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Sieving fractionation and jet mill micronization affect the functional properties of wheat flour

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ABSTRACT

The particle size of wheat flour has a significant effect on its functional properties. Three fractions of roller milled wheat flour were obtained using sieving: a coarse fraction (CF) with $d_{50} > 200$ μm, a middle fraction (MF) with 100 μm < d_{50} < 200 μm and a fine fraction (FF) with $d_{50} < 100$ μm. An extra fine fraction was received by pulverizing CF in a jet mill (JCF). Particle size volume distributions were determined and further samples characterisation included: chemical composition, water holding capacity (WHC), starch damage, swelling capacity, and slurries viscoelasticity. CF presented bimodal granules' volume distribution containing many agglomerates of irregular shape. The fine fractions differed significantly. JCF contained spherical granules, whereas FF irregular granules' fragments with a few free starch granules. JCF presented the highest WHC and granules swelled fast (up to 75 °C) with a great soluble solids leakage. FF presented a delayed gelatinisation and low elasticity, indicating a weak structure.

1. Introduction

Particle size has significant effect on the functionality of wheat flour. In particular, large particles disrupt the dough network, reduce the blistering and decrease the oil uptake during frying when used in coating formulations, whereas the small particles are responsible for most of the water uptake, viscosity, plasticity and smoothness of the dough (Gomez et al., 1987). Particle size reduction can have a number of effects upon a food system with the most significant being the physicochemical changes due to the increase of a particle's surface area (Schubert 1987; Wang and Flores, 2000; Toth et al., 2005). Although flour particle size can be reduced by regrinding a sample, further size reduction by grinding is accompanied by an increased level of starch damage, which negatively affects flour performance in many final products (Yamazaki, 1959). Moreover, refinement of flour reduces the amount of protein and minerals (Anjum et al., 2003).

Jet milling can be an alternative process to reduce flour particle size. It is a fluid energy impact-milling technique which is commonly used to produce particle sizes less than 40 μm (Chamayou and Dodds, 2007) and it is widely used in the chemical, pharmaceutical and mineral (Midoux et al., 1999). The final particle size produced by this method is very much dependent on the material being processed and could very well be processed into the 1000 nm scale (Sanguansri and Augustin, 2006). Superfine powders are produced by accelerating the particles in a high-velocity air stream, the size reduction being the result of interparticle collisions or impacts against solid surface (Létang et al., 2002).

There is limited information about the effect of jet milling on food ingredients' physicochemical characteristics, but there is an increased interest in its applications in food. Different micronization methods have been used to produce insoluble-rich fine fractions with improved characteristics from orange peel and cellulose (Chau et al., 2006). Concerning cereals, jet milling combined with air classification has been successfully used to separate starch from protein in order to produce starch-rich, fine flours. Improved flour is claimed to be produced by remilling wheat flour in a patent (Graveland and Henderson, 1991). In a recent study microparticulated wheat bran was produced using a jet mill and breads enriched with fine bran powder with good quality were produced (Kim et al., 2013).

Favourable exploitation possibilities of cereal flours may be found by producing ultrafine powders with different

Abbreviations: CF, coarse fraction; MF, middle fraction; FF, fine fractions; JCF, jet mill coarse fraction; WHC, Water Holding Capacity (gH_2O/g flour); OHC, Oil Holding Capacity (g oil/ g flour); SP, swelling power (g/g d.m.); SS, soluble solids (g/g d.m.); G′, Storage Modulus (Pa); G″, Loss Modulus (Pa); d_{50}, volume median diameter (μm); d_{43}, De Brouckere mean diameter; d_{32}, Sauter mean.

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functionalities. Furthermore, damaged starch increase, when intense micronization methods are used, should be investigated in order to specify application limits of such technologies.

In the present study two processes, roller and jet milling were used to produce different wheat flour fractions. The effect of particle size, shape and composition on the functional characteristics of the fractions such as WHC, OHC, starch swelling and wheat slurries' viscoelasticity under heating was investigated. The research was undertaken in order to understand the flour properties of small granules' size. When the granule size is controlled, composite flour blends can be produced at scale industry level, resulting in new improved products.

2. Materials and methods

2.1. Flour

Commercial soft wheat flour donated by the Company Loulis Mills S.A., named as middle fraction (MF) with 100 μm < d_{50} < 200 μm was used. Two more fractions of soft wheat flour using extra sieving process were received: a fine fraction (FF) with d_{50} < 100 μm and a coarse fraction (CF) with d_{50} > 200 μm. Sample from the coarse fraction was further pulverized by a jet mill using max compressed air at 8×10^5 bar, giving an extra fine powder (JCF). Model 0101S Jet-O-Mizer Milling (Fluid Energy Processing and Equipment Company, Telford, Pennsylvania, USA) with air pressure 8 bar at feed rate 15 kg/h were used.

2.2. Particle size distribution

Particle size distributions was determined by laser granulometry with a Malvern Mastersizer 2000 diffraction laser particle sizer (Malvern Instruments, Worcestershire, UK), equipped with a Scirocco dry powder unit (Malvern Instruments, Worcestershire, UK). The instrument provides volume weighted size distributions and particle size parameters, such as volume median diameter (d_{50}), De Brouckere mean diameter $\left(d_{43} = \sum n_i d_i^4 / \sum n_i d_i^3\right)$, and Sauter mean diameter $\left(d_{32} = \sum n_i d_i^3 / \sum n_i d_i^2\right)$, where n_i is the number of droplets of diameter d_i.

Median diameter is the value of the particle size which divides the population exactly into two equal halves i.e. there is 50% of the distribution above this value and 50% below. Median diameter is especially important in case of a bimodal distribution. De Brouckere mean diameter is the volume or mass mean diameter of the particles, and Sauter mean diameter is the surface area weighted mean diameter of the particles. The particles were assumed to have a refractive index of 1.53.

2.3. Optical observations–microscopic technique with image analysis

Shape factors' measurements were performed by means of optical microscopy. Several microscope images were recorded from an optical microscope (Kruss Optronik, Germany) with a 10× magnification connected with a camera (SONY, Topica TP-1002DS). Samples were prepared by mixing flour and isopropyl alcohol on a slide and placing a cover slip over the suspension (Wilson and Donelson, 1969). Image analysis was carried out using image analysis software (Image-Pro Plus 7.0, Media Cybernetics, USA). Roundness, aspect and box X/Y were calculated (see also Fig. 2b).

2.4. Colour analysis

Hunter Lab parameters were measured using a Minolta colorimeter (CR-200, Minolta Company, Ramsey, NJ, USA) after being standardized using Hunter lab colour standards. Three replicate samples were measured and the parameters recorded were: L = lightness (black/white), a = chroma (green/red) and b = hue (blue/yellow).

2.5. Compositional analysis

Moisture, gluten (wet and dry) and ash contents were determined by Method 925.10 of AOAC (1998), Method 38-10 of AACC (2000) and Method 08-01 of AACC (2000) respectively. Nitrogen content of flours were determined by the Kjeldahl method with Kjeltec 8100 distillation unit and converted to protein content (N × 5.7) using method 46-10 (AACC, 2000).

2.6. Functional properties

2.6.1. Water and oil holding capacity

The centrifugal method was used to determine the water and oil absorption capacities of the flour. Flour (0.5 g) was vortexed with distilled water (5 mL) for WHC and with oil (5 mL) for OHC, in pre-weighed tube and then centrifuged at 1000g for 30 min. The supernatant was decanted, the tube was weighed, and the absorbed water or oil, respectively, was calculated by difference (sediment weight minus sample weight × 100).

2.6.2. Swelling power

Swelling power was measured according to the method described by Yasui et al. (1999) and Zaidul et al. (2008) with modifications. 200 mg (dry basis) of wheat flour were placed in a tube and added of 5 mL of distilled water. Then, the tubes were placed on a vortex mixture for 10 s and incubated in a water bath at the desired temperature (65, 75, 85 and 95 °C) for 20 min with frequent mixing, then cooled in a water bath at 20 °C for 5 min and centrifuged at 3000g for 10 min. Flour swelling power was calculated according to Eq. (1):

$$\text{Swelling Power}(SP)(g/g\ d.m.) = \frac{\text{weigh of swelled residue}(g)}{\text{weigh of dry residue}(g)} \quad (1)$$

Soluble solids were calculated according to Eq. (2):

$$\text{Soluble Solids}(\text{SS})(\%) = \frac{\text{dry weight of supernatant}}{\text{weigh of flour dry basis}} \times 100 \quad (2)$$

The measurements were done in triplicates.

2.6.3. Starch damage

Starch damage (iodine absorption) was measured with a SDmatic (Chopin, Villeneuve-la-Garenne, France) according to AACC (2000) International method 76-33.01.

2.7. Rheological measurements

Dynamic rheological measurements of flour dispersions of 25% w/w were determined on a controlled stress rheometer (Universal Stress Rheometer/Rheometrics Scientific, Inc., NJ). The measuring system consisted of parallel plate geometry (20 mm diameter, 0.5 mm gap). After finding the linear viscoelastic region (LVR) at different temperatures, dynamic temperature ramp tests were performed at a constant strain of 0.5% in the LVR. The viscoelastic characteristics (G′, G″, $\tan\delta$) were recorded during a heating-cooling cycle experiment (40–90–55 °C). The samples were placed between the plates and allowed to rest for equilibration for 5 min before beginning experiments. A water trap was used in order to avoid water evaporation. Furthermore, paraffin oil was put around the sample. The increasing/decreasing temperature rate was 5 °C/min and sample stayed at 90 °C for 10 min.