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Thermal processing effects on the functional properties and microstructure of lentil, chickpea, and pea flours

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ABSTRACT

Pulses are rich in nutrients. The existence of anti-nutritional components and the length of time required for preparation have, however, limited their frequency of use compared to recommended intake levels. Anti-nutritional components in pulses can be largely removed by heat treatment. Additionally pre-treatment of pulses with heat and processing of seeds into flour could further enhance their use by decreasing processing and preparation times. In this study, trypsin inhibitor activity, functional properties, and microstructural characteristics of flours prepared from different varieties of lentil, chickpea, and pea as affected by roasting and boiling were evaluated. Both thermal treatments resulted in significant reduction ($p<0.05$) in trypsin inhibitor activity ranging from −95.6% to −37.8%. Scanning electron microscopy (SEM) results showed that the roasted pulse flours had similar microstructure (i.e., starch granule and protein matrix structure) to the raw samples. For the pre-boiled flours, amorphous flakes were observed by SEM with no presence of intact starch granules. This is likely due to gelatinization of starch during cooking. Interestingly, flours treated by boiling exhibited significantly higher ($p<0.05$) fat binding capacity, water holding capacity, and gelling capacity, while protein solubility was significantly reduced compared to the raw and roasted pulse flours. Overall, thermal treatments either had no impact or impacted to different extents the emulsifying and foaming properties of the flours. Our results suggest that thermally-treated pulse flours may have very good potential to be used as value-added food ingredients for food applications due to their improved nutritional value and, in some instances, superior functionality.

1. Introduction

The importance of pulses and their health-promoting benefits are widely known. Pulses are an excellent and inexpensive source of protein, complex carbohydrates, fiber, and minerals. Consumption of pulses has been associated with many health benefits, including the reduction of the risks of type 2 diabetes and cardiovascular disease and prevention of the onset of various cancers (Roy, Boye, & Simpson, 2010).

Pulses remain underexploited, however, partially due to the presence of undesirable beany flavors (Walker & Kochhar, 2007), the deficiency of sulfur amino acids in pulse proteins, the presence of antinutritional compounds (Salunkhe, 1982), such as trypsin inhibitors, and the length of time required for preparation. Decreases in trypsin inhibitor content after thermal processing has been extensively reported (Hernández-Infante, Sousa, Montalvo, & Tena, 1998; Marquez & Alonso, 1999; Vidal-Valverde, Frias, Estrella, Gorospe, Ruiz, & Bacon, 1994; Wang, Daun, & Malcolmson, 2003; Wang, Hatcher, Toews, & Gawalko, 2009). Moreover, in addition to increasing the nutritional value of pulses, thermal processing also reduces the unacceptable beany flavor, making pulses more palatable.

Thermal treatment may also have marked impacts on product functionality (e.g., solubility, foaming, gelling, water binding and fat binding properties). Functional properties affect processing applications, food quality and acceptance, and how ingredients are used in foods and in food formulations (Mahajan & Dua, 2002). Generally, these properties are contributed by the protein components of foods and are affected by composition, structure, conformation, interactions with other food components, and the environment (Kinsella & Melachouris, 1976). In pulse flours, however, complex carbohydrates and other components such as pectins and mucilages may also contribute to the overall effect observed; in particular, the starch component of pulse flours has been regarded as a valuable source in the food industry owing to its versatile functionalities (Singh, 2001).

Protein denaturation occurs during thermal treatment, and the nature and type of the proteins as well as the degree to which they are denatured are important factors which can influence the functionality of pulse flours (Wu & Inglett, 1974). Additionally, the structure and physicochemical properties of starch in pulse seeds are altered to varying extents during heat treatment. Depending on the type of starch present and the degree of

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modification, heat treatment may result either in gelatinization or retrogradation (including new crystallization or recrystallization and perfection of the small crystalline regions) of the starch granule (Chung, Liu, & Hoover, 2009; Donovan, Lorenz, & Kulp, 1983), a phenomenon that may also influence functionality.

Lentil (*Lens culinaris* L.), chickpea (*Cicer arietinum* L.), and pea (*Pisum sativum* L.) are the most common pulses consumed in many countries. Unfortunately, consumption of pulses as human food in many western countries is relatively low compared to many parts of the world. The development of new ready-to-use pulse ingredients could stimulate production while potentially increasing pulse consumption in the west. Researchers have emphasized extending the consumption and use of grain legumes as functional ingredients in the form of flours which could be used in various food applications such as baked goods, snacks, soups, beverages, salad dressings, and dips amongst others (Kon & Burtea, 1979).

Thermal treatments, including moist heating, dry and wet heating, autoclaving, boiling, and drum-drying processes, reportedly reduced nitrogen solubility, emulsifying properties, foaming properties, and gelling capacity in the flours of soy, peanut, cowpea, yam bean, winged bean, and chickpea but also increased water-holding and fat-binding capacities (Abbey & Ibeh, 1988; Bencini, 1986; McWatters & Holmes, 1979; Narayana & Narasinga Rao, 1982; Obatolu, Fasoyiro, & Ogunsunmi, 2007; Prinyawiwatkul, Beuchat, McWatters, & Phillips, 1997). Most of these studies were performed by applying thermal treatment to the whole seeds before grinding them into flours, and the pulse species used were also limited making it difficult to obtain and compare data on the effects of thermal treatments on the different pulses. The present study was, therefore, undertaken in order to systematically compare the influence of two different thermal treatments (roasting and boiling) on the trypsin inhibitor activity (TIA), functional properties (i.e., solubility, color, fat and water absorption capacity, gelling, foaming and emulsifying properties), and microstructure of flours prepared from various varieties of pulses grown in Canada. Pulse varieties included in this study were Desi chickpea, Kabuli chickpea, red lentil, green lentil, and yellow pea with and without decortication. The varieties were selected based on their relative economic importance in Canadian production.

2. Materials and methods

2.1. Materials

Flours of green lentil (with and without hulls), red lentil (with and without hulls), dehulled Kabuli chickpea were provided by the Canadian International Grains Institute (Winnipeg, MB, Canada). Dehulled Desi chickpea and dehulled yellow pea flours were commercial products and were provided by Diefenbaker Seed Processors Ltd. (Elbow, SK, Canada), and Parrheim Foods Inc. (Saskatoon, SK, Canada), respectively. All other materials and chemicals used were purchased from regular suppliers and were of analytical grade. Millipore filtered water was used for all experiments.

The Kabuli chickpea seeds were dehulled by increasing the moisture to 14%, drying at 70 °C for 20 min prior to dehulling using a dehuller/splitter, made by SK Engineering & Construction India Pvt Ltd. (Gurgaon, India). Lentils seeds were not tempered, and were directly dehulled using a Buhler pilot scale dehuller and splitter (Buhler, Markham, Ontario) operated at 530 rpm. The whole and dehulled seeds were first milled using a Jacobson 120–B lab scale hammer mill (Minneapolis, MN, USA) with a 1.5 mm screen, and then pin milled using a Hosokawa Alpine 100-UPZ pin mill (Runcorn, Cheshire, England) at 18,500 rpm.

2.2. Thermal processing methods

For roasting, pulse flours were evenly spread thinly on aluminum dishes, and were roasted for 1 min in an oven (Double model OD302, Fisher & Paykel Appliances Ltd., Huntington Beach, CA, USA) preheated to 80 °C. After cooling to room temperature the flours were stored in air-tight plastic containers at 4 °C until analyzed. For boiling (hydrothermal processing), the pulse flours (10% w/v) were dispersed in Millipore water under agitation for 1 h at 20 °C, boiled in a water bath at 90 °C for 20 min, stored overnight in a freezer at −40 °C, freeze-dried in a VirTis model 50-SRC-5 freeze-drier (VirTis Co., Inc., Gardiner, NY, USA), and then ground with a domestic coffee grinder (model BA-800, Hudson's Bay Co., Toronto, ON, Canada). Samples were stored at 4 °C in airtight containers and sealed plastic bags until further analysis.

2.3. Proximate analysis

The pulse flours prior to heat treatment were analyzed to determine their proximate composition using official methods. Protein content was determined with a LECO apparatus (LECO FP-428, LECO Corp., St. Joseph, MI, USA) using the AOAC Dumas method (1995) and a nitrogen conversion factor of 6.25. Fat content was determined with a SER 148 Solvent Extractor (Velp Scientica srl, Milan, Italy) equipped with six Soxhlet posts according to the official method of the AACC (2003b). Moisture was determined according to the AACC official method (1983a) by drying the samples overnight at 100 °C in a Fisher Isotemp Vacuum Oven (Fisher Scientific Co., Montreal, QC, Canada). Ash content was determined according to the AACC official method (2003a), crude fiber was analyzed according to the AOCS official method Ba 6a-05 (1998) and total carbohydrate content was calculated by difference. All determinations were done in triplicate, and average values were calculated.

2.4. Trypsin inhibitor activity (TIA)

The TIA was determined based on the methods of Kakade, Simons, and Liener (1969) and Hamerstrand, Black, and Glover (1981) with some modifications as follows: instead of the addition of aliquots (0, 0.6, 1.0, 1.4, and 1.8 mL) of sample suspension and adjustment to 2.0 mL, 2.0-mL aliquots of the diluted sample extract were added to the triplicate sets of test tubes for testing, and the samples were centrifuged at 2060 *g* for 10 min before the absorbance was measured at 410 nm. The dilution factors used were selected based on 1 mL aliquots of each solution producing trypsin inhibitions between 40% and 60%. Dilution factors of about 10, 15, 10, 50, and 20 were necessary for raw red lentils, green lentils, yellow peas, Desi chickpeas, and Kabuli chickpeas, respectively, and 2 for roasted and boiled pulse flours.

2.5. Scanning electron microscopy

A thin layer of each of the raw, roasted, and boiled flours of lentil, chickpea, and pea was deposited on a double-sided adhesive carbon tape mounted on an aluminum specimen holder, and any unattached particles were removed. The specimen holder was sputter-coated with approximately 10 nm gold using a sputter coater (model 108, Kurt J. Lesker Co., Clairton, PA, USA) and then transferred to a scanning electron microscope (model S-3000N, Hitachi, Tokyo, Japan). Samples were examined at a voltage of 5 kV.

2.6. Functional properties

2.6.1. Protein solubility

Protein solubility was determined at pH levels of 3, 5, and 7 using the method of Betschart (1974) with slight modifications as described by Boye, Aksay, Roufik, Ribéreau, Mondor, Farnworth, and Rajamohamed (2010). The amount of protein in the supernatant was determined by the method of Bradford (1976) with a Cary 300 Bio UV–visible spectrophotometer (Varian Canada, Inc., St-Laurent, QC, Canada). The percent solubility was calculated as the percentage ratio of protein in the supernatant to that of the total protein in the initial sample.