Effects of milk composition, stir-out time, and pressing duration on curd moisture and yield

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ABSTRACT

A study was undertaken to investigate the effects of milk composition (i.e., protein level and protein:fat ratio), stir-out time, and pressing duration on curd moisture and yield. Milks of varying protein levels and protein:fat ratios were renneted under normal commercial conditions in a pilot-scale cheese vat. During the syneresis phase of cheese making, curd was removed at differing times, and curd moisture and yield were monitored over a 22-h pressing period. Curd moisture after pressing decreased with longer stir-out time and pressing duration, and an interactive effect was observed of stir-out time and pressing duration on curd moisture and yield. Milk total solids were shown to affect curd moisture after pressing, which has implications for milk standardization; that is, it indicates a need to standardize on a milk solids basis as well as on a protein:fat basis. In this study, a decreased protein:fat ratio was associated with increased total solids in milk and resulted in decreased curd moisture and increased curd yield after pressing. The variation in total solids of the milk explains the apparent contradiction between decreased curd moisture and increased curd yield. This study points to a role for process analytic technology in minimizing variation in cheese characteristics through better control of cheesemilk composition, in-vat process monitoring (coagulation and syneresis), and post-vat moisture reduction (curd pressing). Increased control of curd composition at draining would facilitate increased control of the final cheese grade and quality.

Key words: syneresis, stir-out time, pressing, curd moisture and yield

INTRODUCTION

Final cheese moisture is affected by many cheese-processing conditions such as coagulation time, curd

particle size, stirring, cooking temperature, and ex-vat curd handling (e.g., dry stirring, cheddaring, salting, duration between salting and pressing, and ripening conditions; Gilles, 1976; Johnston, 2000). Moisture content of cheese after pressing has important implications for the theoretical calculation of salt absorption during the subsequent salting phase, and on water displacement and the loss of weight that accompany it (Geurts, 1978). Understanding the factors that determine cheese moisture content after pressing is essential for control of moisture, salt, and ripening. Control of cheese moisture is paramount to maximizing yield and profitability (Jimenez-Marqueza et al., 2005).

Milk composition is the most important factor affecting cheese yields, of which approximately 93% of the DM is protein and fat. Fenelon and Guinee (1999) concluded that when using a seasonal milk supply with varying composition it is important to standardize milk to fixed casein:fat ratio. They listed stage of lactation, plane of nutrition, differences in somatic cell counts, health status of cow, duration of cold storage, and efficiency of standardization practices as causes of variation in milk composition. Guinee et al. (2007) reported that, for the Irish cheese industry between 2001 and 2003, the protein:fat ratio of milk for manufacture of Cheddar cheese varied from 0.84 to 1.02, with protein varying from 3.0 to 3.6% (wt/wt) and fat from 3.3 to 4.2%. This variation is due to natural, seasonal-induced variations in levels and relative proportions of fat, protein, casein, and lactose (Banks et al., 1981; Bruhn and Franke, 1991; O’Brien et al., 1999). Guinee et al. (2007) concluded that variations in the protein:fat ratio of cheese milk with a fixed protein level would affect manufacturing efficiency, composition, and quality of Cheddar cheese, and that relatively little published research exists on this topic. Their study showed that protein:fat ratios of cheese milk in the range of 0.70 to 1.15 had marked implications, not only for cheese composition, but also for cheese yield and the percentage recoveries of milk fat and water to cheese.

It is widely known that insoluble Ca is solubilized in milk with acidification (Dalgleish and Law, 1989). This

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results in a reduction in cross-linking within casein micelles, leading to weaker, more flexible rennet gels and consequential effects on the textural properties of the final cheese (Choi et al., 2004). Higher levels of total Ca in cheese tend to give firmer and less meltable cheeses than those with low Ca concentration (Lucey and Fox, 1993; Guinee et al., 2002; Joshi et al., 2004).

Walstra (2004) reported on the syneresis of curd throughout cheese manufacture, where curd pressing, typically at 10 to 100 kPa, leads to a coherent mass of curd. In some cheeses, the outer layer of curd grains fuse together, forming a rind that reduces further expression of whey. The formation of a rind is greatly assisted by rapid moisture removal from this outer layer, assisted by application of cheesecloth. Lower moisture content before pressing results in lower moisture expression during pressing. Initial moisture content before pressing has important implications for the curd moisture post-pressing because of the formation of a closed rind at an earlier stage or of a greater rind thickness (Walstra, 2004).

Geurts (1978) studied the distribution of moisture in unsalted cheese. He concluded that temperature distribution plays a role, with moisture moving away from areas of high temperature or areas of high pressure (e.g., the bottom of the cheese loaf). After a certain period of pressing, the fusion of the curd grains becomes complete and the decreased curd permeability impedes further moisture movement (Luyten, 1988). Reinbold and Ernstrom (1988) showed that moisture control in the vat reduces moisture variation in large blocks of Cheddar cheese.

Dejmek and Walstra (2004) showed that external pressure on the curd influences the amount of syneresis. Pressing causes the greatest disruption of milk fat globules. During pressing, fat globules can coalesce whereas free fat and fat globule membrane material can be released (Lopez et al., 2007). These authors studied Emmental cheese microstructure after pressing, by using confocal laser scanning microscopy, and reported that fat globules became embedded in cheese cavities and in the protein matrix and that these fat globules may limit casein aggregation and curd formation as well as curd syneresis by blocking the flow of whey through the cavities. They showed that free fat is susceptible to oiling off during pressing, leading to small fat losses during pressing; that is, whey expelled had a fat content of 0.5 g/kg in Emmental cheese after 4 h of pressing at 0.4 kPa at a room temperature of 24°C.

The objective of this study was to investigate the effects of milk composition (i.e., protein levels and protein:fat ratios), stir-out time (i.e., different periods in-vat post-cutting), and pressing duration on curd moisture and yield.

Table 1. Experimental treatments showing milk protein levels (P_M), protein:fat ratios (PF_M), milk fat (F_M), and total solids (TS_M) in the cheesemilk formulations

Treatment ¹	P_M , %	PF_M	F_M , %	TS_M , %
a1	3.3	3.33	0.99	9.0
a2	3.3	1.43	2.31	10.3
a3	3.3	0.91	3.63	11.6
b1	3.7	3.33	1.11	10.1
b2	3.7	1.43	2.59	11.6
b3	3.7	0.91	4.07	13.0

¹a and b represent the different P_M levels, and 1, 2, and 3 represent the 3 PF_M levels.

MATERIALS AND METHODS

Experimental Design

Curd protein and fat contents were varied by coagulating milk that was formulated with 2 experimental factors: milk protein level (P_M) and protein:fat ratio (PF_M ; Table 1). Three randomized factorial replicates were used in this study. Two P_M levels, 3.3 and 3.7%, and 3 PF_M ratios, 3.33, 1.43, and 0.91, were studied in triplicate, giving a total of 18 trials. Curd was drained periodically during syneresis, at 15, 35, 55, and 75 min after cutting time (t_{cut}). A pressure of approximately 23 kPa was applied to 80 g of curd over a 22-h period to simulate the pressing phase during cheesemaking.

Milk Preparation and Gel Formation

Milk was recombined in an 11-L cheese vat (Pierre Guerin Technologies, Mauze, France), as described in Everard et al. (2008), from low-heat skim milk powder (Teagasc, Co. Cork, Ireland), distilled water, and cream (Dairygold, Co. Cork, Ireland) at $42 \pm 0.1^\circ\text{C}$ while being stirred at 44 rpm. Temperature was controlled by a water bath (model Y28 with controller type VFP, Grant Instruments Ltd., Cambridge, UK) connected to a heating jacket on the vat. Milk was formulated to target composition using least squares optimization by means of the Solver tool in Microsoft Excel (v. 10; Microsoft Corp., Redmond, WA). The recombined milk was then cooled to approximately 8°C and stirred constantly at 10 rpm overnight.

A fixed profile of coagulation temperature, milk pH, rennet, calcium chloride concentration, cutting program, and stirring speeds was employed. On the day of curd manufacture, calcium chloride ($\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$) was added to the milk (2.04 mM) and pH was adjusted to 6.7 using HCl (1 M) at $20 \pm 0.1^\circ\text{C}$. The milk was then heated to $32 \pm 0.1^\circ\text{C}$ and allowed to equilibrate; then, 100% recombinant chymosin (Chy-Max Extra, EC 3.4.23.4, isozyme B, 600 international milk clotting units/mL; Chr Hansen Ireland Ltd., Cork, Ireland) was

Figure 1. Schematic of cheese curd pressing apparatus used in this study.

added to the milk (0.18 g of chymosin/kg of milk at 10% dilution in distilled water) in the vat while being stirred constantly at 31 rpm. Stirring was stopped after 3 min and stirrers were replaced with cutting blades.

Rheological Determination of Cutting Time and Cutting Procedure

After stirring the rennet homogeneously into the milk, a 20-mL sample of milk was removed immediately from the vat and placed in a small amplitude oscillatory rheometer (AR 2000 EX Rheometer, TA Instruments, Crawley, UK), which was prewarmed to the renneting temperature, $32 \pm 0.1^\circ\text{C}$, to determine t_{cut} . The rheometer geometry consisted of a cylindrical bob and cup used in oscillation mode at a shear strain of 0.01 and a frequency of 1 Hz, within the linear viscoelastic region (strain <0.03) reported for rennet milk gels (Mishra et al., 2005). The milk coagulum was cut when the elastic modulus (G') reached 35 Pa. Cutting was carried out using a twin set of cutting blades. The moment of initiating gel cutting (i.e., t_{cut}) was taken as the reference time ($t = 0$) for all subsequent syneresis-related measurements. The cutting program consisted of 3 cutting and rest cycles of 1 min duration (Johnston et al., 1998; Everard et al., 2008). The curd was cut at 10 rpm for 40 s, allowed to rest for 20 s, cut at 22 rpm for 40 s, allowed to rest for 20 s, and finally cut again at 22 rpm for 40 s and allowed to rest again for 20 s.

After gel cutting, the cutting blades were replaced by the stirrers; stirring (at 16 rpm) commenced at $t = 4$ min and continued over the course of syneresis.

Curd Drainage and Pressing

Quantities of curd-whey mixture (~ 270 mL) were removed from the vat for analysis, using a specially designed on-line sampler, at 15, 35, 55, and 75 min. Upon removal from the vat, whey was immediately drained from the curd, and the yield and moisture of curd were determined as outlined by Everard et al. (2008). Curd (~ 80 g) was accurately weighed onto cheesecloth in a 100-mL beaker, and the curd and cheesecloth were transferred into cylindrical drainage vessels so that the curd loaf surface would be covered by cheesecloth during pressing (Figure 1). A cylindrical weight (~ 4.5 kg) was placed on top of the curd and cheesecloth, so that the curd loaf was formed into a cylindrical shape under a pressure of approximately 23 kPa (Figure 1). Drainage vessels were set up to allow whey to flow easily away from the curd during pressing (Figure 1).

Measurements of Curd Properties During Syneresis and Pressing

Samples of approximately 3 g of curd were accurately weighed immediately after draining into preweighed aluminum dishes for determination of curd moisture (M_C), by drying in triplicate in a convection oven at 102°C for 16 h (Everard et al., 2008). Whey fat was measured using the Rose-Gottlieb method (IDF, 1987) and whey protein was determined by the Kjeldahl method (AOAC, 1984). Curd fat (F_C) and protein (P_C) were calculated by difference.

The drainage apparatus was weighed after pressing periods of 3, 5, and 22 h. Curd yields (Y_C) from cheese milk were calculated for each period and denoted Y_{C3} , Y_{C5} , and Y_{C22} , respectively.

After pressing for 22 h, the moisture content of the pressed curd (M_{C22}) was determined by grating the curd loaf and drying the grated curd as for M_C determination.

Statistical Analysis

Analysis of variance was carried out by using the Proc Mixed procedure in SAS 9.1 (SAS Institute Inc., Cary, NC) to determine the effects of the P_M , PF_M , stir-out time (ts), and pressing duration (tp) on curd moisture and yield values.

RESULTS AND DISCUSSION

As expected, M_C decreased significantly with increased stir-out time; that is, time in the cheese vat post-cutting (Table 2 and Figure 2). This effect was approximately logarithmic.

Figure 2. The effect of stir-out time (*ts*) on curd moisture at draining (*M_C*) according to cheesemilk formulation. Shown are logarithmic type trendlines of the data: a1 (*R*² = 0.85), a2 (*R*² = 0.86), a3 (*R*² = 0.87), b1 (*R*² = 0.81), b2 (*R*² = 0.72), and b3 (*R*² = 0.95); see Table 1 for treatment designations.

The composition of cheesemilk, as influenced by formulation (*P_M* and *PF_M*), also influenced *M_C* (Table 2). This was related to protein and fat levels, which varied with protein and fat levels of the milk; that is, higher total solids in the milk resulted in lower water content in the coagulum and produced lower moisture content in the curd at draining (Figure 2). This has relevance for cheese manufacture, as it demonstrates that milk standardization can facilitate curd consistency at draining, provided that milk composition (protein and fat levels and not merely protein:fat ratio, but also total solids) can be fixed. Guinee et al. (2006) reported a significant decrease in cheese moisture with increasing milk protein and fat levels (increasing milk protein from 3.3 to 3.6 or 4.0%, wt/wt) for Cheddar cheese. The study also concluded no significant effects on cheese moisture due to method of protein standardization (i.e., using phosphocasein, milk protein concentrate, or ultrafiltered milk retentate). A significant increase in recovery of fat and protein in cheese was observed with milk protein level. Studies have shown that simultaneously increasing milk protein and fat levels (i.e., increasing

milk protein in the range 3.0 to 4.5%, wt/wt, at a constant fat to protein ratio) resulted in linear increases in actual and moisture-adjusted Cheddar cheese yields (Fenelon and Guinee, 1999).
Curd moisture decreased with *tp* as expected (Table 2), on an approximately logarithmic basis (i.e., the effect of pressing was proportional to the logarithm of time of pressing; Figure 3). Stir-out time also affected curd yield after pressing, and an interactive effect was observed of stir-out time × pressing duration on curd moisture and curd yield after pressing (Table 2). This implies that control of curd moisture at draining is a crucial element in achieving consistent control over cheese moisture.

Interestingly, the effect of milk composition on curd moisture at draining was also reflected after pressing (Figure 4); that is, formulation affected *M_C*, with curd moisture (before and after pressing) increasing as *PF_M* increased (Table 2), and this in turn had a clear effect on curd moisture after pressing (Figure 3). Similarly, curd yield after pressing (*Y_{C3}*, *Y_{C5}*, and *Y_{C22}*) decreased with increasing *M_C* (Table 3 and Figure 5).

Simultaneous with decreases in *M_C* associated with lower *PF_M*, *Y_{C22}* was found to increase (Table 3). The contrasting effects of decreased moisture and increased curd yield, an apparent contradiction, require some further elucidation. To discern the related effects of composition, stir-out time, and duration of pressing, one must take into account 2 dimensions of composition within the experimental treatments; namely (1) increases in fat level at constant total solids (with reduction in protein level) and (2) increases in protein levels in the milk at constant fat level (with increases in total solids). In case (1), increasing fat level at constant total solids was found to decrease *M_C* and after pressing (e.g., *M_{C22}*; Table 3). The effect on curd yield after pressing depended on the initial solids level in the milk: at low solids level (from b1 to a2), a positive effect was found on curd yield; at high solids level (from b2 to a3), the effect was not significant (Figure 5). In case (2), although ANOVA on the experimental variables showed

Table 2. Analysis of variance and *F* statistic showing the effects of milk protein level (*P_M*), protein:fat ratio (*PF_M*), stir-out time (*ts*), and pressing duration (*tp*) on moisture and curd yield values, along with their interactive effects, using mixed model analysis

Item ¹	<i>P_M</i>	<i>PF_M</i>	<i>ts</i>	<i>tp</i>	<i>P_M</i> × <i>PF_M</i>	<i>P_M</i> × <i>ts</i>	<i>PF_M</i> × <i>ts</i>	<i>P_M</i> × <i>tp</i>	<i>PF_M</i> × <i>tp</i>	<i>ts</i> × <i>tp</i>
df	1	2	3	2	2	3	6	2	4	6
<i>M_C</i>	29.96***	376.0***	145.51***	—	0.06 ^{NS}	1.29 ^{NS}	0.91 ^{NS}	—	—	—
<i>M_{C22}</i>	1.20 ^{NS}	203.7***	44.27***	—	1.04 ^{NS}	0.34 ^{NS}	3.84**	—	—	—
<i>Y_C</i>	3.55 ^{NS}	9.73**	73.03***	1,470***	0.16 ^{NS}	0.74 ^{NS}	1.50 ^{NS}	0.36 ^{NS}	1.91 ^{NS}	4.42***
<i>M_{CP}</i>	0.29 ^{NS}	276.9***	95.26***	953.7***	0.56 ^{NS}	0.29 ^{NS}	2.79*	1.34 ^{NS}	4.48**	12.44***

¹*M_C* = curd moisture content at draining; *M_{C22}* = curd moisture after 22 h of pressing; *Y_C* = curd yield from milk over the stir-out period; *M_{CP}* = curd moisture during pressing; *Y_C* and *M_{CP}* represent response values after any duration of pressing; that is, 3, 5, or 22 h.
P* < 0.05; *P* < 0.01; ****P* < 0.001.

Figure 3. Trend for moisture after pressing for 3 h (M_{C3} , -; $R^2 = 0.91$), 5 h (M_{C5} , $\times$; $R^2 = 0.90$), and 22 h (M_{C22} , +; $R^2 = 0.82$) versus curd moisture at draining (M_C), showing the decrease in moisture after pressing with pressing duration (tp).

that protein level in milk at a constant fat level had a significant overall effect on curd moisture at draining, the effect at the level of individual formulations was not significant and it did not show a significant effect on moisture of pressed curd (Table 3 and Figure 5).

Protein level in milk at constant fat level did not have an overall effect on curd yield after pressing, but an effect was observed for some milk formulations (a2, b2), with increasing protein level resulting in a significant increase in final yield, where $PF_M = 1.43$ (Table 3).

Figure 4. Influence of milk formulation and curd moisture at draining (M_C) on curd moisture after pressing for 22 h, M_{C22} , according to cheesemilk formulation: a1 ($\diamond$), a2 ($\square$), a3 (Δ), b1 (-), b2 ($\times$), and b3 (+); see Table 1 for treatment designations.

Figure 5. Effects milk formulation and curd moisture at draining (M_C) on curd yield after pressing for 22 h (Y_{C22}) according to cheesemilk formulation: a1 ($\diamond$), a2 ($\square$), a3 (Δ), b1 ($-$), b2 ($\times$), and b3 ($+$); see Table 1 for treatment designations.

CONCLUSIONS

This study showed an interactive effect between stir-out time and pressing duration on curd moisture and yield. It was observed in this study that milk total solids, involving fat or casein, has an effect on curd moisture after pressing, which has implications for milk standardization; that is, showing a need to standardize on a fat and casein basis and not just on a protein:fat

basis. Increasing milk fat level at constant total solids was found to decrease curd moisture at draining and after pressing (i.e., moisture in cheese is associated with protein more than with fat). However, protein level in milk did not affect curd yield or moisture after pressing; this confirms the importance of moisture control at drainage. Decreased protein:fat ratio in this study was associated with increased total solids in milk and resulted in decreased curd moisture and increased curd

Table 3. Average values for curd moisture at draining (M_C) and after pressing for 22 h (M_{C22}) and curd yield after pressing (Y_{C22}) according to cheesemilk composition

Design code	Case ¹		Curd moisture and yield		
	(1)	(2)	M_C	M_{C22}	Y_{C22}
a1		●	85.1 ^a	58.1 ^a	13.8 ^a
a2	↑	●	82.0 ^b	51.1 ^b	17.5 ^b
a3	↑	●	79.6 ^c	47.8 ^c	20.1 ^{cd}
b1	●	↓	84.2 ^a	58.6 ^a	15.1 ^a
b2	●	↓	81.0 ^b	52.3 ^b	19.3 ^d
b3		↓	78.7 ^c	47.5 ^c	21.5 ^c

^{a-d}Values with common superscripts within a column are not significantly different.
¹Case (1) = increase in fat level in milk at constant total solids, b1 to a2; b2 to a3; case (2) = increase in protein level in milk at constant fat level, a1 to b1, a2 to b2, a3 to b3; see Table 1 for treatment designations.

yield after pressing. It is apparent that the main factor was the variation in total solids of the milk, which explains the apparent contradiction between decreased curd moisture and increased curd yield. This study points to a role for process analytical technology in minimizing variation in cheese characteristics through better control of cheese milk composition, in-vat process monitoring (coagulation and syneresis), and post-vat moisture reduction (curd pressing).

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