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Comparison of properties of raw pulse flours with those of jet-cooked, drum-dried flours☆

Frederick C. Felker*, James A. Kenar, Jeffrey A. Byars, Mukti Singh, Sean X. Liu

Functional Foods Research Unit, United States Department of Agriculture, Agricultural Research Service, National Center for Agricultural Utilization Research, 1815 N. University Street, Peoria, IL 61604, USA

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ABSTRACT

The properties of whole bean flours of navy, pinto, and black beans and chickpeas were compared with those of flours that had been passed through a steam jet cooker and drum dried. Analysis of structure, particle size, color, solubility, pasting characteristics, dietary fiber, oligosaccharides, and protein digestibility revealed differences from raw flours with potential advantages for food applications, including increased soluble fiber on average from 53 to 62 g/kg. Hot water solubility increased from 10 to 37 g/100 g, while particle size, water absorption index, and viscosity after pasting were decreased. Color changes in the flours suggested solubilization and redistribution of seed coat pigments. The treatments increased extractability of raffinose family oligosaccharides from 34 to 37 mg g^{-1}. Starch granules were dissolved during jet-cooking, and the dried product consisted of a uniform composite matrix. These results revealed changes in the physicochemical and functional properties of bean flours with the potential to increase the utilization of pulse flours in foods.

1. Introduction

The value of pulses as a dietary source of protein, fiber, vitamins, antioxidants, minerals, and various beneficial minor components is well known, and recently efforts to promote the increased consumption of pulses have expanded (McCrory, Hamaker, Lovejoy, & Eichelsdoerfer, 2010; Simons & Hall, 2017; Tiwari & Singh, 2012). Pulses are recognized as an excellent protein source, ranging from 180 to 300 g/kg, and have double the amount of protein relative to cereals (Dalgetty & Baik, 2003). They are also widely recognized as a major source of dietary fiber (Tosh & Yada, 2010). Among the forms in which pulses are now being marketed, flours based on whole, uncooked beans are becoming more widely available. These flours can be used as a base ingredient and incorporated into various foods such as bread (D'Appolonia, 1978), crackers (Han, Janz, & Gerlat, 2010), cookies (Zucco, Borsuk, & Arntfield, 2011), pita bread (Borsuk, Arntfield, Lukow, Swallow, & Malcolmson, 2012), muffins (Shevkani & Singh, 2014) and cakes (Singh, Byars, & Liu, 2015), soups, beverages, breading, hummus, refried beans, and dips (Kon & Burtea, 1979). Some attributes of pulse flours that affect their acceptability and the extent of incorporation for a given recipe include texture, solubility, appearance, and objectionable beany flavors (Salunkhe, 1982; Walker & Kochhar, 1982). The reduction of objectionable traits and improvement of functional characteristics would greatly increase the utility of bean flours.

Steam jet-cooking is an industrially scalable technology used widely to prepare aqueous starch dispersions for many commercial uses, including papermaking applications, biobased fuels, adhesives, etc. (Kasica & Eden, 1992). When carried out under excess steam conditions, the shear applied to the product is increased so as to completely break down the starch granule structure, solubilize polymer components, and reduce their molecular weight (Byars, 2003; Klem & Brogly, 1981). Excess steam jet-cooking of wheat flour was shown to substantially alter the wheat gluten and enable its interaction with oil droplets in starch-oil composites (Felker, Singh, & Fanta, 2012). Inglett and coworkers have shown that excess steam jet-cooking barley flour can influence the total phenolics, water-holding capacities and viscoelastic properties of the flour (Inglett, Chen, & Berhow, 2011). Min, Lee, Yoo, Inglett, and Lee (2010) confirmed the breakdown of native starch in excess steam jet-cooked buckwheat flour and observed an increase in water hydration and thickening properties of the flour. Thermal cooking of dried beans has been shown to increase the solubility of insoluble pectins and partially depolymerize the hemicellulose (Marconi, Ruggeri, Cappelloni, Leonardi, & Carnovale, 2000). An

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* Corresponding author.
E-mail address: frederick.felker@ars.usda.gov (F.C. Felker).

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extrusion study with pea hulls revealed conversion of insoluble fiber to soluble fiber in proportion to the severity of the treatment (Ralet, Della Valle, & Thibault, 1993). Thermal jet-cooking of pea flour was used to drive off volatile flavor components, and the spray-dried product showed high water binding capacity (Comer, 1977). While the effect of soaking and cooking pulses is mainly in the direction of rendering cell wall components more soluble, the results reported vary based on whether the cooking water is retained or discarded in determination of the fiber content (Kutos, Golob, Kac, & Plestenjak, 2003; Rehinan, Rashid, & Shah, 2004). Generally, soaking or cooking pulses have been shown to reduce or extract soluble components such as vitamins and minerals (Addy, Salami, Ibocli, & Remawa, 1995; Rincon, Ros, & Collins, 1993), reduce the amount of insoluble dietary fiber and increase soluble fiber (Arrigoni, Caprez, Amadò, & Neukom, 1986; Peña, Vergara, & Carpita, 2001) and increase the protein content (Wang, Hatcher, Tyler, Toews, & Gawalko, 2010). A study of flour made from conventionally cooked pinto beans revealed differences from raw flour in most chemical and functional properties but not in the sensory attributes of cookies made with up to 40% inclusion level (Simons & Hall, 2017). Flours made from chickpeas pre-cooked with sodium bicarbonate and citric acid were drum-dried (Bencini, 1986), and increased water absorption capacity and flour slurry viscosity were found compared to raw flour. None of the previous reports of pulse processing utilized excess steam jet-cooking, which imparts more shear force than thermal jet-cooking or conventional cooking, followed by drum drying of the total cooked product with none of the soluble components removed.

Our research is aimed at determining which processing technologies could be used as a new approach to mitigate some of the negative attributes of pulse flours or impart better functional characteristics to enhance their acceptability as a base ingredient and improve their potential compatibility with various food systems. Therefore this study was made to compare native flours with those treated by jet-cooking and drum-drying. Since aqueous jet-cooked dispersions can be conveniently drum-dried and milled to a fine powder, a material outwardly similar to the original pulse flours was easily prepared. In this study, some properties of commercially obtained whole bean flours of navy, pinto and black beans and chickpeas and their steam jet-cooked, drum-dried counterparts are compared. The properties examined include the particle size distribution and particle structure, color, solubility, water absorption, pasting characteristics, protein digestibility, raffinose family oligosaccharide content, and dietary fiber profile.

2. Materials and methods

2.1. Chemicals

Uncooked whole grain flours of navy bean, pinto bean, black bean, and chickpea were obtained from Best Cooking Pulses, Manitoba, Canada. Trypsin (T0303), chymotrypsin (C4129), and raffinose, stachyose, and verbascose standards were obtained from Sigma-Aldrich, St. Louis, MO, USA, and sodium caseinate from American Casein Co., Burlington, NJ, USA. Acetanilide was obtained from Perkin-Elmer, Shelton, CT, USA.

2.2. Jet-cooking, drum-drying, and milling

The jet-cooking and drum-drying procedures were performed as described by Fanta and Christianson (1996) using pilot plant scale equipment typically used for investigations of starch based technology. A slurry of flour (200 g) in deionized water (800 mL) was prepared by gentle mixing for 2 min in a 2 L stainless steel blender. The slurry was then passed through a hydroheater (M103, Hydro-Thermal, Waukesha, WI, USA) using a progressive cavity pump (Moyno, Robbins & Meyers, Springfield, OH, USA) with a pumping rate of 1 L min^{-1}. The jet-cooker was operated at a temperature of 138 °C using steam line pressure from the boiler at 579 kPa (70 psig) with a back pressure of 380 kPa (40 psig). The solids content of the jet-cooked dispersions ranged between 110 and 114 g/kg and was determined by removing a small amount of the hot dispersion and then freeze drying accurately weighed portions (in duplicate) of each dispersion. The cooled jet-cooked dispersions of the four bean flours had a pH between 6.10 and 6.38. Dispersions were dried on a steam heated double drum drier (Model 20, Drum Dryer and Flaker Co., South Bend, IN, USA) with a steam pressure of 310 kPa (30 psig). The drum-dried flakes were milled in a Retsch Model ZM 200 ultra centrifugal mill (Retsch GmbH, Haan, Germany) using a 0.12-mm ring sieve, a six-tooth rotor, and a rotor speed of 10,000 rpm. Flours processed by jet-cooking and drum-drying are designated JCDD.

2.3. Light microscopy

Samples were dispersed in a drop of water on a microscope slide at room temperature and observed with a Zeiss Axioskop light microscope equipped with an Axiocam ICc 3 digital camera (Carl Zeiss, Inc., Thornwood, NY, USA) using phase contrast optics.

2.4. Particle size analysis

Raw and milled JCDD flours were analyzed with 8-inch test sieves and a Retsch Model AS-200 vibratory sieve shaker (Retsch GmbH, Haan, Germany) using an amplitude of 2 mm and sieving duration of 10 min. The sieves used were mesh sizes 40 (420 μm), 60 (250 μm), 80 (177 μm), 100 (149 μm), 140 (105 μm), 170 (88 μm), and 200 (74 μm).

2.5. Color analysis

Color was determined using a Labscan XE Hunter Colorimeter (Hunter Color Laboratories Inc., Reston, VA, USA) using Universal software version 4.01. The CIELAB scale was used to obtain the L* (lightness scale 100 = white, 0 = black), a* (redness), and b* (yellowness) values. Flours were photographed in adjacent cells of a Corning Falcon polystyrene 24-well microplate (Fisher Scientific, Chicago, IL, USA) using a Canon 4200F flatbed scanner (Canon U.S.A., Inc., Melville, NY, USA).

2.6. Pasting analysis

Pasting analysis was performed as described by Byars and Singh (2016). Each material at 80 g/kg dry weight basis (dwb) was measured with the pasting cell of an AR2000 rheometer (TA Instruments, New Castle, DE, USA). Samples were stirred at 960 rpm for 30 s at 25 °C, and then stirred at 160 rpm for the remainder of the test. The samples were heated to 95 °C at a rate of 6 °C/min, held at 95 °C for 5 min, and cooled to 50 °C at 6 °C/min.

2.7. Water solubility index (WSI) and water absorption index (WAI)

The WSI and WAI of each material were measured following a method based on Anderson, Conway, and Peplinski (1970). Each material (0.8 g dwb) was dispersed in 10 mL water and heated in a water bath at 30 or 95 °C for 30 min. Samples were cooled to room temperature and centrifuged at 1250 × *g* for 30 min. The supernatant was decanted, and the WSI was calculated using the weight of the solids recovered from the supernatant after drying under vacuum at 55 °C as a percentage of the starting solids. The WAI was calculated using the weight of the sediment divided by the starting solids less the solids in the supernatant. Since the WAI at 30 and 95 °C were substantially different, the percent solid of the supernatants were also calculated.

2.8. Nitrogen analysis

Nitrogen contents were measured using a LECO CHN628 carbon/