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Rheological, thermal conductivity, and microscopic studies on porous-structured noodles for shortened cooking time

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ABSTRACT

The porous structure of wheat-based noodles was built up with maltodextrin to shorten their cooking times. The use of maltodextrin increased the water solubility of wheat flour while the pasting parameters were significantly reduced with increasing levels of maltodextrin. The Mixolab results showed that the mixing stability of wheat dough was positively enhanced by maltodextrin. When maltodextrin was incorporated into the noodle formulation, it was effective in improving the rheological characteristics of noodles by increasing their maximum force to extension and extensibility. After being cooked, the noodles with maltodextrin exhibited higher thermal conductivity and lower firmness, possibly indicating shortened cooking time. The scanning electron microscopic observation demonstrated that the use of maltodextrin produced noodles with the highly porous structure, which seems to be advantage for quick rehydration during cooking. Overall similarities in the sensory noodle attributes were observed between the control and maltodextrin (5 g/100 g) noodles.

1. Introduction

Noodles are gaining popularity in the world because of various advantages including convenience, longer shelf-life, and affordable price. Noodle manufacturers supplied 97.7 billion servings in 2015 and the global demands are on the rise (WINA, 2015). With this trend, large automated plant systems have been therefore established at the industrial level for mass and sanitary production. The process of noodles is generally involved in sheeting and cutting of dough followed by dehydration while pastas are extruded through a die under pressure (Gulia, Dhaka, & Khatkar, 2014). Thin and long strips slit from sheeted dough are thus characteristic of noodles. To be specific, the crumbly dough produced by mixing raw materials is compounded, sheeted by passing through a series of rollers with decreasing gaps, slit to noodle strands, and finally dehydrated by air-drying or deep-frying. This process contributes to the increased density of the noodles, well-developed gluten network, improved chewy texture, and lower cooking loss (Kinsella, 2001). On the other hand, the tight and dense structure of the noodles can play a negative role in their rehydration during cooking. Specifically, non-expanded and non-fried noodles require prolonged cooking times. Thus, one of the technical challenges in improving the quality attributes of noodles is to shorten their cooking times. Several preceding studies have been found to improve the cooking time of noodles. The addition of guar gum (Yu & Ngadi, 2004) and salt (Fu, 2008) increased the rehydration of the noodles during cooking. Also, the noodles containing emulsifiers such as polysorbate-60 and diacetyl tartaric esters of mono-glycerides (DATEM) exhibited reduced cooking times (Ding & Yang, 2013). In these studies, the changes in the cooking times were explained by the greater affinity of the tested ingredients to water or higher degree of starch gelatinization. However, no scientific approaches have been reported to reduce the cooking time of noodles by modifying their structure.

In this study, maltodextrin was incorporated into the formulation of noodles and evaluated as a rehydration improver for the noodles. The effects of the maltodextrin on the physicochemical properties of wheat flour were characterized and the cooking times of the maltodextrin-incorporated noodles were evaluated in terms of rheological property, thermal conductivity, and porous structure.

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2. Materials and methods

2.1. Materials

Maltodextrin was provided from a commercial source. All-purpose flour was obtained from CJ Co. Ltd. (Seoul, Korea), and its proximate chemical composition (ash, protein, moisture, and carbohydrate (by difference)) was measured based on the AOAC-approved methods (AOAC, 2005) that were determined to be 0.41, 8.99, 12.36, and 75.61 g/100 g, respectively. They were stored in a plastic bag at 4 °C before further experimental uses.

2.2. Determination of water hydration property

Wheat flour (3 g) was replaced with maltodextrin (5 and 10 g/100 g by weight), suspended in 30 mL of distilled water, agitated at two different temperatures (25 and 100 °C) for 30 min, and then cooled at 4 °C for 3 min. After centrifugation at 15,000*g* for 30 min, the supernatant was poured into an aluminum dish and dried at 105 °C until constant weight was obtained. The weights of the wet sediment and dried supernatant were measured to calculate the water absorption index and water solubility (Heo, Lee, Shim, Yoo, & Lee, 2013).

2.3. Pasting property measurement

The effect of maltodextrin on the pasting properties of wheat flour was investigated by using a starch pasting cell attached to a controlled-stress rheometer (AR1500ex, TA Instruments, New Castle, DE, USA) (Baek, Kim, & Lee, 2014). Wheat flour was replaced with maltodextrin at 0, 5, and 10 g/100 g by weight. Wheat flour with and without the maltodextrin was added in an aluminum canister with distilled water to produce a 28 g suspension (10.5 g/100 g) whose viscosity was monitored during the programmed heating-cooling cycle. The suspension was equilibrated at 50 °C for 1 min, heated to 95 °C at a heating rate of 12 K/min, and held at 95 °C for 2.5 min. It was followed by cooling to 50 °C at 12 K/min and holding at 50 °C for 2 min. The pasting curves were the mean values of three measurements.

2.4. Mixolab measurement

The changes in the thermo-mechanical properties of wheat flour with maltodextrin were investigated by using a Mixolab (Chopin, Tripetteet Renaud, Paris, France). Wheat flour was replaced with maltodextrin at 0, 5, and 10 g/100 g by weight and the blend was loaded into a Mixolab bowl. Distilled water was automatically added to reach optimum consistency (1.1 Nm). During mixing, a dough sample was subjected to the programmed heating and cooling cycle (holding at 30 °C for 8 min, heating to 90 °C for 15 min (4 K/min), holding at 90 °C for 7 min, cooling to 50 °C over 5 min (4 K/min), and finally holding at 50 °C for 5 min).

2.5. Noodle preparation

The formulation of the control noodle consisted of all-purpose wheat flour (CJ Co. Ltd.), sodium chloride (CJ Co. Ltd.), potato starch (Samyang Genex Co., Seoul, Korea), and water. For the noodles containing maltodextrin, wheat flour was replaced with maltodextrin at 0, 5, and 10 g/100 g by weight as presented in Table 1. Sodium chloride was dissolved in water and added into the wheat flour. The ingredients were blended in a KitchenAid mixer (St. Joseph, MI, USA) for 3 min. The dough was hand-kneaded for 2 min and passed through a series of sheeting rollers (BE-8200, Bethel, Seoul, Korea) to produce a uniform dough sheet (1.4 mm thickness) which was cut into strips (25 cm long and 2 mm wide) with a roller cutter. The noodle samples were dried at 40 °C for 24 h in a dry oven.

Table 1
Formulation of noodles with maltodextrin.

Ingredients (g)	Control	Maltodextrin (5 g/100 g)	Maltodextrin (10 g/100 g)
All-purpose wheat flour	100.0	95.0	90.0
Maltodextrin	0	5.0	10.0
Potato starch	13.1	13.1	13.1
NaCl	1.5	1.5	1.5
Water	39.0	39.0	39.0

2.6. Tensile property measurement

The tensile properties of noodles were investigated by using a texture analyzer (TMS-Pro, Food Technology Co., Virginia, USA). The noodle strands (5 cm long) were subjected to the tension test which was conducted with a Kieffer dough and gluten extensibility rig at a crosshead speed of 3.3 mm/s. The plots of force versus distance were recorded to obtain R_{max} and E values. R_{max} is the maximum peak force which is a measure of the resistance of dough to stretching, and E indicates the distance to rupture which is the extensibility of dough (Heo et al., 2013).

2.7. Thermal conductivity analysis

The effect of maltodextrin on the thermal conductivity of noodles after cooking was determined by a thermal conductivity analyzer (C-Therm TCi, C-Therm technologies Ltd., New Brunswick, Canada) employing the modified transient plane source technique. The thermal conductivity analyzer generated one-dimensional upward heat flow, resulting in a rise in temperature at the interface between the noodle sample and sensor. The temperature increase induced a voltage change that was correlated to square root of time ($\Delta V = m\sqrt{time}$, m : slope). Since the voltage change was related to thermal conductivity through a calibration with reference materials whose thermal conductivity were already known (Smith & diPalma, 2007), the thermal conductivity was obtained from the slope of the curve. The disc-shaped noodle (4 cm diameter, 1.4 mm thickness) containing maltodextrin (0, 5, and 10 g/100 g by weight) was prepared and freeze-dried in a freeze dryer (TFD Series, Ilshin Lab Co., Ltd., Kyunggi-do, Korea). The noodle sample was cooked in boiling water for 2.5 min and cooled at room temperature for 5 min. It was then placed on the thermal sensor and a weight (500 g) was loaded on the sample, followed by the thermal conductivity analysis.

2.8. Firmness measurement

The firmness of the noodles after cooking was investigated by using a texture analyzer (TMS-Pro, Food Technology Co., Virginia, USA) with a blade probe (90 mm wide, 30 mm high, 5 mm thick). The noodles were cooked for 2.5 min and three noodle strands were placed perpendicularly to the probe on the platform of the texture analyzer. The probe was then lowered at a constant speed of 60 mm/min to compress the noodles to 70% deformation.

2.9. Structural analysis

The noodles prepared with maltodextrin were freeze-dried after cooking, mounted on an aluminum stud using double-sided tape, and coated with a layer of platinum. Scanning electron microscopy