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Ultrasonic Investigation of the Effect of Vegetable Shortening and Mixing Time on the Mechanical Properties of Bread Dough

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ABSTRACT: Mixing is a critical stage in breadmaking since it controls gluten development and nucleation of gas bubbles in the dough. Bubbles affect the rheology of the dough and largely govern the quality of the final product. This study used ultrasound (at a frequency where it is sensitive to the presence of bubbles) to nondestructively examine dough properties as a function of mixing time in doughs prepared from strong red spring wheat flour with various amounts of shortening (0%, 2%, 4%, 8% flour weight basis). The doughs were mixed for various times at atmospheric pressure or under vacuum (to minimize bubble nucleation). Ultrasonic velocity and attenuation (nominally at 50 kHz) were measured in the dough, and dough density was measured independently from specific gravity determinations. Ultrasonic velocity decreased substantially as mixing time increased (and more bubbles were entrained) for all doughs mixed in air; for example, in doughs made without shortening, velocity decreased from 165 to 105 ms^{-1}, although superimposed on this overall decrease was a peak in velocity at optimum mixing time. Changes in attenuation coefficient due to the addition of shortening were evident in both air-mixed and vacuum-mixed doughs, suggesting that ultrasound was sensitive to changes in the properties of the dough matrix during dough development and to plasticization of the gluten polymers by the shortening. Due to its ability to probe the effect of mixing times and ingredients on dough properties, ultrasound has the potential to be deployed as an online quality control tool in the baking industry.

Keywords: bakery ingredients, dough properties, mixing, ultrasound

Introduction

The dough mixing operation is expected to perform 3 important functions in breadmaking: (1) blend ingredients into a macroscopically homogenous mass, (2) develop the gluten polymers in the dough so that a viscoelastic material with good gas retention properties is created, and (3) incorporate air as discrete bubbles so that they inflate during dough fermentation to produce the aerated crumb structure of the loaf (Bloksma 1990a; Campbell and others 1998; Scanlon and Zghal 2001; Marsh and Cauvain 2007). Because the distribution of gas bubble sizes created in dough during mixing has a direct effect on the gas cell structure in the baked loaf (Baker and Mize 1941), different ingredients are frequently blended during mixing so that the resulting structure of the loaf is improved (Kamel and Hoover 1992; Campbell and others 2001; Schiraldi and Fessas 2001). Inevitably, these ingredients affect the mechanical properties of the dough during mixing and its behavior during subsequent processing operations (Bloksma and Bushuk 1988; Eliasson and Larsson 1993).

Shortening is an ingredient used to improve loaf volume and to obtain a bread crumb with a fine and uniform gas cell structure composed of thin gas cell walls (Baker and Mize 1942), so that in almost all baked products, oils and fats are essential quality improving ingredients (Smith and Johansson 2004; Mousia and others 2007). However, a renewed focus on limiting the intake of potential health-compromising ingredients such as shortening (Coveney and Santich 1997; Drewnowski and Darmon 2005) has driven food science researchers to critically evaluate the role that such ingredients play in food quality with a view to reducing the amounts used (Mousia and others 2007). In an examination of the role of solid shortening in the stabilization of air nuclei in the dough, it has been shown that fat crystals are redistributed during mixing and preferentially adsorb at the numerous dough matrix-gas bubble interfaces (Baker and Mize 1942; Baldwin and others 1963; Brooker 1996). It is therefore useful in an examination of the effect of shortening on gas cell structure in the bread if interactions between shortening and gas bubbles in the dough can be determined, preferably quantitatively.

In ultrasonic materials' characterization techniques, the sound propagation characteristics of sound at high frequencies (> 18 kHz) are analyzed to understand the physical properties and structure of the material. Many foods have been analyzed with ultrasound (McClements 1997; Povey 1997) including wheat flour doughs (Kidmose and others 2001; Létang and others 2001; Elmehdi and others 2004; Ross and others 2004). Longitudinal ultrasonic pulses with wavelengths larger than the mean gas bubble size are useful because their sensitivity to the presence of compressible regions, such as would arise from air bubbles in dough (Elmehdi and others 2004; Leroy and others 2008), allows ready investigation of a material in which bubbles profoundly affect product quality (Campbell and Shah 1999; Cauvain and others 1999). Therefore, ultrasound would appear to be a promising tool for probing how shortening interacts with gas bubbles in dough systems during mixing, especially because the opacity of dough precludes using optical techniques for this purpose.

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The objective of this study was to show that low-frequency ultrasound (< 50 kHz) can be used to examine how gas bubble entrainment in dough, induced by varying mixing time, is affected by the addition of shortening.

Materials and Methods

Materials

All flour used was milled from Canada Western Red Spring (CWRS) wheat on the CIGI pilot mill (Winnipeg, MB, Canada); flour protein content was 12.4% (14% mb). Sodium chloride was reagent grade (Fisher Scientific, Nepean, ON, Canada). Distilled water was used for making dough samples. Commercial vegetable shortening (partially hydrogenated soybean and palm oil) was purchased from J. M. Smucker Inc. (Toronto, ON, Canada).

Dough mixing at atmospheric pressure

Control dough samples were prepared by mechanical development of the dough using the Canadian Short Process Method (Preston and others 1982) using flour (100 g), salt (2.4% fwb [flour weight basis]) and water (61% fwb, to give optimum dough handling characteristics). Doughs were also prepared using the same ingredients as control doughs, but with the addition of shortening (2%, 4%, or 8% fwb). Ingredients were mixed at 165 rpm using a GRL-200 mixer at 30 °C (Hlynka and Anderson 1955). Mixing times in the range from 1.5 to 6.7 min were employed to obtain an overall picture of the mixing process from the hydration of flour particles through optimum dough development (10% past peak) until overmixing had occurred. Duplicates were prepared for each dough mixed for a particular mixing time.

To obtain the optimum dough mixing time (10% past peak resistance in the mixing curve), 5 dough samples were mixed for all treatments. Optimal mixing time was calculated by averaging the optimum mixing times obtained from the 5 mixing curves.

Dough mixing under vacuum

Headspace pressure during mixing was manipulated by drawing a vacuum on the outlet of the mixing bowl to reduce the number of bubbles entrained during mixing (Campbell and others 1998). Ingredients were mixed for 1 min at atmospheric pressure to allow flour particles to hydrate, after which the vacuum was applied for the remaining mixing time. Pressure inside the mixing bowl was measured with a digital pressure meter (ACSI Digital Pressure Meter, St. Louis, Mo., U.S.A.) positioned between the mixer bowl and the vacuum pump. The headspace pressure in the mixing bowl was maintained at approximately 0.04 atm throughout mixing (following the initial 1 min at atmospheric pressure). Duplicates were prepared for each dough mixed under vacuum for a particular mixing time.

Density measurements

Dough densities were measured to ascertain the amount of air incorporated into the dough using specific gravimetric bottles of 25 mL capacity (Kimble Glass Inc., Vineland, N.J., U.S.A.) using 5 g subsamples of dough. Five subsamples were excised using scissors from each mixed dough, with the dough retained in a Tupperware container to avoid moisture losses.

Equipment used for ultrasonic experiments

Ultrasonic velocity and attenuation were measured in transmission by sandwiching (using ultrasonic coupling gel) the dough sample in direct contact between 2 Panametrics transducers with a nominal frequency of 50 kHz. A custom-built apparatus was used to situate each transducer in the centre of a plexi-glass sheet where the face of the transducer was flushed with the face of the sheet. Locking nuts held the transducer in place so that when the distance between sheets was set, so too was the distance between transducers. The transmitted signal was amplified and displayed on a computer-controlled oscilloscope (Tektronix TDS 420 A, Chicago, Ill., U.S.A.) connected to a computer where data were stored.

Ultrasound parameters

The ultrasonic velocity and attenuation were determined as per Elmehdi and others (2004). In brief, the transit time and amplitude of the 1st oscillation in the pulse that propagated through dough subsamples of 5 different thicknesses (1 to 5 mm) were measured. This procedure eliminates offset due to losses of acoustic signal at the transducer–sample interface so that velocity and attenuation could be accurately determined. The values of transit time were plotted as a function of sample thickness, and velocity through the dough was calculated from the inverse of the slope. A graph of amplitude against thickness was plotted and a single exponential decay curve was fitted to permit the intensity attenuation coefficient to be determined.

Experimental design

To obviate delay associated with changing the mixer configuration for vacuum and atmospheric mixing analyses, experiments were performed as 2 sets. The 1st set comprised all doughs mixed at atmospheric pressure and the other set corresponded to doughs mixed under vacuum (0.04 atm). Each set encompassed doughs mixed in duplicate at the various mixing times with different levels of shortening (added on a flour weight basis of 0%, 2%, 4%, or 8%). The order in which experiments in the 2 sets were conducted was randomized.

Statistical analysis

Data were analyzed using SAS software program, version 8.1 (SAS Inst. Inc., Cary, N.C., U.S.A.). Data were analyzed using analysis of variance (ANOVA) with a criterion of $P \leq 0.01$ to detect significant differences among treatments using the LSD method.

Results

Previous research has shown that the number of gas cells per unit volume changes when dough is mixed for different times (Campbell and others 1998). From experiments where dough is mixed in a headspace containing different gases (Baker and Mize 1937), it was concluded that the properties of the dough matrix also change with mixing time. Therefore, by comparing doughs mixed under vacuum for various mixing times with their air-mixed counterparts it should be possible to evaluate the effect of altering the properties of the dough matrix due to mixing and due to the addition of shortening independent of any effect arising from entrainment of bubbles in the dough.

Effects of shortening on dough development time

To select mixing times that were technologically appropriate, we evaluated the variation in optimal mixing time as the amount of shortening was increased. Optimum mixing time for doughs mixed at atmospheric pressure with and without the addition of shortening is shown in Table 1. In general, the addition of shortening "weakened" the dough since optimal consistency was attained at shorter mixing times ($P < 0.0001$), a result consistent with other studies (Singh and others 2002). Because doughs mixed under vacuum do not exhibit a peak in torque attributable to dough development (Baker and Mize 1937), the concept of "optimum mixing time" is not meaningful for vacuum-mixed doughs and so these doughs were mixed for identical mixing times as their counterparts mixed at atmospheric pressure.

Effects of shortening on dough density

Dough densities exhibit different patterns as a function of mixing time depending on mixer headspace pressure (Figure 1). When doughs were mixed in air, dough density progressively decreased as a function of mixing time. High density values were observed when dough was undermixed at atmospheric pressure, indicating little entrainment of air, whereas at long mixing times, dough density was substantially lower due to increased incorporation of air within the dough (Baker and Mize 1937, 1946; Junge and others 1981). Interestingly, after resistance to mixing had reached a maximum, the rate of dough density decline, and presumably the rate of air occlusion, increased. For example, for the control dough, density decreased by 60 kg m^{-3} upon mixing from 2 to 5.6 min (undermixing), but it declined by 70 kg m^{-3} when mixed beyond optimum mixing time (5.6 min) to an overmixed state (6.7 min).

In contrast to doughs mixed in air, the densities of doughs prepared under vacuum (0.04 atm) were essentially unaffected by mixing time. Vacuum-mixed doughs had significantly higher dough densities irrespective of the amount of shortening because gas cell nuclei were virtually eliminated in the doughs mixed under high vacuum (Baker and Mize 1941).

Regardless of the effect of bubble entrainment during mixing, there was a significant effect of shortening ($P < 0.0001$) on dough densities. At all mixing times, dough density was lower as more shortening was added, and this density-depression effect was evident for both vacuum-mixed and air-mixed doughs.

Table 1 — Effects of shortening on optimum mixing time of bread dough.

Amount of shortening (% fwb)[A]	Optimum mixing time (min)[B]
0 (Control)	5.61 ± 0.09^{a}
2	4.91 ± 0.08^{b}
4	4.43 ± 0.05^{c}
8	4.10 ± 0.04^{d}

[A] fwb: flour weight basis.

[B] Mixing time values are the mean ± SD, $n = 5$; numbers with different superscripts are significantly different.

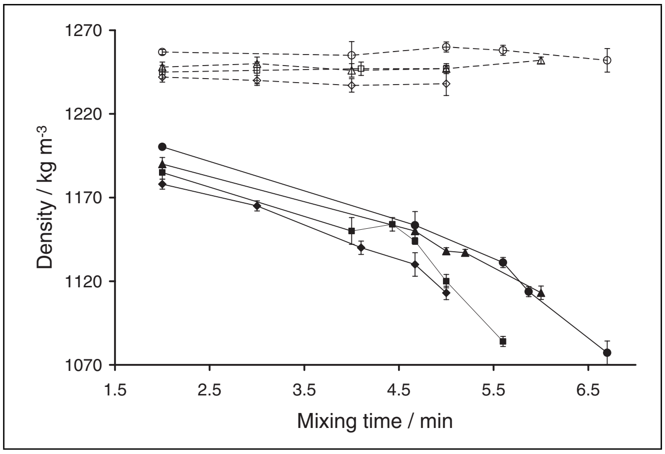

Figure 1 — Effect of mixing time in air (closed symbols) and under vacuum (open symbols) on the density of dough containing 0% (●,○), 2% (▲,△), 4% (■,□), or 8% (♦,◇) shortening (% fwb).

Effects of shortening on ultrasonic velocity measurements of bread dough

Ultrasonic velocity in dough as a function of mixing time at atmospheric pressure is shown in Figure 2A. The ultrasonic velocities followed the trend of dough density variation in response to mixing time, with velocity decreasing with increasing mixing time as more air is entrained. In general terms, a larger velocity means that a material of a given density is less compressible, since $v^2 = \beta\rho^{-1}$, where v is the ultrasonic velocity, β the longitudinal modulus of the dough and ρ its density. Because gas bubbles are much more compressible than the dough matrix, the velocity of sound in the dough is markedly affected by even small volume fractions of gas bubbles at these frequencies (Elmehdi and others 2004). Therefore, more bubbles lower the longitudinal modulus of the dough, and thus the velocity of ultrasound propagating through the dough was lower.

It is conceivable that a discernible shoulder in the pattern of velocity decrease was observed at the optimum mixing time for all doughs. This shoulder occurred at earlier mix times as the amount of shortening was increased, consistent with this perturbation in the pattern of velocity decrease being a measure of the optimal mix times (Table 1). Changes in ultrasound velocity when a dough is mixed past its optimum have previously been reported (Ross and others 2004). The presence of the shoulder may be due to an increase in velocity brought about by a maximal alignment of

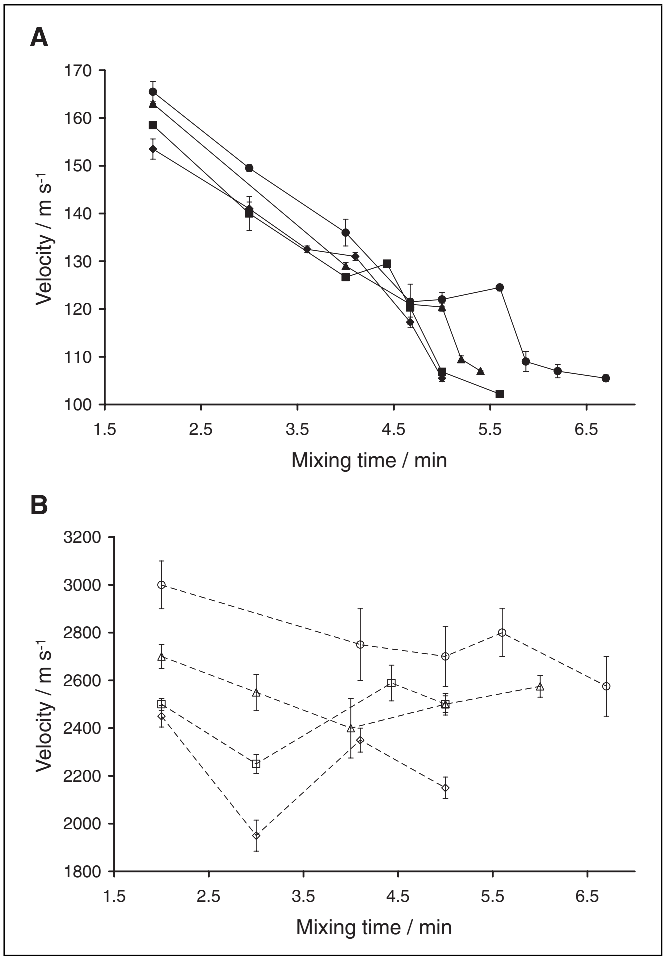

Figure 2 — Effect of mixing time in air (A) and under vacuum (B) on ultrasonic velocity for doughs containing 0% (●,○), 2% (▲,△), 4% (■,□), or 8% (♦,◇) shortening (% fwb).

glutenin polymers (Bloksma 1990b) that stiffens the dough matrix, and this offsets the decrease in ultrasonic velocity brought about by increasing numbers of bubbles (Elmehdi and others 2004). Addition of shortening significantly lowered ($P < 0.0001$) the velocity at which sound propagates through the dough, although the pattern of velocity change with mixing time was unaltered (Figure 2A).

To observe the effects of shortening and mixing time on the ultrasonic velocity independent of the effect of the bubbles, doughs were mixed under vacuum. Some changes in dough rheology, as determined by ultrasonic velocity, were observed with longer mixing times under vacuum (Figure 2B), but the relative changes in velocity with mixing time were much less pronounced than those brought about by mixing the dough at atmospheric pressure. It is important to note the very high velocities for all vacuum-mixed doughs compared to their air-mixed counterparts (compare Figure 2A and 2B). Because the doughs mixed under vacuum have substantially fewer air bubbles in comparison to the doughs mixed in air (Campbell and others 1998), the absence of gas bubbles is responsible for the dramatic increase in the ultrasonic velocity, a result consistent with previously reported results using a fixed mixing time (Elmehdi and others 2004, 2005). Shortening had a significant effect on velocity at the $P < 0.0001$ level, with a general trend of lower ultrasonic velocities with addition of shortening, although there was some crossover at different mixing times. In these bubble-free doughs, the lower velocities must arise from the shortening decreasing the longitudinal modulus of the dough matrix, just as greater amounts of shortening lower the shear modulus of dough (Fu and others 1997).

Effects of shortening on attenuation coefficient measurements of bread dough

It is apparent from the scales of Figure 3A and 3B that differences in ultrasonic attenuation between vacuum and air mixed doughs as a function of dough mixing are not as pronounced as those of velocity. Despite the attenuation coefficient's lesser sensitivity to the effect of mixing time, it generally increased when dough was mixed for longer in air (Figure 3A). Although a decrease in the rise of the attenuation coefficient in the region of optimum mixing time may exist (Figure 3A), the shoulder in the ultrasonic velocity pattern at optimal mixing time was more prominent (Figure 2A). Ross and others (2004) reported that there appeared to be a peak in attenuation coefficient at optimum mixing time in their ultrasonic analyses of bread dough, but their analyses were performed at much higher frequencies (3 to 5 MHz). Notwithstanding these mixing time effects, increasing the amount of shortening significantly increased ($P < 0.0001$) the attenuation coefficient of the air-mixed doughs (Figure 3A).

For dough prepared under vacuum, mixing time significantly increased ($P < 0.0001$) the attenuation coefficient (Figure 3B), a result that contrasts with the small changes in velocity as mixing time increased (Figure 2B). It can be concluded that changes in the attenuation coefficient of air-mixed dough can be ascribed to changes in the dough matrix brought about by the mixing action as well as from increased amounts of bubbles. Similarly, there were significant ($P < 0.0001$) changes in the dough matrix brought about by increasing amounts of shortening (Figure 3B). It is likely that the changes in dough matrix properties are brought about by the interaction of shortening with the hydrated protein polymers of the dough matrix (Bloksma and Bushuk 1988; Fu and others 1997; Watanabe and others 2002).

Discussion

Air entrainment effect of shortening

From Figure 1, it can be seen that densities of doughs are lowered as greater amounts of shortening are added, and this is true whether or not bubbles are present in the dough. A hypothesis that shortening aids air entrainment into the dough (Pyler 1988) is only plausible if increased mixing time induces greater density depression in the doughs that contain shortening compared to the control dough (0%). To determine any enhanced air entrainment effect associated with shortening, the gas-free densities of the doughs were calculated from a linear extrapolation of density to the $P = 0$ atm intercept for doughs mixed at atmospheric pressure and under vacuum ($P = 0.04$ atm). This determination was performed for each mixing time for each dough system (control, 2%, 4%, 8% shortening). A 2-point calibration is justified because a linear relationship exists between dough density and headspace pressure in the mixing bowl (Campbell and others 1998; Elmehdi and others 2004). As has previously been observed (Chin and Campbell 2005), one might expect an increase in the gas-free dough density with increase in mixing time up to optimal mixing time due to polymer alignment (Wellner and others 2005). Such a trend was indeed observed in these experiments, but since not all gas-free dough densities at different mix times were significantly different, the gas-free dough densities reported in Table 2 are average values over

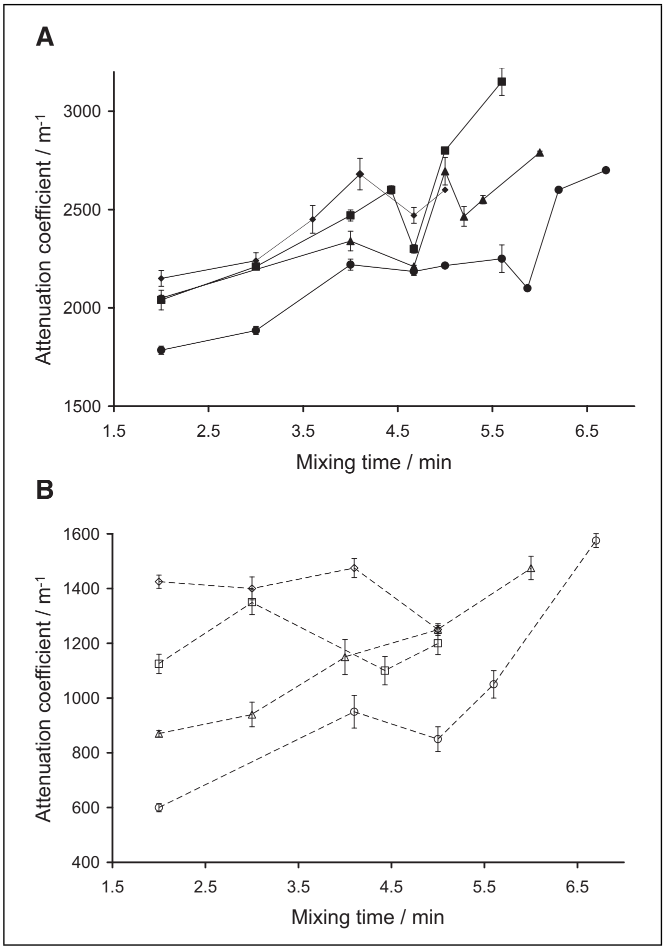

Figure 3 — Effect of mixing time in air (A) and under vacuum (B) on the attenuation coefficient of doughs containing 0% (●,○), 2% (▲,△), 4% (■,□), or 8% (◆,◇) shortening (% fwb).

all mixing times. It can be seen that greater amounts of shortening lower the density of the dough matrix, indicative of an enhanced free-volume effect of this ingredient that is consistent with shortening acting as a plasticizer (Bloksma and Bushuk 1988; Fu and others 1997).

From the gas-free dough density (ρ_{dm}) values of Table 2, the dough density (ρ) values at a given mixing time were converted to void fraction (ϕ) using the relation:

$$\phi = 1 - (\rho/\rho_{dm}). \tag{1}$$

Calculation of void fractions simplifies the interpretation of ultrasonic results as a function of the aeration properties of the dough (see subsequently), but it also allows us to evaluate whether enhanced entrainment of air bubbles in the dough arises as mixing proceeds (Figure 4). From Figure 4, there is little evidence that shortening increases the amount of air entrained during mixing, except perhaps when the doughs were overmixed, and this is not a technologically useful attribute in the baking industry. As such, this confirms (but with larger amounts of shortening) the conclusion of Mousia and others' (2007) study that shortening has no effect on dough aeration.

Effects of gas bubbles on ultrasonic velocity in dough

When ultrasonic velocity is plotted against void fraction (Figure 5), the data fall into 2 groups: vacuum-mixed doughs have high velocities and small void fractions, while air-mixed doughs exhibit lower velocities and the void fraction covers a much wider range resulting from variation in the amount of entrainment of air bubbles due to mixing time manipulation. For example, in the control doughs, the velocity dropped from 3000 ms^{-1} to less than 200 ms^{-1} when void fraction increased from 0.003 to 0.048. At higher ϕ values, the decrease in velocity was less rapid. Thus, ultrasonic velocity at this frequency (approximately 50 kHz) is extremely sensitive to the presence of gas bubbles in the dough especially at low ϕ (Elmehdi and others 2005; Leroy and others 2008), and this is true if these bubble numbers are manipulated by altering mixing time at constant headspace pressure or by altered headspace pressure at constant mixing time (Elmehdi and others 2004).

In soft highly hydrated materials, such as wheat flour doughs, the bulk modulus is very much larger than the shear modulus ($B^* >> G^*$) (Létang and others 2001). Then, on the assumption that dough approximates to a liquid containing bubbles (so that the compressibility is the reciprocal of the bulk modulus), the ultrasonic velocity of the doughs with different amounts of shortening can be modeled in this long wavelength regime using Urick's equation (Povey 1997). Here, total compressibility is the sum of compressibilities of bubbles and matrix weighted by their respective volume fractions:

$$\kappa_{dough} = \phi \cdot \kappa_{air} + (1 - \phi) \cdot \kappa_{dm} \tag{2}$$

where κ_{dough}, κ_{air}, and κ_{dm} are the compressibilities of the dough, air, and dough matrix, respectively. Since $\rho_{dm} \geq \rho_{dough} >> \rho_{air}$, $\kappa_{air} >> \kappa_{dm}$, and from before, $v^2 = (\kappa\rho)^{-1}$, then:

$$v_{dough} = v_{air}\sqrt{\frac{\rho_{air}}{\rho_{dm}\phi}} \tag{3}$$

In this way, it is apparent that the compressibility of the dough matrix is not a factor in this simplified examination of the dependence of ultrasonic velocity on the volume fraction of gas bubbles in the dough (ϕ). As such, the differences in the velocity in the dough matrix as shortening increases that are evident in Figure 2B do not affect the velocity of ultrasound propagating in the dough. The line in Figure 5 is the relation of Eq. 3 and it can be seen that ignoring the compressibility of the dough matrix in predicting dough velocity is plausible to a 1st approximation (Figure 5). However, treating the dough as a liquid containing bubbles is not entirely correct since the experimental velocities are all greater than the values predicted by Eq. 3 due to the nonnegligible effect of the shear modulus of the dough matrix (recall that $v^2 = (B + 4/3G)\rho^{-1}$ for a solid compared to $v^2 = B\rho^{-1}$ for a liquid). In addition, there is a substantially enhanced velocity for the vacuum-mixed doughs, a phenomenon that has been observed previously and modeled by Elmehdi and others (2004). Nevertheless, the qualitative form of the

Table 2— Effects of shortening on gas-free density of bread dough.

Amount of shortening (% fwb)^A	Gas-free density (kg m^{-3})^B
0 (Control)	1262 ± 0.9^a
2	1255 ± 2.2^b
4	1254 ± 2.9^b
8	1245 ± 1.3^c

^{A}fwb: flour weight basis.
^{B}Density values are the mean ± SD, $n = 40$ (averaged over all mixing times); numbers with different superscripts are significantly different.

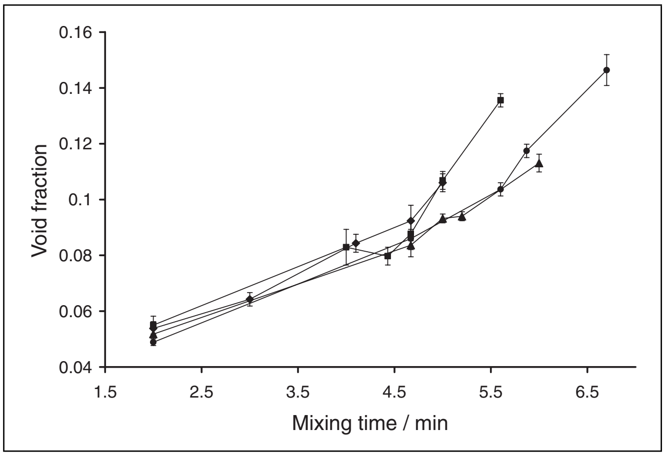

Figure 4 — Void fraction in doughs mixed in air for various times. Doughs prepared with 0% (●), 2% (▲), 4% (■), or 8% (◆) shortening (% fwb).

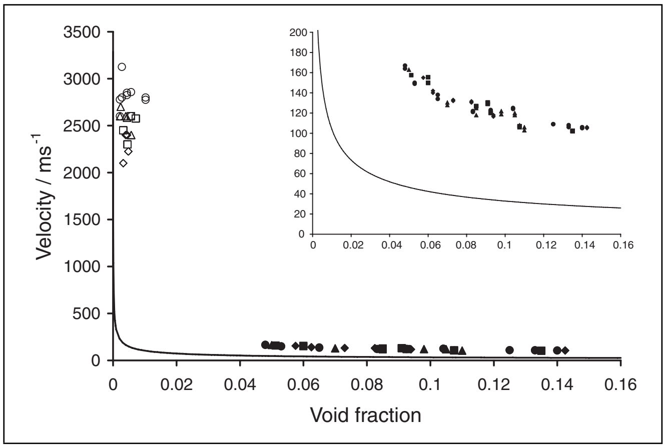

Figure 5 — Ultrasonic velocity of doughs prepared with various amounts of shortening (see symbols of Figure 1) as a function of void fraction manipulated by entraining different amounts of air by mixing for various times (individual results for dough duplicates shown). Inset expands velocity scale for doughs mixed at atmospheric pressure.

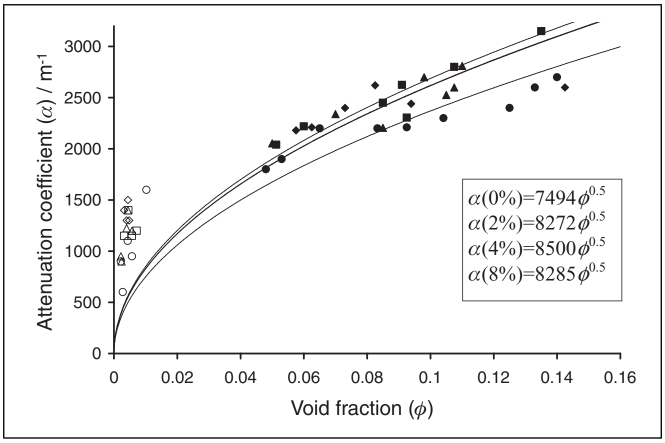

Figure 6—Attenuation coefficient of doughs prepared with different amounts of shortening (see symbols of Figure 1) as a function of void fraction manipulated by entraining different amounts of air by mixing for various times. Lines represent fits to data (equations within box) as explained in the text.

v against ϕ relationship in Figure 5 indicates that the compressibility of bubbles dominates the velocity result for dough at this lower frequency and the effect that shortening has on the dough matrix is only manifest as a slight change in the velocity of the dough. This result would not be expected at all ultrasonic frequencies (Elmehdi and others 2005; Leroy and others 2008; Scanlon and others 2008).

Effects of air bubbles and shortening on the attenuation coefficient of dough

The relationship between attenuation coefficient and void fraction (ϕ) is shown in Figure 6. It is clear that the attenuation coefficient increases with the amount of gas in the dough, so that the bubbles make a significant contribution to the dough's attenuation. As discussed by Scanlon and others (2008), in this long wavelength regime we expect an approximately square root dependence on ϕ for the attenuation coefficient at low volume fractions of bubbles. The lines in Figure 6 trace a $k_s\phi^{0.5}$ dependence, where k_s is an adjustable parameter that varies according to the amount of shortening in the dough; its value was determined by minimizing the difference between model and experimental attenuations of the air-mixed doughs. Since k_s increases with the addition of shortening, shortening's effect on dough matrix attenuation (Figure 3B) is seen as an enhanced attenuation in the dough in addition to the contribution that bubbles make to the dough's attenuation coefficient. An exception to this conclusion occurs at 8% shortening, an effect also seen in shear testing of dough (Fu and others 1997), where the dissipative component of the shear modulus, G'', was not greater when more than 4% shortening was added to the dough. We therefore propose that the plasticizing effect of shortening on the gluten polymers in the dough (Fu and others 1997) contributes significantly to the long wavelength attenuation of ultrasound in dough. In other high molecular weight polymers (Longin and others 1998), shear relaxations induced by longitudinal waves are of the same order as volumetric relaxations. Therefore, it is not implausible that the plasticization effect of shortening on the shear modulus of the dough matrix is evident in the attenuation coefficient of the dough even though velocity is essentially unaffected.

Conclusions

Low-frequency (50 kHz) ultrasound can be successfully used to investigate the effect of mixing time and shortening on the mechanical properties of dough. Ultrasonic velocity dropped drastically as the amount of gas bubbles entrained into the dough increased with mixing time, but it was barely affected by increased amounts of shortening. The attenuation coefficient of dough was affected by the amount of gas bubbles in the dough as well as by the plasticizing effect of shortening on the shear modulus of the dough matrix.

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