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Influence of jet milling and particle size on the composition, physicochemical and mechanical properties of barley and rye flours

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ABSTRACT

Finer barley and rye flours were produced by jet milling at two feed rates. The effect of reduced particle size on composition and several physicochemical and mechanical properties of all flours were evaluated. Moisture content decreased as the size of the granules decreased. Differences on ash and protein contents were observed. Jet milling increased the amount of damaged starch in both rye and barley flours. True density increased with decreased particle size whereas porosity and bulk density increased. The solvent retention capacity profile was also affected by jet milling. Barley was richer in phenolics and had greater antioxidant activity than rye. Regarding colour, both rye and barley flours when subjected to jet milling became brighter, whereas their yellowness was not altered significantly. The minimum gelation concentration for all flours was 16% w/v. Barley flour gels were stronger, firmer and more elastic than the rye ones.

1. Introduction

Barley is the fourth major cereal crop in the world and initially it was mainly utilised in malting and brewing and as animal feed. In recent years, studies have shown that it has a high content of dietary fiber and a high proportion of soluble fiber, especially β-glucan. So it became an important cereal from both a nutritional and functional point of view and started to incorporate into human diet. This was further supported by its phenolic content (Alu'datt et al., 2012). Studies have shown that the presence of β-glucan and phenolic compounds have the potential to lower cholesterol and blood glucose levels (Cavallero, Empilli, Brighenti, & Stanca, 2002). Due to its high phenolic content, it has greater antioxidant activity than rice and wheat (Madhujith, Izydorczyk, & Shahidi, 2006). Moreover, barley is used as protein diet fortification (Sarac & Henry, 1998) as its proteins are a rich source of the limiting essential aminoacids (Newman, El-Negoumy, & Eslick, 1978).

Rye is another widely grown cereal. It is used in bread and other products of human consumption or as animal feed. It has a high content of dietary fibers, mainly arabinoxylans which are very important for breadmaking quality. β-Glucan is present in lower amounts than in barley (Rakha, Aman, & Andersson, 2010). Overall, and compared to wheat, rye contains higher levels of arabinoxylans and has a lower gluten content.

Flour is a powder which is made by milling mainly cereal grains, beans, or other seeds or roots. Jet milling is classified as a fluid energy impact-milling technique generally used for producing ultrafine powders. The final particle size produced by this method is very much dependent on the material being processed (Protonotariou, Drakos, Evageliou, Ritzoulis, & Mandala, 2014). The jet mill is a static machine with no grinding media. Its milling component consists of a chamber with a nozzle or nozzles. The particles to be pulverised are accelerated by pressurised gas or steam jets, and the grinding effect is produced by interparticle collision or by impact against solid surfaces (Tuunila & Nystrom, 1998). The most significant variables in jet milling are feed rate, volumetric flow rate of grinding air and the height of an inside classification tube for grinding at constant pressure. The finest product size is obtained with smallest material feed rate, highest grinding air flow rate and with the shortest classification tube (Teng, Wang, Linjie, Young, & Gogos, 2009). The vibration rate of feeder is another important parameter as it affects the feed rate and thus, particle size. Lower vibration rate of feeder results in lower feed rate and lower particle size.

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In the present work we studied flours from barley and rye. Furthermore, we subjected them to jet milling at two vibration rates of feeder (90 and 70%) and thus, two different feed rates (~4 and ~1 kg/h) producing flours with different particle diameters. The effect of particle size, as well as the composition and some physicochemical and mechanical parameters such as solvent retention capacity profile, water and oil absorbance capacity, pasting and gelation properties, colour, porosity, density, phenolic content and antioxidant activity of both flours were investigated.

2. Materials and methods

2.1. Materials

2.1.1. Flours

Commercial barley (B) and rye (R) flours were kindly donated by Loulis Mills S.A. Both flours were subjected to further pulverization using an air jet mill (Model 0101S Jet-O-Mizer Milling, Fluid Energy Processing and Equipment, Telford, PA, USA) with an air pressure of 8 bar. Flours B1 and R1 resulted from operating the jet mill at a vibration rate of feeder of 90% whereas B2 and R2 at 70%. The corresponding feed rates were 4.42, 3.35, 1.33 and 1.17 kg/h for B1, R1, B2 and R2, respectively.

2.1.2. Reagents

Folin-Ciocalteau reagent was from Merck (Darmstadt, Germany). All the remaining reagents were of analytical grade and they were purchased from Sigma-Aldrich (Steinheim, Germany). Distilled water was used throughout.

2.2. Methods

2.2.1. Particle size measurements

Flour particle size was determined with a Malvern Mastersizer 2000 (Malvern Instruments, Worcestershire, UK), equipped with a Sirocco dry powder accessory (Malvern Instruments, Worcestershire, UK). The refractive index of the solid particles and absorption parameter were 1.53 and 0.7, respectively. Particle size data were reported as weighted mean diameters d_{43} ($=\sum n_i d_i^4/\sum n_i d_i^3$) where, n_i is the number of particles with diameter d_i. At least three measurements were conducted on each flour sample and the mean particle diameters reported were calculated as the average of the measurements.

2.2.2. Chemical composition of flours

The moisture, protein, fat and ash content of all flour samples was determined according to the standard methods. Moisture was determined by the air oven method (AOAC 925.10, 1998), fat by the soxhlet method (AOAC 945.16, 2000) whereas ash by the incineration method (AACC 08-01, 2000). Total proteins ($N \times 6.25$) were determined by the Kjeldahl method (AACC 46-10, 2000) using a Kjeltec distillation unit (GEHARDT, Paris, France). The percentage of carbohydrates was determined as difference.

2.2.3. Determination of damaged starch content

Damaged starch content of flour samples was determined by SDmatic (Chopin Technologies, France) amperometric method (AACC 76-33.01, 2011). The obtained results were provided in American Association of Cereal Chemists (AACC) units.

2.2.4. Solvent retention capacity profile (SRC)

The solvent retention capacity profile (SRC) and alkaline water retention capacity (AWRC) were obtained according to the Approved Methods 56-11 and 56-10, respectively (AACC, 2000). The SRC/AWRC values were expressed on 14.0% moisture basis and calculated as follows:

$$\%\text{SRC/AWRC} = \left[\frac{\text{gel weight}}{\text{flour weight}} \times \left(\frac{86}{100 - \%\,\text{flour moisture}}\right) - 1\right] \times 100 \quad (1)$$

All analyses were performed in triplicate. SRC profile included lactic acid, sucrose and sodium carbonate retention capacities.

2.2.5. Water absorption capacity (WAC) and Oil absorption capacity (OAC)

Flour samples (0.5 g) were vortexed with 5 mL distilled water for WAC or 5 mL of sunflower oil for OAC in pre-weighed centrifuge tubes, allowed to standfor 30 min, and then centrifuged at 3000×g for 30 or 40 min for WAC or OAC, respectively. The supernatants were drained off. WAC and OAC were calculated as:

$$\%\text{WAC/OAC} = \left(\frac{W_2 - W_1}{W_0}\right) \times 100 \quad (2)$$

where W_2 is the weight of centrifuge tube plus the sediments, W_1 is the weight of centrifuge tube plus sample and W_0 is the weight of the sample.

2.2.6. True density, bulk density and porosity measurements

The volume of solids (V_s) was measured with a gas pycnometer (Stereopycnometer SPY-3, Quantachrome, Syosset, N.Y., USA) using helium as the displacement fluid. A portion of each flour sample was added in a cylinder with a known volume (V_b) and weighed (m). The samples were placed in the sample chamber of the pycnometer and pressurized. True and bulk density and porosity were calculated according to the following equations:

$$\text{True density } (\rho_s) = m/V_s \quad (3)$$

$$\text{Bulk density } (\rho_b) = m/V_b \quad (4)$$

$$\text{Porosity} = 1 - (\rho_s/\rho_b) \quad (5)$$

2.2.7. Colour characteristics of flour

Colour measurement of flour samples was carried out using a Minolta colorimeter (CR-200, Minolta Company, Ramsey, NJ, USA). The values reported for lightness L^* ($L^* = 100$ means white; $L^* = 0$ means black), chroma α^* ($+a^*$ means redness; $-a^*$ means greenness) and hue b^* ($+b^*$ means yellow; $-b^*$ means blue) parameters of the CIELAB system were the mean of three measurements at three different locations of each flour sample. The total colour difference (ΔE^*) was calculated by applying the following equation:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta \alpha^*)^2 + (\Delta b^*)^2} \quad (6)$$

2.2.8. Extraction of free soluble phenolic compounds

Free soluble phenolic compounds were extracted according to Adom and Liu (2002), slightly modified. At room temperature, flour sample (2 g) was extracted three times with 80% aqueous ethanol: twice with 10 mL of ethanol and once with 5 mL. Each step of extraction lasted 10 min. The suspensions were centrifuged at 6200×g for 10 min and the supernatants were collected and combined. The final volume was brought to 25 mL with 80% aqueous ethanol. The extracts were stored at −20 °C until they were analysed.

2.2.9. Determination of total phenolics content

The colorimetric Folin-Ciocalteu method (Singleton & Rossi, 1965) was used in order to estimate the total phenolic compounds