Rheological Properties of White Salted Noodles with Different Amylose Content at Small and Large Deformation

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ABSTRACT

Cereal Chem. 81(2):226–231

The rheological properties of cooked white salted noodles made from eight wheat cultivars with varied amylose content were analyzed at small and large deformation. Their dynamic shear viscoelasticity was measured using a rheometer with parallel plate geometry. Compressive force and creep-recovery curves were measured using various probes and sample shapes. Noodles with lower amylose content showed a lower storage shear modulus (G') and a higher frequency dependence of G'. The G' values of noodles were highly correlated with amylose content in wheat flour and with G' values of 30 and 40% starch gels. Remarkable differences in the characteristics of creep-recovery curves were observed between cultivars. The difference in amylose content in wheat flour reflected the creep–recovery properties of noodles. A negative correlation was demonstrated between amylose content and both maximum creep and recovery compliance. The compressive force required for 20, 50, 80, and 95% strains was compared. At 20 and 50% strain, noodles made from lower amylose wheat flour showed lower compressive force. Noodles of waxy wheat had a higher compressive force than nonwaxy noodles when the strain was >80%, indicating the waxy wheat noodles are soft but difficult to completely cut through.

White salted noodles are referred to as udon and are a popular wheat food in Japan. Wheat quality requirements for white salted noodles are bright and creamy color, smooth and glossy surface appearance, soft texture with a slight surface firmness, and elasticity (Crosbie et al 1998). Texture is probably the most important criteria for judging the eating quality of noodles. Starch is the main component of wheat flour and its properties are important to the quality of white salted noodles (Oda et al 1980; Toyokawa et al 1989a,b). Most starch consists of the polysaccharide molecules amylose and amylopectin. The ratio of amylose to amylopectin affects the physicochemical properties of starch (Parovuroi et al 1997; Fredikson et al 1998; Yuryev et al 1998; Sasaki et al 2000). Wheat flour with lower amylose content was reported to be suitable for making noodles with better eating quality (Oda et al 1980). Zhao et al (1998) indicated that the granule-bound starch synthase (GBSS) in the starch granules of wheat flour was related to the noodle quality. However, Batey et al (1997) reported a nonlinear relationship between amylose content and noodle quality. A clear relationship between amylose content and noodle quality has not been demonstrated. Wheat flour with varying levels of amylose content is required for testing. Several waxy wheats, lacking three waxy proteins (Wx-A1, Wx-B1, and Wx-D1), were produced by cross-breeding or mutation (Nakamura et al 1995; Yamamori et al 1995; Kiribuchi-Otobe et al 1997; Yasui et al 1997; Zhao and Sharp 1998; Morris and Konzak 2001). Moreover, in recent years, several low-amylose cultivars lacking two waxy proteins (Wx-A1 and Wx-B1) have been released for making white salted noodles. Because of these developments, wheat flour with a wide range of amylose content is available.

Texture of white salted noodles is evaluated using sensory assessment and instrumental tests. Sensory assessment is subjective, and evaluation varies with panel members because of individual preferences. Instrumental texture analysis is useful to study the various noodle qualities of wheat flour materials and requires a much smaller sample quantity than sensory assessment. Some instrumental methods have been used to estimate noodle texture. For measurement of noodle firmness, a large deformation measurement is usually used (Oh et al 1983; Edwards et al 1993; Epstein et al 2002; Park et al 2003). The viscoelastic properties of noodles are analyzed using a dynamic mechanical test at small deformation to study the fundamental linear viscoelastic properties (Shimizu et al 1958; Edwards et al 1996; Bejosano and Corke 1998; Hatcher et al 2002). The creep-recovery method is a simple approach for measuring the rheological properties of dough, but there is little information about creep-recovery properties of cooked noodles. The rheological properties of noodles can differ in scale and type of deformation. Rheological properties at large deformation are considered to be related to masticatory impression, whereas properties at small deformation are related to the initial perception of the palate (Sherman 1969). However, there is little information about the relationship between rheological parameters measured by each method. In the present study, the dynamic viscoelasticity of cooked noodles was measured under shear deformation, and both creep-recovery and compression tests were conducted under uniaxial compression. The objective of this study was to determine the relationship between amylose content and rheological properties of white salted noodles made from wheat flour with different amylose content. We compared the various rheological parameters of cooked noodles with a wide range of amylose content at both small and large deformation.

MATERIALS AND METHODS

Samples

Two waxy wheat lines (*Triticum aestivum* L.), Tanikei H1881 and K107Wx2, and six nonwaxy lines, Norin 61, Bandouwase, Kanto 107, Kanto 117, Kanto 119, and Kanto 122 were grown during 1999-2000 at the National Agriculture Research Center, Tsukuba, Japan. Norin 61 and Bandouwase have three waxy proteins. Kanto 107, Kanto 117, Kanto 119, and Kanto 122 lack Wx-A1 and Wx-B1 proteins and are called low-amylose lines in this study. Tanikei H1881 and K107Wx2 have no waxy proteins.

Milling

Wheat grains were tempered overnight to 14% moisture on a dry basis and then milled using a test mill (Quadrumat Jr. Brabender, Duisburg, Germany) with a 70GG mesh sieve. Protein content (N × 5.7) was determined using a nitrogen/protein determinator (FP-528, Leco Co.). Amylose content was determined by the method of Gibson et al (1997) using an amylopectin-amylose

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Publication no. C-2004-0129-05R.

assay kit (Megazyme Int. Ireland Ltd.) after isolating starch using the dough-ball method of Wolf (1964). α-Amylase activity in wheat flour was determined by the method of McCleary and Sheehan (1987) using an α-amylase assay kit (Megazyme); one unit of activity was defined as a Ceralpha Unit.

Preparation of White Salted Noodles

White salted noodles were made from 150 g (13.5% wb) of flour by adding 60 mL of 5% (w/v) NaCl solution. Mixing was done with a mixer fitted with a flat beater (N-50, Hobart Co., Troy, OH) on low speed for 10 min. The mixed dough was sheeted through the rolls of a pasta machine (Imperia, Italy) with initial gap setting of 3.66 mm. After the first pass, the noodle sheet was folded and passed twice through the rollers at this same setting. The dough was then sheeted three times at successively reduced gap setting of 3.34, 2.84, and 2.21 mm. The dough sheet was then cut into disks 20 and 35 mm in diameter and a strip 4 × 40 mm. After the raw noodles were placed in a covered container for 30 min, the noodles were cooked for 15 min in 400 mL of boiling water with continuous stirring. The cooked noodles were then placed in cold water for 1 min and used for rheological analysis after draining.

Noodle Rheological Properties

The dynamic viscoelasticity of cooked noodles was measured using a rheometer (RheoStress RS75, Haake, Germany) with parallel plate (35 mm in diameter). Cooked noodles were stored at 5°C for 1 hr, and cut again into disks 35 mm in diameter to fit the plate geometry of the rheometer. The disks were compressed until the force reached 0.5 N to define the measurement position. Dynamic viscoelasticity was measured in a frequency range of 0.01–10 Hz at 25°C and constant stress (50 Pa). At this stress level, all samples showed linear behavior in the preliminary stress sweep test. Silicone oil was applied to the exposed surfaces of the sample to prevent evaporation during the experiment. For comparing the dynamic viscoelasticity of cooked noodle and starch gel, 30 and 40% starch gels were prepared using isolated starches from the same samples and measured as described previously (Sasaki et al 2002).

A creep meter (Rheoner RE-33005, Yamaden Co. Ltd, Japan) equipped with a 2-kg load cell was used for compressive creep-recovery and compression measurements. Creep-recovery measurement was performed at 25°C using a disk-shaped probe (55 mm diameter). A noodle disk 20 mm in diameter was placed in the center of a base plate, and a uniaxial stress was applied to compress the noodles and maintained for 1 min. Compression speed of 10 mm/sec was used to give instantaneous stress to the sample. The stress was suddenly removed, and the noodles were allowed to recover for 1 min. The applied force was determined for a variety of samples as the deformation was maintained at <10%. At this level, all samples showed linear viscoelastic behavior in the preliminary stress sweep test. The applied static force of waxy wheat was 0.15 N, that of low amylose lines 0.49–0.69 N, and that of Norin 61 and Bandouwase was 1.96 N.

A compression test was performed at 25°C using a disk-shaped probe (55 mm diameter) and a blade probe with a constant surface of 3.5 × 50 mm. A disk 20 mm in diameter and a strip of cooked noodle 4 × 40 mm were placed in the center of a base plate and compressed by two types of probes. For the strip noodle, one and two strands were placed side-by-side and compressed by two types of probes. When using a blade probe, one or two strands of strip noodle were cut crosswise.

Cooked noodles were uniaxially compressed by a probe at a constant rate of deformation (1 mm/sec) to 99% of the original noodle thickness beyond the linear region. The force required for a definite strain was used for comparisons.

Statistical Analysis

Chemical properties of wheat flour were analyzed in duplicate. Rheological properties of cooked noodles were measured in triplicate or greater. The general linear model (SAS Institute, Cary, NC) was used to analyze data. Analysis of variance was conducted using Tukey's studentized range test at the 5% significance level.

RESULTS AND DISCUSSION

Flour Properties

Flour yields were 53.7–68.2%. Eight cultivars had a wide range of amylose content (Table I). The amylose content of starch isolated from two waxy wheat lines, Tanikei H1881 and K107Wx2, were 1.4 and 1.7%, respectively. Kanto 122 had a significantly lower amylose content than the other three low-amylose lines

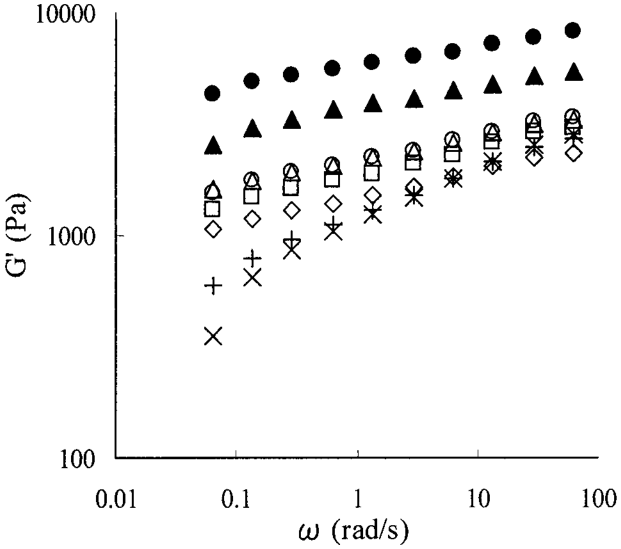

Fig. 1. Frequency dependence of storage shear modulus (G') of cooked noodles. Norin 61 (●), Bandouwase (▲), Kanto 117 (○), Kanto 107 (△), Kanto 119 (□), Kanto 122 (◇), Tanikei (×), k107Wx2 (+).

TABLE I
Amylose and Protein Content of Wheat Flour, and Dynamic Viscoelasticity for Cooked Noodles

Sample	Amylose (%)	Protein (%)[a]	G' (kPa)	G'' (kPa)	Tan δ[b]
Norin 61	27.7a[c]	12.2ab	4.86a	0.76a	0.159a
Bandouwase	27.6a	11.9a	4.33ab	0.69a	0.159a
Kanto 117	24.1b	12.3b	2.61bc	0.55a	0.212ab
Kanto 107	23.6bc	12.3b	2.61bc	0.52a	0.198ab
Kanto 119	22.8c	12.8cd	2.30bc	0.55a	0.240b
Kanto 122	18.5d	12.1ab	2.19bc	0.51a	0.233b
Tanikei H1881	1.7e	13.0d	1.76c	0.71a	0.405c
K107Wx2	1.4e	12.7c	1.79c	0.72a	0.405c

[a] 13.5% wb.
[b] G' storage shear modulus, G'' loss shear modulus, tan δ loss tangent.
[c] Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

(Kanto 117, Kanto 107, and Kanto 119). Norin 61 and Bandouwase with three waxy proteins showed similar amylose content. The protein content of wheat flour was 11.9–13.0% (13.5% wb). Protein content of wheat flours is an important factor in determining the properties of food products. Park et al (2003) reported that protein content of wheat flour correlated with hardness of noodles. However, a wide range of variation in the protein content was not found in these wheat flours (Table I). Wheat flour had an amylase activity range of 0.069–0.199 U/g. No sample exhibited high amylase activity.

Dynamic Viscoelasticity of Cooked Noodles

Table I showed the storage shear modulus (*G′*), loss shear modulus (*G″*) and loss tangent (tan δ) of cooked noodles. The values at 1 Hz were used for comparison. Noodles made from cultivars with three waxy proteins (Norin 61 and Bandouwase) showed the highest *G′*. Noodles of low-amylose lines exhibited a lower *G′* than lines with higher amylose content. Noodles of low-amylose lines also exhibited a higher *G′* than waxy lines. Noodles made from waxy lines had very soft textures and showed very low *G′* compared with that of other cultivars. *G′* values of noodles correlated with amylose content in wheat flour ($r = 0.72^*$). Keetles et al (1996) suggested that breakdown of the amylopectin matrix severely weakens the granule structure and results in softer starch gels when heated with water. On the other hand, amylose helps reduce loss in the granular rigidity of swollen starch granules (Hermansson and Svegmark 1996). Amylose plays a major role in forming a firm gel structure in cooked noodles, and the amylose content of wheat flour has a great influence on the elastic component of cooked noodles. Low-amylose lines showed comparatively lower G″; however, the significant difference of *G″* between different cultivars was not recognized. For tan δ (*G″*/*G′*), the values clearly differed in amylose content of wheat flour. Wheat flour with lower amylose content showed higher tan δ and the value of waxy lines was much higher. A large negative correlation was observed between amylose content and tan δ of noodles ($r = -0.99^{**}$). Tan δ describes the ratio of the viscous to elastic fraction (Kulicke et al 1996). This indicates that the amylose content in wheat flour contributes greatly to the elastic properties rather than the viscous properties of cooked noodles, resulting in the high correlation with tan δ. Figure 1 showed the frequency dependence of the *G′* of noodles. Noodles with lower amylose content exhibited a higher frequency dependence of *G′*. The frequency dependence of waxy lines was extremely high compared with other cultivars, which indicates that waxy lines noodles had a less developed network and a weaker structure (Kulicke et al 1996).

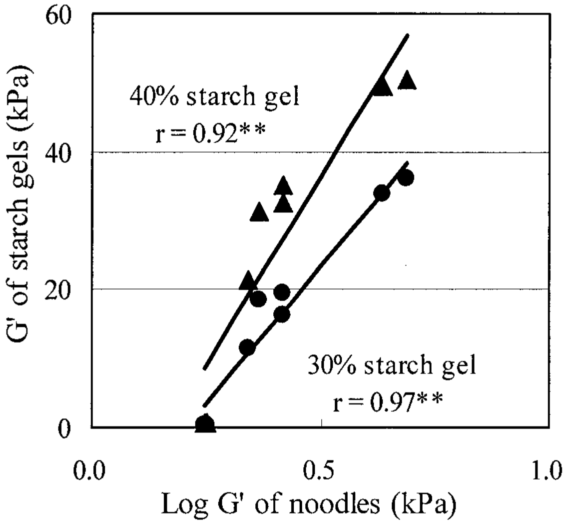

Fig. 2. Relationships between storage shear modulus (*G′*) of cooked noodles and starch gels.

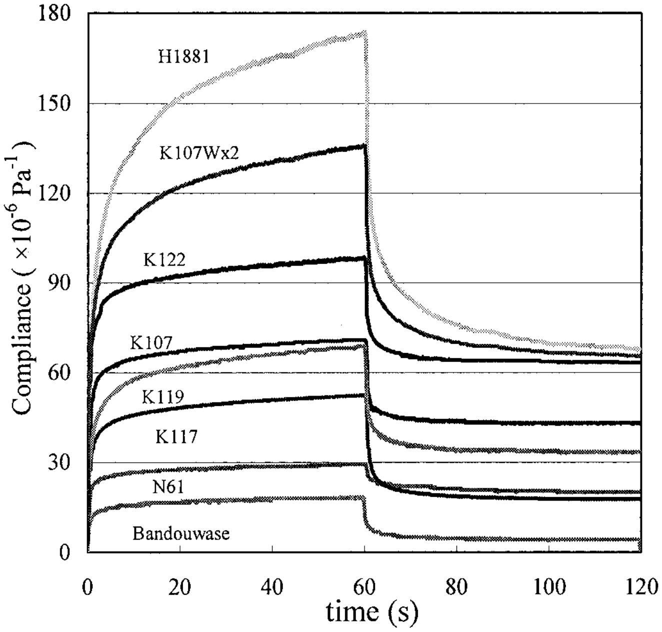

Fig. 3. Creep compliance curve for cooked noodles measured with a disk-shaped probe.

We previously evaluated the dynamic viscoelasticity of 30 and 40% starch gels using starches isolated from the same samples used here (Sasaki et al 2002) because the starch concentration is high in wheat products. The difference in dynamic viscoelasticity of noodles between cultivars showed similar results when using 30 and 40% starch gel. Consequently, we compared the *G′* values of cooked noodles and starch gels with various amylose contents (Fig. 2). The high correlation between log *G′* of cooked noodles and *G′* of starch gels was observed, suggesting that starch gel properties strongly reflected noodle quality. This result agrees with the suggestion of Ross et al (1997) that starch properties in gels more closely describe starch properties in noodles.

The dynamic modulus of dough is affected by flour protein content (Edwards et al 1993). However, wheat flours used in this experiment had a narrow range of protein content and a clear relationship between protein content and noodle quality was not detected.

Creep-Recovery Test

The strain during the creep-recovery test was converted to compliance for comparison of cultivars because the applied stress was different for cultivars in this experiment. Figure 3 shows the creep compliance curves of cooked noodles disks 20 mm in diameter analyzed using a disk-shaped probe. We chose 1 min for each creep and recovery time because longer times could change the rheological properties of noodles resulting from drying. When a constant stress was given, the noodles exhibited an immediate deformation called instantaneous elastic deformation (Bourne 2002) and the creep compliance increased with time. After removal of stress, a partial strain recovery was observed in all samples. A clear distinction in creep curves was recognized among cultivars. Norin 61, and Bandouwase noodles with higher amylose content approached a steady state quickly where the strain rate is constant. They also showed very little increase in strain under constant stress. Noodles of low-amylose lines (Kanto 107, 117, 119, and 122) showed faster strain increases during steady state than Norin 61, and Bandouwase. For waxy lines, the creep curves were extremely steep and they took a longer time to reach steady state. For comparison of noodles with different amylose content, we estimated maximum creep compliance, reached after 1 min, and maximum recovery compliance as the difference between maximum creep compliance and unrecoverable compliance by the method of Wang and Sun (2002) (Table II). Maximum creep compliance was significantly affected by amylose content and a negative correlation was observed ($r = -0.95^{**}$). Increasing the amylose content of wheat flour suppressed the maximum creep compliance and increased the resistance to deformation. Noodles of low-amylose lines showed higher values than Norin 61, and Bandouwase noodles with higher amylose content. Bandouwase noodles exhibited the lowest creep compliance, which means that these noodles were the most resistant to deformation because of a strong noodle structure. Waxy line noodles had the greatest maximum creep compliance, indicating that they were most susceptible to deformation because of a very weak noodle structure. Maximum recovery compliance was also significantly affected by amylose content and a negative correlation was recognized ($r = -0.94^{**}$). Increasing the amylose content of wheat flour suppressed recovery compliance. The ratio of recovery compliance to maximum compliance (R) was also determined (Table II) by the method of Carson and Sun (2001). They reported that a combination of recovery compliance and the ratio were significant for springiness of bread by sensory measurement. With regard to cooked noodles, amylose content of wheat flour had a remarkable effect on recovery compliance. However, a significant relationship between amylose content and R was not found. The tendency of compliance between cultivars as measured by a creep test was similar to that of G' determined by dynamic viscoelasticity meaurement. These observations explain that rheological properties of cooked noodles under small deformation reflect the amylose content of wheat flour.

Compression Test

Compressive force of all samples showed a continuous increase with increased shear, and no peak was found. The force required to achieve a given percentage compression was used for comparisons. The thickness of the cooked noodles was 2.28–2.78 mm. Figure 4 compared compressive force of cooked noodles with varying shapes (disk type, and one and two strips of noodles). The tendency to find differences between cultivars was similar among various shaped samples. The shape of noodles did not have as much influence on the difference of rheological properties between cultivars. The compressive force required for 20, 50, 80, and 95% strain was compared using a disk-shaped probe and a blade probe (Table III). When compressed over all surfaces by a disk-shaped probe, the force of some samples exceeded the force capacity before 95% strain, and the force at 95% could not be detected. At 20 and 50% strain, noodles with lower amylose content showed lower compressive force by both probes. Especially at 50%, the differences in force were clear among lines with higher amylose, low-amylose lines, and waxy lines. However, at 80 and 95% strain, the order changed. When using a blade probe, waxy lines showed a higher compressive force than the low-amylose lines, Norin 61, and Bandouwase at 80 and 95% strain. Figure 4 shows clearly different orders of compressive force for each cultivar between 50 and 95% strain. The compressive force

TABLE II
Creep-Recovery Parameters of Cooked Noodles

Sample	Maximum Creep Compliance ($\times10^{-6}$/Pa)	Maximum Recovery Compliance ($\times10^{-6}$/Pa)	R[a] (%)
Norin 61	29.4a[b]	9.3a	31.5a
Bandouwase	14.9a	10.6a	71.4c
Kanto 117	52.4b	34.7b	66.3c
Kanto 107	70.9c	27.7b	39.1a
Kanto 119	68.9c	35.3b	51.3b
Kanto 122	98.1d	34.9b	35.5a
Tanikei H1881	173.6f	105.7d	60.9bc
K107Wx2	135.8e	70.3c	51.8b

[a] Maximum recovery compliance/maximum creep compliance × 100.
[b] Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

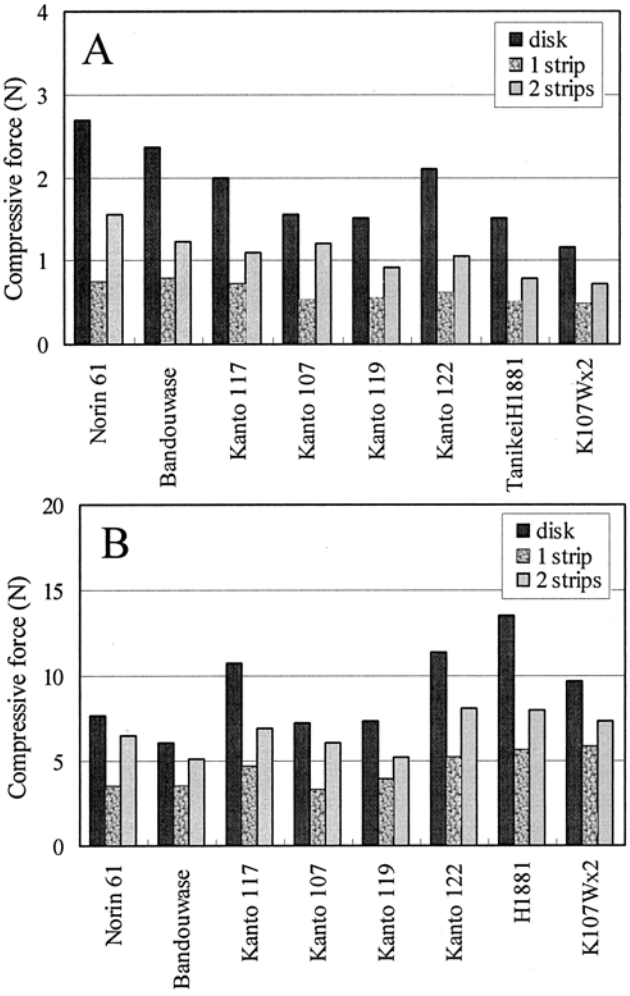

Fig. 4. Compressive force required for 50% (**A**) and 95% (**B**) strain measured with a blade probe.

TABLE III
Compressive Force (N) Required for Strain Measured Using a Strip of Noodle

	Disk-Shaped Probe			Blade Probe			
Sample	20% Strain	50% Strain	80% Strain	20% Strain	50% Strain	80% Strain	95% Strain
Norin 61	0.60a[a]	4.48a	13.96a	0.19a	0.75ab	1.87a–c	3.50a
Bandouwase	0.53a	4.36a	13.58a	0.20a	0.78ab	1.95a–c	2.34a
Kanto 117	0.35a	3.21ab	12.20a	0.18ab	0.71a–c	2.14a–c	4.65a–c
Kanto 107	0.36a	3.48ab	13.39a	0.15ab	0.53cd	1.56a	3.28a
Kanto 119	0.32a	2.56b	10.87a	0.14ab	0.56b–d	1.67ab	3.89ab
Kanto 122	0.36a	2.69b	10.66a	0.16ab	0.61a–d	2.18bc	5.20bc
Tanikei H1881	0.29a	2.03b	11.78a	0.12ab	0.49d	2.28c	5.68c
K107Wx2	0.27a	1.98b	11.85a	0.10b	0.48d	2.28c	5.90c

[a] Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

required for 50% was highly correlated with the amylose content of wheat flour when measuring one and two strands of noodles by both a disk-shaped probe ($r = 0.84^{**}, 0.82^{*}$) and a blade probe ($r = 0.76^{*}, 0.83^{*}$). However, such a correlation was not detected at 80 and 95% strain. Compressive force is thought to be related to the sensory perception of firmness (Oh et al 1983; Yun et al 1997). Compressive peak force is used as an indicator of differences in firmness between samples (Edwards et al 1993). At 50% strain, the compressive force may be influenced by the firmness of cooked noodles, especially surface firmness. Amylose contributes to the rigidity of the gel structure through retrogradation and maintains the integrity of swollen starch granules (Keetles et al 1996; Hermansson and Svegmark 1996; Mei-Lin et al 1997). Because swelling is mainly a property of amylopectin, and amylose acts as a diluent (Tester and Morrison 1990, 1992), starch with higher amylopectin swells rapidly and it is hard to maintain the stability of the swollen granules. Overswelling and breakdown of starch granule inhibit gelling and induce stickiness (Seib 2000). This suggests that cooked noodles with lower amylose swell more easily and induce the disintegration of starch granules, resulting in softer and sticky texture. On the other hand, the compressive stress at values >80% strain may be related to a resistance to completely cut off cooked noodles. Cooked noodles made from waxy lines showed lower compressive force at 50% strain; however, higher values at 95% strain compared with other cultivars. Results indicate that cooked noodles made from waxy lines have a softer texture but are resistant to completely cut through due to sticky properties resulting from overswelling and breakdown of amylopectin. Comparison of compressive force evaluated at various strains could prove the unique properties of waxy line noodles.

CONCLUSIONS

White salted noodles made from wheat flour with different amylose content exhibited clearly different rheological properties. Noodles of low amylose lines showed lower storage shear modulus (G') obtained by dynamic viscoelasticity measurement than those of lines with higher amylose. Noodles made from waxy lines showed very low G' and a higher frequency dependence of G'. A large negative correlation was observed between amylose content and tan δ of noodles. The high correlation between G' of cooked noodles and concentrated starch gels was recognized. This suggests that starch gel properties can explain noodle quality to some extent. The differences of amylose content in wheat flour also affected the creep-recovery curves. Increased amylose content in wheat flour suppressed the creep and recovery compliance of noodles. Results indicated that rheological characteristics of cooked noodles when measured at small deformation strongly reflect its amylose content. For compression tests at larger deformation, differences in compressive force between cultivars were not as wide compared with other measurements at small deformation. The effect of amylose content on compressive force depended on the scale of strain applied. At 50% strain, the compressive force correlated with amylose content. However, at values >80% strain, the linear relationship between amylose content and compressive force was not observed. Noodles of waxy lines showed unique characteristics for compressive stress. This demonstrates that the texture of waxy line noodles was very soft but difficult to cut completely. Waxy wheat flour has unique characteristics for noodle texture. Rheological parameters estimated in this study could exhibit characteristics of noodles made from wheat flour with a wide range of amylose content.

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[Received March 10, 2003. Accepted August 28, 2003.]