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APPLICATION OF ULTRASOUND TO THE EVALUATION OF RHEOLOGICAL PROPERTIES OF RAW ASIAN NOODLES FORTIFIED WITH BARLEY β-GLUCAN

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ABSTRACT

An ultrasonic technique (1 MHz) was employed to investigate the capability of ultrasound to evaluate barley β-glucan (BBG) supplementation (0%, 2.5% and 5%) on the mechanical properties of raw noodles. The noodles were subjected to a 20% strain using a texture analyzer in which a custom holder for ultrasonic transducers enabled stress relaxation and ultrasonic propagation to be observed over 300 s. Ultrasonic velocity and attenuation increased and decreased, respectively, with an increase in noodle BBG content. Similarly, the longitudinal storage modulus M' increased, while the long-time values of the longitudinal loss modulus M'' decreased, as the BBG content was increased. The stress relaxation parameter %SR20s decreased significantly, while Peleg's K_1 and K_2 values increased with increasing BBG content, supporting the ultrasonic findings that the noodles displayed an enhanced resistance to deformation with an increase of BBG content. The ultrasonic technique discerned changes in the mechanical behavior of functional food products.

PRACTICAL APPLICATIONS

This research describes the use of a relatively inexpensive ultrasonic technique to discriminate and quantify desirable improvements in raw Asian white salted noodles on the basis of their fundamental rheological parameters. The test is rapid and allows the calculation of multiple parameters to highlight the texture benefits of adding BBG to noodle flour.

INTRODUCTION

Noodles are a traditional staple of the Asian diet with ~161 million tonnes of wheat used for noodle production annually (Bui and Small 2007). Recently, the gross domestic products of many Asian countries have increased significantly, allowing customers with discretionary income to incorporate health and nutritional concerns into their purchases. β-glucans have demonstrated ability to lower cholesterol, reduce the glycemic index and reduce colon cancer (Yokoyama *et al.* 1997; Jadhav *et al.* 1998; Slavin *et al.* 2000). Previous research in our lab (Hatcher *et al.* 2005) had demonstrated the ability to incorporate barley flour, high in barley β-glucan (BBG), into Asian noodles. The availability of commercially purified BBG offers an additional opportunity to garner the health benefits of BBG without impacting noodle color, a desirable quality attribute in addition to texture.

Traditionally, higher flour protein content in combination with a balanced gluten strength, extensibility and elasticity (due to the gluten's gliadin and glutenin components) is necessary for a high-quality noodle product. This is due to a desirable noodle texture, combining a firmer "bite" with a chewy mouthfeel. Commercial Asian manufacturers normally employ sensory panels consisting of regional or local housewives to gather insight into family preferences and purchasing patterns. While such a practice is ideal for regional markets, it is not possible to apply across a country or between countries as local preferences in texture and taste vary considerably. It is therefore essential that an objective, rheologically based method be developed to address the numerous sensory panels' preferences and allow researchers to ascertain the biochemical/physical reasons for these preferences. Longitudinally polarized ultrasound, at frequencies higher than 20 kHz, is an elastic wave in which the material being tested is alternatively compressed and rarified in the direction in which the wave is traveling. It is known (e.g., see McClements (1995)) that the molecular bonds of a material's constituents influence the speed with which an ultrasonic wave propagates through the material, with the speed of wave propagation and the wave's attenuation depending on the strength, character and dynamics of these molecular bonds.

Povey and Wilkinson (1980) used low-power ultrasonics to measure and distinguish egg white quality for screening eggs for use in commercial meringue production. Lee *et al.* (1992) applied ultrasound to study the rheological properties of cheese and dough and found good qualitative agreement between the ultrasonic technique and traditional rheometry. From a baking perspective, Elmehdi and Kovacs (2003) demonstrated that ultrasonic velocity was sensitive to thermal transitions and could be used to measure changes in the physical, chemical and biological properties of wheat proteins as they relate to pasta, noodles and baking quality. Ross *et al.* (2004) demonstrated that ultrasound velocity and attenuation correlated with traditional peak flour dough mixing as well as storage and loss shear moduli. Ultrasonic investigation of wheat starch retrogradation was accomplished by Lionetto *et al.* (2005) who demonstrated that wave velocity and attenuation changed as a result of recrystallization of the amylopectin molecules. They reported that the ultrasonic results correlated with results obtained from X-ray diffraction and differential scanning calorimetry. The influence of specific mechanical energy, SME, input on the ultrasonic characteristics of extruded dough at different moisture contents were reported by Owolabi *et al.* (2008). They demonstrated the influence of SME on the velocity and attenuation coefficients depending upon dough moisture levels. Bellido and Hatcher (2010, 2011) demonstrated that measurements of the ultrasonic wave characteristics (velocity and attenuation) can be used to evaluate a noodle's physical properties, allowing the complex longitudinal modulus to be determined as per the approach of Elmehdi *et al.* (2004). Additional research in the 30–50 kHz region (Diep *et al.* 2013) confirmed this technique's usefulness in discriminating raw noodle rheological parameters, storage and loss moduli, as a function of wheat class and variety. While protein content has been considered the key component to noodle texture quality (Miskelly and Moss 1985), Diep *et al.*'s work indicated that this was not an overall factor but rather that the quality of the gluten protein was critical.

The objective of this paper is to demonstrate that ultrasound at higher frequencies can also be utilized as an analytical tool, and specifically to investigate and discern rheological differences in raw noodles supplemented with BBG, thereby targeting a health conscious market.

MATERIALS AND METHODS

Wheat Samples, Milling, Analyses and Noodle Preparation

The mill check wheat represented a composite of CWRS samples collected across western Canada during the 2011 harvest. Flour (50 g), 34% water (w/w), 1% (w/w) NaCl and 2.5% or 5% BBG (Alkem Laboratories, Mumbai, India) were mixed using a centrifuge mixer (SpeedMixer DAC 150FV, Landrum, SC) for 30 s at 3,000 rpm (Diep *et al.* 2013). The aggregated dough crumbs were sheeted using an Ohtake laboratory noodle machine (Ohtake, Tokyo, Japan) using seven passes as per Bellido and Hatcher (2010).

Ultrasonic Measurements

Ultrasound measurements were performed with two broadband 10 MHz Panametrics transducers (Olympus NDT Canada Ltd., AB, Canada), which were mounted on a TA-XT Plus unit (Texture Technologies, Scarsdale, NY). The vertical position of the top transducer was controlled precisely by TA-XT Plus software (0.01 mm resolution), while the bottom transducer was fixed to the stationary base, allowing compression and relaxation tests to be performed and simultaneously monitored with the acquisition of ultrasonic signals. Two acrylic plates (1/4 inch thick) were bonded to the transducer surfaces to provide a suitable time delay to the acoustic signals. A sheeted noodle sample was placed on the bottom delay plate, and the compression test was then initiated by gradually lowering the top transducer/delay plate toward the noodle. When the top delay plate was about 3 mm above the noodle surface, the ultrasonic acquisition program (written in MATLAB) was started, so that both the transmitted ultrasonic signals and the applied force could be monitored as soon as the top transducer delay plate touched the noodle. Noodle thickness was automatically determined by the difference between the transducer's initial height (5 mm) and the distance when a force of 0.39 N was achieved. For the stress relaxation process, an additional 20% strain (based on this noodle thickness) was imposed on the noodle. The ultrasonic measurements were initiated when the bottom transducer received a voltage signal from an arbitrary waveform generator (Model 645, Berkeley Nucleonics Corp., San Rafael, CA), thereby generating an ultrasonic pulse that propagated through the noodle to the top transducer. The received signal was amplified (Panametrics 5072 PR, Olympus), displayed on a digital oscilloscope (TDS 2024, Tektronix Canada Inc., Toronto, Canada), averaged over 128 acquisitions and captured by in-house developed software using MATLAB (MathWorks, Natick, MA). The digitized waveforms were analyzed using custom software (developed in-house using IGOR 6, Wavemetrics.com) to determine the phase velocity and attenuation. These data, in conjunction with the measured noodle density, were used to calculate the complex longitudinal modulus (Elmehdi *et al.* 2004).

Stress Relaxation Measurements

Stress relaxation measurements were performed on the raw dough sheet as per Hatcher *et al.* (2008), employing the ultrasonic acrylic plates to exert uniaxial compression on the raw noodles during their ultrasonic measurements. K_1 and K_2 were determined by the method of Peleg (1979) with transformation of the force-versus-time measurements calculated using a macro provided with the TX-XT Plus unit (Texture Technologies, Scarsdale, NY). %SR20s was calculated as per Hatcher *et al.* (2008) using uniaxial compression and a 20% deformation of the raw noodle sheet. The tests were performed on three separately prepared dough sheets.

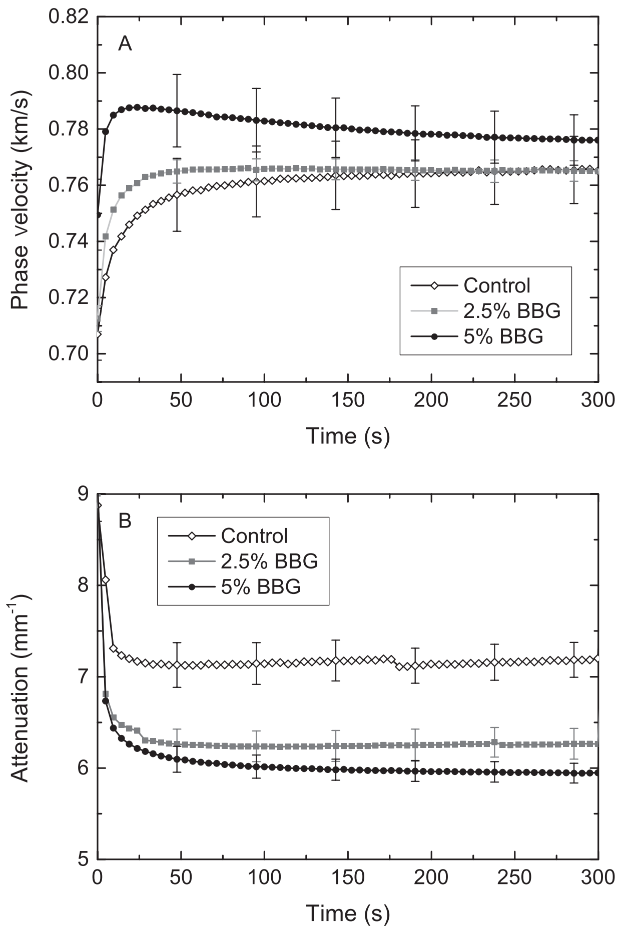

FIG. 1. PHASE VELOCITY (A) AND ATTENUATION (B) AT 1.0 MHZ AS A FUNCTION OF RELAXATION TIME FOR RAW CWRS NOODLES WITH BBG CONTENTS OF 0% (CONTROL, OPEN DIAMONDS), 2.5% (SOLID GRAY SQUARES) AND 5.0% (SOLID DARK GRAY CIRCLES)
Bars represent standard deviation of the triplicate tests for each level of BBG.

RESULTS

The raw control noodles (0% BBG) and those prepared with 2.5% BBG displayed a rapid increase in wave velocity during the first 20–25 s of the relaxation period followed by a leveling off for the remaining 275 s of the test. The 5% BBG addition samples displayed a similar initial rapid increase in velocity, significantly exceeding that of either of the other two samples, before slowly declining to velocity values slightly above those of the control (Fig. 1A). Examination of the corresponding attenuation data (Fig. 1B) indicates that attenuation declined rapidly during the initial relaxation period, and remained relatively constant after the first 25 s. The control noodle displayed the highest attenuation values with a significant decrease observed upon 2.5% BBG addition. The raw noodles prepared with 5% BBG displayed further lowering of the attenuation. The decrease in attenuation with the increasing levels of BBG suggests a lowering of the effect of viscoelastic relaxations on the dynamic mechanical properties with addition of this polymer, consistent with the role of BBG–protein interactions on consolidating the molecular configurations in the raw noodle dough.

Analysis of the storage modulus (M') revealed that the addition of both 2.5% and 5% BBG significantly increased M' compared with the control flour noodle (Fig. 2A). This indicates that the addition of the BBG results in firmer (less compressible) noodles. Research conducted on BBG in gluten-free rice flour indicated that BBG addition also resulted in an increased shear modulus (G'), consistent with the idea of enhanced intermolecular interactions between BBG and proteins. BBG is hydroscopic in nature, and as such, it would compete with both the noodle flour's starch and protein for water in the dough crumb/sheet. However, direct comparison of the two moduli, M' and G'

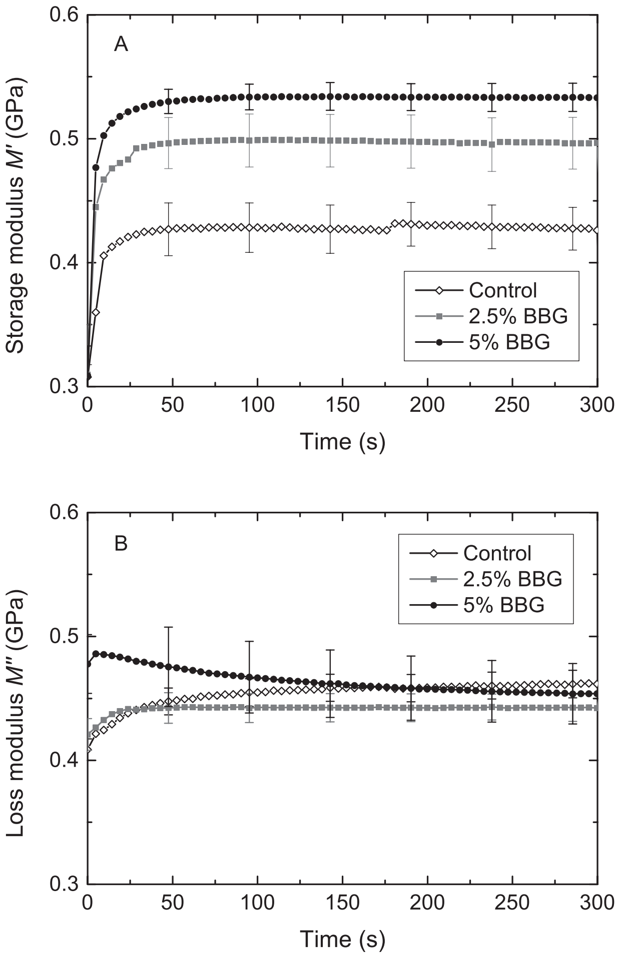

FIG. 2. RELAXATION TIME DEPENDENCE OF (A) M' AND (B) M'' AT 1.0 MHZ FOR RAW NOODLES MADE FROM CWRS FLOUR, COMPARING THE CONTROL (NO BBG, OPEN DIAMONDS), WITH DOUGHS CONTAINING 2.5% (SOLID GRAY SQUARES) AND 5.0% (SOLID DARK GRAY CIRCLES) BBG

Bars represent standard deviation of the triplicate tests for each level of BBG.

is limited because of the much higher water absorption levels used in that study (Ronda *et al.* 2013). In an investigation of water and BBG addition on wheat dough viscoelasticity, Skendi *et al.* (2010) also found that BBG addition had a very significant effect on G' as well as G'' even though the levels added at 0.2–1.0% were low compared with our study. Their work also identified that addition of BBG to an inferior (gluten strength) flour raised the G' values to those of a good gluten strength flour in the absence of BBG, thereby offering commercial processing opportunities in tailoring flour quality for a particular product.

Examination of the loss modulus (M''), Fig. 2B, revealed that the relaxation behavior is different for the BBG raw noodles relative to the raw control dough, with M'' for the control dough increasing throughout the 300-second time window, M'' for the 2.5% BBG dough remaining roughly constant after the initial 30 s and M'' for the 5% BBG dough decreasing over the same time interval. However, after the first 100 s, there appears to be no significant difference in the overall magnitude of M'' for the three dough.

Analysis of $\tan\delta_L \equiv M''/M'$ (Fig. 3) shows that the loss tangent has significantly lower values for both 2.5% and 5.0% BBG additions compared with the control. This trend is mostly due to the larger values of M' for the two BBG dough (Fig. 2A), confirming that BBG addition leads to a firmer dough. However, while the $\tan\delta_L$ values were lower than the control, no difference was detected between noodles at either level of BBG addition.

In summary, the ultrasonic data, especially for M', clearly demonstrate that the addition of BBG results in firmer raw noodles. Changes in the relaxation behavior are also seen with BBG addition, motivating further research to investigate the molecular mechanism responsible.

An alternate means of confirming the rheological impact of the BBG addition on the noodles was performed. Stress relaxation parameters %SR20s, K_1 and K_2 (Hatcher *et al.* 2008) were measured on the raw noodles and are shown in Table 1.

The significant decline in %SR20s upon the addition of 2.5% BBG indicates that the raw noodle was dissipating the compressional strain energy slower than the control suggesting that it was firmer. Increased addition of the BBG to 5%, while decreasing the %SR20s value slightly, does not

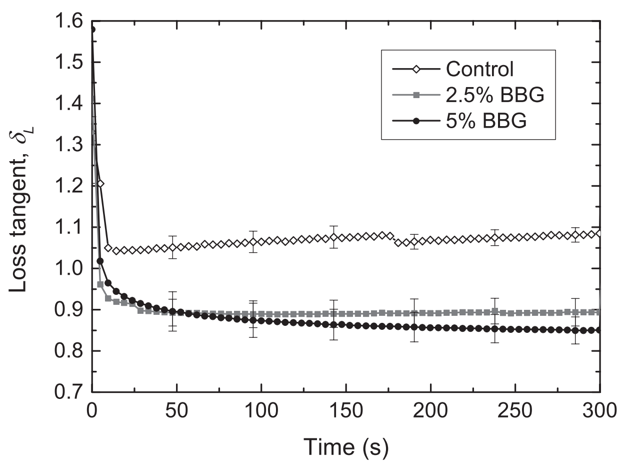

FIG. 3. COMPARISON OF $\tan\delta_L$ VALUES OF RAW NOODLE SHEETS PREPARED WITH CWRS FLOUR WITH BBG CONTENTS OF 0% (CONTROL, OPEN DIAMONDS), 2.5% (SOLID GRAY SQUARES) AND 5.0% (SOLID DARK GRAY CIRCLES)

Bars represent standard deviation of the triplicate tests for each level of BBG.

TABLE 1. STRESS RELAXATION PARAMETERS OF RAW CWRS NOODLE SHEETS AUGMENTED WITH BARLEY β-GLUCAN

	Control (CWRS)			2.5% BBG addition			5.0% BBG addition		
Parameter	Mean	SD	CV%	Mean	SD	CV%	Mean	SD	CV%
%SR20s	17.3	0.64	3.69	14.8	0.76	5.14	13.2	0.15	1.14
K_1	33.8	3.34	9.88	37.4	1.16	3.11	36.3	1.69	4.68
K_2	4.09	0.27	6.48	4.88	0.28	5.72	5.74	0.16	2.80

BBG, barley β-glucan; CV, coefficient of variation; SD, standard deviation.

imply a significant further increase in raw noodle firmness. While the K_1 value of the 2.5% BBG addition is greater than the control, implying a higher elastic/firmer behavior, the above average variance associated with the K_1 control value means that this increase is not deemed significant. However at the 5% BBG addition, the K_1 value is significantly greater than for the raw control noodle. K_2 (the extent of relaxation) is an indicator of the residual stress in the noodle when the noodle is allowed to relax. Addition of the 2.5% BBG resulted in a significant increase in the K_2 value of the raw noodles, which was further significantly increased upon addition of the 5% BBG, confirming the more elastic behavior (enhanced firmness) of the BBG augmented noodles.

CONCLUSIONS

Application of an ultrasonic technique at an elevated frequency (~1.0 MHz) to the measurement of raw noodle texture has highlighted the advantages and changes that occur to a white salted Asian noodle with the addition of BBG. This inexpensive ultrasonic method allows for the measurement of longitudinal phase velocity and attenuation, which, in conjunction with the density of raw noodle, allows the calculation of the material's longitudinal mechanical moduli. It is the determination of these dynamic mechanical moduli that provides new information on noodle texture.

The advantages of BBG addition revealed by this technique could offer significant economic savings to commercial noodle manufacturers, as earlier research (Miskelly and Moss 1985) indicated that higher protein flour (which is more expensive) was required to improve noodle texture. The addition of the BBG overcomes this issue while offering additional competitive marketing claims. Commercial noodle manufacturers are constantly searching for additives for their noodles to increase their adoption by the consumer. At the 5% BBG level, manufacturers are able to state that their noodle has beneficial health properties because of the BBG content. An additional benefit shown by this research is that both the ultrasonic measurements and the independent stress relaxation parameters indicate that noodles augmented with BBG offer a desirable, firmer noodle than the control.

NOMENCLATURE

CWRS	Canada Western Red Spring Wheat
M'	storage modulus
M''	loss modulus
$\tan\delta$	ratio of loss modulus/storage modulus
K_1	initial rate of relaxation
K_2	extent of relaxation
%SR20s	percent stress relaxation at 20 s past maximum force

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