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Dough rheological properties and noodle-making performance of non-waxy and waxy whole-wheat flour blends

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A B S T R A C T

Dough rheological properties and noodle-making performance of non-waxy whole-wheat flour (WWF) with partial- or full-waxy (PW- or FW-) WWF substitution were studied. The substitution levels were 0, 250, 500, 750, and 1000 g/kg, respectively. FW-WWF reduced the peak viscosity and pasting temperature of WWF blends as its substitution level was increased due to its higher proportions of B-type starch granules and short amylopectin chains, while PW-WWF increased peak viscosity with the increasing substitution level because of its higher amylopectin content. As demonstrated by farinograph and rheometer measurements, FW-WWF interfered with gluten development because of the increased competition for water by arabinoxylans and amylopectin; however, PW-WWF enhanced dough strength due primarily to its increased protein content. Consequently, FW-WWF showed a detrimental effect on cooked noodle texture as the cooked noodle hardness was reduced by 50% at the 1000 g/kg substitution level. In contrast, PW-WWF enhanced noodle integrity and elasticity by increasing cooked noodle cohesiveness and resilience by 10.1% and 14.8%, respectively, at the 1000 g/kg substitution level. The results suggest that with waxy WWF substitution, the changes in starch composition, arabinoxylans, and protein content could modify the interactions among flour components and influence the quality characteristics of noodle products.

1. Introduction

Noodles are one of the most important foods consumed in Asian countries and account for an average of 20–50% of the total wheat flour usage (Hou, 2010a). In fact, nowadays Asian noodle has become a global food. In addition to the popularization of whole-grain foods, whole-wheat noodles that contain high dietary fiber and phytochemicals have received increasing attention from consumers who desire low-calorie and healthy foods (Dykes and Rooney, 2007). The development of noodles enriched with natural dietary fiber and bioactive substances is regarded as an effective way to promote high-fiber food consumption and increase health benefits for consumers (Chen et al., 2011). However, the presence of wheat bran, the primary dietary fiber source, not only causes rough surfaces because of larger particle size, but also negatively affects noodle texture due to the weakening of dough strength. Therefore, much effort is needed to improve the quality of noodles made from whole-wheat flour (WWF), especially concerning sensory and textural characteristics.

Wheat dough is generally regarded as a composite material in which gluten forms a continuous matrix and starch granules act as filling substances within the matrix (Edwards et al., 2002). The final quality of noodle products depends on the properties of protein and starch. Starch occupies the largest volume fraction of solids in wheat dough. The physicochemical properties of starch, such as amylose content, amylose/amylopectin ratio, granule structure, and the interactions with other flour components, have significant impacts on the quality of Asian noodle products (Baik and Lee, 2003; Park and Baik, 2004). The thermodynamic properties of noodle flour and rheological behavior of noodle dough are associated with the size of starch granules and fine structure of amylopectin. A- and B-type

Abbreviations: AACCI, AACC International; A-L, Lipid-complexed Amylose; ANOVA, Analysis of Variance; AX, Arabinoxylan; DP, Degree of Polymerization; FV, Final Viscosity; FW, Full-Waxy; GBSS, Granular Bound Starch Synthase; PPO, Polyphenol Oxidase; PV, Peak Viscosity; PW, Partial-Waxy; RVA, Rapid Visco Analyzer; RVU, Rapid Visco Units; SV, Setback Value; TAM, Total Amylose Content; TPA, Texture Profile Analysis; WWD, Whole-Wheat Dough; WWF, Whole-Wheat Flour; WWN, Whole-Wheat Noodle.

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granules are the two distinct populations of starch granules in wheat endosperm; they differ in chemical composition, gelatinization behaviors, and pasting properties. A-type granules usually display higher peak viscosity in pasting profiles than B-type granules because of their larger swollen mass. B-type granules generally show lower starch viscosity due to their smaller granule sizes, and delayed gelatinization time because of higher phospholipid contents that stabilize granule structure through complexation with amylose (Morrison and Laignelet, 1983). The fine structure of amylopectin affects the crystallinity of starch granules; a high proportion of short chains in amylopectin causes crystalline defects in starch granules, which results in fast water diffusion and a low pasting temperature (Mcpherson and Jane, 1999). Noodle dough made from reconstituted flours consisting of smaller starch granules exhibits lower elasticity due to more dense packing of starch granules in gluten network and less open air space in dough sheet (Huang and Lai, 2010).

Starch is referred to as "waxy" when it is composed primarily of amylopectin. Waxy wheat samples are characterized by a distinct reduction in amylose content due to the absence of granular bound starch synthase (GBSS) (Nakamura et al., 1995). Wheat has three genetic loci encoding GBSS. When grain lacks all three GBSS genes, it is referred to as full-waxy (FW) wheat; when grain lacks only one or two GBSS genes, it has an intermediate amylose level and is referred to as partial-waxy (PW) (Bettge et al., 2001). Waxy wheat starches show diverse structures and functionalities. Many studies have reported the applications of waxy wheat starch/flour in Asian noodle products. Guo et al., (2003) reported that waxy flour addition resulted in a higher flour swelling volume and a lower falling number, and increased the cohesiveness, springiness, and resilience of cooked noodles. Baik and Lee (2003) found that as the addition level was increased in flour blends, waxy wheat starch enhanced the water retention capacity of noodle flour and noodle cooking yield. It has been reported that using a high proportion of amylopectin can achieve the preferred texture of Udon; it provides a soft and elastic texture because of its high paste viscosity, low gelatinization temperature, and high swelling power (Zhao et al., 1998).

Previous studies indicate that waxy wheat flour modifies the rheological characteristics and sensory quality of noodles made from refined flour (Baik and Lee, 2003; Guo et al., 2003; Zhao et al., 1998). However, few scientific studies have examined the influences of waxy wheat flour on the characteristics of whole-wheat dough (WWD) and the qualities of whole-wheat noodles (WWN). We previously reported that fine grinding of WWF or the use of selected phosphate salts could improve the quality of WWN (Niu et al., 2014a; Niu et al., 2014b). Nevertheless, approaches to modify the ratio of amylose to amylopectin and substitute waxy WWF for non-waxy WWF to improve the quality of WWN have not yet been examined.

In the present study, FW- and PW-WWFs were prepared using one FW wheat cultivar and one PW wheat cultivar, respectively. The objective was to investigate the dough rheological properties and noodle-making performance of WWF with partial- and full-waxy WWF substitution at levels of 0, 250, 500, 750, and 1000 g/kg. The color, cooking qualities, and textural properties of WWN made from the flour blends were evaluated. This work is expected to help illustrate the interactions among the flour components in whole-wheat system, and provide valuable guidance for the quality improvement of WWN and other similar whole-wheat products.

2. Materials and methods

2.1. Materials

Non-waxy WWF (NW-WWF) (Ultragrain® hard white) was kindly provided by Ardent Mills (Denver, Colorado, US). FW and PW wheat samples were supplied by World Wide Wheat, LLC (Phoenix, Arizona, US). The FW wheat was a three GBSS null white wheat cultivar, while the PW wheat was a *wx*-B1 null white wheat line. It was reported that the FW wheat cultivar was bred with free polyphenol oxidase (PPO) activity, and the PW wheat line was cultivated with a lower PPO activity than the regular level.

FW- and PW-WWFs were produced according to the method of Niu et al. (2014a). FW- or PW-WWF was substituted for NW-WWF at levels of 0, 250, 500, 750, and 1000 g/kg. All ingredients used were food grade.

2.2. Arabinoxylan, protein, wet gluten content, and starch composition

The arabinoxylan (AX) content in WWF blends was determined according to the method of Douglas (1981) by using phloroglucinol and acetic acid for extraction. Protein, wet gluten, and total starch contents were analyzed according to AACC International approved methods 46–11.02, 38–12.02, and 76–13.01, respectively (AACCI, 2010). Total amylose (TAM), lipid-complexed amylose (A-L), and amylopectin contents were measured using the colorimetric method outlined by Morrison and Laignelet (1983). Starch granule size distributions were analyzed according the method of Shinde et al. (2003) using a coulter counter (Beckman Coulter, Miami, Florida, US). A 10-μm threshold diameter was used for differentiating A- and B-type starch granule populations. Damaged starch was determined according to AACC International approved method 76–31.01 (AACCI, 2010). The chain-length distribution of amylopectin was evaluated using a high-performance anion-exchange chromatograph, according to the procedure of Kim and Huber (2010).

2.3. Pasting properties of flour blends

The pasting properties of WWF blends were determined with a rapid visco analyzer (RVA, Model Super-3, Newport Scientific, Australia) using AACC International approved method 76-21 (AACCI, 2010). A 3.5 g of WWF sample (140 g/kg moisture basis) and 25 mL distilled water were mixed to form a slurry that was manually homogenized using a plastic paddle to avoid lump formation before the RVA test. RVA tests were conducted in a programmed heating and cooling cycle for 13 min. The parameters recorded were expressed in rapid visco units (RVU).

2.4. Dough mixing properties

Dough mixing properties were evaluated using a farinograph (Brabender, Duisburg, Germany) following AACC International approved method 54-21 (AACCI, 2010). Parameters measured were water absorption (percentage of water required to yield a dough consistency of 500 BU) and stability time (time that dough consistency remains at 500 BU).

2.5. Rheological properties

The rheological properties of WWD were measured using an AR1000 rheometer (TA Instruments, New Castle, Delaware, US), according to the method of Li et al. (2013). Parallel plate geometry (40 mm diameter, 1 mm gap) was selected as the testing probe. For each test, a 3 g of WWD was placed between the plates after optimum dough mixing in a farinograph with optimum water absorption. Frequency sweep tests were performed from 0.1 to 100.0 Hz. The elastic modulus (G') and viscous modulus (G'') parameters were recorded as a function of frequency. The tan δ value (G''/G') and complex modulus $|G^*|$ $[(G^*)^2 = (G')^2 + (G'')^2]$ were determined as well.