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Impact of high pressure treatment on functional, rheological, pasting, and structural properties of lentil starch dispersions

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ABSTRACT

Lentil starch (LS) dispersions (flour to water 1:4 w/w) were subjected to high pressure (HP) treatment at 0.1, 400, 500 and 600 MPa for 10 min, followed by evaluation on the functional, particle size, rheological, pasting, and structural properties of post-process samples. Water holding capacity of pressurized starch increased with the pressure intensity due to increase in damaged starch. The amount of resistant starch increased from 5 to 6.8% after pressure treatment at 600 MPa. An increase in starch granule particle size (196–207 μm) was obvious after HP treatment. The lentil starch was completely gelatinized after pressure treatment at 600 MPa for 10 min as evidenced from differential scanning calorimetry, rheometry, X-ray diffraction (XRD) and scanning electron microscopy observation. The elastic modulus, G′ of lentil starch gel was less frequency dependent, and higher in magnitude at high pressure (>500 MPa) than at lower pressure range (≤400 MPa). XRD analysis revealed the disappearance of two diffraction peak intensities at 14.86° and 22.82° at 600 MPa for 10 min, which confirms the transformation of crystalline to amorphous region of lentil starch. Pasting properties were significantly influenced by the pressure treatment especially at 600 MPa, resulting in a considerable decrease in peak viscosity, breakdown and final viscosity, and an increase in peak time. It can be inferred that the functional properties of pressure-treated LS are mainly based on the structural destruction of granules.

1. Introduction

Pulses are one of the most important cultivated crops in the world. They are considered as a staple food in many parts of the world because of their high-quality protein, and nutrient-dense carbohydrates. They are an excellent source of both soluble and insoluble dietary fibers (Tosh & Yada, 2010). Among legumes, lentils (*Lens culinaris*) have attracted attention as they are considered to be an excellent dietary source of phytochemicals (including lipophilic and hydrophilic compounds) possessing high antioxidant capacity (Azarpazhooh & Boye, 2012; Duen˜as, Hernaíndez, & Estrella, 2002; Zhang et al., 2014). Furthermore, pulses contain significant amounts of resistant starch (RS, a fraction that is resistant to digestion), especially RSII and RSIII, which has many potential health benefits similar to dietary fiber. Therefore, there is a keen interest in acquiring a complete understanding of the bioactive phytochemicals in lentils to improve and make the best use of their nutritive value. Additionally, pulses including lentils are slowly digested, which contributes to a low glycemic index profile (Jenkins et al., 1983), and eating pulses also reduces serum cholesterol.

Starch is one of the major storage polysaccharides in the pulses and comprises two major types of α-glucans at the molecular level: the linear amylose and the branched amylopectin. It is a granule with alternating semicrystalline and amorphous domains in concentric growth rings. The native starch granules do not dissolve in cold water, whereas gelatinized starch has been widely used as a major food ingredient in food industry and many other applications including paper, textile, and thermoplastic industries. Starch in excess water undergoes a thermal/pressure induced transition known as gelatinization. Under these circumstances, ordered native starch granules swell, amylopectin crystallites break down, and form a thick viscous mass.

HP treatment has been successfully employed for the gelatinization of various starches while maintaining their granular integrity (Kawaia, Fukami, & Yamamoto, 2012; Oh, Pinder, Hemar, Anema, & Wong, 2008). The extent of pressure-assisted starch gelatinization/gelation depends upon many factors including pressure intensity, holding time, starch concentration, temperature, and type of starches or preparation techniques. Several starch gelatinization theories and models have been proposed in the literature

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(Donovan, 1979; Evans & Haisman, 1982); however, none of these can fully explain the gelatinization mechanisms (Ratnayake, Otani, & Jackson, 2009). Nevertheless, HP-gelatinized starch shows properties dissimilar to thermally-treated starch gelatinization (Knorr, Heinz, & Buckow, 2006). HP-treated starch samples show a lower rate of retrogradation than the thermally treated starch samples (Ezaki & Hayashi, 1992). Therefore, it is believed that the HP treated starchy foods may impart value-added texture properties after processing and throughout their shelf life. Unfortunately, there is a dearth of information on changes to granule morphology, crystallinity, functionality, X-ray pattern and particle size during the progress of the HP treatment. Therefore, an attempt is made to understand the HP induced gelatinization mechanism, and post-pressure effect on the functionality and structure of pulse starch. Lentil has been considered as a model starch for the study since it has wider acceptability for the development of various food products including extruded snacks, gluten-free food products.

The objective of this work was to examine the effects of HP treatment (400, 500, and 600 MPa for 10 min) on the functional, rheological, thermal and structural properties of lentil starch (LS), and compare with untreated starch. The structure of starch was characterized by scanning electron microscopy, laser diffraction particle size analyzer, and X-ray diffraction (XRD).

2. Materials and methods

2.1. Materials

Commercial Indian split red lentil seeds (Cv. L-4076) were purchased locally. Split lentils were ground in a laboratory roller mill (Quadrumat® Junior, Brabender, Germany) and passed through U.S. Standard sieve numbers 70-mesh (210-μm). Flour samples were collected, packed in airtight polyethylene terephthalate (PET) containers, and stored at 25 ± 2 °C.

2.2. Starch isolation and purification

The LS was isolated by the wet method as described by Joshi et al. (2013) with a little modification. Briefly, lentil flour was extracted in alkaline sodium hydroxide solution (1:10 w/v, pH 8.0) for an hour with stirring to solubilize the protein and to facilitate the separation of starch. The mixture was centrifuged at 3360 g for 15 min, and the supernatant was decanted off. The starch was washed by resuspending in distilled water for several time, and sieved through 325-mesh screen (44-μm). Purified starch was then air dried at 35 °C for 24 h (Adhikari, Howes, Shrestha, Tsai, & Bhandari, 2006), and the dried starch sample was kept in a sealed container at 4 °C until further use.

2.3. Sample preparation

LS dispersions were prepared by mixing the required amount of flour and water in a beaker to maintain flour to water (F/W) ratio (w/v) of 1:4. Preliminary studies carried out with selected starch to water ratios (1:1; 1:2; 1:3, and 1:4) for HP experiments, and found that sample with starch to water ratio of 1:4 the most suitable for all measurements, and, therefore, the ratio was selected for the whole study. All LS dispersions were kept for an hour at room temperature (25 ± 1 °C) for hydration before the HP treatment.

2.4. High hydrostatic pressure treatment

The pressure treatment was carried out with the use of a laboratory-scale high pressure equipment (QFP 2 L-700 Avure Technologies, OH, USA), with a pressure vessel 100 mm in diameter and 254 mm in height. Samples were treated at selected pressures (400, 500 and 600 MPa) for 10 min. Water was used as the pressure-transmitting medium. The initial temperature of the water was 26 °C, which was sharply increased to 38 °C due to the adiabatic effect during pressurization of 600 MPa. The compression rate was 4.2 MPa/s while the decompression rate was 40 MPa/s. Pressure, time, and temperature were controlled by a computer program attached to the HP unit, being constantly monitored and recorded during the process. After HP treatment, samples were freeze–dried (FD) for about 72 h and ground to powder for further use. All the pressure treatments were performed in duplicate.

2.5. Proximate composition and starch property

Starch samples were analyzed for their moisture, crude protein (N × 6.25) and ash content following the standard method of analysis (AOAC, 2005). Resistant starch and starch damage of samples were determined enzymatically using the Resistant Starch Assay Kit (AOAC Method 2002.02), Starch damage assay kit respectively (AACC Method 76-31.01).

2.6. Water holding capacity, water solubility index, and sediment volume fraction

The water holding capacity (WHC) and sediment volume fraction (⊘) of all LS samples were determined at 25 °C following the centrifugal techniques (Ahmed, Al-Foudari, Al-Salman, & Almusallam, 2014; McConnell, Eastwood, & Mitchell, 1974). The water solubility index (% WSI) was calculated as the dry residue weight to original dry sample weight multiplied by 100. All measurements were performed in triplicates.

2.7. Tristimulus color measurement

Visual color was measured using a Hunter colorimeter model Color Flex (Hunter Associates Laboratory, Reston, VA) in terms of *L* (lightness), *a* (redness and greenness) and *b* (yellowness and blueness). The instrument (45°/0° geometry, 10° observer) was calibrated with a standard black and white tile followed by measurement of samples. A glass cell containing the lentil sample was placed above the light source and *L*, *a* and *b* values were recorded. Color measurements were taken in triplicates.

2.8. Scanning electron microscopy

The microstructure and morphology of the HP treated FD lentil starch samples were examined through a scanning electron microscope (SEM) (JEOL, JSM-5410LV, Tokyo, Japan). Each sample was coated with gold in a sputter coater (Structure Probe, West Chester, PA) before being scanned and photographed at various magnifications (250×, 1500× and 4000×). An accelerating potential of 15 kV was used during micrography during image acquisition. Particle size was measured by the software attached to the instrument which allows for detailed (diameter) measurements. About 50 particles were selected randomly for the particle size measurement.

2.9. Particle size distribution using light scattering

The particle-size distribution of the HP treated FD starch samples was measured by laser light scattering using a Malvern Mastersizer 3000 instrument (Malvern Instruments Ltd, Worcestershire, UK) with Hydro EV Flexible volume wet dispersion. The refractive index values used for water and lentil starch were 1.33 and 1.41 respectively. The lens used had a focal length of 300 mm which allowed particle size measurement from 0.01 to 3500 μm. The particle size distributions (PSDs), i.e., particle size at 10% (Dv10), 50% (Dv50) and 90% (Dv90) of the volume distribution were