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1 **Evaluation of production of Cheddar cheese from micellar**  
2 **casein concentrate**

3

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13

14 **ABSTRACT**

15 The objective of this study was to evaluate the production of Cheddar cheese using  
16 micellar casein concentrate (MCC), a novel milk ingredient powder with a high casein  
17 content (~92%). Four types of Cheddar cheese were manufactured and ripened for 180  
18 days from the following starting materials: standardized control milk (control), skim  
19 milk with cream (SC), reconstituted MCC with cream (MC) and reconstituted low-heat  
20 skim milk powder with cream (PC). Only minor differences were found in composition  
21 between treatments, but MC cheese showed higher levels of proteolysis compared to  
22 other treatments, linked to significantly higher plasmin and chymosin activities. No  
23 differences were observed in hardness between treatments (60, 120 and 180 days), but  
24 the springiness and cohesiveness of MC and PC cheeses were significantly higher than  
25 that of the control and SC cheeses at 60, 120 and 180 days. In conclusion, the use of  
26 casein-dominant dairy streams has the potential for production of Cheddar cheese with  
27 tailored functionality.

28        **1. Introduction**

29            Global milk production was approximately 843 million tonnes in 2018 (FAO,  
30 2019); among dairy products (i.e., cheese, casein and butter), cheese production used  
31 the highest proportion of milk. Whey protein powder, production of which is  
32 traditionally associated with the manufacture of cheese, represents 57% of the market  
33 for global protein supplement for exercising and nutrition, while there is a huge  
34 market for whey protein powders in infant formula. Cheese output is increasing at a  
35 rate of 2% yearly while the demand for whey protein has been growing at 6-7%  
36 yearly (Hoogwegt Group, 2019). Nowadays, whey protein with high quality is  
37 required as it can be used to manufacture a range of food ingredients or products with  
38 nutrition and functional properties (Boland, 2011). Kelly (2019) reported that the  
39 ultrafiltration (UF) properties of sweet and acid whey are influenced by their high or  
40 low pH, respectively. However, microfiltration (MF) permeate made directly from  
41 skim milk is considered to be an ideal whey source for whey protein ingredients  
42 production. Therefore, recovering whey protein from milk rather than cheese whey  
43 could improve the whey quality and is an option for whey protein ingredients  
44 manufacture.

45            During membrane filtration of skim milk, native micellar casein is concentrated  
46 in the retentate, which could be recovered and concentrated to produce micellar  
47 casein concentrate (MCC). This is a novel dairy ingredient powder with a high casein  
48 fraction of 85-95% of total protein which may be used in functional and nutritional

49 applications (Crowley et al., 2018). As the traditional way to manufacture Cheddar  
50 cheese is followed by whey protein manufacture, the concept of recovering whey  
51 protein before Cheddar cheese manufacture is of interest.

52 In terms of the protein ingredients being used for Cheddar cheese manufacture,  
53 low heat skim milk powder (LHSMP) can be used to enhance cheese yield giving a  
54 constant cheese production throughout the year (Freeman et al., 1970). LHSMP is  
55 produced from skim milk using low temperatures during manufacture and is mostly  
56 used for condensed milk, UHT-treated fluid milk and ice-cream (Augustin &  
57 Margetts, 2003). Unlike reconstituted medium- and high-heat skim milk powder that  
58 have impaired rennet coagulation ability, the rennet coagulation properties of  
59 LHSMP are good as the whey protein is not highly denatured (Ménard et al., 2005).  
60 With only physical separation processing, the micellar casein in MCC may have  
61 better rennet coagulation properties compared to LHSMP. The rennet coagulation  
62 properties and cheese-making potential of MCC may be better than those of LHSMP.

63 Two main factors that influence cheese yield are lactation and seasonality. The  
64 gross composition of bovine milk varies with the stage of lactation. Kuchtlík et al.  
65 (2008) reported that protein and casein content increase and lactose content decreases  
66 through the lactation. After 200 days lactation, cows are in the late lactation stage,  
67 which requires the udder tissue to repair and recover for next lactation. During late  
68 lactation, milk yield decreases dramatically, which may influence cheese yield,  
69 unless milk is standardised. Also, at specific times of the year, the milk volume  
70 decreases, and the composition and rennet coagulation properties of milk are

71 significantly influenced (Freeman et al., 1970; O'Brien et al., 1999). Both cheese  
72 yield and manufacturing efficiency are influenced by seasonal variation of milk  
73 protein and fat composition (Barbano & Sherbon, 1984).

74 To solve the problem of low cheese yield, one solution is adding LHSMP to  
75 low-protein milk to increase the protein composition (Freeman et al., 1970). Another  
76 possibility may be making Cheddar cheese with MCC that is manufactured as a co-  
77 product of high-quality whey protein.

78 This study aimed to evaluate the production of Cheddar cheese from micellar  
79 casein concentrate, with LHSMP used for comparison. The consequence of this  
80 manufacture was evaluated concerning composition, proteolysis, texture and  
81 functionality.

82

## 83 **2 Materials and Methods**

### 84 *2.1 Preparation of cheese milk*

85 Micellar casein concentrate (MCC) powder was obtained from Teagasc  
86 (Moorepark, Fermoy Co. Cork, Ireland); whereby pasteurized bovine skim milk was  
87 microfiltered at 50 °C using 0.14- $\mu$ m TAMI Isoflux ceramic membranes (TAMI,  
88 Lyons, France). MF was performed in a batch mode involving two diafiltration steps  
89 to produce a final 3X MF retentate (liquid MCC) which was evaporated at 65 °C  
90 using a pilot plant single-effect falling-film evaporator (Anhydro F1 Laboratory;

91 Copenhagen, Denmark). This was followed by spray-drying of the evaporated liquid  
92 MCC in a single-stage spray dryer (Anhydro Laboratory Spray Dryer, SPX Flow  
93 Technology, Denmark) equipped with nozzle atomisation at inlet and outlet  
94 temperatures of 185 and 85°C, respectively. The protein content (91.6% casein) of  
95 MCC was determined by the Kjeldahl method (IDF, 1986). MCC powder and low  
96 heat skim milk powder (LHSMP; WPNI=6.0) (Uelzena, Uelzen, Germany) were  
97 rehydrated using a Silverson mixer at 55 °C for 2 h.

98         Raw milk was obtained from a local farm in Cork, Ireland. Skim milk and cream  
99 were separated from raw milk using a separator. Composition of milk samples was  
100 measured by MilkoScan™ Mars (Foss, Hilleroed, Denmark) and casein content was  
101 calculated by multiplying the casein percentage of protein of the milk sample (an  
102 estimated percentage of 78% for milk and LHSMP milk and 91.6% for MCC).  
103 Control milk was prepared by combining raw milk and skim milk to a casein: fat  
104 ratio of 0.7:1. Both reconstituted MCC and reconstituted LHSMP were made up to  
105 the same casein level as skim milk. Reconstituted MCC and LHSMP and skim milk  
106 were blended with cream and lactose according to the same standardization ratio  
107 (casein: fat of 0.70:1.00) and lactose content (~5%) as control milk to obtain three  
108 more vats: skim milk with cream (SC), reconstituted MCC milk with cream (MC)  
109 and reconstituted LHSMP milk with cream (PC). All milk samples were pasteurized  
110 at 72 °C for 15 s (Microthermics Inc., Raleigh, NC, USA) and stored at 4 °C until  
111 analysis and cheese-making.

## 112 2.2 Rennet Coagulation Properties

113 Dynamic oscillatory analysis (small amplitude oscillatory measurement) of  
114 renneted control milk, SC milk, MC milk and PC milk was performed using a Peltier  
115 concentric cylinder geometry, which comprised of an aluminium conical rotor [42.01  
116 mm (h) by 28.02 mm (d)], on an AR-G2 controlled stress rheometer (Waters TA  
117 Instruments, Leatherhead, Surrey, UK). Aliquots (25 mL) of each sample were pre-  
118 warmed in a water bath at 32°C for 15 min, and 80 µL of a 1:10 (v/v) dilution of  
119 Maxiren™ (Chr Hansen A/S, Hørsholm, Denmark) was added. The sample was  
120 placed immediately in the preheated cup (32 °C), the frequency of oscillation was set  
121 at 0.6283 rad s<sup>-1</sup>, and the storage modulus, G' of the sample was recorded  
122 continuously as a function of time at a low-amplitude shear strain (0.01) over 90 min.  
123 Each sample was analysed in triplicate (Ibáñez et al., 2015).

## 124 2.3 Cheese Manufacture

125 Cheddar cheeses were made from 20 L control, SC, MC and PC milks which  
126 were prepared, pasteurised and stored at 4 °C overnight before cheese-making.  
127 Cheddar-type cheeses were manufactured according to a standard Cheddar cheese  
128 manufacture protocol (Fox et al., 2000). An aliquot of 6 g (0.03% w/w) of Cheddar  
129 cheese starter culture (R604Y Chr. Hansen Ltd., Little Island, Co. Cork, Ireland) was  
130 added into each sample and allowed ripen for 30 min, followed by 0.09% (v/w) of 1  
131 mol L<sup>-1</sup> CaCl<sub>2</sub> and 60 IMCU L<sup>-1</sup> rennet being added to all samples. Whey was drained  
132 when the pH dropped to 6.2 and curd was cheddared. When the pH decreased to 5.4,



133 the curd was milled into small pieces and salted at a level of 2.5% (w/w) NaCl. The  
134 curds were then wrapped in cheesecloth and moved to 2-kg circular moulds, which  
135 were pressed at a pressure of 2.5 kg cm<sup>-2</sup> for 14 h. The cheeses were then removed,  
136 vacuum-packed and ripened at 8 °C for 180 days.

#### 137 *2.4 Compositional analysis*

138 Gross composition of cheeses was analysed at 14 days old. Moisture was  
139 determined by oven-drying method (IDF 1982), protein (%N×6.38) by the Kjeldahl  
140 method (IDF 1986) and salt was analysed by titration with AgNO<sub>3</sub> (Fox, 1963). The  
141 pH was measured at 14, 30, 60, 120 and 180 days of ripening by using a calibrated  
142 pH probe placed in contact with dry grated cheeses. All results were determined in  
143 triplicate.

#### 144 *2.5 Microbiological analysis*

145 Enumeration of starter lactic acid bacteria (LAB) was performed using LM 17  
146 agar plates (Terzaghi and Sandine 1975), incubated for 3 days at 30 °C. Enumeration  
147 of non-starter lactic acid bacteria (NSLAB) was performed on Rogosa agar plates  
148 (Rogosa and Mitchell 1951), incubated anaerobically for 5 days at 30 °C .  
149 Enumeration of LAB and NSLAB were performed in duplicate after 60 and 90 days  
150 of ripening.

151

152

153 *2.6 Analysis of proteolysis*

154 Urea-polyacrylamide gel electrophoresis (urea-PAGE) of cheese samples was  
155 used to study the proteolysis of  $\alpha_{S1}$ - and  $\beta$ -casein (CN) during ripening using the  
156 method of Andrews (1983) with modifications of Shalabi and Fox (1987). The pH  
157 4.6-soluble and insoluble fraction were prepared (Kuchroo & Fox, 1982), and peptide  
158 profiles of pH 4.6-soluble fractions filtered through 0.22- $\mu$ m cellulose acetate filters  
159 (Sartorius GmbH, Gottingen, Germany) were analysed by reverse-phase high-  
160 performance liquid chromatography (HPLC) using an ultra-performance liquid  
161 chromatography (UPLC) Waters Acquity UPLC H-Class Core System (Waters,  
162 Milford, MA, USA), with a Waters Acquity UPLC TUV Detector (dual-wavelength;  
163 Waters) operated by Empower 3 software (Waters Corp., Milford, MA, USA),  
164 following the method of Mane et al. (2019).

165 For determination of free amino acids (FAA), frozen pH 4.6-soluble fractions  
166 were de-proteinised by mixing equal volumes of 24% (w v<sup>-1</sup>) trichloroacetic acid  
167 (TCA) and sample and following the method of Fenelon and Guinee (2000).

168 *2.7 Plasmin activity*

169 The plasmin activity of cheese samples at 180 days of ripening was measured  
170 using the coumarin peptide method (Richardson & Pearce, 1981). A standard curve  
171 of the emission intensity at 460 nm was constructed using 7-amido-4-methyl  
172 coumarin (AMC), and results expressed in nmol AMC min<sup>-1</sup> mL<sup>-1</sup>, which was  
173 defined as one unit of plasmin activity.

174 *2.8 Residual coagulant assay*

175 Grated cheese samples (50 mg) were extracted by dissolving cheese in 1 mL of  
176 0.1 M trisodium citrate, followed by 30 minutes incubation at 37 °C. Fat was  
177 separated by centrifugation at 1000 g (Sigma 1-16K, Harz, Germany) for 1 min, and  
178 the aqueous layer was used for analysis. An aliquot of 70 µL citrate dispersion of  
179 cheese was incubated with 30 µL of 1 mg mL<sup>-1</sup> aqueous solution of a synthetic  
180 heptapeptide substrate (Pro-Thr-Glu-Phe-[NO<sub>2</sub>-Phe]-Arg-Leu) in 400 µL 0.1 M  
181 sodium formate buffer, at 37 °C, pH 3.2, for 24 h. The mixture was heated at 70 °C  
182 for 10 min to stop the reaction, followed by centrifugation at 16,000g for 10 min, and  
183 the supernatant was used for UPLC analysis. Substrate and product levels were  
184 determined using the reversed-phase HPLC system described above, following the  
185 method of Hurley et al. (1999).

186 *2.9 Texture profile analysis*

187 Texture profile analysis was performed using a Texture Analyzer TA-XT2i  
188 (Stable Micro Systems, Godalming, Surrey, UK) at 60, 120, and 180 days of ripening.  
189 Cheese samples were cut into 20 mm height, 20 mm diameter cylinders and kept at  
190 4 °C overnight. Cheese cylinders were compressed to 25% of the initial height in two  
191 continuous compressions with a speed of 1 mm s<sup>-1</sup>. Hardness, cohesiveness and  
192 springiness were measured (Truong et al., 2002), and five cheese samples were  
193 measured for each treatment.

194

195 *2.10 Meltability*

196 Meltability was analyzed using the Schreiber meltability test as described by  
197 Altan et al. (2005). Cheese samples were heated at 232 °C for 5 min, and meltability  
198 was measured as the percentage increase in diameter of the original samples.  
199 Analyses were performed in triplicate at 60, 120, 180 days of ripening.

200 *2.11 Dynamic small amplitude oscillatory rheology*

201 The rheological properties of meltability of cheese after 180 days ripening were  
202 analysed with a controlled stress AR-G2 rheometer (TA Instruments, Waters LLC,  
203 Leatherhead, Surrey, UK) according to the method of Ibáñez et al. (2015). Storage  
204 modulus ( $G'$ ), loss modulus ( $G''$ ), and loss tangent (LT) were measured during  
205 heating. The maximum LT ( $LT_{max}$ ) and the temperature where  $LT=1$ , which are  
206 indicators of melting, were also recorded. Each sample was analysed in triplicate.

207 *2.12 Colour measurements*

208 Colour values were measured using a Konika-Minolta colourimeter CR400  
209 (Konika-Minolta Optics Inc., Osaka, Japan) at 14, 30, 60, 120, 180 days of ripening.  
210 The measurement used the CIELAB system based on illuminant D65 and a visual  
211 angle of 2°. Five random readings were taken on fresh-cut cheese at 20°C. The  
212 Euclidean distance between the colour of control cheese and that for other treatments  
213 was calculated by  $\Delta E^*_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$  where  $\Delta L^* = L^*_{sample} -$   
214  $L^*_{control}$ ,  $\Delta a^* = a^*_{sample} - a^*_{control}$  and  $\Delta b^* = b^*_{sample} - b^*_{control}$  (Mahy et al., 1994).

### 215 2.13 Statistical analysis

216 Control, SC, MC and PC cheeses were made in three independent trials,  $4 \times 3$   
217 blocks. Statistical analysis was carried out using one-way analysis of variance  
218 (ANOVA) with R project for Windows version i386 3.4.0 to establish significant  
219 differences between samples. The probability level used for statistical significance  
220 was  $P < 0.05$ .

221

## 222 3 Results and Discussion

### 223 3.1 Rennet coagulation properties

224 The rennet coagulation properties of milk samples are shown in Table 1. During  
225 the first 10 min, G' value of all the treatments was low and constant, after which the  
226 G' value of all samples increased, with the MC and PC samples exhibiting a slower  
227 rate of increase compared to other samples (Fig. 1). The gel strength (G' value) at 90  
228 min of MC and PC samples was significantly ( $P < 0.05$ ) lower than that of other  
229 samples. The gel strength of MC and PC kept increasing and did not reach a constant  
230 level during the analysis, while control and SC reached stable values at 45 min. The  
231 loss tangent at 90 min of MC sample was significantly ( $P < 0.05$ ) higher than that of  
232 the other treatments.

233 Martin et al. (2010) reported that, during the manufacture of milk protein  
234 concentrate (MPC), casein micelles were not damaged; however, the minerals

235 removed through diafiltration and decreased calcium ionic strength could depress  
236 rennet coagulation. The rennet coagulation ability of reconstituted MPC could be  
237 restored by adding extra calcium ions. The production of MCC involves two  
238 diafiltration steps, which may reduce soluble calcium levels; thus, 0.09% (v/w) of 1  
239 mol L<sup>-1</sup> CaCl<sub>2</sub> was added to all of the batches before cheese manufacture.

### 240 3.2 Cheese composition and pH

241 The composition of cheese at 14 days of ripening and pH of cheese samples at  
242 14, 30, 60, 120 and 180days of ripening are shown in Table 2; the results presented  
243 are means of data from the three trials. Guinee et al. (2007) stated that different casein  
244 to fat ratio can influence the protein and fat content of cheese. As the casein: fat ratio  
245 of milk was adjusted to 0.7 for all samples, no statistically significant differences  
246 ( $P>0.05$ ) were found in cheese protein and fat contents between all treatments, and  
247 the use of MCC or LHSMP for Cheddar cheese manufacture did not affect these  
248 parameters.

249 The moisture content of PC cheese was significantly ( $P<0.05$ ) higher than that of SC  
250 and MC cheese; no significant differences ( $P>0.05$ ) were found for moisture content  
251 between control, SC and MC cheese. The salt content of MC cheese was significantly  
252 ( $P<0.05$ ) higher than that of control and SC cheese. The pH of MC cheese was  
253 significantly ( $P<0.05$ ) higher than that of other treatments, the reason for which is  
254 not clear. No significant differences ( $P>0.05$ ) were found for moisture in non-fat  
255 substances (MNFS) and fat in dry matter (FDM) for all treatments; MNFS is an

256 important parameter for Cheddar cheese quality, so it is important that all batches of  
257 cheese sample had similar levels of MNFS (Fox et al., 2000; Bogenrief & Olson,  
258 1995).

### 259 3.3 Proteolysis

260 Table 2 shows the level of pH 4.6-SN/TN (%) of control, SC, MC and PC cheeses at  
261 180 days of ripening; pH 4.6-SN/TN is an index of proteolysis (Sousa et al., 2001).  
262 Significantly ( $P<0.05$ ) higher pH 4.6-SN/TN levels were found in MC cheese than in  
263 SC and PC cheese. In addition, the levels of pH 4.6-SN/TN were significantly ( $P<0.05$ )  
264 lower in PC than control cheese. The value (23%) found at 180 days of ripening in this  
265 study was comparable with previous studies on Cheddar cheese (Lucey et al., 2005;  
266 O'Mahony et al., 2005). The main agent producing pH 4.6-soluble nitrogen is the  
267 coagulant (O'Keeffe et al., 1978), while Farkye & Fox (1992) reported that plasmin,  
268 the principal indigenous milk proteinase, is also important for primary proteolysis in  
269 Cheddar cheese during ripening.

270 Urea-PAGE electrophoretograms of cheese samples during ripening are shown in  
271 Fig. 2. All cheese samples showed break-down of  $\beta$ - and  $\alpha_{S1}$ -CN, but lower levels of  
272 intact  $\beta$ - and  $\alpha_{S1}$ -CN were apparent during ripening in MC cheese. Due to the action of  
273 plasmin,  $\beta$ -CN is hydrolysed to  $\beta$ -CN (f29-209),  $\beta$ -CN (f106-209) and  $\beta$ -CN (f108-209)  
274 (Eigel et al., 1984). The levels of  $\beta$ -CN (f106-209) and  $\beta$ -CN (f108-209) of MC cheese  
275 were higher than other treatments during ripening, which suggests higher plasmin  
276 activity. Also, in Fig. 2, the MC cheese showed the lowest level of intact  $\alpha_{S1}$ -CN level,

277 followed by PC cheese, control and SC cheese from 60 to 180 days of ripening; at 180  
278 days of ripening, no intact  $\alpha_{S1}$ -CN was found in MC and PC samples. Residual  
279 chymosin in cheese hydrolyses  $\alpha_{S1}$ -CN to  $\alpha_{S1}$ -CN (f24-199) and  $\alpha_{S1}$ -CN (f102-199) and,  
280 as the residual chymosin activity increases, the breakdown of  $\alpha_{S1}$ -CN increases  
281 (Sheehan et al., 2008). The faster breakdown of  $\alpha_{S1}$ -CN of MC and PC samples may  
282 indicate higher residual chymosin activity in these samples.

283 The peptide profiles of the pH 4.6-soluble extracts for control, SC, MC and PC  
284 cheeses at 180 days of ripening were generated by ultra-performance liquid  
285 chromatography (Fig. 3). The highest peak areas were observed at the retention time of  
286 1 to 5 min for all treatments. The peak area of peptides that were eluted later (28-45  
287 min retention time) was higher in MC sample compared to the other treatments.  
288 Peptides in the pH 4.6-soluble extracts reflect the effect of proteinases and peptidases  
289 of starter (Fox & McSweeney, 1997). The number of peptide peaks for all treatments  
290 was similar, which suggests that the proteolysis for all treatments broadly followed  
291 similar pathways, but differences in peak area indicate that there was more extensive  
292 proteolysis in MC cheese compared to the other treatments.

293 The individual FAA levels of all treatments at 120 and 180 days of ripening are  
294 shown in Fig. 4 (A and B). The major FAA determined in cheese were glutamic acid,  
295 valine, leucine, phenylalanine, histidine and lysine; Bansal et al. (2009) also reported  
296 that glutamic acid, valine, leucine, phenylalanine histidine and lysine are the principal  
297 FAA in Cheddar cheese after 180 days of ripening. No significant differences ( $P>0.05$ )  
298 were found between treatments at 120 days of ripening. At 180 days of ripening,



299 significantly ( $P<0.05$ ) higher concentrations of threonine, serine, glycine, alanine,  
300 valine, methionine, isoleucine, phenylalanine, histidine and proline were found in  
301 control and SC cheese than that of MC and PC cheese. No significant differences  
302 ( $P>0.05$ ) were found between treatments in the levels of aspartic acid, glutamic acid,  
303 leucine, tyrosine and arginine. From 120 to 180 days of ripening, the concentrations of  
304 glutamic acid, alanine, leucine, tyrosine and phenylalanine increased significantly  
305 ( $P<0.05$ ) for all treatments, while only control and SC cheese had a significant increase  
306 in the concentration of threonine, glycine, valine and isoleucine. The total FAA levels  
307 of all treatments at 120 and 180 days of ripening are shown in Fig. 4 (C). No significant  
308 differences ( $P>0.05$ ) were found between all treatments at 120 days of ripening, but  
309 significantly higher ( $P<0.05$ ) levels of total FAA were found in control cheese than in  
310 MC and PC cheeses at 180 days of ripening. No significant differences ( $P>0.05$ ) were  
311 found between control and SC cheese at 180 days of ripening.

312 Fox and McSweeney (1996) reported that peptidases of starter and non-starter lactic  
313 acid bacteria are the principal agents releasing FAA in Cheddar cheese during ripening.  
314 No significant ( $P>0.05$ ) differences were found for the numbers of starter bacteria and  
315 NSLAB between treatments in this study (result not shown). Therefore, the release of  
316 the FAA by starter and NSLAB should not have been an influence in this regard, and  
317 so the reasons for this difference is not clear.

318

319

### 320 3.4 Plasmin and residual chymosin activities in cheese

321 The plasmin activity of MC cheese was significantly ( $P<0.05$ ) higher than that of the  
322 other cheese batches (Table 3) which is consistent with the result of urea PAGE  
323 electrophoresis. The plasmin activity of PC cheese was significantly ( $P<0.05$ ) lower  
324 than that of the other cheese samples. As the pH increases, the hydrolysis of  $\beta$ -CN  
325 increases since plasmin has an alkaline optimum pH (Watkinson et al., 2001).

326 Aaltonen and Ollikainen (2011) reported that in diafiltration, with the removal of  
327 whey protein, the concentration of inhibitors of both plasmin and plasminogen  
328 activators decreases, which promotes the conversion from plasminogen to plasmin and  
329 thus increases plasmin activity. In this study, MCC was made using microfiltration,  
330 which may have enhanced the plasmin activity of retentate by removing inhibitors in  
331 the permeate, resulting in the higher plasmin activity and more  $\beta$ -CN breakdown. MC  
332 cheese showed significantly ( $P<0.05$ ) higher residual chymosin activity compared to  
333 the other treatments (Table 3), which is consistent with the faster breakdown of  $\alpha_{S1}$ -CN  
334 in that cheese. No significant differences ( $P>0.05$ ) were found between the residual  
335 chymosin activities of control and SC cheese, so the recombination of fat and skim milk  
336 did not affect the retention of coagulant during cheese manufacture. The residual  
337 chymosin activity of PC cheese was significantly ( $P<0.05$ ) lower than that of control  
338 cheese. The MC cheese apparently retained more coagulant compared to control, SC  
339 and PC cheeses; the percentage of retained chymosin in cheese curd depends on the pH

340 at the curd-cutting stage, pH at whey drainage, cooking temperature and method  
341 (Hurley et al., 1999).

### 342 3.5 Texture profile analysis

343 No significant changes ( $P>0.05$ ) were found in the hardness of MC and PC  
344 cheeses from 60 to 180 days of ripening (Fig. 5). The hardness of control cheese  
345 significantly ( $P<0.05$ ) decreased between 60 and 120 days of ripening, while that of  
346 SC cheese significantly ( $P<0.05$ ) increased. At 60 days of ripening, the hardness of  
347 control cheese was significantly ( $P<0.05$ ) higher than that of SC and PC cheeses. No  
348 significant differences ( $P>0.05$ ) were observed in the hardness of the cheeses made  
349 by different treatments at 120 and 180 days of ripening. Chevanan and  
350 Muthukumarappan (2007) reported that the contents of calcium, phosphate, and  
351 residual lactose affect the texture profile of Cheddar cheese. The cheese-milk of SC,  
352 MC and PC samples was reconstituted according to the composition of control  
353 cheese-milk, which would not influence lactose content. In this study, extra calcium  
354 chloride was added to all treatments, but the addition of calcium chloride does not  
355 cause significant changes to the texture of ripened Cheddar cheese (Soodam et al.,  
356 2015).

357 From 60 days to 180 days of ripening, the springiness and cohesiveness of MC  
358 cheese decreased, and the springiness and cohesiveness of MC and PC cheeses were  
359 significantly ( $P<0.05$ ) higher than that of control and SC cheese at 60 and 180 days of  
360 ripening. At 120 days of ripening, the springiness of MC cheese was significantly

361 ( $P<0.05$ ) higher than that of the other treatments and the cohesiveness of MC and PC  
362 cheeses was significantly ( $P<0.05$ ) higher than that of control and SC cheese. Everard  
363 et al. (2006) found that higher pH of Cheddar cheese was associated with increased  
364 springiness and cohesiveness; the pH of MC cheese was significantly ( $P<0.05$ ) higher  
365 than that for the other treatments (Table 2), which may explain the increases in  
366 springiness and cohesiveness. O'Mahony et al. (2005) reported that, as levels of  
367 secondary proteolysis increase, the charged groups released from peptides would  
368 associate with free water, which may lead to increased cohesiveness and springiness  
369 during ripening.

### 370 *3.6 Meltability*

371 Meltability (percentage increase in diameter) of Cheddar cheeses was  
372 determined by the Schreiber method; results are shown in Fig. 6. The four types of  
373 cheeses showed increases in meltability between 60 and 180 days. At 60 and 120  
374 days of ripening, no significant differences ( $P>0.05$ ) for meltability were found  
375 between control and SC cheese. Significantly ( $P<0.05$ ) higher meltability was found  
376 in control cheese compared to SC cheese. At 60, 120 and 180 days of ripening, the  
377 meltability of MC cheese was significantly higher ( $P<0.05$ ) than that of cheese from  
378 the other treatments. At 120 and 180 days of ripening, the meltability of PC cheese  
379 was significantly lower ( $P<0.05$ ) than that of cheese from the other treatments.

380 The lower meltability of PC cheese may be caused by the changes of casein in  
381 protein during drying of milk powder. Moiseev et al. (2017) reported that Mozzarella

382 cheese made with reconstituted non-fat milk powder has lower meltability than the  
383 control, due to the drying process of non-fat milk powder decreasing the stability and  
384 dispersity of casein micelles and promoting demineralization of calcium salts. Dave  
385 et al. (2003) found that the meltability of Mozzarella cheese is related to the  
386 breakdown of ( $\alpha_{S1}$ -CN and  $\alpha_{S1}$ -CN (f24-199)) and breakdown of intact  $\beta$ -casein,  
387 while Bogenrief and Olson (1995) reported that hydrolysis of  $\beta$ -casein increases the  
388 meltability of Cheddar cheese. Hydrolysis of  $\beta$ -casein is primarily related to the  
389 action of plasmin (Eigel et al., 1984) and, although both MC and PC cheeses were  
390 made from powder, and showed a higher breakdown of  $\alpha_{S1}$ -casein and  $\beta$ -casein, the  
391 meltability of MC cheese was significantly higher than that of PC.

### 392 *3.7 Dynamic small amplitude oscillatory rheology*

393 The results of the rheology of meltability of all treatments at 180 days of  
394 ripening are shown in Table 4. Higher LT value indicates a higher extent of melting  
395 (Lucey et al., 2003). MC cheese showed significantly higher ( $P<0.05$ )  $LT_{max}$  values  
396 than PC cheese, followed by control and SC cheese. The temperature at  $LT_{max}$  of MC  
397 and PC cheeses was significantly higher ( $P<0.05$ ) than that of control and SC cheese.  
398 The  $LT_{max}$  is an indicator of cheese meltability (Mounsey & O'Riordan, 1999); the  
399 more thermal energy needed to melt cheese, the higher the  $LT_{max}$  temperature of  
400 cheese will be.

401 In the Schreiber test for cheese meltability, MC cheese also exhibited the  
402 highest percentage increase in diameter (Fig. 4). There were differences between

403 Schreiber melting test and dynamic small amplitude rheology for control, SC and PC  
404 cheese. Cooke et al. (2013) stated that differences between results generated by those  
405 tests may be linked to the more complete fat melting during the higher temperature  
406 of the Schreiber melting test. MC cheese exhibited the lowest temperature when  
407  $LT=1$  compared to the rest of the treatments ( $P<0.05$ ). At the point of  $LT=1$ , cheese  
408 is considered to start transforming from a solid to a viscous form (Gunasekaran &  
409 Ak, 2002). MC cheese thus commenced melting at the lowest temperature and had  
410 the highest meltability compared to the other treatments, which may be linked to the  
411 more extensive proteolysis of casein.

### 412 *3.8 Cheese colour*

413 The colour values of samples at 180 days of ripening are shown in Table 5.  
414 Whiteness ( $L^*$  values) of control, SC cheese was significantly higher ( $P<0.05$ ) than  
415 that of MC cheese at 180 days of ripening. The greenness of MC and PC cheeses was  
416 significantly lower (higher  $a^*$  values) ( $P<0.05$ ) than that of control or SC cheese at  
417 180 days of ripening. The yellowness ( $b^*$  values) of MC cheese was significantly  
418 lower ( $P<0.05$ ) than that of SC cheese at 180 days of ripening. Ibáñez et al. (2015)  
419 reported that the whiteness of cheese may be related to proteolysis; lower whiteness  
420 of MC cheese may thus be attributed to higher proteolysis. The  $\Delta E^*_{ab}$  values are also  
421 shown in Table 5. Sharma (2003) reported that  $\Delta E^*_{ab}$  of above 2.3 leads to a just  
422 noticeable difference (JND) and, on this basis, overall, no JND was found between

423 control cheese and the other treatments. Overall, no visible difference was found  
424 between the cheeses made from protein ingredient and control and SC cheese.

425

## 426 **Conclusions**

427 Cheddar cheeses were made from standardised cheese milk, skim milk with cream,  
428 reconstituted MCC with cream and reconstituted LHSMP with cream according to the  
429 same casein, fat and lactose content. Only minor differences in composition were found  
430 with cheese made from reconstituted MCC with added cream compared to control  
431 cheese. The cheese manufactured with MCC had significantly higher ( $P<0.05$ ) levels  
432 of pH 4.6-SN/TN than cheese manufactured with skim milk or LHSMP with cream.  
433 The level of intact  $\beta$ -and  $\alpha_{S1}$ -CN of MC cheese was lower than rest treatments,  
434 consistent with significantly ( $P<0.05$ ) higher plasmin and chymosin activity. No  
435 significant difference ( $P>0.05$ ) were found in hardness between all treatments.  
436 Significantly higher ( $P<0.05$ ) springiness and cohesiveness were found in cheese  
437 manufactured from MCC and LHSMP powder, meltability and maximum loss tangent  
438 in MC cheese were significantly ( $P<0.05$ ) higher than that of the other treatments. No  
439 overall differences of colour were found between all treatments. Use of novel casein-  
440 dominant dairy streams such as MCC has potential for production of Cheddar cheese  
441 with tailored functionality. The results of this study suggest that using reconstituted  
442 LHSMP with cream for the manufacture of Cheddar cheese may result in changes in

443 functionality, while using reconstituted MCC with cream for the manufacture of  
444 Cheddar cheese may be more feasible.

445

446

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451 **References**

- 452 Aaltonen, T., & Ollikainen, P. (2011). Effect of microfiltration of milk on plasmin  
453 activity. *International Dairy Journal*, 21, 193-197.
- 454 Altan, A., Turhan, M., & Gunasekaran, S. (2005). Short communication: comparison  
455 of covered and uncovered Schreiber test for cheese meltability evaluation. *Journal*  
456 *of Dairy Science*, 88, 857-861.
- 457 Andrews, A. T. (1983). Proteinases in normal bovine milk and their action on  
458 caseins. *Journal of Dairy Research*, 50, 45-55.
- 459 Augustin, M. A., & Margetts, C. L. (2003). Powdered milk | Milk Powders in the  
460 Marketplace. In B. Caballero, P. Finglas & F. Toldra (Eds.), *Encyclopedia of food*  
461 *sciences and nutrition* (2nd edn) (pp. 4694–4702). London, UK: Academic.
- 462 Bansal, N., Drake, M. A., Piraino, P., Broe, M. L., Harboe, M., Fox, P. F., &  
463 McSweeney, P. L. H. (2009). Suitability of recombinant camel (*Camelus*  
464 *dromedarius*) chymosin as a coagulant for Cheddar cheese. *International Dairy*  
465 *Journal*, 19, 510-517.
- 466 Barbano, D. M., & Sherbon, J. W. (1984). Cheddar cheese yields in New  
467 York. *Journal of Dairy Science*, 67, 1873-1883.
- 468 Bogenrief, D. D., and Olson, N. F. (1995). Hydrolysis of  $\beta$ -casein increases Cheddar  
469 cheese meltability. *Milchwissenschaft*, 50, 678-682.
- 470 Boland, M. (2011). Whey proteins. In G. O. Phillips & P. A. Williams (Eds.),  
471 *Handbook of Food Proteins* (pp. 30–55). Cambridge, UK: Woodhead Publishing.
- 472 Bourne, M. C. (1978). Texture profile analysis. *Food Technology*, 32, 62–66,72.

473 Chevanan, N., & Muthukumarappan, K. (2007). Effect of calcium and phosphorus,  
474 residual lactose, and salt-to-moisture ratio on the melting characteristics and  
475 hardness of Cheddar cheese during ripening. *Journal of Food Science*, *72*, 168-176.

476 Cooke, D. R., Khosrowshahi, A., & McSweeney, P. L. H. (2013). Effect of gum  
477 tragacanth on the rheological and functional properties of full-fat and half-fat  
478 Cheddar cheese. *Dairy Science & Technology*, *93*, 45–62.

479 Crowley, S. V., Burlot, E., Silva, J. V. C., McCarthy, N. A., Wijayanti, H. B.,  
480 Fenelon, M. A., & O'Mahony, J. A. (2018). Rehydration behaviour of spray-dried  
481 micellar casein concentrates produced using microfiltration of skim milk at cold or  
482 warm temperatures. *International Dairy Journal*, *81*, 72-79.

483 Dave, R. I., McMahan, D. J., Oberg, C., and Broadbent, J. R. (2003). Influence of  
484 coagulant level on proteolysis and functionality of Mozzarella cheeses made using  
485 direct acidification. *Journal of Dairy Science*, *86*, 114-126.

486 Eigel, W. N., Butler, J. E., Ernstrom, C. A., Farrell, H. M., Harwalkar, V. R., Jenness,  
487 R., & Whitney, R. M. (1984). Nomenclature of proteins of cow's milk: Fifth revision.  
488 *Journal of Dairy Science*, *67*,1599-1631.

489 Everard, C. D., O'Callaghan, D. J., Howard, T. V., O'Donnell, C.P., Sheehan, E.M.,  
490 & Delahunty, C.M. (2006). Relationships between sensory and rheological  
491 measurements of texture in maturing commercial Cheddar cheese over a range of  
492 moisture and pH at the point of manufacture. *Journal Texture Studies*, *37*, 361-382.

493 FAO. (2019). Dairy Market Review, March 2019. Food and Agriculture  
494 Organisation, Rome.

495 Farkye, N., & Fox, P. F. (1992). Contribution of plasmin to Cheddar cheese ripening:  
496 effect of added plasmin. *Journal of Dairy Research*, 59, 209.

497 Fenelon, M. A., & Guinee, T. P. (2000). Primary proteolysis and textural changes  
498 during ripening in Cheddar cheeses manufactured to different fat contents.  
499 *International Dairy Journal*, 10, 151-158.

500 Fox, P. F. (1963). *Potentiometric determination of salt in cheese*. *Journal of Dairy*  
501 *Science*, 46, 744-745.

502 Fox, P. F., & McSweeney, P. L. H. (1996). Proteolysis in cheese during ripening.  
503 *Food Reviews International*, 12, 457-509.

504 Fox, P. F., & McSweeney, P. L. H. (1997). Rennets: their role in milk coagulation  
505 and cheese ripening. In B.A. Law (Ed.), *Microbiology and Biochemistry of Cheese*  
506 *and Fermented Milk* (second ed.) (pp. 1-49). London, UK: Blackie Academic and  
507 Professional.

508 Fox, P. F., Guinee, T. P., Cogan, T. M., McSweeney, P. L. H. (2000). *Fundamentals*  
509 *of Cheese Science*. MD, USA: Aspen Publishers, Gaithersburg.

510 Freeman, T. R., Bucy, J. L., & Hassan, Z. (1970). Use of nonfat dry milk in the  
511 production of Cheddar cheese. *Journal of Dairy Science*, 53, 727-733.

512 Guinee, T. P., Mulholland, E.O., Kelly, J., & O'Callaghan, D. J. (2007). Effect of  
513 protein-to-fat ratio of milk on the composition, manufacturing efficiency and yield  
514 of Cheddar cheese. *Journal of Dairy Science*, 90, 110-123.

515 Gunasekaran, S., and Ak., M. M. (2002). *Cheese Rheology and Texture*. FL, USA:  
516 CRC Press LLC.

517 Hoogwegt.com. (2019). Market Matters Demand for Whey Products Looks Bright.  
518 [online] Available at: [https://hoogwegt.com/media/2612/horizons\\_june-2019.pdf](https://hoogwegt.com/media/2612/horizons_june-2019.pdf)  
519 [Accessed 2 Nov. 2019].

520 Hurley, M. J., O'Driscoll, B. M., Kelly, A. L., & McSweeney, P. L. H. (1999). Novel  
521 assay for the determination of residual coagulant activity in cheese. *International*  
522 *Dairy Journal*, 9, 553-558.

523 Ibáñez, R. A., Waldron, D. S., & McSweeney, P. L. H. (2015). Effect of pectin on  
524 the composition, microbiology, texture, and functionality of reduced-fat Cheddar  
525 cheese. *Dairy Science & Technology*, 96, 297-316.

526 IDF. (1982). *Determination of the total solids content of cheese and processed cheese.*  
527 *IDF standard 4A*. Brussels, Belgium: International Dairy Federation.

528 IDF. (1986). *Determination of nitrogen content (Kjeldahl method) and calculation*  
529 *of crude protein content. IDF standard 20A*. Brussels, Belgium: International Dairy  
530 Federation.

531 Kelly, P. (2019). Manufacture of whey protein products: concentrates, isolate, whey  
532 protein fractions and microparticulated. In H. C. Deeth & N. Bansal (Eds.), *Whey*  
533 *Proteins* (pp. 97–122). London, UK: Elsevier Applied Science.

534 Kuchroo, C. N., & Fox, P. F., (1982). Soluble nitrogen in Cheddar cheese;  
535 comparison of extraction procedures. *Milchwissenschaft*, 37, 331-335.

536 Kuchtík, J., Šustová, K., Urban, T., & Zapletal, D. (2008). Effect of the stage of  
537 lactation on milk composition, its properties and the quality of rennet curdling in East  
538 Friesian ewes. *Czech J. Animal Science*, 53, 55-63.

539 Lucey, J. A., Johnson, M. E., Horne, D. S. (2003). Invited review: perspectives on  
540 the basis of the rheology and texture properties of cheese. *Journal of Dairy Science*,  
541 86, 2725-2743

542 Lucey, J. A., Mishra, R., Hassan, A., & Johnson, M. E. (2005). Rheological and calcium  
543 equilibrium changes during ripening of Cheddar cheese. *International Dairy Journal*,  
544 15, 645-653.

545 Lucey, J., & Fox, P. F. (1992). Rennet coagulation properties of late-lactation milk:  
546 Effect of pH adjustment, addition of CaCl<sub>2</sub>, variation in rennet level and blending  
547 with mid-lactation milk. *Irish Journal of Agricultural and Food, Research*, 31, 173-  
548 184.

549 Mahy, M., Van Eyckden, L., & Oosterlinck, A., (1994). Evaluation of uniform color  
550 spaces developed after the adoption of CIELAB and CIELUV. *Color Research and*  
551 *Application*, 19, 105-121.

552 Mane, A., Ciocia, F., Beck, T. K., Lillevang, S. K., & McSweeney, P. L. H.  
553 (2019). Proteolysis in Danish Blue cheese during ripening. *International Dairy*  
554 *Journal*, 97, 191-200.

555 Martin, G. J. O., Williams, R. P. W., & Dunstan, D. E. (2010). Effect of manufacture  
556 and reconstitution of milk protein concentrate powder on the size and rennet gelation  
557 behaviour of casein micelles. *International Dairy Journal*, 20, 128-131.

558 Ménard, O., Camier, B., Guyomarc'h, F., (2005). Effect of heat treatment at alkaline  
559 pH on the rennet coagulation properties of skim milk. *Lait*, 85, 515-526.

560 Moiseev, N., Suchkova, E. & Iakovchenko, N. (2017). Possibility of using  
561 reconstituted milk in manufacture of cheese with cheddaring and cheese curd  
562 stretching. *Agronomy Research*, 15, 1358-1368.

563 Mounsey, J. S., and O’Riordan, E. D. (1999). Empirical and dynamic rheological  
564 data correlation to characterize melt characteristics of imitation cheese. *Journal of*  
565 *Food Science*. 64, 701-703.

566 O’Brien, B., Mehra, R., Connolly, J. F., & Harrington, D. (1999). Seasonal variation  
567 in the composition of Irish manufacturing and retail milks. *Irish Journal of*  
568 *Agricultural and Food Research*, 38, 53-64.

569 O’Keeffe, R. B., Fox, P. F., Daly, C. (1978). Proteolysis in Cheddar cheese: role of  
570 coagulant and starter bacteria. *Journal of Dairy Research*, 45, 465–477.

571 O’Mahony, J. A., Lucey, J. A. & McSweeney, P. L. H. (2005). Chymosinmediated  
572 proteolysis, calcium solubilisation, and texture development during the ripening of  
573 Cheddar cheese. *Journal of Dairy Science*, 88, 3101-3114.

574 Richardson, B. C. & Pearce, K. N. (1981). The determination of plasmin in dairy  
575 products. *Journal of Dairy Science and Technology*, 16, 209-220.

576 Rogosa, M., Mitchell, J. A. & Wiseman, R. F. (1951). A selective medium for the  
577 isolation and enumeration of oral and faecal lactobacilli. *Journal of Bacteriology*, 62,  
578 132-133.

579 Shalabi, S. I. & Fox, P. F. (1987). Electrophoretic analysis of cheese, comparison of  
580 methods. *Irish Journal of Food Science and Technology*, 11, 135-151.

581 Sharma, G. & Bala, R. (2003). *Digital Color Imaging Handbook* (1st ed.). FL, USA:  
582 CRC Press LLC.

583 Sheehan, J. J., Wilkinson, M. G. & McSweeney, P. L. H. (2008). Influence of  
584 processing and ripening parameters on starter, non-starter and propionic acid bacteria  
585 and on the ripening characteristics of semi-hard cheese. *International Dairy Journal*,  
586 18, 905-917.

587 Soodam, K., Ong, L., Powell, I. B., Kentish, S. E., & Gras, S. L. (2015). Effect of  
588 calcium chloride addition and draining pH on the microstructure and texture of full  
589 fat Cheddar cheese during ripening. *Food Chemistry*, 181, 111-118.

590 Sousa, M. J., Ardo, Y., & McSweeney, P. L. H. (2001). Advances in the study of  
591 proteolysis during cheese ripening. *International Dairy Journal*, 11, 327-345.

592 Terzaghi, B. E. & Sandine, W. E. (1975). Improved medium for lactic streptococci  
593 and their bacteriophages. *Applied Microbiology*, 29, 807-813.

594 Truong, V. D., Daubert, C. R., Drake, M. A., & Baxter, S. (2002). Vane rheometry  
595 for textural characterization of cheddar cheeses: correlation with other instrumental  
596 and sensory measurements. *LWT - Food Science and Technology*, 35, 305-314.

597 Watkinson, P., Croker, C., Crawford, R., Dodds, C., Johnston, K., McKenna, A., &  
598 White, N. (2001). Effect of cheese pH and ripening time on model cheese textural  
599 properties and proteolysis. *International Dairy Journal*, 11, 455-464.