the feed port by a twin-screw, loss-in-weight gravimetric feeder, Model LWFD5-20 (K-Tron Corp., Pitman, NJ, USA) at a rate of 20 kg/h (wwb). Water was supplied to the extruder by a triplex variable stroke piston pump with 12 mm plungers, Type VE-P33 (Bran and Luebbe, Wheeling, IL, USA) to provide a final moisture content of 17%. The pulse formulations were extruded through two circular dies each with a 3.5-mm diameter opening. Pressure at the die was monitored using a pressure transducer, Type PT412-5M (Dynisco Instruments, Sharon, MA, USA). A PLC+ Industrial computer (Allen-Bradley, Milwaukee, WI, USA) using Intouch software (FITSYS PLUS ver. 1.23) was used to collect extruder parameter data at 1 s intervals for a total of 5 min. Data were collected approximately 10 min after the operation conditions of torque and pressure were at a steady state.

2.3. Total available carbohydrate (TAC) assay

The determination of TAC was carried out by the Anthrona method as described by Osborne and Voogt (1986) using 0.8 g of sample. The samples were pre-treated with 15 mL of 52% HClO₄ and kept for 18 h in the dark. After this period, distilled water was added, the sample was filtered and the volume of the filtrate was adjusted to 100 mL. Finally, the solution was further diluted to 10%, and 5 mL of 0.1% anthrona solution in 73% H₂SO₄ was added. Samples were kept in a boiling water bath for 12 min where the anthrone reaction with sugars yielded a green color, and absorbance was measured at 630 nm on a UV/ViS Spectrometer EZ210 (Perkin Elmer, Waltham, MA, USA) equipped with Lambda software PESSION ver. 1.2. The absorbance of the sample solution was compared to a 10–100 µg/mL concentration range standard glucose calibration curve. TAC values were expressed as g/100 g sample.

2.4. Soluble sugars assay

Soluble sugars were determined by High Performance Liquid Chromatography (HPLC) according to Sánchez-Mata et al. (1998). Triplicate subsamples of 1 g of pulse flour were extracted twice with 40 mL of 80% ethanol in a water bath maintained at a temperature of 55–60 °C for 45 min with constant stirring. After each extraction, the samples were centrifuged for 15 min at 1075 × g on a Sorval RC-5 centrifuge (Thermo Scientific, Waltham, MA, USA) and the supernatants were pooled and filtered. The resultant extract was reduced in volume by using a rotary vacuum evaporator set to 70 °C to evaporate the ethanol. The concentrate was brought up to 5 mL with distilled water. Next, the samples were passed through a previously washed (5 mL of methanol followed by 5 mL of water) Sep-Pak C18 cartridge (Waters, Milford, MA, USA). Two milliliters of filtrate was mixed with 8 mL of acetonitrile to yield a total volume of 10 mL. Samples were filtered through a 0.45 µm Millipore membrane (Millipore, Bedford, MA, USA) before injection (200 µL aliquots) into the HPLC. The HPLC was equipped with PU II isocratic pumping system (Micron AnAlítica, SA, Spain), a Rheodyne valve, and a differential refractometer R401 detector (Jasco, Madrid, Spain). The chromatographic column used was a Luna 5 µm NH₂ 100 R (250 mm × 4.60 mm) (Phenomenex, Torrance, CA, USA). The mobile phase was acetonitrile:water (80:20). Operating conditions were a flow rate of 0.9 mL/min and ambient temperature. All chromatograms were processed using Cromanc XP software (Micronec, Spain). The resultant peak areas in the chromatograms were plotted against concentrations obtained from standards (external standard method). Due to the lack of a commercial standard for ciceritol, this sugar was quantified using the
calibration curve of raffinose, as previously reported by Sanchez-Mata et al. (1998).

2.5. Soluble and insoluble dietary fiber assay

Soluble and insoluble dietary fiber were determined according to AOAC enzymatic–gravimetric method 993.19 for soluble dietary fiber (SDF) and method 991.42 for insoluble dietary fiber (IDF) (AOAC, 1993, chap. 45).

2.6. Statistical analysis

Analysis of variance (ANOVA) using the procedures of the Statistical Analysis System (SAS Institute, 1989), followed by Duncan’s test, was conducted to analyze data at the 95% confidence level. Values were means of triplicate analyses.

3. Results and discussion

Concentrations of total available carbohydrates (TAC) in raw lentil, chickpea and dry pea flours ranged from 625 to 657 g/kg dry matter (Table 1). Similar values, 589 g/kg dry matter (Berrios et al., 2002) and 678 g/kg dry matter (Berrios, Swanson, & Adeline Cheong, 1999), were reported for black bean flours. Dry pea had the highest concentration of TAC, followed by chickpea and lentil. Similar trends in TAC content for these pulses were reported by Nutritiondata.com (2009). Sosulsiki, Garrant, and Slinkard (1976) and Cheong, 1999), were reported for black bean flours. Dry pea had the highest concentration of TAC, followed by chickpea and lentil. Similar trends in TAC content for these pulses were reported by Nutritiondata.com (2009). Sosulsiki, Garrant, and Slinkard (1976) and Cheong, 1999) for black bean flours.

Table 1

<table>
<thead>
<tr>
<th></th>
<th>Lentil</th>
<th>Chickpea</th>
<th>Dry pea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw</td>
<td>62.490a</td>
<td>64.463bc</td>
<td>65.708b</td>
</tr>
<tr>
<td>Raw-formulated</td>
<td>66.572ab</td>
<td>66.935a</td>
<td>74.296bc</td>
</tr>
<tr>
<td>Extruded</td>
<td>61.426b</td>
<td>52.536ab</td>
<td>63.921ab</td>
</tr>
<tr>
<td>Extruded-formulated</td>
<td>62.937ab</td>
<td>63.463ab</td>
<td>73.856ab</td>
</tr>
</tbody>
</table>

Values represent means of three replicate analyses. Significant differences within and between columns are separated by a comma. Significance levels in case of columns are distinguished by different letters (p < 0.05).

In the case of formulated flours, the simple sugars determined to be present in highest concentration in all three pulses were the monosaccharides ribose and fructose and the disaccharides sucrose and maltose. The major disaccharides in the pulse flours were sucrose and maltose (Tables 2–4). Melibiose was present in minor concentration in dry pea and chickpea flours, and trace amounts were detected in lentil flour. Martin-Cabrejas et al. (2006) reported that sucrose was present in high levels in chickpea flour. Sanchez-Mata et al. (1998) reported the presence of melibiose in dry pea flour at a level similar to that determined in this study.

In the case of formulated flours, the simple sugars determined to be present in highest concentration in all three pulses were the monosaccharides ribose and fructose and the disaccharides sucrose and maltose (Tables 2–4). The concentrations of these sugars in the formulated flours are a clear indication of the influence exerted by the ingredients used in the formulations.
moisture (17%) used. Borejszo and Khan (1992) reported that the raffinose and stachyose concentrations in pinto bean flours were reduced by extrusion processing. Berrios and Pan (2001) and Berrios et al. (2002) reported that extrusion processing reduced the total oligosaccharide levels in black bean flours and that the extent of their reduction depended on the extrusion conditions employed. A possible mechanism for the reduction in oligosaccharide levels is that the 2\(^\text{-}\)1-furanosidic bonds in sucrose and raffinose could be broken during extrusion cooking forming lower molecular weight sugars (Chiang & Johnson, 1977). A significant exception to the observed reduction in oligosaccharide levels in extrudates was the higher concentrations of raffinose, stachyose and ciceritol in most chickpea extrudates. This may be the result of an analytical error which needs to be confirmed in a future study.

The oligosaccharides raffinose and stachyose are of particular importance in pulse-based foods since a number of researchers (Calloway & Murphy, 1968; Fleming, 1981; Reddy et al., 1980) have demonstrated that these sugars are the principal causes of flatulence in humans and other monogastric animals. Therefore, the observed reduction in the concentrations of these sugars during extrusion processing, indicates great potential for the fabrication of pulse-based snacks with reduced concentrations of flatulence-producing factors.

Fig. 1. Chromatographic profile of sugars in raw chickpea flour.

Table 2
Soluble sugar contents of dry pea flour samples (g/100 g).

<table>
<thead>
<tr>
<th>Sugar</th>
<th>Ribose</th>
<th>Fructose</th>
<th>Glucose</th>
<th>Galactose</th>
<th>Sucrose</th>
<th>Maltose</th>
<th>Melibiose</th>
<th>Raffinose</th>
<th>Ciceritol</th>
<th>Stachyose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw</td>
<td>0.521b</td>
<td>0.124a</td>
<td>0.042a</td>
<td>0.722a</td>
<td>0.647a</td>
<td>0.191b</td>
<td>0.159b</td>
<td>1.564b</td>
<td>ND</td>
<td>2.019a</td>
</tr>
<tr>
<td>Raw-formulated</td>
<td>0.704b</td>
<td>0.211b</td>
<td>0.054a</td>
<td>0.584a</td>
<td>0.688b</td>
<td>0.130b</td>
<td>0.123b</td>
<td>1.407b</td>
<td>ND</td>
<td>2.192a</td>
</tr>
<tr>
<td>Extruded</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>1.299c</td>
<td>ND</td>
<td>0.089a</td>
<td>0.816a</td>
<td>ND</td>
<td>1.529a</td>
<td></td>
</tr>
<tr>
<td>Formulated-extruded</td>
<td>0.211a</td>
<td>0.096a</td>
<td>0.057b</td>
<td>0.134b</td>
<td>0.856b</td>
<td>0.107a</td>
<td>0.205b</td>
<td>1.435b</td>
<td>ND</td>
<td>2.435a</td>
</tr>
</tbody>
</table>

Values represent means of three replicate analyses. ND: not detected. *Means within a column followed by different letters are significantly different (p < 0.05).

Table 3
Soluble sugar contents of chickpea flour samples (g/100 g).

<table>
<thead>
<tr>
<th>Sugar</th>
<th>Ribose</th>
<th>Fructose</th>
<th>Glucose</th>
<th>Galactose</th>
<th>Sucrose</th>
<th>Maltose</th>
<th>Melibiose</th>
<th>Raffinose</th>
<th>Ciceritol</th>
<th>Stachyose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw</td>
<td>0.058b</td>
<td>0.156c</td>
<td>0.028b</td>
<td>0.184a</td>
<td>0.794b</td>
<td>0.168b</td>
<td>0.036b</td>
<td>0.605b</td>
<td>2.686b</td>
<td>1.414c</td>
</tr>
<tr>
<td>Raw-formulated</td>
<td>0.032c</td>
<td>0.063a</td>
<td>0.052b</td>
<td>0.066a</td>
<td>1.003b</td>
<td>0.177b</td>
<td>0.293b</td>
<td>0.754b</td>
<td>2.880b</td>
<td>1.885c</td>
</tr>
<tr>
<td>Extruded</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>1.824c</td>
<td>ND</td>
<td>0.027b</td>
<td>0.957b</td>
<td>ND</td>
<td>2.429b</td>
<td>1.220b</td>
</tr>
<tr>
<td>Formulated-extruded</td>
<td>0.130a</td>
<td>0.092ab</td>
<td>0.025a</td>
<td>0.068a</td>
<td>2.454c</td>
<td>0.130a</td>
<td>0.010a</td>
<td>0.670a</td>
<td>2.117c</td>
<td>0.768a</td>
</tr>
</tbody>
</table>

Values represent means of three replicate analyses. ND: not detected. *Means within a column followed by different letters are significantly different (p < 0.05).

Table 4
Soluble sugar contents of lentil flour samples (g/100 g).

<table>
<thead>
<tr>
<th>Sugar</th>
<th>Ribose</th>
<th>Fructose</th>
<th>Glucose</th>
<th>Galactose</th>
<th>Sucrose</th>
<th>Maltose</th>
<th>Melibiose</th>
<th>Raffinose</th>
<th>Ciceritol</th>
<th>Stachyose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw</td>
<td>0.305c</td>
<td>0.085a</td>
<td>ND</td>
<td>ND</td>
<td>0.697c</td>
<td>0.039a</td>
<td>ND</td>
<td>1.208b</td>
<td>2.249c</td>
<td>NE</td>
</tr>
<tr>
<td>Raw-formulated</td>
<td>0.139a</td>
<td>0.097a</td>
<td>0.031a</td>
<td>0.038b</td>
<td>1.091b</td>
<td>0.045a</td>
<td>0.044a</td>
<td>0.311a</td>
<td>1.705b</td>
<td>1.476a</td>
</tr>
<tr>
<td>Extruded</td>
<td>0.136b</td>
<td>0.103b</td>
<td>0.033a</td>
<td>ND</td>
<td>0.601a</td>
<td>0.133b</td>
<td>0.087b</td>
<td>0.222a</td>
<td>2.372c</td>
<td>1.180ab</td>
</tr>
<tr>
<td>Formulated-extruded</td>
<td>0.029a</td>
<td>0.096a</td>
<td>0.087b</td>
<td>0.029a</td>
<td>0.697c</td>
<td>0.036a</td>
<td>0.140a</td>
<td>0.227a</td>
<td>0.718a</td>
<td>1.053a</td>
</tr>
</tbody>
</table>

Values represent means of three replicate analyses. ND: not detected, NE: not evaluated. *Means within a column followed by different letters are significantly different (p < 0.05).
Duncan’s test was used to compare the average concentrations of insoluble and soluble dietary fiber in the raw and extruded flours (Fig. 3). Insoluble fiber decreased significantly \( (p < 0.05) \) in most processed samples. An exception was chickpea flour where the extruded flour was not significantly different in this respect \( (p < 0.05) \) from the raw sample. The observed reduction in soluble fiber associated with extrusion cooking is in agreement with previous reports for cereal extrudates (Gualberto, Bergman, Kazemzadeh, & Weber, 1997). Berrios and Pan (2001), Berrios (2006) and Berrios et al. (2002) also reported a decrease in insoluble fiber in bean extrudates. The effect of extrusion on soluble fiber concentrations appeared to be inconsistent. The relatively large standard deviations of the soluble fiber means may account for the observed results.

Dietary guidelines stress increasing the amount of dietary fiber in the diet due to the numerous health benefits associated with its consumption, including lower blood cholesterol and reduced risk of heart disease, increased fecal bulk, reduced intestinal transit time and colon cancer, and improved glucose tolerance, which is beneficial to diabetics. The pulses in this study represent an excellent vehicle for introducing higher concentrations of dietary fiber into the diet. Appropriate formulation allowed a further increase in dietary fiber (Fig. 3). The fabrication of value-added, pulse-based snacks with high dietary fiber contents would be an excellent means to provide the population with recommended amounts of these beneficial food components.

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