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Original article

Evaluation of formulation design on the physical and structural properties of commercial cream cheeses

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Summary This study investigated how the compositional properties and formulation design of commercial cream cheese products model cheese influenced physical and structural properties as compared to a model cheese composition. Of the seven products evaluated, three were block format (B), two were spreadable (S) and two were spreadable light (SL), with fat contents ranging from 13.7 to 35.7%. The majority of cream cheese products indicated the inclusion of starter culture, and all formulations contained one or more stabilisers. Protein/moisture (p/m) ratio, i.e. the effective protein concentration in the non-fat substance, was seen to most strongly correlate with material properties, with a positive slope for fracture stress ($R^2 = 0.808$) and modulus of deformability ($R^2 = 0.721$). In terms of outliers, the datapoint for SL2 on this modulus *versus* p/m graph was lower than its regression line, and one rationale is that lower fat content (13.7%) gave a lower modulus from the milkfat component at 10°C test temperature. B1, with the highest p/m of 0.17, had a more dense distribution of larger fat globules coated with proteins than B2 and B3. Fracture stress and modulus of deformability were noted to be higher for full-fat than for lower fat cheese. In all products, elastic characteristics dominated viscous flow as expected. Findings have demonstrated that significant variance exists across the material properties of commerical cream cheeses, and which shows specific dependencies on their formulation.

Keywords Composition, cream cheese, ingredient, microstructure, rheology, texture.

Introduction

Cream cheese is typically made from a mixture of milk and cream, which undergoes acidification, heat treatment and shearing to create the appropriate structure during processing. The structure can be quite tolerant to variations in formulation, which can be adjusted to produce different formats with varying material and sensory properties by controlling process and formulation variables (Guinee *et al*., 1993; Almena-Aliste & Kindstedt, 2005; Kim *et al*., 2022). There are four main different cream cheese categories according to USDA (1994) specifications based on fat and moisture content. In the category of cream cheese, the minimum milkfat content should be 33% by weight of the final product, with no more than 55% moisture content. Neufchatel cheese should be 20~33% milkfat with less than 65% moisture content. When it comes to reduced-fat cream cheese, it should be 16.5~20% milkfat with less than 70% moisture content, and lastly, light cream cheese should contain no more than 16.5% milkfat with a maximum moisture content of 70%.

Cream cheese products continue to be widely consumed, from fresh types to processed forms such as spreads and cheesecakes. The versatility of the product has encouraged its popularity, and thus, it has become one of the most popular soft fresh cheese products in Asian countries in recent years. The steady surge in demand is attributed to its subtle flavour and rich texture, and utilisation is represented across many sweet and savoury product areas, particularly in the food service sector.

In this way, manufacturers have broadened their varieties to correspond to different end user and consumer applications, such as improved spreadability and low fat (and even extending into non-dairy formats in response to current trends towards vegan-type products) (Ningtyas *et al*., 2018; Wolfschoon-Pombo

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et al., 2018). Adjustment of product properties to achieve specific functionality can be provided through compositional or process modifications, such as the addition of milk-derived powder and gum, which are commonly used to supplement protein or replace fat, whilst maintaining a desirable structure and consumer acceptability (Guinee & Hickey, 2009). Therefore, a greater knowledge of how ingredients behave provides a better understanding of the role of each component in cream cheese structure.

Commercial cream products can have a broad range of composition, being less constrained in terms of regulatory requirements compared with many other dairy products. Such variation can allow for greater control over product attributes such as product quality, stability and cost (Macdougall *et al.*, 2019). Properties can vary depending on how much moisture, protein and fat are distributed in the structure, along with their spatial arrangements and strength of the interactions within the structure (Brighenti *et al.*, 2008; Truong *et al.*, 2016). In this sense, the structure of cream cheese can be generically described as a fat-in-protein emulsion particle gel. Basically, the corpuscular structures consist of fat globules surrounded and stabilised with whey proteins and casein micelles in cream cheese (Ong *et al.*, 2018; Macdougall *et al.*, 2019). It has been reported that significant rearrangement in proteins and fat globules occurs, and proteins surround fat globules with a larger interface, which makes an increased interaction between proteins and fat globules in cream cheese, leading to a network comprising protein–protein, protein–fat and fat–fat interactions. Their interactions have been reported to be responsible for determining the physical properties of cream cheese varieties, and the network is broken up during processing into a particle gel (Wendin *et al.*, 2000; Brighenti *et al.*, 2008; Coutouly *et al.*, 2014; Macdougall *et al.*, 2019).

In addition, each commercial product tends to include at least one gum. The use of gums has been essential to produce a desirable structure, particularly in low-fat cream cheese products, as water phase binding gums replaced fat in the structure of these cheese varieties (Guinee & Hickey, 2009). The use of gums is often used to mitigate for syneresis during storage (Wolfschoon-Pombo *et al.*, 2018). Although the fundamental information about ingredients in manufacturing cream cheese has been established, specific information relating formulation, and processing conditions to product properties and functionality tend to be mainly in the domain of intellectual property or as trade secrets (Phadungath, 2005). Therefore, a deeper understanding of the role of the relationships between formulation, process, structure, and material properties is required to find more iterative ways of imparting requisite functionality.

There has been little literature that analysed the different composition, ingredients and manufacturing processes between cream cheese products. Therefore, this study aimed to investigate the effect of varying composition and ingredients in the process on the structural and rheological properties in cream cheese varieties. The structural and rheological properties were determined by compressive fracture testing, small amplitude oscillatory and forced serum determination of seven different commercial products. CLSM was performed to compare the distribution of internal structures, and the relationships with rheological properties were explored. The information obtained from this study will provide a useful baseline of structural and rheological properties using techniques for further study and industrial sectors.

Materials and methods

Commercial cream cheese product collection

For this study, seven commercial cream cheese products were collected. Six commercial cream cheese products were purchased at local supermarkets, and one product was provided by Fonterra Co-operative Group Limited. It was ensured that the products had less than a month variation in expiration date between them in order to minimise variables, and then, they were stored at 5°C until analysis.

Model cream cheese preparation

For a reference, a model cream cheese was prepared to compare with the properties of commercial cream cheese products. Our study adapted the same approach to produce model cream cheese, as described by Kim *et al.* (2022) with slight modification. 10.5% of skim milk powder (SMP, Fonterra Co-operative Group Limited, NZ) and 10.3% of anhydrous milk fat (AMF, Fonterra Co-operative Group Limited, NZ) were dissolved in deionised water at 55°C for 30 min. The dissolved cheese milk was blended using an Ultra-turrax homogeniser (IKA, T25, Germany) at 13500 rpm for 2 min and then homogenised with 1st-stage 180 bar and 2nd-stage 50 bar (APV 2000, Copenhagen, Denmark). The composition of cheese milk was checked by MilkoScan FT2 (Foss, Hillerød, Denmark) to ensure cheese milk had the targeted composition of 10.5% fat and 3.4% protein. The homogenised milk was inoculated with a mix of commercial starter cultures (*Lactococcus lactis* subsp. *lactis*, *Lactococcus lactis* subsp. *cremoris*, *Lactococcus lactis* subsp. *diacetyl lactis* and *Leuconostoc mesenteroides*) provided by Microbial Fermentation Unit of Fonterra's Research & Development Centre and cultured at 28°C for 16 h until it reached pH 4.7. The curd was collected by centrifugation at 8000 rpm for 30 min and blended with a mixture of 0.8% salt and 0.3% locust bean gum

(LBG, Sigma-Aldrich, Co., USA) by Thermomix (Vorwerk & Co., Germany) for 30 min at 75°C. It was hot filled and stored at 5°C before analytical tests.

Chemical composition

The fat content in model cream cheese was determined by the AOAC (2005) method 933.05 using ether and petroleum ether, and the protein content was analysed by the AOAC (2005) method 920.123 using the Kjeldahl method. The moisture content in cream cheese was determined by drying at 135°C for 2 h (AOAC, 2005; method 930.15). The moisture content was calculated as a percentage by the following equation.

$$\text{Moisture content}(\%) = \frac{\mathit{Wet\ cheese\ weight}(g) - \mathit{Dried\ cheese\ weight}(g)}{\mathit{Wet\ cheese\ weight}(g)} \times 100.$$

The composition of commercial products, including fat, protein and carbohydrate along with ingredients, was collected from the respective nutritional and ingredient declaration as listed on the package of each commercial product. The information is listed in Table 1.

Compressive fracture measurements

Cylindrical samples were prepared, 19 mm in diameter and 25 mm in height, and tested by a TA-XT Plus Texture Analyser (Stable Micro Systems, Godalming, England) performing a lubricated double compression. This test gives fracture and rheological properties in the first compression and empirical adhesion area with the tension stroke. The samples were cut with a cork borer, enclosed with plastic film and kept at 10°C in the refrigerator before testing at ambient laboratory temperatures. Each sample was taken just before testing from the refrigerator and after lubrication with mineral oil, experienced two successive 80% compressions using 60-mm Teflon probe with a 50 kg load cell and compression speed of 0.83 mm/s. Six duplicates were taken from each sample. From the obtained data, fracture stress and modulus of deformability were calculated, and from the literature (Zoon, 1991), these properties are associated with the sensory descriptors of firmness and stiffness (or rigidity), respectively. Fracture strain was also calculated, and the closely related property of relative compression at fracture is associated with longness or shortness (Zoon, 1991).

Rheological measurements

Rheological properties were analysed by an Anton Paar MCR 302 rheometer (Graz, Austria) according to the small amplitude oscillatory rheology method. The 2-mm-high samples were cut and placed on a 25-mm serrated plate to avoid slippage of sample during oscillation tests (Rosenberg *et al.*, 1995; Brighenti *et al.*, 2018). Frequency sweep measurements were carried out for the linear viscoelastic area at 5°C between 0.1- and 10-Hz amplitude. A temperature sweep test was conducted with the same-size serrated plate, and mineral oil was added to the sample outer surface to prevent evaporation. The results were obtained by heating from 10 to 90°C and cooling down immediately from 90°C to 10°C at a rate of 3°C a minute. The samples were measured under an angular frequency of 10 s^{-1} at a strain rate of 0.03%. All the samples were tested in duplicate. The data of the storage modulus (G'), loss modulus (G'') and loss tangent ($\tan \delta = G''/G'$) were obtained using the RheoPlus software (Anton Paar, Austria).

Forced serum determination

To determine forced serum release, samples were analysed by the centrifugation method with reference to

Table 1 Composition and ingredients of cream cheese products

Product	Fat (%)	Moisture (%)	Protein (%)	Carbohydrate (%)	Ingredients
B1	34.2	53.1	8.8	2.5	Whole milk, cream, salt, culture, LBG[1]
B2	29.3	59.9	6.6	2.6	Milk, cream, milk solids, salt, LBG, starter culture
B3	33.3	54.1	5.4	5.5	Milk, cream, starter culture, salt, gums (GG[2], LBG, XG[3])
S1	35.7	51.6	4.1	5.4	Cream, skim milk, milk solids, emulsifying salts (450, 451, 452, 339), salt, lactic acid, stabiliser (401)
S2	24.4	65.9	5.4	4.1	Milk, cream, milk solids, gum (GG), starter culture
SL1	16.5	62.1	5.0	14.5	Skim milk, cream, maltodextrin, milk solids, stabilisers (460, 466, 401), lactic acid, emulsifying salts (450, 451, 452, 339), salt
SL2	13.7	71.9	8.0	4.0	Milk, skim milk, cream, milk solids, salt, gums (LBG, GG), sorbic acid, starter culture, enzymes
Model	31.2	52.9	6.8	-	Skim milk powder, Anhydrous milk fat, salt, LBG, starter culture

[1]GG, [2]LBG and [3]XG indicate guar gum, locust bean gum and xanthan gum, respectively.

previous studies (Kocher & Foegeding, 1993; Wolfschoon-Pombo *et al.*, 2018). Samples were cylindrically cut, 7.5 mm in diameter and 10 mm in height, by using a cork borer. The samples were spun using a filtered tube with 0.45-μm pore size filter (Merck KGaA, Darmstadt, Germany) to avoid mixing with expelled serum and cream cheese matrix. The determination of the expressible serum of cream cheese products was carried out based on a stepwise increase in g-force. Increasing speed was applied between 100 g and 12 000 g (9 points) at 20°C for 20 min to examine the serum release behaviour and distinguish the differences between samples. Before each centrifugal step, both inner and outer tubes were weighed, and the weighed sample was put into the inner tube. After centrifugation, the inner tube was removed and the outer tube with expressible serum was weighed. The quantity of released serum was measured in duplicate and calculated as a percentage of sample weight before centrifugation.

$$\text{Total released serum } (\%) = \frac{\textit{Released serum weight } (g)}{\textit{Sample weight } (g)} \times 100$$

Confocal laser scanning microscopy

The microstructure of cream cheese products was analysed using a Leica SP5 Confocal Laser Scanning Microscope (CLSM, Leica Microsystems, Wetzlar, Germany). Samples were cut using a razor blade, the protein was stained with a mixture of 0.2% Fast Green, and the fat was stained with 0.5% Nile red. The two staining solutions were mixed in the ratio of 1:1 with polyethylene glycol. 10 μL of mixed dye solution was added to the sample with a coverslip and left for 2 h for sufficient dyeing before examination. An argon laser at 488 nm and a helium/neon laser at 633 nm were used for excitation of the two dyes at room temperature. The samples were observed with a 63× immersion objective, and the images were collected and viewed using the Leica LAS Lite software (Leica Microsystems, Wetzlar, Germany). Six samples were used for each cheese, and from these, a representative image was selected for qualitative analysis.

Statistical analysis

Data were expressed as mean values and standard deviations of the mean. To determine the significant differences ($P < 0.05$) between means, Minitab Statistical Software (Minitab Version 17, State College, Pennsylvania, USA) was used for the analysis of variance (ANOVA) using Tukey's test.

Results and discussion

Cream cheese compositional analysis

There were variations in the composition and ingredients of the products (Table 1). Three products (B1-3) were a block type, packaged in foil and carton and containing around 30% fat. However, there are also differences within this block category in fracture properties and rheological properties induced partly from the rather high moisture (59.9%) in B2 and the rather low protein (5.4%) in B3. These changes in fracture from different proteins and moistures are detailed in the following section on compressive fracture analysis, and changes in small strain rheology from differences in protein are detailed in the rheological properties' analysis.

The other four products were split into two groups labelled as spreadable and spreadable lite, based on the fat contents and packaging type (S1-2, SL1-2). They were packaged in a plastic tub and had fat content below 25%, except S1 (35.7% fat). Although it is unclear to identify the exact manufacturing process, presumably S1 and S2 were manufactured as a processed cheese type because they included sodium phosphates, which are commonly used in manufacturing processed cheese products as emulsifying salt (Kawasaki, 2008; FDA, 2017; Huang *et al.*, 2018). The moisture content also varied according to their fat content, ranging between 51.6 and 65.9%. Products with higher fat content showed lower moisture content, presenting a negative correlation with high R-squared, 0.8096 (Fig. 1). This relationship was previously reviewed, and fat and moisture were major components to determine total solids and influence the characteristics of cream cheese (Liu *et al.*, 2008; Brighenti, 2009). This correlation is a consequence of the cheesemaking process from milk as follows. Normally, protein stays near a constant fractional amount; thus, if fat increases, moisture decreases as a consequence of this and *vice versa*. Protein and carbohydrate contents had a relatively smaller range compared with fat and moisture content. However, high carbohydrate or protein content was observed in spreadable cheese, and SL1 and SL2 and more ingredients such as stabilisers and milk solids were added to these products. The most commonly used gums in cream cheese are LBG and guar gum (GG), which are used to improve product qualities such as preventing syneresis, enhancing firmness and maintaining texture during shelf life (Bot & Vervoort, 2006). For these reasons, it can be seen that subsidiary ingredients such as milk solids and stabilisers were used in spreadable and low-fat cream cheese products (S1, S2, SL1 and SL2), and three kinds of gums were included in B3 to provide the desired level of texture. Most cheeses contained starter culture except for S1 and SL1, which included emulsifying salts and lactic acid. All cheeses had stabiliser, the most common being LBG.

Compressive fracture analysis

To examine the textural characteristics of cream cheese products with different composition, the compressive fracture test was carried out. Higher fracture stress and modulus deformability were measured in B products with higher fat and low-moisture content (Fig. 2). The result was in agreement with the observation that the hardness of commercial cream cheese increased with high-fat and low-moisture content producing harder spreadability due to the firm and stiff texture (Brighenti *et al.*, 2008). The compression test on B2 and B3 exhibited that they had a relatively lower levels of structural integrity than B1. This seems to be related to composition of the products as the higher solid and fat contents (at a test temperature of 10°C) in full-fat cream cheese were responsible for firmer and stiffer textural properties than its counterparts. The rigidity of cheese was affected by fat particles and contents, which resulted in changes of rheological and fracture behaviours (Kealy, 2006; Brighenti *et al.*, 2008; Vigneux *et al.*, 2022).

As for S1 product, its composition is supposed to be categorised as full-fat cream cheese, but it displayed lower fracture stress and modulus deformability compared with B products due to being a highly emulsified product as mentioned earlier. Heating is carried out for a certain time with continuous stirring to produce a homogenous mass, causing changes in how the fat globules are connected to the protein network and changes in texture in the final product by altering the interactions (Kawasaki, 2008; Nguyen & Anema, 2017). Low-fat products including S2, SL1 and SL2 characterised noticeably low compressive fracture values, which is consistent with previous studies performed on the textural integrity of cream cheese with different fat levels, where the hardness of cream cheese decreased as the moisture content increased (Ong *et al.*, 2018) and the degree of spreadability had a negative correlation with fat content (Wendin *et al.*, 2000). It is remarkable that SL products did not show big differences in the measured attributes, despite having a lower level of fat or higher moisture content compared with S2 product. It is likely that the inclusion of multiple stabilisers such as cellulose (SL1) or reinforcement by protein ingredients such as milk solids (SL2) is a factor to contribute to textural rigidity. The use of stabilisers or gums has been evaluated as an effective and economical way to control the texture at a desired level in low-fat cream cheese products (Ningtyas *et al.*, 2018; Wolfschoon-Pombo *et al.*, 2018; Brighenti *et al.*, 2020).

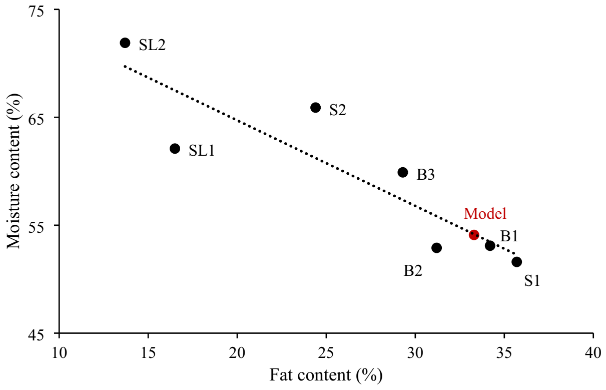

Figure 1 Correlation of fat and moisture in cream cheese products.

Figure 3 shows the correlation between compressive fracture and the ratio of protein to moisture in all products. Protein-to-moisture ratio measures effective protein concentration in the non-fat substance. In addition, dividing protein by moisture gives a protein measure that partly accounts for the large range in moisture contents (51.6–71.9%) in the current work. This ratio correlated with a positive slope with textural properties; that is, as the product had a higher ratio, it generally led to high structural integrity; for example, B products with higher ratio showed significantly higher compressive fracture stress. B1, having a far higher p/m (0.17) compared with that of other commercial cheeses (0.08–0.11), had the highest fracture stress and modulus. Previous investigations summarised the positive correlation of protein with a rigid structure in cream cheese due to protein–water interaction (Lee *et al.*, 2004; Ong *et al.*, 2018). SL2 deviated more from the p/m with fracture stress of modulus of deformability, and whilst there is no obvious single rationale for this, the lower fat content (13.7%) contributed to the lower modulus from the milkfat component at the test temperature of 10°C.

Fracture strain was similar for most (5 of 7 products) being in the range of 0.22 to 0.27. Spreadable product, S1, had a relatively high fracture strain of 0.39, but accounting for its large standard deviation of 0.11, the fracture strain of S1 is probably not significantly different to the fracture strain of the other 5 cream cheeses. Block product B3 had a relatively high fracture strain of 0.84 and a standard deviation of 0.04. The use of multiple stabilisers (LBG, guar gum and xanthan gum) for B3 might contribute to its high fracture strain, but this idea needs further study to determine the mechanism that results in this high fracture strain.

Rheological property analysis

The results of small strain rheological properties of cream cheese products are demonstrated in Figs. 4 and 5. The results are divided into two groups based on

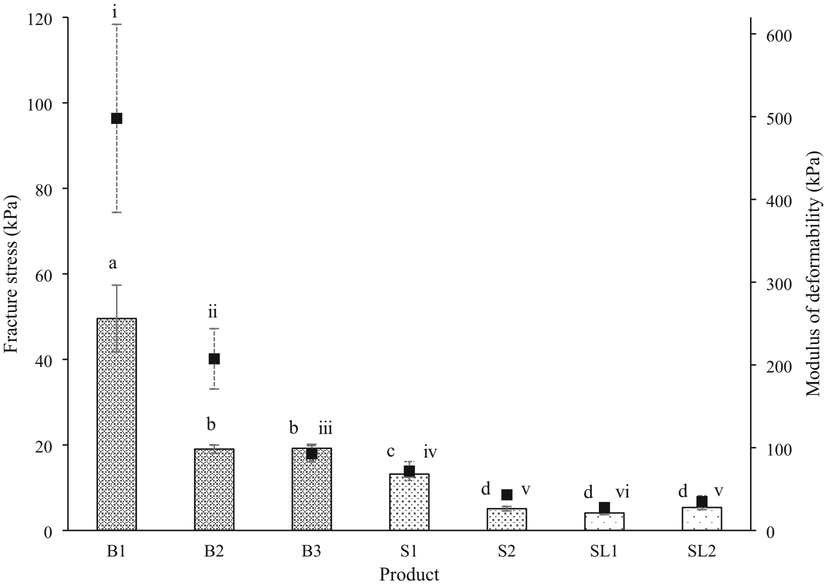

Figure 2 Comparison of the fracture stress and modulus of deformability of commercial cream cheese products. The bars with dotted patterns and square dots indicate the fracture stress and modulus of deformability values, respectively. Values are presented as means of six replicates, and error bars indicate the standard deviation of the mean. Letters indicate significant differences at $P < 0.05$.

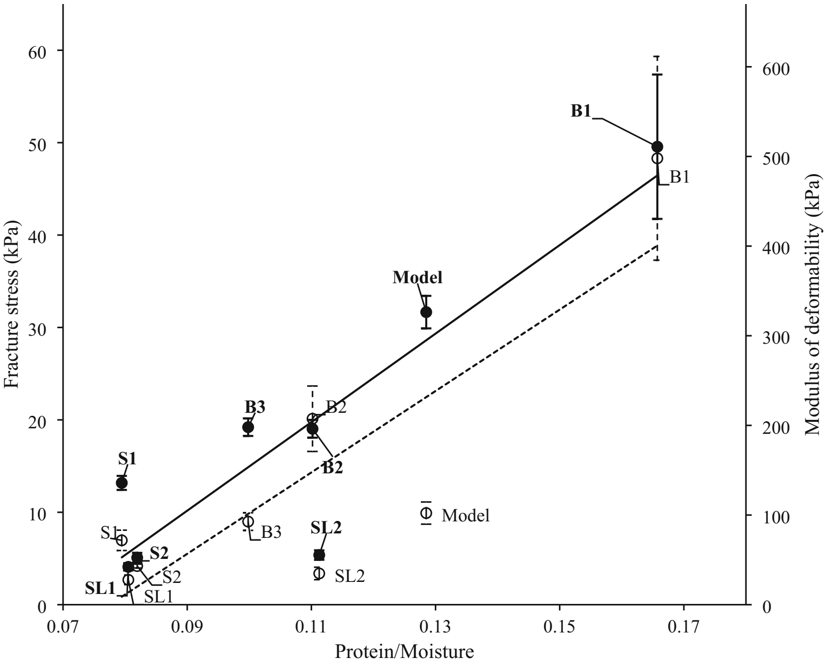

Figure 3 Correlation between compressive fracture values (fracture stress; ● with solid trend line and bold font, modulus of deformability; ○ with dotted line) and the ratio of protein to moisture in cream cheese products.

the packaging type, block (B1-3) and spreadable type (S1-2, SL1-2). The lowest fat products SL1 and SL2 had the lowest storage modulus measured at 5°C. The elastic properties were more dominant, indicating a typical gel-like characteristic, as it was clearly shown that G' was recorded higher than G'' in all products (Fig. 4a). The tan δ below 0.35 in all products confirmed this attribute; the trend is regarded as a typical characteristic of commercial cream cheese products, as similar observations were found in previous studies of rheological analysis of cream cheese products (Sanchez *et al.*, 1994a, 1994b; Coutouly *et al.*, 2014; Brighenti *et al.*, 2018). The pronounced high G' was analysed in the products with greater compressive fracture. The increased G' of B1 with higher protein was observed compared with B2 and B3 as the previous studies

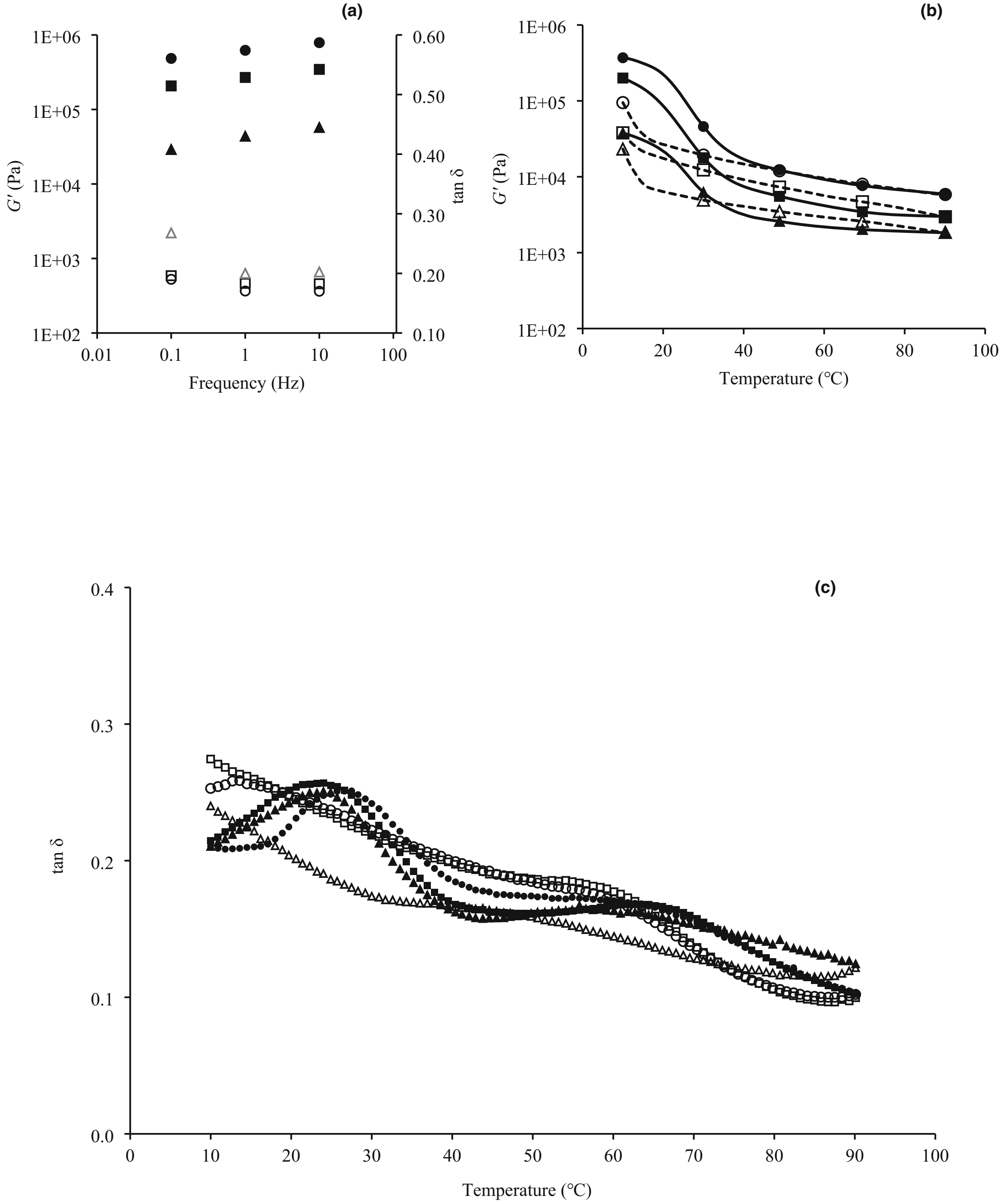

Figure 4 (a) presents storage modulus (G') with B1 (●), B2 (■) and B3 (▲), and loss tangent (tan δ) with B1 (○), B2 (□) and B3 (△) obtained from frequency sweep from 0.1 to 10 Hz. (b) presents G' of temperature sweep during heating from 10 to 90°C, which is shown as B1 (●), B2 (■) and B3 (▲) with solid line (–); cooling from 90 to 10°C as B1 (○), B2 (□) and B3 (△) with dotted line (---). (c) presents tan δ during heating, which is shown as B1 (●), B2 (■) and B3(▲); cooling is shown as B1 (○), B2(□) and B3(△). Values represent the mean of replicate.

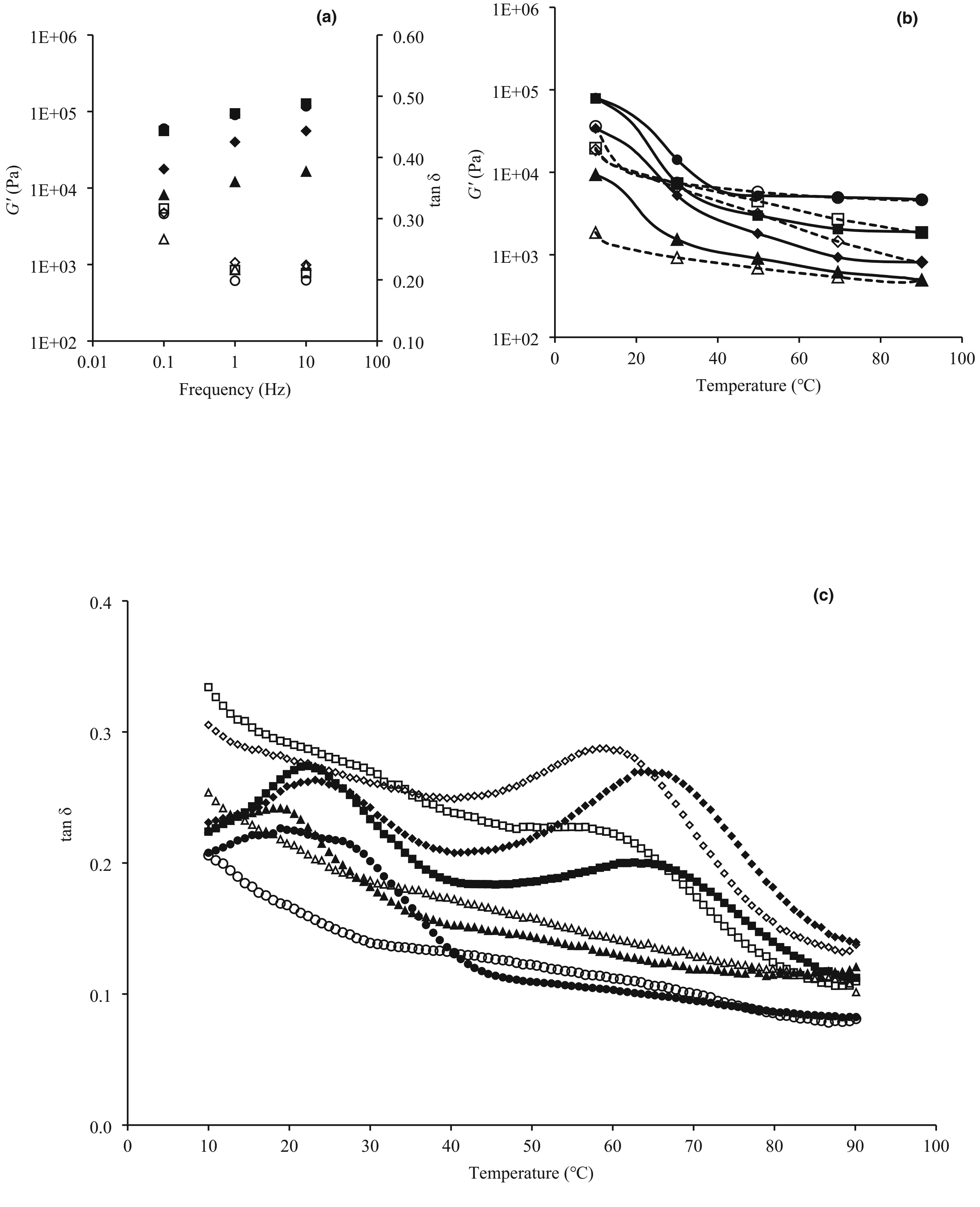

Figure 5 (a) presents storage modulus (*G*′) with S1 (●), S2 (■), SL1 (▲) and SL2 (◆), and loss tangent (tan δ) obtained from frequency sweep test. (b) presents *G*′ of temperature sweep during heating from 10 to 90°C, which is shown as S1 (●), S2 (■), SL1 (▲) and SL2 (◆) with solid line (–); cooling from 90 to 10°C shown as S1 (○), S2 (□), SL1 (△) and SL2 (◇) with dotted line (----). (c) presents tan δ during heating, which is shown as S1 (●), S2 (■), SL1 (▲) and SL2 (◆), and cooling is shown as S1 (○), S2 (□), SL1 (△) and SL2 (◇). Values represent the mean of replicate.

reported that the cream cheese with higher textural properties such as hardness and spreadability showed higher values of rheological properties (Coutouly *et al.*, 2014; Ningtyas *et al.*, 2018). It was also found that B2 had higher G' than B3 during the frequency sweep test, which can be explained that the greater protein contents could be more effective to adsorb onto the fat globules, thus becoming an influential factor to determine the firmer texture and rheological attributes (Bryant *et al.*, 1995; Sodini *et al.*, 2004; Lobato-Calleros *et al.*, 2007). On the contrary, S and SL products presented lower level of G' than B products over the frequency (Fig. 5a). The G' of S2 showed no significant difference with S1, and notably, higher G' was observed in SL2 than SL1 despite having the highest moisture and lowest fat content. This is also presumably due to their higher protein contents and different manufacturing process made from different ingredients.

The changes of G' in B products during heating and cooling are shown in Fig. 4b. During heating, all B products exhibited a steep decrease in G' from 10 to 40°C and a gradual decrease after that. When cream cheeses were exposed to heat, the melting of fat was induced, resulting in a rapid decrease in G'. It is likely that most fat melted by 40°C because over this temperature region, G' did not greatly decrease. The rapid gel weakening by a certain temperature was largely associated with the liquefaction of fat, and some parts were caused by the loose protein interaction and decrease in the strength of hydrogen bonds (Bryant & McClements, 1998; Lucey *et al.*, 2003). The electrostatic and hydrophobic interactions might affect the gradual decrease during the high temperature because cream cheese had relatively low pH close to isoelectric point of milk protein (Lucey *et al.*, 2003). As expected, the G' in all products was recorded, reflecting the order of their compressive fracture values over all temperatures. During the cooling, the G' values steadily increased, and showed a greater increase particularly in full-fat products (B1-3, S1) than in low-fat products at temperatures below 20°C. It was caused by different fat content and reported as a fat crystallisation induced at low temperature, which could contribute to the rapid increase in G' (Truong *et al.*, 2016). It is clearly seen that G' after cooling in all products did not reach the original values before heating, which indicates that the physical properties could not recover the original state once they were heated, as previously reported (Brighenti, 2009).

The profiles of tan δ are shown in Figs. 4c and 5c. The values of tan δ below 0.3 in the heating cycle confirmed cream cheese had a solid-like characteristic in agreement with previous observation on the rheological behaviour (Brighenti *et al.*, 2008; Ningtyas *et al.*, 2018). All B products showed two distinct peaks at 20 ~ 30°C and 60 ~ 70°C during the heating. In addition, it was noticeable in spreadable products that S2 and SL2 had larger higher temperature peaks, whereas no cooling peak was observed in S1 and SL1. The higher protein contents in S2 and SL2 manufactured by rennet clotting could affect the rheological properties, as rennet-induced cheese showed less specific protein interaction at this temperature (Lucey *et al.*, 2003). This is explicitly supported by the fact that no second peak was detected in S1 and SL1, indicating they were produced with typical processed cheese ingredients such as emulsifying salts, unlike S2 and SL2. The tan δ in most rennet coagulated products during the cooling cycle showed a peak around 60°C or below; however, S1 and SL1 exhibited a gradual increase in tan δ without a peak. This also could be due to their ingredients and manufacturing process related to processed cheese manufacturing. After the completion of the cycle of heating and cooling, most tan δ values were higher than their initial points, which confirmed once again that they had lost their original rheological condition.

Forced serum determination

The determination of forced serum by centrifugation is based on a stepwise increase in *g*-force with weighing of the released serum between the steps. B1 showed the lowest released serum quantity at every centrifugal force, compared with other products in B group, whereas B2 showed the highest cumulative released serum quantity at every *g*-force step (Fig. 6a). Released serum quantity was lower in the product with by far the highest protein/moisture ratio (B1) compared with other block products (B1, B2). Most of the moisture in cream cheese is associated with the structure of casein micelles (Huppertz *et al.*, 2017), and therefore, higher casein per moisture is likely to be a factor in reducing released serum.

The total serum quantity of B3 was observed to be lower than that of B2, which might be caused by the multiple use of gums and higher fat content. As can be seen in Table 1, B3 includes a combination of locust bean gum, guar gum and xanthan gum, whilst there is only one stabiliser, locust bean gum, in B2. The use of gum is well known to prevent syneresis during storage and produce cream cheese with a smooth texture (Wielinga, 2009; Macdougall *et al.*, 2019). Multiple gums or stabilisers had effect on water holding capacity and changed rheology of cream cheese (Brighenti *et al.*, 2020). Also, the composition of B3 showed more fat and lower moisture content than B2. It was suggested that more homogenised fat could play a role to reduce syneresis by forming a gel network within the cheese casein matrix because it fills pores in the cheese matrix and thereby inhibits the serum release (Wolfschoon-Pombo *et al.*, 2018).

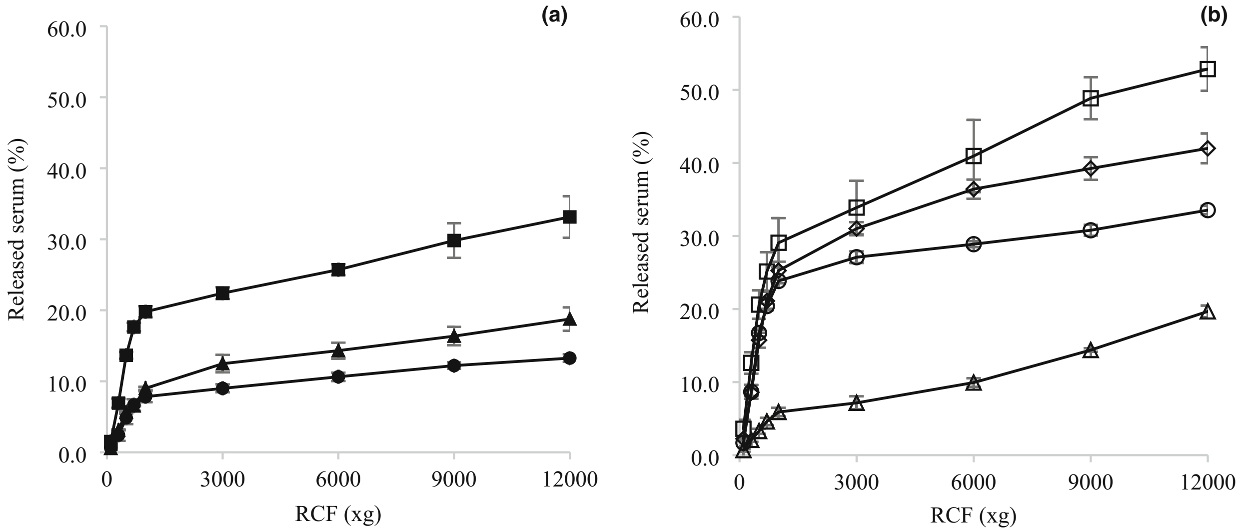

Figure 6 Expelled serum behaviour of commercial cream cheese products. Each released serum is expressed as the percentage of each cumulative total serum according to stepwise RCF. (a) presents the released serum percentage of B1 (●), B2 (■) and B3 (▲). (b) presents the released serum percentage of S1 (○), S2 (□), SL1 (△) and SL2 (◇). Values are presented as means of replicate, and error bars indicate the standard deviation of the mean.

The inhibitory effect of gums on syneresis was observed in SL2 despite it had less fat and more moisture than S2 (Fig. 6b). The expressible serum of SL2 was lower than S2, suggesting a constraining effect of the multiple gums (LBG and GG) on syneresis and offsetting the structural weakness. The processed spreadable cream cheese products (S1 and SL1) had lower released serum quantity when compared to natural spreadable cream cheese products. Highly emulsified cream cheese is likely to have a more stable structure that interrupts the release of serum from the texture. Interestingly, the released serum behaviour showed a steep slope in the range from 100 *g* to 1000 *g* in all the products, and more than half of total released serum was released below 1000 *g* centrifugal force. After 1000 *g*, it showed a gradual increasing quantity of expressible serum. Huppertz *et al.* (2017) reported that 60% of total moisture in cream cheese is associated with the structure of casein micelles; around 25 ~ 30% is bound with the surface layer of κ-casein, and about 15% as primary hydration water with casein. Therefore, a certain level of expressible serum can be released by the initial centrifugal force, and some serum can be removed under higher forces, according to how the structure was formed during the manufacturing process.

Confocal laser scanning microscopy

The comparison of confocal images of commercial products is demonstrated in Fig. 7. There have been various reports regarding the microstructure of cream cheese, and most of them explained the structure as an aggregated form of fat globules and protein matrix with a water phase (Fenoul *et al.*, 2008; Ningtyas *et al.*, 2018). More obvious structural differences from confocal laser scanning microscopy included a more-dense distribution consisting of more of the larger fat globules with protein for B1 of p/m 0.17 compared with B2 and B3 (p/m 0.10–0.11) and more of the smaller fat globules in SL1 and SL2 (having lower fat content).

Compared with B2 and B3, B1 showed denser microstructure and more distinguished microgel with larger distribution of fat particles, comprising larger free fat globules and small fat droplets embedded in the protein matrix. The microscopy analysis indicated that the distribution of aggregated protein and fat clusters was associated with the composition and type of manufacturing process and a higher degree of density in rennet-clotting cheese could explain the higher textural and rheological properties. It is also noticeable that the images of S1 and SL1 showed a homogenous structure with protein matrix and fat globules, due to an emulsification process in manufacturing, and had each different distribution when compared to others. This is in agreement with Macdougall *et al.* (2019) who reported that the emulsifier in cream cheese had the effect to create the homogenous distribution of fat and protein in the structure. It also can be suggested that a different structure was created when they went through different manufacturing processes

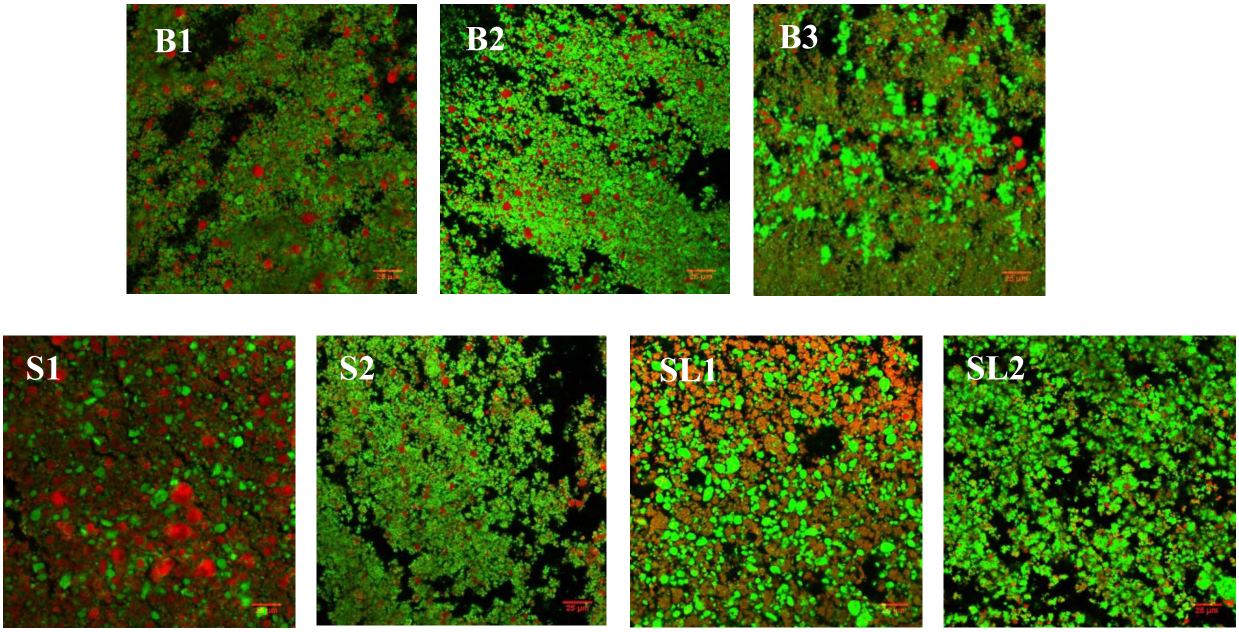

Figure 7 Confocal images of commercial cream cheese products with Nile red and Fast Green for staining fat (red) and protein (green), respectively, at a magnification of 63×. The scale bar indicates 25 {m.

(Mokoonlall *et al.*, 2016). The image of S1 showed a more homogenous and denser structure than SL1 with less water phase because of a different solid matter and fat content. S2, SL1 and SL2, which are classified as low-fat cream cheese, displayed a loosely packed structure and a more interspersed serum phase. A greater amount of serum phase with a loosely packed structure may relate to their lower mechanical and rheological properties in this study. However, the image of SL2 clearly exhibited the protein dominant distribution in accordance with the lowest fat and highest level of protein. The equivalent level of compressive fractures and G' in SL2 compared with low-fat products could be attributed to the predominant protein matrix as the image shows.

Conclusions

The composition and ingredients of cream cheese affected the structural and physical properties of commercial and model cream cheese product. As a result of comparing composition, there was a high correlation between fat and moisture contents in the selected products. The ingredients of cream cheese generally consisted of milk, cream, salt, gum, and starter culture. However, more ingredients such as milk solids, gum and stabilisers could be added to meet a desired level of fracture and rheology affecting texture and serum release. The results of compressive fracture and small strain rheological properties provided insights showing that different composition and ingredients can give rise to different physical properties and structure. Full-fat-level products showed high values of compressive fracture and storage modulus, and high-protein content was also observed to be a contributing component associated with modulating fracture and rheology affecting texture. The ratio of protein to moisture content had high positive correlations with fracture compressive stress and modulus of deformability.

Another important factor was manufacturing process, whether natural or processed cheese, and this determined physical and rheological properties, as well as distinctive cream cheese microstructure, even though they have similar values of compositional properties. Along with these factors, the multiple use of gums and stabilisers had the effect of reinforcing fracture and rheology related to texture and preventing serum release, being related to syneresis by binding more water in the structure. The confocal images showed some variations in the microstructure of each product with different composition, ingredients and manufacturing processes, but which conformed to the generic structure of a protein–fat network (notably with varying amounts of agglomerated fat structures). The current results showed that the methodologies used in this study can be useful tools to assess the structural and rheological properties in cream cheese products made with different ingredients and manufacturing processes. It is also expected to provide practical information to optimise the ingredients, texture and functionality in cream cheese.

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Author contributions

Jiuk Kim: Conceptualization (lead); data curation (lead); formal analysis (lead); investigation (lead); methodology (equal); writing – original draft (lead). **Philip Watkinson:** Methodology (equal); supervision (equal); writing – review and editing (equal). **Lara Matia-Merino:** Supervision (equal); writing – review and editing (equal). **Jeremy Smith:** Supervision (equal); writing – review and editing (equal). **Matt Golding:** Funding acquisition (lead); project administration (lead); supervision (lead); writing – review and editing (equal).

Conflict of interest

There is no conflict of interest between authors.

Ethical guidelines

Ethics approval was not required for this research.

Peer review

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Data availability statement

Data are available on request from the authors.

References

This study investigated the several properties of commercial US cream cheese variety with different compositions. It provides a theoretical basis and support for us to discuss our results.

This recent article introduced cream cheese making process using GDL. It provides benefit of a simpler process than traditional method and their results supports our findings in this article

This article investigated the effects of processing variables on cream cheese properties and microstructure. It is important to discuss the physical and structural properties of commercial cream cheese in our results.

This article explained the effects of different composition and stabilisers on the degree of syneresis in commercial cream cheese products. It provides strong theoretical support to our results.

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