DAIRY FOODS

Cheese Maturity Assessment Using Ultrasonics

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ABSTRACT

The relationship between Mahon cheese maturity and ultrasonic velocity was examined. Moisture and textural properties were used as maturity indicators. The ultrasonic velocity of the cheese varied between 1630 and 1740 m/s, increasing with the curing time mainly because of loss of water, which also produced an increase of the textural properties. Because of the nature of low-intensity ultrasonics, velocity was better related to those textural parameters that involved small displacements. Ultrasonic velocity decreased with increasing temperature because of the negative temperature coefficient of the ultrasonic velocity of fat and the melting of fat. These results highlight the potential use of ultrasonic velocity measurements to rapidly and nondestructively assess cheese maturity.
(**Key words:** Mahon cheese, maturity, temperature, ultrasonic velocity)

Abbreviation key: TPA = texture profile analysis.

INTRODUCTION

In the food industry low-intensity ultrasonics can be used in process control applications (e.g., liquid level and flow meters) or to measure acoustical properties to relate them with quality parameters of foods (16). Ultrasonic measurements have been used to provide information about the concentration, location, structure, and physical state of components in food materials (15).

The techniques and equipment that are presently used in the food technology applications rely on those used in nondestructive testing of metals and medical applications, where ultrasound has been widely used (15). Among the acoustical parameters (e.g., velocity, attenuation, and frequency spectrum) velocity is the most widely used, probably because it is the simplest and the most reliable measurement (16).

The advantages of ultrasonic sensors and techniques over the traditional analytical methods are that they are rapid, nondestructive, precise, and fully automated (16). For these reasons, the application of these techniques to new processes and products is being investigated. In fact, ultrasound has already been used to assess the quality of vegetables, meat, and dairy products (10), although most of the work has addressed measuring the fat thickness of live cattle (3, 7, 18).

In the dairy industry ultrasonics has been used to determine structural defects in Parmesan cheese (13) and to determine the optimum cut time for cheese making (6). Lee et al. (9) used ultrasound to determine the rheological properties of small cubes of cheese. Their results show that changes in cheese structure could probably be monitored and, as a consequence, ultrasonic measurements could be used to assess changes during ripening.

Mahon cheese (Minorca, Spain) matures unwrapped in temperature- and humidity-controlled chambers. During the maturation process, textural properties change and water is lost. Sometimes it is difficult to assess the state of cheese maturity, because of the lack of uniformity in maturing chambers and differences in milk and manufacturing conditions. At present, there are no nondestructive methods to determine the state of cheese maturity, and the only parameters used are time of curing or empirical methods such as evaluation by the cheese grader's thumb pressure (8). Therefore, it would be of great interest to find a relationship between ultrasonic parameters such as velocity or attenuation and cheese maturity.

So it should be considered that some ultrasonic parameters are affected by the temperature of the sample. The ultrasonic velocity in solids is related to bulk and shear modulus (16). Since these parameters are temperature dependent, velocity is affected by the temperature of the medium.

The aim of this study was to assess cheese maturity measured by moisture and textural properties with the ultrasonic velocity. The influence of temperature on the ultrasonic measurements was also determined.

MATERIALS AND METHODS

Raw Material

The pieces of cheese were manufactured by a company in Minorca, Spain. This company manufactures

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cheese of the certified origin Mahon. The pieces of cheese were parallel piped-shaped, with dimensions of approximately 20 × 20 × 8 cm. They were matured in the company chamber, where 83% relative humidity and 12°C were maintained. The pieces were transported to the laboratory in less than 14 h in refrigerated vehicles. Three batches were used for the study.

Sample Preparation

For the ultrasonic velocity measurements, whole pieces of cheese were wrapped in plastic film to avoid water loss and placed in temperature-controlled (±0.1°C) chambers for at least 48 h, until the cheese had reached 12°C (curing temperature). This time was long enough to ensure temperature uniformity within the samples. To determine the influence of temperature on velocity, five temperatures (5, 12, 17, 20, 25°C) were considered. Once the ultrasonic measurements were performed, the moisture and textural properties of the cheese were determined.

During cheese maturation, water loss produces a moisture profile within the cheese. To prevent this factor affecting the texture and moisture measurements, all the samples to be measured were obtained from the center of the cheese. The samples for the texture profile analysis (**TPA**) were cut into 2-cm cubes. For the puncture test, a 2-cm thickness slice was used. The samples wrapped in plastic film were placed in temperature-controlled chambers for at least 4 h, until the cheese samples had reached 12°C.

Moisture Determination

Moisture content was determined for all the samples used for ultrasonic measurements by weighing samples before and after drying in an oven (1).

Texture

To quantify the maturity differences between the cheeses, a TPA was performed on the cheese samples. A 100N Lloyd load cell (model PLC 100N, Segensworth Fareham, England) was fitted on a Lloyd Universal Testing Machine (Model L1000R, Segensworth Fareham, England). Generalized TPA curves (2) were obtained with 10 replicates for each type of cheese. The crosshead speed was 10 mm/min, and the cube was compressed 1 cm (50%). The curves were digitized and transferred to a spreadsheet, where the following parameters were computed:

Deformability Modulus: equivalent to Young s Modulus and is computed from the slope of the first straight portion of the TPA curve, with the following equation:

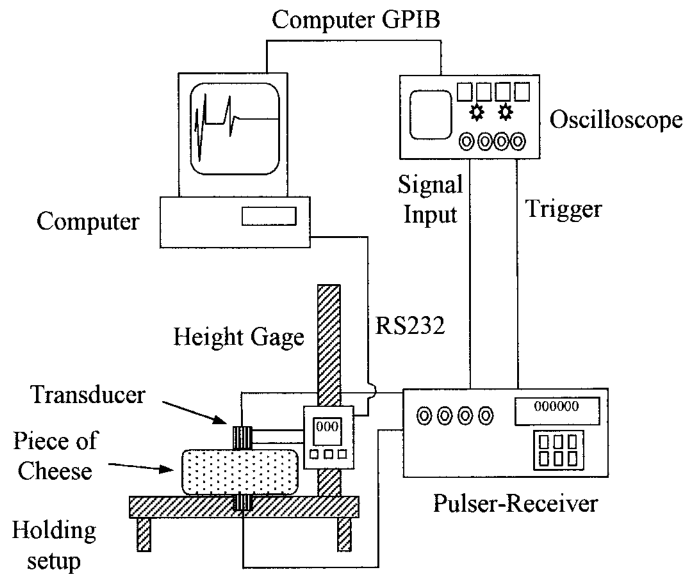

Figure 1. Ultrasonic experimental setup used to calculate the ultrasonic velocity in cheese. GPIB = General Purpose Interface Board. RS232 = Recommendation Standard 232.

$$E = \text{Slope} \times \frac{L}{A} \quad (1)$$

Where L is the height of the cube and A is the contact surface.

Hardness/area: defined as the peak force during the first compression cycle divided by the contact surface.

Compression work/area: the area under the first curve of compression divided by the contact surface.

For the puncture tests the same texture analyzer and load cell were used, and a cylindrical punch with a diameter of 8 mm was fitted to the cell. The crosshead speed was 10 mm/min and the compression distance was 2 mm. A slice of each type of cheese was punctured 10 times, and the following parameters were calculated from the digitized curve:

Punction slope: the slope of the first straight part of the punction curve.

Maximum: the highest value in the puncture test in this compression distance.

Punction work: the area under the curve force-distance in the test for the compression distance considered.

Ultrasonic Measurements

The experimental setup (Figure 1) for velocity measurements consisted of a couple of narrow-band ultrasonic transducers (1 MHz, 0.75-in crystal diameter, A314S-SU model, Panametrics, Waltham, MA), a pulser-receiver (Toneburst Computer Controled, Model

PR5000-HP, Matec Instruments, Northborough, MA) and a digital storage oscilloscope (Tektronix TM TDS 420, Tektronix, Inc. Wilsonville, OR) linked to a personal computer with a general purpose interface bus. To compute the time of flight, five acquisitions were performed and averaged. A digital height gage with an accuracy of 4×10^{-5} m (Electronic Height Gage, model 752A, Athol, MA) was used to measure the sample thickness, and the value was sent to the computer through a RS232 interface. The system delays produced in the transducers, generator-receiver, and digitizer were computed, measuring the pulse transit times across a set of calibration cylinders of different thickness. The delay time (DYT) was obtained from the intercept on the time versus thickness graph. This delay was introduced in the velocity computation. The velocity (v) was computed (Equation 2) with proprietary software that was developed to capture the signal, calculate the time of flight (TOF), and read the distance (D) from the height gage. The average accuracy of the ultrasonic measurements was 0.95 m/s.

$$V = \frac{D}{TOF - DYT} \qquad (2)$$

The pieces of cheese were placed between the transducers and the ultrasonic velocity was measured over three points in the center of the cheese (previously marked with a stencil). Five velocity measurements were performed on each point and then averaged. To determine the influence of temperature on velocity only the first batch was considered.

To minimize the energy losses in the sample-transducer interface, olive oil was used as a couplant. In addition to its good transmission characteristics, this couplant was chosen because olive oil surface treatment is allowed (by the Regulatory Council) in the production of Mahon cheese.

RESULTS AND DISCUSSION

Table 1 shows the moisture and texture properties of the three batches that were analyzed. As expected, in all batches moisture decreased with curing time, and all the textural parameters considered increased. This increase may be due to the water loss and the proteolysis of the protein matrix. Visser (17) reported an increase in the deformability modulus and the stress at fracture when Gouda cheese was aged, stating that the increase could be attributed to the decrease in the water content. The deformability modulus and the slope in puncture provided the higher increase (631 and 539%, respectively, average for the three batches) being hardness and the compression work the ones with lower increase (135 and 202%). Theses figures show that the textural properties that involved small displacements had a higher increase than those that involved larger displacements.

Although water content decreased for all batches (Figure 2), each seemed to behave in a different manner. Moreover, the differences were also important within the batches. The same behavior was observed for all the textural parameters shown in Table 1. So, even when all the pieces of cheese were matured by the same producer, curing time was not a good indicator of cheese maturity. The differences were probably due to nonuniformities in the maturing conditions and the manufacturing procedure and to differences in the raw material used in different seasons.

In solid materials, ultrasonic velocity is related to the square root of the elastic modulus of the material (E) and its density by the relationship (16):

$$v = \sqrt{\frac{E}{\rho}} = \sqrt{\frac{K + \frac{4}{3}G}{\rho}} \qquad (3)$$

Where K is the bulk modulus and G the shear modulus.

Usually the differences in the moduli of food materials are greater than are those in density and, therefore, the ultrasonic velocity variations are more influenced by the elastic modulus than by the density (10). As long as the density increase (7% for this study) during Mahon cheese maturation would result in a velocity decrease, the main influence on the possible velocity increase will be due to the changes in the elastic properties of cheese. It should also be considered that the bulk modulus of cheese greatly exceeds the shear (14). To illustrate, the shear modulus of food gels is usually less than 1000 N/m^2, which is about six orders of magnitude smaller than bulk modulus (typically 2×10^9 N/m^2; 10). Consequently the changes in velocity will be mainly linked to the differences in the bulk modulus of the samples.

A decrease in water content causes an increase in the deformability modulus and probably in the bulk modulus, therefore an increase of velocity is expected (Equation 3) being the TPA measurements and the ultrasonic velocity indirectly related. This fact was confirmed with the experimental results plotted in Figure 3. The ultrasonic velocity ranges from 1630 m/s for the softest cheese to 1740 m/s for the hardest one. When fitting a linear model to the experimental data (all the batches) the explained variance was 76%; the observed variability probably was due to the differences between batches previously mentioned.

Table 1. Physical properties of the Mahon cheese analyzed.

Batch	Curing time (d)	Moisture (wt %)	Deformability modulus (kPa)	Hardness/ area (N/cm^2)	Compression work/area (Nmm/cm^2)	Slope punction (N/mm)	Max. punction (N)	Punction work (Nmm)
1	36	43.11 ± 0.08	907 ± 77	9.4 ± 0.7	74 ± 5	8.0 ± 1.0	9.4 ± 1.0	11.4 ± 1.7
1	66	39.13 ± 0.04	1017 ± 230	11.9 ± 0.8	94 ± 8	12.1 ± 2.5	14.3 ± 0.7	16.1 ± 1.9
1	95	35.56 ± 0.02	1140 ± 129	13.7 ± 1.0	103 ± 7	9.1 ± 1.3	13.1 ± 0.8	14.6 ± 1.5
1	128	36.56 ± 0.07	1559 ± 130	11.3 ± 1.1	91 ± 8	16.5 ± 5.8	16.4 ± 2.1	21.4 ± 2.6
1	158	36.40 ± 0.05	2024 ± 94	16.6 ± 1.2	130 ± 9	17.6 ± 2.7	21.9 ± 2.1	28.2 ± 3.8
1	301	29.26 ± 0.07	3025 ± 500	22.8 ± 1.6	180 ± 12	31.9 ± 13.0	35.1 ± 3.8	49.5 ± 5.1
1	321	30.12 ± 0.02	2972 ± 330	22.9 ± 1.4	167 ± 7	26.1 ± 3.9	32.2 ± 2.0	42.4 ± 5.1
2	32	41.38 ± 0.05	307 ± 36	12.7 ± 1.2	58 ± 3	4.7 ± 0.7	5.8 ± 0.5	6.9 ± 1.1
2	76	41.19 ± 0.04	777 ± 65	12.1 ± 1.5	85 ± 5	7.5 ± 1.2	10.2 ± 2.0	12.0 ± 0.3
2	202	32.09 ± 0.02	2051 ± 100	16.2 ± 0.9	125 ± 9	16.8 ± 2.0	24.4 ± 1.9	33.0 ± 5.2
2	360	27.05 ± 0.06	3124 ± 290	23.8 ± 2	201 ± 15	37.1 ± 9.5	42.8 ± 2.5	56.2 ± 4.8
3	26	44.45 ± 0.04	340 ± 21	6.4 ± 0.5	33 ± 3	3.8 ± 1.0	3.5 ± 0.5	4.80 ± 0.2
3	38	44.73 ± 0.03	251 ± 32	4.7 ± 0.2	32 ± 3	2.5 ± 0.5	3.1 ± 0.2	4.51 ± 0.8
3	52	42.65 ± 0.07	277 ± 55	6.6 ± 0.4	36 ± 6	3.4 ± 0.2	3.7 ± 0.2	4.42 ± 0.6
3	54	43.96 ± 0.02	311 ± 31	6.5 ± 0.6	33 ± 4	4.6 ± 0.9	3.9 0.6	5.00 ± 0.3
3	109	41.15 ± 0.02	280 ± 51	5.4 ± 0.5	30 ± 3	3.6 ± 0.3	4.6 ± 0.3	5.42 ± 0.6
3	139	38.18 ± 0.07	755 ± 75	6.6 ± 0.6	38 ± 5	7.6 ± 1.5	6.9 ± 0.9	8.03 ± 1.3
3	147	41.10 ± 0.05	640 ± 36	7.5 ± 1.3	41 ± 5	6.5 ± 1.1	4.8 ± 0.1	5.63 ± 0.5
3	167	34.06 ± 0.02	1723 ± 130	10.8 ± 1.4	87 ± 7	17.3 ± 2.8	14.6 ± 1.1	20.19 ± 2.3
3	176	36.02 ± 0.03	1492 ± 140	9.8 ± 1.7	79 ± 10	18.3 ± 2.8	13.3 ± 1.5	15.42 ± 1.9
3	228	32.98 ± 0.01	2121 ± 280	12.6 ± 1.5	102 ± 9	17.6 ± 2.5	15.0 ± 2.1	20.19 ± 2.2

Based on Equation 3 the ultrasonic velocity was plotted against the square root of the textural parameters (Figures 4 and 5). When plotting velocity versus more objective parameters than time such as the textural parameters, the differences between the batches decrease. The ultrasonic velocity was measured over the whole width of the cheese where a texture profile is established; however, the textural parameters were determined with cubes extracted from the center of the cheese. This fact may increase the dispersion of the measurements; when samples are more homogeneous the variability would probably decrease. Table 2 shows the slope, intercept, and percentage of explained variance when a linear model is used to relate velocity with the physical properties determined. In all cases, velocity is clearly related to the square root of the textural values and to the water content, and the explained variance is always higher than the one corresponding to the relationship with time (76%). However among all the textural parameters, the best explained variance corresponds to the deformability modulus (92%) and the slope in puncture (90%). As long as the ultrasonic

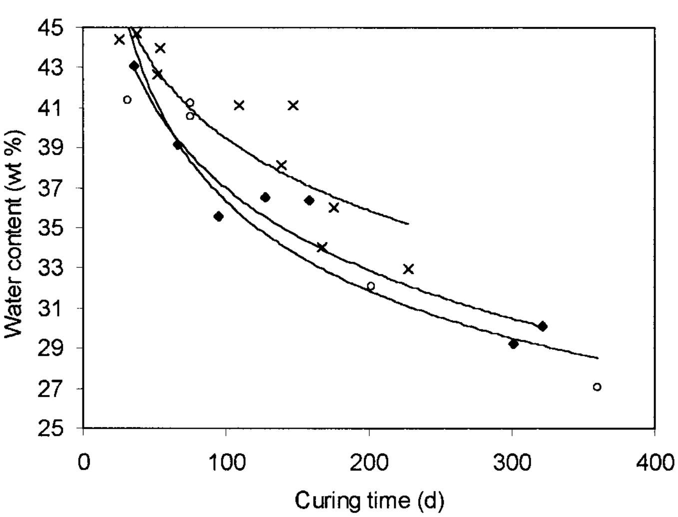

Figure 2. Changes in moisture in Mahon cheese during maturation: batch 1 (♦), batch 2 (○), and batch 3 (×).

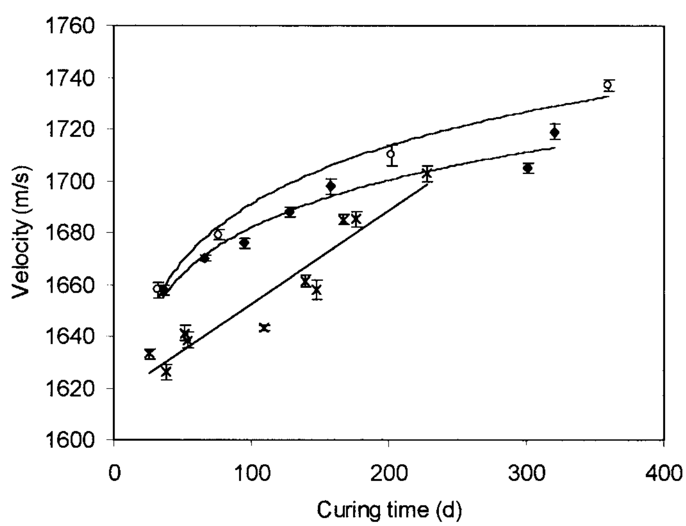

Figure 3. Change of ultrasonic velocity with curing time in Mahon cheese: batch 1 (♦), batch 2 (○), and batch 3 (×).

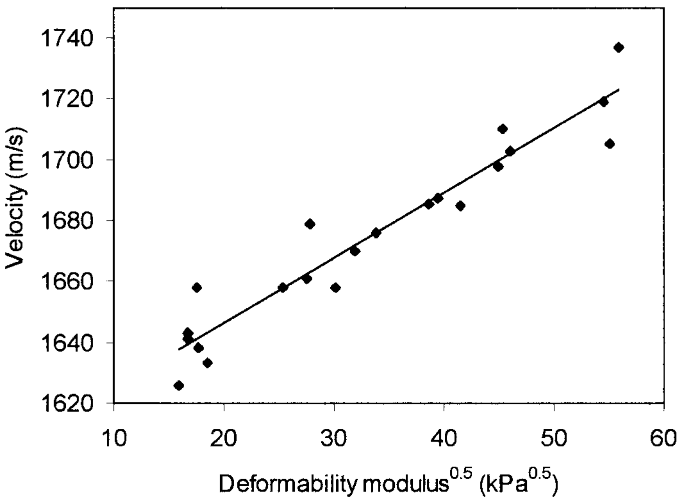

Figure 4. Ultrasonic velocity dependence on the deformability modulus.

Table 2. Linear parameters for the relationships between velocity and different cheese properties.

	Slope	Intercept	% Variance
Moisture, wt %	–529	1975	86
Deformability modulus, kPa	2	1604	92
Hardness/area, N/cm^2	34.2	1560.0	83
Compression work/area, Nmm/cm^2	10	1583	86
Slope punction, N/mm	21.9	1601.1	90
Maximum punction, N	20.4	1603.4	88
Punction work, Nmm	16.9	1607.8	87

waves involve very small particle displacements when traveling through a material, the ultrasonic velocity may be closely related to properties that involve small displacements, such as the deformability modulus or the slope in puncture.

When the square root of the deformability modulus and the moisture in a linear model are included to compute the ultrasonic velocity, only a small increase in the explained variance was obtained (93%). This finding can be explained by the well-established relationship between the deformability modulus and the moisture during maturation of Mahon cheese.

Considering that the textural parameters and moisture represent objective indicators of Mahon cheese maturity, it can be concluded that the ultrasonic velocity could be used to assess maturity. Similar results have been found for avocados, in which velocity decrease with the ripening was linked to the loss of firmness (12). Miles et al. (11) also reported the same type of relationship for adipose tissue, determining that the ultrasonic measurements could be used to assess the suitability of the tissue for bacon manufacturing.

These results show that an ultrasonic sensor could be used to monitor and determine the maturity of pieces of cheese, which is of great interest not only for producers but also for retailers. As long as these measurements are nondestructive and rapid and can be automated, they have a great potential for cheese classification. This technology could also be applied to other types of cheese with similar maturing processes.

Textural parameters such as the deformability modulus and hardness are temperature dependent and thus velocity is expected to be affected by the temperature of the product. This fact has been proven for food products such as oils and cod fillets (4, 11). To determine this influence, experiments at different temperatures were carried out. Figure 6 shows the influence of temperature

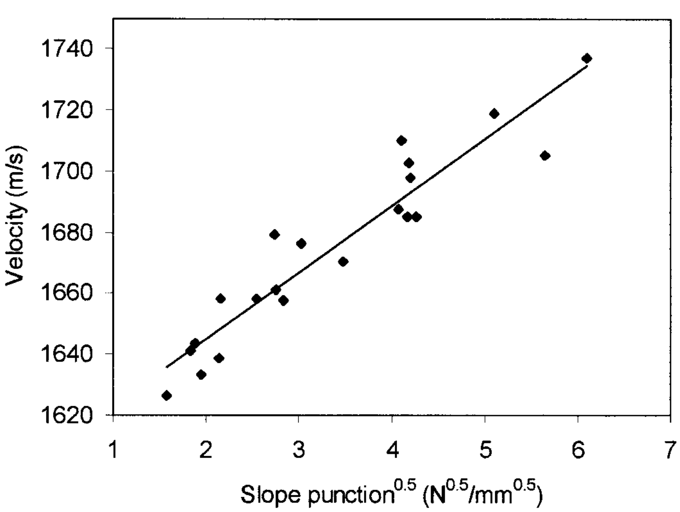

Figure 5. Ultrasonic velocity dependence on the slope in punction.

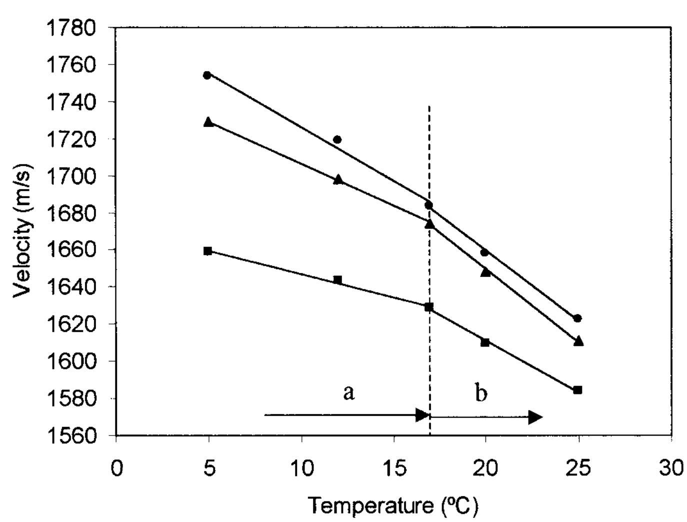

Figure 6. Variation of the ultrasonic velocity with temperature for different degrees of maturity, 36 d (■), 152 d (▲), and 321 d (●). Zone “a” and “b” different melting behaviors.

on velocity for three different curing times corresponding to the first batch. In all cases, velocity decreased with higher temperatures and two parts with different slope (Table 3) could be distinguished in the curve. Miles et al. (11) also found changes in the slope of the velocity-temperature curve for adipose tissue. In the first part of the curve (a) velocity moderately decreases with the increase of temperature, which could be due to the negative correlation coefficient of the ultrasonic velocity of the solid fat and the increase of the liquid content as a consequence of fat melting. In the second part of the curve the increase of the liquid content (high melting) together with the phenomenon known as "oiling off" or "fat leakage" could be the cause of the more abrupt fall in the slope. The slope of each part represents the accuracy of the measurements, therefore a value of -2.5 m/s^{-1}°C^{-1} for the slope found in the first part of the curve for a cheese with 36 d of maturity, indicates that a change of ±1°C would produce a variation of ±2.5 m/s. Table 3 shows that the slope of the first part (a) increases with the curing time. During cheese maturation water is lost and, in consequence, and the percentage of fat, which is the main factor responsible for velocity variation with temperature, increases. This result shows that the velocity-temperature relationship could lead to the assessment of the fat content of cheese as studies have proved for products such as fish (5).

It can be concluded that for cheese maturity classification purposes, the influence of temperature ultrasonic measurements must be considered. Figure 7 shows the response surface when temperature (T) is used to determine maturity. Equation 4 is the result of fitting a multiple linear regression model to the experimental data using the deformability modulus (DM) as the maturity indicator. The explained variance for the model was 92%.

$$v = 1652.74 + 2.12(DM)^{0.5} - 4.94\,T \quad (4)$$

From the latest equation it is possible to know the state of maturity (measured by textural properties)

Table 3. Slopes for the two parts (a, b) of the curve velocity-temperature, for the different curing times considered.

Curing time (d)	Slope a	Slope b
36	−2.5	−7.4
66	−3.4	−6.4
95	−4.2	−5.6
128	−4.2	−6.5
158	−4.5	−7.9
301	−5.7	−7.9
321	−5.7	−7.6

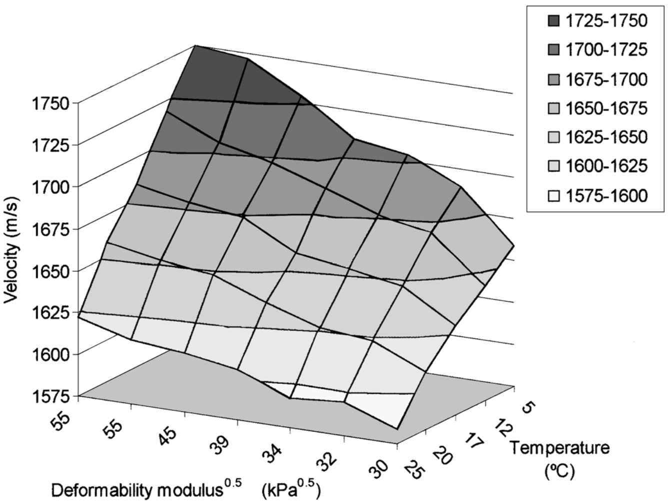

Figure 7. Ultrasonic velocity dependence on the deformability modulus and the temperature of the sample.

from the measurement of the ultrasonic velocity and the knowledge of the temperature at which it has been performed.

These relationships were obtained for Mahon cheese samples provided by the same producer. More research with other producers and other types of cheese with similar curing processes is needed.

CONCLUSIONS

Curing time is not a good indicator of Mahon cheese maturity; moisture and textural parameters are more objective indicators. Ultrasonic velocity decreases with the curing time as a consequence of loss of water and the increase of the textural parameters. Because of their sensitivity to moisture content, ultrasonic velocity measurements can be used to rapidly and nondestructively determine cheese maturity. Ultrasonic velocity measurements are affected by the temperature and must be taken into account for maturity determinations. Future work needs to establish the feasibility of using these techniques for other types of cheese.

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