

Effects of Starch Amylose Content of Wheat on Textural Properties of White Salted Noodles

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ABSTRACT

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White salted noodles were prepared through reconstitution of fractionated flour components with blends of waxy and regular wheat starches to determine the effects of amylose content on textural properties of white salted noodles without interference of protein variation. As the proportion of waxy wheat starch increased from 0 to 52% in starch blends, there were increases in peak viscosity from 210 to 640 BU and decreases in peak temperature from 95.5 to 70.0°C. Water retention capacity of waxy wheat starches (80–81%) was much higher than that of regular wheat starch (55–62%). As the waxy wheat starch ratio increased in the starch blends, there were consistent decreases in hardness of cooked

noodles prepared from reconstituted flours, no changes in springiness and increases in cohesiveness. White salted noodles produced from blends of regular and waxy wheat flours became softer as the proportion of waxy wheat flour increased, even when protein content of flour blends increased. Amylose content of starch correlated positively with hardness and negatively with cohesiveness of cooked white salted noodles. Protein content of flour blends correlated negatively with hardness of cooked noodles, which were prepared from blends of regular (10.5% protein) and waxy wheat flours (> 16.4% protein).

Noodles are one of the most important staple foods in many Asian countries (Huang and Morrison 1988). About 40% of the wheat consumed in Asian countries is used in noodle production (Oda 1982). Since Asian noodles are made from simple ingredients, i.e., wheat flour, water, salt and alkali, using a sheet-and-press process instead of extrusion, the characteristics of flour mainly determine the eating quality of noodles.

Constituting the highest portion of wheat flour, starch has significant effects on the eating quality of noodles, especially on textural properties. Texture is one of the most important quality parameters for noodles. Therefore, there has been considerable research on starch properties related to the textural quality of noodles. High paste viscosity and breakdown (Moss 1979; Oda et al 1980; Lee et al 1987; Crosbie et al 1990; Konik et al 1992; Baik 1994), low gelatinization temperature (Oh et al 1985b; Endo et al 1988) and high swelling power of starch (Crosbie 1991; McCormick et al 1991) have been reported as desirable for textural properties of white salted noodles in Japan and Korea. Oda et al (1980) also reported that the amylose content of flour negatively correlated with amylograph peak viscosity and eating quality of white salted noodles.

Hoshino et al (2000) and Yamaguchi et al (2000) observed that reducing amylose content by adding waxy wheat flour to regular wheat flour improves the textural properties of noodles, as determined by sensory tests. However, in their study, noodles were made from blends of regular and waxy wheat flours to adjust amylose content without consideration of the effect of protein in the flour blend. In another study (Toyokawa et al 1989), due to a lack of waxy wheat starch, waxy corn starch was used for the adjustment of amylose content to determine the effect of amylose content on noodle quality without the interference of protein. In the present study, the role of amylose content on textural properties of white salted noodles was investigated without the interference of protein by preparing reconstituted flours with waxy starch from recently developed waxy wheat lines.

The objectives of this study were to examine the textural properties of white salted noodles with selected amylose contents and to determine the relationship between amylose content and the textural properties of white salted noodles.

MATERIALS AND METHODS

A soft white winter wheat cv. Madsen, a hard white spring wheat cv. Klasic and two advanced breeding lines of waxy wheat from Northwest Plant Breeding Company (Pullman, WA), herein referred to as Waxy I and Waxy II, were used for this study. Both Waxy I and Waxy II were derived from the Kanto 107 / Bai-Ho // ID377S. Protein quality of two waxy wheat lines, as determined by the SDS sedimentation volume test based on constant protein, was similar to that of ID377S. Wheat was milled to flour of 60% extraction on a Bühler experimental mill according to approved method 26-31 (AACC 2000). Flours were fractionated into gluten, solubles, tailings starch and prime starch according to the method of Czuchajowska and Pomeranz (1993) and yield of each fraction was determined. Gluten, solubles and tailings starch were lyophilized and ground on a cyclone mill (Udy Co., Fort Collins, CO) fitted with a perforated screen with 0.25-mm openings. Prime starches were dried at 24°C for three days. After drying, the prime starches were ground on a cyclone mill fitted with a perforated screen with 0.25-mm openings. The moisture content of lyophilized gluten and tailings starch were adjusted to the moisture content of prime starch (≈10%).

Chemical Analyses

Moisture content of flour, gluten, solubles, tailings starch and prime starch was determined by oven drying for 1 hr at 130°C (Approved Method 44-15A, AACC 2000). Ash content of starch was determined by dry combustion for 16 hr at 580°C (Approved Method 08-01). Protein content (N × 5.7) was determined using a Leco instrument (Leco Corp., St. Joseph, MI) equipped with a thermoconductivity detector. Amylose content of prime starch was determined by iodometric method as described by Morrison and Laignelet (1983).

Pasting Properties of Starch

Pasting properties of starches (waxy, regular from Madsen and blends of waxy and regular wheat starches) were determined in duplicate using a Brabender Viscoamylograph according to a modified method of Shuey and Tipples (1980). Amylose content of starch blends was adjusted from 11.0 to 22.2% by mixing regular starch with 12 to 52% waxy starch. Starch (40 g, db) was suspended in 450 mL of distilled water. The starch slurry was heated at 1.5°C/min from 30°C to the temperature at which a peak in the pasting curve appeared. That temperature was maintained for 30 min, then the starch slurry was cooled at a rate of 1.5°C/min to 50°C and held at that temperature for 30 min. Peak viscosity and temperature, breakdown, and setback were obtained from the pasting curve.

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Reconstituted Flours and Blends of Regular and Waxy Wheat Flours

Flour fractions, solubles, gluten, tailings starch and prime starch of Madsen or Klasic were combined to prepare reconstituted flours. The starch blends were prepared by mixing prime starches of Madsen or Klasic and two lines of waxy wheat. The proportions of each flour fraction for making reconstituted flours were similar to the yield of each fraction during fractionation. Proportions of each flour fraction for making the reconstituted flour of Madsen (11% protein) were 3.8% solubles, 2.9% tailing starch, 16.5% gluten and 76.8% prime starch. The reconstituted flour of Klasic (11% protein) contained 2.7% solubles, 5.0% tailings starch, 14.2% gluten and 78.1% prime starch. Amylose content in the starch blends was adjusted from 11.0 to 20.2% by mixing prime starches of Madsen or Klasic with 12 to 52% of prime starch from waxy wheat. Protein content of the reconstituted flours with more than 26% waxy wheat starch was adjusted to 13% by increasing the proportion of gluten to improve the sheeting characteristics of reconstituted flour for making noodles.

Wheat flours of regular wheat Madsen and waxy wheat were blended in various ratios to prepare the composite flours, of which amylose content ranged from 18.4 to 20.2%.

Water Retention Capacity of Starch

Water retention capacity of prime starch was determined by the method of Sollars (1973). Prime starch (5 g, 14% mb) was weighed into a 50-mL centrifuge tube and 25 mL of distilled water was added. The starch was dispersed thoroughly for 30 sec using a vortex mixer every 5 min for 20 min. It was then centrifuged for 15 min at 1,000 × g, the supernatant decanted and the tube drained for 10 min at a 45° angle. The tube was weighed and the gain in weight expressed as percent of the starch.

Preparation of White Salted Noodles

White salted noodles were prepared from the reconstituted flours and blends of regular and waxy wheat flours. Flour (100 g, 14% mb) and 35 mL of 6.25% sodium chloride solution were mixed in

TABLE I
Amylose Content and Amylograph Pasting Properties of Regular Starch, Waxy Starch, and Blends of Regular and Waxy Starches^a

| Starch | Amylose ^b (%) | Amylograph | | | |
|----------------------------|--------------------------|-----------------|---------------------|----------------|--------------|
| | | Peak Temp. (°C) | Peak Viscosity (BU) | Breakdown (BU) | Setback (BU) |
| Madsen | 23.0 | 95.5a | 210j | 0j | 380a |
| Starch blends with Waxy I | | | | | |
| 12% | 20.2 | 94.0b | 320i | 80i | 280e |
| 16% | 19.3 | 93.5c | 370h | 120h | 280e |
| 20% | 18.4 | 90.0f | 410f | 140g | 230f |
| 26% | 17.0 | 90.0f | 420e | 150f | 190g |
| 39% | 14.0 | 72.3g | 450d | 230d | 30i |
| 52% | 11.0 | 70.0h | 640c | 320c | 30h |
| Waxy I | 0.0 | 66.5i | 1,780b | 1,030b | 10j |
| Starch blends with Waxy II | | | | | |
| 12% | 20.2 | 93.0d | 400g | 120h | 340b |
| 16% | 19.3 | 93.0d | 420e | 140f | 320c |
| 20% | 18.4 | 91.0e | 450d | 150e | 290d |
| Waxy II | 0.0 | 67.5i | 1,820a | 1,120a | 60j |

^a Means within the same column followed by the same letter are not statistically different ($P < 0.05$).

^b Amylose content of blends of waxy and nonwaxy wheat starches was calculated from the measured amylose content of regular and waxy starches.

TABLE II
Water Retention Capacity of Starch, Water Absorption of Flour for Making Noodles, Thickness of Dough Sheet, Cooking Loss of Noodles and Textural Characteristics of Cooked White Salted Noodles Prepared from Flour (as is) and Reconstituted Flours^a

| Wheat Flour | WRC ^b (%) | Absorption (mL) | Thickness (mm) | Cooking Loss (%) | Hardness (N) | Springiness (Ratio) | Cohesiveness (Ratio) |
|-----------------------------------|----------------------|-----------------|----------------|------------------|--------------|---------------------|----------------------|
| Madsen (as is) | ... | 35 | 1.54a | 9.2b | 5.33a | 0.905a | 0.559c |
| Reconstituted flour (11% protein) | | | | | | | |
| Madsen with Waxy I starch | | | | | | | |
| 0% | 62.0 | 42 | 1.52a | 9.8ab | 3.98b | 0.901a | 0.653b |
| 12% | 64.3 | 44 | 1.54a | 10.3a | 3.51c | 0.909a | 0.674a |
| 16% | 65.0 | 44 | 1.55a | 10.1a | 3.06de | 0.915a | 0.670a |
| 20% | 65.8 | 45 | 1.53a | 10.5a | 2.66f | 0.890a | 0.674a |
| Madsen with Waxy II starch | | | | | | | |
| 12% | 64.2 | 43 | 1.52a | 9.7ab | 3.65c | 0.911a | 0.664a |
| 16% | 64.9 | 44 | 1.53a | 9.7ab | 3.23d | 0.926a | 0.672a |
| 20% | 65.6 | 44 | 1.53a | 9.4b | 3.00e | 0.913a | 0.670a |
| Klasic (as is) | ... | 35 | 1.83a | 7.2c | 6.29b | 0.911a | 0.593c |
| Reconstituted flour (11% protein) | | | | | | | |
| Klasic with Waxy I starch | | | | | | | |
| 0% | 55.0 | 37 | 1.86a | 8.5ab | 8.65a | 0.882b | 0.561d |
| 12% | 58.1 | 39 | 1.85a | 8.0b | 5.52c | 0.882b | 0.629b |
| 16% | 59.2 | 40 | 1.82a | 9.0a | 4.63d | 0.889b | 0.650a |
| 20% | 60.2 | 41 | 1.80a | 8.0b | 4.44e | 0.919a | 0.650a |
| Reconstituted flour (13% protein) | | | | | | | |
| Madsen with Waxy I starch | | | | | | | |
| 0% | 62.0 | 42 | 1.70a | 10.5a | 5.90a | 0.910a | 0.550b |
| 26% | 66.9 | 45 | 1.70a | 7.3c | 4.23b | 0.910a | 0.580a |
| 39% | 69.4 | 47 | 1.67a | 9.4b | 3.30c | 0.915a | 0.574ab |
| 52% | 71.9 | 49 | 1.61a | 8.0c | 2.84d | 0.905a | 0.596a |

^a Means within the same column followed by the same letter in the reconstituted Madsen or Klasic flours are not statistically different ($P < 0.05$).

^b Water retention capacity of starch.

a Hobart mixer for 30 sec at slow speed and then for 4 min at medium speed. The absorption of reconstituted Madsen and Klasic flours for noodle making was determined subjectively by how well the dough could be processed into noodles during sheeting and cutting (Oh et al 1985a). The absorption of reconstituted flours that included waxy wheat starch for making noodles was predicted using a formula based on the absorption of reconstituted flours of Madsen (42%) or Klasic (37%) and water retention capacity of waxy and regular wheat starches: Absorption of reconstituted flours (mL) = $(A \times B) + (A \times C \times D) / E$, where *A* is absorption of reconstituted flours of Madsen or Klasic (mL); *B* is proportion of regular wheat starch; *C* is proportion of waxy wheat starch; *D* is water retention capacity of waxy wheat starch (%); and *E* is water retention capacity of regular wheat starch (%).

The dough was rested for 1 hr after mixing. The dough was then passed through the rolls of a noodle machine (Ohtake Noodle Machine Mfg. Co., Tokyo, Japan) at a 3-mm gap; it was then folded and passed through the sheeting rolls twice for flours and three times for reconstituted flours. The dough sheet was rested for 1 hr and then put through the sheeting rolls three times at progressively smaller gap settings of 2.40, 1.85, and 1.30 mm. For reconstituted flour, the dough was passed through the sheeting rolls one more time at 1.30 mm. The sheet was cut through no. 12 cutting rolls into strips \approx 30 cm in length. The thickness of the noodle dough sheet was measured before cutting into strands. Noodles were put into plastic bags and stored at 4°C for 24 hr until being cooked. Before cooking the noodles were allowed to rest at 23°C for 1 hr.

Cooking Loss and Texture of Noodles

Noodles (30 g) were cooked in 1L of boiling distilled water for 18 min and rinsed with cold water. Cooking water was collected for determination of cooking loss. Cooking loss of noodles (%) was calculated as described by Lee et al (1998): Cooking loss = (residue in cooking water [g]/noodle weight before cooking [g]) \times 100.

Two replicates of cooked noodles were prepared; each time, four sets of noodles were tested using a TA-XT2 texture analyzer (Stable Micro System, Haslemere, England) within 5 min of cooking. Five strands of cooked noodles were placed parallel on a flat metal plate and compressed twice to 70% of the noodle height at a speed of 0.8 mm/sec using a 3.175-mm metal blade. From the force-time curve of the TPA, hardness (height of the first peak) and springiness (ratio between the recovered height after first compression and the height of first compression) were determined. Cohesiveness was the ratio between the area under the second peak and the area under the first peak.

Statistical Analysis

Chemical analyses and pasting property test of starch were performed in duplicate in a completely randomized design. Duplicate sets of white salted noodles were prepared from reconstituted flours and flour blends, cooked and tested for cooking loss and textural properties in a completely randomized design. Data were subjected to analysis of variance, the Fisher's least significant difference test, and correlation analysis at $P < 0.05$ using the Statistical Analysis System (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Pasting Properties of Wheat Starches

The protein content of flour from soft white winter wheat cv. Madsen, hard white spring wheat cv. Klasic, and the two advanced lines of waxy wheat was 10.5, 15.9, and 17.8% (Waxy I) and 16.4% (Waxy II), respectively. Prime starches fractionated from regular and waxy wheat flours exhibited protein content $<0.7\%$ and ash content $<0.1\%$.

Amylose content and amylograph pasting properties of regular wheat starch (Madsen), waxy wheat starch and blends of regular and waxy wheat starches are presented in Table I. The amylose content of regular wheat starch was 23.0%, whereas no amylose was detected in either of the two waxy wheat starches, as determined by the iodometric method. The peak temperature of regular starch was 95.5°C, while the peak temperature of waxy starch ranged from 66.5 to 67.5°C. Peak viscosities of starch were $>1,780$ BU in the two waxy starches and only 210 BU in the regular starch. These results are in agreement with reports by Kiribuchi-Otobe et al (1997) and Grant et al (2001) that waxy starch exhibited lower peak temperature and higher peak viscosity than nonwaxy starch in amylograph pasting properties. On the other hand, Sasaki et al (2000) observed lower Rapid Visco Analyzer peak viscosity in waxy starch than in nonwaxy and partial waxy starches. This discrepancy was likely due to differences in starch concentrations used for pasting property tests. The starch concentration for the pasting property test was 8.9% in this study, while 12% starch was used by Sasaki et al (2000). Seib (2000) also observed opposite trends in the storage modulus of gels prepared from 10 and 25% of a regular and a partial waxy starch. Differences in pasting properties between two waxy starches were probably due to their differences in granular size distribution, branch chain length distribution of amylopectin, crystallinity or minor constituents.

Incorporation of waxy starch into regular starch resulted in significant changes in pasting properties. The peak temperature of starch blends decreased to 94.0°C with 12% Waxy I starch, to 93.5°C with 16% and to 90.0°C with 20 or 26%. A much larger decrease in peak temperature, to $<72.3^\circ\text{C}$, was observed when more than 39% waxy starch was incorporated. There were consistent increases in peak viscosity from 210 to 640 BU, increase in breakdown from 0 to 320 BU and decrease in setback from 380 to 30 BU as the proportion of Waxy I starch increased from 0 to 52%. Similar effects of Waxy II starch on pasting properties of its blends with regular starch were observed. The association between lower amylose content of starch and lower peak viscosity temperature as well as higher peak viscosity in nonwaxy and partial waxy wheat was also reported by Sasaki et al (2000). Large changes in peak temperature from 90.0 to $<72.3^\circ\text{C}$, breakdown from 150 BU to >230 BU and setback from 190 to <30 BU were observed when the proportion of Waxy I starch in the starch blends increased from 26% to $>39\%$. Accordingly, amylograph curves of starch blends showed two distinctive patterns depending on the proportion of waxy starch (Fig. 1). Starch blends containing $<26\%$ waxy starch exhibited similar shape of amylograph curves to regular starch, with high peak temperature, low peak viscosity, low breakdown and large setback. Starch blends with $>37\%$ waxy starch exhibited amylograph curves with low peak temperature, high peak viscosity, high breakdown and small setback, similar to those features observed in waxy starches.

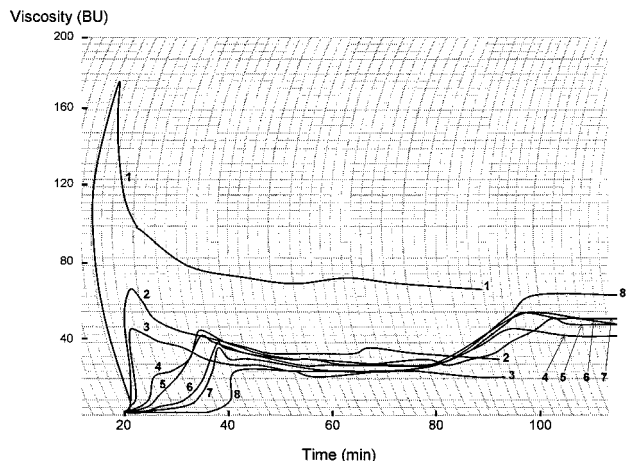


Fig. 1. Amylograph curves of waxy starch (1), regular starch (8), and blends of regular and waxy starch (2-7). Proportion of waxy starch was 52% in 2, 39% in 3, 26% in 4, 20% in 5, 16% in 6 and 12% in 7.

The peak temperature and setback of starches positively correlated with amylose content in starch blends of waxy and regular wheat starches ($r = 0.912$, $P < 0.001$ and $r = 0.871$, $P < 0.001$, respectively), whereas peak viscosity and breakdown viscosity negatively correlated with amylose content of starch blends ($r = -0.967$, $P < 0.001$ and $r = -0.963$, $P < 0.001$, respectively).

Absorption, Thickness and Cooking Loss of White Salted Noodles

Water retention capacity of starch from Madsen, Klasic, and the two lines of waxy wheat were 62, 55, and 81% (Waxy I) and 80% (Waxy II), respectively. Since the water retention capacity of waxy wheat starches was much higher than for regular wheat starches, it was necessary to adjust water absorption for making noodles in the reconstituted flours. The optimum absorption of reconstituted flours of Madsen and Klasic for noodle making was determined subjectively by how well the dough could be processed into noodles during sheeting and cutting (Oh et al 1985a). The absorption of reconstituted flours with waxy wheat starch was calculated based on the water absorption of reconstituted flours of Madsen or Klasic and the water retention capacity of starch blends (Table II). Accordingly, water absorption of reconstituted flours increased as the proportion of added waxy wheat starch increased. Noodle dough prepared from reconstituted flours with various proportions of waxy starch and with the absorptions estimated as described exhibited optimum sheeting and cutting properties.

The thickness of noodle dough sheets prepared from Madsen flour or reconstituted Madsen flours, with or without waxy wheat starch, was similar, ranging from 1.52 to 1.55 mm regardless of the type or proportion of added waxy wheat starch (Table II). Similarly, there was no difference in thickness of noodle dough sheets between Klasic flour and reconstituted Klasic flours, with or without various proportions of waxy wheat starches.

Reconstituted Madsen flour with 11% protein content did not form a noodle dough sheet of acceptable quality when more than 26% of waxy wheat starch was incorporated to maintain amylose content of starch below 17% in reconstituted flour. The noodle dough sheet, after being passed through the rolls in the noodle making machine, exhibited streaks of flour on the surface, formed stiff and uneven dough and separated into several layers. A uniform and smooth noodle dough sheet without separation was produced from reconstituted Madsen flour with >26% waxy wheat starch by increasing the protein content from 11 to 13%. The thickness of noodle dough sheets prepared from Madsen flour and reconstituted Madsen flours, with or without waxy wheat starch, and with 13% protein, ranged from 1.61 to 1.72 mm, higher than the thickness of noodle dough sheets prepared from Madsen flour with 11% protein.

The thickness of noodle dough sheets prepared from Waxy I flour and Waxy II flour were 1.94 mm and 1.87 mm, respectively, much higher than the thickness of noodle dough sheets prepared from Madsen flour (Table III). The thickness of noodle dough sheets prepared from blends of Madsen and waxy wheat flours ranged from 1.60 to 1.68 mm. Overall, differences in starch components did not influence the thickness of the noodle dough sheet.

Cooking loss of noodles prepared from reconstituted Madsen flours with 11% protein content and with Waxy I starch ranged from 10.1 to 10.5%, higher than the cooking loss of noodles prepared from Madsen flour (9.2 %) (Table II). The cooking loss of noodles prepared from reconstituted Klasic flours with Waxy I starch ranged from 8.0 to 9.0%, also higher than the cooking loss of noodles prepared from Klasic flour (7.2%). The greater cooking loss of noodles prepared from reconstituted flour was probably due to the lower degree of protein network formation. This reduced protein network formation may be less able to hold flour components together during dough mixing in the reconstituted flours

TABLE III
Thickness of Noodle Dough Sheet, Cooking Loss, and Textural Characteristics of Cooked White Salted Noodles Prepared from Regular and Waxy Wheat Flours and Blends of Nonwaxy and Waxy Wheat Flours^a

| Sample | Protein ^b (%) | Thickness (mm) | Cooking Loss (%) | Hardness (N) | Springiness (Ratio) | Cohesiveness (Ratio) |
|---------------------|--------------------------|----------------|------------------|--------------|---------------------|----------------------|
| Flour (as is) | | | | | | |
| Madsen | 10.5 | 1.54b | 9.2a | 5.33a | 0.905ab | 0.559b |
| Waxy I | 17.8 | 1.93a | 6.2d | 3.14g | 0.934a | 0.641a |
| Waxy II | 16.4 | 1.87a | 7.2cd | 3.02g | 0.901ab | 0.619a |
| Blends of flours | | | | | | |
| Madsen with Waxy I | | | | | | |
| 12% | 11.4 | 1.66b | 8.3abc | 4.51de | 0.896b | 0.566b |
| 16% | 11.7 | 1.63b | 7.7bc | 4.39e | 0.890ab | 0.572b |
| 20% | 12.0 | 1.60b | 8.5ab | 3.93f | 0.891b | 0.568b |
| Madsen with Waxy II | | | | | | |
| 12% | 11.2 | 1.66b | 8.0a-c | 5.11b | 0.884b | 0.557b |
| 16% | 11.4 | 1.68b | 8.0a-c | 4.79c | 0.917ab | 0.549b |
| 20% | 11.7 | 1.66b | 8.8ab | 4.65cd | 0.913ab | 0.551b |

^a Means within the same column followed by the same letter are not statistically different ($P < 0.05$).

^b Protein content of flour blends was calculated from the protein content of regular and waxy flours.

TABLE IV
Correlation Coefficients Between Amylograph Pasting Viscosities of Starch and Texture Profile Analysis Parameters of White Salted Noodles Prepared from Reconstituted Flours with Various Percentages of Waxy Wheat Starches or from Blends of Waxy and Regular Wheat Flour^{a-c}

| Textural Parameters | Amylose Content | Peak Viscosity | Breakdown | Setback |
|---|------------------|------------------|------------------|------------------|
| Reconstituted flours of Madsen ($n = 7$) | | | | |
| Hardness | 0.9182 (0.0035) | -0.7478 (0.0533) | -0.8174 (0.0247) | 0.7667 (0.0443) |
| Springiness | -0.1432 (0.7596) | 0.3180 (0.4870) | 0.3115 (0.4964) | 0.3713 (0.4122) |
| Cohesiveness | -0.8649 (0.0120) | 0.7078 (0.0752) | 0.7763 (0.0401) | -0.7766 (0.0400) |
| Flours (as is) and Flour Blends ($n = 9$) | | | | |
| Hardness | 0.9152 (0.0005) | -0.8953 (0.0011) | -0.8860 (0.0015) | 0.9718 (0.0001) |
| Springiness | -0.5005 (0.1699) | 0.4953 (0.1752) | 0.4910 (0.1795) | -0.4069 (0.2771) |
| Cohesiveness | -0.9458 (0.0001) | 0.9421 (0.0001) | 0.9486 (0.0001) | -0.9623 (0.0001) |

^a Reconstituted flour was prepared from gluten, water solubles, tailings starch, and prime starches of Madsen.

^b Protein content in reconstituted flours was 11%.

^c Values within parentheses are level of significance (P).

than in wheat flour. The cooking loss of noodles prepared from reconstituted flour with 13% protein ranged from 8.0 to 10.5%.

The cooking loss of noodles prepared from Waxy I flour and Waxy II flour was 6.2 and 7.2% (Table III), respectively, exhibiting a lower cooking loss compared to that of noodles prepared from Madsen flour (9.2%). The lower cooking loss of waxy wheat flours could be due to their higher protein content. Protein forms a network during mixing and holds flour components together. The cooking loss of noodles prepared from blends of Madsen and waxy wheat flours ranged from 7.7 to 8.8% and was not different between flour blends with various proportions of waxy wheat flours.

Texture of Cooked White Salted Noodles Prepared from Reconstituted Flours

TPA parameters of cooked noodles prepared from flours of Madsen and Klasic, and their reconstituted flours with 11% protein, are listed in Table II. The hardness of cooked noodles prepared from reconstituted Madsen flour with 11% protein decreased significantly from 3.98 to 2.66 N as the proportion of waxy wheat starch in reconstituted flours increased from 0 to 20%. Salt strengthens the gluten in noodle dough and increases the firmness of cooked noodles (Rho 1986). The increase in cutting strength of cooked noodle dough as salt content increased from 2 to 4% was also reported by Jin et al (1989). However, the hardness of cooked noodles prepared from Madsen reconstituted flour with waxy wheat starch decreased, even though the amount of salt used increased because of their increased water absorption. A decrease in hardness value of cooked white salted noodles with reduced amylose content adjusted by waxy corn starch was reported by Toyokawa et al (1989). The springiness of cooked noodles prepared from reconstituted Madsen flour did not exhibit differences as the waxy wheat starch proportion increased, suggesting that starch composition had little influence on the springiness of white salted noodles. The close relationship between springiness of cooked white salted noodles and protein content of flour was reported by Yun et al (1996). The cohesiveness of cooked noodles prepared from reconstituted Madsen flour increased from 0.653 to >0.670 when 12 to 20% of waxy wheat starch was incorporated in the reconstituted Madsen flour.

Similar to the TPA parameters of noodles prepared from reconstituted Madsen flour, there were significant decreases in hardness, no changes in springiness and increases in the cohesiveness of cooked white salted noodles prepared from reconstituted Klasic flour with incorporation of waxy wheat starches. Compared to the corresponding wheat flours, reconstituted flours without waxy starch produced softer textured noodles in Madsen, but harder noodles in Klasic. The increased hardness of cooked noodles prepared from reconstituted Klasic flour could be due to an additional sheeting of noodle dough during noodle preparation. Hard white wheat cv. Klasic has relatively strong protein and probably formed a much stronger protein network than soft wheat cv. Madsen with the additional sheeting.

Adding waxy wheat starch to the prime starch portion of reconstituted Klasic flour resulted in a significant reduction in the hardness of cooked noodles, from 8.65 to 4.44 N with waxy I wheat starch. The cohesiveness value of cooked noodles prepared from reconstituted Klasic flour with waxy starch ranged from 0.629 to 0.650, exhibiting higher values in noodles with waxy wheat starch.

The TPA parameters of cooked noodles prepared from reconstituted Madsen flours with 13% protein are presented in Table II. The TPA parameters of noodles with 13% protein showed similar trends to the TPA parameters of cooked noodles prepared from reconstituted Madsen flour with 11% protein content. As the proportion of waxy wheat starch in reconstituted Madsen flour increased, hardness of cooked noodles decreased. The reconstituted flours with waxy wheat starch produced noodles with lower hardness and higher cohesiveness than the reconstituted Madsen flour without waxy wheat starch. There were no significant differences in springiness of cooked noodles.

Hardness of reconstituted Madsen flour without waxy starch increased from 3.98 to 5.90 with an increase in protein content from 11 to 13% (Table II). Even with 26% waxy I starch, hardness of noodles with 13% protein (4.23 N) remained higher than that of noodles of 11% protein without waxy starch (3.98 N). The hardness of reconstituted flour of 11% protein was always higher in Klasic than in Madsen, regardless of waxy starch substitution. These results indicate that both protein content and quality of flour impart significant influence on hardness of cooked noodles along with starch properties.

Texture of Cooked White Salted Noodles Prepared from Flour Blends

TPA parameters of cooked noodles prepared from Madsen flour, the two waxy wheat flours and the blends of Madsen flour and two waxy wheat flours are listed in Table III. The protein content of the two waxy wheat flours (17.8 and 16.4%) was much higher than that of Madsen flour (10.5%). Higher flour protein content contributes to a higher hardness value of cooked noodles (Oh et al 1985b; Baik et al 1994; Yun et al 1996). Although the protein content of waxy wheat flours was much higher than that of regular wheat flour, noodles prepared from waxy wheat flour were much softer than those prepared from regular wheat flours. Accordingly, the hardness of cooked noodles prepared from blends of flours decreased significantly with the addition of waxy wheat flour, even though the protein content of flour blends increased. These results suggest that the expected increase in the hardness of cooked noodles due to the increase in protein content of flour blends can be reversed by the decrease in starch amylose content. No significant difference was observed in the springiness of cooked noodles prepared from Madsen flour, Waxy I flour or Waxy II flour. The springiness of cooked noodles prepared from blends of flours also did not exhibit differences, ranging from 0.884 to 0.917. The cohesiveness of cooked noodles prepared from waxy wheat flours was higher than noodles prepared from Madsen flour. However, there were no differences in the cohesiveness of noodles prepared from blends of flours.

Correlation Between Starch Properties and TPA Parameters of Cooked White Salted Noodles

The correlation coefficients between starch properties and TPA parameters of cooked noodles prepared from reconstituted Madsen flours with 11% protein are listed in Table IV. Amylose content of starch in reconstituted Madsen flour was positively correlated with hardness of cooked noodles prepared from reconstituted Madsen flours with a wide range of starch amylose content (11.0 to 20.2%) ($r = 0.918$, $P < 0.01$). A negative correlation was observed between amylose content of starch and cohesiveness of cooked white salted noodles ($r = -0.865$, $P < 0.05$). Toyokawa et al (1989) prepared white salted noodles from flours containing corn starches of various amylose content and reported a positive correlation between amylose content of flour and hardness of cooked white salted noodles in sensory tests. Peak viscosity of starch exhibited a negative relationship with hardness, but a positive relationship with cohesiveness of noodles at the 10% significance level. Breakdown viscosity of starch was negatively correlated with hardness ($r = -0.817$, $P < 0.05$) and cohesiveness ($r = -0.776$, $P < 0.05$) of cooked white salted noodles prepared from reconstituted Madsen flour. High amylograph peak viscosity and breakdown have been reported to be negatively correlated with white salted noodle hardness, which is regarded as a desirable eating quality of white salted noodles (Nagao et al 1977; Moss 1979; Oda et al 1980; Crosbie 1991; Konik et al 1992; Crosbie et al 1992; Yun et al 1996). Amylograph setback of starch in reconstituted Madsen flour was positively correlated with hardness ($r = 0.767$, $P < 0.05$) and negatively correlated with cohesiveness ($r = -0.777$, $P < 0.05$). Hardness of noodles prepared from blends of regular and waxy wheat flours correlated positively with amylose content and setback,

and negatively with peak viscosity and breakdown (Table IV), even though the protein content of flour blends increased as the proportion of added waxy wheat flour increased. There was a negative relationship between protein content of flour blends and hardness of noodles ($r = -0.915$, $P < 0.001$), indicating that the effect of protein content on hardness of cooked noodles was nullified or at least significantly diminished by changes in starch amylose content. Accordingly, wheat flours with protein content much higher than 10% can still produce soft textured white salted noodles when amylose content of starch is reduced. Springiness of noodles exhibited no relationship with parameters of starch properties. In contrast to hardness, cohesiveness of noodles correlated negatively with amylose content and positively with peak viscosity of starch.

CONCLUSIONS

Reconstituted flours and flour blends with decreased amylose content require more water for making noodles compared to regular wheat flour. As wheat flour contains <23% amylose, noodles become softer and more cohesive compared to noodles produced from wheat flours with regular starch. Springiness of cooked noodles is not affected by the amylose content of starch. There exist strong correlations between TPA parameters of cooked noodles and amylose content and pasting properties of starch. White salted noodles with soft texture and high cohesiveness can be produced from wheat flours with reduced amylose content.

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