Using ultrasound to characterize fresh yellow alkaline noodles

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Summary of research

Researchers at the Canadian Grain Commission evaluated using low-intensity ultrasound to characterize changes in the mechanical properties of fresh yellow alkaline noodles prepared with different ingredients (Bellido & Hatcher, 2009a). Their research found that the ultrasonic technique could provide technologically relevant information about the rheological properties of fresh noodles. It is a simple and reliable way to determine important textural parameters of yellow alkaline noodles and distinguish between them.

To compare the results of ultrasonic testing with a commonly-used test, the researchers evaluated samples of fresh noodles using stress relaxation testing. Results from these tests showed that ultrasonic velocity increased and attenuation decreased ($p<0.05$) with either an increase of sodium chloride concentration (1 to 3%, flour basis) or the addition of 2% transglutaminase to the fresh noodle formula. These changes to the fresh noodle formula gave the noodles increased mechanical strength. This increased strength was shown by changes in the longitudinal mechanical moduli (a modulus derived from applying ultrasonic waves as the external, probing force).

The velocity, attenuation and storage mechanical modulus obtained from ultrasonic experiments were correlated with the maximum stress detected by stress relaxation tests the researchers performed on the noodle samples.

Making yellow alkaline noodles

Yellow alkaline noodles are an important part of Asian cuisine and are economically significant. Because each region has its own preferred recipe, noodles can vary in composition depending on where they are made. However, the most common types are made with:

- Flour
- Water
- Alkaline salts (primarily sodium and potassium carbonates or kansui)
- Sodium chloride (salt) as desired (Hatcher, 2001)

The type and quality of wheat flour used affects how the noodle dough is processed and the quality of the dough and the noodles (Hatcher, Edwards, & Dexter, 2001; Hatcher et al., 2008b; Bellido & Hatcher, 2009b).

Low-intensity ultrasound

Traditionally, noodle manufacturers have used sensory panels to assess noodle texture. Sensory panels are groups of experts who assess the taste, smell or feel of products. Using a sensory panel is inadequate for quality control purposes in a high-throughput mechanized factory environment.

Low-intensity ultrasonic techniques have been used to learn about the material characteristics of a product for years (Povey, 1997). In this technique:

- A sound wave is transmitted through a material.
- The interaction of the wave with the material is quantified in terms of ultrasonic velocity and attenuation.

The researchers related the ultrasonic parameters to the mechanical properties and microstructure of the noodles. They used mathematical theory describing wave propagation in model food systems that are structurally similar to noodles (Bloksma & Bushuk). Using a wide range of ultrasonic frequencies it would be possible to probe structures in the food material with different length scales (Elmehdi, 2001; Bellido, 2007; Leroy et al., 2008), though at this initial stage a single frequency of 50 kHz was used.

Low-intensity ultrasound does not change the properties of food material, even though enough energy is transmitted to capture the properties of the food material. In addition, it permits probing opaque materials such as dough, unlike light scattering or other light propagation-based techniques.

Even though low-intensity ultrasound is potentially useful in a manufacturing environment, the food industry has not made much use of it. Currently, the industry does not use low-intensity ultrasound to monitor the quality of wheat-based products (Povey, 1997; Scanlon, 2004). Previous studies by other researchers have found that low-intensity ultrasonic techniques are sensitive to changes in the mechanical properties of dough caused by:

- The presence and growth of gas bubbles of various sizes during fermentation
- The use of various levels of water and salts (Létang et al., 2001; Elmehdi, Page & Scanlon, 2004; Bellido, 2007; Leroy et al., 2008)

Attempts to use ultrasound to see differences between doughs made from different kinds of wheat have shown mixed degrees of success (Kidmose, Pedersen & Nielsen, 2001; Alava et al., 2007; Hatcher et al., 2008b).

Experiment to test ultrasonic characterization

Materials used in the experiment

To evaluate the sensitivity of ultrasound to changes in the mechanical properties of fresh yellow alkaline noodles, researchers prepared noodles with different ingredients, including:

- 2 different classes of Canadian wheat flour (hard white spring and durum wheat flour)
- 3 different additive treatments including transglutaminase

Transglutaminase catalyzes acyl-transfer reactions between peptide-bound glutamyl residues and ε-amino groups of lysine residues, producing non-disulphide covalent cross-links between proteins. This enzymatic protein cross-linking is expected to stiffen the gluten protein structure (Basman, Koksel & Ng, 2002; Autio et al., 2005).

Flour

The researchers used durum flour and hard spring wheat flour.

To make durum flour, the researchers:

- Milled AC Strongfield, a variety of Canada Western Amber Durum (CWAD) wheat into semolina
- Reduced the semolina into straight-grade flour (Hatcher et al., 2008b)

To make hard white spring wheat flour, the researchers milled a composite (more than 99%) of multiple samples of the Snowbird variety of Canada Western Hard Spring wheat (CWHWS) into straight-grade flour of 74% extraction. (Hatcher et al., 2008b) To minimize the effect of flour particle size on noodle quality, they milled and bolted both flours over 132 μm sieves to ensure comparable particle size distributions (Hatcher et al., 2008b).

The researchers determined the protein content (%N x 5.7) with combustion nitrogen analysis. Using American Association of Cereal Chemists Approved Methods (AACC, 2000) they determined gluten index, ash content and Rapid Visco Analysis flour pasting parameters.

Noodles

Using an asymmetrical speed mixer, the researchers mixed the following:

- 50 grams of flour
- Sodium chloride
- Transglutaminase enzyme with kansui (depending on the treatment)

The levels of salt, kansui and transglutaminase in the experimental noodle formulas (w/w, flour basis) were:

- SK1 = 1% NaCl + 1% kansui
- SK2 = 3% NaCl + 1% kansui
- SKT = 1% NaCl + 1% kansui + 2% transglutaminase

To make the noodle specimens, the researchers:

- Sheeted the dough on a laboratory noodle machine with an initial gap setting of 3.0 mm, folded longitudinally, and re-sheeted to duplicate the lamination process used by commercial noodle manufacturers.
- Took the resulting sheet through 7 further reductions (Kruger, Anderson & Dexter, 1994)on the machine with rolls maintained at 28°C. They incorporated a 45-second delay between passages to improve sample reproducibility.
- Cut disks (5 cm diameter) from the noodle sheet using a sharp-edged metal borer. They obtained 9 specimens from each noodle sheet and divided these into 3 groups:
    - 5 specimens – used to obtain 5 ultrasonic measurements at different thicknesses
    - 1 specimen – used for stress relaxation measurements
    - 3 specimens – used for density measurements
- Allowed the specimens rest at room temperature (22°C) for 1 hour. This allows the transglutaminase enzyme to activate when incorporated into wheat flour dough (Alava et al., 2007).

Noodle temperature during rheological measurements was 23°C.

Methods used in the experiment

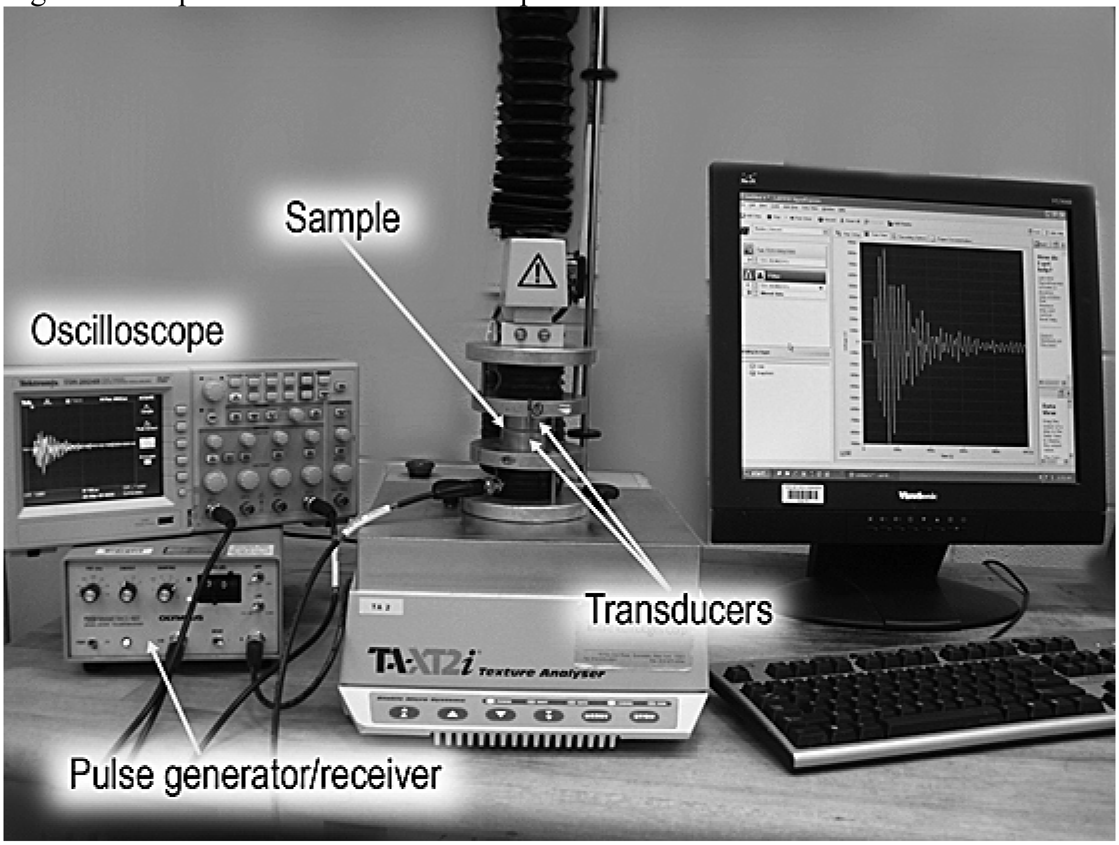
In order to understand how effective ultrasonic testing was at discriminating the texture of fresh noodles, the researchers compared the measurements from the ultrasonic testing with the results from a stress relaxation test. To interpret the results, the researchers conducted a statistical analysis.

Rheological measurements using ultrasound

The experimental set-up was

- An ultrasonic pulse generator/receiver
- A pair of transducers with a central frequency of 40 kHz
- A digital oscilloscope

Figure 1 – Experimental ultrasonic set-up



To measure ultrasonic properties, the researchers:

1. Obtained noodle samples with varying thicknesses by stacking
2. Excited the transmitted transducer with a short positive voltage spike generated from the ultrasonic pulse generator/receiver to produce an ultrasonic pulse that was transmitted through the noodle specimen. The second transducer (receiver) detected the pulse.
3. Amplified the transmitted pulse with a signal amplifier in the ultrasonic pulse generator/receiver, and averaged the transmitted pulse (120 times) using the average function of the oscilloscope. This reduced random noise and increased the signal-to-noise ratio.
4. After being downloaded to a computer, the pulse was filtered (bandwidth 30 – 50 kHz) and the pulse's transit time and amplitude was taken from the first dip of each filtered waveform.
5. Determined the ultrasonic velocity from the plots of the transit time of the ultrasonic pulse against dough thickness.
6. Obtained the signal attenuation coefficient from a plot of the intensity of ultrasonic signal as a function of dough thickness.

Stress relaxation test

The researchers carried out stress relaxation measurements using a texture analyzer.

1. Dough specimens were compressed between compression platens.
2. Stress relaxation was measured under uniaxial compression.
3. Fresh noodles were decompressed to 20% of original thickness and the stress required to keep this degree of deformation for 1 minute (Bellido & Hatcher, 2009b).
4. From the stress relaxation curves, the maximum compression stress (σ_{max}) in kPa, the dimensionless parameters *S** (area under the stress relaxation curve) and overall residual stress (*P**) were obtained (Bellido & Hatcher, 2009b).
    - (1/*S**) is the reciprocal of *S**and is indicative of the overall rate of relaxation.
    - (*P**) is the overall residual stress and is indicative of the residual stress in the sample.
    - A higher overall rate of relaxation and a higher overall residual stress are typical of soft solid foods with a greater elastic-like behaviour (Bellido & Hatcher, 2009b).

Density measurements

Density is needed to calculate:

- Modulus of noodles
- Ultrasonic velocity
- Ultrasonic attenuation.

The researchers measured density based on the principle of water displacement (Bellido et al., 2009).

Statistical analysis

The researchers completed a statistical analysis of their findings to understand how the results from ultrasonic testing compared to those from stress relaxation. To complete their statistical analysis, the researchers:

1. Replicated all of the tests 3 times (n=3) using a batch of freshly prepared noodles for each test.
2. Determined analysis of variance (ANOVA) using the General Linear Model (GLM) of SAS.
3. Used Fischer's Lease Significant Difference (LSD) test to compare the mean values of parameters obtained from:
    - Density and ultrasonic measurements (ultrasonic velocity, attenuation, storage modulus, loss modulus, ratio of loss to storage modulus)
    - Stress relaxation measurements (maximum stress, average rate of relaxation and residual stress).

Note: The use of significance was $p<0.05$, unless stated otherwise.

Discussion about the results of the experiment

This study shows that ultrasound is capable of:

- Characterizing the rheological behaviour of noodles from a non-empirical (objective) perspective
- Responding to a parameter of technological interest. Example: Maximum compress stress relates to noodle firmness (Bellido et al., 2006) and it is well correlated with sensory scores on the force required to compress a noodle between the molars (Oh et al., 1983)

Flour characteristics

Table 1 shows the chemical and physical characteristics of the flour used to make the noodle specimens.

- Both flours had equivalent protein contents and gluten indices.
- Ash content of the amber durum flour is higher than that of the hard white spring flour. Higher ash content is typical when yellow pigment-rich durum wheat is milled into flour.
- Durum flour had significantly greater Farinograph water absorption capacity because of the starch damage caused by milling the harder durum wheat into flour. Rapid Visco Analyzer tests also showed this higher starch damage because durum flour resulted in a paste with reduced peak viscosity and final viscosity.
- Excessive starch damage is undesirable in noodles made from bread wheat flour (Hatcher, Edwards & Dexter, 2008a). However, high starch damage in durum flour has less of an effect on noodles made from it (Hatcher, Edwards & Dexter, 2008a).

Table 1 – Proximate analyses of the experimental wheat (Canada Western Hard White Spring (CWHWS) and Canada Western Amber Durum (CWAD)) flours used for the production of fresh yellow alkaline noodles.

Analysis	CWHWS	CWAD	LSD[b]
Analytical			
Protein content (CNA[a]), %	13.2	13.1	-
Gluten index, %	95.8	93.6	-
Ash Content, %	0.41	0.62	-
Moisture (w.b.), %	14.9	14.2	-
Farinogram			
Absorption, %	62.4	76.4	-
Dough Development Time, min	10.0	4.3	-
Stability, min	14.8	5.8	-
RVA Pasting and Swellling Parameters[c]			
Peak Viscosity, Pa s	3.117	2.203	0.051
Trough, Pa s	1.725	1.324	0.031
Breakdown, Pa s	1.391	0.879	0.061
Final viscosity, Pa s	3.130	2.712	0.032
Setback, Pa s	1.306	1.388	0.042
Stability ratio	0.81	0.40	0.02
Setback ratio	0.45	1.05	0.05

(a) Combustion nitrogen analysis
(b) Least significant difference (p=0.05)
(c) Breakdown = (Peak Viscosity – Hot Peak Viscosity);
Setback = (Cool Paste Viscosity – Hot Peak Viscosity);
Stability ratio = [(Final Viscosity – Trough)/Trough];
Setback ratio = [(Peak Viscosity – Trough)/Peak Viscosity].

Ultrasonic properties

It is possible to use ultrasonic velocity measurements to investigate and quantify the effects various ingredients have on the physical properties of yellow alkaline noodles (Figure 3A). The researchers found that the velocity of the ultrasound wave increased significantly in either type of noodle after either the SK2 or SKT treatments relative to a control treatment.

Figure 3A

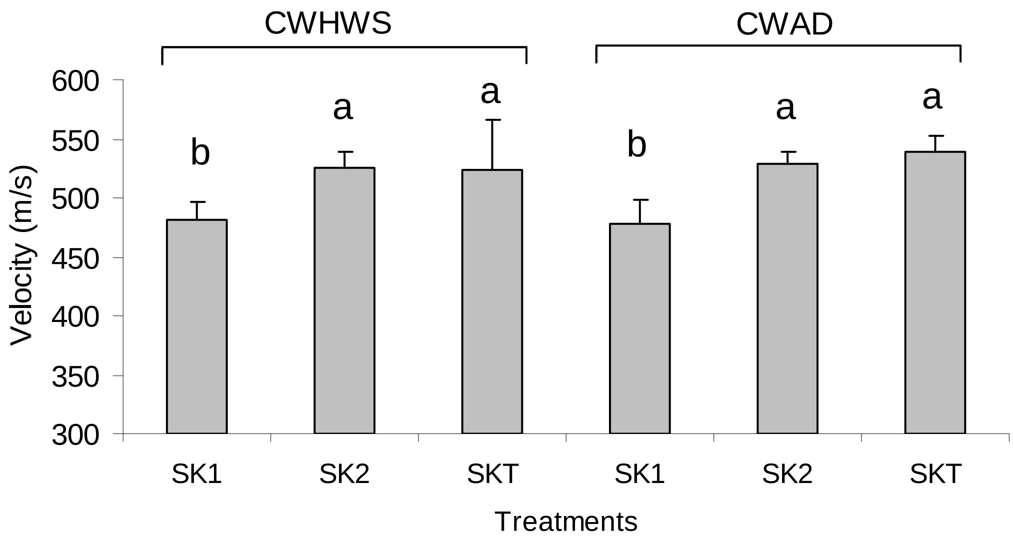
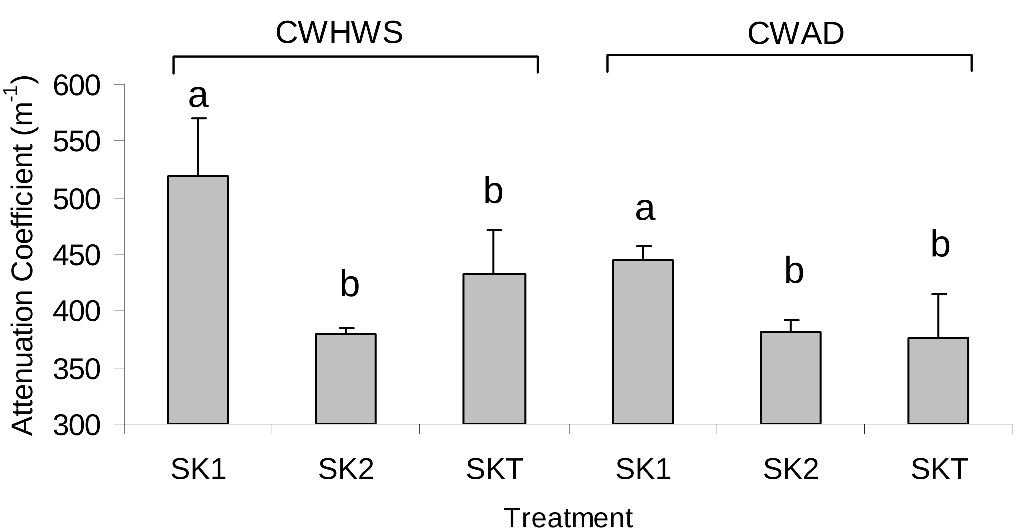


Figure 3 – Ultrasonic velocity (A) and attenuation (B) obtained from fresh YAN noodles formulated with CWHWS or CWAD wheat flour and with different combinations of ingredients. SK1= 1% NaCl + 1% *kansui*, SK2= 3% NaCl + 1% *kansui* and SKT=1% NaCl + 1% *kansui* + 2% transglutaminase.

Figure 3B



Because ultrasonic velocity is greater in stiffer materials, ultrasonic velocity appeared to be sensitive to the stiffening effects of sodium chloride (Bloksma & Bushuk, 1988) and transglutaminase (Autio et al., 2005; Steffolani et al., 2008) on dough rheology. However, the ultrasonic data showed that ultrasonic velocity measurements could not discriminate differences in the properties of noodles made from 2 different classes of wheat. This is consistent with findings from earlier ultrasonic studies on bread dough (Kidmose, Pedersen & Nielsen, 2001).

The researchers decided that the ultrasonic technique yields velocity measurements free from artifacts. They determined ultrasonic velocity from the inverse slope of the best-fit line passing through the plotted data (Figure 2A). The excellent fit of the straight line ($R^2 = 0.997$) shows that the effects on transit times due to stacking the noodle specimens were too small to be detected by the researchers' experiments.

Figure 2A

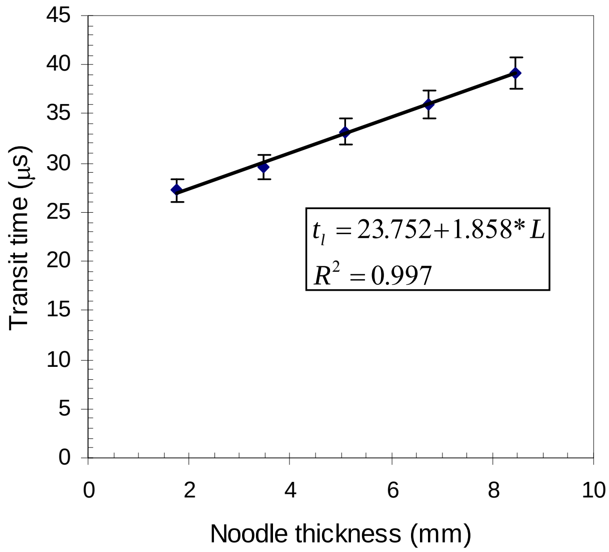
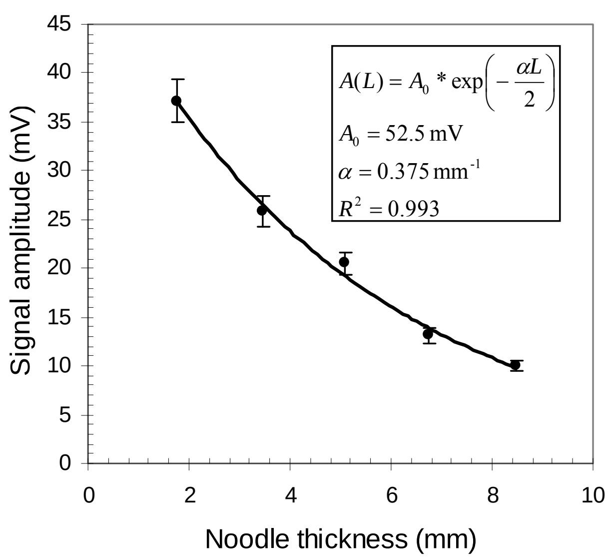


Figure 2 – Pulse time of flight (A) and ultrasonic signal amplitude (B) as a function of sample thickness for fresh YAN doughs made from two wheat classes and various ingredients (fwb), as illustrated here for CWAD dough formulated with SKT treatment (1% NaCl + 1% kansui and 2% transglutaminase). Error bars denote SD (n=3). See text for details.

Figure 2B



Attenuation coefficient

The researchers found that ultrasonic attenuation in fresh noodles was smaller in noodles that had been prepared with additional salt (SK2) and transglutaminase (SKT) (Figure 2B). The attenuation data shows that the dough samples became stiffer after salt was added, just as the ultrasonic velocity data showed. The dough samples also became stiffer after transglutaminase was added as shown in the ultrasonic velocity data.

Mechanical properties obtained from ultrasonic measurements

Table 2 shows the mechanical properties for the experimental yellow alkaline noodles derived from the density and ultrasonic measurements at a frequency of 40 kHz. Results show that:

- Ultrasound was sensitive to changes in the mechanical properties of yellow alkaline noodles caused by adding either:
  - More sodium chloride (SK2 versus SK1)
  - Tansglutaminase enzyme (SKT versus SK1).
- Noodles made with SK2 and SKT had a significantly higher ($p<0.05$) higher mechanical modulus than noodles made with SK1.

When transglutaminase enzyme was used in the noodles, the elastic component of the longitudinal modulus was sensitive to the stiffening effects of salt and the transglutaminase enzyme. M' values increased by nearly 30%.

Ultrasound analysis of viscoelastic behaviour of noodle showed that when compared to the standard formula (SK1), dough made from SK2 or SKT and hard white spring wheat flour resulted in noodles with more elastic-like behaviour (as measured by a lower M"/M' ratio) (Table 2). This effect was not seen in noodles made with durum wheat flour.

The researchers proposed in an earlier study (Bellido & Hatcher, 2009b) that because a relatively smaller fraction of disulfide bonds participate in cross-linking the network protein structure of proteins in amber durum, the rheological properties of noodles made from durum wheat flour would be less susceptible to the cleavage of the disulphide bonds caused by L-cysteine. Similarly, one interpretation of the observed differences in the M"/M' ratio for durum wheat and hard white spring wheat noodles (Table 2) is that transglutaminase did not bring about as much of a change in the viscoelasticity of durum wheat noodles because durum wheat has a lower fraction of gluten proteins with a high molecular weight (hence a lower number of intermolecular disulfide bonds in its protein newtwork) than hard white spring wheat.

Table 2 – Density, storage modulus (*M'*), loss modulus (*M"*) and ratio *M"*/*M'* for fresh YAN made from two classes of Canadian wheat (Canada Western Hard White Spring and Canada Western Amber Durum) flour and different combinations of salts and/or an enzyme. SK1= 1% NaCl + 1% *kansui*, SK2= 3% NaCl + 1% *kansui* and SKT=1% NaCl + 1% *kansui* + 2% transglutaminase.

Treatment	Density (kg/m^3) [1]	*M'* (MPa) [1,2]	*M"* (MPa) [1,2]	*M"/M'* [1,2]
CWHWS				
SK1	1262 ± 23 b	231 ± 95 b	286 ± 23 ab	1.24 ± 0.05 a
SK2	1265 ± 14 b	300 ± 26 a	285 ± 15 ab	0.96 ± 0.12 c
SKT	1303 ± 18 a	296 ± 48 a	326 ± 61 a	1.10 ± 0.07 b
CWAD				
SK1	1277 ± 8 ab	245 ± 21 b	251 ± 28 b	1.02 ± 0.03 bc
SK2	1260 ± 20 b	301 ± 13 a	291 ± 79 ab	0.97 ± 0.03 bc
SKT	1281 ± 2 ab	317 ± 21 a	307 ± 29 ab	0.97 ± 0.01 bc
$LSD_{0.05}$	28	47	57	0.14

(1) Values within the same column with different letters are significantly different at $p<0.05$.
(2) Values derived from triplicate measurements of ultrasonic velocity and attenuation.

Stress relaxation testing

Canadian Grain Commission researchers used 3 parameters to characterize the stress relaxation behaviour of YAN:

- Maximum compress stress (σ_{max})
- Overall rate of relaxation (1/*S**)
- Residual stress (*P**)

Stress relaxation testing showed that SK2 and SKT treatments produced firmer noodle doughs than the SKI treatment (Table 3). This result is similar to the rheological information obtained from the ultrasonic experiments (Table 2).

Table 3 – Maximum compression stress (σ_{max}), overall rate of relaxation (1/*S**) and residual stress (P^*) obtained from stress relaxation testing of fresh YAN made from two classes of Canadian wheat flour and different combinations of ingredients. SK1= 1% NaCl + 1% kansui, SK2= 3% NaCl + 1% kansui and SKT=1% NaCl + 1% kansui+ 2% transglutaminase.

Treatment	σ_{max} (kPa) [1,2]	*1/S** [1,2]	*P** [1,2]
CWHWS			
SK1	18.9 ± 0.3 c	1.37 ± 0.01 a	0.68 ± 0.01 b
SK2	21.8 ± 1.5 ab	1.42 ± 0.05 a	0.65 ± 0.01 c
SKT	22.4 ± 0.4 a	1.42 ± 0.03 a	0.66 ± 0.01 bc
CWAD			
SK1	20.2 ± 0.4 bc	1.24 ± 0.03 b	0.77 ± 0.02 a
SK2	21.3 ± 1.8 ab	1.21 ± 0.01 b	0.79 ± 0.01 a
SKT	21.4 ± 1.4 ab	1.22 ± 0.02 b	0.78 ± 0.01 a
	2.1	0.05	0.02

(1) Values within the same column with different letters are significantly different at $p<0.05$.
(2) Values derived from triplicate measurements.

Stress relaxation testing showed that durum wheat flour yielded noodles with stronger elastic-like behaviour (greater overall rate of relaxation and residual stress) than hard white spring wheat flour. The greater elastic-like mechanical behaviour of durum wheat noodles compared to hard white spring wheat noodles was also captured by the ultrasonic parameter measuring viscoelastic behaviour (M'/M'; Table 2). However, statistical analysis for the pooled data showed that the correlation between these parameters (overall rate of relaxation, residual stress, M"/M') were not strong enough to be statistically significant (Table 4).

Table 4 – Correlation Coefficients (*R*) and Probability Values[1] (*p*) between Stress Relaxation and Ultrasonic Rheological Parameters.

	Maximum Stress	1/*S**	*P**
Velocity (*v*)	0.529 *0.024*	-0.034 *ns*	0.025 *ns*
Attenuation (α)	-0.537 *0.022*	0.246 *ns*	-0.291 *ns*
Density (ρ)	0.201 *ns*	0.259 *ns*	-0.169 *ns*
M'	0.566 *0.014*	-0.078 *ns*	0.098 *ns*
M"	0.304 *ns*	0.180 *ns*	-0.226 *ns*
M"/M'	-0.410 *0.091*	0.316 *ns*	-0.382 *ns*
M	0.485 *0.041*	0.059 *ns*	-0.070 *ns*

[1]*ns* denotes not significant at 5% of probability.

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Glossary of terms

Attenuation – Degree the strength of a sound wave is weakened by the material with which it is interacting.

Kansui – Blend of sodium and potassium carbonate salts which make a noodle alkaline. Causes flavonoids in wheat to turn yellow. Consumers prefer yellow noodles.

Modulus – Magnitude of a physical constant representing the capacity of a material for resisting deformation when subjected to external force.
$p<0.05$: Signifies that 2 treatments yielded statistically different results.

Rheology – Science of the deformation and flow of matter. Used to explain how the properties of a material affect its deformation and flow under external forces. Example: Rheology would explain how a sensory response such as bread firmness is related to its physical behaviour under compression testing. Example: Maximum force is registered at 20% compression.

Texture – Structural arrange of the components of a food and the stimuli that this structure imparts to the human sensory apparatus.

Transglutaminase – An enzyme. Causes proteins to link, stiffening the gluten protein structure in noodles.

Velocity – How fast the sound wave can travel in a material.

Viscoelastic – A material displaying properties between those of liquid (viscous) and solid (elastic) materials.

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