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Physicochemical properties of jet milled wheat flours and doughs

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ABSTRACT

The aim of this study was to evaluate the physicochemical properties of white wheat flour pulverized by jet mill and the rheological behavior of the resultant doughs. A commercial coarse (control) wheat flour with $d_{50} < 75$ μm (CON) was micronized by jet-mill under two different feed rates, resulting in fine and ultrafine flour preparations with $d_{50} < 21$ μm (JM1) and $d_{50} < 12$ μm (JM2), respectively; d_{50} value was reduced with decreasing feed rate. The levels of damaged starch (5.3–11.5% as is) and water soluble arabinoxylans (0.4–0.5% d.b.) increased ($p < 0.05$) with reduction of flour particle size, while no changes in apparent peak molecular weight, determined by HPSEC–RI, and primary structure of the AXs (e.g. degree of branching) estimated by ^{1}H NMR, were noted upon flour jet-milling. Starch gelatinization properties and dough rheological behavior of CON, JM1, JM2 flours and a mixture (CON:JM1 1:1), covering a particle size range applicable to actual breadmaking processes, were studied. Calorimetry of aqueous flour dispersions (flour:water 30:70 w/w) showed a decrease in starch gelatinization enthalpy of the flours containing jet mill fractions compared to control flour. For the jet mill flours, the creep-recovery test of doughs (flour:water 56:44) revealed an increase ($p < 0.05$) in resistance to deformation, elasticity and zero shear rate viscosity. Additionally, Texture Profile Analysis (TPA) and compression - stress relaxation testing after lubricated squeezing flow (LSF) revealed that with decreasing flour particle size, the doughs become harder with higher consistency, more sticky and gummy and exhibit longer half relaxation time, lower relaxation rate and higher elongational viscosity.

1. Introduction

Jet milling is a high air-pressure milling technique that produces powder micro-particles, with a relatively narrow particle size distribution. One or more air jets (nozzles) are used for acceleration of the feeding material particles to high velocity when they are introduced in the milling chamber of the unit (Lee, McShane, Wood, & Shenoy, 2008); moreover, there is no temperature increase in the chamber during grinding which is very important, particularly for thermo-sensitive materials. Jet mills have been widely used by the industry for processing various materials into ultrafine powders, such as minerals, ceramics, chemicals, colorants, pharmaceuticals and cosmetics. However, research on potential applications of jet milling in food systems has been restricted to obtain micro-particulate insoluble fibers (Chau, Wen, & Wang, 2006), psyllium seed husk (Van Craeyveld, Delcour, & Courtin, 2008) and starches from various sources (Hossen et al., 2011a) as well as to produce wheat starch with very low protein content, in combination with air classification and other milling techniques (Letang, Samson, Lassere, Chaurand, & Abecassis, 2001), and β-glucan concentrates from oat bran (Sibakov, Abecassis, Barron, & Poutanen, 2014). Recent studies have focussed on pulverization of cereal flours using jet milling and its effect on properties of micronized flours from rice (Hossen et al., 2011b), wheat (Angelidis, Protonotariou, Mandala, & Rosell, 2016; Protonotariou, Batzaki, Yanniotis, & Mandala, 2016; Protonotariou, Drakos, Evageliou, Ritzoulis, & Mandala, 2014; Protonotariou, Mandala, & Rosell, 2015), rye and barley (Drakos et al., 2017).

Reduction of flour particle size by micronization techniques largely affects their functional properties, such as water absorption and damaged starch, as well as extractability and molecular characteristics of their constituents, e.g. arabinoxylans (Angelidis et al., 2016; Hossen et al., 2011a, b; Izydorczyk, Chornick, Paulley,

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Edwards, & Dexter, 2008; Konopka & Drzewiecki, 2004; Leon, Barrera, Perez, Ribotta, & Rosell, 2006; Letang et al., 2001; Protonotariou et al., 2014; Sapirstein, David, Preston, & Dexter, 2007; Sibakov et al., 2014; Van Craeyveld et al., 2008; 2009). In turn, these properties are important determinants of starch gelatinization characteristics (Angelidis et al., 2016; Barrera, Leon, & Ribotta, 2012; Leon et al., 2006; Morrison, Tester, & Gidley, 1994) and rheological behavior of flour doughs, including their breadmaking performance (Konopka & Drzewiecki, 2004; Leon et al., 2006; Protonotariou et al. 2016). Studies on the impact of jet milling on white wheat flour properties are limited (Angelidis et al., 2016; Protonotariou et al., 2014), while the rheological behavior of bread dough from the fine flour fractions prepared by jet milling has not yet been explored. Moreover, information about the effect of jet milling on the physicochemical properties of arabinoxylans, such as extractability, molecular size and structural features, are restricted to those originated from psyllium seed husk and oat bran (Sibakov et al., 2014; Van Craeyveld et al., 2008). The molecular characteristics of these cell wall polysaccharides have an impact on bread making performance of wheat flours, and largely influence their bioactivity, e.g. postprandial glucose, insulin and immunological responses (Biliaderis, Izydorczyk, & Rattan, 1995; Garcia et al., 2007; Izydorczyk & Biliaderis, 2007; Lu, Walker, Muir, Mascara, & O'Dea, 2000; Lu, Walker, Muir, & O'Dea, 2004; Zhou et al., 2010). The aim of the present study was to explore the effect of jet milling on white wheat flour properties, including starch damage and gelatinization, solubility and molecular features of arabinoxylans as well as the bread dough rheological behavior.

2. Materials and methods

2.1. Flour samples

A commercial wheat flour with extraction rate 70% (T70), provided by Loulis Mills S.A. (Sourpi, Magnisia, Greece) and denoted as CON (coarse flour), was milled with a pilot air jet mill (Model 0101S Jet-O-Mizer Milling, Fluid Energy Processing & Equipment Company, Telford, Pennsylvania, USA) using air pressure 8 bar (Table 1). Two flour streams with different particle size, symbolized as JM1 (fine flour) and JM2 (ultrafine flour), were derived from the CON sample by operating the jet mill at two different feed rates, 2.7 and 1.5 kg/h, attained by using 90% and 50% of the maximum vibration rate of the feeder, respectively. An additional flour sample named as MIX that was a mixture of CON and JM1 samples at a weight ratio 1:1 was also examined for its functional properties. The latter preparation was included in the present study as a flour sample with an intermediate particle size range that is appropriate for breadmaking; in this way, the potential use of jet milling flour fractions in the bakery industry would be broadened.

Table 1
Granulometric distribution of wheat flour samples.

Code	Flour samples	Particle size parameters		
	Description	$<d_{10}$ (μm)	$<d_{50}$ (μm)	$<d_{90}$ (μm)
CON	Coarse commercial flour	25 [a]	75	235
MIX	CON:JM1 1:1 mixture	17	24	65
JM1	Fine jet mill flour (feed rate 2.7 kg/h)	12	21	40
JM2	Ultrafine jet mill flour (feed rate 1.5 kg/h)	9	12	20

[a] Values are means of six measurements.

2.2. Flour physicochemical analyses

Particle size distribution of wheat flour samples was determined by an Olympus BX51 microscope equipped with dry lenses and a microscope digital camera Olympus DP70 (Japan), using the Olympus micro DP70 software and captures were analyzed using the image analysis software, ImageJ (version 1.47). All images were converted into an 8-bit and black/white binary format. A global scale was set, allowing ImageJ to measure the actual distance based on pixel measurements. Six captures for each flour sample were analyzed; the number of flour particles that were analyzed per capture was about 100, 300, 500 and 900 for CON, MIX, JM1, and JM2 sample, respectively. The $<d_{10}$, $<d_{50}$ and $<d_{90}$ particle size parameters were estimated based on particle diameter distribution calculated by particle surface areas.

Color parameters (L^*, a^* and b^* values) of wheat flours were measured using a Chromameter (Konica Minolta, CR-400 Series) calibrated with a white tile ($L^* = 96.9$, $a^* = -0.04$, $b^* = 1.84$). Five measurements from each sample were performed.

The moisture and ash contents (% flour dry base, d.b.) of flour streams were determined according to the American Association of Cereal Chemists International official methods 44–15.02 and 08–01.01, respectively (AACC International, 2010). The total pentosans content in tested flours was determined according to the phloroglucinol method of Douglas (1981); analytical grade reagents used for this analysis were obtained from Sigma–Aldrich (St. Louis, MO, USA).

The total starch and damaged starch contents (% as is) were determined using the respective assay kits available from Megazyme (Megazyme International Ireland Ltd., Wicklow Ireland). The effect of flour jet milling on starch damage was also evaluated by cross polarized light microscopy using the Olympus BX51 microscope.

All the above chemical analyses were carried out in at least triplicate measurements.

2.3. Characterization of flour arabinoxylans

2.3.1. Extraction and purification of water-soluble arabinoxylans

Water-soluble arabinoxylans (AXs) were extracted from commercial and jet milled wheat flour streams and purified following the method described by Izydorczyk, Biliaderis, and Bushuk (1990). The flours were firstly refluxed (100 g flour/1L of aqueous ethanol 82% v/v, 2 h × 85 °C) to inactivate endogenous arabinoxylan hydrolases, filtered and dried (25–30 °C × 18 h). Aqueous extraction of AXs was carried out by mixing 100 g of refluxed flour with 500 ml of distilled water and stirred in a commercial blender for 15 min at room temperature. The slurries were centrifuged (2450 × *g*, 20 min) and thereafter, the supernatants were filtered and concentrated to 1/3 of the initial volume under vacuum (at 95 °C). The filtrate was stirred for 30 min with Fuller's earth (20 g/l extract, Sigma-Aldrich) to remove thermally coagulated proteins (adsorption). The extracts were then incubated overnight (pH 6.9, 37 °C) with porcine pancreas α-amylase (300,000 U Megazyme Ltd., 3 mM $CaCl_2$) and were dialyzed (cellulose membranes, molecular weight cut-off = 14,000, Sigma-Aldrich) with distilled water; α-amylase was subsequently inactivated (90 °C × 30 min) and the suspension was centrifuged (2450 × *g*, 20 min). The supernatants were selectively precipitated with ammonium sulfate, $(NH_4)_2SO_4$, (95% saturation, 25 °C × 18 h) to remove arabinogalactans (remain soluble), and the precipitated AXs were recovered by centrifugation (2450 × *g*, 20 min), re-dissolved in distilled water, exhaustively dialyzed for removal of $(NH_4)_2SO_4$ and finally, freeze-dried. This isolation protocol of water-extractable arabinoxylans (WEAX) yielded highly purified preparations with greater than 90%