Ultrasonic Determination of Chicken Composition

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An ultrasonic technique has been developed for measuring the composition of chicken meat. The relationship between the composition and ultrasonic velocity of chicken meat was determined using chicken analogues of different composition, prepared from dried chicken powder, corn oil, and distilled water. The ultrasonic velocity of chicken analogues was measured at temperatures from 5 to 35 °C using an ultrasonic spectrometer. The ultrasonic velocity increased with solids-nonfat (SNF) content at all temperatures but had a more complex dependence on fat content. Around 15 °C the ultrasonic velocity was independent of fat content; however, at lower temperatures it increased with fat content, and at higher temperatures it decreased. Semiempirical equations were developed to describe the relationship between ultrasonic velocity and chicken composition. To determine the usefulness of these equations, the ultrasonic velocities of various chicken meats were measured. The compositions of the chicken meats predicted on the basis of ultrasonic measurements were in good agreement with those determined by using standard methods ($r^2 > 0.97$). The ultrasonic technique could also be used to measure the solid fat content of chicken fat. This study shows that ultrasonic velocity measurements can be used to characterize chicken composition. This method has great potential for application in the food industry because it is simple, fast, nondestructive, and reliable.

Keywords: *Chicken; composition; ultrasound; analysis*

INTRODUCTION

The chemical composition of meat has a large influence on its nutritional value, functional properties, sensory quality, storage conditions, and commercial value. Analytical techniques are therefore needed to grade the quality of raw meat and to characterize meat composition during processing and storage. Traditional analytical techniques are of limited value because they are time-consuming and destructive, and so there is a strong emphasis on the development of rapid and nondestructive techniques.

Low-intensity ultrasound can be used to determine the physicochemical properties of many foods, including composition, structure, and physical state (Javanaud, 1988; Povey and McClements, 1988; Povey, 1989; McClements, 1994, 1995, 1997). Ultrasound has advantages over many traditional analytical techniques because measurements are rapid, nondestructive, precise, and fully automated and can be made in a laboratory or on-line (McClements, 1997). In addition, it is possible to analyze optically opaque samples without the need of extensive sample preparation. The great potential of ultrasound as an analytical tool accounts for the fact that many workers are currently investigating its application to food analysis (McClements, 1997).

Ultrasonics is widely used for measuring meat composition in both live animals and carcasses, and several commercial ultrasonic instruments have been developed for this purpose (Miles et al., 1991; Whittaker et al., 1992; Park et al., 1994; Kestor, 1997). These instruments rely on knowledge of the relationship between the ultrasonic properties and composition of meat, which is still fairly poorly understood. Recent studies have shown that the ultrasonic velocity of fish tissue can be related to its composition (solids-nonfat, moisture, and fat content) using semiempirical equations (Ghaedian et al., 1997, 1998). The purpose of the present study is to develop similar equations for chicken meat and to show that ultrasonic velocity measurements can be used to determine chicken meat composition. This study is part of a project aimed at developing practical ultrasonic techniques for the rapid and nondestructive analysis of meat composition.

ULTRASONIC PROPERTIES OF HETEROGENEOUS MATERIALS

Ultrasonic analysis relies on establishing a relationship between the ultrasonic properties and composition of a material. This relationship can be developed by measuring the ultrasonic properties of a series of samples of known composition and then finding an empirical equation that best fits the results. Alternatively, theoretically equations that are derived from a mathematical consideration of the propagation of ultrasonic waves through a material can be used. In this study, we use a combination of theoretical and empirical approaches to establish a semiempirical relationship between the ultrasonic velocity and the composition of chicken meat. The bulk physical properties of a material are related to its ultrasonic velocity c by the equation (Blitz, 1963)

$$1/c^2 = \rho/\epsilon \quad (1)$$

where ϵ is the appropriate elastic modulus (which depends on the nature of the material being analyzed and the type of ultrasonic waves used) and ρ is the

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density of the material. For bulk solids $\epsilon = K + 4G/3$, where K is the bulk modulus and G is the shear modulus, and for fluids $\epsilon = K = 1/\kappa$, where κ is the adiabatic compressibility.

Ghaedian et al. (1997) showed that the ultrasonic velocity of fish meat could be described by the following equation:

$$1/c^2 = \kappa\rho \tag{2}$$

This equation assumes that the meat can be treated as a liquid; that is, the shear modulus is much smaller than the bulk modulus, which is also valid for chicken tissue (unless it is frozen). In multicomponent materials, such as chicken tissue, it is necessary to take into account the influence of composition on ultrasonic velocity. To a first approximation, the ultrasonic properties of a multicomponent material can be described by (McClements, 1991)

$$1/c^2 = \sum_{j=1}^{n}\phi_j\rho_j \sum_{j=1}^{n}\phi_j\kappa_j \tag{3}$$

where ρ_j, κ_j, and ϕ_j are, respectively, the density, adiabatic compressibility, and volume fraction of component j. The adiabatic compressibility of a material can be calculated from knowledge of its density and ultrasonic velocity using eq 2. Equation 3 can be simplified if one assumes that the densities of the various components are approximately similar:

$$1/c^2 = \sum_{j=1}^{n}\phi_j/c_j^2 \tag{4}$$

It has been shown that this simple relationship gives a good description of the ultrasonic properties of food materials in which the densities of the various phases are similar and the scattering of ultrasound is not appreciable (Miles et al., 1985; Javanaud, 1988; McClements and Povey, 1988, 1992; McClements, 1994). This equation is easier to use than eq 3 because it requires only information about the ultrasonic velocities of the component phases, but for many systems it is not as accurate.

MATERIALS AND METHODS

Materials. Domestic chicken fillets (*Gallus gallus*) were purchased from a local supermarket. Samples were kept in a sealed plastic bag in a refrigerator prior to analysis. All samples were used within 2 days of purchase. Corn oil was purchased from a local supermarket and used without purification. Polyoxyethylene sorbitan monolaurate (Tween 20), a nonionic emulsifier, was purchased from the Sigma Chemical Co. (St. Louis, MO). Xanthan gum, a polysaccharide produced by the bacterium *Xanthomonas compestris*, was obtained from Kelco (San Diego, CA). Distilled water was used in the preparation of all samples.

Proximate Analysis of Chicken. Fat, protein, moisture, and ash contents of the chicken fillets were determined by using standard methods. Fat content was determined by extraction with chloroform/methanol (2:1) using a Waring blender (Model 33BL79, New Hartford, CT) at low speed for 3 min (Lee et al., 1996). Protein content was determined according to a Kjeldahl method (Method 24.028; AOAC, 1984). Moisture content was determined by measuring the mass before and after drying in an oven at 105 °C for 24 h (Method 24.003; AOAC, 1984). Ash content was determined by measuring the mass of a dried sample before and after it was incinerated in a muffle furnace (Method 24.009; AOAC, 1984). Values are reported as the average of measurements on two separate samples.

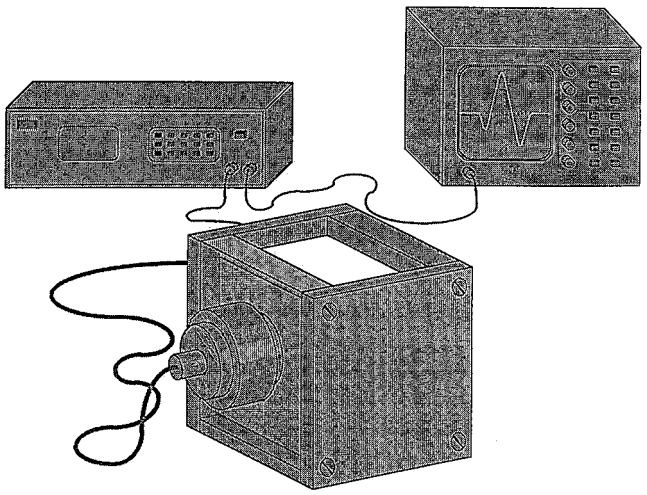

Figure 1. Frequency scanning pulse echo reflectometer (FSUPER) used to measure the ultrasonic velocity of chicken.

Chicken Fillet Preparation. Chicken fillets (≈35 g) were placed in the ultrasonic measurement cell (Figure 1) and their ultrasonic properties measured after they had been allowed to equilibrate to the appropriate temperature for >15 min. After completion of ultrasonic measurements, the same samples were analyzed for fat, protein, moisture, and ash using the AOAC methods described above.

Preparation of Chicken Analogues. The composition of chicken meat varies according to the sex, age, nutritional status, and health of the animal and the time of year. Nevertheless, most chicken meat has protein contents between 15 and 30%, fat contents between 1.6 and 20%, and moisture contents between 55 and 76% (Bodwell and Anderson, 1986). For this reason, we prepared a series of chicken analogues with compositions similar to those found in real chicken.

Dried powdered chicken was prepared from chicken fillets with an initial composition of ≈77% water, ≈20% protein, ≈1.6% fat, and ≈1.4% ash (as determined by the AOAC methods described above). About 1 kg of these minced deskinned chicken fillets was dried in an oven at 100 °C for 24 h. The resulting dried chicken powder was ground using a pestle and mortar and mixed thoroughly. This powder was then stored in a sealed plastic bag and kept in a refrigerator prior to use.

Chicken analogues were prepared by homogenizing dried chicken powder, corn oil, and distilled water using a Waring blender (Model 33BL79, New Hartford, CT) at high speed for 3 min. Corn oil was used, rather than chicken oil, because it was much less prone to lipid oxidation and because it did not crystallize at the temperatures used. Most liquid edible oils have similar ultrasonic velocities (McClements and Povey, 1988), and therefore we do not expect the use of corn oil, rather than chicken oil, to have a significant influence on our findings. When the chicken analogues were poured into glass beakers and allowed to stand on the bench for 10 min, it was observed that some of the protein sedimented to the bottom of the container while some of the oil droplets rose to the top. For this reason a small quantity of thickening agent (0.1% santhan) and emulsifier (2% Tween 20) was added to the samples to prevent instability due to coalescence, creaming, or sedimentation.

Particle Size Measurements of Chicken Analogues. A laser light scattering technique (LA 900, Horiba Instruments, Irvine, CA) was used to measure the size of the oil droplets and insoluble protein particles in the chicken analogues. Protein particles were separated from oil droplets by centrifuging chicken analogues at a low speed so that the droplets moved to the top of the container and the protein to the bottom. The fractions were then separated, washed with water, and

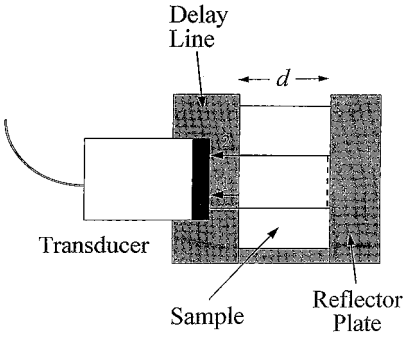

Figure 2. Schematic of the measurement cell used to carry out the ultrasonic measurements. See text for details of full measurement procedure.

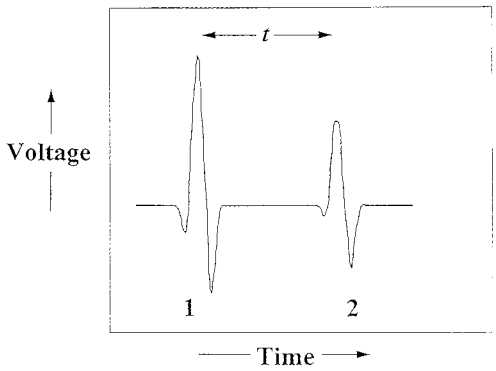

Figure 3. Oscilloscope display. The ultrasonic velocity of chicken meat is determined by measuring the time difference between successive echoes (see text for details).

recentrifuged, prior to analysis by the light scattering technique. The protein particles were found to have a diameter of ≈150 μm and the fat droplets a diameter of ≈11 μm.

Ultrasonic Measurements. The ultrasonic velocity of samples was measured using an ultrasonic spectrometer (McClements and Fairley, 1991, 1992). The experimental arrangement (Figure 1) for measurements consisted of a custom-designed cell, a broad-band ultrasonic transducer (3.5 MHz, 0.5 in. diameter crystal; Model V682, Panametrics, Waltham, MA), a pulser/receiver (200 MHz computer-controlled ultrasonic pulser/receiver; Model 5900PR, Panametrics), a digital storage oscilloscope (Lecroy 9300, Lecroy Instruments, Chestnut Ridge, NY), and a personal computer with appropriate software (LabVIEW for Windows, National Instruments, Austin, TX). The cell consisted of a plexiglass (perspex) delay line and a brass reflector plate, separated by distance of 16 mm, where a sample was placed (Figure 2). The cell containing the sample was placed in a water bath, where it was allowed to equilibrate to the measurement temperature for at least 15 min prior to analysis.

The pulser/receiver generated a broad-band electrical pulse, which was converted into an ultrasonic pulse by the transducer. This pulse propagated along the delay line, until it reached the boundary between the delay line and the sample, where it was partly reflected and partly transmitted. The reflected pulse returned directly to the ultrasonic transducer, where it was converted back into an electrical signal, amplified, and displayed on an oscilloscope (Figure 3). The transmitted pulse traveled across the sample, was reflected by the brass reflector plate, and then traveled back across the sample and through the delay line, where it was detected by the transducer and also displayed on the oscilloscope. The resultant signal was averaged 500 times and then sent from the oscilloscope to a PC via a GPIB card (AT-GPIB/TNT, National Instruments), where it was stored and analyzed.

The ultrasonic group velocity of the sample was determined by analyzing the received signal (Figure 3). The time difference between the echo reflected from the delay line/sample interface and that reflected from the sample/reflector plate interface is the time t taken for the pulse to travel twice the length of the sample. Thus, the ultrasonic velocity could be calculated as $c = 2d/t$, where d is the path length. The path length is fixed and was measured accurately by calibrating the device with distilled water, a material for which the ultrasonic velocity is accurately known: $2d = c_{water}t_{water}$. Values are reported as the average of three measurements on the same sample. This device was capable of measuring the ultrasonic velocity to ±0.5 ms^{-1}.

Ultrasonic measurements were carried out over the temperature range 5−35 °C to establish the temperature dependence of the ultrasonic properties of the chicken analogues and chicken fillets. Samples were kept for ~15 min at the required temperature to reach thermal equilibrium, after which time the measurement procedure required <30 s.

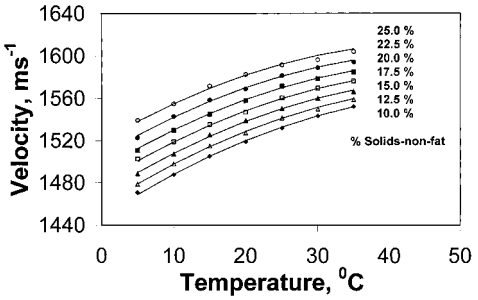

Figure 4. Temperature dependence of the ultrasonic velocity of aqueous solutions containing different concentrations of solids-nonfat (ϕ_{SNF}). The curves represent ϕ_{SNF} values of 10, 12.5, 15, 17.5, 20, 22.5, and 25 from bottom to top. The measured values are represented as symbols, and the values predicted by eq 5 are represented by the curves.

RESULTS AND DISCUSSION

Influence of Solids-Nonfat. The temperature dependence of the ultrasonic velocity of a series of aqueous suspensions containing different concentrations of dried chicken powder was measured (Figure 4). Dried chicken powder contains predominantly protein and minerals (and a small amount of membrane lipids), and therefore its concentration in aqueous solutions will be referred to as solids-nonfat (ϕ_{SNF}), which is the mass fraction of sample that is neither oil nor water. The ultrasonic velocity increases with ϕ_{SNF} at all temperatures and increases with temperature at constant ϕ_{SNF} (Figure 4). An empirical equation was developed to relate the ultrasonic velocity of the aqueous solutions of chicken powder to ϕ_{SNF} and temperature:

$$c_{AQ} = k_0 + k_1\phi_{SNF} + k_2\phi_{SNF}^2 + k_3T + k_4T^2 + k_5\phi_{SNF}T \quad (5)$$

Here c_{AQ} is the ultrasonic velocity of the aqueous suspension, T is the temperature (in °C), and the constants k_i are determined by finding the best fit between this equation and the experimental measurements shown in Figure 4 using a standard statistical program (SYSTAT): $k_0 = 1411.3$, $k_1 = 313.3$, $k_2 = 473.8$, $k_3 = 4.830$, $k_4 = -0.0430$, and $k_5 = -3.338$. The predictions of the ultrasonic velocities made by the above equation were in excellent agreement ($r^2 = 0.998$) with the experimental measurements over the entire temperature range (Figure 4). A similar approach proved to be useful for describing the dependence of the ultrasonic velocity of sugar solutions on temperature and solute concentration (Contrera et al., 1992) and for

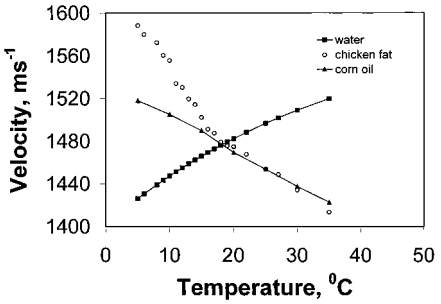

Figure 5. Temperature dependence of the ultrasonic velocity of distilled water, corn oil, and chicken fat.

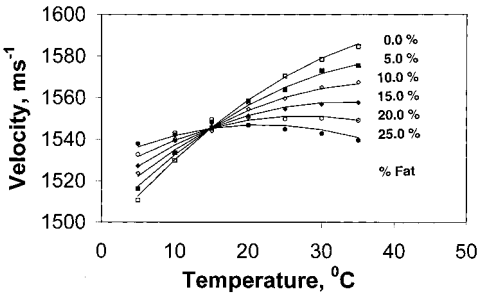

Figure 6. Temperature dependence of the ultrasonic velocity of chicken analogues containing the same overall solids-nonfat content (20 wt %) but different oil contents.

describing the dependence of the ultrasonic velocity of cod fillets on SNF and temperature (Ghaedian et al., 1998).

Influence of Fat Content. Many parts of chicken contain significant amounts of fat, and so it is important to determine the influence of fat on ultrasonic velocity. The temperature dependence of the ultrasonic velocity of pure corn oil and distilled water is shown in Figure 5. At a critical temperature ($T_C \approx 18$ °C), the ultrasonic velocities of the corn oil and water are similar. The ultrasonic velocity of a two-component material is determined by its composition and the ultrasonic velocities of the individual components (eq 4). We would therefore expect the influence of fat on the ultrasonic velocity of chicken to be dependent on the measurement temperature: when $T < T_c$, the ultrasonic velocity should increase with fat (because fat has a higher velocity than water); when $T \approx T_c$, it should be independent of fat (because fat and water have similar velocities); and, when $T > T_c$, it should decrease with fat (because fat has a lower velocity than water). To determine the fat content of a chicken, it is therefore important to make the measurement at a temperature sufficiently above or below T_c. In practice, the critical temperature at which the fat and aqueous phase have similar ultrasonic velocities depends on the solids-nonfats content, decreasing as SNF increases, because the ultrasonic velocity of the aqueous phase increases with SNF (Ghaedian et al., 1997).

The ultrasonic velocities of a series of chicken analogues containing 20 wt % solids-nonfat (chicken powder) and varying amounts of fat (0, 5, 10, 15, 20, and 25 wt % corn oil) were measured over a range of temperatures (Figure 6). These measurements indicate that the ultrasonic velocity is relatively insensitive to fat around 15 °C, increases with fat below this temperature, and decreases with fat above it. To determine the fat content of chicken tissue, it is necessary to measure the ultrasonic velocity at a temperature sufficiently far from the critical temperature, that is, <10 or >20 °C

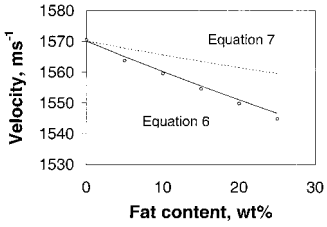

Figure 7. Variation of ultrasonic velocity of chicken analogues with oil content at 25 °C. Each of the samples has the same overall solids-nonfat content (20 wt %). The full curves are the ultrasonic velocities predicted by eqs 6 and 7.

(Figure 6). The dependence of the ultrasonic velocity of the chicken analogue on fat content at 25 °C is shown in Figure 7. The inclination of the line in Figure 7 indicates that the ultrasonic velocity decreased by ~1.0 m s^{-1} per 1% increase in fat content ($r^2 = 0.997$). If the ultrasonic velocity can be measured to within 1 m s^{-1}, then it should be possible to determine the fat content to better than 1% at this temperature.

Fatty tissue can be considered to consist of two phases: an aqueous phase (solids-nonfat plus water) and an oil phase. Ghaedian et al. (1997, 1998) described the relationship between ultrasonic velocity and composition by the relationship

$$1/c^2 = [\phi_{FAT}\rho_{FAT} + (1 - \phi_{FAT})\rho_{AQ}][\Phi_{FAT}\kappa_{FAT} + (1 - \phi_{FAT})\kappa_{AQ}] \quad (6)$$

or, in the case where the densities of the fat and aqueous phases are similar

$$\frac{1}{c^2} = \frac{\phi_{FAT}}{c_{FAT}^2} + \frac{(1 - \phi_{FAT})}{c_{AQ}^2} \quad (7)$$

Here ϕ_{FAT} is the volume fraction of fat present, c_{FAT} and c_{AQ} are the ultrasonic velocities, and ρ_{FAT} and ρ_{AQ} are the densities of the separate fat and aqueous phases, respectively. It must be stressed that c_{AQ} and ρ_{AQ} are the ultrasonic velocity and density of an aqueous phase that has a solids-nonfat content of ϕ_{SNF}. The ultrasonic velocity of a fatty tissue can therefore be related to its composition once the ultrasonic velocity and density of the component phases are known. The ultrasonic velocity of the aqueous phase of chicken analogues from this experiment is given by

$$c_{AQ} = 1411.3 + 313.3\phi_{SNF} + 473.8\phi_{SNF}^2 + 4.830T - 0.0430T^2 - 3.338\phi_{SNF}T \quad (8)$$

The density of the aqueous phase, assuming that the increase in density with ϕ_{SNF} is similar to that for a pure globular protein, is given by (Pavlovskya et al., 1993)

$$\rho_{AQ} = \rho_{water} + 262.5\phi_{SNF} \quad (9)$$

where ρ_{water} is the density of water at the measurement temperature. The temperature dependence of the ultrasonic velocity and the density of corn oil are given by (Chanamai et al., 1998)

$$c_{FAT} = 1538.2 - 3.362T \quad (10)$$

$$\rho_{FAT} = 934.2 - 0.663T \quad (11)$$

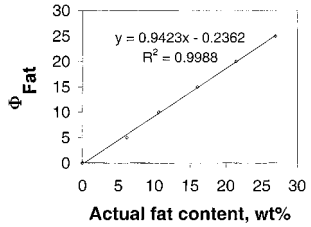

Figure 8. Comparison of fat contents determined by ultrasonic velocity measurements with actual values.

By substituting these values into eqs 6 and 7 we are able to relate the ultrasonic velocity of chicken tissue to its composition and temperature. At 25 °C, there is fairly good agreement between predictions of the ultrasonic velocity made using eq 6 and the experimental measurements (Figure 7), but the predictions of eq 7 considerably overestimate the ultrasonic velocity. For this reason, we suggest that eq 6 should be used to relate the ultrasonic properties of meat to their composition.

The fat content of chicken tissue can be determined at a specific temperature by measuring its ultrasonic velocity and inserting the relevant values for c_{FAT}, ρ_{FAT}, c_{AQ}, and ρ_{AQ} into eq 6. The resulting equation is a quadratic in ϕ_{FAT} that has one physically realistic root, that is, $0 < \phi_{FAT} < 1$. The fat contents of the samples shown in Figure 8 were calculated from the ultrasonic velocity measurements using eq 6 and compared with the actual values (Figure 8). There is an excellent correlation between the predicted values and the actual values ($r^2 = 0.999$).

It is possible to determine both the fat and solids-nonfat contents of chicken tissue by measuring the ultrasonic velocity as a function of temperature and finding the values of ϕ_{SNF} and ϕ_{FAT} that give the best fit between eq 6 and the experimental data (see later).

Influence of Fat Crystallization on the Ultrasonic Velocity of Chicken Fat. The semiempirical equations developed in the previous section assume that the chicken fat remains liquid across the temperature range of interest. We observed that pure chicken fat (extracted from chicken meat by pressing) became milky white when cooled below ~15 °C, indicating that solid fat crystals had formed. The temperature dependence of the ultrasonic velocity of pure chicken fat was compared with that of pure corn oil (Figure 5). The ultrasonic velocities of the two fats were similar above 15 °C (where they were both liquid), but that of the chicken fat increased above that of the corn oil below this temperature, which can be attributed to fat crystallization (McClements, 1997). The variation of solid fat content with temperature was calculated from the ultrasonic velocity measurements using the equation

$$\mathrm{SFC} = \frac{1/c^2 - 1/c_L^2}{1/c_S^2 - 1/c_L^2} \qquad (12)$$

where c is the ultrasonic velocity of the sample and c_L and c_S are the ultrasonic velocities (at the same temperature) of the fat when it is completely liquid and completely solid, respectively. The value of c_L was determined by extrapolating the velocity measurements from the region where the fat was completely liquid, whereas a value of $c_S = 2050 + 5(T + 30)$ ms^{-1} was taken from the literature (McClements, 1997). The ultrasonic velocity technique clearly shows that the SFC

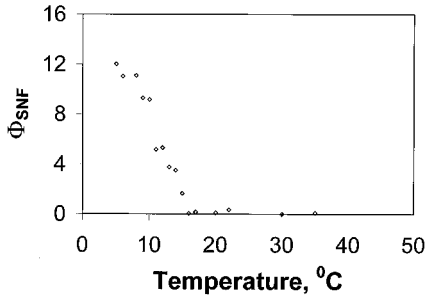

Figure 9. Variation of solids-nonfat (SFC) with temperature for chicken fat calculated from ultrasonic velocity measurements.

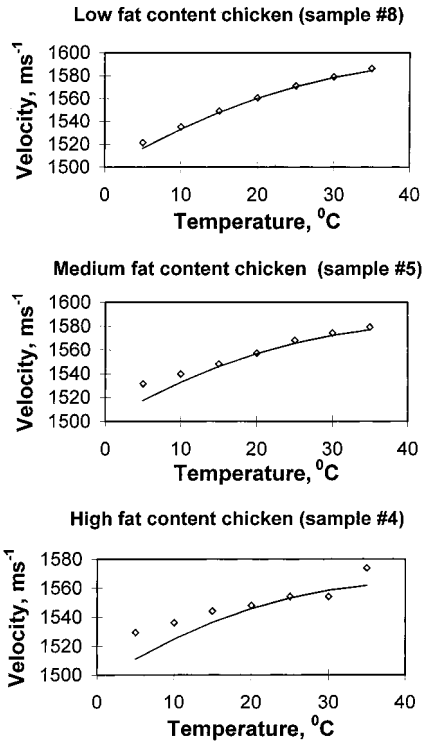

Figure 10. Ultrasonic velocity versus temperature profiles for different chicken fillets. Experimental measurements are open diamonds, and predictions of eq 6 are curves, respectively.

increased as the temperature was decreased below 15 °C (Figure 9). It is therefore important to be aware of the fact that chicken fat may be partly crystalline at the temperatures used in this study. To avoid complications due to fat crystallization in the ultrasonic analysis of chicken composition, it is therefore wise to use temperatures >20 °C, at which the fat is completely liquid.

Influence of Temperature and Composition on Ultrasonic Velocity of Chicken Fillets. The influence of temperature on the ultrasonic velocity of chicken fillets with various compositions was measured (Figure 10). The ultrasonic velocity of all the samples increased with temperature because they consisted predominantly of water (Figure 5). The ultrasonic velocity of chicken samples varied between approximately 1515 and 1610 ms^{-1} depending on temperature and composition. Predictions of the temperature dependence of the ultrasonic velocity of the chicken samples made by using eqs 6, 8−11 and knowledge of the chicken composition (Table 1) were compared with measured values (Figure 10). The values of ϕ_{SNF} used in the calculations were determined from the chicken composition using the

Table 1. Comparison between Composition of Chicken Meat Determined with Standard Methods[a] and Composition of Chicken Fillets Estimated from Ultrasonic Velocity−Temperature Profiles for an Individual Chicken from 20 to 35 °C[b]

chicken sample	composition determined with standard methods (wt %)				composition estimated from ultrasound (wt %)		
	fat	ash	protein	moisture	fat	protein + ash	moisture
1	7.2 (0.2)	2.3 (0.1)	24.7 (0.3)	65.8 (0.2)	7.2	27.8	65.0
2	3.5 (0.1)	2.1 (0.1)	21.6 (0.1)	72.7 (0.1)	3.1	23.2	73.6
3	7.6 (0.4)	1.4 (0.4)	18.3 (0.1)	72.7 (0.1)	7.7	19.2	73.0
4	8.8 (0.2)	1.9 (0.1)	16.2 (0.2)	73.1 (0.2)	8.7	18.5	72.9
5	4.6 (0.1)	2.0 (0.1)	18.4 (0.1)	74.9 (0.1)	4.7	20.5	74.8
6	1.0 (0.1)	2.1 (0.1)	17.2 (0.1)	79.7 (0.1)	0.8	18.5	80.6
7	2.0 (0.1)	2.2 (0.1)	18.1 (0.1)	77.6 (0.2)	2.0	20.2	77.9
8	1.6 (0.1)	2.1 (0.1)	18.7 (0.1)	77.6 (0.2)	1.7	20.7	77.7

[a] Values are means and standard deviations for analysis of two samples from the same chicken samples. [b] This temperature range was used so that fat crystallization did not interfere with the ultrasonic analysis (see text for details). Moisture contents were calculated from 100 − % fat − % (protein + ash).

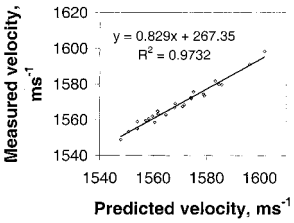

Figure 11. Comparison of measured ultrasonic velocity with values predicted using eq 6 from knowledge of the chicken fillet composition in the temperature range 20−35 °C.

following relationship: ϕ_{SNF} = (% protein + % ash)/(100 − % oil). The volume fraction of oil in the chicken samples was calculated from a knowledge of the oil mass fraction (ϕ_m = % fat/100) and the densities of the component phases:

$$\phi_{FAT} = \left[1 + \frac{\rho_{FAT}}{\rho_{AQ}}\left(\frac{1}{\phi_m} - 1\right)\right]^{-1} \quad (13)$$

There was good agreement between the measured and predicted temperature profiles of the ultrasonic velocity in the temperature range 20−35 °C (over which the chicken fat was completely liquid). Nevertheless, the measured ultrasonic velocity increased significantly above the predicted value at lower temperatures, presumably because of fat crystallization.

There was a high correlation between measured and predicted values in the temperature range 20−35 °C, with $r^2 = 0.97$ for 27 measurements, slope = 0.829, and intercept = 267.35 m s^{-1} (Figure 11). This suggests that the semiempirical equations developed in this paper do give a reasonably good description of the ultrasonic properties of chicken samples, provided that fat crystallization does not occur. If fat crystallization does occur, it is necessary to replace the ultrasonic velocity and density of the liquid fat phase (eqs 10 and 11) with those of a partly crystalline fat phase (McClements, 1997).

Prediction of Chicken Composition. Previous work has shown that it is possible to determine both the fat content and the solids-nonfat content of fish fillets from ultrasonic velocity measurements over a range of temperatures (Ghaedian et al., 1997, 1998). We carried out the same procedure for chicken meat by finding the values of ϕ_{FAT} and ϕ_{SNF} that minimized the error between the measured and predicted ultrasonic velocity−temperature profiles using only the data from 20 to 35 °C (at which the chicken fat was completely liquid). The values determined by using the ultrasonic technique were in reasonable agreement with those determined by using standard methods (Table 1). The correlation coefficients between the chicken composition determined with standard and ultrasonic methods were $r^2 = 0.998$ for fat, $r^2 = 0.977$ for solids-nonfat content, and $r^2 = 0.992$ for moisture. The ultrasonic velocity−temperature profiling technique may therefore prove to be a useful means of determining the composition of chicken meat.

Conclusions. The ultrasonic properties of chicken tissue depend on composition and temperature. The ultrasonic velocity increases with solids-nonfat content at all temperatures but has a more complex dependence on fat content. It is independent of fat content at a critical temperature, increases with fat content below this temperature, and decreases above it. The ultrasonic velocity also increases when the chicken fat crystallizes. By measuring the ultrasonic properties of chicken meat over a range of temperatures, it is possible to determine the fat, solids-nonfat, and solid fat contents. The semiempirical equations developed in this study will also prove to be useful for those who need to predict the ultrasonic velocity of chicken tissue. Our results suggest that ultrasound offers scientists a rapid and nondestructive method of analyzing the composition of chicken.

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