Effects of Salt and Alkaline Reagents on Dynamic Rheological Properties of Raw Oriental Wheat Noodles

Jianping Wu,[1] Trust Beta,[2,3] and Harold Corke[1]

Cereal Chem. 83(2):211–217

ABSTRACT

To gain further understanding of the functionality of ingredients in oriental wheat noodles, the rheological properties of raw noodles made using high protein (Red Bicycle) or low protein (Sandow) wheat flours and various additives (salt or alkaline reagents at concentrations of 0, 0.1, 0.5, 1.0, 2.0, 3.0, and 4.0%) were investigated using frequency sweep and temperature sweep oscillatory tests. Generally, both the elastic modulus (G') and viscous modulus (G'') of raw noodles increased when various levels of salt or alkaline (kansui and NaOH) reagents were included in the formulation, with the exception of Red Bicycle noodles where the G'' was not significantly affected by the salt. The G' was significantly decreased in the presence of sodium chloride at concentrations ≤4.0% and kansui at <0.5%. The change in rheological properties of raw noodles was related to the wheat flour quality, type, level of additive, and frequency. The G', G'', phase angle, and complex viscosity changed in a similar pattern when raw noodles were heated from 25 to 100°C. These parameters decreased initially with increasing temperature until they reached a valley and then increased either to a plateau or continuously in noodles containing kansui. The appearance of valley points at 75.5 and 77.2°C during heating of Sandow and Red Bicycle noodles containing salt, and 89.4, and 83.2°C during heating of Sandow and Red Bicycle noodles containing kansui, respectively, was not associated with starch gelatinization as determined using differential scanning calorimetry. The continuous increase in G', G'', and complex viscosity observed with noodles containing kansui during the hold period at 100°C was attributed to the high pH environment and not to the inactivation of α-amylase.

In addition to wheat flour and water, salt, alkaline reagents, and combinations of salt and alkaline reagents (mixtures) are also important components in wheat noodle manufacturing. It is widely believed that the addition of sodium chloride decreases water absorption (Salovaara 1982; Chung and Kim 1991) but it increases the optimal dough development time (Galal et al 1978; Danno and Hoseney 1982). Dexter et al (1979) reported that the presence of 2% salt in the dough resulted in a smoother and more uniform gluten structure than that observed for unsalted dough. Generally, sodium chloride improves the texture of noodles (Rho 1986) and enhances their flavor (Kubomura 1998).

Alkaline reagents are preferred, especially by Cantonese people, for making alkaline noodles (Corke and Bhattacharya 1999). These are usually used as a mixture of sodium and potassium carbonates (typically 9:1, kansui from Japan) or sodium hydroxide (Moss et al 1986). In some cases, calcium carbonate or sodium/potassium phosphates with or without sodium chloride are also used. The usage range is 0.5–1.7%. Consumers like the yellow color but prefer lower levels of kansui (Kubomura 1998). Alkaline-flour interactions are responsible for several effects, including toughening of the dough resulting in a gum-like texture (Terada et al 1981); increase in both the breaking and cutting forces of noodles (Sung and Sung 1993); retardation of starch gelatinization and increase in starch paste viscosity (Bean et al 1974; Terada et al 1981); inhibition of enzyme activity and suppression of enzymatic darkening (Miskelly and Moss 1985; Moss et al 1986); decrease in the dough development time and dough stability (Lorenz et al 1994); and also contribution to the development of the bright yellow color and flavor enhancement (Miskelly and Moss 1985).

The traditional, empirical rheological methods such as farinograph, mixograph, and alveograph have been developed specifically to predict the baking performance of wheat cultivars (Menjivar 1990; Weipert 1992; Eliasson and Larsson 1993). Dynamic testing methods, developed initially for polymer rheology study (Ferry 1980), are also very helpful in assessing viscoelastic properties of foods such as doughs and noodles. The use of dynamic rheometry to measure the fundamental rheological properties of dough by means of micro-oscillation, has been proposed by Hibberd and Wallace (1966) and Hibberd (1970a,b). This method allows specific expression of well-defined rheological parameters such as elastic or storage modulus (G'), viscous or loss modulus (G''), or complex viscosity (η^*) (Hibberd and Parker 1975). Generally, flour with better baking performance shows higher G' and G'' but lower phase angle (δ) values; however, a simple linear relationship has not been established between these parameters and baking performance (Amemiya and Menjivar 1992; Safari-Ardi and Phan-Thien 1998). It has been hypothesized that elasticity in dough is associated with the formation of three-dimensional networks because of the entanglement coupling or formation of important β-turn conformations (Tatham et al 1985). The role of the disulfide bonds may be to increase the size of the gluten molecule and hence enable entanglement coupling, whereas the viscous flow may be related to the breaking of noncovalent bonds such as hydrogen bonds and changes in hydrophobic interactions (Eliasson and Larsson 1993).

Information on the viscoelastic properties of oriental noodles is rare in literature, probably because for many years efforts, particularly in the Western world, have been expended by cereal scientists in trying to understand the baking properties of wheat (Janssen et al 1996; Kruger 1996). Noodle production is another major use of wheat in addition to bread. It has recently been estimated that the noodle market is growing at a relatively high rate (Corke and Bhattacharya 1999). The influence of some additives such as potassium iodate (KIO_3), L-ascorbic acid (L-AA), glutathione (GSH), and cysteine on dough rheological properties has been reported (Jorgensen 1939; Kuninori and Matsumoto 1963; Smith et al 1970; Hibberd 1970a,b; Jackel 1977; Bloksma 1972; Lillard et al 1982; Dreese et al 1988a,b; Berland and Launary 1995; Dong and Hoseney 1995; Shiau and Yeh 2001; Chiotelli et al 2004). However, the most widely used additives such as salt or alkaline reagents have so far received little attention on their influence on the rheological properties of raw noodles (Edward et al 1996; Yeh and Shiau 1999). Therefore, the objectives of this study were to investigate the effects of salt, alkaline reagents, and their mixtures, and temperature on the dynamic rheological properties of oriental noodles made from a high- and low-protein flour and to elucidate their role in noodle production.

[1] Department of Botany, The University of Hong Kong, Pokfulam Road, Hong Kong.
[2] Department of Food Science, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2.
[3] Corresponding author. Phone: (204) 474-8214. Fax: (204) 474-7630. E-mail: Trust_Beta@UManitoba.CA

DOI: 10.1094/CC-83-0211

MATERIALS AND METHODS

Materials

Both Red Bicycle (RB) and Sandow (SD) brand flours were purchased from Flour Manufacture of Hong Kong (Kowloon, Hong Kong). RB is a high-quality flour with a protein content of 11.8 ± 0.2% and a wet gluten content of 32% of total protein. SD has a relatively low-protein content of 8.6 ± 0.2% and a wet gluten content of 23% of total protein. α-Amylase (EC 3.2.1.1, from *Bacillus*, heat stable, 0.0025 g/100 g of flour) was purchased from Sigma Chemical (St. Louis, MO) and silver nitrate was supplied by BDH Chemical (Poole, England). All other reagents used were analytical grade and purchased from Sigma.

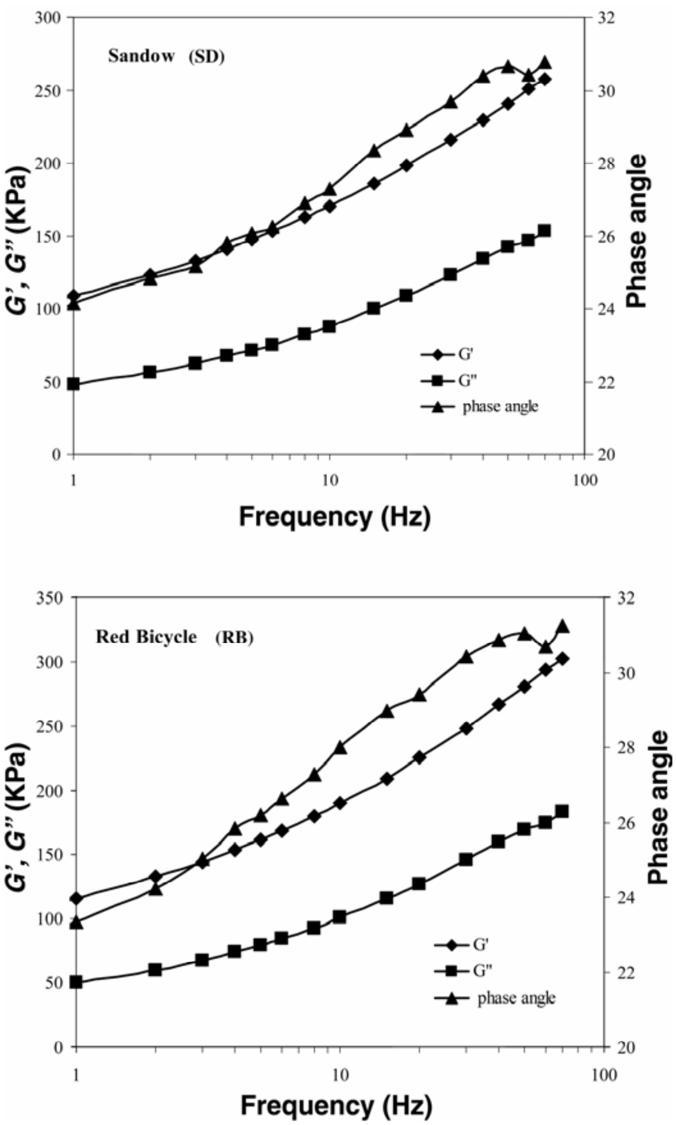

Fig. 1. Elastic modulus (*G'*), viscous modulus (*G"*) and phase angle vs. frequency for Sandow (SD) and Red Bicycle (RB) control raw noodles.

Raw Noodle Preparation

The basic formulation for raw noodle preparation was wheat flour, 100 parts (14% moisture content); water, 33 parts (w/w, on wet wheat flour weight basis); and different levels of salt or alkaline reagents (%, w/w, on wet wheat flour weight basis). Sodium chloride was added at 0.5, 1.0, 2.0, 3.0, and 4.0% levels; kansui (9:1 mixture of sodium and potassium carbonate) and sodium hydroxide were added at 0.1, 0.5, 1.0, and 2.0% levels. Mixtures (1:9 w/w) of sodium carbonate and sodium chloride; (1:9 w/w) kansui and sodium chloride; and (1:9 or 5:5 w/w) sodium carbonate and calcium chloride were added at 1.0%.

For each trial, 100 g of wheat flour and 33 g of water containing different levels of salts or alkaline reagents was mixed by hand at a relatively steady rate of 30–40×/min for 5 min. The crumbly dough was sheeted four times through the first roller gap (2.75 mm) of an electric pasta making machine (Mercato, Italy) and folded in half each time. Then the dough sheet was cut into two equal pieces. The dough halves were rested for 15 min in two separate plastic bags to allow uniform moisture distribution and mellowing of wheat gluten and other components (Miskelly and Moss 1985). Afterward, each of the dough halves was subsequently passed through four roller gaps (2.75, 2.5, 2.0, and 1.6 mm) of the same machine without intermediate resting, sheeting five times for each roller gap. Before rheometer testing, the raw noodle sheet was allowed to rest for 30 min before cutting into circles 30 mm in diameter using a mold.

Rheological Measurements

To compensate for the expansion, we set the final gap setting to 1.6 mm for all samples and allowed the raw noodle sheet to rest for 30 min before the rheological testing. A limitation in our rheological measurements is the possibility that different degrees of expansion of the raw noodles under different formulations would have taken place after the final sheeting. A dynamic rheometer (StressTech, Rheologica Instruments AB, Lund, Sweden) was used to investigate the influence of different treatments on the rheological properties of raw noodles using oscillatory tests (strain controlled). The rheometer was equipped with parallel plates 30 mm in diameter set 1.6 mm apart for noodle sheet testing. The lower parallel plate was maintained at 25°C for frequency sweep oscillatory test. The sample was placed between the plates, and excess dough protruding at the edge of the sensor was carefully trimmed off with a thin blade. To prevent drying of the sample at the edges, a thin layer of palm oil was applied to cover the exposed dough surface. The dough was rested for another 5 min before measurements.

Dynamic oscillatory experiments are ideally conducted within the linear viscoelastic range of a material in which the modulus is independent of the stress or strain, and the relationship between the applied stress and measured quantity is linear. Most visco-

TABLE I
Effects of Adding Salt on Elastic Modulus (*G'*), Viscous Modulus (*G''*), and Phase Angle (δ) of Raw Noodles at 10 Hz Frequency

	Sandow			Red Bicycle		
Salt Addition[a]	*G'*	*G''*	δ	*G'*	*G''*	δ
0.0% (Control)	170.5cd[b]	87.5d	27.3c	189.8a	100.9a	28.0c
0.5%	199.2bc	99.7cd	26.6c	164.8ab	99.7a	30.6c
1.0%	210.6b	103.6c	26.2c	162.2ab	96.3a	31.1c
2.0%	252.5a	121.5b	25.7c	149.3ab	95.8a	38.0ab
3.0%	231.4ab	139.2a	31.1b	135.8bc	94.2a	40.6a
4.0%	161.4d	135.2ab	40.0a	93.3c	93.3a	32.3bc

[a] Salt (%, w/w) on a 14% moisture basis of wheat flour.
[b] Means within columns followed by common letters are not significantly different at $P < 0.05$. Results based on Duncan's multiple range test using SAS software.

elastic materials, including wheat doughs and noodles, behave linearly only at very low stress or strain levels. To determine this linear viscoelastic region of the noodle, a strain sweep measurement was performed at a fixed frequency of 1 Hz. The linear viscoelastic range of 0.1–0.6% was in agreement with previously published data (Dus and Kokini 1990; Lindahl and Eliasson 1992). Subsequent oscillatory measurements were taken at a fixed strain of 0.3% over a frequency range of 0.5–70 Hz. The G', G'', δ (tan $\delta = G''/G'$), and complex viscosity ($\eta*$) values were recorded automatically by software (StressTech v. 3.0). A temperature sweep oscillatory test was performed at 25–100°C at a heating rate of 3°C/min and held for another 10 min under a frequency of 1 Hz and strain of 0.3%. All tests were conducted at least in duplicates.

Differential Scanning Calorimetry (DSC)

DSC assays were performed using a modulated DSC thermal analyzer (2920, TA Instruments, New Castle, DE) connected with a personal computer (IBM 340). Water or solution corresponding to the amount used in oriental noodle production was added and blended manually for 5 min to achieve homogeneity. The dough was allowed to relax for 3 hr in a sealed plastic bag at room temperature to achieve an even distribution of moisture. Portions of dough (≈10 mg) were weighed and hermetically sealed in aluminum DSC pans. The sample pans were heated from 25°C to 160°C at a scanning rate of 10°C/min. An empty pan was used as a reference. All tests were performed in triplicates.

Statistical Analysis

All data were statistically analyzed with a computer software package (v. 6.12, SAS, Cary, NC), using the Duncan Multiple Range Test (DMRT) to differentiate the means among different treatments ($P < 0.05$).

RESULTS AND DISCUSSION

Effect of Sodium Chloride

Representative elastic modulus (G'), viscous modulus (G'') and phase angle graphs of Sandow (SD) and Red Bicycle (RB) controls across the frequency sweep are shown in Fig. 1. It shows that all rheological properties increased with increasing frequency in both raw noodles at a strain of 0.3%. Rheological properties of raw noodles were affected by the type of wheat flour and the level of sodium chloride added to the formulation (Table I). G' of SD noodles increased with increasing salt levels from 0.5 to 2.0%, and then started to decrease. G' decreased significantly at 4% compared with that observed at 2.0%. Adding salts significantly increased G'' in all treated SD noodles, with the exception of the 0.5% treatment. The phase angle of SD noodles was not affected when levels of 0.5 to 2.0% salt were added; however, it was significantly increased at levels of 3.0 and 4.0%. A different response to salt addition was observed in RB raw noodles (Table I). G' of RB noodles was decreased gradually as salt levels increased, but decreased significantly at 3.0 and 4.0% levels. However, G'' of

TABLE II
Effects of Adding Kansui on Elastic Modulus (G'), Viscous Modulus (G''), and Phase Angle (δ) of Raw Noodles at 10 Hz Frequency

	Sandow			Red Bicycle		
Kansui Addition[a]	G'	G''	δ	G'	G''	δ
0.0% (Control)	170.5c[b]	87.5c	27.3ab	189.8b	100.9bc	28.0b
0.1%	162.9c	90.4c	29.0ab	153.5b	95.0c	32.1ab
0.5%	170.8c	103.5bc	31.8a	164.9b	119.9bc	36.0a
1.0%	278.1b	126.2b	24.4b	185.9b	132.1b	35.7a
2.0%	384.5a	173.1a	24.2b	336.5a	211.0a	32.1ab

[a] Kansui (%, w/w) on a 14% moisture basis of wheat flour.
[b] Means within columns followed by common letters are not significantly different at $P < 0.05$. Results based on Duncan's multiple range test using SAS software.

TABLE III
Effects of Adding NaOH on Elastic Modulus (G'), Viscous Modulus (G''), and Phase Angle (δ) of Raw Noodles at 10 Hz Frequency

	Sandow			Red Bicycle		
NaOH Addition[a]	G'	G''	δ	G'	G''	δ
0.0% (Control)	170.5c[b]	87.5c	27.3a	189.8c	100.9c	28.0b
0.1%	178.1c	91.8c	27.3a	205.6bc	114.0bc	27.9b
0.5%	223.3b	111.6b	26.6ab	268.2a	146.5a	29.8a
1.0%	229.2b	103.0b	24.2c	286.2a	143.2a	26.7b
2.0%	297.7a	136.7a	24.7bc	260.0ab	133.0ab	27.1b

[a] NaOH (%, w/w) on a 14% moisture basis of wheat flour.
[b] Means within columns followed by common letters are not significantly different at $P < 0.05$. Results based on Duncan's multiple range test using SAS software.

TABLE IV
Effects of Adding Salt/Salt Mixtures on Elastic Modulus (G'), Viscous Modulus (G''), and Phase Angle (δ) of Raw Noodles at 10 Hz Frequency

Salt/Salt Mixtures	Sandow			Red Bicycle		
Addition[a]	G'	G''	δ	G'	G''	δ
Control	170.6e[b]	87.5d	27.3b	189.8bc	101.0c	28.0c
Na_2CO_3	260.7c	120.1c	24.7c	159.0c	122.5bc	33.2abc
Na_2CO_3/NaCl (1:9)	207.2d	118.7c	29.8a	198.1bc	127.7bc	37.0a
Kansui/NaCl (1:9)	336.4a	159.0a	25.3bc	193.1bc	134.2ab	35.0ab
$Na_2CO_3/CaCl_2$ (1:9)	293.6b	144.3b	26.2bc	271.1a	158.1a	30.3bc
$Na_2CO_3/CaCl_2$ (5:5)	242.1c	120.6c	26.5bc	254.8ab	147.2ab	30.0bc

[a] Salt/salt mixtures (%, w/w) on a 14% moisture basis of wheat flour.
[b] Means within columns followed by common letters are not significantly different at $P < 0.05$. Results based on Duncan's multiple range test using SAS software.

RB noodles was affected little with increasing salt levels. The phase degree of RB noodles increased at salt concentrations of 0.5–3.0% but decreased at 4.0% concentration.

Sodium chloride could influence the rheological properties of noodles by enhancing the association of gluten proteins (Salovaara 1982), thus strengthening the dough and reducing water absorption (Galal et al 1978; Salovaara 1982; Chung and Kim 1991). It should be noted that when *G′* is higher than *G″*, the material would be more elastic than viscous, as found in solid materials such as noodles. The opposite effect of adding salt on *G′* of SD and RB noodles probably could be attributed to the differences in their intrinsic protein quality given that SD had a lower wet gluten amount than RB. However, the role of other components in wheat flour such as starch needs to be determined. Because high salt levels (≥3.0%) could result in deterioration of raw noodle rheological properties, our current findings indicate that when making white salted noodles using high-quality wheat flour, adding salt at levels <2.0% is recommended.

Effect of Alkaline Reagents (kansui and sodium hydroxide)

The influence of kansui on the rheological properties of raw noodles is shown in Table II. Both *G′* and *G″* were little affected at levels <0.5 and 1.0% for SD and RB raw noodles, respectively; however, *G′* and *G″* were significantly increased at concentrations of 1.0 and 2.0% for SD noodle or 2.0% for RB noodle. Phase angle of SD noodles was not significantly affected by kansui except at the 0.5% level; however, phase angle of RB noodles was significantly increased at levels of 0.5 and 1.0%.

Generally, adding NaOH increased both *G′* and *G″* in all treated samples (Table III). Adding sodium hydroxide at 0.5% significantly increased both *G′* and *G″* of SD and RB noodles, suggesting that the effect of NaOH on rheological properties of raw noodles was more pronounced than that of kansui at low levels. *G′* of SD noodles increased with increasing NaOH levels up to 2.0%; however, *G′* of RB noodles started to decrease at 2.0% although it was still significantly higher than that of the control. The phase angle of SD noodles was significantly decreased at concentrations of 1.0 and 2.0%; however, the phase angle of RB noodles was significantly increased at 0.5% although it was not affected at other levels. We observed that the matrix of the dough containing NaOH was not as continuous or as uniform as the dough prepared with common salt or kansui after the compression stage of sheeting, especially at high concentration, suggesting that a much lower dose of NaOH should be employed for noodle making (Moss et al 1986). The changes in rheological properties of raw noodles with kansui or NaOH addition were not only

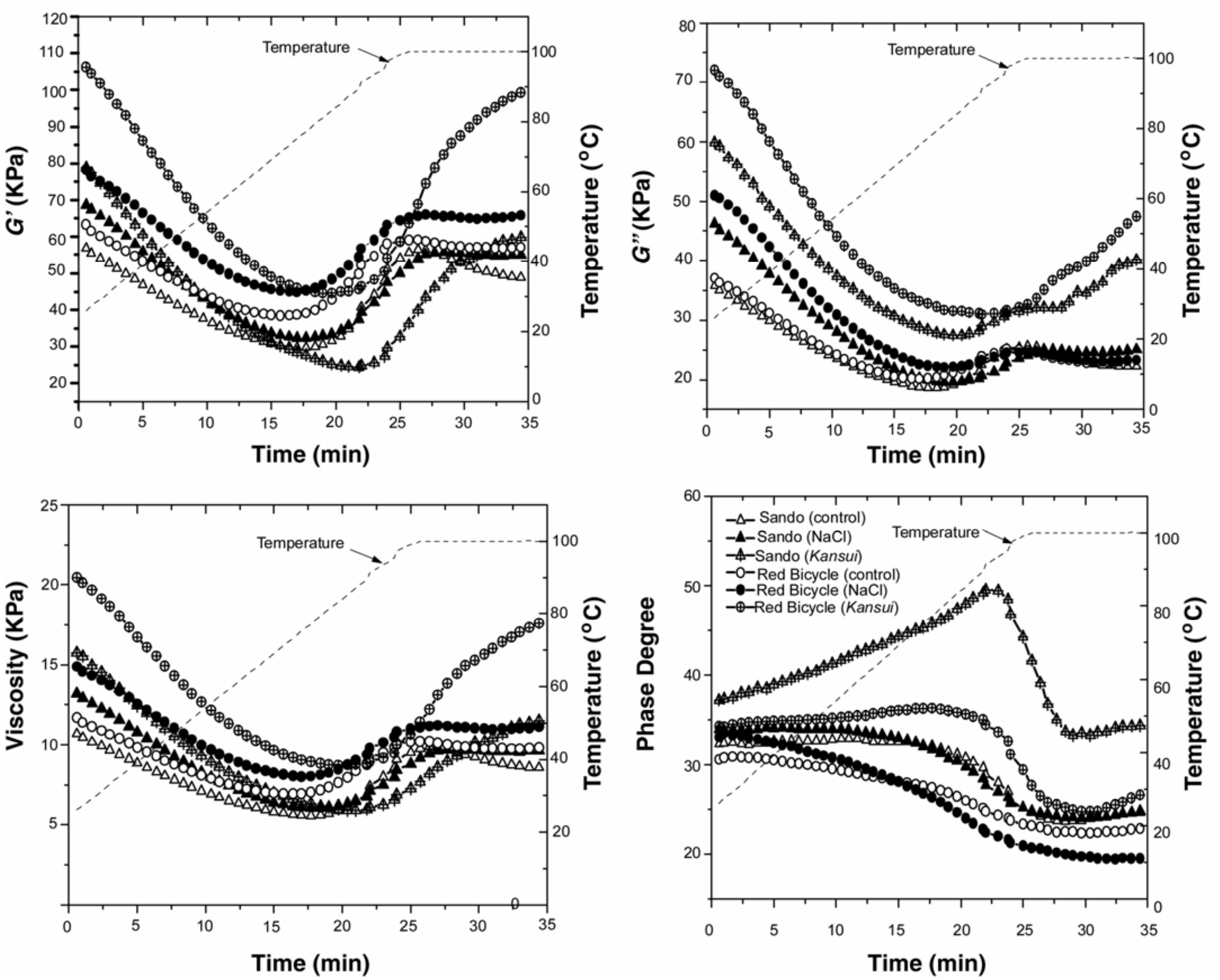

Fig. 2. Rheological properties of raw noodles (*G′*, *G″*, complex viscosity, and phase angle [degree]) vs. time when temperature was scanned from 25 to 100°C at a heating rate of 3°C/min and kept at 100°C for another 10 min. Control group has no additive, while both NaCl and kansui were added at the 1.0% (w/w) level on a 14% moisture basis of wheat flour.

related to the protein matrix but also to the swelling properties of wheat starch granules (Lancaster and Conway 1968; Ragheb et al 1995).

Effect of Combinations of Salt and Alkaline Reagents

The effects of various salt combinations on the rheological properties of raw noodles are shown in Table IV. G' and G'' of SD noodles increased significantly with all treatments. The combination of kansui and NaCl showed the highest G' and G'' values for SD noodles. The highest G' and G'' values for RB noodles were found with the $Na_2CO_3/CaCl_2$ (1:9) combination. Phase angle of SD noodles was decreased in all the treatments, with the exception of the 1:9 Na_2CO_3/NaCl treatment where the value of phase degree was significantly increased (Table IV). On the contrary, the phase angle of RB noodles was significantly increased at the 1:9 Na_2CO_3/NaCl and kansui/NaCl combinations. Compared with the sodium carbonate treatment, adding NaCl to sodium carbonate significantly increased G' of SD noodles but G' of RB noodles was affected little. Adding $CaCl_2$ at a high ratio such as the 1:9 $Na_2CO_3/CaCl_2$ treatment could significantly increase G' of SD noodles; however, adding $CaCl_2$ significantly increased G' of RB noodles at both treatments. A high ratio of $CaCl_2$ such as the 1:9 $Na_2CO_3/CaCl_2$ treatment significantly increased G'' of SD and RB noodles. Compared with the sodium carbonate treatment, the phase angle in SD noodles was not affected by salt mixtures, except for the 1:9 Na_2CO_3/NaCl treatment.

Edward et al (1996) reported that salt did not show any significant influence on G' of wheat doughs, which is contrary to our observations. However, they also reported that treatment with NaOH had the highest G'. Kansui ranked in the middle at concentrations of 1%, which is in agreement with our findings on raw noodles. Generally, adding salt, kansui, NaOH, or their mixtures would increase competition between wheat protein and starch for limited water, resulting in delayed protein hydration and matrix development. Increasing salt concentration would also compress the electrical double layer and reduce the repulsive forces among wheat proteins; however, drastic pH changes with the addition of kansui or NaOH especially, would charge the protein and thus increase the repulsive forces. At the same time, changes in hydrophobic and electrostatic interaction because of the presence of salts or alkaline reagents would play an important role in determining the physical properties of dough (Preston 1989). As gluten is the major component responsible for the network development in dough, the influence on association and dissociation of gluten proteins by the addition of salt and alkaline reagents might have a principal effect on rheological properties, while the detailed mechanisms remain to be explained.

Effect of Temperature

The influence of temperature on the rheological properties of white salted and yellow alkaline noodles was also investigated. G', G'', and viscosity changed with temperature in a similar pattern: initially, they decreased with increasing temperature until they reached a valley point, and then began to increase from their valley points with increasing temperature until reaching 100°C, where they either stabilized for the control and salted noodles or increased further for kansui noodles when the temperature was held at 100°C for an extended period (Fig. 2). The valley point temperature for G' was 75.5 and 77.2°C for SD and RB noodles, respectively, with or without sodium chloride addition. Adding kansui delayed the valley point temperatures to 89.4 and 83.2°C for SD and RB raw noodles, respectively. The maximum G' was observed during the temperature holding period at 100°C for the control and salted noodles, while no maximum G' was observed in the presence of kansui. Adding kansui produced an effect on the phase angle different from that of salt. The phase angle of white salted noodles (and control noodles) decreased gradually with increasing temperature up to 100°C for both flours; however, the phase angle of yellow alkaline noodles prepared with kansui increased slightly for RB within the temperature range of 25–87.2°C, while phase angle significantly increased for SD noodles within the temperature range of 25–93.4°C (Fig. 2). The phase angle of SD and RB noodles was then decreased markedly at 93.4 and 87.2°C, respectively, in the presence of kansui. The decrease lasted for 2–3 min. The phase angle of all types of noodles stabilized for the remaining extended period at 100°C.

The valley point that appeared during heating of raw noodles indicated a phase transition, which is a common phenomenon in noncovalent network gel formed by gelatin or polysaccharides. Dreese et al (1988a) and Yeh and Shiau (1999) also observed a slight decrease in G' at the relatively low temperature range of 30–55°C before a sharp increase appeared in the range of 55–78.5°C and further heating resulted in a decrease before reaching 100°C. The test was performed using wheat flour dough with or without oxido-reductants. Workers have reported that the observed change is due to starch gelatinization after comparing differential scanning thermograms with dynamic measurements (Dreese et al 1988a; He and Hoseney 1991; Kokini et al 1995; Yeh and Shiau 1999). However, LeGrys et al (1980) reported an increase in the G' of gluten-water doughs as a result of heating but attributed the effect to the increased gluten cross-linking rather than to starch gelatinization. Comparing our data with results previously reported by Dreese et al (1988) and Yeh and Shiau (1999), we hypothesize that the relatively high valley temperature range for G' in our experiment is mainly due to the limited water content in raw noodles.

It is well known that a shift to a higher temperature is a commonly observed phenomenon for wheat starch during gelatinization under a decreasing water environment (Eliasson 1980; Ghiasi et al 1982). The transition is characterized by solvent-aided melting of crystallites in the starch granules (Donovan 1979), otherwise gelatinization would be delayed under limited water content. Based on the amount of water during noodle making and the moisture content of wheat flour, the theoretical water content of our raw noodles would be 35.3% on the dry weight basis and, therefore, the actual amount of water used for starch gelatinization would be <35%. However, no gelatinization occurred when the water content of wheat starch was <30% (Hellman et al 1954; Collison and Chilton 1974). It is impossible to differentiate the distribution of water among protein, starch, or other components

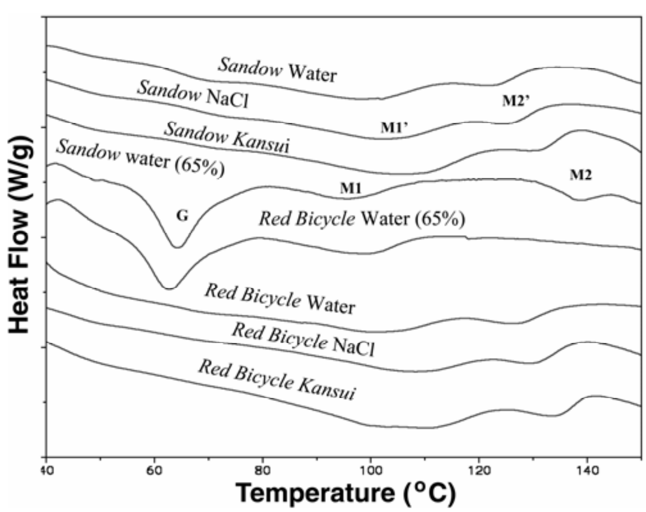

Fig. 3. Differential scanning calorimetry thermograms of wheat flour doughs at limited moisture content. Sample with high moisture content (65%) was used as reference. Water or solution was added at level of 33% on a 14% moisture basis of wheat flour G, M1, and M2 indicated the three successive endothermic peaks at high water content (65%) of doughs, while M1' and M2' indicated the second and third endothermic peaks at low water content (33%) of doughs.

in prepared raw noodles at this stage; therefore, using limited water (e.g., 40%) simply dispersed in wheat starch (Yeh and Shiau 1999) could not properly reflect the true situation as in dough or raw noodles. Alternatively, we prepared homogenous dough at the same water level used in raw noodles for DSC analysis. At 65% water content, the lower temperature endothermic peak (*G*) representing starch gelatinization was distinct in thermograms of both types of flours (Fig. 3). The second transition peak (M1) was associated with the melting of type I amylose-lipid complex for both flours, while the third transition peak (M2) observed only in SD flour was probably attributed to the melting of type II amylose-lipid complexes (Kugimiya et al 1980; Biliaderis and Seneviratne 1990). The absence of the third peak (M2) in the RB sample (65% water content) may due to the different lipid profiles of these samples because the type of amylose-lipid complexes is strongly influenced by the type of lipids involved (Biliaderis 1990; Tufvesson et al 2003). Compared with thermograms of high water content (65%), doughs prepared at 33% water content did not show normal gelatinization endothermal peaks within the normal gelatinization temperature range for wheat starch (Fig. 3). The disappearance of the gelatinization peak could be explained by an insufficient amount of plasticizer (water) involved in this endothermic phenomenon (Garcia et al 1996). However, we observed the second and third transition peaks in doughs made with 33% water content, corresponding to M1' and M2' in Fig. 3. Donovan (1979) reported that there is a marked shift of the gelatinization endotherm to higher temperature as the water concentration is decreased. Therefore, M1' appears to be related to the melting of starch crystallites, while M2' may be related to the delayed melting of amylose-lipid complex (Donovan 1979; Biliaderis et al 1986). We also observed that the temperature of the second transition peak (M1') was much higher than the valley temperature range observed in raw noodles. So the critical change in G' during heating of raw noodle was probably due to aggregation or cross-linking of proteins (Kokini et al 1995) or the influence of beta-turn conformations of gluten proteins (Tatham et al 1985). Other plausible explanations include moisture loss during the process of heating, and interactions with other components in addition to starch gelatinization as previously reported (Dreese et al 1988a; Yeh and Shiau 1999).

The continuous increase in G', G'', and viscosity in the presence of kansui was significant compared with other treatments during the 100°C holding period (Fig. 2). To address whether inhibition of α-amylase had an influence, we tested samples by including silver nitrate (an α-amylase inhibitor) in salted raw noodles. No increase in these rheological parameters was observed during the 100°C holding period in the presence of silver nitrate (data not shown). We therefore excluded the contribution of the inhibition of α-amlyase under alkaline conditions. Sodium hydroxide showed the same effect as kansui (data not shown). Thus, the high pH environment created by the presence of kansui or NaOH was related to this specific phenomenon. High pH could influence the structure and interactions of gluten, while the anions of alkaline agents (OH^-, HCO_3^-, CO_3^{2-}) could also associate at specific sites in the starch granule and create a large hydration sphere (Oosten 1982) thus strengthening the network even at the 100°C holding temperature.

CONCLUSIONS

Rheological properties of raw noodles were greatly influenced not only by wheat flour quality but by the salt or alkaline reagents at various concentration levels. The reaction between high-quality wheat flour or low-protein wheat flour and these reagents indicated some specific complex interactions during noodle making among macromolecular substances and reagents under limited water conditions. Our results also indicated that rheological measurements could be a potentially sensitive tool to determine the optimum level of salt or alkaline reagents to be added based on quality differences among wheat flours. Further research in establishing the relationship between the rheological parameters, such as elastic modulus and viscous modulus, and noodle quality parameters would provide important information. It was quite interesting to obtain the valley temperature during heating of raw noodles. We further demonstrated that this valley temperature was not associated with the functional property of starch gelatinization. Further exploration is needed to elucidate the underlying principles.

ACKNOWLEDGMENTS

We would like to thank Lawrence Ramsden (Department of Botany, the University of Hong Kong) for technical help on rheometer test. We also thank Alister D. Muir of Agriculture and Agri-Food Canada for valuable comments. The financial support of the Hong Kong Research Grants Council is acknowledged.

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[Received June 22, 2005. Accepted November 22, 2005.]