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# A comparison of selected quality characteristics of yoghurts prepared from thermosonicated and conventionally heated milks

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ABSTRACT

Thermosonication (TS) of preheated (45 °C) milk (0.1%, 1.5% and 3.5% fat) for 10 min at an ultrasound frequency of 24 kHz allowed the preparation of yoghurts with rheological properties superior to those of control yoghurts produced from conventionally heated milk (90 °C for 10 min). Texture profile analysis and flow curves showed that yoghurts from the TS milks had stronger gel structures which displayed higher water-holding capacities (WHC) and lower syneresis. Based on averaged data from a sensory panel ($n = 30$), TS yoghurts showed superior texture and colour properties and samples with a fat content of 0.1% scored best in terms of overall acceptability. Retentions of water-soluble (thiamine and riboflavin) and fat-soluble (retinol and tocopherol) vitamins were similar in TS and conventionally prepared yoghurts.



## 1. Introduction

To satisfy a growing consumer demand for high quality food, many novel technologies have been examined in recent years to assess their potential for the safe processing and preservation of foods. One such technology, which could be of benefit in the manufacture of cultured milk products, such as yoghurt, is ultrasonication, since it offers the possibility of combining homogenisation and pasteurisation of milk in a single operation prior to inoculation with starter culture. Several publications have reviewed applications of ultrasound in the food industry, including its antimicrobial potential (Knorr, Zenker, Heinz, & Lee, 2004; Mason, 1999; Mason, Paniwnyk, & Lorimer, 1996; Piyasena, Mohareb, & McKellar, 2003; Zenker, Heinz, & Knorr, 2003). Quality improvements in dairy products, employing ultrasound for homogenisation of milk, inactivation of bacteria and enzymes were reviewed by Villamiel, Van Hamersveld, and De Jong (1999) while the use of sonication combined with heat (thermosonication), to denature certain enzymes and whey proteins in milk, has been described (Villamiel & De Jong, 2000).

A key aspect of quality in yoghurt is associated with the physical properties of the yoghurt gel which should possess a smooth textural character in the mouth during consumption, as well as a low tendency to serum separation during storage. Such features are promoted by pre-culture homogenisation of fat globules Tamime & Robinson, 1999) and by a relatively severe (e.g. 90–95 °C for 10 min) pre-inoculation heat treatment of milk, which results in fairly extensive denaturation of whey proteins (Parnell-Clunies, Kakuda, & Deman, 1986). Reducing or removing the fat from the products generally has an adverse effect on the textural properties of yoghurt gels (Folkenberg & Martens, 2003; Wendin, Solheim, Allmere, & Johansson, 1997). The use of various polysaccharide and protein hydrocolloid additives to enhance firmness and reduce syneresis in such products has been reviewed for both set (Tamime, Barclay, Davies, & Barrantes, 1994) and stirred (Keogh & O'Kennedy, 1998) yoghurts. As a possible alternative to the use of additives to improve textural quality of low fat yoghurt, a recent study by Riener, Noci, Cronin, Morgan, and Lyng (2009) has shown that, compared to products prepared from conventionally heat-treated milk, yoghurt produced from thermosonicated milk (skim, reduced or full fat) had superior physical properties, illustrated, for example, by higher viscosities and greater water-holding capacities. Since the thermosonication (TS) treatment appeared to have the potential to reduce the need for additional supplementation of milk with texture-improving ingredients during yoghurt manufacture, the present study was undertaken to compare additional quality aspects (rheological, sensory and nutritional) of TS-derived and conventionally produced yoghurt cultures.

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## 2. Materials and methods

### 2.1. Milk supply

Freshly delivered pasteurised homogenised milk samples with different fat contents were obtained from a local dairy processor and processed on the same day. In the factory, a two-stage homogeniser (150 bar first stage, 50 bar second stage) was used to homogenise the milks which were pasteurised (72 °C, 15 s) within 12 h of collection. Milks were from the same source as those used in the study of Riener et al. (2009) and were found to have very similar chemical compositions (see Table 1) when analysed as described in the latter study.

### 2.2. TS and conventional heat treatments of milk

TS (45 °C, 10 min, frequency 24 kHz) and conventional heat treatments (90 °C for 10 min) of milk samples were carried out as described by Riener et al. (2009). Globule size, which was also determined as described by the latter authors, was mainly (90%) in the range 0.5–0.6 µm for the fat particles in the TS milk compared to a measured mean globule size of 1.4 µm for the homogenised milk obtained from the supplier.

### 2.3. Yoghurt preparation

Aliquots of the processed milk (100 ml) were equilibrated to 40 °C and inoculated with 1 g of commercial yoghurt starter culture (Yogotherm Yoghurt Culture 77570, Abasia, St. Hyacinthe, Québec, Canada) and incubated for 6 h at 40 °C in 140-ml plastic cups (King Ireland, Dublin, Ireland). Fermentation was then stopped by cooling the samples to 4 °C and the samples were held overnight at this temperature. All textural, rheological and sensory analyses were performed within 24 h.

### 2.4. Textural analysis of intact yoghurt samples

Texture profile analysis (TPA) was conducted using the methods of Bourne (1978), as described by Colmenero, Barreto, Mota, and Carballo (1995). An Instron, Universal Testing Machine (Model No. 5544, Instron Corporation, High Wycombe, England) was used and data were interpreted using the accompanying Instron Blue Hill® 2 software package (Instron Corporation, High Wycombe, UK). The samples were placed centrally under an aluminium cylinder probe (35 mm in diameter) which compressed the sample to a depth of 15 mm in a double compression cycle, using a crosshead speed 1 mm $s^{-1}$. From the measurement of load (N) as a function of time (s) the following attributes were analysed: hardness (H1 and H2 (N), cohesion energy (CE), springiness (SP), chewiness (CW) and gumminess (GM)). Samples were assayed in duplicate for each batch.

**Table 1**
Characteristics of milks used.

| | Fat content (%) | | |
|---|---|---|---|
| | 0.1 | 1.5 | 3.5 |
| Total solids (%) | 8 | 9.5 | 11.6 |
| Protein content (%) | 3.2 | 3.1 | 3.0 |
| Fat (%) | 0.1 | 1.5 | 3.5 |
| Ash (%) | 0.8 | 0.8 | 0.8 |
| Titratable acidity (%)[a] | 0.12 | 0.12 | 0.14 |

[a] Expressed as lactic acid.

### 2.5. Rheological analysis of stirred yoghurt samples

Prior to measurements, the samples were stirred to mimic typical consumer behaviour before yoghurt consumption. Pre-stirring is a common preparatory procedure prior to viscometry testing of yoghurts (Parnell-Clunies et al., 1986; Vercet, Oria, Marquina, Crelier, & Lopez-Buesa, 2002), as it is simple and does not induce substantial loss of structure. The rheological properties were monitored on a Bohlin rheometer (Bohlin Instruments UK, Cirencester, Gloucestershire, UK) and a parallel plate arrangement (Model No. PP55) with 1 mm gap setting at 8 °C constant temperature. Flow curves were performed upward and downward at shear rates ranging from 10 $s^{-1}$ to 290 $s^{-1}$. Both delay time and integration time were set at 5 s. The data obtained for the upward and downward flow curves were separately adjusted to a power law equation: shear stress = ($K \times$ shear rate$^n$), where $K$ is the consistency index, and $n$ is the power law index. This expresses the flow behaviour as Newtonian ($n$ is close to 1) or non-Newtonian ($n$ is far from 1).

### 2.6. Colour measurement

Colour measurements were performed on freshly prepared yoghurt cultures, using a tristimulus colorimeter (Model CR-400 Minolta, Minolta (UK) Ltd., Blakelands North, Milton Keynes, MK14 5BU, England) to determine colour attributes in the Hunter Lab colour space ($L^*$ (lightness), $a^*$ (redness/greenness) and $b^*$ (yellowness/blueness)). The colorimeter was calibrated for internal light (D65) prior to carrying out colour measurements.

### 2.7. Water-holding capacity

To measure the water-holding capacity (WHC), an adapted version of the centrifuge method described by Parnell-Clunies et al. (1986) was used. Samples (2 × 25*g*) from each batch were weighed in centrifuge tubes and all samples were incubated together, after which the set gels were then stored for two days at 4 °C. The tubes were centrifuged at 3000*g* for 10 min at 4 °C. The whey was separated from the samples, which were then reweighed. The WHC was expressed as weight of drained whey per 100 g yoghurt.

### 2.8. Syneresis of yoghurt samples

Syneresis was measured by using 30 g of unstirred yoghurt spread evenly on a Whatman No. 1 filter paper (Whatman Ltd., Maidstone, England) in a funnel, which was placed on top of a 50 ml graduated cylinder. The graduated cylinder was then held at 4 °C for 5 h and the volume of liquid collected was recorded.

### 2.9. Sensory analysis

Sensory analysis, using established procedures as described by Carpenter, Lyon, and Hasdell (2000), was performed on yoghurts manufactured from milk with a fat content of 1.5% or 0.1% and either conventionally heated (10 min, 90 °C) or thermosonicated prior to culturing (400 W, 45 °C outer jacket temperature, treatment time 10 min). The analysis was performed using a triangle test procedure with a sensory panel of 30 untrained assessors. Panellists were presented with three samples, two of which were identical. Panellists were asked to identify the odd sample. In a separate test, panellists were asked to profile samples in terms of a number of quality attributes on a hedonic scale from 1 (least preferred) to 10 (most preferred). The quality descriptors selected were colour, odour, texture, sweetness, creaminess and overall flavour.

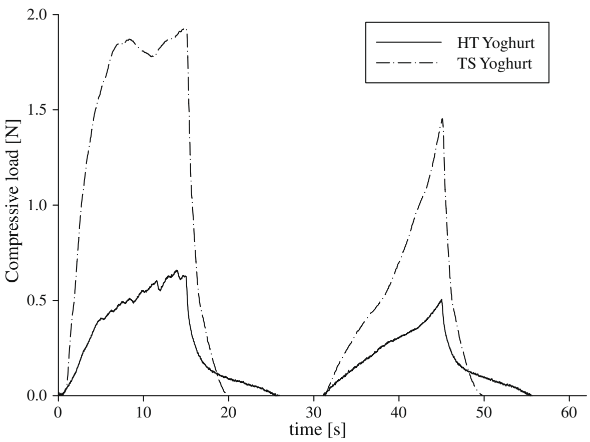


**Fig. 1.** Typical texture profile analysis (TPA) for TS and HT yoghurts (1.5% fat).

### *2.10. Vitamin determination*

#### *2.10.1. General*

The determination of vitamins was carried out on an Agilent 1200 series HPLC system (Agilent Technologies, Waldbronn, Germany) comprising a binary pump, heated column compartment, autosampler and a diode array detector.

#### *2.10.2. Water-soluble vitamins*

Water-soluble vitamins (thiamine and riboflavin) were extracted from 25 g yoghurt samples and clarified using the method of Albala-Hurtado, Veciana-Nogues, Izquierdo-Pulido, and Marine-Font (1997). HPLC analysis was performed on a 150 × 4.6 mm id., 4 μm Synergy Hydro-RP $C_{18}$ column (Phenomenex, Torrance, CA, USA), preceded by a guard column (4 × 3 mm i.d.) packed with the same stationary phase. The mobile phase was a mixture of acetonitrile (solvent A) and a buffer solution (20 mM $KH_2PO_4$) containing an ion pairing agent (0.1% hexane sulfonate) at pH 3.0 (solvent B). The gradient elution programme was: 97% A (0–3 min), and 97–50% A (3–18 min). The flow rate was 1.5 ml $min^{-1}$. Both vitamins were monitored at their absorbance maxima of 265 nm and 245 nm for riboflavin and thiamin, respectively. The retention times were 9.82 min for thiamine and 10.43 min for riboflavin.

#### *2.10.3. Fat-soluble vitamins*

Fat-soluble vitamins were extracted using the method described by Rammell, Cunliffe, and Kieboom (1983) using 2 g of yoghurt. The separation was carried out using the same analytical/guard column system as described above for separation of the water-soluble vitamins. Acetonitrile–methanol (75:25, v/v), at a flow rate of 2.0 ml $min^{-1}$, was used as mobile phase. Both vitamins were monitored at their absorbance maxima, which were 292 nm for tocopherol and 320 nm for retinol. The retention times were 13.41 min for tocopherol and 2.92 min for retinol.

### *2.11. Statistical analysis*

All comparisons between the groups of data were performed by one way analysis of variance using Genstat (Version 10, VSN International, Hemel Hempstead, United Kingdom) and, where significant differences were detected, a Tukey pair-wise comparison of means was performed. Sigmaplot Version 10 SYSTAT, Point Richmond, CA, USA.

## 3. Results and discussion

### *3.1. Texture profile analysis (TPA) on set yoghurts*

A typical stress relaxation plot of compression load vs time is presented in Fig. 1 and clearly shows the much firmer character of the yoghurt from thermosonicated milk compared to its conventionally heated counterpart. This is further illustrated by the additional texture parameters presented in Table 2, in particular, the hardness data where, for example, the mean H1 value for the TS-derived yoghurts (1.8 N) is double that of the conventional samples (0.90 N). Table 1 also illustrates the significant increase in H1 values ($P < 0.01$) occurring in yoghurt samples as a function on an increase of fat content from 0.1% to 3.5%. The ability of fat droplets, acting as active filler particles, to increase the firmness and solid-like properties of acid milk gels has been described by Houze, Cases, Colas, and Cayot (2005). In respect of the other textural properties, yoghurts from TS milk showed higher gumminess and chewiness with mean values of 1.32 vs 0.39 and 17.9 vs 5.7, respectively, while the springiness and cohesiveness parameters were almost the same as those of control yoghurts.

### *3.2. Rheological analysis*

Typical flow behaviour of yoghurts from TS and conventionally treated milk is illustrated in Fig. 2, with the two samples showing similar time-dependent flow profiles and the TS yoghurt displaying a somewhat higher final terminal instantaneous viscosity compared to the conventional control (5.3 vs 2.2 Pa $s^n$). Measurements on the stirred yoghurt samples are summarized in Table 3. There was no treatment effect on the consistency indices of the upward curve and the downward curve (16.5 vs 18.7 Pa $s^n$ and 0.151 vs 0.188 Pa $s^n$ for the upward and downward curves, respectively). However, for both treatments, an increase in the consistency indices could be observed as the fat content increased ($P < 0.001$).

### *3.3. Water-holding capacity*

WHC measurements also showed significant differences between TS and control yoghurts (Table 4). The WHCs of the TS yo-

**Table 2**
Texture properties of yoghurts made from milk heated at 90 °C for 10 min or thermosonicated for 10 min at 45 °C.

| | Conventional Fat content (%) | | | Thermosonicated Fat content (%) | | | Treatment | | Fat content | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.1 | 1.5 | 3.5 | 0.1 | 1.5 | 3.5 | SED | $P^a$ | SED | $P^a$ |
| Hardness (H1) | 0.552 | 0.652 | 1.495 | 1.285 | 1.855 | 2.248 | 0.1778 | *** | 0.250 | ** |
| Hardness (H2) | 0.458 | 0.492 | 1.163 | 0.973 | 1.260 | 1.465 | 0.1223 | *** | 0.1587 | ** |
| Cohesion energy (CE) | 0.598 | 0.630 | 0.629 | 0.341 | 1.182 | 0.579 | 0.1405 | * | 0.1478 | * |
| Springiness (SP) | 74.26 | 78.89 | 91.67 | 86.59 | 90.69 | 91.15 | 2.4101 | ** | 2.78 | ** |
| Chewiness (CW) | 3.6 | 4.8 | 8.7 | 5.7 | 29.9 | 18.2 | 3.91 | ** | 5.16 | * |
| Gumminess (GM) | 0.326 | 0.409 | 0.420 | 0.435 | 2.190 | 1.321 | 0.278 | ** | 0.379 | ** |

SED: standard error of difference.
[a] *, ** and *** refer to $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

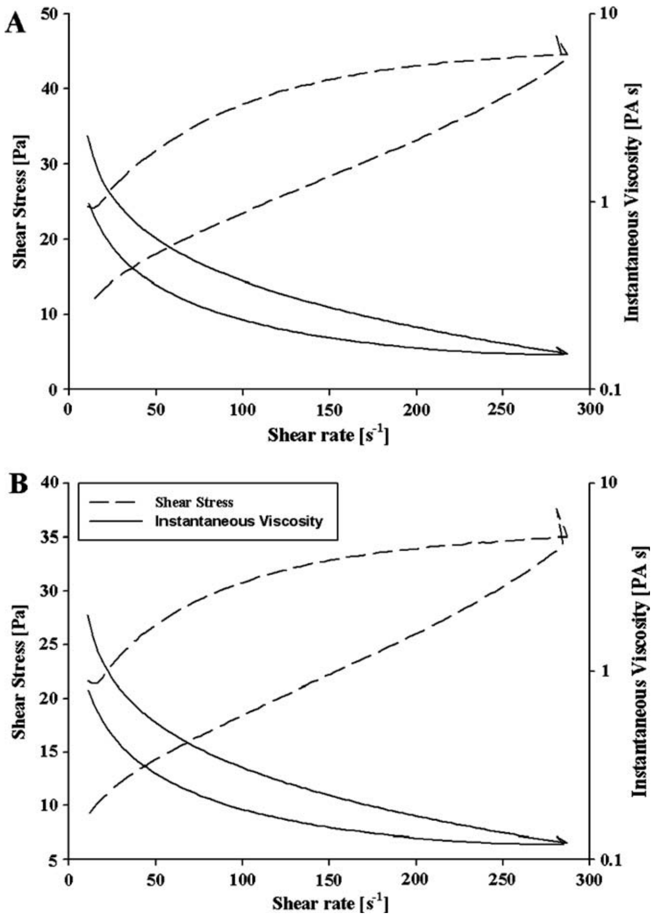


**Fig. 2.** Typical flow curves for TS yoghurt (A) and HT yoghurt (B) with a fat content of 1.5%.

ghurts were significantly higher than those of their HT counterparts ($P < 0.001$) with, for example, TS yoghurt made from 3.5% fat milk exhibiting a WHC more than double that of its HT counterpart. The ability of low-fat thermosonicated milk to yield acceptable yoghurt gels (Riener et al., 2009), is also noted in the present study, where yoghurt produced from TS-treated skim milk had a higher WHC (46%) than had yoghurts prepared from both reduced and full fat conventional HT milk, while skim milk from the latter treatment failed to form a structured set gel. Table 4 also shows that, particularly in the case of the TS yoghurts, WHC increased markedly as the fat content of the samples increased. The ability of fat to improve the water retention ability of proteins within yoghurt type structures has been described by Kinsella (1984) and the data in Table 4 suggest that the reduction in fat globule size achieved by thermosonication (Section 2.7) may further enhance this effect.

### 3.4. Syneresis

Table 4 indicates that gels made from TS milk displayed lower syneresis levels than did their conventional counterparts, although the difference decreased with increasing fat content. Averaged across fat contents, syneresis levels were significantly ($P < 0.05$) lower than in gels produced from conventionally heated milk (43% vs 51%, respectively). This observation is in agreement with the results reported by Vercet et al. (2002), who used thermosonication, in conjunction with pressure after conventional heat treatment, for fortified milk. In the present study, the effect of fat on syneresis was quite marked, with the low fat (0.1%) yoghurt from TS milk displaying a substantially lower level of syneresis than that of its HT counterpart (51% vs 62%), while the corresponding differences for full fat (3.5%) yoghurts were much less (40% vs 38%, respectively). It is well established in the literature that the ability of increasing fat level to enhance WHC in yoghurt is also associated with a reduced tendency of the product to undergo syneresis (Kin-

**Table 3**
Rheological parameters of yoghurts made from milk heated at 90 °C for 10 min or thermosonicated for 10 min at 45 °C.

| | Conventional Fat content (%) | | | Thermosonicated Fat content (%) | | | Treatment | | Fat content | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.1 | 1.5 | 3.5 | 0.1 | 1.5 | 3.5 | SED | $P^a$ | SED | $P^a$ |
| *Flow curves (upward)* | | | | | | | | | | |
| Consistency (Pa $s^n$) | 7.91 | 14.68 | 27.02 | 10.43 | 11.50 | 33.90 | 5.0000 | | 3.231 | *** |
| Flow behaviour | 0.215 | 0.167 | 0.072 | 0.225 | 0.247 | 0.091 | 0.0378 | ** | 0.0399 | ** |
| *Flow curves (downward)* | | | | | | | | | | |
| Consistency (Pa $s^n$) | 1.79 | 2.93 | 4.08 | 2.55 | 3.23 | 4.08 | 0.3422 | * | 0.3242 | ** |
| Flow behaviour | 0.442 | 0.434 | 0.422 | 0.445 | 0.434 | 0.432 | 0.0055 | * | 0.00764 | ** |

SED: standard error of difference.
[a] *, ** and *** refer to $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

**Table 4**
Comparison of selected physical and chemical quality parameters in yoghurts prepared from thermosonicated and conventionally heated milks.

| | Conventional Fat content (%) | | | Thermosonicated Fat content (%) | | | Treatment | | Fat content | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.1 | 1.5 | 3.5 | 0.1 | 1.5 | 3.5 | SED | $P^a$ | SED | $P^a$ |
| $L^*$ | 77.23 | 92.38 | 93.13 | 89.3 | 92.91 | 96.56 | 1.490 | NS | 0.928 | *** |
| $a^*$ | −5.43 | −4.09 | −3.77 | −8.16 | −8.42 | −8.25 | 0.0847 | *** | 1.665 | * |
| $b^*$ | 4.03 | 7.65 | 8.35 | 5.88 | 5.26 | 12.33 | 1.605 | NS | 1.241 | ** |
| WHC (%) | –[b] | 42 | 42 | 46 | 76 | 89 | 4.2 | *** | 5.1 | * |
| Syneresis (%) | 62 | 51 | 40 | 51 | 42 | 38 | 3.53 | ** | 2.46 | ** |
| Thiamine (μg 100 $g^{-1}$) | 60 | 60 | 40 | 60 | 60 | 50 | 4.71 | NS | 2.67 | *** |
| Riboflavin (mg 100 $g^{-1}$) | 110 | 120 | 110 | 120 | 120 | 140 | 5.14 | NS | 8.02 | NS |
| Tocopherol (mg 100 $g^{-1}$) | 0.01 | 0.03 | 0.06 | 0.01 | 0.03 | 0.06 | 0.817 | NS | 6.83 | NS |
| Retinol (μg 100 $g^{-1}$) | 2 | 16 | 20 | 2 | 16 | 20 | 1.560 | NS | 2.64 | ** |

SED: standard error of difference.
[a] *, ** and *** refer to $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.
[b] Not measurable.

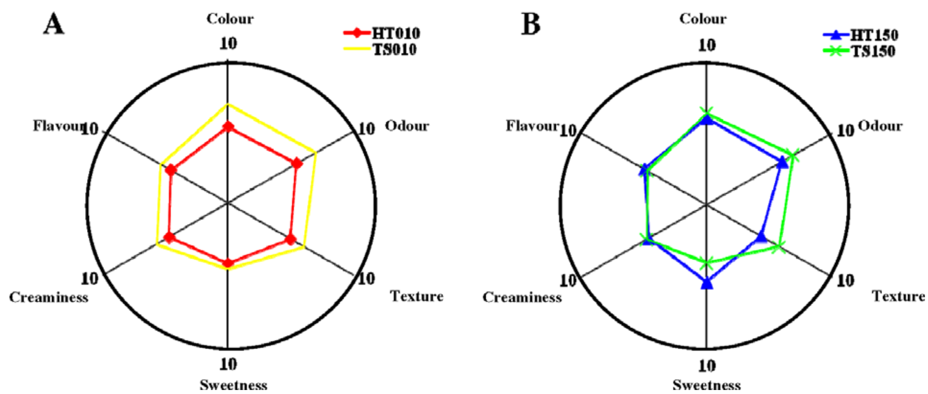


**Fig. 3.** Sensory analysis results for TS and HT yoghurts with fat contents of (A) 0.1% and (B) 1.5%.

sella, 1984). As the fat content increased in the yoghurt from the TS milk (Table 4), there was a significant decrease ($P < 0.01$) in the level of syneresis observed in the product (from 51% to 38%).

Finally, it is worth noting that other studies have described how ultrasonication of milk has brought about quality improvements in yoghurt gels by examining the types of parameters described in Sections 3.1–3.4 of the present study (Vercet et al., 2002; Wu, Hulbert, & Mount, 2001). However, in both of the latter studies the milk samples were subjected to a traditional thermal treatment (90–95 °C for 6–10 min) prior to sonication, so the textural and other properties of both control and sonicated yoghurt gels were obviously strongly influenced by the extensive degree of protein denaturation occurring in the thermal treatment. This was in marked contrast to the much milder thermosonication conditions used in the present study which were found to result in a much lower level of protein denaturation than that measured in yoghurt prepared from conventionally heated milk (Riener et al., 2009).

### 3.5. Colour

Data on the colour properties of the yoghurt samples prepared from milk submitted to the different treatments are presented in Table 4. The TS yoghurt exhibited slightly higher $L^*$ values, on average, than did the product made from conventionally heated milk, but this was largely accounted for by the differences observed within the 0.1% fat sample (77.2 vs 89.3 for TS and HT samples, respectively). By contrast, the significantly lower ($P < 0.001$) redness/greenness values ($a^*$) for TS compared to conventionally treated samples suggests that the thermal impact of thermosonication is less severe than that of the 90 °C (10 min) conventional preheating of milk, thereby leading to a reduced tendency to non-enzymatic browning (Birlouez-Aragon, Sabat, & Gouti, 2002; Braekman, Mortier, Van Renterghem, & De Block, 2001).

### 3.6. Vitamin retention

Table 4 shows no significant differences ($P > 0.05$) in thiamine and riboflavin contents of yoghurts produced from conventionally heated and thermosonicated milk. The concentrations of both vitamins were within the ranges normally found in yoghurt, namely, 20–80 μg 100 $g^{-1}$ of thiamine and 80–250 μg 100 $g^{-1}$ of riboflavin (Öste & Anderson, 1997). While both vitamins are thermally labile under certain conditions (Ball, 2006; Vikram, Ramesh, & Prapulla, 2005), the pre-culture treatments used in the present study did not appear to be sufficiently severe to affect them. The fat-soluble vitamins, α-tocopherol and retinol, were present at representative concentrations in the yoghurt samples and were unaffected by the methods used to treat the milk prior to culturing, as shown in Table 4.

### 3.7. Sensory profiles

Using the triangle test, the 30 member sensory panel detected significant differences between the cultures prepared from TS and HT milk in the case of both 0.1% fat ($P < 0.05$) and 1.5% fat yoghurts ($P < 0.05$). In an attempt to further clarify the nature of the observed differences, panel members were asked to rank the samples using the six quality parameters listed in Section 2.11. Fig. 3 shows the average scores for these descriptors for TS- and HT-derived yoghurts with fat contents of 0.1% (A) and 1.5% (B). The overall acceptability, in terms of higher scores for the larger number of quality parameters, was best for the yoghurt made from the TS 0.1% fat milk, while yoghurt from HT milk with the same fat content was least preferred (Fig. 3(A)). Sensory differences were less pronounced between TS and HT yoghurts from the 1.5% fat milk, with colour, flavour and creaminess scoring the same for both, while texture and odour were better for the TS samples (Fig. 3(B)). It is frequently quite difficult to establish meaningful correlations between objectively measured quality-related parameters of foods and the more subjective and holistic assessments provided by sensory analysis. In the current study, it is possible that the greater firmness/hardness textural features of TS-derived vs conventional set yoghurt, as well as the correspondingly higher terminal viscosities of the stirred products, are related to the preference of the sensory panel for the texture of TS-derived yoghurts from both skim and 1.5% fat milk samples and for the creaminess of the former (Fig. 3(A) and (B)). Overall, the results of the present study suggest that sensory quality is somewhat superior in yoghurt prepared from TS milk compared to the conventional HT derived product.

## 4. Conclusions

This study has shown, that compared to conventional HT treatment of milk, set style yoghurt prepared from TS milk prior to culturing displayed superior quality, as assessed by the measurement of selected rheological, physicochemical and sensory properties. The improvement was particularly marked in the textural and rheological properties of TS yoghurt from skim milk, suggesting that thermosonication may be a useful alternative to the use of texture modifying additives to enhance the quality of low fat yoghurt.

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