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Preliminary study to assess ultrasonic characteristics of *Torta del Casar* – Type cheese

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ABSTRACT

Ultrasound has been used to non-destructively asses the quality of many foods. This paper raises the non-invasive ultrasonic method to control the change in physical properties of organic cheese (*Torta del Casar*) made from the milk of sheep.

For that purpose, we firstly researched the changes of ultrasonic velocity, attenuation and harmonic components during the renneting process by pulse-echo method at different frequencies (500 kHz and 1 MHz). The changes in the liquid media induce these variations. The pH and temperature of the rennet-induced milk sample was also measured simultaneously with the ultrasonic measurements. Total of 3 experiments were conducted in a laboratory environment at [25.6-27.6] ^{o}C, [23.7-28.2] ^{o}C and [32.0-33.1] ^{o}C, respectively. The cutting times determined from ultrasonic measurements were compared to the cutting times from manual methods.

Then, we study the velocity and FFT of the longitudinal and shear waves during cheese maturation by an ultrasonic transmission technique at different frequencies (50 kHz, 100 kHz, 250 kHz and 500 kHz). The maturation experiments at different days were performed on 32 blocks of *Torta del Casar*, including commercial cheeses. The detection temperature interval was [5.0-7.0]^{o}C.

From the obtained results, it appears to be possible to use an ultrasonic device to non-destructively monitor the cheese manufacturing processes (renneting process and maturation).

INTRODUCTION

Several instrumental methods are used to assess food products. Most of the instrumental methods are destructive and cause significant deformation to the sample resulting in imprecise measurements. Ultrasonic measurement provides a non-destructive method for determining food mechanical properties. The number of applications of low intensity ultrasonics (LIU) in the food industry has increased during the last decades. LIU have been used to determine the quality of many foods rapidly and non-destructively by determining their acoustical properties (longitudinal and shear velocities, attenuation, frequency spectrum, ...).

In the dairy industry, LIU has been used to assess cheese characteristics [1, 2, 3], the composition of milk [4], the milk clotting [5, 6], the foreign bodies in food products [7] or the draining stage of cheese production [8].

The number of different cheese types found around the world is practically countless. They are differences in the raw materials and manufacturing procedures. In fact, cheese is the final product of a series of processes including rennet addition to milk, cutting the coagulum, draining the way, shaping and further processing.

The *Torta del Casar* is an organic cheese made from the milk of sheep raised in controlled conditions. The cheese-making process generally follows the flow chart of Fig. 1. The separation of the curds and whey takes place in large vats and any impurities are eliminated here. When the milk reaches 28-32ºC, the rennet is added, which is a liquid obtained from the pistils of the *Cynara Cardunculus* flower. When the curd is formed, it is broken into pieces of around the size of a grain of rice using fine metallic threads. The grains of curd are manually put into the moulds. When the moulds are full, the cheese is pressed and the salting begins. The salt is either put directly onto the cheese or the cheese itself is submerged into brine. It is at this point tan the cheese is matured in chambers with a low temperature (5-9ºC) but a high relative humidity (>90%) for a period of at least sixty days. The cheese has a fine, soft and delicate rind, with a yellowish colour. With a special aroma and strong, mature taste, the cheese is also slightly salty and bitter due to the use of *Cynara Cardunculus* [9].

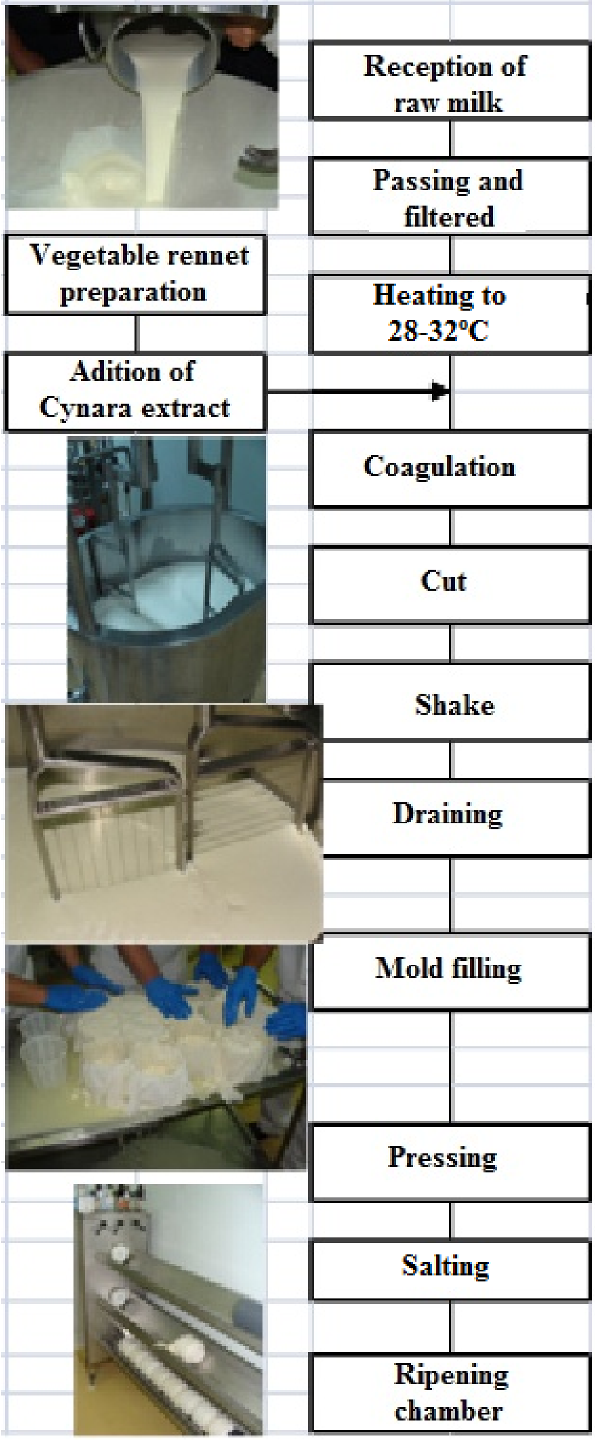

Figure 1. Flowchart of the *Torta del Casar* cheese-making process

The aim of this paper is to describe the ultrasound measurement techniques developed to inspect the milk, curd formation, and curing of *Torta del Casar* type cheeses. In particular, we describe how this inspection is carried out to evaluate the raw milk, the coagulation process (including the optimal cutting time), and the ripening of the cheeses under refrigeration. A preliminary evaluation of the results is presented.

MATERIALS AND METHODS

Material

The experiments were performed with raw sheep milk collected from a local dairy processing centre (*Hnos. Pajuelo SAT*) on two separate days. These samples were used for both the characterization of the raw milk and the coagulation process. During the various inspections, the samples' temperature and pH were monitored constantly.

For the maturation experiments, the same type of *Torta del Casar* cheese was used at different days. To characterize the ripening, 32 cheeses were inspected at various stages (20, 40, 60, and 70 days of ripening). These cheeses were cylinders of about 13 cm diameter and 7 cm height, with the latter shrinking to about 5 cm by the end of ripening. The initial weight of the cheeses was 950 g, decreasing to around 600 g at 60–70 days. The diameter, height, and weight of each sample were measured, and the density was calculated assuming a cylindrical geometry.

Immersion ultrasonic device

The raw milk and curd formation experiments were performed by immersion ultrasound. Total of 3 experiments were conducted in a laboratory environment at [25.6-27.6] ºC, [23.7-28.2] ºC and [32.0-33.1] ºC, respectively. The device used consisted of a pulser-receiver (Panametrics, Model 5077), two pairs of transducers (Panametrics V318SU and V314SU) whose main characteristics are listed in Table 1, and a digital storage oscilloscope (Tektronix TDS 1012B) connected to a PC incorporating the data processing software Tektronix OpenChoice Desktop v1.4. Immersion transducers are single element longitudinal wave transducers, whose wear face is impedance matched to water. The transducers were mounted on a custom-designed metal structure that ensured their perfect face-to-face alignment. Each pair of transducers was used in two measurement modes: through-transmission (T-T) and pulse-echo (P-E). For the latter, one of the transducers acted as a mirror which reflected the ultrasound waves.

Table 1. Frequency f, diameter ϕ, wavelength λ, and near-field N, in milk of the immersion ultrasonic transducers used in the inspection of the milk and the coagulation process

Transducer	f (MHz)	ϕ (mm)	λ (milk) (mm)	N (milk) (mm)
V318	0.5	19	3.0	30
V314	1	19	1.5	60

Each measurement provided simultaneously the data of the ultrasound speed of propagation, the attenuation, and the FFT.

The velocity measurements were computed from the averages $<t_i>$ of the flight times measured between i consecutive echoes of the receiver's A-scan. These echoes appear independently of the working mode, whether transmission or pulse-echo, and are caused by reflections between the transducers facing each other. Since the transducers are separated by a distance d, the echoes are separated by twice that distance (see Fig. 2). Three of four echoes were considered, with application of Eq. [1].

$$v = \frac{2d}{< t_i >} \quad [1]$$

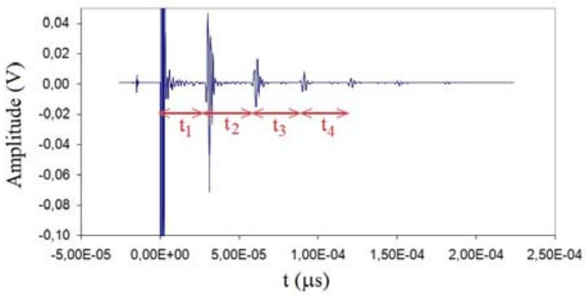

Figure 2. Example of the A-scan signal received by the Panametrics V314 transducer. After the trigger pulse, one observes the echoes of the ultrasound signal

To compute attenuation α in Neper/m, Eq. [2] was used:

$$\alpha = \frac{1}{2d}\ln\left(\frac{A_i}{A_{i+1}}\right) \qquad [2]$$

Where A_i is the amplitude (peak to peak) of the i echo. Three of four echoes were considered and α was determined from the slope of the plot ln (A_i/A_{i+1}) vs. $2d$.

The FFT study was made starting with the arrival of the ultrasound waves at the receiving transducer. The data obtained were the central frequency, and the integrated periodogram at 25% (f_{25}), 50% (f_{50}), 75% (f_{75}), and 99% (f_{99}) of the FFT (see Fig. 3).

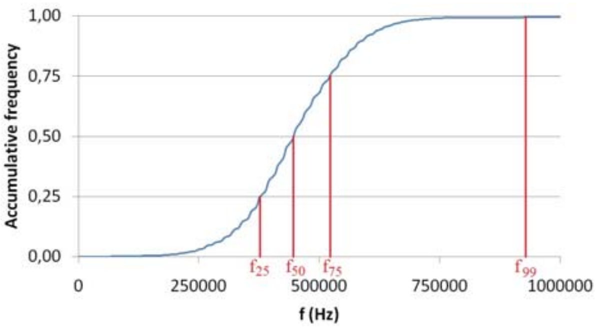

Figure 3. Example of an integrated periodogram of the signal received by the Panametrics V318 transducer. In red are marked the cumulative frequency values at 25% (f_{25}), 50% (f_{50}), 75% (f_{75}), and 99% (f_{99}) of the FFT

Contact ultrasonic device

Ultrasonic inspection of the cheeses during the ripening process was carried out using contact techniques in T-T mode. All measurements were made at controlled temperatures of between 5°C and 7°C. The devices tested were:

- A pulser-receiver (Panametrics, Model 5058PR).
- Two pairs of ultrasonic longitudinal wave transducers (Panametrics V189 and Krautkramer B0,05U/E-S) whose main characteristics are listed in Table 2. Contact transducers are single element that are intended for direct contact with a test piece.
- Three pairs of ultrasonic shear wave transducers (Panametrics V1548, V151, and V150) whose main characteristics are listed in Table 3. Single element contact transducers introduce shear waves directly into the test piece without the use of refracted wave mode conversion. The ratio of the longitudinal to shear wave components is generally below -30dB [10].
- A digital storage oscilloscope (Tektronix TDS 1012B) connected to a PC incorporating the data processing software Tektronix OpenChoice Desktop v1.4.

Table 2. Frequency f, diameter ϕ, wavelength λ_L, and near-field N_L, in cheese of the longitudinal ultrasonic contact transducers used to inspect *Torta del Casar* cheeses during ripening

Transducer	f (MHz)	ϕ (mm)	λ_L (cheese) (mm)	N_L (cheese) (mm)
B0,05U/ E-S	0.05	56	30	26
V189	0.5	38	3	120

Figure 4 shows the experimental set-up used for the measurements. The transducers were mounted on a custom-designed metal structure that ensured their perfect face-to-face alignment. Each pair of transducers was used in T-T mode.

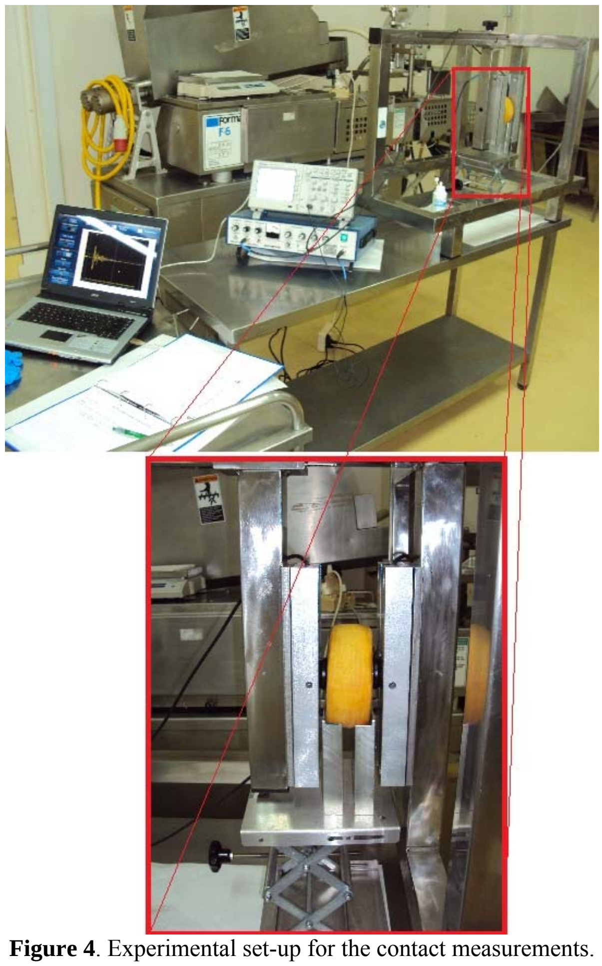

Figure 4. Experimental set-up for the contact measurements. Detail of the contact of the transducers with the *Torta del Casar* cheese

Each measurement provided simultaneously the values of the ultrasound propagation velocities (v_L and v_S), and the FFT.

For v_L and v_S, the transducers were placed at the centre of opposite faces, measuring the transit time (t_L or t_S) of the sound from emission until reception. Since the thickness l of the sample were measured, the determination of v_L and v_S, was immediate from Eq [3] and Eq. [4], respectively:

$$v_L = \frac{l}{t_L - t_{DL}} \quad [3]$$

$$v_S = \frac{l}{t_S - t_{DS}} \quad [4]$$

Where t_{DL} and t_{DS} are the equipment delay times for longitudinal and shear waves, respectively.

The FFT study was performed as indicated for the immersion technique.

Table 3. Frequency f, diameter ϕ, wavelength λ_S and near zone N_S, in cheese of the longitudinal ultrasonic contact transducers used to inspect *Torta del Casar* cheeses during ripening

Trans-ducer	f (MHz)	ϕ (mm)	λ_S (cheese) (mm)	N_S (cheese) (mm)
V1548	0.1	25	7.5	21
V150	0.25	25	3	52
V151	0.5	25	1.5	104

INMERSION TECHNIQUES RESULTS

Selection of the measurement technique

Figure 5 shows the evolution of the velocities measured with the V314 transducer for a milk sample as a function of the distance between transducers. The values correspond to those obtained using both the T-T and the P-E modes. The analogous graph for the V318 transducer is very similar. The vertical line represents the value of the near-field length of the V314 transducer. Two important aspects can be deduced from the values represented:

- The measured ultrasound propagation speed increases with the separation distance, reaching an asymptotic value when just leaving the near-field region. It seems logical therefore, that regardless of the transducer used, the distance travelled by the ultrasonic beam before being reflected must be greater than the transducer's near-field length for the value of the velocity to be coherent.

- The velocity values obtained with the two modes of inspection are similar. Furthermore, as one observes in Fig. 6 which represents the A-scans obtained for a distance between transducers greater than the near-field length, it is irrelevant which of the two modes is used.

In view of the above considerations, we opted in this work to use the pulse-echo mode.

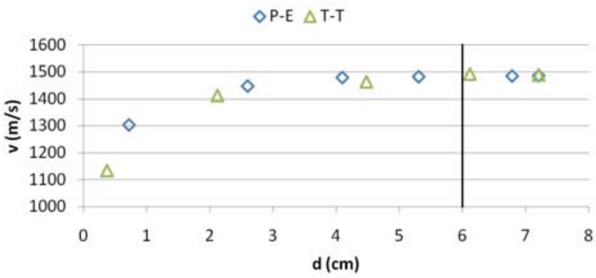

Figure 5. Study with the V314 transducer of the evolution of the speed of ultrasound v versus distance d travelled by the ultrasound beam in pulse-echo and through-transmission modes. The vertical line indicates the transducer's near-field length

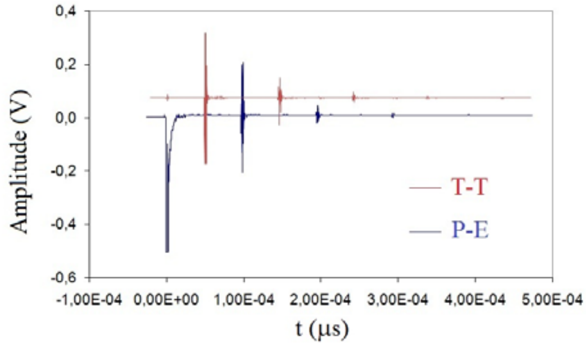

Figure 6. Comparison of the A-scans obtained with the V314 transducer in through-transmission (TT) and pulse-echo (PE) modes for a distance between transducers of d=7.21 cm

Transducer selection

Figure 7 shows the A-scans obtained in pulse-echo mode with the transducers V314 and V318 separated by a distance greater than their respective near-field lengths. As was to be expected, the attenuation of the echoes with the V318 transducer was significantly less than with the V314 device. Indeed, with the latter the 4th echo can hardly be distinguished, while with the V318 one can distinguish up to the 6th. There are two reasons for this:

- The frequency of the V318 is lower than that of the V314. Equivalently therefore, the wavelengths it emits are longer than those emitted by the V314 so that there is less attenuation of its ultrasound waves.

- Since the two transducers are of the same size, the near-field length is greater in V314 than in V318. Consequently, as explained above, it is necessary to separate the V314 transducers more than the V318 transducers, resulting in less attenuation of the waves emitted by the latter.

For the reasons given in this and the previous subsections, the transducer used was the V314 in pulse-echo mode.

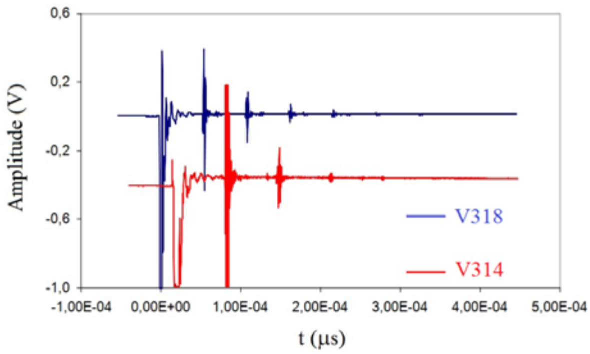

Figure 7. Comparative study of the A-scans obtained with the V318 and V314 transducers

Ultrasonic characterization of the milk and of the coagulation process

With the caveat that the statistical validity of the three trials carried out is clearly limited, the following describes the main results of these three sets of measurements.

For the three raw milks measured, the values of the velocity v obtained with the V314 transducer in pulse-echo mode carried out at 28°C were: (1463±11) m/s, (1504±10) m/s, and (1559±11) m/s. These results are coherent with the literature data. In particular, Donoso et al. report values of v in milk with different fat contents of between 1500 m/s and 1540 m/s [11], and Taifi et al. report values in the range [1514–1597] m/s [12].

With respect to the ultrasonic inspection of the coagulation process, Fig. 8 shows by way of example the temporal evolution of the ultrasound velocity and attenuation of one of the milks during that process. The temperature of the process was maintained within the range [32.0–33.1]°C. As can be seen, the optimal cutting time (vertical black line) indicated by the master cheese-maker (using manual techniques) coincides with a period during which the speed is stable and immediately after a small peak in the attenuation. Thus, the experimental variability would not allow the speed of ultrasound by itself to be used to determine the cutting time. Other studies have reported similar behaviour. In particular, Benedito et al. found that the speed of ultrasound increased during coagulation, while attenuation decreased [4]. Koc et al., in addition to the above, noted that the time at which the attenuation stabilizes corresponds to the onset of coagulation [8]. Nassar et al. made various measurements of the velocity by changing the temperature and pH of the coagulation process, finding that it increases with the coagulation time at different temperatures, pH's, and rennet concentrations [13].

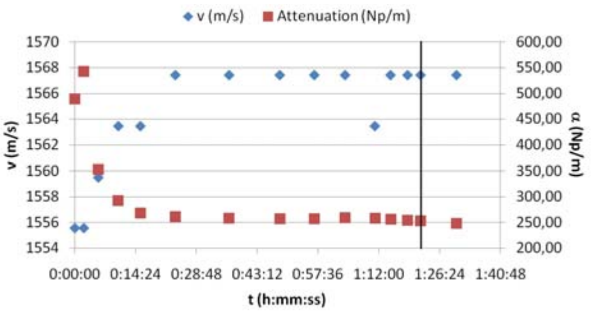

Figure 8. Temporal evolution of the velocity v (m/s) and attenuation α (Np/m) of ultrasound waves during the coagulation process. The black vertical line indicates the optimal cutting time indicated by the master cheese-maker

Similarly, Fig. 9 shows the central frequency and cumulative frequencies at 25% (f_{25}), 50% (f_{50}), 75% (f_{75}), and 99% (f_{99}) of the FFT obtained for the ultrasound signals. Again the black vertical line indicates the optimal cutting time indicated by the master cheese-maker. This cutting time corresponds to a moment immediately after the five frequencies stabilized following a minimum. These two aspects were observed in all the experiments. *A priori*, therefore, this is an interesting result as it would allow the optimal cutting time to be established technically and scientifically rather than artisanally as is done today.

CONTACT TECHNIQUE RESULTS

Transducer selection

Unlike the case of the immersion technique, the inspection of cheeses during the ripening process by the contact technique was done only in T-T mode. The reason for this was that it was impossible with any of the transducers used to distinguish the echoes from the various reflections within each cheese. By way of example, Fig. 10 shows a typical ultrasonic waveform obtained in the inspection of a sample with the B0,05U transducers. The situation was the same for all the inspections with all of the contact transducers. It is possible that the smallness of *Torta del Casar* cheeses (cylindrical, about 13 cm in diameter and 7 cm in height) leads to multiple echoes of the ultrasound waves confined in them, causing interference and overlap in the A-scan. We therefore only used the T-T mode to measure the flight time between the emission and reception of the ultrasound pulse.

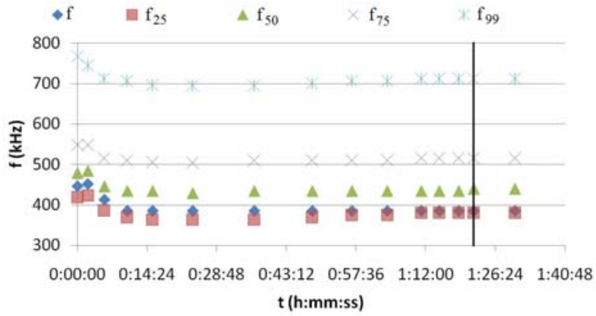

Figure 9. Temporal evolution of the central frequency and cumulative frequencies at 25% (f_{25}), 50% (f_{50}), 75% (f_{75}), and 99% (f_{99}) of the FFT of ultrasound signals obtained during the coagulation process. The black vertical line indicates the optimal cutting time indicated by the master cheese-maker

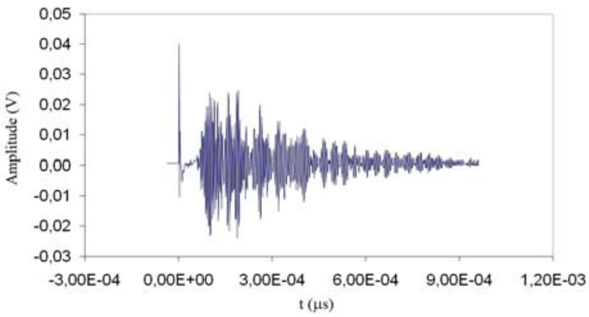

Figure 10. Characteristic A-scan of one of the samples inspected with the B0,05U transducer

With respect to the selection of the best transducers to use for the inspection, we ruled out the V189 and V151 models because of their large near-field lengths (12 cm and 10 cm, respectively), in accordance with the results described in the previous section. *A priori* therefore, one would use the B0,05U transducer pair to determine the longitudinal ultrasonic velocity, and V1548 and V150 for the shear velocity. Figure 11 shows the A-scan of the same sample as in Fig. 10, but performed now with the V150 transducer (this A-scan is fully representative of any of those obtained in the other cheeses with either this or the V1548 transducer). Calculating the shear velocity of ultrasound waves from Eq. [4], and considering the first wave train received to be that corresponding to shear waves, one obtains a value that is identical to that determined for longitudinal waves with the B0,05U transducer (within the margin of error). In particular, from Fig. 10 one obtains v_L=(1606±9) m/s, and from Fig. 11 v_S=(1602±21) m/s, and with the V1548 transducer, v_S=(1598±24) m/s. As noted, this coincidence of the longitudinal and shear velocities was observed with all the cheeses inspected, which obviously should be impossible. It was verified conclusively that these transducers emit only shear waves. One must presume, therefore, that the emitted waves undergo a mode conversion at their incidence on the crust, with a partial transformation into longitudinal waves. For this reason, the signal is received with a flight time similar to that obtained by the longitudinal transducers. A close inspection of Fig. 11 shows that, behind the arrival of the first wave train and with about twice the flight time, there appears a second wave train (shown in red). As this behaviour was characteristic of all the inspections with the transverse transducers, one can consider this second wave train as the arrival of the shear waves originally emitted by the transducer and which have not undergone any mode conversion. The determination of the time of arrival of this shear wave train is not very precise from the A-scan due to the aforementioned wave interference. The error associated with the v_S values is therefore greater.

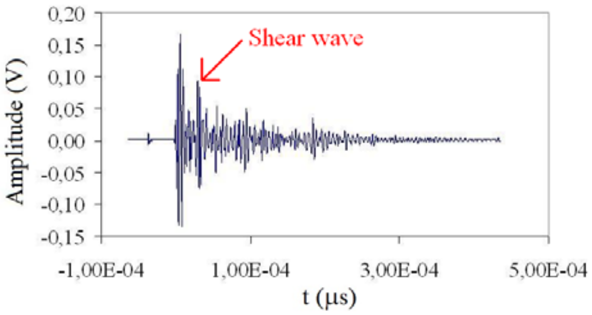

Figure 11. Characteristic A-scan of the same sample as in Fig. 10, but with the V150 transducer. Shown in red is the arrival of the shear wave train

Since the propagation velocity of the longitudinal waves is approximately twice that of the shear waves, the near-field values given in Table 3 for the V1548 and V150 transducers are halved for the longitudinal wave case. Thus, these two transducers allow one to evaluate conveniently both the longitudinal and the shear wave velocities, so that they were the final choice to use in measuring the ultrasonic parameters of the cheeses inspected.

Ultrasonic characterization of the *Torta del Casar* cheese ripening process

There were no major differences in the velocities measured with the different transducers finally selected. We therefore considered for analysis all the values of v_L obtained with the transducers B0,05U, V1548, and V150, and of v_S with the V1548 and V150 devices. The resulting mean values of v_L and v_S of the samples were (1510±170) m/s and (710±170) m/s, respectively, and the median values were 1552 m/s and 736 m/s. The longitudinal velocities are consistent with values reported in the literature. Thus, Benedito et al. in a study of ripening in Cheddar type cheese obtained values of v_L between 1657 m/s and 1693 m/s [1], and in a similar study for Mahon type cheese values between 1620 m/s and 1740 m/s [4]. Haeggström et al. report a value of (1311±50) m/s in processed cheese [7]. Pallav et al. find values in the range [1455–1580] m/s in various Cheddar type cheeses [14], and Saggin et al. in the range [1563–1665] m/s for this same type of cheese [15]. Finally, Cho et al. report values of (1573.4±2.0) m/s, (1618±6) m/s, (1652±5) m/s, and (1648.1±2.4) m/s in Cheddar, Asiago, Romano, and Parmesan type cheeses, respectively [2]. We could find no references to measurements of v_S in any kind of cheese.

With respect to the temporal evolution of samples during ripening, Fig. 12 shows box-and-whisker diagrams of the evolution of the density ρ. This type of diagram displays the five statistics minimum, first quartile, median, third quartile, and maximum, as well as the outliers (values distant by between 1.5 and 3 times the size of the box) and extreme cases (values distant by more than 3 times the size of the box). As can be seen, there was a tendency for the density of the cheeses to decrease during ripening. Nevertheless, some samples had densities that were far removed from the general trend.

Figure 13 shows the temporal evolution of the longitudinal propagation velocity v_L of samples during ripening. One observes that there was no clear trend during the process, with values in general lying between 1400 m/s and 1600 m/s. Over 50% of the samples were within this range throughout ripening. This is consistent with the peculiarity of these cheeses that they generally maintain the same firmness from the beginning to the end of ripening. The ultrasonic behaviour of *Torta del Casar* cheeses is thus very different from that exhibited by other varieties of cheese such as Cheddar and Mahon, in which there is a clear increase in the speed of ultrasound over time [4].

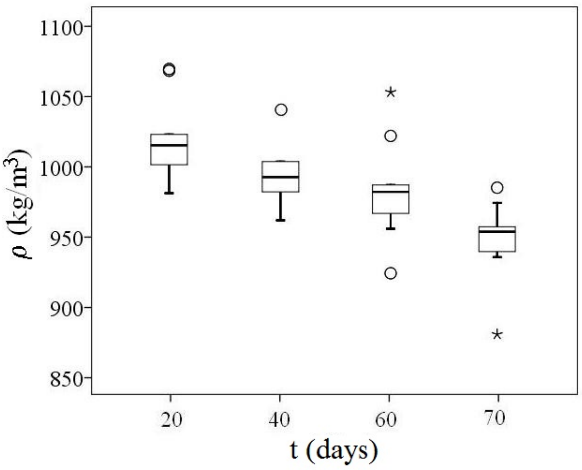

Figure 12. Box-and-whisker diagrams of the temporal evolution of the density ρ of 32 cheeses at various stages of ripening. ○: outliers. *: extreme cases

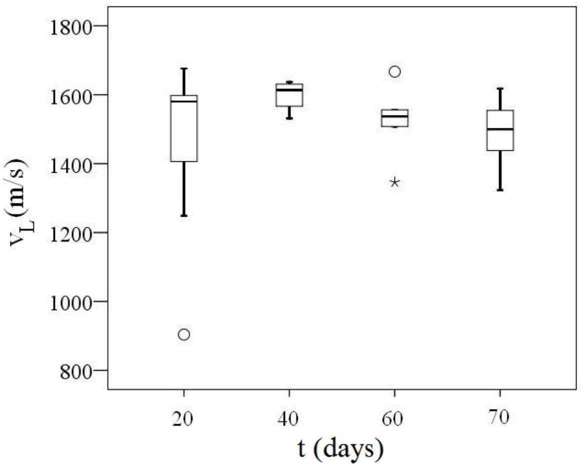

Figure 13. Box-and-whisker diagrams of the temporal evolution of the longitudinal wave propagation velocity, v_L, in the 32 cheeses inspected at various stages of ripening. ○: outliers. *: extreme cases

Finally, Fig. 14 shows the temporal evolution of the velocity of shear wave propagation, v_S, of the cheeses during ripening. In this case, there stands out the dispersion of the data, which is a result of the problem noted above of the imprecision in locating on the A-scan the arrival of the shear wave train. This imprecision also makes it impossible to deduce any trend from the temporal evolution of this parameter.

In contrast, the frequency of the FFT obtained in the inspection of the cheeses does seem to be a significant parameter of their degree of ripening. For example, Figs. 15 and 16 show the 25% cumulative frequency (f_{25}) of the FFT obtained with the V1548 and V150 pairs of transducers. Obviously, since these devices have different resonant frequencies (100 kHz and 250 kHz, respectively), it would make no sense to represent the frequency parameters for these two transducers together. One observes that in both cases the frequency tends to increase with ripening. I.e., lower ultrasound frequencies are absorbed more rapidly than high frequencies as the cheese matures.

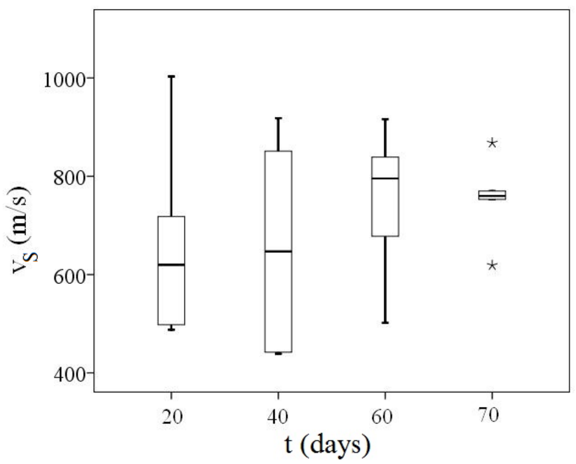

Figure 14. Box-and-whisker diagrams of the temporal evolution of the shear wave propagation velocity, v_S, in the 32 cheeses inspected at various stages of ripening. ○: outliers. *: extreme cases

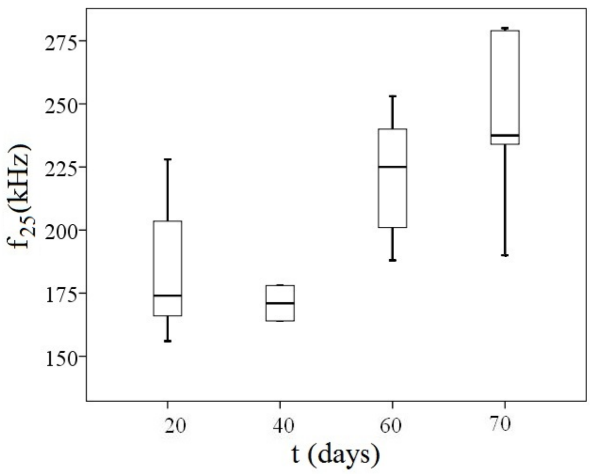

Figure 15. Box-and-whisker diagrams of the temporal evolution of the 25% cumulative frequency (f_{25}) of the FFT obtained with the V1548 pair of transducers in the ultrasonic inspection of the 32 cheeses, at different stages of ripening

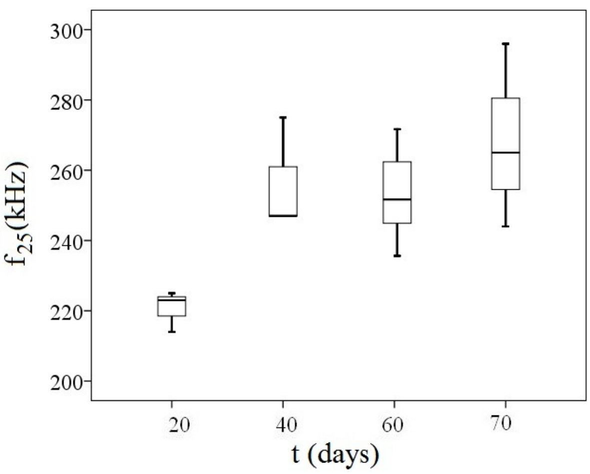

Figure 16. Box-and-whisker diagrams of the temporal evolution of the 25% cumulative frequency (f_{25}) of the FFT obtained with the V150 pair of transducers in the ultrasonic inspection of the 32 cheeses, at different stages of ripening

CONCLUSIONS

The aim of this paper was to describe the ultrasound measurement techniques developed to inspect the milk, curd formation, and curing of *Torta del Casar* type cheeses.

For that purpose, we firstly researched the changes of ultrasonic velocity, attenuation and harmonic components during the renneting process by pulse-echo method at different frequencies. The optimal cutting time coincides with a period during which the speed is stable and immediately after a small peak in the attenuation and after the frequencies stabilized following a minimum. This is an interesting result as it would allow the optimal cutting time to be established technically and scientifically rather than artisanally as is done today.

Then, we study the velocity and FFT of the longitudinal and shear waves during cheese maturation by an ultrasonic transmission technique at different frequencies. For velocities, one observes that there was no clear trend during the process. In contrast, the frequency tends to increase with ripening. I.e., lower ultrasound frequencies are absorbed more rapidly than high frequencies as the cheese matures.

From the obtained results, it appears to be possible to use an ultrasonic device to non-destructively monitor the *Torta del Casar* – type cheese manufacturing processes (renneting process and maturation).

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