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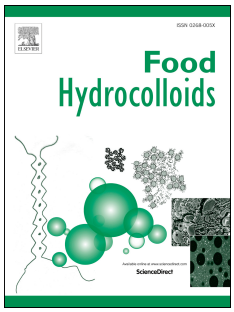

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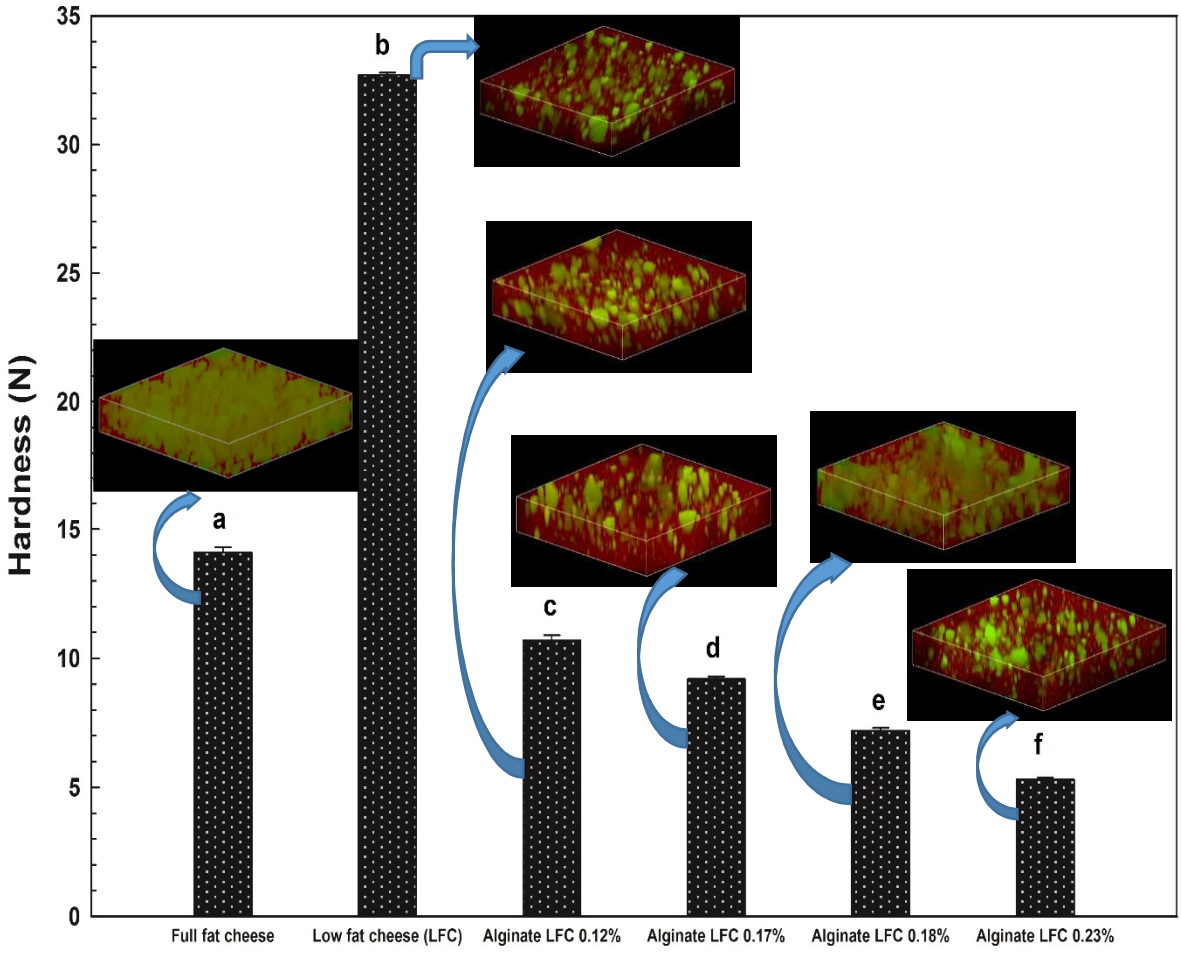
Hardness (N)
35
30
25
20
15
10
5
0
a
b
c
d
e
f
Full fat cheese
Low fat cheese (LFC)
Alginate LFC 0.12%
Alginate LFC 0.17%
Alginate LFC 0.18%
Alginate LFC 0.23%

Modifying textural and microstructural properties of low fat Cheddar cheese using sodium alginate

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Abstract

Low fat Cheddar cheese (LFC) with up to 91% fat reduction were prepared using four levels of sodium alginate (alginate): 0.12 (LFCA1), 0.17 (LFCA2), 0.18 (LFCA3) and 0.23% (w/w) (LFCA4). Control full fat cheese (CFFC) and control low fat cheese (CLFC) were used for comparison. Physical characteristics, namely texture profile, microstructure, transverse relaxation time (T_2) distribution (measured by low-field NMR) and color were analysed periodically during ripening until 180 days. Texture profile analysis illustrated a significant improvement in texture of alginate added LFC ($P<0.05$) as compared to CLFC. The textural attributes of LFCA1 ripened for 30 days were comparable to CFFC ripened for 60 days and beyond. A close resemblance in textural attributes between alginate added LFC and CFFC, not previously reported when using other fat replacers, was observed. Scanning electron micrograph (SEM) images revealed that alginate added LFCs had smoother surfaces as compared to CFFC and CLFC, and the dense and compact protein matrix characteristic of CLFC was not observed. Confocal laser scanning microscopy (CLSM) suggested that the fat particle size, area and volume were affected in all LFCs due to their lower fat level and these parameters increased during ripening in CFFC. NMR results revealed increase in higher mobility water fraction in alginate added cheese compared to CFFC and CLFC. Hunter *L, a* and *b* values for alginate added LFCs indicated that they were whiter than CLFC and less yellowish than CFFC at the beginning of ripening; the color of some of the alginate added LFCs was comparable to CFFC after 120 days of ripening. Overall, addition of alginate significantly improved the textural, microstructural properties and color of LFCs, affirming its potential as a promising texture modifier.

Key words: Low fat cheese; Cheese, Alginate; Cheddar; Rennet and Milk

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1 Introduction

Cheese contains complex matrix of milk protein, fat, lactose, water and minerals (Mistry & Anderson, 1993). Fat provides smoothness and it acts as a filler between protein network in cheese. Decreasing the fat content increases the density of protein network and decreases the moisture to protein ratio in cheese, which consequently increases the hardness in LFC (Johnson, 2016; Rogers, McMahon, Daubert, Berry, & Foegeding, 2010).Cheese develops undesirable hard and rubbery texture when fat is reduced (Mistry, 2001; Rogers et al., 2010; Zisu, 2005). Texture of a food material is an attribute resulting from a combination of physical and chemical properties, and is perceived mainly by the sense of touch, sight and hearing (Buffa, Trujillo, Pavia, & Guamis, 2001). Body and texture of cheese are important parameters for its consumer acceptance and are reflection of its microstructure (Buffa et al., 2001; Mistry & Anderson, 1993).

A clear understanding of the role of fat and its replacers in the development of cheese microstructure is imperative to produce LFC with smoother texture (Mistry & Anderson, 1993). There are several reports on the size and shape of milk fat particles in cheese visualized by scanning electron microscopy (SEM) (Cunha, Dias, & Viotto, 2010; Ong, Dagastine, Kentish, & Gras, 2011, 2012; Wang et al., 2014). Microstructure of reduced fat cheese and LFC revealed fewer fat particles in a large stretch of protein network, whereas full fat cheese exhibited the protein network interspersed with numerous fat particles (Drake, Boylston, & Swanson, 1996a). Furthermore, low fat hard cheese such as Cheddar may give a dull appearance due to reduction in light scattering properties of milk fat particles (Mistry & Anderson, 1993). Hence, color is also a very important parameter for the quality evaluation of cheese as it is regarded as a primary factor by the consumers when making a buying decision (Pinho, Mendes, Alves, & Ferreira, 2004).

Various modification techniques and strategies have been applied to produce LFC with characteristics comparable to its full fat counterpart (Banks, 2004; Chatli, Gandhi, & Singh, 2017; Drake & Swanson, 1995). Approaches towards improving LFC include increasing moisture to protein ratio (using various fat replacers), hydrolysing some proteins, altering protein-protein interactions and creating large filler phase (Banks, 2004; Mistry, 2001). Carbohydrate based fat replacers (starch, pectin, beta glucan, modified starch etc.) when added in cheese, strongly bind water (increasing the moisture to protein ratio) and work in a manner that mimics the mouth feel of fat (Aryana & Haque, 2001; Diamantino, Beraldo, Sunakozawa, & Penna, 2014). In addition, protein based (micro-particulated proteins, whey

protein isolate, gelatin, egg protein etc.) and fat based replacers have been used to manufacture LFC. Several researchers have reported improvement in textural properties of low-fat Cheddar cheese using fat replacers such as Dairy Lo™, Simplesse™, Novagel™ and Stellar™ and Avicel Plus® CM 2159 (Küçüköner, 1996), β-glucan (Konuklar, Inglett, Warner, & Carriere, 2004; Sahan, Yasar, Hayaloglu, Karaca, & Kaya, 2008) and lecithin (Drake, Truong, & Daubert, 1999). Among hydrocolloids, alginate can be used as a fat replacer. Few patents (Hine, 1994; Liot & Stenbaek, 2014; Merrill & Singh, 2014) provide reference to potential use of alginate (as a powder, micro gel or as a slurry) as an ingredient in low fat cheese, but details about its effect on textural and microstructural properties of cheese are lacking. No scientific published research study has utilized alginate alone as a fat replacer in a low-fat Cheddar cheese milk. A recent study has included alginate at a higher concentration (0.3%) to improve properties of low-fat Mozzarella cheese made from buffalo milk (Chatli et al., 2017). Effect of adding alginate on cheese microstructure was also not included in that study.

In this study, sodium alginate (alginate) was chosen as a fat replacer to prepare low-fat Cheddar cheese. It was hypothesized that the textural properties of LFCs would improve due to the higher water binding capacity of alginate. Furthermore, alginate gel particles (generated *in situ* due to cross-linking of alginate molecules by Ca^{2+} present in milk and any added calcium chloride) would act like hydrated filler particles in protein network of the LFC. Formation of *in situ* alginate particles in milk in the presence of Ca^{2+} has been confirmed by our recent study (Khanal, Bhandari, Prakash, & Bansal, 2017).

The objective of this study was to determine the effect of addition of alginate in the cheese milk on physical characteristics such as texture, microstructure and color of low fat Cheddar cheese and to compare those with the control full fat cheese (CFFC) and control low fat cheese (CLFC).

2 Materials and Methods

2.1 Materials

Commercially available skim milk (0.11g/100 g fat), cream (39.5 g/100 g fat) and skim milk powder (SMP) (moisture: 3.9 g/100 g, protein: 32.5 g/100 g, fat: 0.8 g/100 g, lactose: 55 g/100 g, minerals: 7.8 g/100 g) were used. Starter culture FD-DVS R-707 *(Lactococcus lactis subsp. lactis and Lactococcus lactis subsp. cremoris)* was obtained from Chr. Hansen Pty. Ltd., VIC, Australia. Rennet (Chymax plus, FPC, 200 IMCU /mL) was purchased from

Cheeselinks, VIC, Australia. Sodium alginate (Grindsted® alginate FD 155) was obtained from Danisco, NSW, Australia.

2.2 Cheese Making

Alginate added LFCs were manufactured using four levels of alginate. Table 1 shows six different formulations of milk used to prepare cheese including CFFC and CLFC. All samples were prepared in triplicate.

Cheddar cheese was prepared according to the method described by Bansal et al. (2009) with some modifications. Briefly, milk was standardised mixing skim milk and cream using Pearson's square method (Tamime & Robinson, 2007). Appropriate levels of stock solution (5 g/ 100 g) of alginate were added to milk to achieve the desired alginate concentration. Dilution of solids due to addition of alginate solution was compensated by adding skim milk powder. The final volume of cheese milk was 20 L for all formulations. The cheese milk was cooled and equilibrated to 32°C in cheese vats. FD-DVS R-707 culture was propagated in skim milk at 32°C (50 U / 500 mL) according to manufacturer's instructions. The propagated culture (0.1 g/100 g of cheese milk) was mixed with cheese milk homogenously followed by addition of $CaCl_2$ (1.5 mM) and then incubated at 32°C for 30 min. Rennet was added at a rate of 200 μL/1000 mL, then the milk was left for 45 min without any disturbance for coagulation. Curd was cut into cubes (1.5 cm^3 in size) after 45 min and healed for 10 min without stirring. Then the curd was cooked at 39°C until the pH reached 6.2, at which point the whey was drained. After whey drainage, the curd was cheddared until the pH reached 5.2. The curd was then milled, salted at 2.5% (w/w of the curd), moulded and pressed (550 kPa) for 18 h. The pressed cheese was vacuum-packed in air-tight plastic bags and ripened at 8°C. The cheese samples were analysed at day 7 (D7), day 30 (D30), day 60 (D50), day 120 (D120) and day 180 (D180) from the date of manufacture.

2.3 Compositional analysis

Moisture (Vacuum oven, 925.10), fat (Gerber method, 989.05,), protein (Kjeldhal method, 2001.14) and total ash (muffle furnace, 923.03) content in cheese were determined according to method described in AOAC (2005). All compositional parameters of cheese were determined at D7 of ripening period.

2.4 Texture profile analysis (TPA)

TPA was conducted according to Lashkari, Khosrowshahi Asl, Madadlou, & Alizadeh (2014) with some modifications using TA-XT2 Texture Analyser (Stable Micro Systems, UK). A

flat probe of 35 mm diameter was attached to the moving cross head. Cylindrical cheese samples (12 × 10 mm), taken from a depth of 5 mm in the cheese block at 8˚C with a cork borer, were placed in air-tight plastic bags, kept refrigerated at 4°C for 4 h to equilibrate and then set aside at 21 ± 1°C for 45 min. Samples were compressed in two cycle tests at a speed of 1.2 mm/sec with 33% deformation from the initial height of the sample. Textural parameters such as hardness, cohesiveness, gumminess, chewiness and springiness were determined. Cheese samples were analysed for textural attributes at D7, D30, D60, D120, D180 of the ripening period. Hardness (N) was recorded as the maximum force during the first compression cycle. Springiness was the height regained after the first compression. Cohesiveness was considered as the ratio of positive force area under the second and first compression cycle. Gumminess was calculated as hardness × cohesiveness and chewiness was calculated as gumminess × springiness (Frau, Simal, Femenia, Sanjuán, & Rosselló, 1999). Each sample was analysed in duplicate.

2.5 Color measurement

Color measurements on cheese were made using Minolta Konica Chroma Meter CR-400 (Konica Minolta, INC, Japan). Hunter *L*, *a* and *b* values for color measurements were determined. The instrument was calibrated with a white tile (Y = 94.93, x = 0.3131, y = 0.3197) (Pinho et al., 2004). Duplicate analysis was carried out for each sample.

2.6 Microstructure analysis

2.6.1 Confocal laser scanning microscopy (CLSM) and image analysis

Microstructure of cheese was analysed using Olympus Fluoview FV1000 BX2 upright confocal laser scanning microscope (CLSM, Zeiss, Berlin, Germany). Cheese samples were prepared according to Auty, Twomey, Guinee, & Mulvihill (2001) with some modifications. Briefly, cheese samples were cut into 10 mm × 10 mm × 1 mm thick strips with a razor blade. Nile Red (1 mg/10 g in ethanol) was used to label the fat and Rhodamine B (10 mg/100 g in ethanol) was used to label the protein in cheese. To see the dual images of both fat and protein, mixtures of Rhodamine B and Nile red (1:1) were used. Samples were examined using 63× magnification objective and confocal illumination was obtained by an air-cooled Ar/Kr laser. Rhodamine B was excited at 555 nm and Nile red was excited at 488 nm. The pinhole diameter was 1 Array Unit. RGB color images (8-bit, 1024 pixel in size) were acquired using a zoom factor of 1 with averaging of 2. Zen software was used to acquire digital images. Images obtained from two different wavelengths were combined in the

overlaid images in which Rhodamine B stained protein appeared red, Nile red stained fat appeared green and air pockets along with voids appeared black.

CLSM micrographs were analysed using ImageJ Software (Research Services Branch, Maryland, U.S.A.). Particle counts, area covered and average size of fat particles were determined using "Analyse particles" menu of ImageJ software. During image analysis, Pixel (1024) and area of the sample (101.6 µm) were used to set the scale of the images. The images were then flattened using band pass filters and adjusted with the color threshold to transform it to a binary image with all fat particles appearing as black pixels and all protein appearing as white pixels. The average area, count and average size of fat particles calculated were only representative of 2D images of the cheese and not the absolute of the whole cheese samples. Bins for the range of different sized data of fat particles were created from all the images to construct histograms to illustrate the distribution of fat particles in cheese. This method has been previously used to compare mean diameter of fat particles obtained from laser diffraction and CLSM (Ong, Dagastine, Kentish, & Gras, 2010). Image analysis of 3D images was carried out by (Fiji Is Just) ImageJ (Laboratory for Optical and Computational Instrumentation, Wisconsin, USA). Images were opened in a green (fat) channel by splitting the channels and processed by median filter of 2-pixel radius. Images were subjected to thresholding process prior to determining the volume occupied by fat particles in 3D images by 3D object counter. Six replicates micrographs of each treatment of cheese were used for image analysis.

2.6.3 Scanning electron microscopy (SEM)

SEM imaging was carried out according to Aryana & Haque (2001). Briefly, the cheese samples were sliced in 1 mm × 1 cm × 1 cm strips. Samples were first fixed in 2.5% glutaraldehyde (solution prepared in water at pH 5.5) overnight at room temperature and washed three times with water for 10 minutes for each wash. Then, samples were dehydrated with series of ethanol concentrations from 10 to 100%. Dehydration was performed for 10 minutes for each ethanol concentration. The samples were then frozen and fractured under the liquid nitrogen with a cooled razor blade. Fractured samples were thawed in 100% ethanol followed by washing in fresh ethanol. Finally, samples were critical point dried in a Tousimis Autosamdri 815 (Tousimis Automatic, Rockville, USA). Samples were mounted on stubs with double-sided carbon sticky tape and coated with a thin layer (15 mm thickness) of iridium in a Baltek iridium coater (Baltek, USA). A high vacuum SEM (Philips XL30 scanning electron microscope) (Philips, Tokyo, Japan) at 10 kV was used to view each

sample at a magnification of 4000×. The SEM was used to visually compare the images of different cheese samples.

2.6.4 Low field-nuclear magnetic resonance (LF-NMR)

The moisture and fat distribution in cheese samples (CFFC, CLFC and LFCA1 at 180 d ripening time) measured as transverse relaxation time (T_2) was determined by LF-NMR. The T_2 has been used to represent the water retention in cheese and indicates interactions of protons within its vicinity (Lilbæk et al., 2006). LF-NMR measurement was performed using a MesoMR23-060V-I NMR analysing system (Niumag Corporation, Shanghai, China) equipped with 25 mm diameter probe. The magnetic field strength was 0.52 ± 0.05 T and the corresponding resonance frequency for protons was 21.3 MHz. Approximately 0.5 g of sample was placed in NMR tube and then inserted in to NMR probe. The T_2 was measured using the Carr-Purcell-Meiboom-Gill (CPMG) sequence with 3000 echoes and 4 scan repetitions. The SIRT algorithm was employed in the 100,000-iterative fitting. The intensity of the resulting T_2 distribution spectrum was normalized by the weight of sample. All the measurements were performed in duplicate.

2.7 Statistical analysis

Data analysis was performed using Minitab-16 statistical software (Minitab Inc., USA). General linear model of analysis of variance (ANOVA) and Tukey's comparison was used to study differences between means at 95% confidence limit ($P<0.05$).

3 Results and discussions

3.1 Compositional analysis of cheese

Composition of different cheese samples is shown in Table 2. As expected, significant difference ($P<0.05$) in moisture, fat and protein content was observed in all LFCs compared to that of CFFC. There was a reduction in fat content by 84, 90, 91, 82.5, and 87 % in CLFC, LFCA1, LFCA2, LFCA3 and LFCA4, respectively, compared to that of CFFC. Higher level of protein in all LFCs in this study was in accordance with the findings of Aryana & Haque (2001); Kumar et al. (2011) and Kavas, Oysun, Kinik, & Uysal (2004). Higher amount of protein and moisture in LFCs were also reported by other researchers when using different fat replacers such as Simplesse®D-100, starch and Dairy-Lo™ (Katsiari & Voutsinas, 1994; Koca & Metin, 2004; Lobato-Calleros, Ramírez-Santiago, Vernon-Carter, & Alvarez-Ramirez, 2014). Moisture content was increased in alginate added LFCs due to higher water

holding capacity of the alginate. Owing to higher water retention capacity of fat replacers, the driving force involved to expel the water from the cheese curd is lowered (McMahon, Alleyne, Fife, & Oberg, 1996).

3.2 Texture profile analysis (TPA) of cheese

All cheese samples were analysed for the textural parameters during ripening from D7 to D180 (Table 3). At D7, alginate added LFCs showed significantly ($P<0.05$) lower hardness, chewiness and gumminess than CLFC and CFFC, whereas their cohesiveness and springiness did not differ from that of CFFC, except LFCA3 (for springiness).

When hardness was compared over the ripening period from D30 to D180, it decreased significantly ($P<0.05$) in all cheese samples as ripening progressed. At each ripening time, the hardness, gumminess and chewiness of CLFC were significantly higher ($P<0.05$) than CFFC, whereas all alginate added LFCs demonstrated significantly ($P<0.05$) softer, less gummy and less chewy characteristics than both CFFC and CLFC. The textural attributes demonstrated were improved with increasing alginate concentration, LFCA4 being least hard, gummy and chewy at each time point. From D30 onwards, the textural attributes of LFCA1 were comparable to that of CFFC that was matured for longer than 60 days. For example, the hardness of LFCA1 at D30 was comparable to that of CFFC at D60 and so on. Increased hardness in CLFC compared to CFFC was associated with reduction in fat content and the resulting high protein density which makes the cheese highly resistant to deformation (Cunha et al., 2010). The decrease in hardness in alginate added LFCs could be attributed to alginate's capacity to bind water, thus increasing the moisture content of cheese, and to form discrete gel particles in situ in the presence of Ca^{2+} in cheese milk (Khanal et al., 2017) where fat replacers are used, water plays a role of plasticizer in between protein molecules and thus makes the cheese softer (Sahan et al., 2008). In addition, interactions between protein and polysaccharide are crucial to develop the structure and stability of the product, and types of polysaccharide and their charge are responsible to govern the nature of these interactions (Hosseini et al., 2013). Furthermore, higher protein content is another factor for the harder texture in CLFC. Sahan et al. (2008) illustrated decrease in gumminess in low fat Kashar cheese added with Avicel Plus® CM 2159 or β-glucan; and Volikakis, Biliaderis, Vamvakas, & Zerfiridis (2004) with commercial oat β-glucan. According to Sahan et al. (2008), reduction in gumminess was caused by the removal of fat from cheese.

Springiness did not change in each sample over the ripening period from D30 to D120. Similar observation was reported by Sahan et al. (2008) with other fat replacers in low fat

Kashar cheese. Springiness decreased ($P<0.05$) in LFCA3 and LFCA4 as compared to CFFC and CLFC at D120 and onwards, while no significant differences were observed between LFCA1, LFCA2, CFFC and CLFC at all time points. Addition of alginate affected the cohesiveness of cheese (Table 3), but the effect was dependent on the concentration of alginate and the age of cheese. CLFC was more cohesive ($P<0.05$) than CFFC at all time points of ripening period. LFCA1 was more cohesive than CFFC until D120, whereas LFCA2, 3 and 4 were not different with CFFC. At D180, no differences in cohesiveness was detected between alginate added LFCs and CFFC. The denser protein matrix in CLFC is associated with higher springiness and cohesiveness (Lobato-Calleros, Robles-Martinez, Caballero-Perez, & Vernon-Carter, 2000). With increasing quantity of alginate in cheese, cohesiveness decreased as compared to CLFC and became similar to CFFC. Other fat replacers such as β-glucan concentrate (Volikakis et al., 2004), Simplesse® D-100 and Novagel™ NC-200 (Romeih, Michaelidou, Biliaderis, & Zerfiridis, 2002) have been also associated with the decrease in cohesiveness in different types of LFCs..

Results of TPA suggested that there was a continuous improvement in all textural parameters in all cheeses during ripening from D7 to D180 and this was due to on-going proteolysis (Romeih et al., 2002). Textural attributes changed with increased alginate concentration and similar trends were reported by adding other fat replacers such as lecithin (Drake et al., 1999), Simplesse® and Dairy-Lo™ (Kavas et al., 2004), β-glucan hydrocolloid suspension (Konuklar, Inglett, Carriere, & Felker, 2004) and soy protein isolate. Increase in alginate concentration formed softer rennet gel and resulted in lower G' in our previous study, indicating alginate particles acted as fillers in protein matrix to soften the texture of gel (Khanal et al., 2017). Texture of cheese is directly influenced by water holding capacity (WHC) of the rennet gel. The WHC of protein gels is influenced by the interactions between milk proteins and sodium alginate. Protein-polysaccharide interactions that affect WHC capacity include electrostatic forces, hydrogen bonds, covalent bonds, excluded volume, hydrophobic interactions, ionic bridging and Van der Waals interactions (Chen, Chen, & Hsieh, 2016; Yao et al., 2018). In case of alginate, interaction is facilitated by hydrophobic or hydrogen bonding between proteins and its hydroxyl groups of mannuronic or guluronic acid residues (Chen et al., 2016).

The TPA parameters of LFCA1 closely resembled to those of CFFC; such a close resemblance in textural parameters of a low fat cheese with full fat cheese has not been

previously reported when using other fat replacers (Drake, Herrett, Boylston, & Swanson, 1996b; Koca & Metin, 2004; Konuklar, Inglett, Carriere, et al., 2004; Oliveira et al., 2010).

3.2 Color measurement

Comparison of Hunter *L*, *a* and *b* values within each time point of ripening period revealed significantly lower ($P<0.05$) *L* and *b* values of all LFCs than those of CFFC (Table 4), CLFC being the lowest, indicating they were darker and less yellow as compared to CFFC. Similar decrease in *L* value was also reported by Deegan, Holopainen, McSweeney, Alatossava, & Tuorila (2014) in reduced fat cheese. Significantly lower *b* value in CLFC was due to the difference in yellowness attributed to low fat percentage as compared to CFFC (Cunha et al., 2010). Deep yellow color in CFFC is due to effective light scattering by large amounts of fat globules (Deegan et al., 2014). The *L* and *b* values increased by increasing alginate concentration in LFCs. The *L* value of LFCA2, LFCA3 and LFCA4 at D120; and LFCA3 and LFCA4 at D180 were not significantly different ($P>0.05$) to CFFC. Increase in lightness (L value) by adding alginate was attributed to increase in moisture to protein ratio, which subsequently increases the surface area occupied by scattering centres (Rahimi, Khosrowshahi, Madadlou, & Aziznia, 2007). Furthermore, similar increase in *L* value have also been reported using gum tragacanth and Salatrim® as fat replacers in low and reduced fat Mozzarella cheese by Rahimi et al. (2007) and by Rudan, Barbano, & Kindstedt (1998) in low fat white brined cheese. All LFCs showed significantly ($P<0.5$) higher *a* values (negative) compared to that of CFFC at D7, D30 and D60 but not at D120 and D180. The negative *a* value found in this study indicated tendency of the samples towards green color (Pinho et al., 2004). During ripening, the difference between L values of CFFC and LFCA3 and LFCA4 were narrowing and the LFCA4 was not significantly ($P<0.05$) different than the CFFC at D120 and D180.

3.4 Cheese Microstructure

Representative 2D (Figures 1, 2 and 3) and 3D CLSM images (Figures 4 and 5) clearly demonstrates that CFFC samples exhibited more fat particles (as expected) and the number of fat particles decreased in all LFCs samples. Fat particles are more scattered in D7 samples (as seen in both 2D and 3D images) and coalesced as ripening progressed, especially in CFFC due to the presence of higher amount of fat as compared to LFC samples. Pronounced clumping and coalescence of fat particles have been previously reported with increased fat content in cheese (Guinee, Auty, & Fenelon, 2000). The 2D images were further analysed to

determine parameters such as area, size and numbers of fat particles, whereas 3D images were used to determine their volume.

Image analysis of CLSM micrographs revealed abundant numbers of small particles (ranging from up to0.5 µm) in all cheese samples throughout the ripening process (Figures 6, 7 and 8). Fat particles of >0.6 µm were present in larger number in CFFC as compared to LFCs. As evident in their respective 2D and 3D images, the size of fat particles in CFFC profoundly increased during ripening from D7 to D180 whereas their size in LFCs increased subtly.

Fat particles in all LFCs were significantly smaller ($P<0.05$) in size, area (in 2D images) and volume (in 3D images) as compared to CFFC over the ripening period (Figures 9 A and B and D). The size and area of the fat particles increased ($P<0.05$) from D7 to D180 in CFFC but not in LFCs. The volumes, area and size of fat particles in alginate added LFCs were not different from CLFC (except LFCA2 for volume), suggesting alginate did not affect these parameters. The fat particles in this study were larger as the cheese milk was not homogenized. Results by Ong et al. (2010) also reported larger fat particles (the mean diameters of up to 9 µm) for raw un-homogenised milk. Large numbers ($P<0.05$) of fat particles were present in CFFC at D7 and D120 as compared to D180 (Figure 9 C). Wang, Li, Wang, & Özkan (2010) also reported total numbers and area covered by fat particles in CFFC were higher due to inclusion of more amount of fat in milk used for cheese preparation. At D180, number of fat particles detected in CFFC and all LFCs samples were not different, possibly due to coalescence of fat particles in CFFC during cheese ripening.

Though CLSM provided information regarding difference in effect on fat particle size, area and volume in all LFCs compared to that of CFFC, we could not able to observe alginate particles by CLSM despite the use of alginate specific staining. Hence, images were further viewed through SEM in an attempt to visualise the alginate. The alginate was not observed in SEM either (Figure 10). However, SEM images revealed (Figure 10) increased smoothness in cheese with increasing alginate concentration and no noticeable phase separation between protein and alginate was seen. Due to de-lipidation during sample preparation for SEM, voids spaces were left intact where fat particles used to be in the samples (Aryana & Haque, 2001). This fact is further evident by CFFC showing more and larger voids and more open structure as compared to LFCs. On the other hand, there was a dense protein network with less numbers of voids present in CLFC. Similar microstructural images were also observed by Diamantino et al. (2014); and Lobato-Calleros et al. (2007) for CFFC and CLFC. The surface

of the LFCA1 displayed an increase in porous and spongy character, smoothness and cohesive appearance, this porous microstructure could provide more space for water entrapment and result in a softer texture. Addition of alginate could have interfered with the aggregation of caseins resulting in the formation of inhomogeneous casein network with porous and smooth microstructure. Also, alginate being negatively charged polysaccharide interacts with positively charged proteins at low pH and forms highly structured open porous protein network (Chen et al., 2016). The protein network seemed to be covered over in a cheese having higher alginate concentration. Some small white aggregates were scattered over the protein network (indicated by red arrow in Figure 10) in all alginate added LFCs. Such aggregates were also noted by Drake et al. (1996b) when using lecithin as a fat replacer in reduced fat cheese.

3.5 LF-NMR results

Fig. 11 shows the transverse relaxation time (T_2) spectra of CFFC, CLFC and LFCA1. The T_2 and the corresponding peak area can reflect the mobility and distribution of molecules (e.g., water and fat) containing hydrogen protons in a cheese matrix, respectively. A longer transverse relaxation time indicates lower binding energy and higher mobility of molecules containing hydrogen protons. The cheese matrix affects the relaxation of protons in water owing to interactions between macromolecules and water. Hence, different states of water molecules yield a spectrum of transverse relaxation time (T_2) (Altan, Oztop, McCarthy, & McCarthy, 2011). The relaxation is not only affected by water translation and rotation of molecules, chemical exchange between water molecules and biopolymers or other solutes also have an impact on it (Gianferri, Maioli, Delfini, & Brosio, 2007).

Multiple relaxation times in cheese are due to its heterogeneous matrix. The protons in less mobile and more mobile fractions of water in cheese corresponds to the components with shorter and longer relaxation time, respectively (Altan et al., 2011). Generally, three peaks were observed in the T_2 distribution spectrum of cheese samples. The first peak (T_{21}) between the shortest relaxation time of 0.05-2 ms corresponded to protons of the tightly bound water molecules accumulated in the large open channel of the protein network (Bordoni et al., 2011). The second peak (T_{22}) between the medium relaxation time of 3-30 ms was designated to protons of water molecules entrapped inside the protein gel- network within the cheese matrix (Gianferri et al., 2007). Finally, the third peak (T_{23}) between the longest relaxation time of 40-400 ms was ascribed to protons of fat molecules within the cheese matrix. As shown in Table 5, no significant differences were observed in T_{21}, T_{22} and T_{23} relaxation

times between CLFC and CFFC, while the T_{21}, T_{22} and T_{23} relaxation times of LFCA1 were longer than CLFC and CFFC, suggesting a higher mobility of water and lipid molecules in LFCA1. This relaxation time data was in accordance with the moisture data in Table 2. Moreover, no significant differences were observed in T_{21} peak area between LFCA1 and CLFC, while the T_{21} (A_{21}) peak area of LFCA1 and CLFC was larger than that of CFFC, which might be attributed to the lower number of hydrophilic compounds (e.g., protein and water) in CFFC. For the major peak T_{22} (A_{22}), the peak area was not significantly different between CLFC and CFFC, while the corresponding peak area of LFCA1 was significantly ($P<0.05$) larger compared to CLFC and CFFC. Therefore, these results suggested that the increase in water content in alginate added low-fat cheese was mainly caused by an increase in the amount of water in fraction T_{22}. This increase in higher mobility water fraction in LFCA might be responsible for its softer texture (Table 3). In addition, the T_{23} peak area of LFCA1, CLFC and CFFC were generally in agreement with the corresponding fat content (Table 2). The relaxation time of cheese is sensitive to the level of water and ratio of protein to water (Chaland, Mariette, Marchal, & De Certaines, 2000). Similar kind of easily distinguishable relaxation time for fat and water proton molecules was reported by Chaland et al. (2000) in cheese samples.

4. Conclusions

This study investigates the effect of adding alginate to the development of texture, colour and microstructure of LFCs. Present results indicated that fat reduction in cheese led to increase in hardness, denser microstructure and poor color development. Addition of alginate in LFCs improved these attributes, making alginate added cheese (at as low as 0.12% addition) comparable to CFFC. Furthermore, alginate added LFCs were softer, more cohesive, chewier and smoother than CLFC and CFFC; and one of the combinations (LFCCA1) closely resembled CFFC in terms of textural parameters. It was possible to see the relaxation time of water protons and fat protons by LF-NMR and provided insights into the existence of fat and water in cheese. NMR results verified presence of high amount of higher mobility water in alginate added LFC which might contribute to its softer texture. Study on digestibility, tribology and sensory properties of alginate added LFCs will be the focus of future research.

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597 PhD Thesis), Victoria University, Werribee Campus, VIC, Australia.

598 Table 1. Composition of milk and levels of alginate used for Cheddar cheese making.

S N	Samples code	Fat (g / 100 g)	Protein (g / 100 g)	Added (g / 100 g)
1	Full fat control cheese (CFFC)	2.92 ± 0.02^{a}	3.54 ± 0.09^{a}	0
2	Low fat control cheese (CLFC)	0.44 ± 0.02^{b}	3.70 ± 0.13^{a}	0
6	Low fat cheese (LFCA1)	0.48 ± 0.01^{b}	3.60 ± 0.06^{a}	0.12
7	Low fat cheese (LFCA2)	0.47 ± 0.01^{b}	3.68 ± 0.12^{a}	0.17
3	Low fat cheese (LFCA3)	1.08 ± 0.01^{c}	3.74 ± 0.06^{a}	0.18
4	Low fat cheese (LFCA4)	1.04 ± 0.02^{c}	3.78 ± 0.08^{a}	0.23

599 Fat and protein content are expressed as the mean ± standard error (n = 6). Means in a single
600 column with different superscripts are significantly different ($P<0.05$).

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Table 2. Composition of Cheddar cheese with or without added alginate at different levels.

Cheese	Total fat (g/100g)	Total protein (g/100g)	Moisture (g/100g)	Ash (g/100g)
CFFC	31.5 ± 0.7^{a}	29.5 ± 0.6^{d}	34.5 ± 0.5^{d}	4.8 ± 0.1^{b}
CLFC	5.0 ± 0.2^{bc}	42.2 ± 0.6^{a}	41.9 ± 0.5^{c}	5.9 ± 0.2^{a}
LFCA1	3.1 ± 0.2^{d}	35.8 ± 0.5^{b}	50.3 ± 0.3^{b}	5.6 ± 0.02^{a}
LFCA2	2.7 ± 0.1^{d}	35.6 ± 0.4^{b}	51.7 ± 0.7^{b}	5.5 ± 0.1^{a}
LFCA3	5.5 ± 0.4^{b}	33.0 ± 0.3^{c}	52.1 ± 0.3^{b}	4.9 ± 0.03^{b}
LFCA4	3.8 ± 0.1^{cd}	31.7 ± 0.4^{c}	54.6 ± 0.5^{a}	4.8 ± 0.1^{b}

All results are expressed as the mean ± standard error (n = 6). Means in a single column with different superscripts are significantly different (P<0.05). DB is on dry basis.

649 Table 3. Textural characteristics of Cheddar cheese with or without added alginate at
650 different levels obtained by texture analyser.

Ripening time	Sample	Hardness (N)	Springiness	Gumminess (N)	Chewiness	Cohesiveness
D7	CFFC	39.79 ± 0.9^{B}	0.94 ± 0.0^{A}	28.38 ± 0.70^{B}	26.88 ± 0.5^{B}	0.71 ± 0.03^{B}
	CLFC	55.19 ± 0.70^{A}	0.92 ± 0.01^{AB}	45.82 ± 1.3^{A}	42.03 ± 1.6^{A}	0.82 ± 0.02^{A}
	LFCA1	32.85 ± 0.40^{C}	0.94 ± 0.01^{AB}	24.06 ± 0.8^{C}	22.60 ± 0.7^{C}	0.73 ± 0.02^{B}
	LFCA2	26.26 ± 0.31^{D}	0.91 ± 0.003^{AB}	20.24 ± 0.31^{D}	18.45 ± 0.4^{D}	0.77 ± 0.01^{AB}
	LFCA3	24.15 ± 0.72^{D}	0.90 ± 0.01^{B}	18.19 ± 1.0^{DE}	16.42 ± 1.1^{DE}	0.75 ± 0.02^{AB}
	LFCA4	20.04 ± 0.95^{E}	0.92 ± 0.01^{AB}	14.81 ± 0.42^{E}	13.67 ± 0.5^{E}	0.73 ± 0.01^{B}
D30	CFFC	21.70 ± 0.30^{d}	0.97 ± 0.007^{a}	17.81 ± 0.24^{d}	17.26 ± 0.21^{d}	0.82 ± 0.82^{defgh}
	CLFC	44.55 ± 0.45^{a}	0.95 ± 0.003^{abc}	39.52 ± 0.47^{a}	37.72 ± 0.40^{a}	0.89 ± 0.88^{a}
	LFCA1	18.17 ± 0.11^{ef}	0.95 ± 0.004^{abc}	15.70 ± 0.07^{e}	15.02 ± 0.06^{e}	0.86 ± 0.86^{abc}
	LFCA2	15.26 ± 0.33^{h}	0.91 ± 0.003^{bcdefgh}	12.78 ± 0.28^{g}	13.14 ± 0.56^{g}	0.84 ± 0.83^{cdef}
	LFCA3	8.22 ± 0.09^{lm}	0.92 ± 0.02^{bcdefgh}	6.76 ± 0.10^{kl}	6.20 ± 0.17^{kl}	0.82 ± 0.82^{defgh}
	LFCA4	6.27 ± 0.04^{no}	0.90 ± 0.01^{defgh}	5.19 ± 0.06^{mn}	4.71 ± 0.08^{mn}	0.82 ± 0.82^{defg}
D60	CFFC	19.01 ± 0.20^{e}	0.95 ± 0.01^{abcd}	15.34 ± 0.25^{ef}	14.56 ± 0.32^{ef}	0.80 ± 0.006^{fgh}
	CLFC	44.64 ± 0.23^{a}	0.95 ± 0.004^{abc}	39.60 ± 0.42^{a}	37.78 ± 0.48^{a}	0.89 ± 0.006^{a}
	LFCA1	17.00 ± 0.09^{g}	0.92 ± 0.0^{abcdefg}	14.67 ± 0.12^{ef}	13.62 ± 0.11^{fg}	0.86 ± 0.005^{abc}
	LFCA2	14.10 ± 0.23^{i}	0.92 ± 0.005^{abcdefg}	11.95 ± 0.23^{gh}	11.09 ± 0.22^{h}	0.85 ± 0.003^{bcd}
	LFCA3	8.10 ± 0.06^{m}	0.91 ± 0.007^{bcdefgh}	6.70 ± 0.03^{kl}	6.14 ± 0.06^{kl}	0.83 ± 0.005^{defg}
	LFCA4	5.70 ± 0.08^{o}	0.90 ± 0.01^{efgh}	4.66 ± 0.07^{mn}	4.18 ± 0.05^{mn}	0.82 ± 0.002^{defgh}
D120	CFFC	17.93 ± 0.21^{fg}	0.96 ± 0.01^{ab}	14.43 ± 0.30^{e}	13.86 ± 0.41^{efg}	0.81 ± 0.01^{gh}
	CLFC	$37\ 41 \pm 0.25^{b}$	0.93 ± 0.01^{abcdefg}	32.70 ± 0.35^{b}	30.50 ± 0.37^{b}	0.87 ± 0.005^{ab}
	LFCA1	14.91 ± 0.22^{hi}	0.92 ± 0.005^{abcdefg}	12.47 ± 0.19^{gh}	11.50 ± 0.20^{h}	0.85 ± 0.003^{bcde}
	LFCA2	12.32 ± 0.1^{j}	0.92 ± 0.007^{bcdefgh}	10.11 ± 0.06^{i}	9.3 ± 0.10^{i}	0.82 ± 0.008^{defgh}
	LFCA3	7.2 ± 0.12^{mn}	0.89 ± 0.008^{gh}	5.7 ± 0.09^{lm}	5.10 ± 0.11^{lm}	0.80 ± 0.006^{h}
	LFCA4	5.41 ± 0.11^{o}	0.89 ± 0.009^{efgh}	4.30 ± 0.06^{n}	3.85 ± 0.07^{mn}	0.80 ± 0.008^{h}
D180	CFFC	14.1 ± 0.18^{i}	0.94 ± 0.07^{abcde}	11.50 ± 0.17^{h}	10.8 ± 0.17^{h}	0.82 ± 0.008^{efgh}
	CLFC	32.7 ± 0.10^{c}	0.94 ± 0.009^{abcdef}	28.3 ± 0.14^{c}	26.6 ± 0.26^{c}	0.90 ± 0.002^{abc}
	LFCA1	10.7 ± 0.20^{k}	0.91 ± 0.006^{cdefgh}	8.9 ± 0.17^{j}	8.1 ± 0.18^{ij}	0.83 ± 0.004^{defg}
	LFCA2	9.2 ± 0.09^{l}	0.92 ± 0.007^{bcdefgh}	7.5 ± 0.10^{k}	6.9 ± 0.08^{jk}	0.81 ± 0.00^{fgh}
	LFCA3	7.2 ± 0.13^{mn}	0.90 ± 0.008^{fgh}	5.7 ± 0.09^{lm}	5.10 ± 0.07^{lm}	0.80 ± 0.007^{h}
	LFCA4	5.3 ± 0.11^{o}	0.87 ± 0.01^{h}	4.23 ± 0.10^{n}	3.4 ± 0.09^{n}	0.80 ± 0.007^{h}

651 All results are expressed as the mean ± standard error (n = 6). Means in a single column with
652 different superscripts are significantly different ($P<0.05$).
653 ^{abc} denotes comparison between cheeses over the time period from D30 to D180.
654 ^{ABC} denotes comparison between cheeses at D7.
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Table 4. Haunter L, a and b values of cheese obtained by colorimeter.

Ripening time	Samples	*L*	*a*	*b*
Day 7	CFFC	65.5 ± 0.4^{a}	-5.5 ± 0.4^{b}	20.9 ± 0.9^{a}
	CLFC	44. 4 ± 1.8^{e}	-4.4 ± 0.3^{a}	9.9 ± 0.6^{d}
	LFCA1	52.7 ± 0.5^{d}	-4.9 ± 0.3^{a}	11.3 ± 0.4^{c}
	LFCA2	58.2 ± 0.4^{c}	-4.8 ± 0.2^{a}	12.5 ± 0.9^{b}
	LFCA3	58.7 ± 0.4^{c}	-4.4 ± 0.2^{a}	12.7 ± 0.3^{b}
	LFCA4	60.7 ± 0.9^{b}	-4.8 ± 0.2^{a}	12.6 ± 0.3^{b}
Day 30	CFFC	64.2 ± 1.8 ^{a}	-5.2 ± 0.4^{b}	20.8 ± 0.3^{a}
	CLFC	45.6 ± 0.9^{d}	-4.5 ± 0.4^{a}	8.5 ± 0.2^{d}
	LFCA1	53.5 ± 1.4^{c}	-4.3 ± 0.3^{a}	11.0 ± 0.4^{c}
	LFCA2	54.0 ± 0.6^{c}	-4.4 ± 0.2^{a}	11.0 ± 0.7^{c}
	LFCA3	58.6 ± 1.2^{b}	-4.4 ± 0.1^{a}	12.2 ± 0.7^{b}
	LFCA4	58.3 ± 0.8^{b}	-4.4 ± 0.2^{a}	12.0 ± 0.7^{b}
Day 60	CFFC	63.1 ± 2.3^{a}	-5.5 ± 0.2^{a}	20.1 ± 1.5^{a}
	CLFC	46.2 ± 0.6^{d}	-4.6 ± 0.3^{b}	8.1 ± 0.4^{c}
	LFCA1	54.6 ± 1.2^{c}	-4.6 ± 0.2^{a}	11.0 ± 1.0^{b}
	LFCA2	54.8 ± 1.2^{c}	-4.5 ± 0.58^{a}	10.7 ± 0.3^{b}
	LFCA3	58.3 ± 2.2^{b}	-4.4 ± 0.2^{a}	11.9 ± 0.7^{b}
	LFCA4	58.8 ± 0.4^{b}	-4.6 ± 0.3^{a}	11.7 ± 1.1^{b}
Day 120	CFFC	64.5 ± 1.0^{a}	-4.9 ± 0.3^{a}	21.0 ± 1.5^{a}
	CLFC	48.7 ± 0.7^{c}	-4.4 ± 0.04^{a}	12.1 ± 1.5^{d}
	LFCA1	59.6 ± 1.0^{b}	-4.9 ± 0.2^{a}	15.4 ± 0.8^{c}
	LFCA2	65.9 ± 0.9^{a}	-5.2 ± 0.1^{a}	17.1 ± 0.7^{bc}
	LFCA3	65.9 ± 0.7^{a}	-4.8 ± 0.3^{a}	18.8 ± 0.8^{b}
	LFCA4	65.8 ± 0.4^{a}	-5.2 ± 0.2^{a}	17.5 ± 0.9^{b}
Day 180	CFFC	66.0 ± 1.1 ^{a}	-4.4 ± 0.1^{a}	21.6 ± 0.5^{a}
	CLFC	49.2 ± 0.2^{c}	-4.0 ± 0.1^{a}	10.6 ± 0.2^{d}
	LFCA1	56.9 ± 1.2^{b}	-4.2 ± 0.1^{a}	13.0 ± 0.3^{c}
	LFCA2	58.7 ± 0.3^{b}	- 4.2 ± 0.2^{a}	13.5 ± 0.4^{c}
	LFCA3	65.9 ± 0.7^{a}	-4.5 ± 0.04^{a}	16.3 ± 0.2^{b}
	LFCA4	64.1 ± 0.1^{a}	-4.3± 0.3^{a}	14.8 ± 1.0^{bc}

All results are expressed as the mean ± standard error (n = 6). Means in a single column within a ripening time block with different superscripts are significantly different (P<0.05).

Table 5. The transverse relaxation time (T_2) and corresponding peak area.

Cheese	Relaxation time			Peak area		
	T_{21}	T_{22}	T_{23}	A_{21}	A_{22}	A_{23}
CFFC	0.5 ± 0.0^{a}	9.3 ± 0.0^{a}	81.3 ± 8.0^{a}	382 ± 25^{a}	2157 ± 30^{a}	627 ± 42^{a}
CLFC	0.4 ± 0.1^{a}	9.3 ± 0.0^{a}	93.5 ± 9.2^{a}	536 ± 56^{b}	2099 ± 176^{a}	79 ± 25^{b}
LFCA1	0.7 ± 0.3^{b}	14.2 ± 0.0^{b}	251.6 ± 140.8^{b}	476 ± 43^{c}	2521 ± 78^{b}	21 ± 5^{c}

Relaxation time are expressed as the mean ± standard error (n = 6). Means in a single column with different superscripts are significantly different ($P<0.05$).

720 **Figure captions**

721 Figure 1. 2D images of cheese samples at D7 obtained from CLSM. Images from A to F are
722 CFFC, CLFC, LFCA1, LFCA2, LFCA3, LFCA4 cheese samples, respectively. The fat
723 particles and protein network are stained green and red, respectively.

724 Figure 2. 2D Images of cheese samples at D120 obtained from CLSM. Images from A to F
725 are CFFC, CLFC, LFCA1, LFCA2, LFCA3, LFCA4 cheese samples, respectively. The fat
726 particles and protein network are stained green and red, respectively.

727 Figure 3. 2D images of cheese at D180 samples obtained from CLSM. Images from A to F
728 are CFFC, CLFC, LFCA1, LFCA2, LFCA3, LFCA4 cheese samples, respectively. The fat
729 particles and protein network are stained green and red, respectively.

730 Figure 4. 3D Images of cheese (D120) samples obtained from CLSM. Images from A to F are
731 CFFC, CLFC, LFCA1, LFCA2, LFCA3, LFCA4 cheese samples, respectively. The fat
732 particles and protein network are stained green and red, respectively.

733 Figure 5. 3D Images of cheese (D180) samples obtained from CLSM. Images from A to F are
734 CFFC, CLFC, LFCA1, LFCA2, LFCA3, LFCA4 cheese samples, respectively. The fat
735 particles and protein network are stained green and red, respectively.

736 Figure 6. Fat particle size distribution in D7 samples. A-F distributions are for CFFC, CLFC,
737 LFCA1, LFCA2, LFCA3, LFCA4 cheese samples, respectively. Six replicate images were
738 used for the distribution analysis of each cheese sample.

739 Figure 7. Fat particle size distribution in D120 samples. A-F distributions are for CFFC,
740 CLFC, LFCA1, LFCA2, LFCA3, LFCA4 cheese samples, respectively. Six replicate images
741 were used for the distribution analysis of each cheese sample.

742 Figure 8. Fat particle size distribution in D180 samples. A-F distributions are for CFFC,
743 CLFC, LFCA1, LFCA2, LFCA3, LFCA4 cheese samples, respectively. Six replicate images
744 were used for the distribution analysis of each cheese sample.

745 Figure 9. Average size, area and total number of fat particles in 2D images during ripening
746 (A-C) and volume covered by fat particles at 180D, obtained by 3D image analysis (D) in six
747 different optical fields. All results are expressed as the mean ± standard error (n = 6). Means
748 in a single figure with different letters are significantly different ($P<0.05$).

Figure 10. Images of cheeses (at D180 old) obtained from SEM. Images from A to F are CFFC, CLFC, LFCA1, LFCA2, LFCA3, LFCA4, respectively. Small white aggregates are scattered over the protein network (indicated by red arrow) in alginate added cheese.

Figure 11. Transverse relaxation spectra of 180 days aged cheese showing distribution of transverse relaxation time (T_2) obtained by LF-NMR.

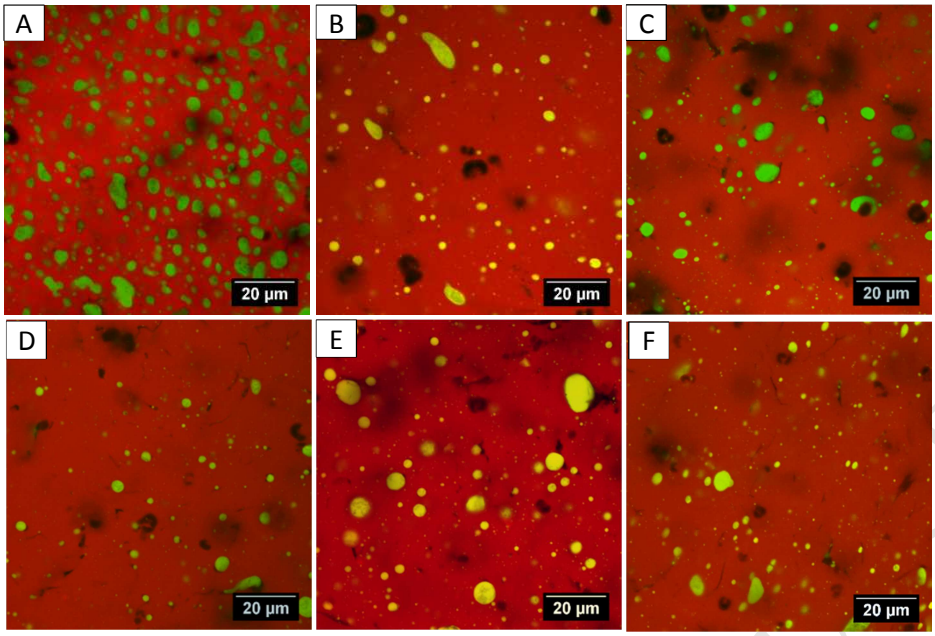


Figure 1.

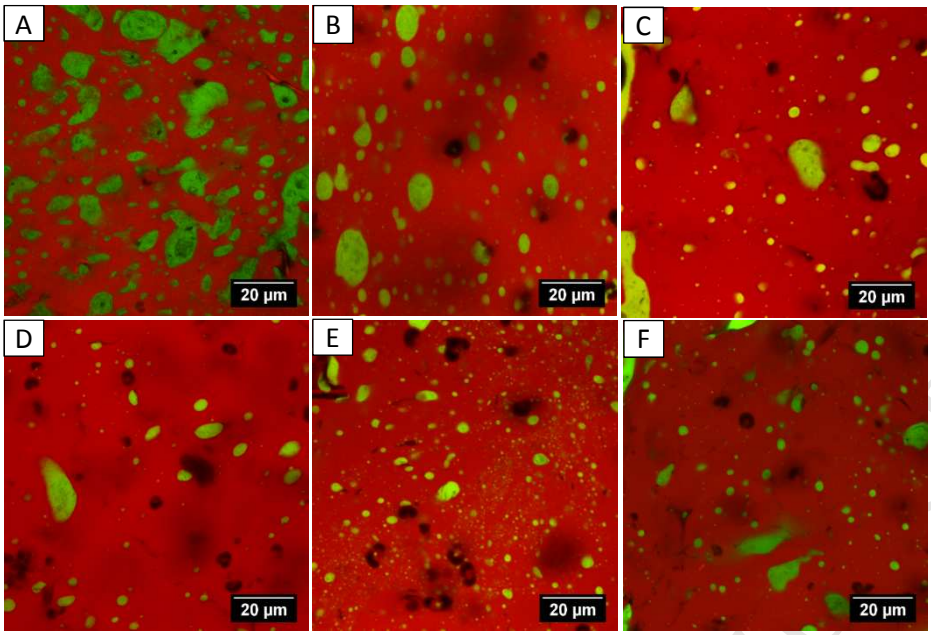


Figure 2.

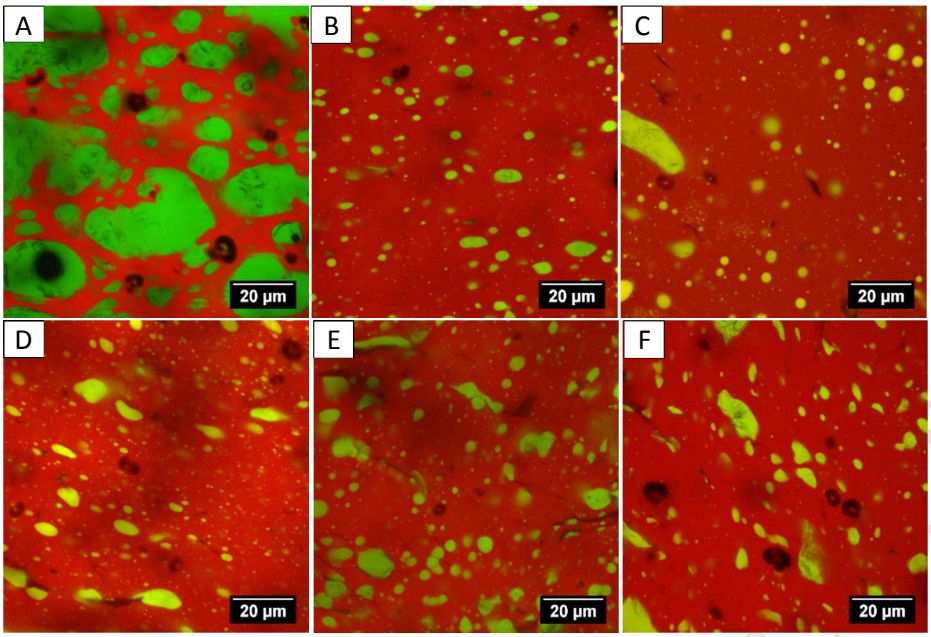


Figure 3.

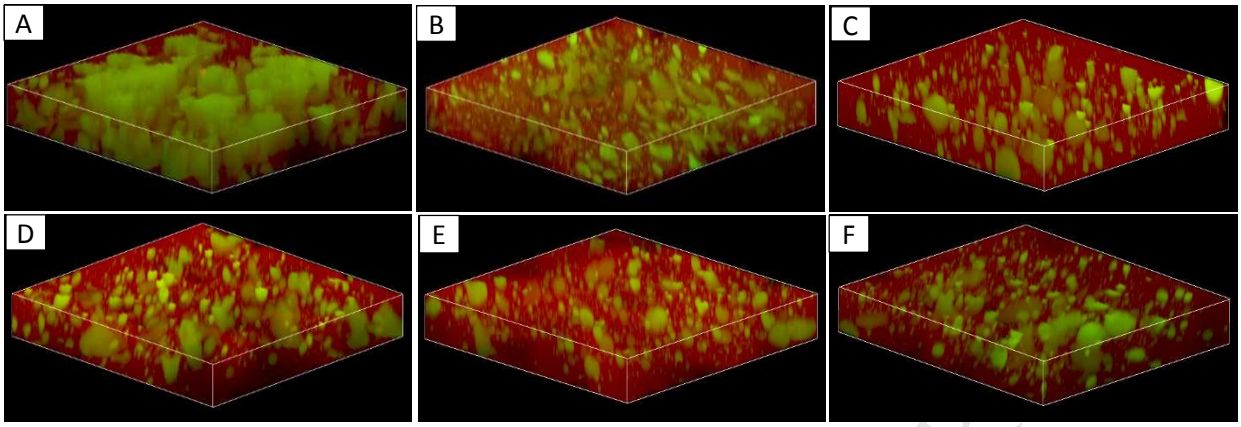


Figure 4.

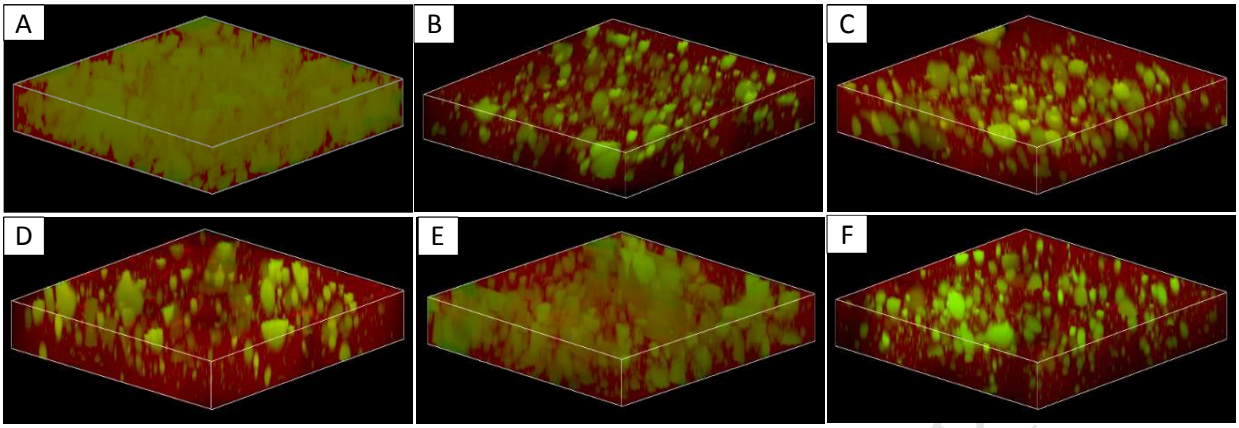
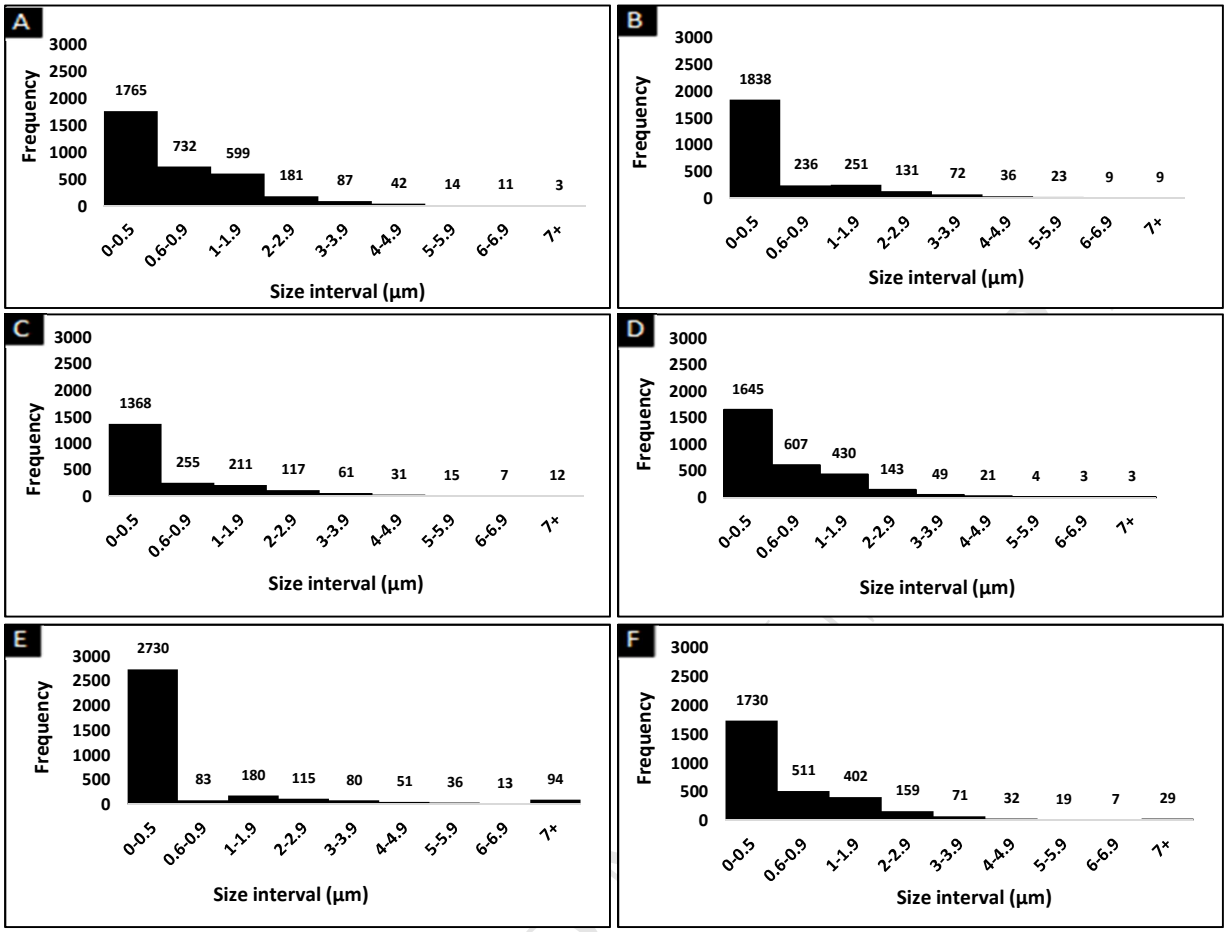


Figure 5.



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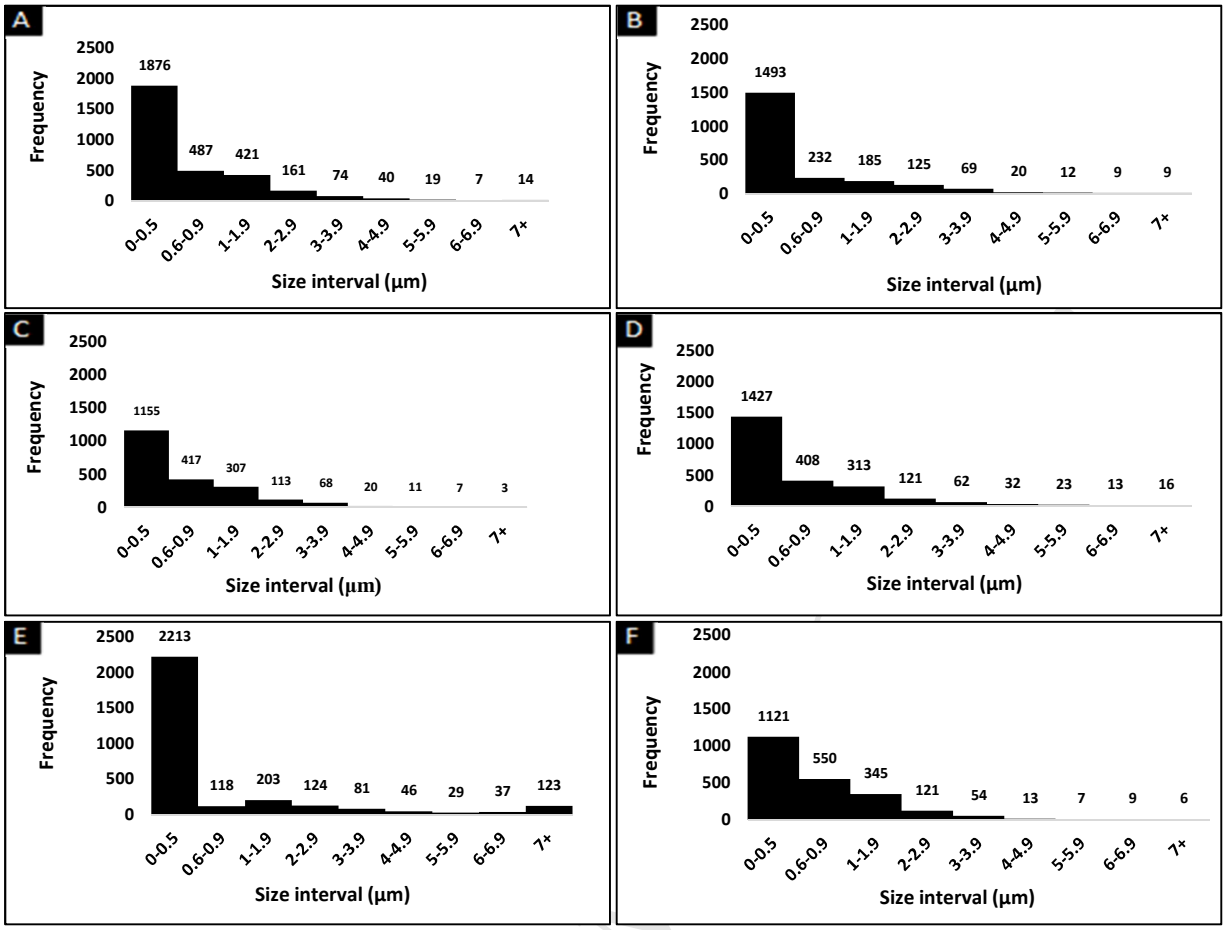

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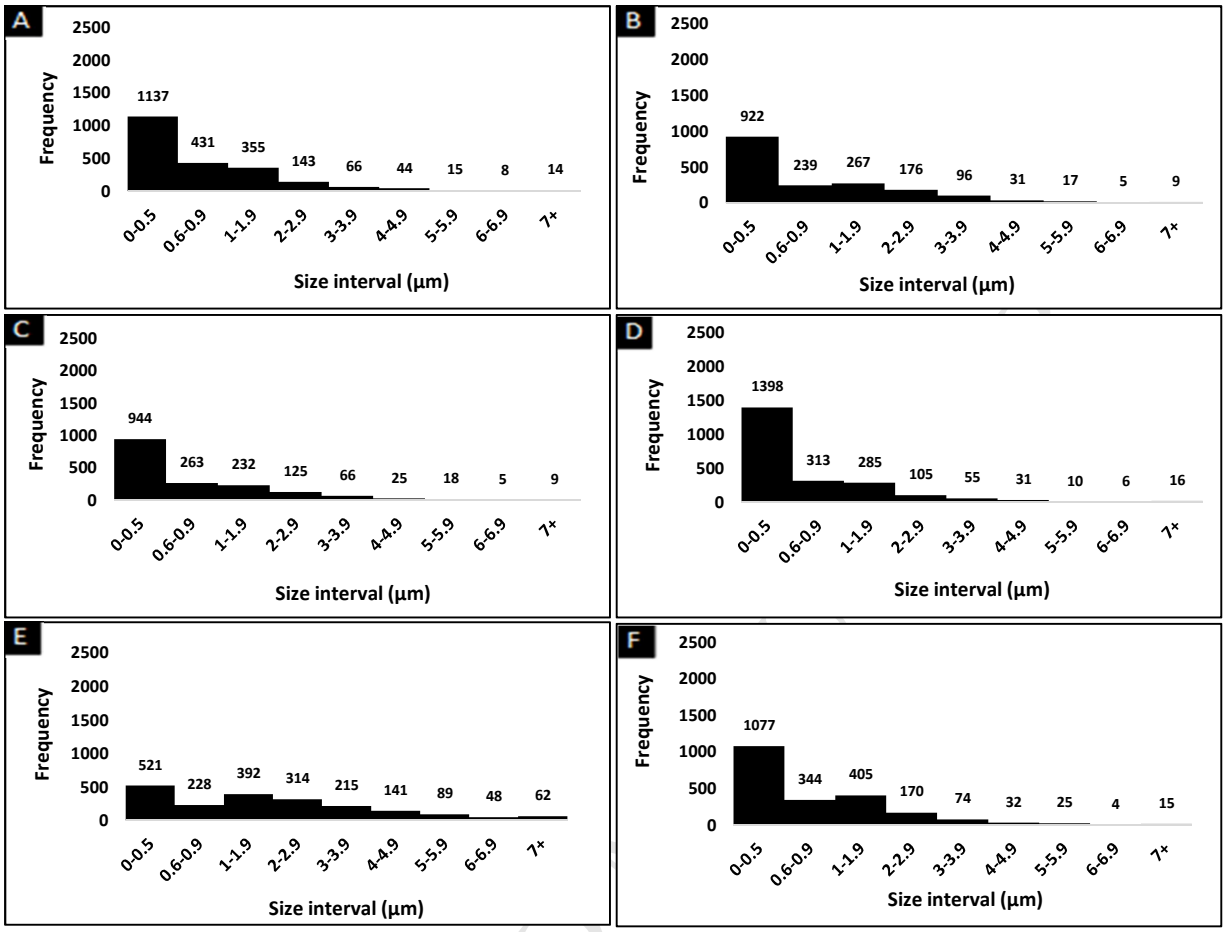
A
Frequency
2500
2000
1500
1000
500
0
1137
431
355
143
66
44
15
8
14
0-0.5
0.6-0.9
1-1.9
2-2.9
3-3.9
4-4.9
5-5.9
6-6.9
7+
Size interval (µm)
B
Frequency
922
239
267
176
96
31
17
5
9
Size interval (µm)
C
Frequency
944
263
232
125
66
25
18
5
9
Size interval (µm)
D
Frequency
1398
313
285
105
55
31
10
6
16
Size interval (µm)
E
Frequency
521
228
392
314
215
141
89
48
62
Size interval (µm)
F
Frequency
1077
344
405
170
74
32
25
4
15
Size interval (µm)

Figure 8.

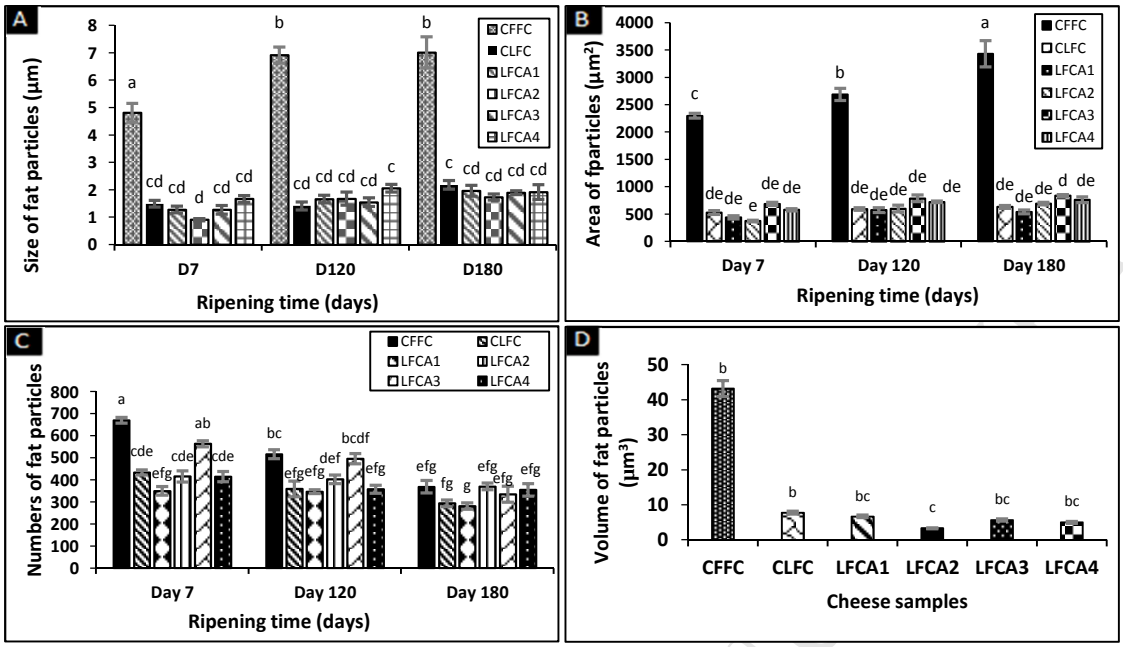
A
Size of fat particles (µm)
Ripening time (days)
D7
D120
D180
CFFC
CLFC
LFCA1
LFCA2
LFCA3
LFCA4
B
Area of fparticles (µm²)
Ripening time (days)
Day 7
Day 120
Day 180
C
Numbers of fat particles
Ripening time (days)
D
Volume of fat particles (µm³)
Cheese samples

Figure 9.

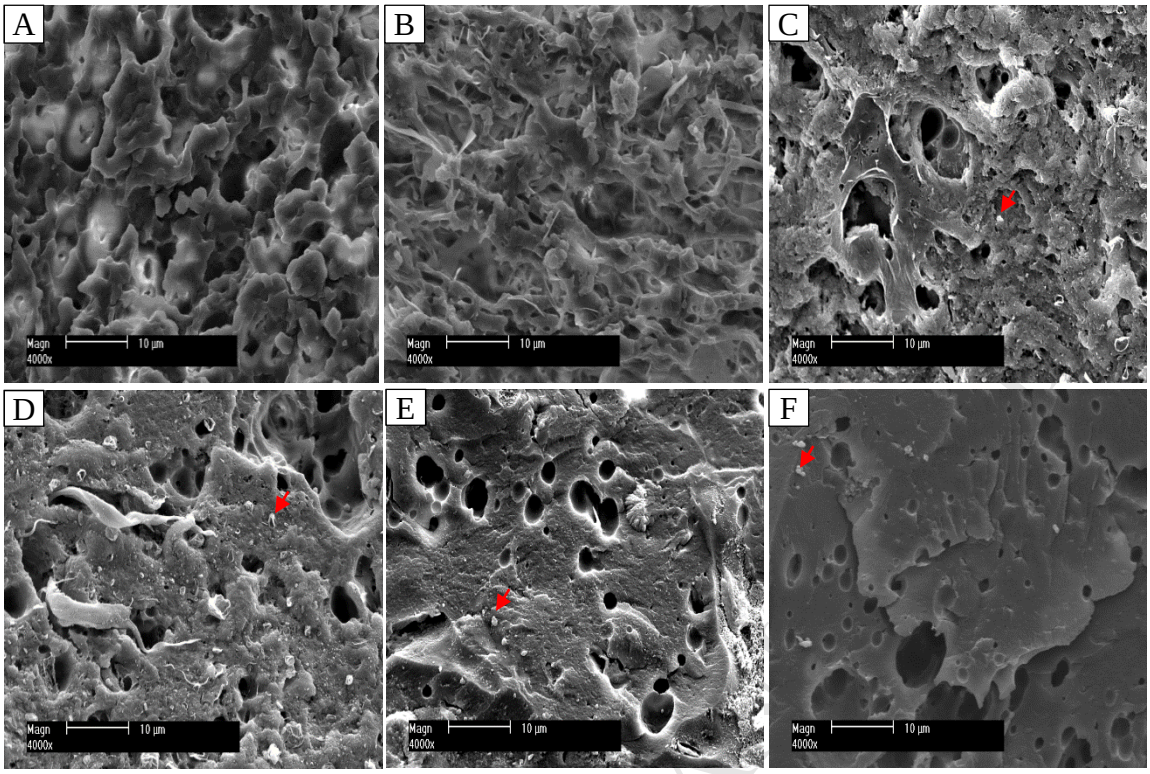

Figure 10.

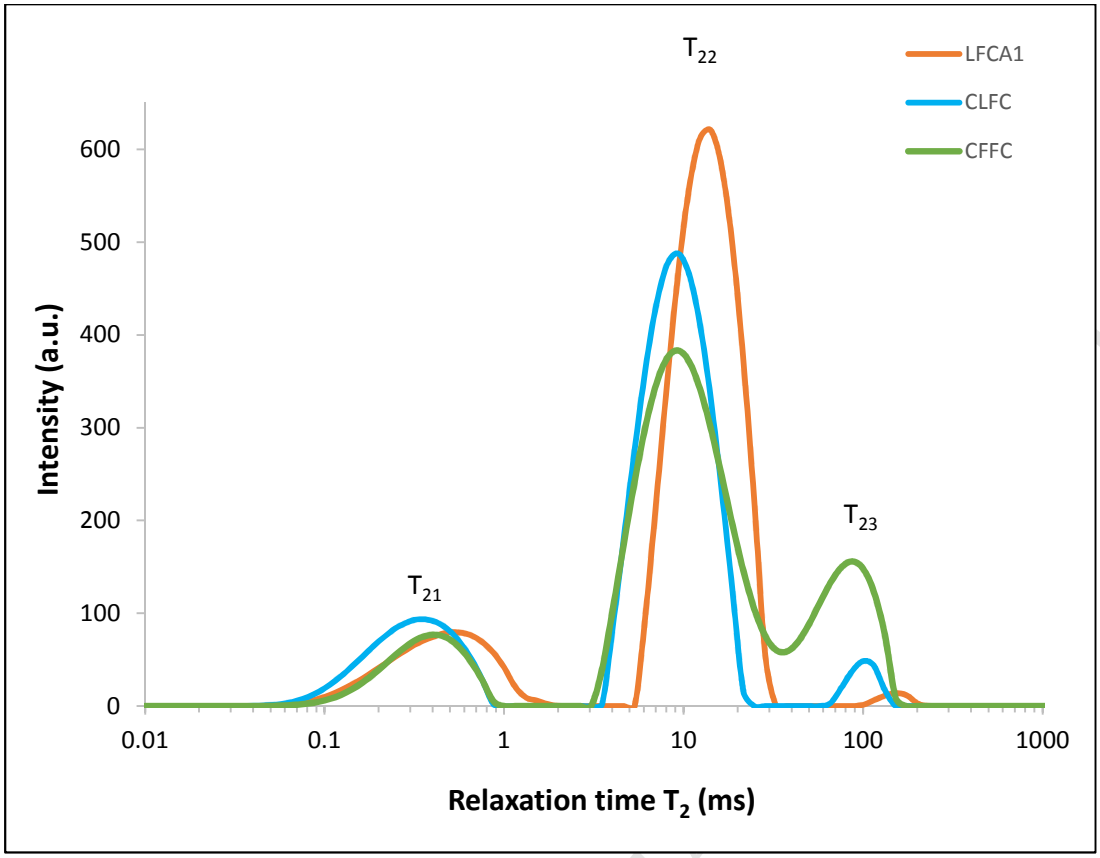

Figure 11.

Highlights

1. Low fat Cheddar cheese (LFC) with four concentrations of alginate were prepared.
2. Fat level in alginate added LFC was reduced by up to 91% as compared to control full fat cheese (CFFC).
3. Textural properties of one of the alginate cheese containing only 3.1% fat were similar to those of CFFC.
4. Microstructure revealed smoother texture in alginate added LFC compared to control LFC.
5. Micrographs suggested there was effect on the fat particle size, area and volume in all LFCs.
6. Higher mobility water fraction was found in alginate added cheese compared to CFFC and CLFC by NMR.
7. Color of some of the alginate added LFCs was comparable to CFFC after 120 days of ripening.