Use of ultrasound to discern differences in Asian noodles prepared across wheat classes and between varieties

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Diep, S., Daugelaite, D., Strybulevych, A., Scanlon, M., Page, J. and Hatcher, D. 2014. **Use of ultrasound to discern differences in Asian noodles prepared across wheat classes and between varieties**. Can. J. Plant Sci. **94**: xxx–xxx. Nine wheat varieties, five Canada Western Red Spring (CWRS) and four Canada Prairie Spring Red (CPSR), grown at the same locations and composited by variety, were milled to yield 65% extraction flours, which were used to form yellow alkaline raw and cooked noodles. The CWRS flours were $\sim$2% higher in protein content than the CPSR varieties, with varieties within each class exhibiting a wide range in dough strength as determined by Farinograph dough development time and stability. The ultrasonic velocity and attenuation of the raw noodles were measured at 40 kHz in disk-shaped samples, enabling the longitudinal storage modulus, loss modulus and tan Δ to be determined. Significant differences ($P = 0.05$) between classes and within a class were found to exist for all ultrasonic parameters. In general, the CPSR varieties generated the highest storage moduli values, the lowest loss moduli, and the lowest tan Δ values, indicating this class/varieties exhibited a more elastic (firmer) raw noodle than the CWRS varieties even at a 2% lower protein content. A significant correlation, $r = 0.72, 0.70$, $P = 0.03$, was also found between raw noodle velocity and M″, respectively, with cooked noodle bite as determined by maximum cutting stress.

Key words: Ultrasonics, wheat noodles, rheology

Diep, S., Daugelaite, D., Strybulevych, A., Scanlon, M., Page, J. et Hatcher, D. 2014. **Recours aux ultrasons pour discerner les variations dans les nouilles asiatiques préparées avec du blé de différentes classes et variétés**. Can. J. Plant Sci. **94**: xxx–xxx. Neuf variétés de blé, soit cinq de blé roux de printemps de l'Ouest canadien (CWRS) et quatre de blé roux de printemps Canada Prairie (CPSR), cultivées au même endroit puis regroupées par cultivar ont été moulues pour donner des farines à 65 % d'extraction dont on s'est ensuite servi pour fabriquer des nouilles jaunes alcalines crues et cuites. Les farines CWRS contenaient environ 2 % plus de protéines que celles issues du blé CPSR, les variétés dans chaque classe donnant une pâte dont la résistance varie considérablement, comme on l'a déterminé au moyen d'un farinographe, d'après la durée du pétrissage et la stabilité de la pâte. On a établi la vitesse et l'atténuation des ultrasons dans les nouilles crues à 40 kHz à partir d'échantillons en forme de disque, ce qui a permis de déterminer le module de conservation longitudinal, le module de perte et tan Δ. Tous les paramètres des ultrasons varient de façon significative ($P = 0{,}05$) d'une classe à l'autre et à l'intérieur d'une même classe. En général, les variétés CPSR donnent la valeur la plus élevée pour le module de conservation, la valeur la plus faible pour le module de perte et la valeur la plus faible pour tan Δ, signe que ces classes/variétés de blé produisent des nouilles crues plus élastiques (fermes) que le blé CWRS, même si elles renferment 2 % moins de protéines. Les auteurs ont aussi relevé une corrélation significative, $r = 0{,}72$, $0{,}70$, $P = 0{,}03$, entre la vélocité des ultrasons et M″ chez les nouilles crues, comme on a pu l'établir d'après la résistance maximale à la coupe.

Mots clés: Ultrasons, nouilles de blé, rhéologie

Noodles are a staple food for many people living in Asia (Huang and Morrison 1988; Ye et al. 2009), with up to 161 million tonnes of wheat used for noodle production each year in Asia (Bui and Small 2007). In China, Japan and Korea it is estimated that approximately 20–50% of total wheat flour consumption is in the form of noodles (He et al. 2010). In these regions, noodles are commonly made from wheat flour; however flours from other cereals, such as rice and buckwheat or starches from mung bean, tapioca and sweet potato have been used (Lu and Nip 2006; Hou 2001; Fu 2008). Variations in noodles with respect to ingredients, size, color, shape and method of manufacture are all due to regional preferences resulting in a diversity of noodle products in the market place (Hou 2001; Lu and Nip 2006). Noodles made with wheat flour, however, remain the most popular noodle consumed worldwide (Hou 2001; Fu 2008).

Industry classifies wheat noodles into two broad categories based on the type of salt used in their formulation and basic processing methods (Fu 2008).

Abbreviations: **CPSR**, Canada Prairie Spring Red; **CWRS**, Canada Western Red Spring; **DDT**, dough development times; **DST**, dough stability; **MCS**, maximum cutting stress

Wheat noodles made with the inclusion of alkaline salts, mainly sodium carbonate (Na_2CO_3) and/or potassium carbonate (K_2CO_3) in varying proportions, are known as yellow alkaline noodles and the salts ratio plays a critical role in noodle color and texture (Hou 2001; Bui and Small 2007). Those products made solely with regular salt (NaCl) are known as white salted noodles (Hou 2001; Fu 2008). While alkaline noodles make up less than 10% of the noodle production in China, in Japan alkaline noodles dominate the market share over regular salted noodles due to the increased consumption of the popular, alkali containing, instant noodle (Hou 2001; Fu 2008).

To ensure optimum noodle quality, manufacturers employ panels of trained sensory analysts (Nagao 1996; Hatcher 2010). In addition, noodle quality is also assessed based on analytical instrumentation where unbiased results are used for research purposes as well as to compare and confirm noodle quality results determined by sensory analyses (Hatcher 2010).

Protein content and quality directly impact the textural properties of noodles where protein requirements are specific for a noodle type. Wheat flour streams from different wheat sources can be selected and blended to meet appropriate protein specifications (Huang and Morrison 1988; Crosbie et al. 1992; Hou 2001; Hatcher 2001; Fu 2008). The quality of protein is relative to dough or gluten strength, where stronger doughs have been shown to provide more firm and elastic noodles (Miskelly and Moss 1985; Hou 2001; Crosbie and Ross 2004; Carson and Edwards 2009; Okusu et al. 2010).

Gluten, made up primarily of gliadin and glutenin proteins, is responsible for dough viscoelastic behaviour and is formed during the mixing of flour and water (Hamer et al. 2009; Shewry et al. 2009; Carson and Edwards 2009). Gliadin is considered to provide the extensibility or viscous flow behaviour while glutenin provides the elasticity of wheat doughs (Shewry et al. 2009; Zhou et al. 2011). Sufficient overall gluten strength as well as a good balance of extensibility and elasticity is essential in producing a high-quality noodle product. Gluten that is too strong may cause excessive dough shrinkage during sheeting, while gluten that is too weak may tend to dough rippling or tearing during dough handling and sheeting (Hatcher 2001).

Using instrumental analyses to determine noodle quality has advantages over sensory analyses because noodle quality differences due to small but significant formulation and processing modifications may not be discernible by sensory panels (Tsuji 1984; Hatcher 2010). Developments in the field of ultrasonics have led to a fast, robust and non-destructive analytical tool that has the ability to evaluate and predict the rheological properties of food products (Povey and McClements 1988; McClements 1995; McClements and Gunasekaran 1997; Got et al. 1999; Kidmose et al. 2001; Létang et al. 2001; Coupland and Saggin 2003; Coupland 2004; Juodeikiene and Basinskeine 2004; Elmehdi et al. 2004; Dolatowski et al. 2007; Cobus et al. 2007). However, minimal investigation of wheat flour noodles by ultrasonic techniques has been undertaken (Bellido and Hatcher 2010).

Ultrasound in a fluid is a pressure wave at inaudible frequencies higher than 16 kHz (Povey and McClements 1988; Dolatowski et al. 2007; Bermudez-Aguirre et al. 2011). As the ultrasonic wave travels through the fluid, the fluid is alternatively compressed and rarified, so that the particle displacements are parallel to the direction in which the wave is traveling, i.e., the wave is longitudinal. In solids, shear waves (particle displacements perpendicular to the propagation direction) can also propagate, but ultrasonic waves with this polarization will not be directly investigated here. Wavelengths of these ultrasonic waves vary with frequency, and can range from a few centimeters to a few micrometers in such media as water and biological tissues (Got et al. 1999). Ultrasound is usually pulsed, with each pulse containing at most several sinusoidal oscillations of the pressure about its average value. How an ultrasonic wave propagates through a material, such as a noodle, is a function of the elastic molecular bonds of the material's constituents (McClements 1995; Dolatowski et al. 2007; Bermudez-Aguirre et al. 2011). The speed of wave propagation, as well as its attenuation through losses, depends on the strength and character of these molecular bonds, as well as on the molecular masses and their separations; as a result, the wave speed and attenuation are a function of the material's elastic modulus and density. Thus, measurements of the ultrasonic wave characteristics of velocity and attenuation can be used to understand a material's physical properties (Coupland 2004). Those interested in using ultrasound as a non-destructive analytical tool will employ low-energy ultrasonic waves, so that the material returns to its normal physical and chemical state once the wave has passed (McClements 1995; Coupland 2004).

The objective of this paper is to demonstrate how ultrasound can be utilized as an analytical tool to investigate and discern rheological differences in raw noodle texture.

MATERIALS AND METHODS

Wheat Samples

Composites of nine varieties, grown at six sites in western Canada, representing two different Canadian wheat classes, were harvested in 2009 and used in this study. The Canada Western Red Spring (CWRS) and Canada Prairie Spring Red (CPSR) classes were selected based upon their dominance of wheat production in Canada as well as their suitability for noodle production. The CWRS wheat varieties were Harvest, 5602HR, 5603HR, Unity VB, AC Barrie, while the CPSR wheat varieties chosen were 5700PR, 5701PR, 5702PR and HY985. These varieties were selected as they provided significant, distinguishable differences in their flour protein content as well as their gluten strength (farinograph dough development time in combination with stability), within and between their respective wheat classes.

Wheat Flour Milling

Moisture levels of the cleaned samples were determined; the grain samples were pre-tempered prior to scouring and then re-tempered to 16.3% moisture for CWRS and 16.0% moisture for CPSR. Samples were milled using a laboratory-scale tandem Buhler Mill (Model MLU-202), as per Martin and Dexter (1991), and selected streams were blended to produce a 65% extraction patent flour. While Japan generally employs a 40% extraction level for its highest quality noodles, this level is seldom used outside of Japan as it is not economically viable for the majority of Asian millers selling to their noodle manufacturers. The 65% extraction level was chosen to be an optimum extraction level to allow both higher and lower extraction noodle manufacturers to assess the data and make comparisons to their own processes. The blended flour was stored in plastic buckets at 4°C until required.

Flour Analyses

Flour protein was determined using combustion nitrogen analysis using a LECO, Model FP-248 Dumas combustion nitrogen analysis analyzer (LECO Corp., St. Joseph, MI) calibrated with EDTA. Gluten strength was assessed using a Brabender Farinograph (AACC Method 54-21) whereby both dough development times (min) as well as dough stability (min) were used as indicators of gluten strength. Wet Gluten and flour ash were determined by AACC methods 38-12 and 08-01 respectively (AACC International 2010).

Noodle Preparation

All noodle samples were made under controlled environments of 24.5 ± 0.3°C and 48 ± 2% relative humidity. The 65% patent flours were used to make yellow alkaline noodles following a randomized triplicate block design. Flour (50 g), 34% water (wt/wt) and a 1% (wt/wt) 9:1 mixture of sodium carbonate (Na_2CO_3) and potassium carbonate (K_2CO_3) were mixed together using a double pin centrifuge mixer (SpeedMixer DAC 150FV, Landrum, SC) for 30 s at 3000 rpm. In order to provide a sufficient number of circular raw noodle dough discs (30) for the ultrasonic measurements of increasing levels of noodle thickness (two to seven layers), three 50-g batches of noodle dough (34% moisture, 1% alkaline) were made from the same wheat variety flour and immediately aggregated together.

The resulting aggregated dough crumbs (150 g) were sheeted using an Ohtake laboratory noodle machine (Ohtake, Tokyo, Japan) with a starting roll gap setting of 3.0 mm, folded once longitudinally after the first pass and sheeted again to laminate the noodle sheet together as per commercial practice. The noodle sheet was subsequently passed through the rollers, maintained at 28°C, seven more times, with 45-s delays between passes using a 15% reduction in thicknesses, until a final thickness of 1.1 mm was achieved as per Hatcher et al. (2008).

Once the final sheet thickness was achieved, a portion of the noodle sheet was cut into strands for standard texture tests while the remainder was cut into 4.5 cm diameter circular disks using a sharp-edged metal circular borer for ultrasonic evaluations. All samples were stored in sealed containers or plastic bags until the appropriate tests were carried out. All tests were performed after a 1-h rest period.

Ultrasonic Measurements

The ultrasonic tests were carried out using a pulse generator/receiver (Panametrics NDT Model 5072 PR, Olympus NDT Canada Ltd., AB) connected to a pair of Panametric transducers (4.4 cm diameter) with a central frequency of 40 kHz (Olympus NDT Canada Ltd., AB). The transducers were mounted on a TA-XT Plus (Texture Technologies, Scarsdale, NY) unit and a digital oscilloscope (Tektronix Digital Processing Oscilloscope model TDS 2024, Tektronix Canada Inc., Toronto, ON) was used to capture the transmitted waves, as per Fig. 1. Prior to testing, the TA-XT Plus machine was calibrated for force by placing a certified 2.0-kg mass on its load cell. Distance measurements were calibrated using a crosshead speed of 20 mm s^{-1} with a resolution of 0.01 mm as recommended by the equipment manufacturer. The various noodle layer thicknesses were determined

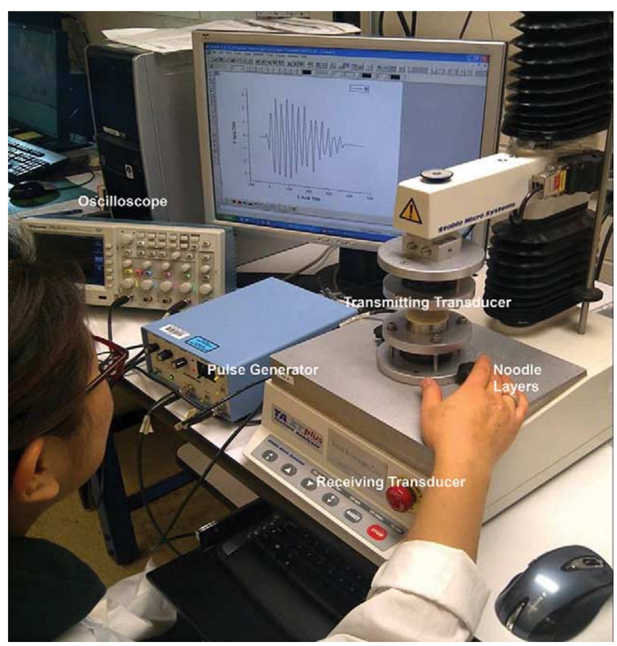

Fig. 1. Ultrasonic setup used to evaluate noodle dough sheets.

based upon the calibrated starting height of the transducer minus the distance travelled until achieving a contact force of 20 mN with the noodle layer.

Ultrasonic velocity and attenuation coefficient were measured for raw noodles of increasing sheet thickness by layering the noodle discs (4.5 cm diameter) one on top of the other, with mineral oil between layers to ensure good coupling between layers, so that the ultrasonic pulse traveled through the multilayer sample with negligible interfacial losses (Bellido and Hatcher 2011). The circular noodle sheets were kept in a sealed plastic bag at room temperature before ultrasonic measurements were made to ensure that the noodle sheets did not dry out prior to testing. Each measurement of thickness and wave propagation characteristics was made using fresh pieces of raw noodle discs to ensure no mechanical influence from the previous test.

After propagating through the noodle sample, the transmitted ultrasonic wave was detected by the receiving transducer, with the detected signal being then amplified by a signal amplifier in the pulse generator unit and averaged 120 times using the averaging function on the oscilloscope. This reduced random noise (e.g., from receiver amplifier) and increased the signal to noise ratio. Mounting of the transducers, using custom design holders, on the TA-XT Plus machine allowed for control of the distance between transducers of varying layered noodle thicknesses to a resolution of 0.01 mm.

The digitized waveforms were filtered using a wave-filtering program coded by the Ultrasonics Research Group in the Physics and Astronomy Department (University of Manitoba) using MatLab (version 8.0, Mathworks, Natick, MA). Further analysis of the filtered waves to determine wave velocities and attenuation coefficients was done using Origin software (Origin 8.5, OriginLab, Northampton, MA). Phase velocities (v) were determined by taking the reciprocal of the slope of the line fitted to a plot of the transit time of the first sinusoidal oscillation in the pulse as a function of noodle thickness (Elmehdi et al. 2004). The attenuation coefficient (α) was determined by plotting logarithmically the amplitude of the signal, as determined from the maximum or minimum value of the first sinusoidal oscillation of the wave pulse, as a function of noodle thickness. By using the following equation, which governs the dependence of the amplitude A on thickness L,

$$A(L) = A_0 \exp\,[-\alpha\, L/2], \tag{1}$$

this logarithmic plot reveals the linear decrease of log(A) with thickness, from which the attenuation coefficient α can be readily extracted. Here A_0 is the amplitude of the ultrasonic signal at the input face of the noodle sheets (at $L = 0$).

Density measurements of the raw noodle sheet samples were determined using the water displacement method and were the average of triplicate measurements. The masses of the raw noodle sheets were determined to an accuracy of ± 0.0001 g (Metler AE100). Weighed samples were placed into a 25-mL specific gravity bottle and filled with deionised water. Density was calculated based on the mass of the sample and the amount of water displaced due to the raw noodle. The mechanical properties of the noodles, M' (storage modulus), M'' (loss modulus) and tan Δ ($M''/M1$) were determined as per Elmehdi et al. (2004).

Cooked Noodle Texture Analysis (Maximum Cutting Stress)

Optimum cook time for each noodle sample was determined as per Hatcher et al. (2008) based upon four of five cooked noodle strands no longer displaying a central core when pressed between two plexiglass sheets.

Texture of cooked noodles was assessed using a TA-XT Plus (Texture Technologies, Scarsdale, NY) with a fixture and procedure similar to those described by Oh et al. (1983). Assessment of cooked noodle "bite" or firmness was determined by maximum cutting stress (MCS) as per Oh et al. (1983) with modifications (Hatcher et al. 2008). All texture tests were performed in a completely randomized design incorporating triplicate measurement for every noodle. The MCS testing of the cooked noodle began exactly 10 min after the rinse step. The texture analyzer was calibrated for force and distance (force resolution of 9.8 mN and distance resolution of 0.01 mm) prior to any texture measurements (Bellido and Hatcher 2010).

Maximum cutting stress was assessed on three strands of noodles at a test speed of 0.40 mm s^{-1} in which the probe descends a total of 4.95 mm in every MCS measurement. Cooked noodle thickness was calculated by determining the difference in probe height from the starting point of the crosshead to the point at which 20 mN force is recorded by the TA-XT Plus unit. The width of the three noodles was determined using a digital mechanical caliper. Utilizing the MCS curves, maximum peak force divided by the contact area is used to calculate noodle firmness.

Statistical Analysis

All tests were randomly replicated three times for every wheat flour variety, using fresh noodles analysed 1 h after production. All statistical analyses were carried out using SAS software (SAS Institute, Inc., Cary, NC) version 9.2. Analysis of variance (ANOVA) was determined by using Proc GLM with significance of $P = 0.05$. Correlations among means of measured variables from the various tests were done using Proc CORR in SAS software.

RESULTS

Flour and Dough Properties

Flour protein content of the samples used in this study ranged from 11.3 to 15.4%. CWRS flour ranged from 13.9% (Unity VB) to 15.4% (5602HR) while CPSR flour extended from 11.3% (5702PR) to 12.3% on a

Table 1. Flour and dough properties of wheat varieties from CWRS[z] and CPSR[y] wheat classes used for the production of fresh yellow alkaline noodles

Sample	Flour protein[x] (%)	Flour moisture (%)	Flour ash[x] (%)	Wet gluten (%)	Dough develop. time (min)	Dough stability (min)	Cooked noodle MCS (g mm^{-2})
AC Barrie[z]	14.1	15.5	0.34	41.9	10.25	21.5	38.7*b*
Harvest[z]	14.4	15.5	0.36	44.0	7.25	16.0	38.5*b*
Unity VB[z]	13.9	15.5	0.35	42.3	17.75	23.0	39.8*b*
5602HR[z]	15.4	15.5	0.36	45.6	23.75	21.5	43.0*a*
5603HR[z]	14.3	15.5	0.35	42.0	9.75	24.0	38.8*b*
HY985[y]	12.3	15.2	0.37	32.5	20.75	23.0	35.6*c*
5700PR[y]	12.3	15.2	0.34	32.2	19.25	19.0	37.7*bc*
5701PR[y]	12.3	15.1	0.36	33.4	19.75	22.5	30.3*d*
5702PR[y]	11.3	14.9	0.35	32.5	9.75	11.5	29.4*d*

[z]Canada Western Red Spring (CWRS).
[y]Canada Prairie Spring Red (CPSR).
[x]On a 14% moisture basis.
a–d Author?

14.0 m.b. (Table 1). On average, CWRS flours had approximately 2% or more flour protein than CPSR flours with correspondingly higher wet gluten content, which is responsible for dough viscoelastic behaviour. Overall, CWRS flours were found to contain an average of 10% more gluten than the CPSR flours (Table 1).

The general assumption is that flours containing higher protein content or gluten would result in stronger doughs. These varieties were specifically chosen, however, to demonstrate the evaluation of dough strength using ultrasonics, validating the approach by comparing the ultrasonic results with farinograph dough development times (DDT) and dough stability (DST). The higher protein CWRS flours were generally weaker (Harvest, 5603HR and AC Barrie) in dough strength (as assessed via DDT) than the 2% lower protein CPSR flours. Dough stability values of the ~2% lower protein CPSR flours were found to be comparable to the CWRS flours with the exception of the CPSR variety 5702PR, where the DST of this sample was the shortest among all samples tested (11.5 min). This exception is thought to be due to its ~3% lower protein content than all CWRS varieties and 1% lower flour protein content than all other CPSR samples.

The flour ash contents of all the samples investigated in this study ranged from 0.34 to 0.37%, confirming that these flours and extraction rate were acceptable for making good quality yellow alkaline Asian noodles (Akashi et al. 1999; Okusu et al. 2010).

Ultrasonic Velocities in the Noodles

The measured velocity of ultrasonic waves that propagated through noodle samples of different thicknesses were analyzed in the same manner as previous ultrasonic assessments of bread dough properties by Elmehdi (2001), Mehta et al. (2009) and Fan (2007).

Analysis of the results shows that velocity values of the ultrasonic waves travelling through the noodle samples ranged between 0.4493 and 0.5075 mm μs^{-1} (449 – 507 m s^{-1}), with noodle samples CWRS 5602HR and CPSR 5702PR displaying the highest and lowest velocities, respectively. A recent study using ultrasound to investigate noodle dough rheological properties as a function of added stiffening agents by Bellido and Hatcher (2011) showed that ultrasonic velocities were greater in noodles containing transglutaminase and increasing salt concentrations. Analysis of the noodle flour properties (Table 1) indicated that flour protein was 2% or more higher in CWRS varieties than in CPSR varieties, thus providing for more protein-protein interactions and resulting in a more entangled dough matrix. The relationship between these two parameters (flour protein and wave velocity) was found to be positive, strong and significant (0.92; $P < 0.001$) suggesting that wave velocities were influenced by flour protein content. Additionally, ANOVA comparisons of wave velocities by wheat class found that the higher protein containing CWRS wheat class noodles had significantly ($P = 0.05$) higher velocities than the CPSR wheat class noodles, supporting the concept that flour protein content may influence the speed at which sound propagates through raw noodle doughs. Care should be taken in assuming that protein content is the sole factor, however, because within the CWRS class no significant difference was found between Harvest (14.4% protein) and Unity (13.9% protein) wave velocities. Additionally, within CPSR varieties, three varieties exhibited identical protein content, 12.3%, yet 5701PR displayed a significantly higher velocity than either 5700PR or HY985 and was statistically equivalent to CWRS variety Unity VB (13.9% protein).

These specific comparisons of different varieties within the two wheat classes suggest that flour protein content may not be entirely responsible (despite strong correlations) for higher wave velocities, as indicated especially by CPSR 5701PR. It may be that specific higher quality proteins exist in this variety, because farinograph DDT and DST are comparable with those of much higher protein CWRS samples (Table 1). Because all of the CPSR and CWRS varieties have the same high molecular weight glutenin subunit composition (Dr. O. Lukow, Cereal Research Centre, Agriculture and Agri-Food Canada, personal communication), these findings suggest that the low molecular weight protein glutenin components and/or gliadins of 5701PR may be responsible for generating a more developed dough matrix, thus forming a structure that is comparable in stiffness with higher protein containing samples.

Attenuation Coefficient of Ultrasonic Waves Propagating Through Raw Noodles

Attenuation coefficients for all nine raw noodle samples were determined by logarithmically plotting the amplitude of the first-arriving minimum oscillation in the transmitted waveforms as a function of noodle thickness (Fig. 3).

The slope, $-0.434\alpha/2$, of a linear fit to log[A(L)] versus L (e.g., see Fig. 2) was used to determine the attenuation coefficient, α, of all samples investigated in this study. Figure 4 highlights the measured attenuation coefficient values for the raw noodle samples.

The attenuation coefficient (α) values of the raw noodles ranged between 0.4484 and 0.5870 mm^{-1} (448–587 m^{-1}), with CWRS 5603HR and CPSR HY985 being the most and least attenuating samples, respectively. The CWRS noodle samples were observed to be more attenuating than CPSR noodle samples. This may be due to the higher protein content in the CWRS samples, giving them a more developed dough matrix, thereby causing greater absorption or scattering of energy from the propagating ultrasonic waves. Interestingly, the CWRS noodles prepared from AC Barrie and Unity VB do not conform to this observed trend and were significantly ($P = 0.05$) lower in attenuation than the other CWRS varieties, being comparable with CPSR variety 5701PR. As well, the AC Barrie attenuation, while higher, was also not significantly different from that of CPSR variety 5702PR. The lack of differentiation of attenuation solely on protein content (5702PR has 2.8% less protein that AC Barrie) lends further credence to the idea that there may be an additional underlying factor that is affecting attenuation in the different varieties.

Elmehdi et al. (2004) and Mehta et al. (2009) showed that wheat doughs mixed under vacuum were less attenuating than those which were mixed in open air. It has been suggested by many researchers (e.g., Kidmose et al. 2001; Coupland 2004; Garcia-Alvarez et al. 2005) and demonstrated directly by Leroy et al. (2008a,b) that intracellular air spaces are largely responsible for the high attenuation observed in the frequency range of 50 kHz to 5 MHz, suggesting that entrapped air could possibly explain why the CWRS noodle samples were more attenuative.

It is acknowledged that while the multiple sheeting passes (seven) in noodle manufacturing would substantially decrease the amount of air trapped in the dough crumbs as a result of mixing, it may not entirely eliminate all the small microscopic bubbles within the dough matrix. Elmehdi et al. (2004) and Leroy et al. (2008a) showed that air-free dough mixed under vacuum had a density value of approximately 1290 kg m^{-3}. Recognizing that moisture content is significantly higher in bread dough than noodles, which in itself might be expected to decrease bread dough density relative to noodle dough, all of the noodle dough samples used in this study exhibited lower densities (1270–1281 kg m^{-3}) than their reported value for vacuum-mixed bread

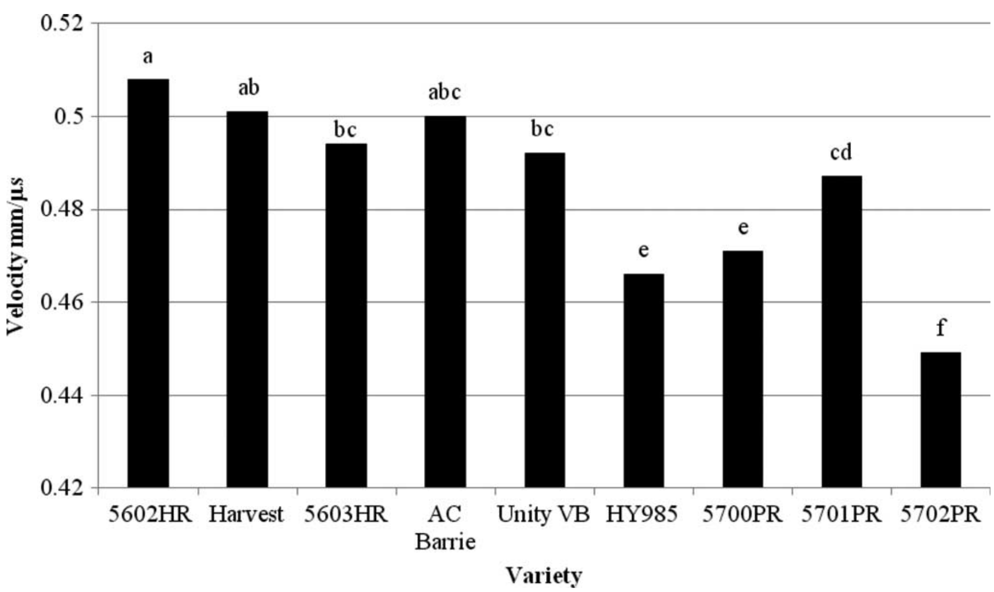

Fig. 2. Velocities of all wheat variety raw noodle samples. Bars with different letters are significantly different at the $P = 0.05$ level.

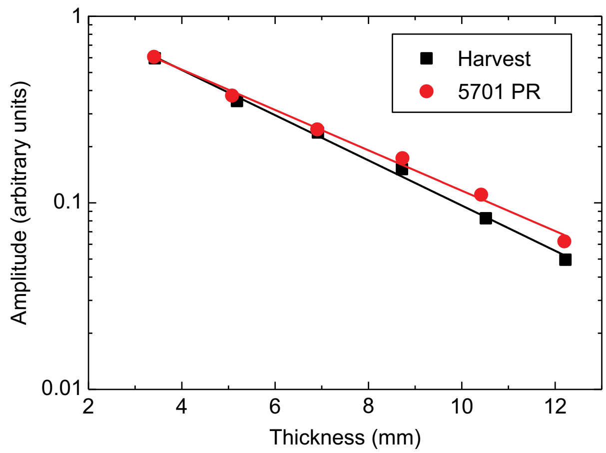

Fig. 3. Log plot of amplitude versus dough thickness for Harvest and 5701 PR varieties. The amplitude was measured at the first minimum of the transmitted waveform. The solid lines are least squares fits of a straight line to the logarithm of the amplitude.

dough, suggesting the presence of tiny air bubbles in our sheeted noodle doughs. However no meaningful correlation was detected between attenuation and noodle specific density.

Raw Noodle Dough Rheological Properties Derived from Ultrasonic Wave Properties

Measured frequency-dependent wave velocities and attenuation coefficients can be utilized in conjunction with their density to calculate the longitudinal modulus of raw noodle dough, broken into the storage or elastic modulus (M′) and the loss modulus (M″) (Elmehdi et al. 2004; Mehta et al. 2009). Bellido and Hatcher (2011) utilized these parameters, derived from ultrasonic characteristics of durum and common wheat raw noodle doughs, to study rheological behaviour and discern differences.

The calculated storage moduli of this study's raw noodles ranged from 117 to 167 MPa at a frequency of 40 kHz (Fig. 5). These values of M' are of similar magnitude to those reported by Bellido and Hatcher (2011) for common and durum wheat noodles.

CWRS 5603HR and CPSR HY985 were observed to have the lowest and highest calculated storage (elastic) moduli, respectively. Surprisingly the CPSR noodles HY985, 5700PR and 5701PR were comparable, if not more elastic (firmer) in behaviour than the CWRS noodle varieties 5602HR, Harvest and 5603HR that contain 2–3% more protein.

Loss Modulus (M″) of Raw Noodle Doughs

Loss moduli were determined for the noodle samples and ranged between 159 and 214 MPa. These values are consistent with results from Bellido and Hatcher (2011). The CWRS variety 5602HR exhibited the highest loss modulus, while the noodles prepared from CPSR variety 5702PR displayed the smallest (Fig. 4). All of the raw CWRS noodle samples had larger loss moduli than the CPSR noodle samples with the exception of CPSR noodle variety 5701PR. Furthermore, comparison of M″ values of raw noodle doughs by wheat class, indicated that CWRS class noodles dissipated more energy as a result of their more viscous nature.

calculated Tan Δ Values of Raw Noodle Doughs

Calculation of tan Δ (or M″M″) can provide further insight into the mechanical behaviour of raw noodle doughs. The tan Δ values are shown in Fig. 6.

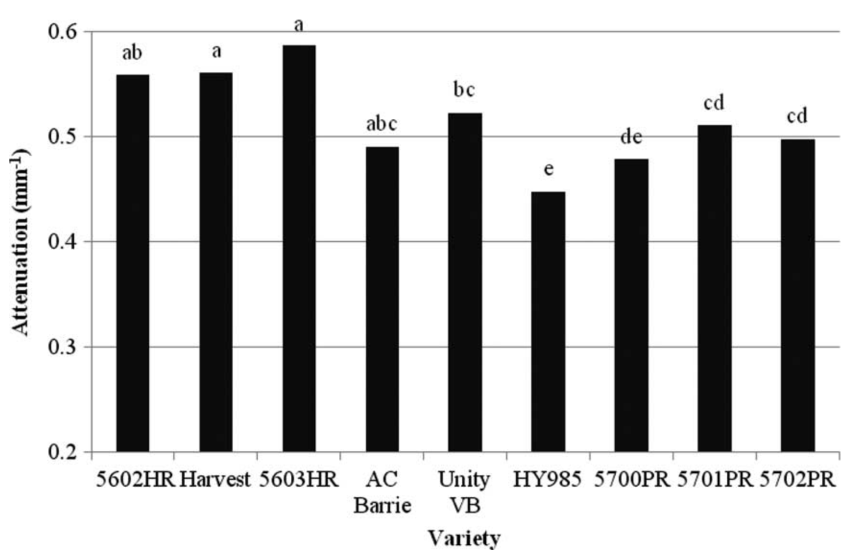

Fig. 4. Attenuation coefficient (α) values for the raw noodle samples. Bars with different letters are significantly different at the $P =$ 0.05 level.

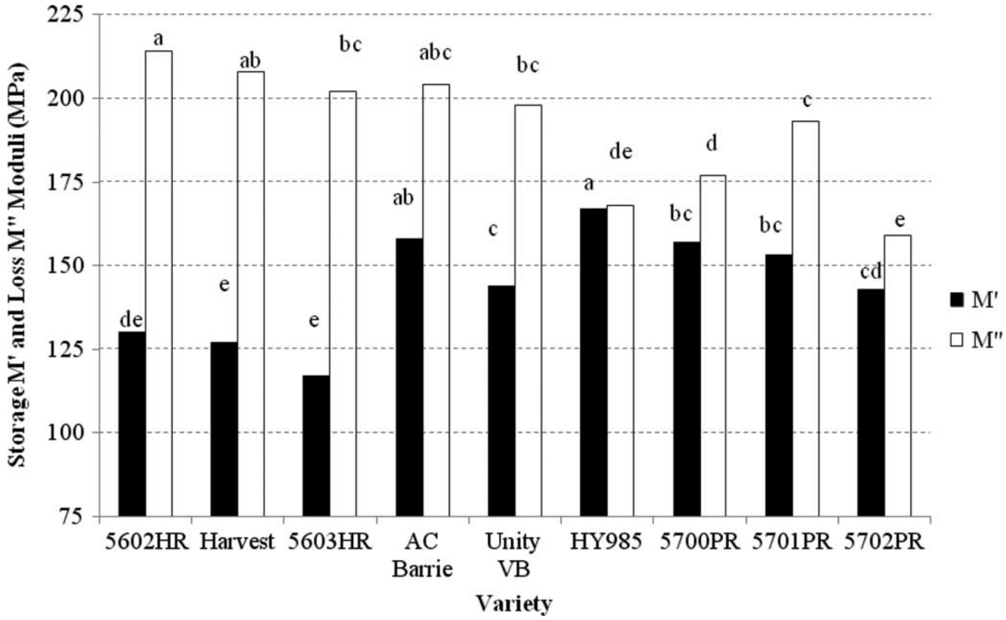

Fig. 5. Storage (elastic) (M′) and loss (viscous) (M″) longitudinal moduli of raw noodles of named wheat varieties. Bars with different letters are significantly different at the $P = 0.05$ level.

The calculated tan Δ values for the raw noodle discs ranged from 1.00 to 1.72 and are slightly lower than those reported by Bellido and Hatcher (2011) for similar material. The behaviour of a material is more elastic when tan Δ value is lower (Bellido and Hatcher 2011). Of the nine varieties evaluated, CPSR HY985 had the lowest tan Δ value, thus exhibiting the most elastic behaviour. Although it would be assumed that the higher protein containing CWRS noodle samples would be more elastic in behaviour, these findings again support the idea that it is the nature of the flour proteins associated with the CPSR noodles themselves, i.e., either the low molecular weight glutenin and/or the gliadin component, that is responsible for the more elastic behaviour (lower tan Δ values). While CWRS varieties have a proven record of producing good bread-making

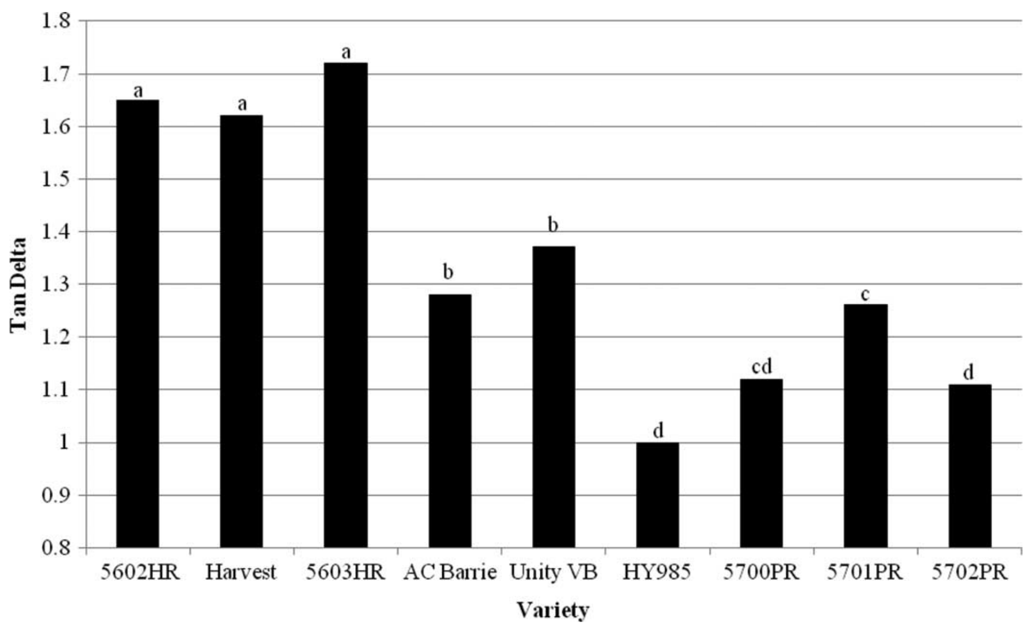

Fig. 6. Tan Δ values for all wheat raw noodle samples. Bars with different letters are significantly different at the $P = 0.05$ level.

flours, their composition may not be optimum for the production of yellow alkaline noodles.

Statistical analysis of tan Δ values by wheat class indicates that CPSR class noodles exhibited significantly ($P = 0.05$) more elastic behaviour than CWRS variety noodles. Additionally, this analysis also revealed that AC Barrie and Unity, while of equivalent protein to other CWRS varieties, were significantly different in terms of tan Δ, confirming the critical nature of the quality of the protein components to noodle performance.

Cooked Noodle Texture (MCS)

Examination of the cooked noodle texture characteristic (Table 1) indicated extremes in MCS, matching the maximum and minimum protein content of the noodle flours and consistent with the premise that increasing protein improves noodle texture (Miskelly and Moss 1985). The correlation between MCS and protein content was strong ($r = 0.87$) and significant ($P = 0.002$). However, upon closer inspection it was noted that Unity, while having the second highest MCS value, had significantly lower protein, at 13.9%, than other CWRS varieties. Additionally, the CPSR variety 5700PR exhibited an equivalent MCS value to all but the highest protein CWRS variety, yet had only a 12.3% protein content. The impact of the nature of the flour protein quality was also evident by the finding that CPSR variety 5701 PR, at the identical 12.3% protein content, displayed a dramatic and significantly lower MCS value than all other CPSR varieties at the same protein content.

Recognizing that the MCS test was performed on a cooked noodle, which has both its protein and starch matrix denatured by the cooking process, it was of interest to note that a significant correlation did exist between MCS and the raw noodle velocity value ($r = 0.72$, $P = 0.03$). as well as M″ ($r = 0.70$, $P = 0.03$). No significant relationship ($P < 0.05$), however, was detected between MCS and M′ although a modest correlation with tan Δ ($r = 0.60$, but $P = 0.09$) was observed. No relationship between MCS and gluten strength characteristics assessed by Farinograph DDT or stability (DST) were noted.

CONCLUSION

The data presented in this paper indicate that ultrasonic measurements can be used to discriminate between noodle flours based upon sensitivity to raw noodle fundamental rheological properties. It was anticipated that, in general, the higher protein CWRS varieties would exhibit higher velocity than the 2% lower protein CPSR varieties. It was, however, unexpected to observe higher storage (M′) and lower loss (M″) moduli in the CPSR varieties, with both of these mechanical parameters discriminating varieties within their own class, even at equivalent protein content. Furthermore, the finding that the significantly lower protein CPSR class varieties generally produced noodles of a more elastic, firmer nature (tan Δ) than their CWRS counterparts was unexpected. The fact that the cooked noodle texture parameter MCS, in spite of the denaturing cooking process, significantly correlated with raw noodle ultrasonic wave velocity and M″, does suggest ultrasonics can offer discrimination even in a modified denatured product.

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