Comparison of Ricotta cheese made by high pressure treatment with that produced by heat treatment of sweet whey

Souhail BESBES 1, Christophe BLECKER * 1, Hamadi ATTIA 2, Carine MASSAUX 1, Claude DEROANNE 1

SUMMARY

In this study, reconstituted sweet whey was acidified and then treated by high hydrostatic pressure in order to obtain Ricotta-like product. At pH 5.2, whey protein aggregation was effective beyond 200 MPa for an application time of 30 min. Moist yield was appreciably improved when pressurisation time increased at 400 MPa. It seemed that granulometric properties of Ricotta-like cheese were not affected by increasing pressurisation time. Ricotta-like products obtained after pressurisation at 400 MPa for 30, 45 and 60 min, have shown a lower yield and hardness but a higher cohesiveness than traditional Ricotta cheese. They also had more homogenous granulometric profiles.

Key-words: whey, whey protein, high hydrostatic pressure (HHP), heat-treatment (HT), Ricotta.
1 – INTRODUCTION

High hydrostatic pressure treatments are being increasingly studied in dairy research. Some studies have been carried out on the effect of high pressure on milk pasteurisation. MUSSA and RAMASWAMY (1997) reported kinetics of microbial destruction for treatments up to 350 MPa. FELIPE et al. (1997) compared high-pressure treatments up to 500 MPa for 10 min and heat pasteurisation of goat’s milk. DESOBRY-BANON et al. (1994) investigated acid and rennet coagulation of high-pressurized milk.

On the other hand, a large amount of work was reported on the high pressure-induced aggregation and gelation of whey proteins. The sensitivity of β-lactoglobulin to pressure is well documented (HAYASHI et al., 1987; DUMAY et al., 1994; DUFOR et al., 1994; STAPELFELDT and SKIBSTED, 1999; KOLAKOWSKI et al., 2001). This protein seems to play a major role in the aggregation of whey protein concentrate (WPC) under pressure. At protein concentration high enough, WPC has been found to form pressure-set gels in the pressure range 200-400 MPa (VAN CAMP et al., 1996).

High hydrostatic pressure treatment was evaluated as food processing alternative to classical heat treatment technology (TONELLO, 1997; MICHEL et al., 2001). It was stated that high-pressure treatment showed some technical and sensory advantages (FARR, 1990; MICHEL et al., 2001). Thus, this treatment allowed the uniform and the instantaneous transmission of pressure throughout the product and was independent of the product volume. Once the desired pressure is reached, the pressure can be maintained without the need for further energy input. Furthermore, pressure treatment is being looked upon with interest since the nutritional and sensory properties are not adversely affected by the pressure process (FARR, 1990; MICHEL et al., 2001). Similarly, this treatment leads to a new or a modified texture properties of food products (FARR, 1990).

In this paper, a study is presented concerning the substitution of heat treatment by high-pressure treatment in order to imitate Ricotta cheese. Ricotta cheese is very popular in particular in Mediterranean countries. It is a white, soft, moist and grainy curd (MAHRAN et al., 1998) generally prepared by heat-treatment precipitation of whey proteins. Yields of Ricotta were determined at various pressures (up to 400 MPa) and pressurisation times (up to 60 min). Some physico-chemical characteristics of Ricotta-like cheese were compared to those of a reference product prepared by heat treatment.

2 – MATERIALS AND METHODS

2.1 Sweet whey preparation and analyses

Commercial dried sweet whey, purchased from ORFFA (Londerzeel, Belgium), was used to prepare ricotta cheese. It was vacuum-packed and stored at 5°C in order to ensure its quality constancy. Dried sweet whey was obtained...
from pasteurized, concentrated and atomized sweet whey. The powder was dispersed in water to 6% (wt:wt) by shaking for 1 h, in an Erlenmeyer flask at room temperature, and allowed to stand maximum 1 h at 5°C before processing, either heat treatment or high pressure treatment (figure 1). Moisture, fat, ash and the content of the different nitrogen fractions were determined according to the methods described by Afnor (1999), from the reconstituted sweet whey (table 1).

**Figure 1**

Schematic diagram of discontinuous process for the production of high pressure- and heat-induced Ricotta cheese

### 2.2 Ricotta cheese manufacture

Ricotta cheese was made as shown in figure 1. A standardized processing was used in order to produce stable Ricotta cheese. Reconstituted whey was added with sodium chloride (3.5 g·L⁻¹) and then, the pH was adjusted to 5.2 or 5.9 with acetic acid (2.5% v:v). Acetic acid was chosen because it gives higher cheese yield and firmness than citric and lactic acids (MAHRAN et al., 1999). Usually salt and acid are separately added during the heat treatment at different temperatures, 45°C and 80-85°C, respectively (MAUBOIS and KOSIKOWSKY,
as high pressure treatment involves batch processing, such an operation is not possible when using high-pressure process. For this reason, we chose the simultaneous addition of both ingredients, i.e. salt and acid, at room temperature. Then, we compared the effects of heat and pressure treatment.

Mixture was shaken during 5-10 min before heating or pressurization. The curd induced by heat or by pressure was left in the serum 10-15 min before draining (MAHRAN et al., 1999). The curd was separated from deproteinated whey on a belt of 170 mesh (ENDECOTTS, London, Great Britain) at a temperature of 5°C overall night. The ricotta cheese was packed in food plastic containers type AGEBIO Y0468 (DELTALAB, Liège, Belgium), sealed, and then stored at 5°C before analysis.

### 2.2.1 High pressure processing

Samples of 300 mL were placed into high-density polyethylene bottles (MERCK Eurolab, Leuven, Belgium), avoiding any headspace. They were treated using discontinuous high hydrostatic pressure equipment (Engineered Pressure System International NV, Temse, Belgium). The pressure was raised to the desired value (100 to 400 MPa) and maintained at this value for 20 to 60 min. The temperature of the samples was controlled at 25 ± 3°C through a jacket surrounding the pressure vessel. Cooling of the vessel was necessary because of the temperature increase induced by pressure (3°C per 100 MPa). High-pressure treatment was performed in quadruplicate.

### 2.2.2 Heat treatment

Whey mixture was divided into three Erlenmeyer covered flasks, then they were heated at 85 ± 3°C for 10 min using a water bath. We should notice that

<table>
<thead>
<tr>
<th>Sweet whey Dry matter (95.94 ± 0.04%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TN a</td>
</tr>
<tr>
<td>NPN a</td>
</tr>
<tr>
<td>NCN a</td>
</tr>
<tr>
<td>Proteins a</td>
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<tr>
<td>CN a</td>
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<tr>
<td>Soluble proteins a</td>
</tr>
<tr>
<td>Ash a</td>
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<tr>
<td>Fat a</td>
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<tr>
<td>Lactose b</td>
</tr>
</tbody>
</table>

**Table 1**

Chemical composition of used sweet whey expressed in g/100 g of dry matter

TN: total nitrogen, NPN: non protein nitrogen; NCN: non casein nitrogen, CN: casein nitrogen,

a: The means (± SD) of three independent experiments are shown, b: The means (± SD) of two independent experiments are shown.
this treatment temperature (85°C) was reached after 35 min heating. The temperature was followed up with a copper-constantan thermocouple (OMEGA, USA).

2.3 Analytical methods

All analytical determinations were performed at least in triplicate. Values of different parameters were expressed as the mean ± standard deviation (SD).

2.3.1 Determination of protein solubility after pressurisation

Nitrogen Solubility Index “NSI” was used to evaluate whey protein solubility after pressurisation of whey at pH 5.2 and 5.9. Samples of 300 mL were centrifuged at 6000 rpm/min for 30 min at a temperature of 10°C (Beckman, rotor JA 14, Great Britain). Nitrogen was determined by Kjeldahl method (Afnor, 1999) on 5 mL of supernatant. The “NSI” was expressed as follows:

\[ \% \text{ NSI} = \frac{\text{nitrogen concentration in supernatant} \times 100}{\text{initial nitrogen concentration}}. \]

2.3.2 Total proteins and total solids in cheese samples

Total protein content of Ricotta samples was determined by Kjeldahl method (Afnor, 1999). Total solids content was determined according to NF V04-282 in agreement with ISO 5534 (Afnor, 1999).

2.3.3 Evaluation of water holding capacity of cheese samples

Water holding capacity was based on the determination of water quantity released from the Ricotta cheese after centrifugation (KOCHER and FOEGEDING, 1993). A sample of 5 g of cheese was centrifuged at 9500 rpm/min for 30 min at a temperature of 10°C (Beckman, rotor J2-21, Great Britain). The centrifuged tubes were drained for 15 min. Water holding capacity was expressed as follows:

\[ \text{WHC} = \frac{\text{initial moisture} - \text{loss of water}}{\text{initial moisture}} \times 100. \]

2.3.4 Evaluation of cheese yield

Cheese yield is either the cheese quantity obtained from a given quantity of milk or the proportion of some milk components in cheese (VANDEWEGHE, 1987). Hence, cheese yield can be expressed in several ways:

- Moist Yield (MY): the moist weight of serum cheese obtained from 1 L of whey after 16 h draining,
- Dry Yield (DY): the dry weight of serum cheese obtained from 1 L of whey after 16 h draining,
- Dry Matter Yield (DMY): the percentage of dry matter recuperated in cheese from total solids in whey.

It was expressed as follows:

\[ \text{DMY} = \frac{\text{DY} \times 100}{\text{total solid in 1 L of whey}}, \]

- Protein Yield (PY): the weight (g) of recuperated protein in cheese from 1 L of whey. It was expressed as the percentage of protein reported to dry
matter of whey \((\text{PY/DMW})\) or reported to the total protein in 1 L of whey \((\text{PY/TPW})\).

They were expressed as follows:

\[
\begin{align*}
\text{PY/DMW} &= (\text{MY} \times \text{protein content}) \times 100 / \text{dry matter content in whey}, \\
\text{PY/TPW} &= (\text{MY} \times \text{protein content}) \times 100 / \text{protein content in whey}.
\end{align*}
\]

### 2.3.5 Characterisation of textural properties

A sample of 20 g of Ricotta cheese was placed into food plastic container type AGEBIO Y0468 (DELTALAB, Liege, Belgium) and then glazed to obtain a smooth surface and a homogenous cheese without air bubbles. Heat and pressure induced ricotta was kept in a refrigerator at 5°C at least 1 h before measurement.

Ricotta cheese texture parameters were determined by a Texture Profile Analysis (TPA) procedure using a texture analyzer SMS TAXT2 (Great Britain) with a cylinder probe of 12.5 mm diameter. The plunger was driven twice at a speed of 0.5 mm/s for a 5 mm displacement. The imposed time between the two compressions was of 5 s. The resulting force-time curves were analysed using the Texture Profile Analysis (TPA) method (BOURNE, 1978). Textural parameters of hardness and cohesiveness were measured at 5°C to compare the texture of the two kinds of Ricotta cheese.

### 2.3.6 Granulometric study of cheese particles

Granulometric profiles of heat and pressure induced cheese were obtained using the laser granulometre (MALVERN, Master Sizer 2000, Great Britain). Data were recorded and analyzed with the Master Sizer 2000 software. Measure was carried on following TERRAY and THEVENET (1995).

Cheese sample was directly incorporated in the appropriate compartment (Hydro 2000 S (A)), where it was diluted in circulating distilled water until the required concentration, which was indicated on a colored scale, was reached. After that, measurements started and lasted for 12 s.

### 3 – RESULTS AND DISCUSSION

#### 3.1 Effects of hydrostatic pressure on the denaturation of whey protein

##### 3.1.1 Effects of high hydrostatic pressure on the nitrogen solubility index

The effects of pressure, from 100 to 400 MPa, for 30 min, on the nitrogen solubility index “NSI” were shown in figure 2. The NSI was determined at pH 5.2 and pH 5.9. These results indicated that whey proteins are less soluble at pH 5.2 than pH 5.9. At the latter pH value, the curd formation was not observed after pressurisation. So, the sweet whey was acidified at pH 5.2 to prepare
Ricotta cheese, in spite of the fact that several authors reported that traditional Ricotta cheese was preferably manufactured with whey, skim milk or their mixture at pH 5.9 (MAUBOIS et KOSIKOWSKI, 1978; ABDEL-RAFFEE et al., 1996; MARIAN et al., 1999). It is worthy to note that the pH value of 5.2 corresponds to the critical pH point of β-lactoglobulin.

Figure 2 showed that NSI decreased significantly above a pressure of 200 MPa maintained during 30 min at 25°C. This solubility variation was due to an irreversible pressure-induced whey protein denaturation. The effect of the pressure on the denaturation/aggregation of whey proteins was most important at their isoelectric point (VAN CAMP and HUYGHEBAERT, 1995a). At this pH, intramolecular and inter-molecular electrostatic interactions increased. Reversible effects such as partial unfolding or dissociation of polymeric structures were reported below 100-200 MPa (JAENICKE, 1991). Higher pressure (> 200 MPa) caused irreversible effects on proteins. These include unfolding of monomeric proteins and their aggregation (ZIPP and KANTZAM, 1973; SILVA et al., 1989).

3.1.2 Effect of high hydrostatic pressure on the cheese yield

Figure 3 illustrated the evolution of moist cheese yield over the pressure range 100 to 400 MPa for 30 min. The small whey protein denaturation under 200 MPa explained the moist yield zero value (figure 2). Proteins did not precipitate because their surface hydrophobicity was slight. Insoluble protein aggregates were observed above 200 MPa and the cheese yield increased as the pressure increased. In fact, increasing pressure induced more denaturation of whey proteins, which coagulated and formed Ricotta-like cheese. The important solubility loss can indicate that the exposition of hydrophobic groups to pressure higher than 200 MPa decreased the hydrophilic character of whey pro-
proteins, which agglomerated near their critical pH point. JOHNSTON et al. (1992) found an increase in hydrophobic groups on the surface of the milk proteins and also noticed a decrease in non-casein nitrogen after treatment indicating precipitation of the whey proteins. Pressurisation of whey under 400 MPa during 30 min at 25°C resulted in the best cheese yield. For this reason, the effect of pressurisation time on the cheese yield was only studied at this pressure. Some studies of HHP effect on whey protein showed that β-lactoglobulin is the most sensible to pressure. Aggregation of this protein was observed until

**Figure 3**

Effect of whey pressurisation (30 min at pH 5.2) on the moist cheese yield (MY). The means (± SD) of four independent experiments are shown

**Figure 4**

Effect of pressurisation time, at 400 MPa, on the moist cheese yield (MY). The means (± SD) of four independent experiments are shown
200 MPa during 30 min at 25°C (NAKAMURA et al., 1993; DUMAY et al., 1997). LOPEZ FANDINO et al. (1996), in a study on the milk used to prepare cheese, showed that cheese yield increased when they used pressurised milk. Pressurisation of milk for 30 min at 300 and 400 MPa resulted in a mean curd weight increase of 14 and 20% respectively and a substantial decrease in protein loss in the whey fraction (7.5 and 15%, respectively). In addition to the greater retention of β-lactoglobulin in the curd, the total volume of whey also decreased by 4.5 and by 5.8% in milk treated for 30 min at 300 and 400 MPa, respectively (LOPEZ FANDINO et al., 1996).

The effects of pressure at 400 MPa on the cheese yield were shown in figure 4. Cheese yield increased with the pressurisation time. LOPEZ FANDINO et al. (1996) also showed that the curd weight and protein loss in the whey were greatest during the first 20 min of pressure-treatment at 400 MPa. They observed a very rapid denaturation of β-lactoglobulin (amounting to 78%) in the first 10 min of pressurisation. Thus, the increase in moist yield of Ricotta-like cheese may be attributed firstly (t ≤ 20 min) to a considerable denaturation of the β-lactoglobulin and secondly (t > 20 min) to a probable incorporation of other whey components such as lactose and fat (§ 3.2.2).

### 3.2 Comparison between heat-induced and pressure-induced Ricotta-like cheese

#### 3.2.1 Effects of pressure and heat treatment on the rennet clotting properties of whey

After heat treatment, the major part of the aggregates floated on the flask surface, whereas pressure treatment showed sedimentation of the protein aggregates (results not shown). This could be explained by the reduction of molar protein volume (VAN CAMP et HUYGHEBAERT, 1995b; FELIPPE et al., 1997). Protein pressurisation essentially induced the destruction of hydrophobic interactions causing the dissociation and the unfolding of monomers and their aggregation (CAYOT et LORIENT, 1998). The replacement of heat treatment by HHP to prepare Ricotta-like cheese produced a new product. High pressure-induced cheeses are glossy, soft and homogenous in comparison with traditional heat-induced ricotta cheese, which are granular (figure 5). It could be concluded that the aggregation mechanisms differ between pressure and heat-induced cheese. This is probably because pressure induced protein denaturation by the disruption of hydrophobic and ion-pair bonds, and unfolding of the proteins. In contrast, heat-induced denaturation resulted in the formation or destruction of covalent bonds (FARR, 1990).

#### 3.2.2 Yield evaluation

The influence of heat and pressure treatments on the yield of Ricotta-like cheese is shown in table 2. Compared to high-pressure treatment, heat treatment gave better moist, dry and protein yields. This could be attributed to the different susceptibilities of the whey proteins to denaturation under the two treatments (FELIPE et al., 1997). In fact, heat treatment induced more protein denaturation and unfolding than pressure treatment.
Table 2
Influence of denaturing treatment (HT or HHP) on the yield of Ricotta cheese prepared at pH 5.2 (a)

<table>
<thead>
<tr>
<th></th>
<th>Ricotta HT</th>
<th>Ricotta HHP (400 MPa, 30 min, 25°C)</th>
<th>Ricotta HHP (400 MPa, 45 min, 25°C)</th>
<th>Ricotta HHP (400 MPa, 60 min, 25°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MY (g·L−1)</td>
<td>31.87 ± 0.51</td>
<td>13.00 ± 0.50</td>
<td>19.80 ± 0.40</td>
<td>22.25 ± 0.50</td>
</tr>
<tr>
<td>DY (g·L−1)</td>
<td>4.68 ± 0.22</td>
<td>2.05 ± 0.08</td>
<td>2.52 ± 0.06</td>
<td>2.88 ± 0.07</td>
</tr>
<tr>
<td>DMY (%)</td>
<td>8.13 ± 0.38</td>
<td>3.57 ± 0.15</td>
<td>4.48 ± 0.11</td>
<td>5.00 ± 0.13</td>
</tr>
<tr>
<td>PY/DMW (%)</td>
<td>4.77 ± 0.22</td>
<td>2.76 ± 0.18</td>
<td>2.41 ± 0.05</td>
<td>2.92 ± 0.10</td>
</tr>
<tr>
<td>PY/TPW (%)</td>
<td>38.6 ± 1.93</td>
<td>22.38 ± 1.48</td>
<td>19.99 ± 0.46</td>
<td>24.53 ± 0.84</td>
</tr>
</tbody>
</table>

HT: heat treatment; HHP: high hydrostatic pressure, MY: moist yield, DY: dry yield, DMY: dry matter yield, PY: protein yield, DMW: dry matter of whey, TPW: total protein of whey. (a): The means (± SD) of three independent experiments are shown.

Application of 400 MPa during 30, 45 and 60 min showed that moist and dry yields increased when pressure time increased whereas protein yield did not change. This increase of dry weight was probably due to the retention of other whey components such as lactose and fat. Since β-lactoglobulin was more susceptible to high pressure denaturation than other whey proteins (LOPEZ FANDINO et al., 1996; HINRICHS et al., 1996), we can relate the increase of dry weight to the structural modifications of β-lactoglobulin allowing the contraction of new interactions between this protein and other whey components.

3.2.3 Chemical composition of cheese

Protein and dry contents of Ricotta cheeses as well as their water holding capacity are shown in table 3. Dry and protein contents were similar for the two
denaturing treatments. Nevertheless, Ricotta-like cheese (400 MPa for 30 min at 25°C) showed higher contents than other pressure-induced Ricotta-like cheeses (400 MPa for 45 and 60 min). In fact, protein-aggregates formed a “cake” the surface and the thickness of which increased when the pressure time and the moist cheese increased and then the water drainage speed decreased. The quantity of water in samples was more important when pressure time increased for the same draining time. This drained water washed out, parts of soluble components such as lactose and minerals. Consequently, protein content in cheese increased. Protein content of cheese prepared under 400 MPa for 30 min was 1.7 times as important as those of other pressure-induced cheese (400 MPa for 45 and 60 min).

Water holding capacity of cheese prepared at 400 MPa for 30 min was more important than that of other pressure-induced cheeses (400 MPa for 45 and 60 min). Pressure-induced cheese (400 MPa for 30 min) showed the most important water holding capacities compared to the other cheeses (400 MPa for 45 and 60 min). This can be explained by a more important water loss during draining. The heat-induced cheese had an important water binding capacity compared to pressure induced cheese. Moreover, CHEFTEL and DUMAY (1996) showed that pressure-induced β-lactoglobulin gels were more exudative than heat-induced gels.

Table 3

<table>
<thead>
<tr>
<th></th>
<th>Ricotta HT</th>
<th>Ricotta HHP (400 MPa, 30 min, 25°C)</th>
<th>Ricotta HHP (400 MPa, 45 min, 25°C)</th>
<th>Ricotta HHP (400 MPa, 60 min, 25°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TS (g/100 g)</td>
<td>14.70 ± 0.42 (a)</td>
<td>15.81 ± 0.04 (c)</td>
<td>12.73 ± 0.05 (c)</td>
<td>12.93 ± 0.05 (c)</td>
</tr>
<tr>
<td>P (g/100 g)</td>
<td>8.61 ± 0.26 (a)</td>
<td>12.24 ± 0.30 (c)</td>
<td>7.01 ± 0.01 (c)</td>
<td>7.57 ± 0.08 (c)</td>
</tr>
<tr>
<td>WHC (%)</td>
<td>41.09 ± 1.45 (b)</td>
<td>31.47 ± 3.52 (b)</td>
<td>27.84 ± 1.02 (b)</td>
<td>28.18 ± 4.79 (b)</td>
</tr>
</tbody>
</table>

HT: heat treatment; HHP: high hydrostatic pressure, TS: total solids, P: protein content, WHC: water holding capacity.

(a): The means (± SD) of nine independent experiments are shown; (b): The means (± SD) of four independent experiments are shown; (c): The means (± SD) of three independent experiments are shown.

3.2.4 Texture properties

Hardness and cohesiveness of cheese are shown in table 4. There were significant differences in appearance and in textural properties between pressure- and heat-induced cheeses. These results would apparently indicate that the unfolding mechanism was different between pressure- and heat-induced cheeses. The high-pressure treatment results in a novel texture.

Heat-induced cheese was harder than pressure-induced cheeses. This could be due to the important water holding capacity and dry matter of traditional cheese. Comparable results were previously found with pressure- and heat-induced food protein gels (OKAMOTO et al., 1990).
Table 4
Effect of heat treatment and pressure on the Ricotta cheese texture properties evaluated by TPA method (BOURNE, 1978)

<table>
<thead>
<tr>
<th></th>
<th>Ricotta HT</th>
<th>Ricotta HHP (400 MPa, 30 min, 25°C)</th>
<th>Ricotta HHP (400 MPa, 45 min, 25°C)</th>
<th>Ricotta HHP (400 MPa, 60 min, 25°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness (N)</td>
<td>1.72 ± 0.03 (a)</td>
<td>0.52 ± 0.07 (b)</td>
<td>0.28 ± 0.01 (b)</td>
<td>0.24 ± 0.02 (b)</td>
</tr>
<tr>
<td>Cohesiveness</td>
<td>0.56 ± 0.02 (a)</td>
<td>0.75 ± 0.04 (b)</td>
<td>0.55 ± 0.01 (b)</td>
<td>0.56 ± 0.01 (b)</td>
</tr>
</tbody>
</table>

HT: heat treatment; HHP: high hydrostatic pressure; (a): The means (± SD) of six independent experiments are shown; (b): The means (± SD) of three independent experiments are shown.

Ricotta-like cheese (400 MPa for 30 min at 25°C) was harder and more cohesive than the other pressure-induced cheeses (400 MPa for 45 and 60 min at 25°C). This may be explained by their higher content in dry matters (table 3). In similar conditions, but without the drainage step, an increase in pressure time improved the gel strength significantly for the whey protein concentrate (WPC) model systems (VAN CAMP and HUYGHEBAERT, 1995b; VAN CAMP et al., 1996). Thus, the negative effect of the pressure time on texture properties of Ricotta-like cheese was surely related to the drainage phenomenon. In fact, drainage speed increased when the pressure time decreased (§ 3.2.3).

3.2.5 Granulometric properties

The size distributions of cheese aggregates are shown in figure 6. These results confirmed that the pressure-induced cheeses were homogenous in view of the little variance between repetitions for the same sample contrary to heat induced Ricotta cheese. On the other hand, figure 6 (A, B, C) showed that the pressure time had no influence on the particle size distribution. So, granulometric profiles of pressure-induced cheeses (400 MPa for 30, 45 and 60 min) were comparable. The sizes of particles, which formed in pressure-induced cheese and in traditional heat-induced Ricotta cheese, were differently distributed (from 0.04 µ to 30 µ and from 0.04 µ to 100 µ, respectively). Granulometric profiles of pressure- and heat-induced cheeses were comparable from 0.04 µ to 30 µ. Nevertheless, apparition of aggregates having a size higher than 30 µ was observed in traditional Ricotta cheese. These aggregates came from the partial polymerization of small ones. This hypothesis can be confirmed by the fact that pressure-induced cheeses contained more particles with a size less than 0.42 µ compared to heat-induced cheese (68.85% against 56.29%).

Pressure-induced Ricotta cheeses were composed of aggregates which represented the following volumetric percentages:

- Φ < 0.42 µ (68.85%),
- 0.42 µ < Φ < 8.71 µ (29.96%),
- 8.71 µ < Φ < 30 µ (1.23%).

On the other hand, heat-induced Ricotta cheeses were composed of aggregates which represented the following volumetric percentages:
\[ \Phi < 0.42 \mu \text{ (56.29\%),} \]
\[ 0.42 \mu < \Phi < 8.71 \mu \text{ (37.91\%),} \]
\[ 8.71 \mu < \Phi < 30 \mu \text{ (1.32\%),} \]
\[ 30 \mu < \Phi < 100 \mu \text{ (4.48\%).} \]

Figure 6

Granulometric properties of ricotta cheese prepared by high hydrostatic pressure (A, B, C) and by heat treatment (D)

A: Ricotta prepared at 400 MPa during 30 min at 25°C; B: Ricotta prepared at 400 MPa during 45 min at 25°C; C: Ricotta prepared at 400 MPa during 60 min at 25°C; D: Ricotta prepared using heat treatment process. Error bars indicate Standard deviation of six experiments.
4 – CONCLUSION

Application of high hydrostatic pressure to sweet whey allowed obtaining homogenous, soft and bright Ricotta-like cheese. Since large volume pressure vessels are nowadays available from manufacturers and since the processing cost becomes progressively affordable, some industrial applications of high hydrostatic pressure have been put in place. Within this context, high pressure represents a potential technology for high quality Ricotta-like cheese by achieving protein aggregation, permitting microbial inactivation and preserving nutritional and sensory properties. These last advantages need however to be more deeply investigated.

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