Noodles. II. The Surface Firmness of Cooked Noodles from Soft and Hard Wheat Flours[1]

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ABSTRACT

Surface firmness of cooked noodles was determined by applying an increasing compressive force to the surface of cooked noodles and measuring the initial slope of the force-distance curve. The steeper the slope, the firmer the surface. The coefficient of variation of the method was less than 7%, and the instrument data agreed with the subjective assessment of surface firmness by an untrained taste panel ($r = 0.89$, $P < 0.01$). Surface firmness increased with increased rest time of the mixed dough prior to sheeting, increased rate of reducing dough thickness, decreased cooking time, and substitution of deionized water for tap water during cooking. The high pH of tap water was mainly responsible for its detrimental effect on surface firmness.

Cereal Chem. 62(6):431–436

The eating quality of cooked noodles depends largely on their firmness, resilience, and surface characteristics. Several instrumental methods have been developed to measure the firmness and resilience of cooked noodles and pasta (Matsuo and Irvine 1971, Oh et al 1983, Walsh 1971). The surface stickiness of cooked pasta has also been measured by instrumentation (D'Egidio et al 1982, Dexter et al 1983a, Voisey et al 1978). Dexter et al (1983b) reported that cooked pasta showed a wide variation in stickiness that was influenced not only by wheat cultivar but also by the noodle drying process, quality of cooking water, cooking time, and elapsed time after cooking. Unlike pasta, which is normally eaten in dishes containing limited water, oriental noodles are often eaten in a water-rich condition, such as soup. Thus, surface stickiness may be less critical in cooked noodles than in pasta, but surface firmness and smoothness are important in noodles. Accordingly, we report here a method using instrumentation to determine the surface firmness of cooked noodles.

MATERIALS AND METHODS

Noodles

Noodle samples IV–VI (Table I) were commercial dry noodles obtained from Japan, Korea, and Singapore. Dry noodles I–IV (Table I) were prepared in our laboratory by the method of Oh et al (1983) from two soft (one soft red winter and one U.S. Western white) and from two hard red winter wheat flours having 9.8–10.2% and 13–13.3% protein, respectively. Absorption for noodlemaking was determined from the handling characteristics of a dough. Too much water gave a sticky dough that stretched excessively during handling, but too little water gave a stiff dough that resisted sheeting. Handling and sheeting differences in a dough were readily detectable when absorption varied one percentage point above or below optimum.

Laboratory noodles were made using a roll speed of 10 rpm (roll diameter, 18 cm) and a reduction in roll-gap setting of 15%. The roll gap was reduced stepwise from 5.5 mm to 1.3 mm for all noodles. In some experiments, roll speed was varied between 4 and 20 rpm with reduction set at 30% in each sheeting step. In other experiments, the roll speed was set at 8 rpm, and the reduction percentage and the number of sheeting steps were varied. At 10, 20, 30, 40, and 50% reduction, 13, 6, 4, 3, and 2 sheeting steps, respectively, were used. There was no resting period between sheeting steps, and dough was sheeted in the same direction each time.

Cooking and Sample Preparation for Instron Testing

Noodles (10 g) were cooked in 1,000 ml of tap water or deionized water. After each minute of cooking, noodles were removed and squeezed between transparent plates. Noodles were cooked until the white core disappeared; this was the cooking time. Cooking loss was determined by evaporation of an aliquot (900 ml) of the cooking water. The proportion of solids lost during cooking was calculated on a bone-dry basis. Cutting stress was determined as previously described (Oh et al 1983).

The deionized water was obtained by distillation followed by passage through a Sybron/Barnstead column (Barnstead Co., Boston, MA) fitted with a high-capacity ion-exchange resin and a charcoal column. The mineral contents of deionized and tap water were determined using a Perkin-Elmer atomic-absorption spectrophotometer (model 460, Perkin-Elmer Corp., Oak Brook, IL). The tap water was from the municipal water treatment plant, where lime had been added at the level of 0.18 g/L. Tap water had a pH of 9.2 and total titratable alkalinity of 0.63 meq/L.

In some cooking experiments, a series of 1 m*M* Tris (hydroxymethyl) aminomethane phosphate buffers with pH 6–10 were used as cooking water. After cooking, the pH of the buffer solutions varied less than 0.2 units from their initial pH, except for a 0.5-unit decrease of the pH 10 buffer solution. In other experiments, calcium and magnesium salts, in the form of chloride, sulfate, or acetate, were added to deionized water containing 1 m*M* sodium bicarbonate. The pH was adjusted to 9.2 by adding 0.1 *N* NaOH. After cooking, the pH of the cooking water varied from 8.9 to 9.3.

Surface Firmness

The Instron Universal Testing Instrument (model 1130, Instron Corp., Canton, MA) was fitted with a 2,000-g compression cell and a blunt blade (Oh et al 1983). The crosshead and chart speeds were 1 cm/min and 50 cm/min, respectively. Cooked noodles were cooled in running tap water for 1 min, drained; and one noodle strand was placed on an aluminum sample holder and covered with polyethylene film for 2 min before testing firmness. The sample holder was fitted with a ruled surface (finest divisions 0.5 mm) to determine the width of the noodle strand estimated to the nearest 0.1 mm. Excess water on the surface of the noodle was wiped off gently with the finger tip. In some experiments, cooked noodles were placed in polyethylene bags and stored at 25°C for different periods of time. Approximately 3 min before testing, a noodle strand was removed from the bag, placed on the sample holder, and covered for 2 min before testing as before.

An increasing compressive force was applied to the surface of one noodle strand by the blunt blade (3.5-mm wide). The blade compressed the noodle by no more than 10% of its thickness. After three compressions on one strand, a second noodle strand was tested in an identical manner. The force on the noodle surface was calculated using the contact area, and from the force-distance curve the initial compression slope was determined as an index of surface

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firmness. The slope was calculated from a line connecting the initial point where noodle contact began (A in Fig. 1) to the point on the curve where the force registered 60 g/cm^2 (B in Fig. 1). The dry noodle sample was cooked a second time and two more noodle strands compressed. From the total of 12 slope measurements, the mean was reported as surface firmness in units of g/mm.

Taste Panel

The surface firmness of cooked noodles was evaluated by five Asian graduate students who were accustomed to eating noodles. The panelists were coached on the characteristics of noodle surfaces and on the method of scoring. The seven noodle samples (Table I) were randomly coded and cooked simultaneously to optimum. After cooling and rinsing, a serving (20 g) was placed in a small cup and evaluated at room temperature. Panelists were advised that a firm surface has a smooth and solid mouthfeel without mushiness. The panelist scored samples by placing a mark on a structured line scaled from 1 to 10, with 10 being the most firm and smooth. Noodle II in Table I was identified as the reference and given an arbitrary score of 5 for surface firmness.

Scanning Electron Microscopy

Cooked noodle samples were quick-frozen in isopentane cooled in liquid nitrogen. Frozen noodles were dried in an Edward tissue freeze-drier (Edward High Vacuum Inc., Grand Island, NY) at −60° C. Specimens were attached to stubs with silver paste and coated under vacuum with approximately 6 nm of carbon and then with 10 nm of gold-palladium. The surface and the cross section of the specimen were examined with an ETEC U-1 Autoscan scanning electron microscope (Perkin-Elmer Electron Beam Technology, Hayward, CA) operating at 10 kV, and a representative area was photographed on Polaroid film, type 55.

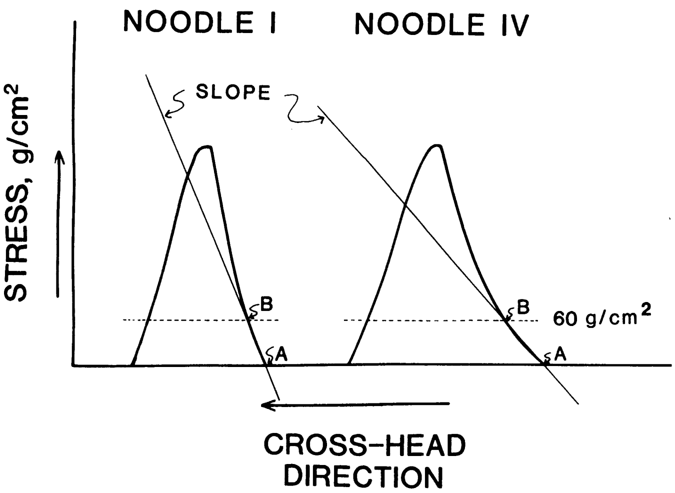

Fig. 1. Instron force-distance curves for noodle samples I and IV. **A** is the point of initial contact of the blade; point **B** is where the curve intersects 60 g/cm^2 of compression stress.

RESULTS AND DISCUSSION

Dry noodles are a class of oriental noodles having the simplest formula and method of preparation (Oh et al 1983). Dry noodles contain flour, water, and sodium chloride, and are prepared by mixing, resting, sheeting, cutting, and drying. The characteristics preferred in dry noodles are a white appearance, minimum disintegration during cooking, and a smooth surface without mushiness. The chewiness preferred in the cooked noodle depends on regional preferences; the Chinese often prefer strong chewy noodles, and the Japanese eat large amounts of soft noodles.

In this work, the optimum cooking times for dry noodles in tap water, as determined by visual disappearance of the white noodle core, were 10–12 min and 14 min for the laboratory-made noodles from the two soft and the two hard wheat flours, respectively, and 7–10 min for the three commercial noodles (Table I). The optimum cooking times were reproducible to the nearest minute, since noodles were removed and tested each minute during cooking.

Two typical force-distance curves used to determine surface firmness are shown in Figure 1. The optimally cooked noodle from hard wheat flour IV gave an Instron surface firmness of 28 g/mm, compared to 54 g/mm for the noodle from soft flour I. Thus, the surface of noodle IV was softer than that of noodle I, even though noodle IV had a higher internal strength than that of noodle I as measured by cutting stress (29 g/mm^2 for noodle IV and 26.5 g/mm^2 for noodle I, Table I). In Figure 1 surface firmness could also have been determined from the compression distance at 60 g/cm^2; however, the magnitude of difference for compression distance was less than that for slope.

The determination of surface firmness of noodles by the compression slope on the Instron was reproducible. Noodle samples I and IV were cooked 10 times in both tap water and deionized water. The coefficient of variation was 6.2% in deionized water and 6.8% in tap water.

When the measured surface firmness of cooked noodles was compared with the sensory evaluation, the surface firmness measured by the Instron showed a significant positive correlation with sensory firmness ($r = 0.89$, $P < 0.01$). Table I summarizes the experimental data, which indicate that the instrument was measuring surface firmness as perceived by the human palate.

The surface of noodles from soft and hard wheats was examined by scanning electron microscopy (SEM) at different cooking times. The photomicrographs of the rolled surfaces revealed smooth and

TABLE I
Surface Firmness of Noodles Cooked to Optimum

Noodle	Protein (%, db) Flour	Protein (%, db) Cooked Noodle	Cooking Time (min)	Cooking Loss (%)	Cutting Stress[a] (g/mm^2)	Surface Firmness[a] Deionized Water (g/mm)	Surface Firmness[a] Tap Water (g/mm)	Surface Firmness[a] Sensory Evaluation[b]
I[c]	10.2	10.0	12	6.8	26.5	71	54	7.3
II[c]	9.8	9.4	10	6.5	22.3	59	44	5.0
III[c]	13.0	13.5	14	6.7	30.5	55	38	3.0
IV[c]	13.3	13.4	14	6.6	29.0	44	28	2.2
V[d]	···	10.8	7	6.6	28.0	53	40	4.3
VI[d]	···	11.4	10	7.3	27.0	65	50	4.5
VII[d]	···	9.6	9	7.6	25.5	60	43	4.0
LSD[e] ($P = 0.05$)	···	···	···	···	1.7	2.2	2.7	0.4

[a] Cutting stress values are means of triplicate Instron measurements. Surface firmness values are means of 12 measurements.
[b] Noodles used for sensory evaluation were cooked in tap water. Sensory firmness scale was 1–10, with 10 the firmest value.
[c] Noodle I made from soft red winter wheat flour, Mennel Milling Co., Fostoria, OH; noodle II made from U.S. Western white flour, Fisher Mills Inc., Seattle, WA; noodle III made from hard red winter wheat flour, Ross Industries, Wichita, KS; noodle IV made from hard red winter wheat flour, Kansas State University pilot mill, Manhattan.
[d] Commercial noodle.
[e] Least significant difference. Difference between two means exceeding this value are significant.

rough areas (Fig. 2) as first reported for Japanese noodles by Dexter et al (1979). In general, the cooked surface of the two soft wheat noodles was smoother and firmer than that of the two hard wheat noodles. This difference is only in part a result of the shorter cooking time for soft wheat noodles. Noodles I and IV represent the extreme differences in surface firmness found between soft and hard wheat noodles. Pitting of the rolled surface of noodle IV increased with cooking time until the severely eroded zones covered over 90% of the noodle surface at optimum cooking (14 min). At the other extreme, pitting of the surface of the soft wheat noodle (I) was only 40% at optimum cooking (12 min), and after 15 min cooking only approximately 60%. An SEM cross-sectional view of

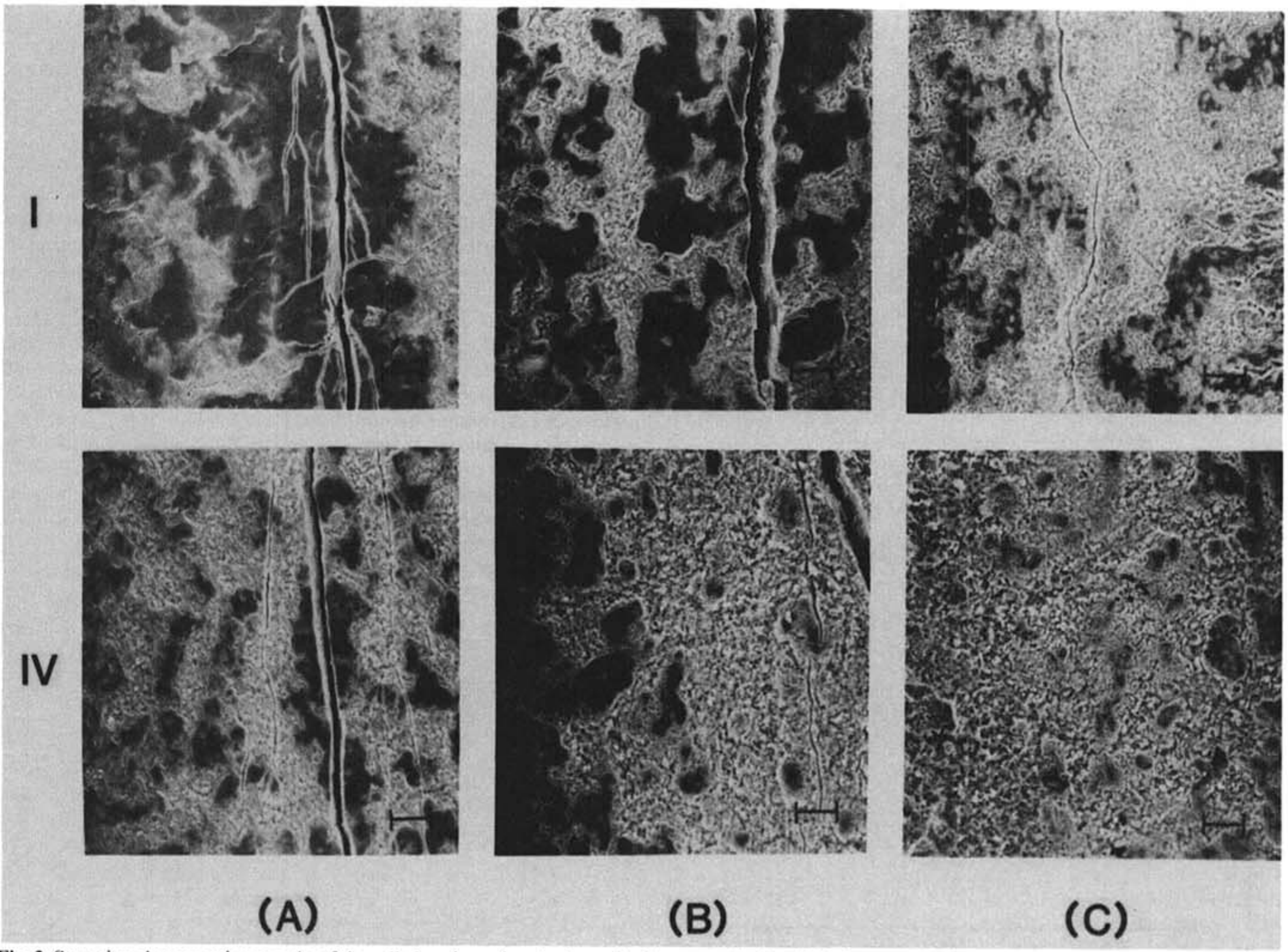

Fig. 2. Scanning electron micrographs of the rolled surface of cooked noodles from samples I and IV after cooking for 5 min (**A**), 10 min (**B**), and 15 min (**C**). Scale bar indicates 200 μm.

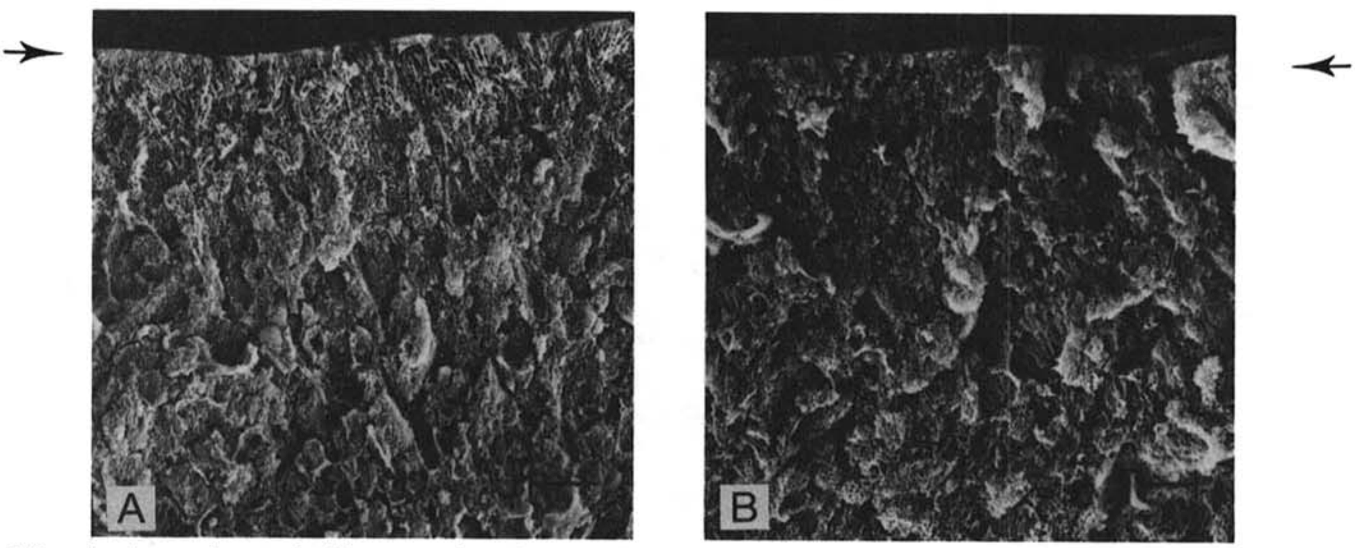

Fig. 3. Scanning electron micrographs of the cross sections of noodles I (**A**) and IV (**B**) cooked for 10 min. Arrows indicate the rolled surface of the noodle. The cross-sectional fracture was made after the samples were freeze-dried. Scale bar indicates 20 μm.

the noodles after cooking 10 min confirmed the minimal erosion at the surface of the soft wheat noodle (Fig. 3A) compared to the hard wheat noodle (Fig. 3B).

The differences between noodles in surface firmness was not caused by differences in cooking loss (Table I). Protein strength has been suggested as a possible cause for the difference in surface integrity of cooked pasta by Dexter et al (1981). They proposed that strong gluten in pasta may give a more rigid, less flexible structure than weak gluten, and that such a structure would be more susceptible to rupture under the stresses of swelling and protein denaturation during cooking (Dexter and Matsuo 1979, Wasik 1978). It has also been suggested that denaturation of a thin protein film during high-temperature drying of pasta might improve surface stability during cooking (Dexter et al 1978, 1983a).

Another hypothesis, which we support, is that surface firmness depends on the degree of gluten development in the noodle (Dexter et al 1979). In noodlemaking, absorption is low and mixing and sheeting times are fixed. It seems likely that the degree of gluten development varies for different flours. Irvine et al (1961) showed that low-protein semolina and a soft white farina required longer mixing for dough development at 26–36% absorption than high-protein semolina. Finney and Shogren (1972) also demonstrated that a low-protein (<12%) bread flour required longer mixing for development than a high-protein flour of equal quality. In our work, noodle I was made from a soft red winter wheat flour of 10.2% protein, whereas noodle IV was made from a hard red winter wheat flour of 13.3% protein. The gluten matrix in noodle IV may have been more developed than that in noodle I. Dexter et al (1979) found more gluten development in noodles made from a durum flour (9.1% protein) than in those from a blend of soft wheat and Australian standard white. The durum noodle had poor cooking quality. Pasta doughs lack full development (Matsuo et al 1978).

During cooking of hard wheat noodle IV, the bond between surface starch and protein is weakened in excess hot water, but the bond between surface protein and the remaining developed protein matrix stays strong. The surface starch (especially damaged starch,

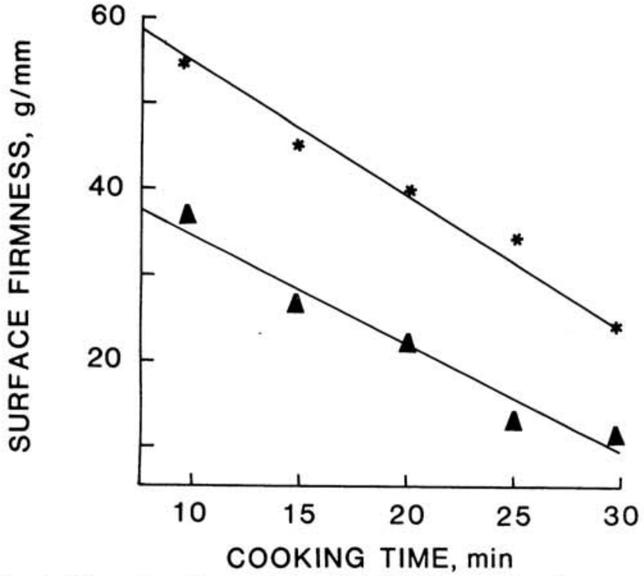

Fig. 4. Effect of cooking period at 98 ± 0.5° C on surface firmness of noodles. * = Sample I, and ▲ = sample IV.

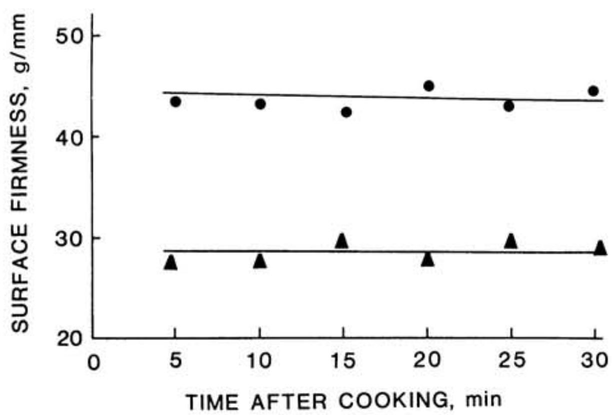

Fig. 5. Effect of holding time after cooking (25° C) on surface firmness of noodles cooked to optimum. • = Sample II, and ▲ = sample IV.

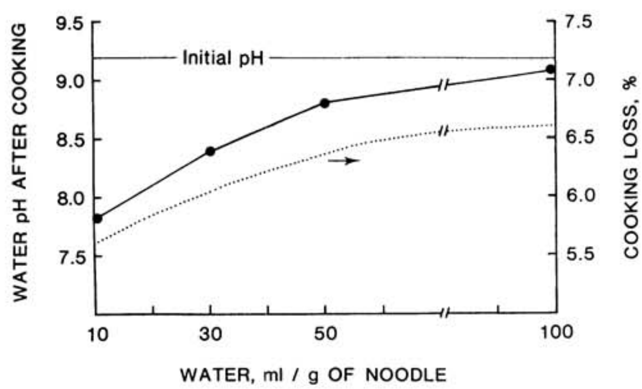

Fig. 7. Effects of varying proportions of cooking water volume to noodle weight on the water pH after cooking and cooking loss. • = Water pH, and · · · · = cooking loss.

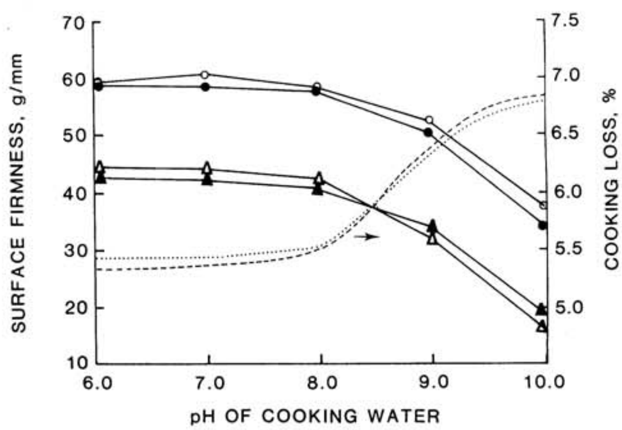

Fig. 6. Effect of cooking water pH on surface firmness and cooking loss of noodles cooked to optimum. Surface firmness: o = sample II, and Δ = sample IV cooked in deionized water. • = Sample II, and ▲ = sample IV cooked in tap water. Cooking loss: · · · · = sample IV in tap water, and ---- = sample IV in deionized water.

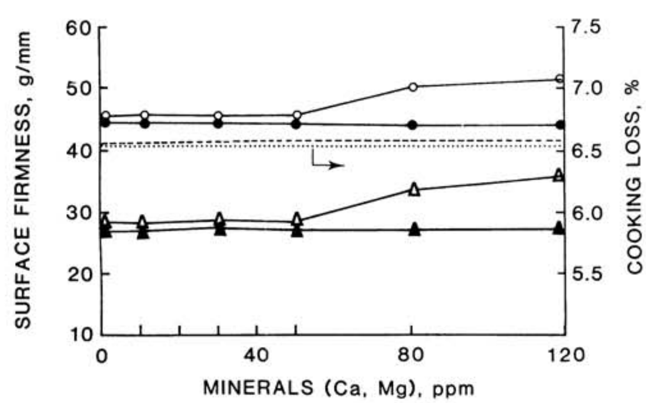

Fig. 8. Effect of calcium and magnesium in cooking water on surface firmness and cooking loss of noodles cooked to optimum. Surface firmness: o = sample II and Δ = sample IV cooked with added calcium; • = sample II and ▲ = sample IV cooked with added magnesium. Cooking loss: · · · · = sample IV with added calcium and ---- = sample IV with added magnesium.

Oh et al 1985b) is etched away, leaving behind the denatured protein matrix. The pitting of cooked noodles, as shown by SEM (Fig. 2), may be due to erosion of surface starch. The voids between the surface proteins of cooked noodle IV fill with water, which decreases surface firmness. The gluten-rich surface of noodle IV feels less smooth to the palate and more watery and mushy than when the noodle surface is coated with a starch paste. When gluten is not fully developed, as in noodle I, solids eroded from the surface are chunks of protein and starch, because the gluten matrix is poorly developed. The remaining surface still contains swollen, gelatinized starch. Table I shows that the protein content of cooked noodle IV did increase slightly, whereas that of noodle I decreased. The influence of gluten development on surface firmness should be examined further.

The surfaces of soft wheat noodle I and hard wheat noodle IV became softer with increasing cooking time (Fig. 4). Because thick noodles require longer cooking, it is prudent to make noodles thin to improve surface characteristics of cooked noodles. This fact may be particularly important in using hard wheat flours for noodles, because hard wheat noodles require longer cooking than soft wheat noodles of the same thickness.

In contrast to internal firmness (cutting stress) of cooked noodles (Oh et al 1983) or pasta (Voisey et al 1978), both of which decreased with holding time after cooking, the surface firmness of cooked noodles did not change with holding time (Fig. 5). The internal strength of noodles, as measured by the Instron, appears to depend on the resistance of the noodle core to cutting or compressing. At optimum cooking time, the core has been cooked in limited water, so the noodle gives a high cutting stress. As the noodle rests after cooking, water migrates into the core of the noodle, and the noodle's cutting stress declines.

In contrast to the core of the noodle, the noodle surface is always exposed to excess water during cooking and resting. The starch and other polymers on the surface swell relatively unimpeded, and any moisture migrating from it towards the core is apparently replenished by water vapor in the container. As a result, the surface firmness is not affected by holding up to 30 min after cooking.

Noodles cooked in deionized water had a firmer surface than those cooked in tap water (Table I). The soft surface of noodles cooked in tap water was related mainly to the high pH of tap water. When noodles were cooked in 1 m*M* Tris buffer, the surface firmness of the cooked noodle was not affected between pH 6 and 8 but decreased rapidly above pH 8 (Fig. 6). Cooking loss showed a trend opposite to surface firmness. At pH 6–8 cooking loss remained unchanged, but it increased rapidly above pH 8. Deionized and tap water showed the same trends in surface firmness and cooking loss. These data indicate that the alkalinity of the local tap water, pH 9.2 (Table II), was responsible for the lower surface firmness of the noodles cooked in tap water. The swelling and dispersion of starch granules at an alkaline pH, as well as the possible swelling of gluten, would accentuate the erosion of starch from the noodle surface.

The pH of tap water and cooking loss after cooking were affected by the ratio of cooking water to noodles. Figure 7 shows that the cooking water pH and the cooking loss decreased as the ratio of cooking water to noodles decreased. When the ratio exceeded ~100 ml of cooked water per gram of noodle, pH and cooking loss remained constant.

Calcium and magnesium ions at pH 9.2, and at the concentration found in local tap water (Table II), had little effect on surface firmness and cooking loss (Fig. 8). Addition of sodium to the cooking water was not tested because the noodle contained 2% sodium chloride. Acetate, chloride, and sulfate forms of the mineral ions made little difference in surface firmness. When the concentration of calcium in the cooking water was greater than 80 ppm, the surface firmness of the cooked noodle increased. Calcium salts are known to increase the structure of water and thereby decrease the swelling of starch (Gough and Pybus 1973). Calcium salts also have an appreciable "tightening" effect on bread doughs (Ponte 1971).

Dough Sheeting and Resting

The effects of roll speed and reduction percentage in roll gap on surface firmness were examined. Figure 9 shows that surface firmness increased as the roll speed decreased, while firmness increased with increased reduction percentage at a constant roll speed. Surface firmness as affected by sheeting is discussed in more detail by Oh et al (1985a).

Resting dough before sheeting is known to improve dough sheeting properties by allowing uniform moisture distribution and mellowing of wheat gluten, especially below pH 7 (Terada et al 1978). Figure 10 shows that an initial resting period of up to 1 hr increased surface firmness. At the same time, noodle thickness did not change (data not shown). Thus, even after prolonged resting, noodles made from hard wheat flour IV always gave a softer surface after cooking than noodles made from soft wheat flour II. The excess softening of the noodle surface made from hard wheat flour IV could not be corrected by lengthening the dough rest time.

TABLE II
Properties of Deionized and Tap Water Used in Cooking Noodles

Property	Deionized Water	Tap Water
Conductivity (mS/cm)	75.5	2.5
pH	4.5	9.2
Na (ppm)	0.01	29.0
K (ppm)	0.01	6.3
Ca (ppm)	0.025	36.0
Mg (ppm)	0.02	10.0

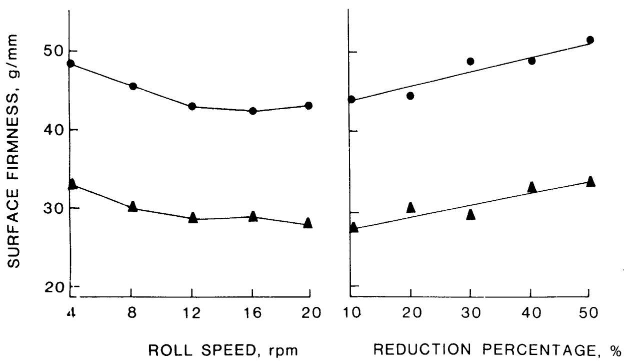

Fig. 9. Left: Effect of roll speed on surface firmness of noodles cooked to optimum. A reduction percentage of 30% was used for all roll speeds. **Right:** Effect of reduction percentage in roll gap on surface firmness of noodles cooked to optimum. The roll speed was 8 rpm at all reduction percentages. ● = Sample II, and ▲ = Sample IV.

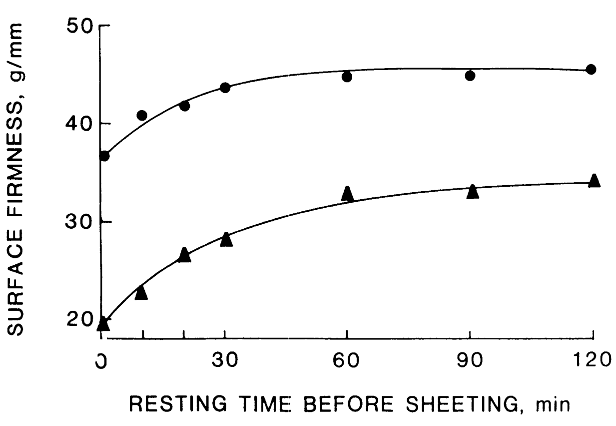

Fig. 10. Effect of dough resting period before sheeting on surface firmness of noodles cooked to optimum. ● = Sample II, and ▲ = Sample IV.

ACKNOWLEDGMENT

We thank the Kansas Wheat Commission for financial support.

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[Received November 13, 1984. Revision received March 19, 1985. Accepted March 26, 1985.]