International Dairy Journal 93 (2019) 57–71

Contents lists available at ScienceDirect

International Dairy Journal

journal homepage: www.elsevier.com/locate/idairyj

Review

Science and technology of cultured cream products: A review

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ARTICLE INFO

Article history:
Received 4 September 2018
Received in revised form
17 January 2019
Accepted 25 January 2019
Available online 19 February 2019

ABSTRACT

Cultured cream, produced by fermentation, has several culinary uses requiring different properties, and this may necessitate using different production technologies. Products with reduced fat content are increasingly popular, but compromised sensory properties are not desired. Here, the technology for the production of cultured cream and the influence of various parameters on its properties are reviewed; the effect of homogenisation on cream of varying fat content and the subsequent fermentation of this cream is given special focus. The structure of low fat (10–15%) cultured cream is dominated by a milk protein acid gel; high fat (≥30%) cultured cream is dominated by a gel structure consisting of coagulated protein-covered fat globules. Cultured cream with approximately 20% fat has neither a dense protein acid gel nor a high density of coagulated protein-covered fat globules. Quality challenges presented by the latter products may be mitigated by addition of milk protein.

Contents

1. Introduction to cultured cream products

Cultured cream, also known as sour cream, fermented cream and crème fraîche, is a traditional dairy product in many countries and has a variety of uses. It is popular in Europe (less so in southern Europe), Eastern Europe and Australasia, as well as North America and Mexico; usage in some of these countries is traditional, in others adopted. Cultured cream may also be available in other countries with an international cuisine, but is less common in countries without a tradition for milk production, such as Western Africa and the Far East. Its origin is the spontaneous fermentation of milk at ambient temperature, during which the milk fat rises to the

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https://doi.org/10.1016/j.idairyj.2019.01.011

surface and both the cream layer and the underlying milk simultaneously obtain a sour and aromatic taste during the fermentation. Its rich taste and creamy mouthfeel makes cultured cream a popular ingredient in many recipes, some of which are also specialities in particular countries. Cultured cream may be added to stews and other meat dishes, used as a garnish for meat and fish, vegetables and salads and some cakes, or used as an ingredient in baking. Blending cultured cream with herbs and spices for use as a dip has become increasingly popular (Meunier-Goddik, 2012). Cultured cream may also show stability with regards to acidity and heat and can therefore be added to acid and/or hot food without separation into free fat and casein particles.

Cultured cream should be a smooth, shiny, viscous product with a mildly sour taste and a gentle flavour of diacetyl (Lyck, Nilsson, & Tamime, 2006). However, its physical quality properties vary according to the fat content, even though these different products are largely used in the same way. What is considered the optimal consistency of cultured cream depends partially on the intended use of the product and can range from being viscous and pourable, to being stiff and spoonable. The appearance and consistency of cultured cream can have several quality challenges including whey separation, grainy consistency, jelly-like, or being too thin or too thick, too ropy and lumpy or inhomogeneous (Meunier-Goddik, 2012). There are several reasons for these quality variations and problems that are all related to the complex synergy between fat content, homogenisation and heat treatment of the cream, type of starter culture used, conditions during fermentation, treatment of the cultured cream after fermentation, cooling process, and finally the storage and distribution of the cultured cream.

The industrialisation of cultured cream production has developed in several directions over the years, along with changes in consumption patterns, dietary trends and the development of processing equipment. According to Codex Alimentarius (1976), cream may contain between 10 and 50% milk fat. Logically, this same range also applies to cultured cream and therefore products with a fat content lower than 10%, or containing fat other than milk fat, should not be described as cultured cream. However, with dietary trends moving towards reducing nutritional energy intake, there are products on the international market that contain considerably less than 10% fat but nevertheless bear the name of cultured cream.

There are various cream products known, for example, as double cream (45–50% fat); full cream or whipping cream (≥30% fat, according to country standards); light, or single cream (approximately 20% fat) and also cream with a fat level of >10%, known variously as “half and half”, “extra-light” or coffee cream. Different countries may have slightly differing grouping of cream according to fat content (Smiddy, Kelly, & Huppertz, 2006). These cream varieties may be fermented to produce a cultured product with these different fat contents. For instance, the USDA lists specifications (USDA, 2000) for cultured cream products with varying fat content as: Sour cream: > 18% fat; Reduced fat sour cream: minimum 25% reduction in fat equivalent to 13.5% or less of total fat; Light sour cream: <9% fat; Low fat sour cream: <6% fat and Non-fat sour cream: <1% fat. Several of these product categories have such a low fat content that it could be argued that the products are more like cultured milk or cultured buttermilk and it could be argued that the word “cream” is misleading and should not be used.

Reduced-fat cultured cream products present a greater technological and quality challenge than their more fat-rich relatives due to their inferior consistency, water retention and mouthfeel. Such problems may be improved by the addition of non-dairy ingredients, such as various hydrocolloids and/or emulsifiers. However, with the aim of producing pure, or clean-label, dairy products, additives are avoided wherever possible in some countries.

Crème fraîche is a type of cultured cream and has various definitions, depending on country, but a strict dividing line between the products seems to be vague. Some countries market only crème fraîche, others only cultured cream – and several countries market both products. Kosikowski (1977) indicated that crème fraîche is only slightly acidified, to pH 6.2–6.3 and has a fat content of 50%, but this does not seem to be the present understanding of the product and crème fraîche is usually described as a soured cream similar to cultured cream. In some countries, crème fraîche is marketed as having greater heat stability than products named cultured cream. Although high fat crème fraîche (≥30% fat) possibly differs from high fat cultured cream only by use of a slightly higher homogenisation pressure, crème fraîche and cultured cream with lower fat contents (18, 15, 10%) often contain both emulsifiers (section 6.3) and hydrocolloids (section 6.2) to increase viscosity, stabilise proteins, and prevent whey separation (Born, 2006; Meunier-Goddik, 2012). Processing technology and these additions also make it possible to add these reduced fat products to hot dishes with less risk of producing grainy particles or a separation of fat in the final dishes.

The industrial processing of cultured cream presents several challenges in production. These challenges vary according to the fat content of the cream to be fermented. In particular, poor viscosity and other consistency parameters as well as whey separation become more challenging with a reduction of fat content, and yet the consumer expects the cultured cream to meet sensory standards whatever the fat content. A standard process to make commercial cultured cream usually involves fat standardisation followed by homogenisation and heat treatment of the cream. A suitable starter culture of lactic acid bacteria (LAB) is then added, followed by fermentation at a temperature at which the chosen culture grows well, producing lactic acid and volatile aroma compounds. All the relevant unit operations can, however, be greatly varied and this influences the quality and properties of the final product. A generalised flow chart for the commercial production of cultured cream is shown in Fig. 1. Process steps shown with dashed box lines illustrate the many steps in the process where there is most variation. In this review, we describe the technology of these stages and report on the possible effects on important quality parameters.

2. General aspects of homogenisation of milk and cream

Homogenisation of milk or cream is a common unit operation in the dairy industry and its main function is to stabilise the fat phase in the cream and prevent the fat fraction from rising to the surface, known as “creaming”. The basic principles of milk homogenisation are well described by Mulder and Walstra (1974), Walstra (1984), Wilbey (2003) and Walstra, Wouters, and Geurts (2006), while Truong, Palmer, Bansal, and Bhandari (2016) have recently reviewed the effect of milk fat globule size on the physical functionality of dairy products. Useful information on the effect of various processing parameters on the quality of unfermented cream is given by Kessler (2002) and Kessler and Fink (1992).

A proteinaceous membrane, largely derived from the membrane of the milk-producing cells in the udder, surrounds milk fat globules of varying size (<0.2 – >15 μm, average 3.3 μm). The milk fat globule membrane (MFGM) consists almost exclusively of protein (70%) and phospholipids (25%). The MFGM proteins are several and have an extremely complex composition and structure. This is especially challenging to analyse in detail as the results obtained are, to a great extent, dependent upon the methods used for the isolation of the protein components in the MFGM (Dewettinck et al., 2008; Holzmüller, Gmack, Griebel, & Kulozik, 2016a; Holzmüller & Kulozik, 2016; Holzmüller, Müller, Himbert, &

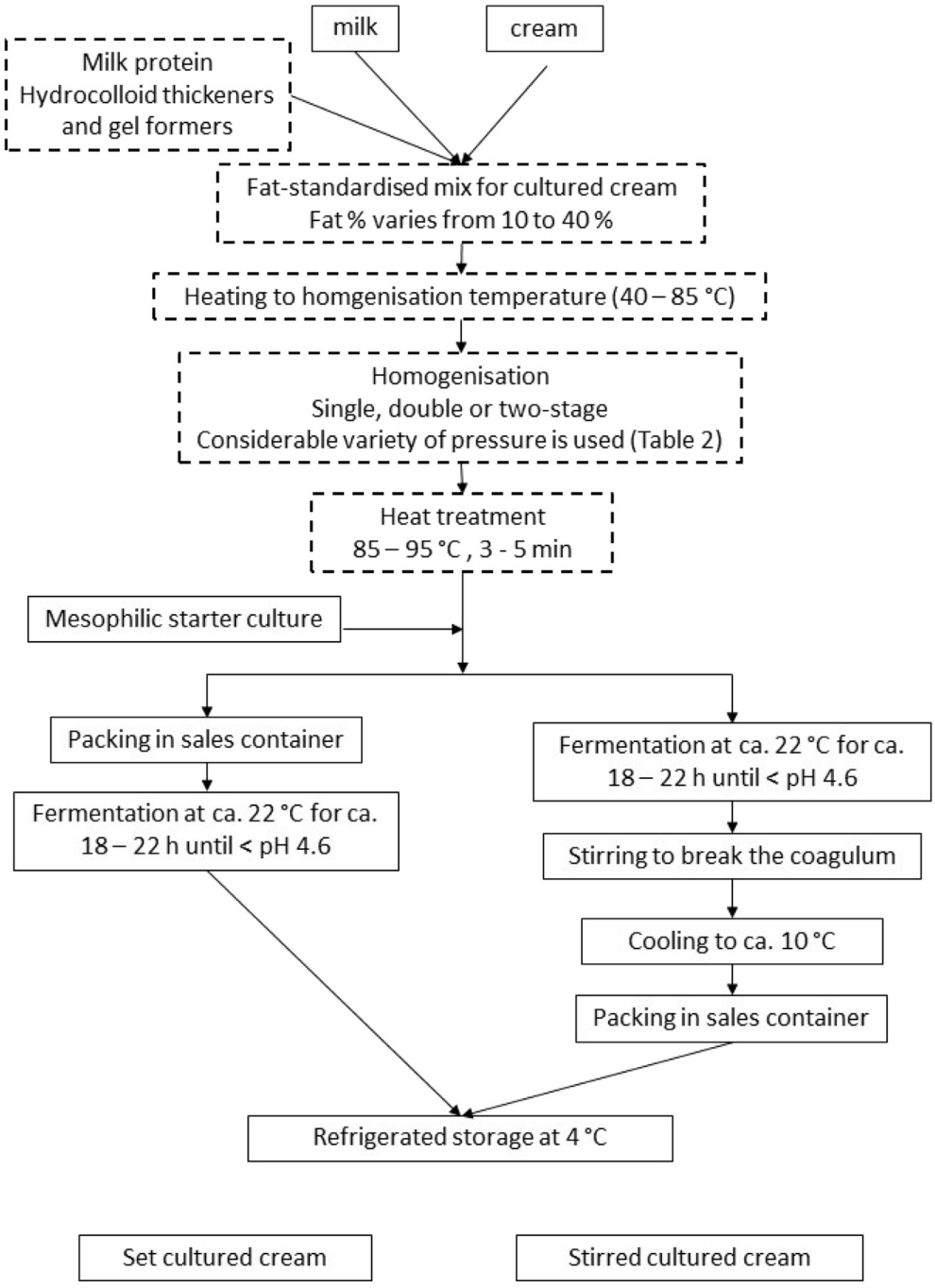

Fig. 1. Process flow chart for cultured cream. Dashed box frames indicate steps where considerable variations in the parameters are given in the literature. These variations are further discussed in sections 3, 3.2, 5.2 and 6.

Kulozik, 2016b; Zamora, Ferragut, Guamis, & Trujillo, 2012). According to Mather (2000), more than 40 different polypeptides have been identified in the MFGM, but the membrane proteins are calculated to make up only 1–3% of the total amount of milk proteins (Holzmüller et al., 2016a; Ricco, 2004).

The various proteins have different positions in the MFGM, as illustrated by Dewettinck et al. (2008). Some proteins are found in the interior of the membrane near the fat interface, some are peripheral, and yet others are considered to be loosely attached to the MFGM (Dewettinck et al., 2008). According to Dewettinck et al. (2008) and Holzmüller and Kulozik (2016) the major proteins in the MFGM are: mucin 1 (a glycoprotein), xanthine oxidase/-dehydrogenase, periodic acid Schiff 3 (PAS 3), cluster of differentiation (CD 36), butyrophilin, lactadherin (periodic acid Schiff 6/7), adipophilin and fatty acid binding protein (FABP). It seems, however, that appropriate information about the heat stability of the different proteins in the MFGM is lacking. Cream intended for the production of cultured cream is normally heat treated at rather high temperatures for a relatively long time, for instance 90–95 °C for 3–5 min (see Section 3.2), and this could probably lead to severe denaturation of proteins in the MFGM, as pointed out by Corredig and Dalgleish (1997). If, or possibly how, denatured or native

MFGM proteins influence the properties of the acid gels formed during the acidification of cultured cream seems, however, to be unknown.

The MFGM, like the casein micelles, is negatively charged, and milk is therefore a complex double-colloid system wherein both the micelles and fat globules repel each other (Mulder & Walstra, 1974). However, the unit operations of homogenisation and heat treatment commonly used in dairies have effects on both the protein and the fat phase in milk and cream and the nature of these effects depends, amongst other things, on the large variation in fat content found in different cream products.

The efficiency of homogenisation can be defined as the size reduction of fat globules as a result of the process. Kurzhals (1977) defined homogenisation efficiency as the proportion of fat present as globules under 0.7 μm. The operational parameters used for homogenisation of cream do not seem to be consistent in the available literature. These parameters need, however, to be varied according to both the fat content of the cream and the predicted use of the product.

In this review, the method of homogenisation is designated according to the following definitions:

- Single (also called one-stage in some publications), meaning that the milk or cream is passed once through a homogeniser with one valve;
- Double, when the milk or cream is homogenised once and then homogenised once more, either in the same or in a second homogeniser;
- Two-stage, meaning that the milk or cream is passed through a homogeniser with two homogenisation valves in the same equipment unit.

In two-stage homogenisation of milk, the pressure used for the first stage is much higher (approximately 200 bar) than for the second stage (30–50 bar) and this is often denoted as, for example, 200 + 50 bar (Walstra et al., 2006). Kessler (2002) underlined that two-stage homogenisation is beneficial to avoid unwanted agglomeration by the fat globules after the first stage as these will then be re-dispersed by the relatively low pressure in the second stage. The ratio of the first homogenisation pressure (p_1) and the back pressure (p_2), the so-called Thoma number, affects the efficiency of homogenisation, and shows an optimum at p_2/p_1 of around 0.2, irrespective of p_1, temperature and fat content (Kessler, 2002). Optimal Thoma numbers for cream with a fat content higher than 15% seem, however, not to be available. A good comparison of the effects of double homogenisation contra two-stage homogenisation is not documented, but in general double homogenisation at high pressure will lead to further reduction in the size of fat globules. In comparison, two-stage homogenisation will decrease the size of the fat globules only in the first stage, and then in the second stage disruption of possible clusters of fat globules that might have been formed immediately after the first homogenisation step occurs (Kessler, 2002; Mulder & Walstra, 1974). This disruption will result in a greater number of individual fat globules.

It is, however, usual to adapt the pressure depending on the fat content of the cream. Bylund (2015) suggests that 100–120 bar is suitable for cream containing 20–30% fat and that cream with a lower fat content such as 10–12% should be homogenised at 150–200 bar. Kessler (2002) made similar recommendations for two-stage homogenisation of 260 + 40 bar at 75 °C for cream of 15% fat and 100 + 15 bar at 70 °C for cream with 30% fat. Using a spectrophotometric method to observe turbidity following addition of EDTA to de-clump the fat in the cream, Goulden and Phipps (1964) showed that an increase in the fat content of the cream resulted in a larger mean fat globule diameter after homogenisation, indicating a less efficient homogenisation with increasing fat content of the cream. This indicated that the larger particle size following homogenisation is not purely due to clumping of fat globules. Eibel (1986) showed that the size of fat particles in cream with varying fat content reached a minimum at different pressures. For example, at 15% fat, the median diameter was under 1 μm at all pressures between 100 and 300 bar. At 25% fat, the diameter was at a minimum at 100–150 bar and at 36% fat at 50–80 bar. Above these pressures, the median diameter increased due to aggregation of the globules. In the same work, two-stage homogenisation resulted in smaller globules in comparison with single homogenisation.

A series of factors and parameters may be applied that can influence the effect of homogenisation. Homogenisers from different manufacturers may differ in the construction of the homogenisation valve, and the use of a range of homogenisation pressures and temperatures are reported. In addition, the milk or cream may be homogenised before or after heat treatment.

Homogenisation leads to an increase in the total surface area of fat globules by a factor of 5–10. However, the extent of the size reduction is mainly dependent on homogenisation pressure. During homogenisation, small fat globules are more resistant to disruption than large globules. Some very small fat globules can pass through the homogeniser and emerge with their original fat globule membrane intact (Michalski, Michel, & Geneste, 2002). The size of the globules that are not disrupted will depend mainly on the homogenisation pressure applied and hence an increase in homogenisation pressure leads to disruption of increasingly small fat globules. Thus, after homogenisation, the resulting fat globules are likely to have a membrane composition that ranges from purely original MFGM (the very smallest natural fat globules, which are not disrupted) to almost totally covered with casein (newly-formed globules originating from large fat globules).

With the disruption of the larger fat globules, there is a considerable shortage of MFGM to cover the new, smaller fat globules due to the increase in their total surface area. As a calculated example, a spherical fat globule with a diameter of 8 μm has a surface area of 201 μm^2. Following homogenisation, this globule can be split to 511 fat globules with a diameter of 1 μm, which will have a combined surface area of 1752 μm^2. A new fat–serum interface is created by the adsorption of surface-active protein from the milk serum. The new fat globules thus become covered with a new interfacial membrane, a “pseudomembrane” (also called a secondary MFGM), consisting of original membrane material supplemented with caseins and whey proteins (Huppertz & Kelly, 2006). Using ultracentrifugation, Fox, Holsinger, Caha, and Pallansch (1960) showed that the protein in what they called the fat - protein complex on the surface of the fat globules was casein and their experiments did not reveal the presence of whey proteins in the new fat globule membrane. Others have also found that caseins are the major group of proteins on the fat globule surface after homogenisation (Darling & Butcher, 1978; Henstra & Schmidt, 1970; Keenan, Moon, & Dylewski, 1983; Stevens, 1974). Tomas, Paquet, Courthaudon, and Lorient (1994) added increasing concentrations of anhydrous milk fat to skimmed milk and measured uptake of protein at the fat:protein interface and particle size following homogenisation of the mixes at an uncommonly high pressure (350 bar). They found that a proportion, approximately 15%, of the protein did not adsorb to the fat droplets even at a fat content of 9%. This unadsorbed protein could have been whey proteins. It has also been indicated that homogenisation could distort or open up the casein micelles by interfacial forces during extension of the fat interface and that the surface of the fat globule generally contains a preponderance of what Phipps (1983) describes as submicelles. Fox et al. (1960) postulated that the part of

the casein micelles binding to the fat is not necessarily the surface of the micelles.

No definitive information seems to be available concerning the ratio of casein to whey proteins at the new membrane surface after homogenisation. Walstra et al. (2006) stated that casein comprises about 93% of the proteins in the new fat globule surface layer compared with approximately 80% of the protein in milk plasma, but no specific reference is given for this information. Cano-Ruiz and Richter (1997) found that in homogenised milk containing native whey proteins, caseins were adsorbed preferentially to whey proteins at the surface of the fat globules. When cream was examined after homogenisation, but before pasteurisation, Darling and Butcher (1978) found that the strength of casein binding to the interface between fat globule and serum was greater than that of the whey proteins. They showed that whey proteins were present in the fat globule membrane after homogenisation but concluded that caseins were nevertheless the main proteins in the new membrane. However, after heat treatment (85 °C for 10 min) they found an increased absorption of denatured whey proteins to the membrane. Similar results were obtained by Cano-Ruiz and Richter (1997). Zamora et al. (2012) achieved, however, a greater adsorption of whey proteins to the fat globule surface after a combination of homogenisation (150 + 30 bar at 60 °C) and pasteurisation at 72 °C for 15 s than if homogenisation was omitted. This indicated that a considerable denaturation of whey protein was not necessary for their adsorption to the fat globule surface. The reasons for these findings are probably binding of whey proteins to casein as a result of heat treatment or, as postulated by Zamora et al. (2012), that the damage of the MFGM by homogenisation leaves areas on the MFGM that need to be covered and that a greater direct association of whey proteins with the MFGM occurs. The ratio of casein to whey proteins on the surface of the fat globules in homogenised cream will, however, depend on whether the cream is heat treated before or after homogenisation as also underlined by Ye, Anema, and Singh (2008), although homogenisation before pasteurisation is the preferred practical processing method in milk or cream processing. However, whether the whey proteins adsorb directly to the fat:serum interface or to the casein on the interface does not seem to have been studied in depth.

According to Lopez (2005), only 10–25% of the fat globule surface in homogenised milk is coated by the original MFGM. Homogenisation damages the membrane and some of the components of the original membrane are released into the serum phase. Evidence suggests that, from the moment when the fat globules are disrupted, an immediate readsorption of polar components takes place at the fat:serum interface, probably within the homogeniser itself (Mulder & Walstra, 1974). Darling and Butcher (1978) found that the original MFGM components were not re-adsorbed to the interface to the same extent as in the original state and that some membrane components would therefore remain in the serum phase after homogenisation. Keenan et al. (1983) found, however, that a considerable amount of the original membrane material remains on, or is re-adsorbed to, the fat globule surface during or immediately after homogenisation.

When cream is homogenised at a given pressure, the resulting average diameter of the fat globules is in relation to the fat content and after homogenisation at about 200 bar, the average diameter is approximately 0.5 μm, 0.65 μm and 1.0 μm for milk/cream of 4, 19.5 and 37% fat, respectively (Mulder & Walstra, 1974). An increase in fat content in cream gives a simultaneous decrease in protein content and according to Mulder and Walstra (1974) and Walstra (1984), 0.2 g casein per gram of fat is necessary to provide sufficient effect of homogenisation. As shown in Table 1, cream containing 20% fat only contains approximately 2.7% protein but 4% adsorbable protein would theoretically be necessary to achieve a satisfactory result of homogenisation. This shortfall of protein needed to cover the newly formed small fat globules not only results in their coalescence or aggregation but also to more or less an absence of free protein in the serum phase. This situation is partially alleviated by the somewhat larger fat globules obtained from homogenising cream with this level of fat. If, in addition, the homogenisation pressure is reduced (as is often practised when homogenising cream) considerably less protein is required to cover the newly formed fat globules. However, an accurate assessment of the effect of these two aspects in practical production of cream products does not seem to be available in the literature.

Experiments on the homogenisation of cream with different fat contents have revealed that the size range of the globules after homogenisation would be dependent on the concentration of the surface-active proteins available in the cream (Phipps, 1983). Phipps (1983) also concluded from his experiments on cream with 32% fat and homogenised at approximately 220 bar, that all the available surface-active material was utilised for the stabilisation of the fat globules. His experiments showed that the size of homogenised fat globules decreased only to a certain point beyond which no further reduction occurred due to the shortage of protein for stabilisation of the new fat globules.

Access to sufficient casein micelles or smaller casein particles may thus be considered a prerequisite to obtain a sufficient stabilisation of the greatly increased numbers of fat globules in the homogenised cream. Information concerning the deficiency of casein in homogenised cream seems to be somewhat scarce in the literature. However, Kessler (2002) described that clusters of fat globules would be formed following the homogenisation of cream with a fat content more than 20% and Walstra et al. (2006) claimed that clustering and possible coalescence of fat globules will not occur if the fat content is less than 9%, but that clustering will always take place in cream with more than 18% fat. This is explainable by a lack of available casein to form the new fat globule membranes at this level of fat content (Kessler, 2002).

According to Kilara (2006), approximately 10 mg casein absorbs on each m^2 of the surface of the newly formed fat globules after homogenisation. Depending on the homogenisation conditions, in cream with over 15% fat a lack of casein will occur and fat globules may aggregate immediately after the cream leaves the homogeniser. Such clusters may be formed because of hydrophobic interaction and because of the sharing of the available casein among the globules results in formation of clusters. With treatment of cream

Table 1
Gross composition of full-fat milk and cream of different fat content, and the amount of adsorbable protein calculated to be necessary to achieve satisfactory homogenisation (at 200 bar) of heat-treated milk/cream.[a]

Product	Fat (%)	Protein (%)	Lactose (%)	Protein (%) needed to cover the fat globule	Protein (%) available for gel formation
Full fat cream (whipping cream)	38	2.1	2.9	7.6	−5.6
Cream (pouring cream)	20	2.7	3.9	4	−1.3
Reduced fat cream	10	3.0	4.3	2	1
Full fat milk	3.5	3.4	4.5	0.7	2.3

[a] Data for protein needed to cover the fat globule adapted from Mulder and Walstra (1974) and Walstra (1984); negative values for protein available for gel formation indicate theoretical lack of protein at these fat values.

at temperatures normally recommended (above 40 °C), the leakage of free fat from the fat globules is unlikely (Kessler & Fink, 1992). However, in cases of more extreme lack of membrane-forming material in relation to the fat content of the cream, oiling out of the fat may occur (Kessler, 2002). Whatever, information of how the presence of free fat may influence the quality of the final cultured cream seems not to be available in published literature. Compared with the situation in milk, the higher concentration of fat in cream reduces the time needed for droplets to come into contact, which again increases the possibility of re-aggregation of the newly formed fat globules (Mulder & Walstra, 1974; Walstra, 1984; Wilbey, 2003). Kessler (2002) summed up important aspects of cream homogenisation and stated that, for a stable emulsion, the fat globules should not be too small, the homogenisation temperature should be relatively high and there is a need for the addition of additional membrane–forming material.

3. Aspects of homogenisation temperature and pressure for cream used for cultured cream

Various homogenisation methods, temperatures and pressures have been recommended by different authors for cream destined for cultured cream (Table 2). Recommendations for pressures for the homogenisation of cream for cultured cream products vary between 100 and 205 bar, and with temperatures from 40 to 85 °C.

According to several sources, single homogenisation would be sufficient or, indeed recommended, for the production of cultured cream with a firm consistency (Bodyfelt, Tobias, & Trout, 1988; Bylund, 2015; Doan & Dahle, 1928; Kosikowski, 1977; Lucey, 2004; Mulder & Walstra, 1974). Lyck et al. (2006) gave the following guidelines for adjustment of the homogenisation pressure according to the fat content in the cream: 150–200 bar for 10% fat in the cream, 120–170 bar for 18% cream and 30–50 bar for 38% cream. A reduction of homogenisation pressure will result in lesser size reduction of the larger fat globules and it is therefore usual to homogenise full fat cream at a much lower pressure, for example 50 bar, to compensate for the shortfall of protein, reduce excessive coalescence and aggregation and to form a sufficiently stable emulsion (Lyck et al., 2006).

As shown in Table 2, single homogenisation has been recommended by several authors for cultured cream with 18–20% fat, but with widely differing temperatures and pressures (Bylund, 2015; Doan & Dahle, 1928; Kosikowski, 1977; Lucey, 2004; Lyck et al., 2006; Mulder & Walstra, 1974). Single homogenisation encourages the clustering of fat globules and this causes increased viscosity in both the cream and the cultured cream (Lucey, 2004; Mulder & Walstra, 1974). In cultured cream production, single homogenisation will give greater body to the product, according to Meunier-Goddik (2012). Although such clusters increase the speed of creaming and thereby would be detrimental for sweet cream, they are considered beneficial for the quality of cultured cream, where creaming is less of a problem due to the comparatively short time before the acid gel is formed (Mulder & Walstra, 1974). These aggregates are mainly covered with proteins and, according to Hoffmann (2003), become incorporated in the acid gel formed during the fermentation of the cream. In the dairy industry in general, the homogeniser often has a double head (i.e., two-stage) because of the desire to avoid fat globule clusters. In the light of the information given above, it can be suggested that it would not be advisable to use 2-stage homogenisation for cream destined for cultured cream that has a fat content of over 10–15%, as the fat globule clusters give increased body to the fermented product.

Table 2
Recommendations for the homogenisation of cream for the production of cultured cream containing 18–20% fat.[a]

Reference	Homogenisation		
	Method	Temperature (°C)	Pressure (bar)
Doan and Dahle (1928)	Single	82	>137
Mulder and Walstra (1974)	Single	NG	150–200
Kosikowski (1977)	Single	71	205
Bodyfelt et al. (1988)	Single	40–85	137–205
Lucey (2004)	Single	NG	170–200
Lyck et al. (2006)	Single	60–70	120–170
Bylund (2015)	Single	60–70	100–120
Guthrie (1952)	Double	74	172 + 172
Guthrie (1963)	Double	74	172 + 172
Emmons and Tuckey (1967)	Double	73 + 43	172 + 172
Kosikowski (1977)	Double	71 + 71	172 + 172
Born (2006)	Double	NG	172 + 172
Chandan (2008)	Double	72 + 72	172 + 172

[a] NG, not given.

However, double homogenisation with the use of the same pressure, for instance 172 bar both times, has also been recommended to obtain a firmer cultured cream (Born, 2006; Chandan, 2008; Emmons & Tuckey, 1967; Guthrie, 1952, 1963; Kosikowski, 1977; Lucey, 2004). It would appear that the recommendations by Guthrie (1952; 1963) have been adopted by subsequent researchers, although slightly different temperatures are reported. Emmons and Tuckey (1967) recommended homogenisation conditions for cream with both 18.6% and 10.5–12% fat of 172 bar at 74 °C followed by a second homogenisation at the same pressure but at 43 °C. Other authors recommend double homogenisation, stating that this leads to improved smoothness and in fact increases viscosity (Chandan, 2008; Kosikowski, 1977). Since clusters of fat globules covered with milk-proteins are considered to be beneficial for increasing the viscosity of the cultured cream, double homogenisation should be avoided in the preparation of cream for production of cultured cream products with a fat content of over 18–20%, according to Born (2006). However, with cream containing fat around 10%, the greater ratio of protein:fat would make double homogenisation beneficial. Kessler (2002) showed an increase in gel strength in yoghurt with 10% fat when the mix was homogenised two times at 200 bar, compared with once. In this mix, which contained increased protein (to 4%), a further increase in gel strength was achieved by a third passage at 200 bar. Increasing the pressure of single homogenisation resulted in increasing gel strength even up to 300 bar. A second homogenisation is considered beneficial for the consistency of the fermented cream provided that the fat content is rather low, the protein content is increased and the homogenisation effect leads to the formation of small fat globules which become more easily incorporated in the acid gel network during fermentation.

In the work on cream cheese by Brighenti, Govindasamy-Lucey, Jaeggi, Johnson, and Lucey (2018), a cheese milk mix containing 12% fat was prepared from cream (35% fat) and skim milk, and then subjected to a range of homogenisation pressures and fermentation temperatures. The gel strength of the fermented 12% fat mix was greater following 2-stage homogenisation at 250 + 50 bar, compared with at 100 + 50 bar, but single homogenisation was not applied as a comparison. Experiments on cultured cream (18% fat) in our laboratory showed (Table 3), however, significantly greater viscosity and gel strength of cultured cream (18% fat) produced from cream homogenised once at 175 bar, compared with cultured cream obtained from double homogenisation in a single head homogeniser (Rannie, SPX flow) using first 175 bar and quickly followed by homogenisation at 35 bar. The homogenisation temperature was 65 °C at both steps. In addition, a significantly higher viscosity and gel strength ($p < 0.0001$ and < 0.002, respectively) was obtained in cultured cream by lowering the homogenisation pressures (double homogenisation) in the two steps from

Table 3
Viscosity and gel strength in cultured cream (18% fat) from cream homogenised at 175 bar or 175 and 35 bar.[a]

Conditions	Viscosity (Pa s) **	Gel strength (g) ***
Single homogenisation at 175 bar	2.04 (0.47)	48.15 (0.02)
Double homogenisation at 175 and 35 bar	1.04 (0.16)	30.5 (1.73)

Values are the mean with standard deviation in parentheses. ***$p < 0.0001$; **$p < 0.01$.
[a] Homogenisation temperature: 65 °C. The results are the average of two production blocks with two production replicates in each block, four measurements on each sample.

175 + 35 bar to 120 + 30 bar (Fig. 2). The difference in our results compared with those of Brighenti et al. (2018) can be explained by the ratio between levels of fat and the available protein in the two mixes, which contained 12 and 18% fat, respectively. At 10–12% fat, there is sufficient protein to coat the fat globules following homogenisation as well as form an acid protein gel whereas at 18% fat the shortage of protein prevents this increase in gel strength by raising homogenisation pressure.

Using confocal fluorescence microscopy, visualisation of the structure of unstirred cultured cream produced in our laboratories showed a much more particulate cultured cream and a clearly visible serum phase (black) following single homogenisation (175 bar) of the cream, which may be explained by aggregation of fat globules after homogenisation (Fig. 3a). Double homogenisation at 175 + 35 bar (Fig. 3b) gave a much more uniform and dense structure of the gel, suggesting that the second homogenisation stage has disrupted these aggregates.

At refrigerated storage temperatures, the milk fat is largely crystallised and the homogenisation temperature should exceed that of the melting point of the milk fat, which is about 40 °C (Mulder & Walstra, 1974; Walstra et al., 2006). Goulden and Phipps (1964) underlined in their experiments that it was necessary to ensure complete melting of the fat to obtain reproducible results when homogenising cream of various fat content. At temperatures lower than 40 °C, where some of the fat may be crystallised, the homogenisation effect is much reduced (Kilara, 2006) and also the formation of fat globule clusters is promoted by homogenisation at a temperature around 40 °C (Walstra et al., 2006).

Homogenisation at a higher temperature increases the viscosity and smoothness of cultured cream according to Sommer (1952). The homogenisation temperature of cream for cultured cream products may thus be recommended to be between 40 and 85 °C (Table 2). Increasing the homogenisation temperature above 75 °C may, to some degree, have a positive effect on the consistency of the cultured cream. This may be due to a further reduction in the viscosity of the fat fraction of the cream and therefore increased turbulence within the homogenisation valve, hence leading to an increased effect of the homogenisation (Walstra et al., 2006) and also due to whey protein denaturation. Eibel (1986) showed, however, a marked increase in viscosity of cream with 30% fat following homogenisation over 70 °C and concluded that the most efficient homogenisation was obtained at 70 °C. The viscosity of homogenised cream is highly dependent on both the fat content and temperature of homogenisation. Phipps (1969) presented very useful nomograms computing viscosities and densities of cream based on the fat content and the homogenisation temperature of the cream. He assumed that the behaviour of cream in a homogenisation valve was Newtonian and that any fat clustering or reduction in the size of fat globules brought about by homogenisation had negligible influence upon the viscosity of the homogenised cream at a temperature above 40 °C. Eibel (1986) showed that cream with 30% fat did not, however, show Newtonian viscosity and furthermore showed that two-stage homogenisation gave cream with a radically reduced viscosity. Walstra et al. (2006) indicated that the surface load of protein on the fat globules increases when the homogenisation temperature is, for instance, 70 °C rather than 40 °C because the casein micelles may spread more rapidly over the fat globule surface at higher temperatures. It is, however, not clear from the literature whether this faster adsorption of casein micelles to the

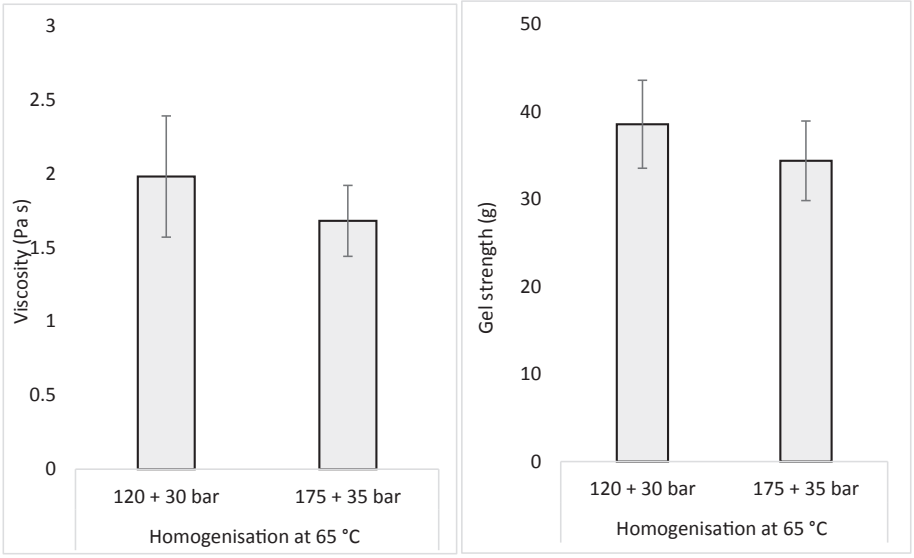

Fig. 2. The effect of the pressure used for double homogenisation of cream (18% fat) on the viscosity and gel strength of cultured cream (three independent productions; compiled from data in our laboratory). Following homogenisation, cream was heat-treated at 95 °C for 5 min and fermented with a mesophilic DL starter culture at 22 °C until pH 4.5. Samples were cooled to 4 °C and measurements made after 2 days. For each homogenisation pressure, the data are obtained from 8 samples, and measurements were made 4 times on each sample. Standard deviations are shown by bars.

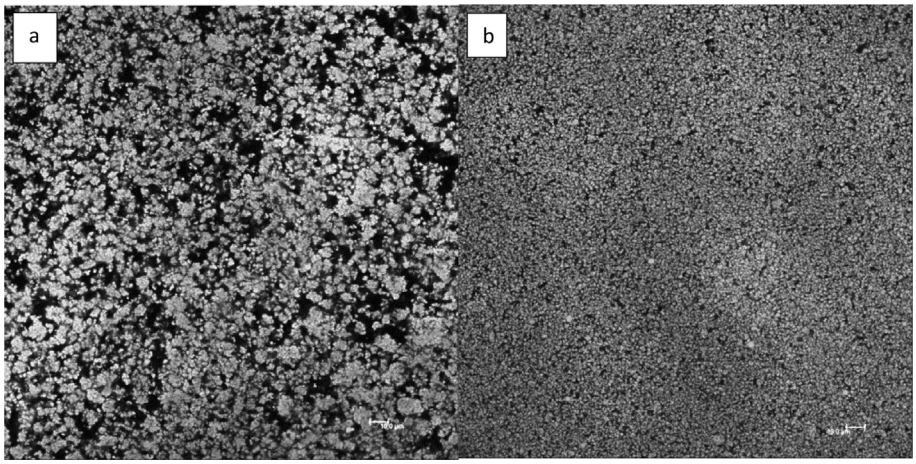

Fig. 3. The structure of fermented cream (18% fat) as shown by confocal fluorescence microscopy (Leica TCS SP5 confocal microscope; Leica Microsystems CMS GmbH, Mannheim, Germany). The cream was given (a) single homogenisation at 175 bar and (b) double homogenisation at 175 and at 35 bar. Both samples were homogenised at a temperature of 65 °C, then heat-treated at 95 °C for 5 min. Samples were acidified using the same DL starter culture until pH 4.5, cooled, and visualised after 5 days of storage at 4 °C. The measure bar indicates 10 μm (unpublished results obtained in our laboratory).

surface of the fat globules increases their stability and improves the consistency of the acid gel formed in cultured cream.

As shown in Table 2, various recommendations for homogenisation temperature are presented in the literature and are normally above 60 °C. The oldest published information has been found in the work of Doan and Dahle (1928). They compared the effect of homogenisation at 82 °C and 32 °C at 137 bar and 241 bar, and concluded that the highest viscosity of cultured cream (18% fat) was obtained with homogenisation at 82 °C at 241 bar. Emmons and Tuckey (1967) recommended homogenisation of the cream at 74 °C following a holding time of 30 min at that temperature. They underlined, however, a certain variation in the procedures adopted in the dairy industry, for instance double homogenisation of the cream at 172 bar at 82–85 °C. Temperatures of 40–85 °C for homogenisation were recommended by Bodyfelt et al. (1988). Kosikowski (1977) recommended 71 °C, while Bylund (2015) and Lyck et al. (2006) prescribe a homogenisation temperature of 60–70 °C. By investigating the effect of homogenisation temperature of cream with 12, 19 and 30% fat, Goulden and Phipps (1964) concluded that the homogenisation effect, the reduction in fat globule size, was increased with increasing temperature in the range of 50–75 °C, with an increased effect of an elevated temperature at higher fat content.

The effect of a moderate increase in homogenisation temperature on rheological properties of cultured cream (18% fat) was confirmed in experiments in our laboratories. A significant increase in viscosity ($p < 0.0001$) and gel strength ($p < 0.0001$) was achieved by increasing the homogenisation temperature of the cream from 55 to 65 °C (Fig. 4). After double homogenisation (175 and 35 or 120 and 30 bar), the cream was heat-treated at 95 °C for 5 min and fermented at 22 °C until pH 4.5. Rheological measurements were made after cooling to 4 °C and storage for 2 d.

One of the main reasons for homogenising the cream for production of cultured cream is to establish an appropriate consistency and viscosity of the product without any wheying off. International standards for quality are, however, not available for this group of products. The viscosity of the product is nevertheless regarded as an important property (Aryana & Olson, 2017). Hoffmann (2003) underlined that cultured cream should be creamy and viscous and have no surface cream layer. Lucey (2004) expressed that cultured cream should be thick and smooth and the study by Shepard, Miracle, Leksrisompong, and Drake (2013) concluded that a "moderate degree" of firmness would be regarded as desirable to most consumers.

3.1. Homogenisation before or after heat treatment

Homogenisation is usually applied prior to heat treatment to reduce the risk of bacterial contamination from the homogeniser, but the cream may also be homogenised aseptically after heat treatment (Lyck et al., 2006; Walstra et al., 2006) or homogenised at such a high temperature that bacterial growth is inhibited. Some sources claim that homogenisation after heat treatment can improve the texture of cultured milk products, but there is little solid scientific evidence to support this (Lyck et al., 2006). The complex synergy between the effect of temperature on the denaturation of whey proteins combined with the increased homogenisation efficiency due to increasing temperature has not, apparently, been methodically studied. Homogenisation lower than 70 °C does not give an observable denaturation of whey proteins and the new fat globules formed will therefore be mostly covered with casein particles of various sizes. However, if homogenisation takes place following high heat treatment, then at that point the whey proteins will be largely attached to the casein micelles. Whether or not the homogenisation effect is improved by the denaturation of whey proteins does not seem to have been investigated. In addition, the influence of these differences in sequence on quality parameters of cultured cream has not been published and exact details of commercial processes in use are normally confidential.

3.2. Heat treatment of cream for production of cultured cream

During heat treatment of milk or cream, pathogenic microorganisms are inactivated making heat treatment a critical step in the processing line of cultured milk products (Clark & Plotka, 2004; Walstra et al., 2006). Heat treatment at 63 °C for 30 min or 72 °C for 15 s is sufficient to inactivate pathogenic microorganisms in milk (Walstra et al., 2006), but for the production of cultured milk products, the milk or cream are subjected to a considerably stronger heat treatment compared with the regulatory minimum for milk pasteurisation, and this is usually 90–95 °C for 3–5 min (Bylund, 2015; Clark & Plotka, 2004; Lyck et al., 2006; Walstra et al., 2006). Whilst reducing the microbiological load in the milk or

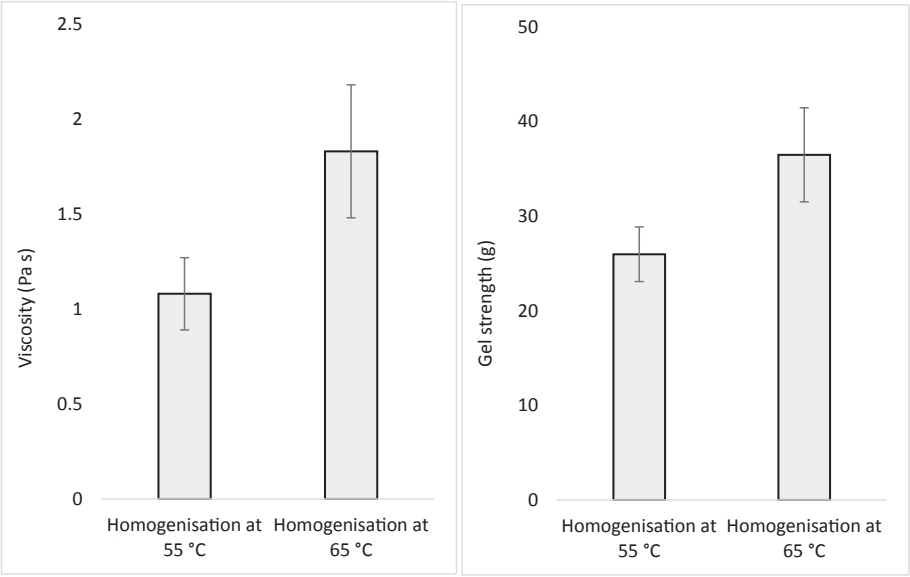

Fig. 4. The effect of homogenisation temperature on the viscosity and gel strength of cultured cream (18% fat, three independent productions, compiled from data in our laboratory). For each homogenisation temperature, the data were obtained from 8 samples, and measurements were made four times on each sample. The data in the figure include measurements from samples that were double homogenised at 175 and at 35 and 120 and at 30 bar. Heat treatment of cream at 95 °C for 5 min, fermentation with a mesophilic DL starter culture at 22 °C until pH 4.5. Samples were cooled to 4° and measurements made after 2 days. Bars show standard deviation.

cream even further, this stronger heat treatment may stimulate spore germination. However, this should not be a problem provided the treated milk or cream is promptly fermented, or is kept at 4 °C until fermentation. The activity of the starter culture may be stimulated by a release of some amino acids from the whey proteins, the loss of some dissolved oxygen, a more reducing medium due to free –SH groups as well as the reduction in potentially competing bacteria of the indigenous microflora of the milk (Lyck et al., 2006; Tamime, Skriver, & Nilsson, 2006). As a result of the high heat treatment, whey proteins are denatured, leading to the exposure of a free thiol group on β-lactoglobulin that can bind to κ-casein on the surface of the casein micelles via sulphur bridges (Walstra et al., 2006). The whey proteins thus become part of the aggregating protein during acid coagulation. A firmer gel and increased viscosity results from the increased amount of gel-forming protein. In addition, the denatured whey proteins bind an increased amount of water, thus reducing syneresis (Walstra et al., 2006). If a milder heat treatment is used, denaturation of β-lactoglobulin is insufficient and a weaker gel is obtained (Lucey, 2004). Denaturation is negligible at 65 °C, but after 5–10 min at 90–95 °C more than 80% of the β-lactoglobulin is denatured (Robinson, Lucey, & Tamime, 2006).

The pH at which milk or cream coagulates depends partially on the severity of the heat treatment used. Heat treatment that is sufficiently high to cause denaturation of whey proteins can raise the pH of gelation from 5.0 to 5.3 due to the association of β-lactoglobulin with κ-casein, which gives the casein:whey protein aggregates a higher isoelectric point. Gelation time is also decreased in sufficiently high heat-treated milk (Lucey, 2004).

4. Acid gel formation in the fermentation of milk and cream

Commercial production of fermented milk products normally includes homogenisation and a heat treatment of the milk sufficient to denature whey proteins. During the subsequent acidification of homogenised milk, the milk proteins aggregate to form a particulate acid gel in which the whey proteins are also incorporated. The fat globules in the homogenised milk or cream are largely covered by milk proteins and are therefore able to partake in the gel network as “pseudoprotein”. In fermented milk, the protein gel network is therefore composed of aggregations and threads of casein/whey protein micelles and the fat globules are incorporated in the gel due to the interaction of the caseins on the fat globules with the rest of the casein. However, it is reasonable to claim that the situation changes when cream is fermented, as there is a probable dearth of protein in the serum phase in cream above approximately 20% fat (Table 1). Brighenti et al. (2018) showed that homogenisation of cream standardised to 12% fat (to be used for the production of cream cheese) resulted in a marked decrease of protein in the serum phase. Before homogenisation, the cream had a serum phase protein content of 2.84%, and this was reduced to 1.28 and 0.4% following homogenisation at 100 + 50 and 250 + 50 bar, respectively. However, systematic matrix experiments do not seem to have been done to show how much free protein is available following homogenisation at varying fat content and homogenisation temperature and pressures.

Many publications describe how the acid protein gel is formed in milk but, to our knowledge, there are few descriptions of the structure of the acid gel when the fat concentration is considerably higher. However, it would appear logical that the fat content, as well as the degree of heat treatment and homogenisation, affects the formation of and the structure of the acid gel. New research on this subject is necessary to develop a solid explanation of how the acid gel is formed in cultured cream with fat content higher than approximately 18%.

As lactic acid is gradually produced by LAB during fermentation of milk and the pH falls below the isoelectric point of casein, a gel is formed. The homogenisation of milk with increasing fat content results in quite different starting points for the fermentation. An increase in fat content requires more protein to cover the surface of the increasing numbers of new, small fat globules following homogenisation, and a homogenised cream will increasingly consist of negatively charged pseudoprotein particles and less free protein. This charge will be neutralised during the fermentation and the casein-covered fat globules form a network along with any available free protein. Fig. 5 illustrates various scenarios we propose for

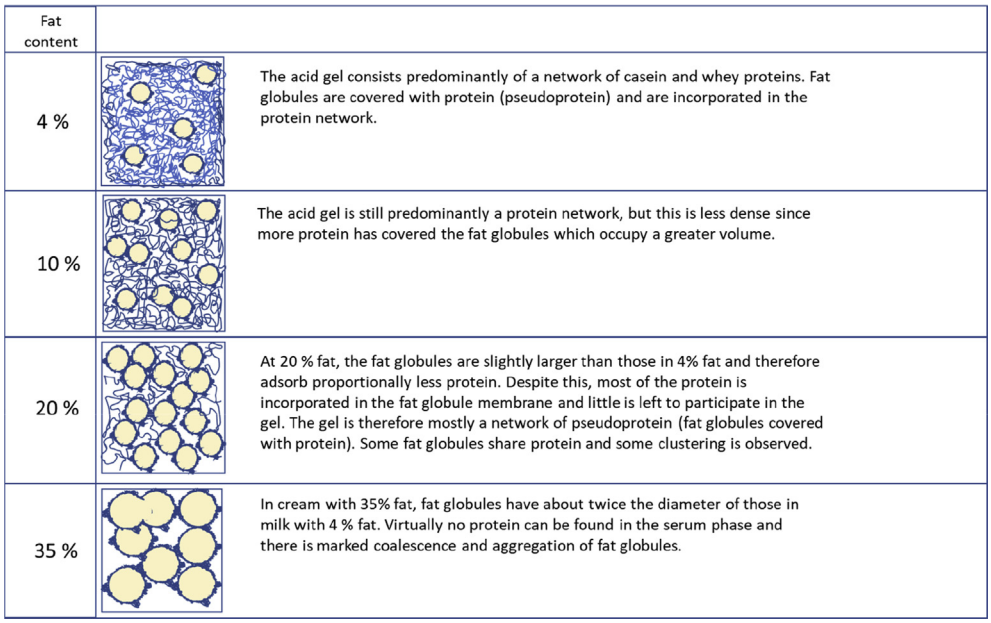

Fig. 5. Schematic presentation of proposed gel structure in cultured milk and cream, homogenised and with varying fat content, at approximately pH 4.5: , fat; , protein.

the structure of acid gels in milk and cream of various fat content. Fermentation of creams with increasing fat content results in gels that decreasingly consist of coagulated free protein. In cultured cream with 35% fat, the network probably consists almost only of agglomerated protein-covered fat globules and clusters, as well as coalesced fat.

5. Microbiological aspects of the fermentation of cream to cultured cream

Cultured cream should have a mildly sour, buttery flavour achieved by using a mesophilic, mixed strain starter culture (DL-culture) of LAB for the fermentation. Such cultures contain multiple strains of *Lactococcus lactis* subsp. *cremoris*, *L. lactis* subsp. *lactis*, *L. lactis* subsp. *lactis* biovar. *diacetylactis* (citrate-positive *L. lactis* subsp. *lactis*), as well as different species and strains of *Leuconostoc* (Tamime et al., 2006). Many of the DL-cultures commercially available originate from traditional dairy or farmstead cultures and their exact composition is often unknown. The majority of bacteria cells in such cultures are of *L. lactis* subsp. *cremoris* and these, and the other lactococci, are responsible for most of the lactic acid production. *L. lactis* subsp. *lactis,* biovar. *diacetylactis*, and *Leuconostoc* are important for their additional ability to metabolise the innate citrate in the milk to flavour compounds during fermentation. The content of citrate in milk is approximately 1800 ppm and proportionally less in cream according to the fat content. The main metabolites formed are diacetyl, acetoin, 2,3 butanediol, acetic acid and carbon dioxide, of which diacetyl is regarded as the most important as it gives the expected buttery taste to the fermented product (Tamime et al., 2006). Citrate is first cleaved to acetic acid and oxaloacetic acid and the latter is then decarboxylated to pyruvate. This pyruvate is superfluous to that required to regenerate NAD that has been reduced during glycolysis and is then condensed with acetaldehyde-thiamine pyrophosphate to form α-acetolactate, an unstable compound. α-acetolactate decomposes spontaneously to diacetyl, by chemical oxidative decarboxylation, or is decarboxylated to acetoin both chemically and enzymatically. Both diacetyl and acetoin may be reduced enzymatically to acetoin and 2,3-butandiol, respectively, and these compounds have no taste or aroma.

Various strategies have been developed to enhance the production of diacetyl (Cogan et al., 2007). However, the amount of diacetyl formed is directed by the availability of oxygen or a high redox potential (Basset, Boquien, Picque, & Corrieu, 1993). It has an extremely low taste threshold and only small amounts are necessary – or, indeed, desirable – in the product. Levels of diacetyl in fermented milk and cream are approximately 1–2 ppm and are seldom over 10 ppm (Pack, Vedamuthu, Sandine, Elliker, & Leesment, 1968). Some reduction of diacetyl to acetoin may occur with concomitant loss of taste and aroma. Although much research has attempted to increase the production of diacetyl in fermented milk products, preventing its reduction to tasteless acetoin is probably more important. Rapid cooling at the end of fermentation would appear to be the most effective method for this (Tamime et al., 2006). An extended incubation time may lead to the reduction of the major volatile aroma compound, diacetyl, to acetoin and 2,3 butandiol, with a concomitant reduction in flavour and aroma (Vedamuthu, 1994).

The astringent taste of acetaldehyde, which is the main aroma compound in yoghurt, is undesirable in cultured cream. Strains of *Leuconostoc* reduce the small, but sensorially detectable, amounts of acetaldehyde that are produced from pyruvate by the lactococci, to ethanol (Liu, Asmundsen, Holland, & Crow, 1997). Strains of *Leuconostoc* are therefore important members of the DL-culture used for the fermentation of cream. Fermentation of milk or cream using this type of culture is usually at approximately 22 °C for approximately 22 h, which maintains the balance of strains in the culture. Although fermentation proceeds faster at a slightly higher temperature (for example approximately 15 h at 30 °C), the *Leuconostoc* strains are less active at this temperature and this can therefore lead to an unwanted build-up of acetaldehyde in the product.

Most starter culture producers offer a selection of this type of culture and their properties may differ due to the balance of the strains in the different cultures as well as particular attributes of some of the individual strains. DL-cultures may be obtained as freeze-dried or as frozen pellets and the preparation of the starter cultures for cream fermentation may involve the pre-fermentation of a bulk starter or may be minimal as in the case of the direct vat set frozen cultures.

5.1. Use of exopolysaccharide-producing strains of LAB in cultured cream production

Some strains of *L. lactis* subsp. *cremoris* secrete extracellular polysaccharides (EPS). EPS production by various lactic acid bacteria has been extensively studied due to the potential use of these substances as natural thickening and gel-forming substances. The properties of EPS include increased product smoothness, higher viscosity and less whey separation, thus making these strains useful in fermented milk products (Dubok & Mollet, 2001). There seems to be general agreement that EPS produced by lactococci are heteropolysaccharides as they comprise several different carbohydrate moieties including galactose, glucose and rhamnose (Marshall, Cowie, & Moreton, 1995). A strain studied by Marshall et al. (1995) produced more than one type of heteropolysaccharide: a large, neutral EPS and a smaller, acidic EPS, which was produced in lower amounts. Knoshaug, Ahlgren, and Trempy (2000) also reported the production of a ropy and a mucoid EPS by different strains of *L. lactis* subsp. *cremoris* and suggested the ropy type of EPS is of particular interest regarding fermented milk products. Analysis of the structure of EPS produced by different strains shows a diversity of monosaccharide units, repeating units, molecular stiffness, branching, charge and size of molecules (Marshall et al., 1995; Ruas-Madiedo & de los Reyes-Gavilán, 2005; Tuinier et al., 2001). Ruas-Madiedo, Hugenholtz, and Zoon (2002) studied four EPS-producing strains of *L. lactis* subsp. *cremoris* and showed that growth temperature affected the amount of EPS formed in a strain-dependent manner. They also showed that differences in viscosity were due to different EPS structures and were particularly related to the stiffness of the molecule.

The diversity of EPS is reflected in the physical properties of the polymers when produced in milk during fermentation. Because of the diversity of the EPS molecules, their association to and reaction with milk proteins varies. The EPS may be neutral and therefore not associate with protein. Such EPS may either have a simple effect of thickening the water phase in the product or it may form a gel. Conversely, if the EPS is charged, it may associate with the milk protein and thence become part of the acid protein gel during fermentation. Gentés, St-Gelais, and Turgeon (2011) studied the fermentation of milk using several strains of thermophilic lactic acid bacteria that produced EPS with known, but different, structures. They found that the gel formation and development of rheological characteristics was influenced more by the structure of the EPS than the amount produced. Viscosity, gel strength and whey retention was enhanced by EPS with high molecular weight, a stiff molecule and little branching. Conversely, low-molecular weight EPS with a smaller, flexible and branching molecule gave lower values for these parameters. They also found that a negatively-charged EPS modified the gel formation process and also increased the elasticity of the casein gel (Gentès, St-Gelais, & Turgeon, 2011). Systematic studies showing the synergism between the structure of EPS produced by different strains of lactococci and the resulting quality characteristics of the fermented product are fragmentary.

Starter cultures containing EPS-producing strains are often referred to as “texturising”. EPS is able to bind large amounts of water and therefore changes the rheological properties of the fermented product. This is very obvious in low fat milk products such as the Scandinavian ropy milks (Narvhus, 2014), but a detailed description of the effect of using EPS-producing cultures for cultured cream seems to be lacking. Nevertheless, EPS-producing cultures are sometimes recommended for cultured cream, with the aim of improving smoothness and consistency as well as reducing whey separation (Dubok & Mollet, 2001; Lucey, 2004).

The effect of an EPS-producing culture on the rheology of cultured cream is dependent on the structure of the EPS it produces, the amount produced and also the time of production in relation to the progression of the fermentation and gel formation. Unfortunately, this kind of information is not available from starter culture producers and neither is the knowledge available to allow choosing an EPS-producing culture to suit a particular product. Use of an EPS-producing culture can make the product slightly ropy. Whilst this may be an advantage for some uses of the product, a highly ropy product would be unsuitable for a cultured cream destined for use as for instance a dip. In our experiments using cultures with different degree of EPS production, we found that non-EPS producing cultures produced a cultured cream with significantly higher viscosity than EPS-producing cultures (Fig. 6). However, in sensorial analysis of the same products, EPS-producing cultures showed an obvious ropy consistency, as expected. It can be inferred from this that under some circumstances, the use of an EPS-producing culture can have a negative effect on the formation and structure of the acid gel as also indicated by Mende, Rohm, and Jaros (2016). Mende et al. (2016) also suggested that EPS produced before gelation would interfere with gel formation, but if produced after

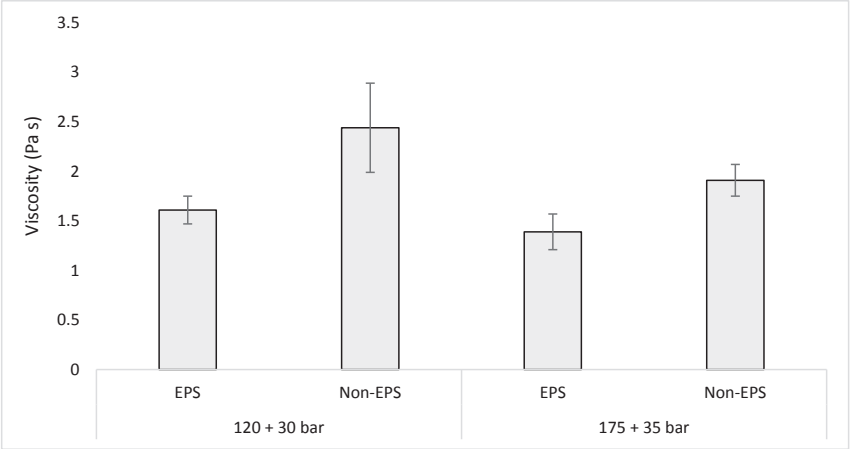

Fig. 6. The effect of EPS-producing culture and non-EPS producing culture on the viscosity of cultured cream (three independent productions, compiled from data in our laboratory). Cream (18% fat) was double homogenised at 120 and at 30 bar or 175 and at 35 bar, at 65 °C. Samples were heat-treated at 95 °C for 5 min, cooled to 22 °C and fermented with a mesophilic DL starter culture to pH 4.5. Cooled samples (4 °C) were measured for viscosity after 2 days of storage, four times on each sample. Bars show standard deviation.

gelation it would instead impinge on rearrangements of the network. Our observations have indicated that a ropy consistency is more noticeable when the overall viscosity of the product, due to other technological factors, is lower. Further research in this field is warranted. It is possible that cultures producing different types and amounts of EPS should be used for cultured cream products with differing fat content and destined for different markets and uses. This detailed knowledge is not at present available.

5.2. Fermentation technology for cultured cream

Following standardisation, homogenisation and heat treatment of the cream, the chosen DL-starter culture is usually added at approximately 22 °C in an amount equivalent to a 1% inoculation of a bulk starter culture (Fig. 1). The cream must then be stirred to disperse the starter culture. This stirring should be gentle but sufficiently thorough because the thickness of the cream can impede a satisfactory dispersion of the starter and the fermentation will be uneven. Fermentation takes approximately 18–20 h at this temperature (Lyck et al., 2006). Brighenti et al. (2018), studied the effect of processing conditions on the texture and rheological properties of both acid gels and the cream cheese produced from these gels. Acid gel formation in fermented cream (12% fat) showed that a fermentation temperature of 26 °C resulted in a significantly firmer gel than cream fermented at 20 °C. There are no equivalent data pertaining to the fermentation temperature with respect to cultured cream of fat content higher than 12%, which would have less or no free protein in the serum phase following homogenisation.

Cultured cream can be produced either as a stirred or set type. Stirred cultured cream is fermented in tanks at approximately 22 °C until a pH around 4.5 is reached. In situations where the ambient temperature is likely to deviate from this temperature, insulated tanks should be used. The cultured cream is then stirred up to a homogenous product and pumped to the packaging machine. A gentle pumping, for example by use of a displacement pump that causes low shear stress in the fluids, should be used to avoid serious damage to the acid gel and thereby an unacceptable reduction in the viscosity of the product. This was illustrated by Steenbergen (1971b) for yoghurt. The filling machine should be specially designed for filling fermented milk or cream products and the velocity of the product through the filling head should be as low as possible (Steenbergen, 1971a). The cooling operation used for the fermented cream leads to a decrease in viscosity and the lower the temperature, the greater the damage inferred to the gel structure during stirring, pumping and packaging. It is therefore beneficial to not cool the cultured cream before packaging, but ensure a rapid cooling afterwards. This may, however, present logistical problems at the dairy since the packaging machine may not always be available at the time needed, thus necessitating a temporary wait in a buffer tank at fermentation temperature. This may result in an unwanted extended fermentation time and therefore a further reduction of pH in the product. The packaged cultured cream is then allowed to reset at 4 °C until distribution to sales outlets. Alternatively, cultured cream may be produced as a set type. Inoculated cream is packaged and then fermented in retail containers at 22 °C until the required pH is reached, and then cooled. In this way, disruptive mechanical agitation of the cultured cream is avoided and the product will have a firmer and unbroken coagulum, although it may be prone to a grainy consistency (Bylund, 2015; Lyck et al., 2006).

6. Ingredients and additives to the cream mix for cultured cream

The stability of oil-in-water dairy emulsions is dependent on the composition of the membrane surrounding the fat globules. Following homogenisation, competition for a place on the fat-serum interface occurs between the components present. An increase in the stability of the emulsion and/or improvements in rheological properties of cultured cream can be achieved in several ways, for example, by the addition of extra milk protein and/or by the addition of hydrocolloids and emulsifiers.

Cultured cream with a fat content of approximately 20% frequently contains added hydrocolloids and emulsifiers to especially improve heat stability. Addition to cultured cream with even lower fat content will improve both heat stability, viscosity and mouthfeel.

Although the literature contains a few references to the use of extra ingredients and additives to cream for the manufacture of cultured cream, there seems to be a considerable variation in these additions and the amounts added to commercial products are not specified. Hydrocolloids and emulsifiers represent large groups of substances with widely varying properties according to their individual chemical composition. In addition these properties are affected by the food environment, their concentrations, their interaction (or not) with milk proteins and whether they interact with other additives (Damoradan, 1997).

6.1. Addition of protein

Milk proteins, in particular caseins, are the natural emulsifying component in homogenised milk or cream as casein has high emulsifying activity, whereas whey proteins have high emulsifying stability (Damodaran, 1997). The shortage of protein to act as membrane material in homogenised cream with over approximately 20% fat leads to aggregation and coalescence of fat globules, as described in Sections 2 and 3 and there is theoretically no, or very little, free protein available to form an acid protein gel between the casein-covered fat globules. Thus, the formation of a coagulum in such cultured cream can be envisaged as protein-covered fat globules that aggregate as the pH falls and repulsing charges are neutralised.

Mulder and Walstra (1974) opined that a certain amount of casein should be available in the plasma to form the necessary smooth and sufficiently firm acid curd. Several authors have mentioned the potential of adding milk protein to cream to improve the rheological properties of cultured cream. Phipps (1983) suggested that it would be of interest to investigate if protein enrichment of the cream would have a positive effect on the lack of potential membrane material and Aryana and Olson (2017) refer that Page and Lavalie (1955) patented a procedure for production of a sour cream-like product fortified with milk protein. Akal and Yetişemiyen (2016) increased the milk protein level in cream containing 18% fat using skimmed milk powder (SMP; 2 and 4%) or demineralised (50% and 70%) whey protein powder (WPP; 2 and 4%). They demonstrated a marked increase in viscosity in cultured cream with all the additions but the samples added 2% SMP attained better overall sensory scores than samples added 4% SMP or any of the samples added demineralised WPP. Costello (2009) mentioned that some producers of organic cultured cream added skimmed milk powder to increase the viscosity. An increase of milk proteins in the cream prior to homogenisation and fermentation would be expected to increase the viscosity of the final coagulum since there would then be some protein available to form an acid protein gel in the serum phase of the product between the protein-covered fat globules. This would therefore improve the rheological properties of cultured cream without adding non-dairy components such as hydrocolloids and emulsifiers.

Preliminary experiments (unpublished results, three independent productions) in our laboratories showed a significant increase in both viscosity ($p < 0.001$) and gel strength ($p < 0.001$) of cultured cream (18% fat) prepared by mixing cream (35% fat) and skimmed milk in which the protein had been increased (2×) using membrane filtration. The cream mix was heated to 55 °C, homogenised at 160 bar and then heat treated at 95 °C for 5 min. After cooling to 22 °C, the cream mix was inoculated with a mesophilic DL-culture. An increase from 2.85 to 3.85% protein resulted in an approximate doubling of gel strength (measured in grams using a texture analyser (TA.HDplus: TTC, Hamilton, MA, USA)). However, systematic scientific research on the effect on the viscosity of cultured cream by increasing the amount of protein is, to our knowledge, not published. Our investigation of the international market does not indicate that it is particularly usual to increase the milk protein content in cultured cream. However, some products do exist.

6.2. Addition of hydrocolloids

Food-grade hydrocolloids such as polysaccharides, proteins or glycoproteins may be added to cultured cream products with the aim to provide a firm texture, increase viscosity and reduce whey separation by virtue of their various compound-specific properties of gel formation, thickening and water binding (Meunier-Goddik, 2012; Tamime & Robinson, 1999). Depending on the hydrocolloid(s) used, the mouthfeel may also be smoother. Commonly-used hydrocolloids include modified starch, pectin, carrageenan, locust bean gum and guar gum and blends of two or more of these ingredients are often used. The necessity for using hydrocolloids, and the type and amount to be used, depends upon on national legislation, the fat content (more is added to low fat products), the likely use of the product and the desired viscosity (Meunier-Goddik, 2012). Their use may, however, be restricted in some countries (Kessler, 2002) and they are not permissible in organic products or desirable in clean label products.

The addition of a sufficient amount of a hydrocolloid to low fat cultured cream can increase the viscosity to near that of the equivalent full fat product, although the texture and mouthfeel will not be the same. In cultured cream that is used for adding to or on hot products, either as a garnish or stirred into warm soups and stews, hydrocolloids can reduce separation and flocculation of the cultured cream on contact with the hot dish. Similar to the behaviour of EPS in cultured milk products, they may react with milk proteins and become an integrated part of the acid gel, act as a thickener or form a gel in the serum phase of the product. Anionic hydrocolloids, such as carboxy-methyl cellulose, pectin and λ-carageenan interact with the positive charges on casein below the isoelectric point and strengthen the gel in an acidified product whereas other polysaccharides improve the rheological properties by thickening the serum phase (Everett & McCloud, 2005).

6.3. Addition of emulsifiers

Emulsifiers are polar compounds with both a hydrophilic and a hydrophobic end and therefore tend to orientate at the interface between oil and water. Low molecular weight non-dairy emulsifiers are usually mono- and diglycerides of fatty acids and lactic acid esters of monoglycerides. If added to milk or cream, they can adsorb to the fat/serum interface of the fat globule during homogenisation, or they can desorb the casein from the homogenised fat globules (Mulder & Walstra, 1974; Walstra et al., 2006). Following the homogenisation of cream, the presence of emulsifiers could therefore result in an increased availability of free milk protein for acid protein gel formation during the fermentation of cream. This would change the structure of the fermented product, in for instance a cultured cream with 18% fat, as the gel would consist to a much greater extent of coagulated protein, rather than gelled protein-covered fat globules. In such a case the fat might exist as small globules which are totally or partially covered by emulsifier. However, emulsifiers form a much thinner and weaker membrane which means that coalescence is more likely to occur. Although this is an advantage in ice cream processing, where leakage of free fat and some aggregation of fat globules and stabilisation of the air bubbles is desired, this is potentially a disadvantage in cream products (Segall & Goff, 2002). Fat globules totally covered with emulsifier would most probably not participate in the acid gel and would therefore be just trapped in the gel as fillers. Hydrocolloids may also act as emulsifying agents by an orientation at the fat:serum interface. Dickinson (2009) described the complexity of the choice of hydrocolloid for this purpose since conditions such as pH, temperature, ionic strength and calcium ion content in the product affect the suitability of the individual hydrocolloid.

7. Conclusions

Cultured cream may be used for a variety of culinary purposes for which particular properties are required. Some consumers demand reduced-fat products but at the same time require these products to have the same properties as the full fat equivalents. Available literature is generally sparse concerning the fermentation of cream and several data gaps have been pointed out in this review. There seems to be a lack of recent research in this field and many production procedures are based on early information as well as industrial experience and secrets that are not available. We have attempted to piece together available knowledge, old and new, to better understand the changes that occur during the processing and fermentation of cream to make cultured cream of various fat content. Without doubt, the technological parameters used for homogenisation of cream of different fat content should be studied in detail and optimum conditions relevant to cultured cream production established.

Considering that Codex Alimentarius defines cream products as having a fat content of ≥10%, it would, in our opinion, be more correct to market products that have a fat content below 10% as cultured milk or cultured buttermilk, rather than cultured cream. In such products, the thick texture associated with cultured cream is only attainable by addition of additional milk protein, thickeners and emulsifiers.

Available literature does not agree on common conditions for homogenisation of cream for cultured cream products with different fat contents and there is a lack of newer experimental results. However, some general conclusions can be made, based on Fig. 5, which can be a starting point for product development and improvement at the individual plant. Different processing equipment, for example, will make it necessary to fine tune each production procedure. In addition, customer preferences and expectations for the product may necessitate further technological adjustments.

In a cultured cream with a low fat content (10–15%), the structure, and thereby rheological properties, of the product is dominated by a protein acid gel. The ratio of milk proteins to fat is such that two-stage homogenisation is probably an advantage. At the other end of the scale, in a cultured cream with a high fat content (above 30%) the rheological properties are determined by an acid gel formed from milk protein-covered fat globules that are also likely to be agglomerated. At refrigerated temperatures, a large proportion of the triglycerides in the fat globules is crystallised and this gives high fat products considerable stiffness. In between these two types of products are cultured creams with a fat content of approximately 20%. In these products, there is very little free

protein following homogenisation and at the same time too little protein-covered fat to give an important contribution to the thickness of the product. Hence products with approximately 20% fat can be regarded as the area that gives the greatest quality challenge. In products above approximately 20% fat, two-stage homogenisation is probably not beneficial to improve viscosity and gel strength. In the production of clean label products, the addition of extra milk protein to the cream before fermentation can give markedly improved consistency properties.

It would be of interest to know whether the casein situated on the surface of the fat globules after homogenisation has the same ability to participate in the acid curd formation as the casein available in the serum phase of the cream. The casein (both micelles and casein particles) on the fat globule surface may both stabilise the fat globules and participate in the acid gel. Such subjects have as far as we can see, not been studied in available published literature.

It can be concluded that there is a need for new research in the following areas, especially if the avoidance of thickeners and emulsifiers is desirable to produce clean label products. Some of these data gaps may be answered by:

1. Systematic matrix studies showing the effect of varying homogenisation temperatures and pressures on the rheological attributes of cultured cream of different fat content;
2. Systematic comparisons of 1-stage (single), 2-stage and double homogenisation of cream with different fat percent and the subsequent effect on rheological properties of cultured cream;
3. Visualisation of the structure of acid gels in cultured cream following different treatments and with differing fat content;
4. Comparison of rheological properties of cultured cream containing EPS, thickeners or gel-forming additives, or increased milk protein level;
5. Structural studies to demonstrate the influence of different EPS-producing strains on the acid gel in cultured cream of differing fat content.

Acknowledgements

The authors acknowledge partial financial support from TINE SA for some of the experimental work reported here.

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