ABSTRACT

37 samples of drinking yoghurt were examined by ultrasonic spectroscopy, sensory analysis, rheology and several other physical measurements. Correlations were made between the different measurements. Among other things very good correlations were found between the ultrasonic results and texture parameters obtained from the sensory evaluation. Furthermore it was shown that ultrasonic results correlated to the mouth feeling called mouth coating. A parameter that is often very difficult to predict from traditional rheological measurements. The correlations to the product compositions seemed to be very strong. Besides dry matter content, fat content etc. it was also revealed that the choice of sweetener had a strong influence on the textural properties. The influence of sugar as an ingredient was not seen in traditional rheology. Surprisingly the correlations between rheology, exemplified by flow curves, and ultrasonic measurements were not particularly good. The results are visualised using Principal Component Analysis (PCA) and Partial Least Square plots (PLS).

INTRODUCTION

The main purpose of this work has been to obtain a better understanding of the strengths and weaknesses of ultrasonic spectrometry (US) as tool for characterisation of food products. The characterisation of drinking yoghurt by US was also made to obtain an understanding of the influence of different combinations of pectin on the physical properties of drinking yoghurt. To support the understanding, designed experiments with different composition of both ingredients (pectin, starch, culture, etc.) as well as raw materials (fat, protein, water, etc.) were set up.

The yoghurts were characterised by sensory analysis, particle size distribution, confocal laser scanning microscopy (CLSM), sub-surface reflections, viscosity (Brookfield single value and StressTech flow curve), sedimentation (Turbiscan MA2000) and ultrasonic spectroscopy.

However the focus in this paper has not been set on the influence of pectin but on the understanding of US as a tool in food characterisation. Therefore the effort has been aimed at the correlations between the US data and the other disciplines. Special attention has been paid to the correlations between ultrasonic measurements and sensory analysis, rheology and Turbiscan measurements. The main purpose is to obtain an improved understanding of the information that can be extracted from an ultrasonic spectrometer.

MATERIALS AND METHODS

The drinking yoghurt was analysed by a high-resolution ultrasonic resonance spectrometer, HR-US 102, from Ultrasonic Scientific, Ireland. The instrument was
equipped with two 1 ml measuring cells and
the temperature was maintained at appropriate
values by an external ThermoHaake wa-
ter bath with a precision of 0.01°C. No stir-
ing was applied during the analysis.

The samples were characterised by their
ultrasonic velocity, \( u \) [m/s], and the corre-
sponding attenuation, \( \alpha \) [Np/m], at four dif-
ferent frequencies and two different tem-
peratures. The frequencies were: 2.5 MHz,
5.0 MHz, 8.0 MHz and 12.0 MHz, and the
 temperatures were 15°C and 32°C. The ve-
locity and the attenuation values were re-
corded relatively to the values of water. The
absolute values are obtained by adding the
recorded values to the values of water at the
appropriate temperatures. In this study the
relative values were used due to the fact that
they only differ from the absolute values by
a constant.

Each of the sixteen US values that char-
acterises a sample is the average of values
recorded over a 30 minutes period. Approxi-
mately 60 data points were included in
each average. All measurements were per-
fomed in duplicate. The results were named
according to a four letter code starting with
either \( v \) (velocity) or \( a \) (attenuation). A two-
digit number (15 or 32) is following the first
letter. It reflects the temperature of the
measurement. Finally a single letter is indi-
cating the frequency used (a: 2.5 MHz; b:
5.0 MHz, c: 8.0 MHz or d: 12.0 MHz). The
variable name for the velocity measured at
15°C and 2.5 MHz would be: \( v_{15a} \); the at-
tenuation measured at 32°C and 12 MHz
would be: \( a_{32d} \) and so forth.

The explorative data analysis was made
using The Unscrambler® v8.0 from CAMO
Process AS, Norway. The values used for
Principal Component Analysis, PCA, and
Partial Least Square Regression, PLS-R
(usually just called PLS), are the averages of
the duplicates. All PCA and PLS analyses
were carried out using centred and weighted
(1/Std) data.

EXPLORATION OF ULTRASONIC
DATA

![Scores and loadings plots from PCA of ultrasonic data.](image)

Figures 1a & 1b. Scores and loadings plots
from PCA of ultrasonic data.

Figures 1a and 1b illustrate the PCA re-
sults from the ultrasonic analysis of the 37
yoghurts. The two first principal com-
ponents describe 96% of the validated variance
in the data set.

It can bee seen from the loadings plot
that all the velocities at each temperature are
contributing with the same information and
that the velocities at the two temperatures
are contributing with approximately the
same type of information. In contrast the
attenuation provides different contributions
at the two different temperatures as well as
at the four different frequencies. The largest
difference is seen at the lowest frequency
(a15a and a32a).

In the scores plot, Fig. 1a, a clear group-
ing of the samples is seen.
Samples 20, 39, and 78 represent a reference that was included in the weekly production of samples. It can be seen that the samples are grouped together indicating a good reproducibility both in production and in the ultrasonic analysis.

Fig. 2 illustrates the influence of the fat content of the products. As shown in the figure, the fats shift the texture in the same direction going from high fat content in the upper right corner to no fat in the lower left corner. As will be discussed later, this indicates that the lower the fat content is the more watery and the less mouthfeel there is.

Fig. 3 illustrates the influence of the milk solid non-fat (MSNF) content of the products. As seen from Fig. 3 the influence of the MSNF is also clearly defined by the ultrasonic results.

Fig. 4 illustrates the influence of sweeteners on the ultrasonic results. It is believed that the result more likely reflects a difference in concentration of the two types of sweeteners rather than a difference in textural properties. As it will be shown later, the correlation between textural properties and US data were not convincing for these experiments.

CORRELATIONS BETWEEN SENSORY AND ULTRASONIC DATA

The 37 samples have been characterised by 16 sensory parameters. Parameters can be seen in Table 1.

As seen in Fig. 5, the best correlations are found between the US data and sensory data that describe physical properties such
as viscosity and mouth coating. Table 1 gives the correlation coefficients of the separate PLS1 correlations between US data and the respective sensory value. Values followed by A indicate a visual characterisation (A = apparent). Values followed by M indicate that the samples have been evaluated in the mouth, S if evaluated by smell, T if evaluated by taste, TM defines texture in the mouth and AT the aftertaste.

Table 1. Correlation coefficients from PLS1 predictions of sensory parameters based on US data.

<table>
<thead>
<tr>
<th>Sensory parameters</th>
<th>Corr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity_A</td>
<td>0.84</td>
</tr>
<tr>
<td>Watery_TM</td>
<td>0.83</td>
</tr>
<tr>
<td>Viscosity_TM</td>
<td>0.81</td>
</tr>
<tr>
<td>Yellow</td>
<td>0.78</td>
</tr>
<tr>
<td>Mouthcoating</td>
<td>0.75</td>
</tr>
<tr>
<td>Sticky_A</td>
<td>0.73</td>
</tr>
<tr>
<td>Time_AT</td>
<td>0.68</td>
</tr>
<tr>
<td>Acidic_S</td>
<td>0.56</td>
</tr>
<tr>
<td>Acidic_T</td>
<td>0.55</td>
</tr>
<tr>
<td>Floury_A</td>
<td>0.54</td>
</tr>
<tr>
<td>Floury_TM</td>
<td>0.53</td>
</tr>
<tr>
<td>Citric_T</td>
<td>0.42</td>
</tr>
<tr>
<td>Acidic_AT</td>
<td>0.36</td>
</tr>
<tr>
<td>Sweetness</td>
<td>0.29</td>
</tr>
<tr>
<td>Sweet_AT</td>
<td>0.27</td>
</tr>
<tr>
<td>Citric_S</td>
<td>0.21</td>
</tr>
</tbody>
</table>

Table 1 shows that the physical parameters such as apparent viscosity, watery mouthfeel and oral viscosity have the highest correlation coefficients whereas the parameters relating to smell and taste are found at the bottom. This relates well to the understanding of the ultrasonic spectrometer as an instrument that belongs in the physical characterisation of products.

CORRELATIONS BETWEEN ULTRASONIC DATA AND TURBISCAN DATA

A Turbiscan MA200, Formulaction, France, was used to analyse the samples. Only the Mean and the Span have been used for making correlations to US data. The Mean value represents an average of the backscattering of light from each sample. High values of Mean could indicate increased solid content in the samples or a decrease in particle size. The Span represents the variation in the backscattering. High values of Span indicate an inhomogeneous sample. Inhomogenity is related to variation in the samples such as inhomogeneous fillings, roughed surface due to graininess etc. The correlation coefficients are shown in Table 3.

Table 2. Correlation coefficients from PLS1 predictions of viscosity parameters based on US data.

<table>
<thead>
<tr>
<th>Rheology parameters</th>
<th>Corr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity</td>
<td>0.62</td>
</tr>
<tr>
<td>K</td>
<td>0.68</td>
</tr>
<tr>
<td>n</td>
<td>0.29</td>
</tr>
</tbody>
</table>

CORRELATIONS BETWEEN ULTRASONIC AND RHEOLOGY

The yoghurts were subjected to viscosity measurements. Traditional one-point measurements were made on a Brookfield instrument from Brookfield Viscometers Ltd., United Kingdom, and flow curves were made on a StressTech Rheometer from Reologica AB, Sweden. The flow curves were fitted to a Power Law model and the consistency index, K, and flow index, n, was used as representatives for the entire flow curve. The correlation coefficients can be seen in Table 2.

Remarkably, the correlations between ultrasonic data and the rheological data are not as strong as expected. Even though it can be argued that US measurements at high frequencies and flow curves are not obviously related, some correlation would be expected based on the previous results from the sensory evaluation.
Figure 6. Correlation loadings from a PLS2 analysis with US data as the x-matrix and Turbiscan data as the y-matrix.

Table 3. Correlation coefficients from PLS1 predictions of Turbiscan parameters based on US data.

<table>
<thead>
<tr>
<th>Turbiscan parameters</th>
<th>Corr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.87</td>
</tr>
<tr>
<td>Span</td>
<td>0.01</td>
</tr>
</tbody>
</table>

The correlation at 0.87 between the Mean value and the US data indicates that the two types of measurements are both sensitive to product composition; whereas the correlation for Span illustrates that the inhomogeneity that could exist due to large particles is not seen. The Mean value from the Turbiscan is a function of particle size and concentration of MSNF. The mean value is mainly influenced by small particles (0.3 – 20 µm) whereas the Turbiscan span value is believed to relate to large particles (>120µm). The particle size of the drinking yoghurt is expected to be in the range of 1 µm, and it is therefore in good agreement that the Span does not catch differences in particle size. It is expected that the US data does contain information relating to particle size and therefore the missing correlation between the span and the US data is not surprising.

CONCLUSION
Ultrasonic measurements on drinking yoghurt have shown that the instrument provides information relating to the composition of the products such as fat content, protein content etc. as well as the concentration of sweetener. Correlations are also found for some sensory parameters such as visual viscosity and mouth coating. In contrast no clear correlation between rheological data such as viscosity and flow curve parameters was found.

It was furthermore indicated that the attenuation was a stronger tool in differentiating between the physical properties than the velocity.

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