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JERSEY MILK SUITABILITY FOR CHEDDAR CHEESE PRODUCTION: PROCESS, YIELD, QUALITY AND FINANCIAL IMPACTS

A thesis submitted as a partial fulfilment for the degree of Doctor of Philosophy

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Julie H. Bland
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DECLARATION OF ORIGINAL AUTHORSHIP

I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged.

Reading, December 2014

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ABSTRACT

The aim of this study was to first evaluate the benefits of including Jersey milk into Holstein-Friesian milk on the Cheddar cheese making process and secondly, using the data gathered, identify the effects and relative importance of a wide range of milk components on milk coagulation properties and the cheese making process.

Blending Jersey and Holstein-Friesian milk led to quadratic trends on the size of casein micelle and fat globule and on coagulation properties. However this was not found to affect the cheese making process. Including Jersey milk was found, on a pilot scale, to increase cheese yield (up to + 35 %) but it did not affect cheese quality, which was defined as compliance with the legal requirements of cheese composition, cheese texture, colour and grading scores. Profitability increased linearly with the inclusion of Jersey milk (up to 11.18 p£ L^{-1} of milk). The commercial trials supported the pilot plant findings, demonstrating that including Jersey milk increased cheese yield without having a negative impact on cheese quality, despite the inherent challenges of scaling up such a process commercially.

The successful use of a large array of milk components to model the cheese making process challenged the commonly accepted view that fat, protein and casein content and protein to fat ratio are the main contributors to the cheese making process as other components such as the size of casein micelle and fat globule were found to also play a key role with small casein micelle and large fat globule reducing coagulation time, improving curd firmness, fat recovery and influencing cheese moisture and fat content.

The findings of this thesis indicated that milk suitability for Cheddar making could be improved by the inclusion of Jersey milk and that more compositional factors need to be taken into account when judging milk suitability.

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LIST OF ABBREVIATIONS

AP: Additional Profit

C/P: Casein to protein ratio

Ca: Calcium

Ca^{2+}: Calcium Ions

CF: Curd Firmness

CFR: Curd Firmness Rate

CMS: Casein Micelle Size

CN: Casein

D(0.5): Volume Median Diameter

D(3.2): Surface Area Moment Mean or Sauter Mean Diameter

D(4.3): Volume Moment Mean or De Brouckere Mean Diameter

FA: Fatty acids

H-F: Holstein-Friesian

J: Jersey

LG: Lactoglobulin

LV: Latent Variables

MCP: Milk Coagulation Properties

MFG: Milk Fat globule

Mg: Magnesium

P/F: Protein to Fat Ratio

PLS: Partial Least Squares

RCT: Rennet Coagulation Time

RER: Range Error Ratio

RMSECV: Root Mean Squares Error of Cross-Validation

SCC: Somatic Cell Count

SEM: Standard Error of the Mean

TA: Titratable Acidity

TPA: Texture Profile Analysis

D°: Degree Dornic

dModY: Distance to Y response Model

K: Potassium

Na: Sodium

CHAPTER 1
INTRODUCTION

1.1. BACKGROUND

In the UK, over one quarter of the milk produced is used for cheese production (DairyCo, 2014d) with Cheddar cheese accounting for 62 % of total cheese production (DairyCo, 2014c). The Cheddar cheese industry is therefore of significant economic importance to the dairy industry. However, with the increasing pressure from retailers and consumers for low-price high-quality food, Cheddar cheese producers in the UK in order to remain viable need to improve their production efficiency while maintaining cheese quality.

The improvement in cheese making efficiency has been mainly achieved through the development of improved equipment design and cheese making techniques, with much lower attention given to milk suitability (Law and Tamine, 2010). Improvements in milk suitability have so far been focus on improving milk hygiene, by reducing somatic cell count and bacterial count, and an increased use of milk pre-treatments such as standardization or ultra-filtration (Kelly et al., 2008). The UK multi component milk pricing system which includes protein and fat content could have encouraged an increase in solids in milk. However this is not the case as the percentage of fat and protein in milk remained relatively constant since 2000 (Centre for Dairy Information, 2010). The total yields of fat and protein have however increased and can be linked to dairy farmers judging that improving milk quantity is easier and more profitable than milk quality. In addition, recent studies have shown a rise of poor or non-coagulating milk (Wedholm et al., 2006; Frederiksen et al., 2011a) lowering the efficiency of cheese production, further highlighting the importance of finding new way of efficiently and profitably improving milk composition suitability to the cheese making process.

Milk composition can be modified by many factors such as cow's diet, breed, protein genetic variants, health, season and rearing conditions (Boland, 2003). However, selection of breed was found to be the most rapid and effective way of altering cow's milk composition and thus its processing properties (Lopez-Villalobos, 2012). High milk solids yielding breeds such as Jersey, Brown Swiss, and Montbéliarde have especially been recommended as a way of improving cheese yield in comparison to the Holstein-Friesian breed (Lucey and Kelly, 1994).

In the UK, Holstein-Friesian milk is the main cheese milk due to its greater availability but also the limited information available on the impact of using high yielding breeds on the cheese making process, cheese quality and profitability. This lack of knowledge especially affects the Jersey breed whose use for cheese making has been hindered by presumed negative effects on cheese texture, which is believed to be softer, and on flavour, with off-flavour occurring due to early lipolysis of the larger and more fragile fat globule (Bliss, 1988). However, these impacts have never been demonstrated scientifically. Therefore as Jersey is the second most popular dairy breed in the UK and has been found through yield equations to significantly improve cheese yield (Lundstedt, 1979; Geary et al., 2010), this breed could have the potential to improve the efficiency of Cheddar cheese making. A detailed investigation of the effect of blending Jersey milk into Holstein-Friesian milk at different inclusion rates on the cheese making process is thus required to evaluate if it would indeed lead to an increase in cheese making efficiency and profitability without compromising cheese quality.

The data gathered on the suitability of Jersey milk for cheese making would in addition provide an opportunity to carry out an in depth investigation of the effect of different milk components on milk suitability to cheese making. This is needed as, even though many

components have been found to affect the cheese making process such as the protein, casein, κ-casein content (Lucey and Kelly, 1994), somatic cell count and bacterial count, calcium content, pH and titratable acidity (Lucey and Fox, 1993), casein micelle and fat globule size (O'Mahony et al., 2005; Michalski et al., 2004), there is limited information available on their relative importance. To date, the main indicators of milk suitability are generally considered to only be levels of protein, fat, protein to fat ratio, somatic cell count and bacterial count.

1.2. OBJECTIVES

The first objective of this thesis was to assess the effect of blending milk on milk composition and coagulation properties and the cheese making process. This is needed as non-additional (non-linear) trends could affect the way milk should be blended to yield the maximum benefit.

The second objective was to assess the effect of including Jersey milk in standard Holstein-Friesian milk on coagulation properties, Cheddar cheese yield and quality, and profit both on a pilot (100 L) and a commercial (18,000 L) scale. Determining the fundamental basis of the effect on cheese quality and profitability is of critical importance if cheese makers are to change their production practices.

Finally the third objective was to investigate the relative importance of a wider range of milk compositional factors than previously tested on coagulation properties and the cheese making process using Partial Least Square analysis, partial correlation and linear regression.

The intended outcome of this research is to improve Cheddar cheese making efficiency by finding the optimal inclusion of Jersey milk and deepen the understanding of the effect of

variation in concentration of different milk components on the cheese making process.

1.3. STRUCTURE OF THE THESIS

This thesis is divided into 9 Chapters:

Chapter 1- "**Introduction**". Introduces the background of the research and the objectives. It also provides a description of each chapter.

Chapter 2- "**Literature review**". Provides a review of the literature on Jersey and Holstein-Friesian milk differences in composition and cheese making capacity.

Chapter 3- "**Non-additive effects of blending Jersey and Holstein-Friesian milk on milk composition and coagulation properties**". In this chapter, the effect of blending Jersey and Holstein-Friesian milk on composition and coagulation properties (determined using a controlled stress rheometer) is evaluated, focusing on the occurrence of non-additive (non-linear) effects. Jersey milk was blended at 0 % to 100 % in 10 % intervals.

Chapter 4- "**Effect of blending Jersey and Holstein-Friesian milk on Cheddar cheese processing, composition and quality**". This chapter presents the effect of using Jersey milk on the production of Cheddar cheese on a pilot scale. Four batches of cheese were produced over 12 months in 100 L cheese vats in the University of Reading pilot plant. Jersey inclusions levels were 0, 25, 50, 75 and 100 %, with 25 % and 75 % being done on alternate repeats.

Chapter 5- "**Estimation of the financial benefit of using Jersey milk at different inclusion rates for Cheddar cheese production using partial budgeting**". This chapter builds on the findings of the previous chapter by determining if using Jersey milk for Cheddar cheese production would be profitable. The cheese yield

and milk composition data were based on the pilot plant findings, milk price was computed using the milk contract price of a commercial cheese maker and cheese price on national market price. In addition, the sensitivity of the results to change in milk and cheese prices, and cheese yield was assessed.

Chapter 6- "**Effect of Jersey milk on the production of Cheddar cheese on a commercial scale"**. This chapter presents the findings of the commercial scale study and compares them to the results of the pilot plant study presented in Chapter 4. Four trials were carried out at Lye Cross Farm Ltd in 18,000 L cheese vats over a 12 months period.

Chapter 7- "**Evaluation of milk compositional variables on coagulation properties using Partial Least Squares**". This chapter investigates the relative effect of a wide range of milk components (16 variables) on coagulation properties assessed using a controlled stress rheometer. Additionally, it determines the potential of Partial Least Squares for this type of analysis.

Chapter 8- "**Effect of milk composition on Cheddar cheese manufacture, yield and quality".** This chapter investigates the effect and relative importance of a number of milk components (16 variables) on Cheddar cheese production using data from a pilot scale operation (100 L) and linear regression after evaluation of multicolinearity using Pearson and Partial correlations.

Chapter 9- "**Overall discussion and recommendations**". This chapter summarizes the results of this thesis and highlights recommendations for future work.

CHAPTER 2
2. LITERATURE REVIEW

2.1. INTRODUCTION

This chapter will review past findings on Jersey (J) milk composition and properties and its suitability for cheese making in comparison with Holstein-Friesian (H-F) milk which is the standard cheese milk in the UK. This is necessary as the latest scientific reviews on J milk date from Armstrong (1959) and McDowell (1988) and much research on J milk has been undertaken since the last review.

This review will first characterize J milk composition and properties and then, using past research on the effect of milk composition on cheese making, make a first judgment of its potential suitability for cheese making. Finally, the findings on the effects of J milk on the cheese making process and cheese quality will be examined.

2.2. JERSEY MILK COMPOSITION

2.2.1. Main components

The J breed is well-known for producing milk with a higher concentration of fat and protein than the H-F breed (**Table 2.1** and **Table 2.2**). The highest difference in fat concentration between J and H-F milk was recorded in the UK (38 %) followed by in New-Zealand (29 %), the USA (27 %), and Australia (24 %). The highest difference in protein concentration was also in the UK (20 %) followed by the USA (19 %) and Australia and New-Zealand (14 %) (**Table 2.2**).

The divergence in concentration values, between countries for both breeds, can be linked to differences in diet, climate and genetic selection. Milk composition also changes with time, as indicated in **Figure 2.1**, since 2000, the J breed in the UK showed a higher milk yield

and a lower fat and protein concentrations, whereas in the Jersey Island, J milk yield stayed more or less constant but fat and protein concentration increased. The lower milk, protein and fat yield of Jersey Island J is due to the importation of semen on the island being prohibited until 2008, thus limiting the genetic improvement of their J herds.

Table 2.1 Average milk composition and yield of Jersey and Holstein-Friesian in the UK, the USA, New Zealand and Australia in 2009-2010.

Country	Jersey milk				Holstein-Friesian milk			
	Fat (%)	Protein (%)	P/F[5]	Yield (kg[6])	Fat (%)	Protein (%)	P/F[5]	Yield (kg[6])
GBR[1]	5.40	3.84	0.71	5,721	3.92	3.18	0.81	8,868
USA[2]	4.62	3.59	0.78	8,307	3.63	3.02	0.83	11,627
AUS[3]	4.82	3.73	0.77	5,352	3.88	3.28	0.84	7,477
NZL[4]	5.73	4.14	0.72	3,131	4.41	3.63	0.82	4,430

[1]Centre for Dairy Information (2010),[2]Norman et al. (2010),[3]Australian Dairy Herd Improvement Scheme (2011),[4]DairyNZ (2011),[5]P/F: Protein to fat ratio,[6] per lactation.

Changes in concentration of milk constituents depending on country and time were pinpointed early on in the review of Armstrong (1959) and later on in the study of Martini et al. (2003) and Heck et al. (2009). Also, individual variation within breeds (Auldist et al., 2004; Carroll et al., 2006) have been reported. However, the J breed was shown to display less individual variation than the H-F breed according to Ji and Haque (2003), J breed having much less genetic diversity than the H-F breed (Stachowicz et al., 2011). Aschaffenburg (1963) and McLean et al. (1984) suggested that variation of milk composition between herds can also be found due to differences in herd management via diet and genetic selection.

Table 2.2 Milk composition of Jersey and Holstein-Friesian.

Milk composition	Breed		Country	
	Jersey	Holstein-Friesian		
Fat (%)	5.32[a]	3.96[b]	AUS	McLean et al. (1984)
	3.99[a]	2.97[b]	USA	Beaulieu and Palmquist (1995)
	4.10[a]	3.33[b]	USA	White et al. (2001)
	6.23[a]	4.88[b]	NZL	Mackle et al. (1996)
	5.82[a]	4.47[b]	NZL	Auldist et al. (2004)
	4.95[b]	4.66[b]	POL	Barlowska et al. (2006)
	5.09[a]	3.79[b]	IRL	Palladino et al. (2010)
Protein (%)	3.93[a]	3.08[b]	AUS	McLean et al. (1984)
	3.61[a]	2.97[b]	USA	Beaulieu and Palmquist (1995)
	3.62[a]	2.87[b]	USA	White et al. (2001)
	3.93[a]	3.51[b]	NZL	Mackle et al. (1996)
	3.98[a]	3.55[b]	NZL	Auldist et al. (2004)
	4.15[a]	3.40[b]	POL	Barlowska et al. (2006)
	4.01[a]	3.43[b]	IRL	Palladino et al. (2010)
Lactose (%)	4.94[a]	4.84[a]	NZL	Mackle et al. (1996)
	4.86[a]	4.81[a]	USA	White et al. (2001)
	4.79[a]	4.83[a]	POL	Barlowska et al. (2006)
Milk yield	11.5[a]	12.6[b]	AUS	McLean et al. (1984)
(kg day^{-1})	24.0[a]	36.1[b]	USA	Beaulieu and Palmquist (1995)
	23.6[a]	36.7[b]	USA	White et al. (2001)
	10.0[a]	13.0[b]	NZL	Mackle et al. (1996)
	14.2[a]	18.0[b]	IRL	Prendiville et al. (2010)
Fat yield	0.95[a]	1.08[a]	USA	Beaulieu and Palmquist (1995)
(kg day^{-1})	0.61[a]	0.63[a]	NZL	Mackle et al. (1996)
	0.75[a]	0.80[b]	IRL	Palladino et al. (2010)
Protein yield	0.85[a]	1.08[b]	USA	Beaulieu and Palmquist (1995)
(kg day^{-1})	0.39[a]	0.45[b]	NZL	Mackle et al. (1996)
	0.58[a]	0.72[b]	IRL	Palladino et al. (2010)

[a,b] Means with different superscript in the same horizontal row are significantly different.

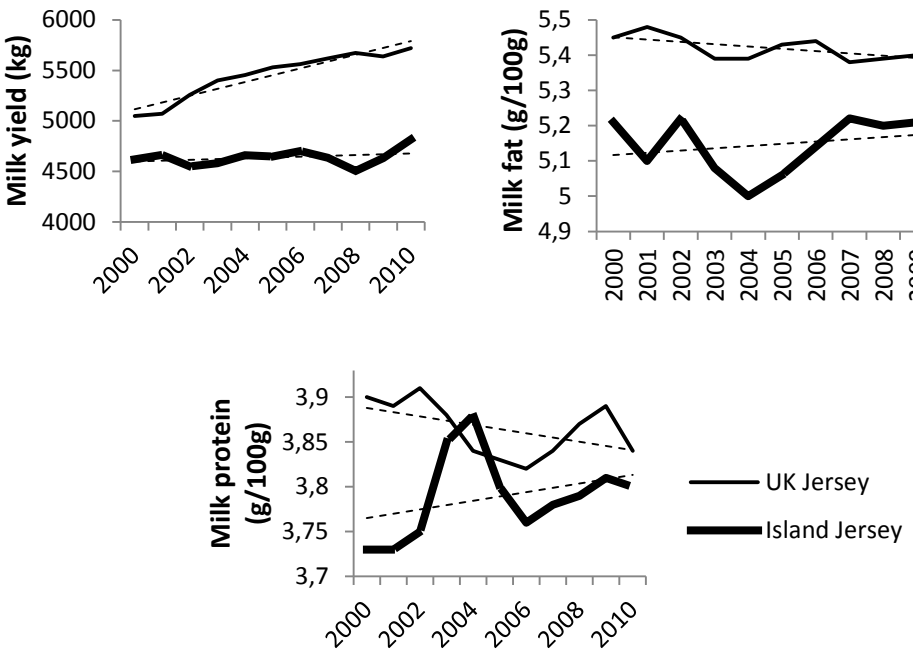

Figure 2.1 Trends in milk yield, protein and fat concentration of the Jersey breed in the UK and Jersey Island (Adapted from Centre for Dairy Information, 2010).

Thus, for a sample to be representative of the average milk supply for the breed, it should not only be composed of a sufficient number of animals but also be derived from a number of different herds. In consequence this review will disregard studies not using representative samples unless it was the only one of its kind. Another problem, which resulted in several disagreements in the literature, is due to differences in defining the Friesian breed. In several studies, Holstein and Friesian are assumed to be the same breed. Whereas in Britain, the Friesian is often defined as a separate lower yielding breed than the Holstein (Centre for Dairy Information, 2010). In this paper it will be assumed that the Friesian and Holstein are the same, unless otherwise stated or if important differences in milk production and composition are found.

The protein to fat ratio of J milk was found to be lower than the H-F's (**Table 2.1**). Lactose concentration was, in most cases, not found to be different between J and H-F, while solids content was found higher for J milk (**Table 2.2**).

In terms of total yield of fat and protein per animal, the J breed was found to have lower levels than the H-F breed in most studies (**Table 2.2**) as it produced a lower volume of milk (**Table 2.1**). It is again in the UK that the highest differences in milk yield were seen, with J breed producing approximately 55 % less milk than H-F (Centre for Dairy Information, 2010). However, some studies did not find any difference in yield of fat and protein (Beaulieu and Palmquist, 1995; Mackle et al., 1996). It can be noted that in the USA the milk yield of both breeds was much higher than in other countries (**Table 2.1 and 2.2**), this is due to the common use of Bovine Growth Hormone, very good selection programs and the very intensive rearing conditions (Capper et al., 2012).

2.2.2. Fat composition

Milk fat has an impact on both the nutritional and technological quality of milk. Milk fat composition is generally believed to be more correlated to the cow's diet rather than its breed (Jenkins and McGuire, 2006). Still, it is generally agreed that J milk fat is nutritionally poorer than H-F milk, due to its higher concentration of short and medium chain fatty acids (FA) (Beaulieu & Palmquist 1995; White et al., 2001; Martini et al., 2003; Soyeurt et al., 2006). As a result, the concentration of detrimental saturated FA is higher. Furthermore, it also has a lower level of long chain trans-fat (Beaulieu & Palmquist 1995) and beneficial conjugated linoleic acid (**Table 2.3**).

Again the J milk fat composition was dependant on the country. Bitman et al. (1995) found USA J to have a higher total value of triglyceride than Danish J and the medium chain FA (C10:00 and C12:00) and C16:1 were decreased and C18:2 and C18:3 were increased. Nonetheless, the differences, between J and H-F, are believed by DePeters and Medrano (1995) not to be significant enough to impact human health. Still, White et al. (2001) suggested that the J milk could be marketed as lower in trans-FA than H-F milk.

Table 2.3 Fatty acid group concentration in Jersey and Holstein-Friesian milk.

Fatty acid (%)	Breed		Country	
	Jersey	Holstein-Friesian		
SCFA[1]	6.8[a]	6.5[b]	USA	Beaulieu and Palmquist (1995)
	2.80[a]	2.52[b]	USA	White et al. (2001)
	8.21[a]	7.92[b]	NZL	Auldist et al. (2004)
MCFA[2]	11.1[a]	7.8[b]	USA	Beaulieu and Palmquist (1995)
	6.99[a]	5.26[b]	USA	White et al. (2001)
	9.66[a]	9.14[b]	NZL	Auldist et al. (2004)
LCFA[3]	68.6[a]	71.2[b]	USA	Beaulieu and Palmquist (1995)
	80.96[a]	82.61[b]	USA	White et al. (2001)
	74.59[a]	73.78[b]	NZL	Auldist et al. (2004)
CLA[4]	0.32[a]	0.41[b]	USA	White et al. (2001)
	1.08[a]	1.53[b]	NZL	Auldist et al. (2004)

[a,b] Means with different superscript in the same horizontal row are significantly different.[1]SCFA:Short chain fatty acid.[2] MCFA: Medium chain fatty acid.[3] LCFA: Long chain fatty acid. [4] CLA: Conjugated linoleic acid.

The main impact of milk lipid on the technological quality of milk is linked to its morphology which can have an effect on product taste as well as on its physical and chemical properties by affecting coalescence and melting temperature (Carroll et al., 2006). J milk fat globule (MFG), compared to those of H-F, are larger but smaller in number (**Table 2.4**). Yet again numerical differences between studies have been seen (**Table 2.4**) which is consistent with the MFG morphometry being dependent on the milk FA composition. Larger MFG are positively correlated with short and medium chain FA, and negatively with trans and long chain FA (Timmen and Patton, 1988; Martini et al., 2003), and finally higher fat concentration with larger MFG (Wiking et al., 2004). Since there is variation in milk FA composition between countries, variation in MFG can be expected.

Table 2.4 Milk fat globule size of Jersey and Holstein-Friesian.

Milk fat globule size	Breed		
	Jersey	**Holstein-Friesian**	
Mean (µm)	4.5[a]	3.5[b]	Singh (2006)
Mean (µm)	5.31[a]	4.93[b]	Martini et al. (2003)
D(0.5)	7.68[a]	6.19[b]	Kielczewska et al. (2008)
Number (globules/mL^{-1})	3.55x109[a]	4.33x109[b]	Martini et al. (2003)

[a,b] Means followed by different superscript in the same horizontal row are significantly different.

2.2.3. Protein composition

The protein composition of J milk has been subject to much less investigation. The few available studies agree that J milk has a higher casein concentration than H-F with approximately 27 % increase in studies in Australia, 21 % in Poland and 14 % in New Zealand (**Table 2.5**). According to McLean et al. (1984), who studied the protein composition in depth, J milk has a higher concentration of total casein (CN), αs1-,β-,κ-CN, total whey protein and α-Lactalbumin than H-F (**Table 2.5**). The study of McLean et al. (1987) gave similar results except that β-lactoglobulin (β-lg) was found to be higher for J milk (**Table 2.5**). McLean et al. (1987) also looked at the urea concentration and found no difference (**Table 2.5**), which is in accordance with White et al. (2001) and Park (1991). However, the study of McLean et al. (1987), Kielczewska et al. (2008) and Park (1991) found no difference in whey protein.

The Casein Micelle Size (CMS) of J was found to be smaller than those of H-F with a ratio of volume to mean size of 0.835 for J and 1.530 for H-F (Ekstrand et al., 1981). These findings are in agreement with the higher prevalence of the κ-CN BB genotype in the J breed which are associated with smaller CMS (Lucey and Kelly, 1994; Horne, 2006).

Table 2.5 Protein fraction concentration in Jersey and Holstein-Friesian milk.

Protein composition (g/ 100 g total protein)	Breed		Country	
	Jersey	Holstein-Friesian		
Casein	30.68[a]	23.91[b]	AUS	McLean et al. (1984)
	30.49[a]	24.1[b]	AUS	McLean et al. (1987)
	33.0[a]	27.2[b]	POL	Kielczewska et al. (2008)
	31.2[a]	27.4[b]	NZL	Auldist et al. (2004)
α-CN	11.9[a]	11.5[a]	NZL	Auldist et al. (2004)
αs1-CN	9.78[a]	8.03[b]	AUS	McLean et al. (1984)
	9.68[a]	8.03[b]	AUS	McLean et al. (1987)
αs2-CN	3.97[a]	2.81[b]	AUS	McLean et al. (1984)
	3.87[a]	2.80[b]	AUS	McLean et al. (1987)
β-CN	10.45[a]	8.52[b]	AUS	McLean et al. (1984)
	10.35[a]	8.51[b]	AUS	McLean et al. (1987)
	13.5[a]	11.0[b]	NZL	Auldist et al. (2004)
κ-CN	3.77[a]	2.61[b]	AUS	McLean et al. (1984)
	3.77[a]	2.61[b]	AUS	McLean et al. (1987)
	4.1[a]	3.8[b]	NZL	Auldist et al. (2004)
Whey protein	8.5[a]	6.8[b]	AUS	McLean et al. (1984)
	8.5[a]	6.8[b]	AUS	McLean et al. (1987)
	7.7[a]	6.8[a]	POL	Kielczewska et al. (2008)
β-Lg	3.48[a]	2.90[a]	AUS	McLean et al. (1984)
	3.58[a]	2.81[b]	AUS	McLean et al. (1987)
	5.3[a]	4.9[b]	NZL	Auldist et al. (2004)
α-La	1.09[a]	0.95[b]	AUS	McLean et al. (1984)
	1.5[a]	1.3[a]	NZL	Auldist et al. (2004)
NPN[1]	3.67[a]	3.19[a]	USA	Park, (1991)
Urea	0.39[a]	0.41[a]	AUS	McLean et al. (1987)
	0.204[a]	0.167[a]	USA	Park (1991)
	0.16[a]	0.15[a]	USA	White et al. (2001)

[a,b] Means followed by different superscript in the same horizontal row are significantly different.[1] NPN: Non-protein nitrogen.

The Buchberger and Dovč (2000) review of studies across countries between 1989 and 1999 also indicated that J had a higher frequency of advantageous BB genotypes of κ- and β-CN for cheese-making, however no differences in β-LG BB was found (**Table 2.6**). The more recent Chinese study of Ren et al. (2011) also found a higher frequency for J of κ-CN BB and no difference in β-LG. The impact of protein genetic variants on milk composition varies depending on the breed studied (McLean et al., 1987) and methodology (Ojala et al., 1997).

The reported specific protein composition of J milk with the increase in total CN and κ-CN concentrations, decrease in CMS, is in accordance with the findings of McLean et al. (1984) and Walsh et al. (1998) on the effect of the BB variant of κ-CN. It is, however, important that the actual state and change in J genomic protein variant be monitored. Large scale genomic projects, as done in Sweden and Denmark, could improve the understanding of different allele frequency and improve selection.

Table 2.6 Advantageous cheese-making genotype frequency in different breeds (Adapted from Buchberger & Dovč, 2000)

	Frequency (% number of animals)		
Genotype	**Jersey**	**Holstein-Friesian**	**Brown Swiss**
κ-Casein BB	31-40	2-3	24-35
β-Casein BB	8-10	<1	3-4
β-Lactoglobulin BB	25-41	32-37	24-35

2.2.4. Somatic cells

Somatic cells count (SCC) are an indicator of poor udder health and due to its impact on milk payments, SCC has been widely investigated. Most studies found no difference between J and H-F milk (Washburn et al., 2002; White et al., 2001; Prendiville et al., 2010). However, others found a lower level of SCC for J milk (Martini et al., 2003) or a

higher level (Sewalem et al., 2006; Berry et al., 2007). Those disagreements could be explained by variation in SCC with time (**Figure 2.2**) in addition to rearing conditions.

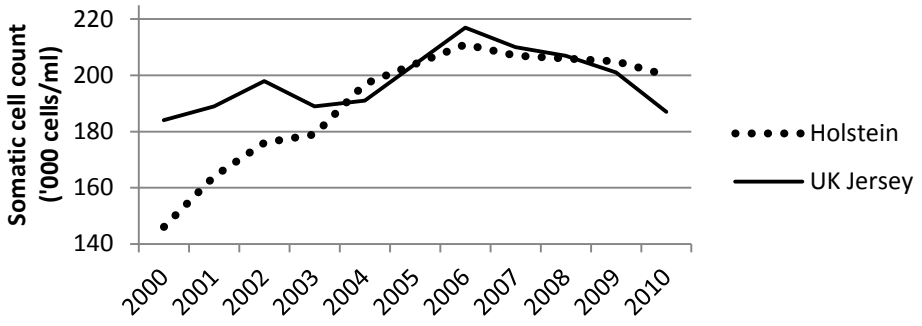

Figure 2.2 Somatic cell count of Holstein and Jersey milk from 2000 to 2010 in the UK (Adapted from Centre for Dairy Information, 2010).

2.2.5. Plasmin activity

Jersey milk was shown to have lower levels of plasmin than H-F by Richardson (1983). However, Bastian and Brown (1996) and Schaar (2009) suggested that this was due to the method of analysis not taking into account the higher CN concentration of J milk and there was in fact no difference in plasmin activity between the two breeds.

2.2.6. Minerals and minor components

Mineral composition influences milk stability and has an impact on milk processability (Tsioulpas et al., 2007). The study of Hermansen et al. (2005) is one of the most detailed and representative studies done on major and trace elements in J and H-F. Samples were collected from numerous herds over a one year period. J milk showed higher levels of calcium (Ca), magnesium (Mg), phosphorus and sulphur (**Table 2.7**) and no differences in potassium (K) and sodium (Na), whose values were not reported. Auldist et al. (2004) agree that J has a higher concentration of Ca and Mg but found a lower level of K and Na in J milk (**Table 2.7**). Czerniewicz et al. (2006) also found J milk to have a higher content

of total Ca (approximately 36 %), colloidal Ca (approximately 46 %), soluble Ca (approximately 19 %) and ionic Ca (approximately 16 %). However, in terms of total Ca fractions, proportions of colloidal and soluble Ca were similar for both breeds. Sundekilde et al. (2011) found J milk to have a higher level of free citrate than H-F milk.

Table 2.7 Minerals concentration in Jersey and Holstein-Friesian milk.

Minerals	**Breed**			
(mg 100g^{-1} milk)	**Jersey**	**Holstein-Friesian**	**Country**	
Calcium (total)	123.0^{a}	109.0^{b}	DNK	Hermansen et al. (2005)
	164.0^{a}	120.6^{b}	POL	Czerniewicz et al. (2006)
	149.0^{a}	126.2^{b}	NZL	Auldist et al. (2004)
Colloidal	112.2^{a}	77.1^{b}	POL	Czerniewicz et al. (2006)
Soluble	51.7^{a}	43.4^{a}	POL	Czerniewicz et al. (2006)
Ionic	8.2^{a}	7.0^{a}	POL	Czerniewicz et al. (2006)
Magnesium	12.7^{a}	11.3^{b}	DNK	Hermansen et al. (2005)
	11.7^{a}	10.9^{b}	NZL	Auldist et al. (2004)
Phosphorous	114.0^{a}	102.0^{b}	DNK	Hermansen et al. (2005)
Sodium	28.0^{a}	35.3^{b}	NZL	Auldist et al. (2004)
Potassium	141.0^{a}	151.2^{b}	NZL	Auldist et al. (2004)
Sulphur	40.0^{a}	34.0^{b}	DNK	Hermansen et al. (2005)

^{a,b} Means followed by different superscript in the same horizontal row are significantly different.

J milk was found to have a higher level of carotenoids, 742 compared to 530 µg 100 g^{-1} fat for H-F by Krukovsky (1961). This was also reported by Whetham and Hammond (1935), McDowell (1988) and Gallier et al. (2011), who also assumed it to be responsible for the yellow coloration of the J milk. However, the level of vitamin A, which is linked to carotenoids, was found to be lower (Whetham and Hammond, 1935; Gallier et al., 2011).

2.2.7. Titratable acidity, pH and other milk properties

The pH and titratable acidity influence milk stability directly and indirectly through their

action on milk minerals (Tsioulpas et al., 2007). Martini et al. (2003) found J milk to have a higher titratable acidity than H-F milk in agreement with Whitehead (1948), however the results were not reported. The study of Czerniewicz et al. (2006) and Kielczewska et al. (2008), using the same herd, found no difference in pH and titratable acidity between J and H-F along with no difference in conductivity, density and freezing point. The reason for this disagreement is unknown. It can be assumed that the titratable acidity of J milk is higher as it was found by two distinct studies in different countries and is coherent with a higher protein content.

2.2.8. Jersey milk composition suitability for cheese-making

The cheese-making capacity of milk has been mainly linked to the protein, Ca, fat, lactose content and CMS (Froc et al., 1988), protein to fat ratio (Guinee et al., 2007) and titratable acidity (De Marchi et al., 2007). Milk fat globule size was shown to have an effect on milk processability according to Michalski et al. (2003; 2004). However, from the numerous studies which have tried to evaluate the effect of milk composition on the cheese-making process, none have totally succeeded due to the important number of interrelated factors (Storry et al., 1983; Coulon et al., 2004).

From the information on milk composition reviewed previously, it can be concluded that J milk has many comparative advantages due to its high CN and protein content, smaller CMS and higher total and ionic Ca concentration, therefore leading to the point of view of many that J milk is better suited to cheese-making than H-F milk (Thompson, 1980; Hayes, 1983; Malacarne et al., 2006; McLean et al., 1984; Glantz et al., 2010). However, some authors did not recommend this milk for cheese making. This was due firstly to its lower protein to fat ratio (Lopez-Villalobos, 2012). The protein to fat ratio of milk has been found to have a positive effect on milk suitability for cheese-making: increasing the curd

formation rate and the curd firmness (Green et al., 1983). Secondly, its higher fat content could also have a negative impact on milk coagulation (Green et al., 1983) and larger MFG could be prone to early lipolysis causing off-flavours (Biss, 1988; Cooper et al., 1911). Cheeses made with larger MFG were also found to have lower moisture content and proteolysis rates, but higher firmness, more yellow colour, higher lipolysis and fat content (Michalski et al., 2003; 2004).

2.2.9. Conclusion

The J breed has been found to produce milk with a higher percentage of most constituents including fat, protein and solids. Lactose was, however, not found to be different while the protein to fat ratio was lower in J milk. The fat and protein fractions were also found to differ with a higher concentration of short and medium chain FA, larger MFG and higher concentrations of most CN grouped into smaller CMS. This can be linked to the prevalence of specific protein genetic variance in the J breed. Plasmin activity and SCC were generally found to be similar. Ca, Mg, P and S were found to be in higher amounts in J. In the case of S and K, the results are conflicting. Even if most studies agree on those differences between J and H-F milks, actual values diverge and this is believed to be due to breed selection and husbandry differences between countries, and with time. Solely from milk composition, it is difficult to judge J milk potential suitability to cheese making due to the number of conflicting positive and negative effects.

2.3. THE EFFECTS OF JERSEY MILK ON CHEESE-MAKING

2.3.1. Jersey milk suitability for cheese making

Milk suitability for cheese-making can be assessed using different properties, such as coagulation time, curd formation rate, curd strength, curd syneresis, fat and protein recovery and, most importantly yield (Cassandro et al., 2008). However only a few studies

have looked at the actual suitability of J milk for cheese-making including cheese yield of J milk compared to H-F.

The study of Auldist et al. (2004), which is one of the most thorough and frequently cited studies on the difference in cheese-making capacity of J and H-F, found that J and H-F milk, when standardized to a protein to fat ratio of 0.80 displayed no significant differences in coagulation time (32.2 vs. 31.4 min) or curd firmness (52.7 vs. 50.2 min), however curd formation was faster (10.3 vs. 12.9 min) in J milk. This is in disagreement with the studies of Martini et al. (2003), Barlowska et al. (2006), Kielczewska et al. (2008) and Poulsen et al. (2013), which using non-standardized milk, found the rennet coagulation time to be shorter and the curd formation rate and curd firmness to be higher. The faster curd formation of J milk was linked to its higher level of Ca, protein and CN. Its smaller CMS can also shorten RCT time and also improved gelation (Glantz et al., 2010).Whitehead (1948) found J curd to have improved syneresis compared to H-F, which, following the same cheese-making process, retained 25 % less whey, although acidity development tended to be lower. This is in accordance, again, with the higher CN content. The higher content of fat and larger globule should, however, decrease syneresis rate (Guinee et al., 2007), suggesting that protein concentration and CMS compensate for the higher fat content and larger fat MFG. A better fat retention was seen for J milk, especially in winter, by Banks et al. (1986) which can be linked to larger MFG (Fox and McSweeney, 2003)

Using a deterministic model based on a yield equation and unstandardized milk composition data, the study of Capper and Cady (2012) found that an increase in Cheddar yield of 23 % can be achieved when J milk is used. In the case of the study of Geary et al. (2010) and Lundstedt (1979), again using a yield equation, the increase was approximately 21 % and 32 % respectively. The sole study found presenting actual cheese yield of J milk

was that of Auldist et al. (2004) which showed an increase in yield of 10 % when using standardized J milk. The J and H-F used in this study had the same κ-CN genotype and the difference in β-LG genotype was accounted for, indicating that the higher levels of main milk constituents and cheese-making capacity are not only due to the specific genotype frequency of the J breed. When the H-F milk was both standardized and the total solid adjusted to J level, no differences in yield could be detected. This suggested that the higher cheese-making capacity of J was only due to higher fat, protein and total solids concentration. The study of Auldist et al. (2004), while discovering many facts about J milk had some limitations; the sample was small, using only 29 cows of each breed and the genotypes were not representative of the real genetic diversity of each breed.

2.3.2. Jersey milk effect on cheese quality

The breed effect on cheese quality defined as the compliance to legislation and the cheese having the desirable organoleptic properties at the time of consumption has not been widely investigated, except in the case of Protected Designation of Origin cheeses (Coulon et al., 2004). However, milk composition is known to influence cheese quality, so it can thus be assumed that using J milk would impact the final product. However, Auldist et al. (2004), using standardized milk found little difference with the exception of salt concentration which was higher for J (1.93 compared to 1.82 g 100 g^{-1} for H-F). However it was not different when the milk was both standardized and adjusted to the same total solid content. In this case only the pH (5.55 compared to 5.38) and ash concentration (4.28 compared to 3.94 g 100 g^{-1}) were found to be significantly higher for J cheese. On the other hand Whitehead (1948) did find a difference in moisture: it was lower (52.4 g 100 g^{-1} water in non-fat substance after 14 days compared to 53.4 g 100 g^{-1}) which in turn made the cheese firmer. This is in agreement with Michalski et al. (2003) and O'Mahony et al. (2005) which found cheese made from milk with larger MFG to be firmer. Furthermore, a

lower moisture is consistent with a higher CN concentration increasing the level of syneresis (Donnelly et al., 1984). The increase in CN and larger MFG should have increased fat retention (Banks et al., 1986) and fat concentration in the final product (Mayes and Sutherland, 1989) however this has not been found by Auldist et al. (2004) and Whitehead (1948). This could be due to early lipolysis, larger MFG being more fragile, impairing fat retention and possibly creating off-flavours as the cheese ages (Cooper et al., 1911; Whetham and Hammond, 1935). Thus, those researchers have recommended that J should not be used for Cheddar cheese-making, advice which is still followed by some cheese makers. In addition, as mentioned previously, higher levels of fat should reduce syneresis, showing again that the effect of fat and size of fat MFG must be compensated by the effect of other milk components. Except for the firmness, no other hedonic differences were found, possibly because no study has focused on it (Coulon et al., 2004). Still, in the case of butter, the colour of the product was found more yellow for J than H-F milk (Whetham and Hammond, 1935) due to a higher level of carotenoids and larger MFG (McDowell, 1988). It is thus possible that cheese colour could also be changed when using J milk.

2.4. CONCLUSIONS

It can be concluded from this review that J milk has a specific composition and properties. Some aspects of J milk would tend to show a higher suitability for cheese-making however the lower protein to fat and higher level of fat and larger MFG have pushed some authors to not endorse the use of J milk for cheese-making due to its perceived negative effect on cheese quality. Nevertheless, the cheese yield was found to be improved and the influence on the end product was not well established due to disagreement between studies. However, more research is needed to understand the extent to which J milk is more suitable than H-F in term of cheese yield, and also quality.

CHAPTER 3

3. NON-ADDITIVE EFFECTS OF BLENDING JERSEY AND HOLSTEIN-FRIESIAN MILK ON MILK COMPOSITION AND COAGULATION PROPERTIES

3.1. INTRODUCTION

In many countries Jersey (J) is increasingly blended with Holstein-Friesian (H-F) milk due to the potential of J milk to improve cheese yield. The level to which the milks are blended is, however, mainly dictated by milk availability and empirical knowledge, as no research has investigated the effect of blending J and H-F and the optimal blending point.

The study of De Marchi et al. (2008), which investigated the difference in cheese making ability of H-F and Brown Swiss milk, and a mixture of the two milks (50 %), found the average curd firmness time for blended milk to be similar to the Brown Swiss, rather than intermediate between the two extremes. Similar non-additional effects were found when well coagulating milk was blended with poorly coagulating milk in two different studies (Okigbo et al., 1985; Frederiksen et al., 2011a). However, the study of Bonfatti et al. (2014) repudiated those findings, having found additional effects when blending well-coagulating and poorly-coagulating milk. As non-additive (non-linear) effects could have implications on the way milk should be blended to yield the maximum benefit in terms of cheese yield and quality; more research is warranted.

The objective of this study was to evaluate the occurrence of non-additive effects when J and H-F milk are blended on composition and coagulation properties, as they have a determinant effect on the cheese making process (Frederiksen et al., 2011b). In addition, the experiment was conducted throughout the year to ascertain possible associated seasonal effects.

3.2. MATERIALS AND METHODS

3.2.1. Experimental Design and Milk Composition

The experiment was carried out 5 times over a 12 month period spaced at regular intervals through the seasons. Milk samples from J and H-F herds were used at different ratios (0 to 100 % at 10 % intervals). Thus, 11 samples were analysed on each of the 5 sampling dates, giving a total of 55 observations.

Analysis for fat, protein, lactose, casein, urea content and Somatic Cell Count (SCC) were performed by the National Milk Laboratory (Glasgow, UK) using a combine flow cytometry and infrared milk analyser (Combifoss 6000, FossEletric, Hillerød, Denmark). The ratio of protein to fat (P/F) and casein to protein (C/P) were calculated from that data.

Size of casein micelle (CMS) was analyse using Zetasizer 5000 (Malvern Instruments Ltd, Worcestershire, UK) following a light scattering method. Milk (35 mL) was centrifuged using a Centaur 2 centrifuge (MSE (UK) Ltd, London, UK) at a speed of 2000 g for 30 min, the fat was then removed manually and the skimmed milk diluted to 1:50 with deionized water (Tsioulpas, 2005). Different diluents can be used and deionized water was chosen for its ease of use. Samples were analysed four times at 25 °C under the protein and size programme. The results were expressed as a z-average (d. nm) and were the average of triplicates, the first reading being disregarded.

Size of MFG was analysed using a laser diffraction method with a Mastersizer S 2000 (Malvern Instruments Ltd, Worcestershire, UK) equipped with a 300RF (reverse Fourier) lens and a He-Ne laser light source (λ = 633 nm) calibrated at the start of the study. To analyse milk fat globule size a few drops of the milk sample were added to deionised water in the dispersion unit. A laser was passed through to generate the scattering pattern and using the Mie theory, the size of the particles was calculated. The refractive index of milk

and water and light absorption coefficient used were 1.46, 1.33 and 0.5x10-5 respectively as reported by O'Mahony et al. (2005). Analyses were done in triplicate and results expressed under the British standards BS2955:1993 as:

- D(0.5) Volume median diameter where 50% of particles are smaller or larger in μm
- D(4.3) Volume Moment Mean or De Brouckere Mean Diameter reflects the size of those particles which constitute the bulk of the sample volume. It is most sensitive to the presence of large particles in the size distribution.
- D(3.2) Surface Area Moment Mean or Sauter mean is most relevant where specific surface area is important e.g. bioavailability, reactivity, dissolution. It is most sensitive to the presence of fine particulates in the size distribution.
- Span the width of the distribution.

Calcium ion concentration (Ca^{2+}) was determined using a Ciba Corning 634 ISE Ca^{2+}/pH Analyser (Bayer Ltd, Newbury, UK) at room temperature (20 ± 1 °C) using the method of Lin (2002). Milk pH was measured using a FE20 desktop pH meter (Mettler-Toledo Ltd., Leicester, UK) and TA was measured using an acid-base titration with a Titralab automatic titrator (Radiometer Analytical, Villeurbanne, FR) titrated with 0.111 M NaOH to pH 8.70 and expressed as Dornic acid (°D).

3.2.2. Milk Coagulation Properties

Milk Coagulation Properties (MCP) were measured using a C-VOR controlled stress rheometer (Bohlin Instruments Ltd., Gloucestershire, UK) following an oscillation method using a measuring system consisting of a bob and cup (C25DIN53019). The frequency and strain were kept constant throughout the test at 0.5 Hz and 2.5 % (Guinee et al., 1997), respectively. Measurements were taken every 14 s. All samples were analysed in triplicate

and randomized order in the 40 h following collection. On the day of measurement, the milk (unpasteurized and unstandardized) was heated over 10 min from 8 °C to the target coagulation temperature 33 °C. No other heat treatment was applied to reverse cold ageing. The pH was not adjusted to enable the effect of different pH to be evaluated.

Marzyme 15 PF (210 IMCU/mL) microbial rennet (Danisco A/S, Copenhagen, DK) was added at a rate of 0.250 mL L^{-1} (after being diluted tenfold), to 50 mL of the heated milk at 33 °C at natural pH. A sample (13 mL) was then placed into the rheometer, and a layer of vegetable oil spread over the milk surface to prevent evaporation. The test was started 1 min after rennet addition allowing for 15 s of mixing.

The following MCP parameters were obtained from the storage modulus: RCT the time in minutes at which the curd attained 0.5 Pa (O'Callaghan et al., 2000), CF the firmness of the curd (Pa), 10 min after RCT and CFR the increase in firmness (Pa min^{-1}) calculated from the time for the gel to firm from 0.5 to 2 Pa.

3.2.3. Statistical Analysis

Statistical analysis was carried out using SPSS PASW Statistics 21.0 (IBM, Hampshire, UK). The effect of J milk on milk composition and coagulation variables was assessed using ANOVA and was found significant at $P < 0.05$. The milk component and coagulation variables found to be significantly affected by the inclusion of J milk were plotted against J inclusion rate and a linear and quadratic model were fitted and compared using an extra sum-of-squares F test. The quadratic model was rejected if $P < 0.05$.

3.3. RESULTS AND DISCUSSIONS

The mean and range of the milk composition and MCP variables studied are shown in **Table 3.1**.

Table 3.1 Milk composition and coagulation properties (Mean ± SEM).

Milk components and properties	**Holstein-Friesian n = 5**	**Jersey n = 5**	***P***
Fat (g/100 g)	3.91 ± 0.04	5.46 ± 0.04	***
Protein (g/100 g)	3.22 ± 0.01	3.87 ± 0.02	***
Protein: fat	0.828 ± 0.011	0.711 ± 0.011	***
Casein (g/100 g)	2.37 ± 0.01	2.94 ± 0.01	***
Casein: protein	0.736 ± 0.001	0.760 ± 0.001	***
Lactose (g/100 g)	4.46 ± 0.00	4.56 ± 0.01	NS
SCC[1] (1,000 cells/mL)	139 ± 11	245 ± 8	***
Ca^{2+}(mg/100 g)	7.93 ± 0.03	8.92 ± 0.42	NS
D(4.3) (µm)	3.48 ± 0.051	4.72 ± 0.041	***
D(3.2) (µm)	0.90 ± 0.04	1.23 ± 0.02	NS
D(0.5) (µm)	3.20 ± 0.04	4.58 ± 0.03	***
Fat globule size span (µm)	1.99 ± 0.02	1.78 ± 0.02	**
Casein micelle size (d. nm)	181 ± 0	160 ± 0	***
pH	6.85 ± 0.01	6.76 ± 0.01	NS
Titratable acidity (°D)	14.57 ± 0.09	16.83 ± 0.15	**
Coagulation Time (min)	58.69 ± 0.60	24.00 ± 0.42	***
Curd Firmness (Pa)	2.01 ± 0.04	12.50 ± 0.45	***
Curd Firmness Rate (Pa/min)	0.138 ± 0.003	0.487 ± 0.022	***

[1]SCC : Somatic cell count, ***$P < 0.001$,**$P < 0.01$, NS: Non-significant.

The ranges and differences in milk composition of J and H-F milk are consistent with past reports (Kielczewska et al., 2008; Frederiksen et al., 2011b). The mean value of RCT (**Table 3.1**) is higher than values found in other studies due to the use of different set points for RCT and testing conditions (Malossini et al., 1996; Guinee et al., 1997; De Marchi et al., 2009). Due to differences in measuring RCT, CF and CFR, comparisons with findings of other workers need to be treated with caution.

3.3.1. Milk composition

Blending the milks resulted in a linear trend for all significantly different variables with the exception of the MFG volume moment mean D(4.3) and CMS which followed a quadratic trend (**Figure 3.1**). However, this was subject to seasonal variation. The D(4.3) relationship was linear in autumn and quadratic in winter, spring and summer. CMS followed a linear trend in autumn and winter and quadratic trend in spring and summer.

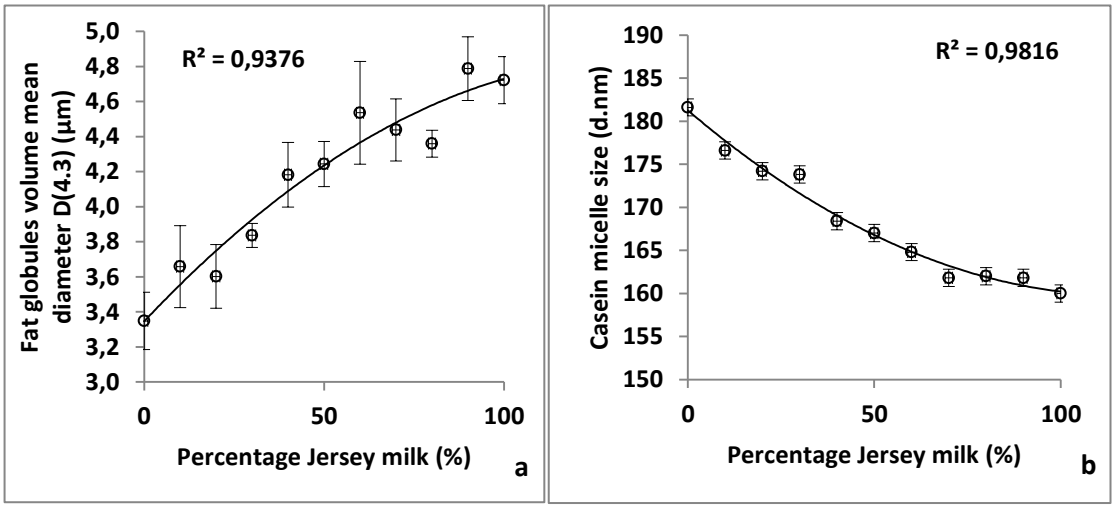

Figure 3.1 Overall effect of the inclusion of Jersey milk in Holstein-Friesian milk on fat globule volume mean diameter (**a**) and casein micelle size (**b**) (n = 55).

The non-additive effect found for D(4.3) and CMS could be linked to the method of measurement, the particle size being highly dependent on the larger globule. However, as seasonal variation were found and the other parameters for size of MFG: D(0.5), D(3.2) and span of MFG did show an additional trend, it is possible that the non-additive effect was a true representation of physical change in D(4.3) and CMS when milk is blended. This effect of blending milk would however be difficult to explain as MFG size has been mainly linked to fat yield and fatty acid composition (Wiking et al., 2004) which could not explain the non-additive effect in this case. Coalescence could result in this sharp increase in size seen when J milk was included, however it is mainly linked to physical stress and

would not display a seasonal effect. In terms of CMS, the main factors influencing it are mineral balance and κ-casein content (Rose and Colvin, 1966), which were not analysed in this study and should be evaluated in future research to ascertain the non-additive effect on D(4.3) and CMS.

3.3.2. Milk coagulation properties

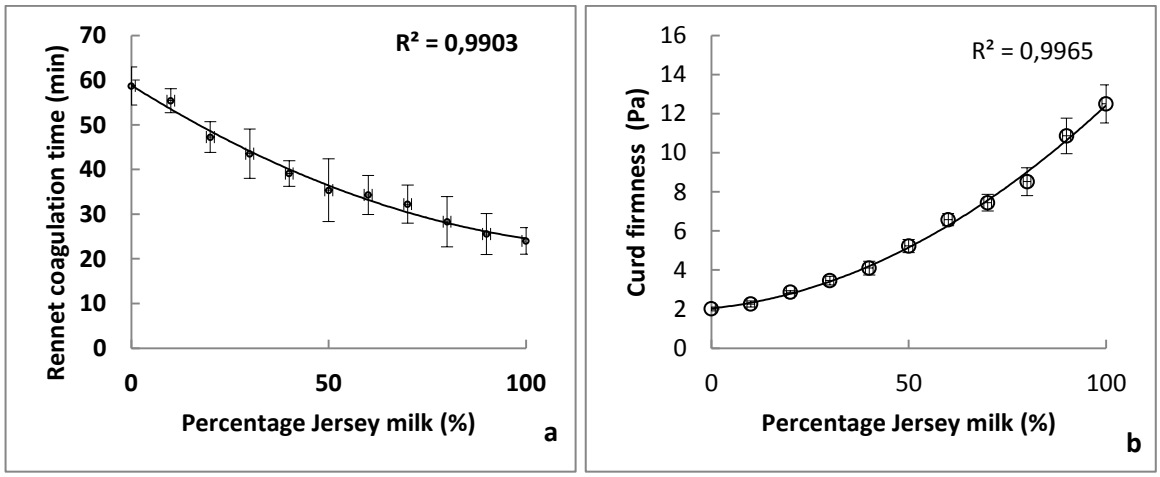

Figure 3.2 Overall effect of the inclusion of Jersey milk in Holstein-Friesian milk on rennet coagulation time (**a**) and curd firmness (**b**) (n = 55).

The relationships of RCT and CF with level of inclusion of J milk were non-additional (**Figure 3.2**) in agreement with the study of De Marchi et al. (2008) and Frederiksen et al. (2011a). Those studies, however, did not include seasonal variation. The non-additional effect seen for the coagulation properties were subject to seasonal variation with the exception of CF. Curd firmness showed a quadratic trend all year round with a higher rate of increase at high inclusion of J milk. In the case of RCT, the relationship was linear in winter and spring and quadratic in autumn and summer, where a higher rate of decrease in RCT was found at an inclusion below 50 % of J milk. A quadratic trend was found for CFR in summer, with a higher rate of increase at high level of J milk than at a low level of

J milk ($R^2 = 0.924$, $P < 0.001$). However the overall trend for CFR was linear with a small regression coefficient due to high variability across seasons ($R^2 = 0.496$, $P < 0.001$).

The non-additive effect on MCP could not be linked to the quadratic trend found in D(4.3) and CMS as they appeared in different seasons. However, a similar quadratic relationship for CF and CFR was found by Guinee et al. (1997) who studied the influence of varying protein and fat content. The trend found in CF and CFR when protein increased was similar to our current study with a higher marginal increase at high rate of J milk and thus protein.

3.4. CONCLUSIONS

The results confirmed the occurrence of non-additional effect when milk is blended both on composition and coagulation properties. Non-additive effects were found for D(4.3) in winter, spring and summer, CMS in spring and summer. The three MCP also presented non-additive effects: RCT in autumn and summer, CF all year round and CFR in summer. From the data collected in this study it was not possible to explain the occurrence of those non-additional effects. Still it was hypothesized that change in mineral balance could have affected CMS and that the increase in protein could have led to the non-additional effect seen for MCP.

Further research is needed on the potential occurrence of non-additive effects during the cheese making process and on cheese yield and composition as it could influence the optimal blending point of J into H-F milk.

CHAPTER 4

4. EFFECT OF BLENDING JERSEY AND HOLSTEIN-FRIESIAN MILK ON CHEDDAR CHEESE PROCESSING, COMPOSITION AND QUALITY

4.1. INTRODUCTION

Milk composition has an important influence on the technical and economic efficiency of cheese making (Storry et al., 1983; Sundekilde et al., 2011). Milk suitability is modified by many factors such as diet, breed, protein genetic variant, health, season and rearing condition. The effects of breed and protein genetic variants, which are inter-related, have been subject to increased interest (Barowska et al., 2006). The Jersey, Brown Swiss, Montbéliarde and other high milk solids yielding breeds have been shown to have a positive impact on cheese-making (Lucey and Kelly, 1994).

The Jersey (J) breed is the second most important dairy breed in the world and it has been suggested that using J milk would improve the efficiency of the cheese making sector in Canada (Thompson, 1980), Wales (Hayes, 1983) and the USA (Capper and Cady, 2012) due to improved longevity, superior udder health, higher cheese yield, reduced feed and water requirements, and an overall reduction in the carbon footprint of Cheddar cheese production.

However, the use of J milk for Cheddar cheese production, while common, is still limited both in terms of the quantity used by individual cheese makers and the number of cheese makers using it. This could be linked to the lack of information available to cheese makers on the effects of using J milk on the cheese making process and cheese yield.

Estimates of cheese yield from J were based mainly on theoretical cheese yield equations

and theoretical increases ranged from 21 % to 32 % compared to Holstein-Friesian (H-F) (Lundstedt, 1979; Geary et al., 2010; Capper and Cady, 2012). The only practical study measuring the actual improvement in yield did so using standardized milk and showed an increase of only 10 % (Auldist et al., 2004).

There also appears to be a presumption in the industry that J milk has a negative impact on cheese quality. Cheese quality can be first defined as the compliance to legislation (International Food Standards, 2003) which specifies a minimum level of fat and maximum moisture. Secondly quality can be defined as the cheese having the desirable organoleptic properties at the time of consumption, which is, commonly assessed using grading at the cheese factories. In the case of J cheese, it is believed to have a higher moisture content due to the lower protein to fat ratio, resulting in lower syneresis (Bliss, 1988) and a buttery, weaker texture and rancid taste due to the higher fat content and larger, more fragiles Milk Fat Globules (MFG), causing early lipolysis (Cooper et al., 1911). However, these fears of negative impact were not supported by past data. Auldist et al. (2004) found that the moisture content and composition of J and H-F Cheddar cheeses made with standardized milk were not different with the exception of a higher salt concentration and lower pH and ash concentration for J cheese. On the other hand, Whitehead (1948) found that Cheddar cheese from non-standardized J milk had a lower moisture content and the cheese was also firmer. However, the cheese making process also had to be adapted to account for differences in acidity development and syneresis. Unfortunately, no information regarding yield was provided. Thus there is a lack of information on the effect of J milk on Cheddar cheese making, composition and sensory properties limiting its use on a commercial scale.

This study therefore investigated the effect of J milk, and blends of J and H-F, on Cheddar

cheese production with the objective of finding the optimal inclusion rate of J milk in H-F milk for improving yield without reducing the quality of the cheese.

4.2. MATERIALS AND METHODS

4.2.1. Experimental Design

The experiment was carried out three times each season between September 2012 and November 2013. The seasons were defined as autumn (September, October and November), winter (December, January and February), spring (March, April, May) and summer (June, July, August).

Samples from the combined evening and morning milking were obtained from the University herd of H-F cows (CEDAR, Reading, UK) and two J farms (Brackley and Slough, UK) and transported to the pilot-scale cheese making facility at the University of Reading. J milk was blended with H-F milk at 0, 25, 50, 75 and 100 % J in H-F milk. Due to time limits, the ratios 25 % and 75 % were performed on alternate repeats. Thus, 4 samples were analysed on each repeat, giving a total of 48 observations.

4.2.2. Milk Composition

Milk sampling was done after the inclusion of J milk and careful mixing but before pasteurization, following BS EN ISO 707:2008. Analysis for fat, protein, lactose, casein, urea content and Somatic Cell Count (SCC) were performed by the National Milk Laboratory (Glasgow, UK) using a combine flow cytometry and infrared milk analyser. The ratio of protein to fat (P/F) and casein to protein (C/P) were calculated from this data.

Size of casein micelle (CMS) was determined using a Zetasizer 500 (Malvern Instruments Ltd, Worcestershire, UK) and size of MFG: volume moment mean D(4.3), surface area moment mean D(3.2), volume median diameter D(0.5) and span using a Mastersizer S

2000 (Malvern Instruments Ltd, Worcestershire, UK) as described in **Chapter 3, section 3.2.1**. Calcium ion concentration (Ca^{2+}) was determined using a Ciba Corning 634 ISE Ca^{2+}/pH Analyser (Bayer Ltd, Newbury, UK) using the method of Lin (2002). Milk pH was measured using a FE20 desktop pH meter (Mettler-Toledo Ltd., Leicester, UK) and titratable acidity (TA) was measured using an acid-base titration with a Titralab automatic titrator (Radiometer Analytical, Villeurbanne, France) titrated with 0.111 M NaOH until pH 8.70 was reached, and expressed as Dornic acid (°D). All on site analyses were performed within 24 h of milk collection while milk sent for analysis at the National Milk Laboratory was conserved using bronopol (0.02 % wt/vol).

4.2.3. Cheese making process

On each occasion four vats of cheese were made over two days. Bulk milk was pasteurized at 71.5 °C, but not standardized, as standardization was not carried out by the large commercial cheese plant on which the cheese making process is based. Approximately 80 kg of milk was weighed to the nearest 0.2 kg using an Avery Berkel L130 (Avery Berkel, Bershire, UK) and placed into each vat and warmed to 33 °C. Starter (RSF 638, Chr. Hansen Laboratories A/S, Hørsholm, Denmark) was added at 0.0269 g kg^{-1} of milk weighed to the closest 0.01g using a Sartorius Secura 10JP (Sartorius UK Ltd., Surrey, UK) and left to ripen for 35 min. Coagulant Marzyme 15 PF (Danisco, Dupont Company, Hertfordshire, UK) was then added at 0.2566 mL kg^{-1}, weighed using the Sartorius Secura balance, after being diluted fivefold with water. Curd was cut at the cheese maker's judgment. The curd and whey were heated to 39 °C in 45 min and then left to scald at this temperature for 50 min. Whey was then drained and the cheddaring process started when the TA reached 0.20 ± 0.05 °D. Curd was milled at TA 0.30 ± 0.05 °D after being weighed using the same balance as for weighing milk and salt added at 24 g kg^{-1} of curd. Salt was weighed to the closest 0.1 g using a Sartorius PT600 balance (Sartorius UK Ltd., Surrey,

UK). Salted curds were left to cool and then filled into round moulds of 5 kg and prepressed at 3 up to 7 kPa, and left to press overnight at 7 kPa. All input and output quantities for each vat produced can be found in **appendices section 2**.

The yield and composition of the whey was determined from the bulked whey collected between drainage until milling, weighed to the nearest 0.02 kg using an Avery Berkel L130. Samples were taken after careful mixing and heated to 40 °C before being analysed using a calibrated milk infrared analyser (Lactoscope, Advanced Instruments Inc., Drachten, Netherlands). White whey, which is the whey expelled during slating and pressing could not be collected due to the design of the press used. Yield was calculated from the weight of milk placed in the vat, and the weight of cheese after pressing and vacuum packing measured using again an Avery Berkel L130. Yield was expressed both in actual yield of cheese (kg) per 100 kg of milk ($\mathbf{Y_A}$), and adjusted yield using a fixed moisture content of 37 % ($\mathbf{Y_{MA}}$) and the following formula:

$$\boldsymbol{Y_{MA}} = \frac{(100 - \boldsymbol{M_C})}{(100 - 37)} \times \boldsymbol{Y_A}$$

$\mathbf{Y_{MA}}$: moisture-adjusted cheese yield as kg 100^{-1} kg, $\mathbf{M_C}$: cheese moisture as kg 100^{-1} kg, $\mathbf{Y_A}$: actual yield as kg 100^{-1} kg.

Theoretical yield ($\mathbf{Y_T}$) was calculated using milk composition data and the Van Slyke equation (Van Slyke and Price, 1949):

$$\boldsymbol{Y_T} = \frac{(0.93\boldsymbol{F_M} + \boldsymbol{C_M} - 0.1)\ 1.09}{100 - \boldsymbol{M_C}}$$

$\mathbf{Y_T}$: theoretical yield, $\mathbf{F_C}$: fat in milk expressed as g 100^{-1}g, $\mathbf{C_m}$: casein in milk expressed as g 100^{-1}g, $\mathbf{M_C}$: cheese moisture as g 100^{-1}g.

Finally cheese yield efficiency ($\mathbf{Y_E}$) was calculated using the actual yield as percentage of theoretical yield:

$$\boldsymbol{Y_E} = \frac{\boldsymbol{Y_A} \times 100}{\boldsymbol{Y_T}}$$

Fat and protein recoveries and losses were calculated using the composition and quantity of milk, cheese and whey based principle described by Banks et al. (1981):

$$\boldsymbol{F_{RC}} = \frac{\boldsymbol{Q_C} \times \boldsymbol{F_C}}{\boldsymbol{Q_M} \times \boldsymbol{F_M}} \times 100$$

$$\boldsymbol{F_{LW}} = \frac{\boldsymbol{Q_W} \times \boldsymbol{F_W}}{\boldsymbol{Q_M} \times \boldsymbol{F_M}} \times 100$$

$\mathbf{F_{RC}}$: fat recovery in cheese, $\mathbf{F_{LW}}$: fat losses in whey, $\mathbf{Q_C}$: quantity of cheese kg, $\mathbf{F_C}$: fat in cheese %, $\mathbf{Q_M}$: quantity of milk kg, $\mathbf{F_M}$: fat in milk %, $\mathbf{Q_W}$: quantity of bulk whey kg, $\mathbf{F_W}$: fat in whey %.

$$\boldsymbol{P_{RC}} = \frac{\boldsymbol{Q_C} \times \boldsymbol{P_C}}{\boldsymbol{Q_M} \times \boldsymbol{P_M}} \times 100$$

$$\boldsymbol{P_{LW}} = \frac{\boldsymbol{Q_W} \times \boldsymbol{F_W}}{\boldsymbol{Q_M} \times \boldsymbol{F_M}} \times 100$$

$\mathbf{P_{RC}}$: protein recovery in cheese, $\mathbf{P_{LW}}$: protein losses in whey, $\mathbf{P_C}$: protein in cheese %, $\mathbf{P_M}$: protein in milk %, $\mathbf{P_W}$: protein in whey %.

Mass balance of total weight and protein plus fat were calculated using the following equations based on the principles described by Banks et al. (1981), however as the white whey was not collected it was not included in the equation:

$$\textbf{Total weight} = \frac{(\mathbf{Q_W} + \boldsymbol{Q_C})}{(\boldsymbol{Q_M} + \boldsymbol{Q_{St}} + \boldsymbol{Q_R} + \boldsymbol{Q_S})} \times 100$$

Total weight: Total weight defined as outputs as a percentage of inputs %, $\mathbf{Q_{St}}$: quantity of starter kg**,** $\mathbf{Q_R}$: quantity of rennet solution kg**,** $\mathbf{Q_S}$: quantity of salt**.**

$$\textbf{Weight of fat + protein} = \frac{\boldsymbol{Q_C}\,(\boldsymbol{P_C} + \boldsymbol{F_C}) + \boldsymbol{Q_W}(\boldsymbol{P_W} + \boldsymbol{F_W})}{\boldsymbol{Q_M}\,(P_M + F_M)} \times 100$$

Weight of fat + protein: fat + protein outputs as a percentage of fat and protein inputs (%).

Time of addition of rennet to cutting, cutting to milling and starter to milling were also recorded.

4.2.4. Cheese composition

Cheese was analysed for fat, protein, moisture, pH and salt 1 month after production, sampling was done following BS EN ISO 707:2008, taking samples from 4 different locations on the cheese and combining them.

Fat content analysis was carried out using the Gerber method (ISO standard 2446/IDF 226). It was ground and 3 g (± 0.0005 g) was quantitatively added into a funnel with stopper inserted. Ten mL of sulphuric acid (98 %) was added to the butyrometer, to digest protein, and 5 mm of warm water was added over the acid. The sample was then added and 1 mL amyl alcohol to enhance fat separation and warm water added to reach 5 mm under the butyrometer shoulder. The stopper was put in place using a key and the butyrometer shaken for 10 min using a protective stand. The butyrometer was then placed stopper up in a waterbath at 65 °C for 5 min and then centrifuged using an Astell Hearson Gerber centrifuge (Astell Scientific, London, United Kingdom) for 5 min at increasing force up to setting 9, with the stopper down. The butyrometer was then placed, stopper down, in the waterbath for 5 min at 65 °C. The butyrometer scale was then read directly, this was done in triplicate for each inclusion rate. The results were presented as g 100 g^{-1} of Fresh Weight

(FW) of cheese.

Protein content was determined by the Kjeldahl nitrogen method based on the ISO 17837:2008 Freshly grated cheese, 1 g, was accurately weighed onto a filter paper in triplicate and placed into a digestion tube. A further digestion tube with 1 g of sucrose acted as a blank and another with 0.2 g of glycine was use to verify accuracy. Two Kjeltab Cu catalyst tablets and 25 mL of concentrated sulphuric acid were added to each digestion tube which was then inserted into the BÜCHI digestion K-424 unit (BÜCHI Labortechnik AG, Postfach, Switzerland). Samples were heated until a clear colour was observed.Distillation was then undertaken using a BÜCHI distillation unit 323 (BÜCHI Labortechnik AG, Postfach, CH), a receiving flask of 250 mL containing 50 mL of 2 % boric acid and a few drops of methyl red. Fifty mL of water and 125 mL of 50 % NaOH solution were added to each digestion tube prior to steam distillation. The liberated ammonia was titrated using 0.05 M sulphuric acid.bThe measurements were then used to calculate the crude protein content using the following equation:

$$\boldsymbol{w_p} = \frac{\mathbf{0.0014} * (\boldsymbol{V_s} - \boldsymbol{V_b}) * 100}{\boldsymbol{m}} \times \mathbf{6.38}$$

$\boldsymbol{w_p}$: crude protein content in g, **0.0014**: g of nitrogen reacting with 1 mL of sulphuric acid 0.05 M., $\mathbf{V_s}$: the volume (mL) of sulphuric acid used to titrate the sample to the closest 0.05 mL, $\mathbf{V_b}$: the volume (mL) of sulphuric acid used to titrate the blank test to the closest 0.05 mL, $\boldsymbol{m}$: the mass of sample in g to the closest 0.001g, **6.38**: the accepted conversion factor between nitrogen content to crude protein content**.**

The results were expressed as g of protein per 100 g of FW cheese.

The moisture content was determined by weighing 10 ± 0.005 g of ground cheese into a dish with 20 ± 0.5 g of sand, along with lid and rod, which had been previously dried for 1

hour at 105 °C and then pre-weighed (± 0.0001 g). The sample was then put into an oven to dry for 23 h at 105 °C and the loss in weight recorded. A Titralab automatic titrator (Radiometer Analytical, Villeurbanne, France) was used to assess salt concentration in cheese. A sample (5 ± 0.001 g) of ground cheese was mixed with 100 mL of water at 40 °C and a 50 mL aliquot was sampled. To this aliquot 5 mL of 1 M nitric acid was added and then it was titrated using a combined silver and mercurous sulphate metal probe MC609/Ag (Radiometer Analytical, Villeurbanne, FR) with silver nitrate 0.1 M to an endpoint of -100 mV. The pH of cheese samples was measured with a Thermo Orion star A111 benchtop pH meter (Thermo Fisher Scientific Ltd, Loughborough, UK) using a specially designed cheese FoodCare pH combination pH probe FC240B (Hanna Instruments Ltd, Leighton Buzzard, UK). All analyses were carried out in triplicate at room temperature (20 ± 0.5 °C).

4.2.5. Quality attributes

The cheese sensory properties were evaluated after 3 months of ageing. The texture of the cheese was analysed using Texture Profile Analysis (TPA) as developed by Szczesniak (1963) and Friedman et al. (1963),where two compression cycle are performed on the sample, with a texture analyser (Model TA-XT2, Stable Micro Systems, Godalming, UK). The parameters were 30 % compression at a speed of 50 mm/s as to be under the fracture force (Shama and Sherman, 1973) and 5 s delay between compressions, this was done in triplicate. Samples were cut into cylinders of 22 mm diameter and 22 mm height (Halmos et al., 2003) after being tempered to room temperature in a vacuum pack overnight. The TPA parameters recorded were:

- hardness which corresponds to the peak load of the first compression cycle (N),
- cohesiveness which is the area under the second compression stoke divided by the

area under the first compression stoke,

- springiness which is the distance of the detected height of the second compression divided by the detected height of the first compression,
- resilience which is the upstroke energy divided by the downstroke energy of the first compression.

Colour was analysed using a ColorQuest II spectrophotometer (HunterLab, Virgina, US). Cheese samples were prepared into cubes (5x5x3 cm) and analysed using the Commission on Illumination Standard (CIE) Illuminant D65 lamp. Results are given as a CIE L*a*b colour scale and colour differences (ΔE*ab) were calculated (Fernández-Vázquez et al., 2011). Analysis was carried out in triplicate

Cheese grading was carried out at room temperature (21±0.5 °C), at 3 and 8 months according to the standard UK grading scheme (NACEPE) awarding points for flavour and aroma (/45), body and texture (/40), colour (/5) and appearance (/10) with regard to standard Cheddar cheese required by retailers. On each occasion a minimum of three graders were used who during the grading were not allowed to talk about the cheese samples.

4.2.6. Statistical analysis

Data were subject to ANOVA and Tuckey HSD using SPSS PASW Statistics 21.0 (IBM, Hampshire, UK) to detect any statistical differences between inclusion rates. Seasonal variation effects were tested the same way. Differences were considered significant at $P < 0.05$.

4.3. RESULTS AND DISCUSSION

4.3.1. Milk composition

Means, ranges and SEM for each blend are presented in **Table 4.1**. The range and differences in composition are in agreement with others studies (Auldist et al., 2004; Barowska et al., 2006; Czerniewicz et al., 2006). The J milk contained significantly higher levels of all components ($P < 0.01$) except lactose, urea, Ca^{2+}, D(3.2), MFG size span and pH which were not significantly different. In addition, the P/F and the C/P ratio and CMS were higher in H-F milk. This difference in P/F and C/P would not be representative of all cheese milk due to the increasingly common standardization of milk to a set P/F or casein to fat ratio. However, not standardizing enabled the evaluation of the effect of increased fat proportion in the cheese, which is often believed to be the cause of poor cheese quality.

In terms of the effect of season on milk composition (**Table 4.1**), only the fat and protein content was modified, for both breeds, with the lowest level found of both components in summer and the highest level in winter but no difference in spring and autumn ($P < 0.05$).

In comparison to the findings of **Chapter 3** where non-additional trend were found for casein micelle size and D(4.3) and the milk coagulation properties, no non-additional effect was found in this study, which could be due to the lower number of inclusion rates use not allowing to differentiate effectively between linear and quadratic trends.

4.3.2. Cheese making process

Table 4.2 presents the results of the effect of J milk on the cheese making process. Again no non-additional was found and while this could be due to the low number of inclusion rates use, it suggests that potential non-additional trend does not impact significantly the cheese making process.

The actual, theoretical and moisture adjusted yield of cheese were significantly improved by the inclusion of J milk ($P < 0.01$). Actual yield was increased by up to 34.6 % when using 100 % J milk compared to H-F milk (**Table 4.2**).This is consistent with the deterministic model based on a yield equation of Lundstedt (1979) which found an increase of approximately 32 %, but was higher than the estimates of Geary et al. (2010) and Capper and Cady (2012) which found increases of 21 % and 23 % respectively. However, this was due to the J milk composition being lower in protein and fat content than in the previous deterministic model. Auldist et al. (2004) showed an increase in yield of 10 % when using standardized J milk.

Theoretical yield predicted a smaller increase in yield (17.74 %) which is lower than the results of the previously cited research (Lundstedt, 1979; Geary et al., 2010; Capper and Cady, 2012). This could be due to the way casein was measured. In the current study casein level was analysed whereas in the deterministic model it was calculated from protein level using higher C/P ratio (0.8) than what was found in the current study (0.73-0.77).

Seasonality variations were found for the theoretical yield, in winter and spring no difference in theoretical yield between inclusion rates were found, while in autumn and summer the theoretical yield increased with increased J milk percentage. This disagrees with actual yield values where the difference between H-F and J was constant throughout the year (**Figure 4.1**) due to similar seasonal effect on actual yield for both breeds.

Table 4.1 Holstein-Friesian and Jersey milk blends composition (Mean ± SEM).

Milk composition	Jersey milk inclusion					*P*	
	0%	25%	50%	75%	100%	Breed Season	
	n = 12	n = 6	n = 12	n = 6	n = 12		
Fat (g/100 g)	3.94 ± 0.07	4.19 ± 0.09	4.70 ± 0.05	5.12 ± 0.12	5.43 ± 0.10	***	*
Protein (g/100 g)	3.15 ± 0.08	3.26 ± 0.03	3.44 ± 0.03	3.58 ± 0.06	3.74 ± 0.05	***	*
Protein: fat	0.780 ± 0.016	0.769 ± 0.017	0.767 ± 0.007	0.774 ± 0.014	0.767 ± 0.010	***	NS
Casein (g/100 g)	2.31 ± 0.02	2.39 ± 0.03	2.55 ± 0.03	2.66 ± 0.05	2.79 ± 0.04	***	NS
Casein: protein	0.747 ± 0.002	0.747 ± 0.003	0.749 ± 0.003	0.744 ± 0.005	0.745 ± 0.003	***	NS
Lactose (g/100 g)	4.44 ± 0.02	4.44 ± 0.03	4.46 ± 0.02	4.47 ± 0.02	4.46 ± 0.02	NS	NS
Urea (mg/100 g)	0.031 ± 0.002	0.026 ± 0.002	0.027 ± 0.003	0.029 ± 0.003	0.023 ± 0.003	NS	NS
SCC[1] (1,000 cells/mL)	162 ± 14	153 ± 17	184 ± 9	217 ± 12	191 ± 10	***	NS
Ca^{2+} (mg/100 g)	7.52 ± 0.25	7.66 ± 0.24	7.44 ± 0.16	7.16 ± 0.21	7.31 ± 0.21	NS	NS
D(4.3) (µm)	3.39 ± 0.08	3.74 ± 0.05	4.09 ± 0.06	4.31 ± 0.11	4.69 ± 0.11	***	NS
D(3.2) (µm)	1.15 ± 0.09	1.21 ± 0.06	1.24 ± 0.08	1.20 ± 0.12	1.39 ± 0.10	NS	NS
D(0.5) (µm)	3.30 ± 0.08	3.66 ± 0.05	4.02 ± 0.05	4.25 ± 0.09	4.70 ± 0.40	***	NS
MFG Span (µm)	2.01 ± 0.15	2.20 ± 0.33	2.03 ± 0.19	1.83 ± 0.03	1.97 ± 0.25	NS	NS
CMS[2] (d. nm)	176 ± 3	170 ± 4	164 ± 2	167 ± 6	158 ± 3	***	NS
pH	6.82 ± 0.02	6.78 ± 0.04	6.78 ± 0.03	6.78 ± 0.05	6.73 ± 0.02	NS	NS
Titratable acidity (°D)	0.15 ± 0.32	0.15 ± 0.55	0.16 ± 0.32	0.16 ± 0.41	0.17 ± 0.46	**	NS

[1]SCC: Somatic Cell Count, [2]MFG: Milk fat globules, [3]CMS: Casein Micelle Size,*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, NS: Non-significant.

Table 4.2 Effect of different inclusion of Jersey in Holstein-Friesian milk on cheese making properties (Mean ± SEM).

Cheese making properties	Jersey milk inclusion (%)				
	0%	**25%**	**50%**	**75%**	**100%**
	n = 12	**n = 6**	**n = 12**	**n = 6**	**n = 12**
Actual yield (kg 100 kg^{-1} of milk)	9.5 ± 0.1^{a}	10.3 ± 0.2^{b}	11.3 ± 0.2^{c}	12.0 ± 0.2^{cd}	12.8 ± 0.2^{d}
Yield increase (%)	0.0 ± 0.0^{a}	9.8 ± 1.4^{b}	19.0 ± 1.3^{c}	25.3 ± 0.8^{d}	34.6 ± 1.9^{e}
Theoretical yield (kg 100 kg^{-1} of milk)	10.6 ± 0.2^{a}	11.2 ± 0.4^{ab}	11.5 ± 0.3^{ab}	12.2 ± 0.5^{b}	12.4 ± 0.3^{b}
Yield MA[1] (kg 100 kg^{-1}of milk)	9.1 ± 0.2^{a}	9.7 ± 0.4^{a}	11.1 ± 0.2^{b}	12.1 ± 0.2^{bc}	12.8 ± 0.2^{c}
Yield whey (kg 100 kg^{-1} of milk)	87.6 ± 0.3^{a}	87.5 ± 0.6^{a}	85.9 ± 0.3^{b}	84.9 ± 0.4^{bc}	84.3 ± 0.4^{c}
Fat whey (g 100g^{-1} of whey)	0.70 ± 0.07^{a}	0.66 ± 0.11^{a}	0.63 ± 0.06^{a}	0.63 ± 0.01^{a}	0.65 ± 0.06^{a}
Protein whey(g 100g^{-1} of whey)	0.88 ± 0.07^{a}	0.86 ± 0.15^{ab}	0.84 ± 0.08^{ab}	0.79 ± 0.04^{ab}	0.78 ± 0.07^{b}
Lactose whey (g 100g^{-1} of whey)	4.51 ± 0.38^{a}	4.48 ± 0.75^{a}	4.58 ± 0.42^{ab}	4.61 ± 0.04^{ab}	4.68 ± 0.39^{b}
Solid whey (g 100g^{-1} of whey)	7.80 ± 0.65^{a}	7.73 ± 1.29^{a}	7.86 ± 0.72^{a}	7.98 ± 0.03^{ab}	8.11 ± 0.68^{b}
Cutting time (min)	48 ± 1.3^{a}	44 ± 1.6^{a}	33 ± 1.1^{b}	30 ± 1.6^{bc}	27 ± 1.6^{c}
Cutting to milling time (min)	190 ± 5.8^{a}	208 ± 7.1^{ab}	208 ± 6.2^{ab}	204 ± 4.9^{ab}	219 ± 6.1^{b}
Rennet to milling time (min)	239 ± 5.1^{a}	252 ± 7.6^{a}	241 ± 6.4^{a}	234 ± 6.0^{a}	243 ± 7.1^{a}

[a-d] Means within a row with different superscripts differ ($P < 0.05$), [1]MA: Moisture adjusted.

Table 4.3 Effect of different inclusion of Jersey in Holstein-Friesian milk on cheese making mass balance (Mean ± SEM).

Cheese making properties	Jersey milk inclusion (%)				
	0%	25%	50%	75%	100%
	n = 12	n = 6	n = 12	n = 6	n = 12
Mass balances[1] (%)					
Total weight	95.89 ± 0.77^{a}	97.42 ± 0.50^{a}	96.81 ± 0.27^{a}	96.50 ± 0.35^{a}	97.06 ± 0.35^{a}
Weight of fat + protein	91.35 ± 1.40^{a}	94.62 ± 1.60^{a}	93.54 ± 1.60^{a}	94.48 ± 1.88^{a}	96.28 ± 1.36^{a}
Recoveries and losses (%)					
Fat recovery (%)	76.60 ± 1.14^{a}	85.14 ± 1.88^{ab}	87.05 ± 2.35^{b}	87.76 ± 4.11^{b}	89.80 ± 4.72^{b}
Fat loss (%)	20.56 ± 0.90^{a}	13.59 ± 0.98^{b}	11.46 ± 0.43^{b}	10.23 ± 0.78^{ab}	8.32 ± 0.63^{c}
Protein recovery (%)	71.61 ± 2.32^{a}	77.40 ± 2.39^{ab}	79.12 ± 1.82^{ab}	78.26 ± 3.85^{ab}	81.25 ± 2.32^{b}
Protein loss (%)	26.60 ± 0.65^{a}	20.69 ± 1.06^{b}	20.83 ± 2.09^{b}	20.26 ± 3.46^{b}	18.27 ± 0.87^{b}

[a-d] Means within a row with different superscripts differ ($P < 0.05$), [1]Mass balance defined as outputs (Bulk whey and cheese) as a percentage of inputs (Pasteurized milk, starter, rennet and salt) for total weight and weight of fat + protein.

Differences between actual yield and yield moisture adjusted to 37 % were found only for H-F cheese which had lower moisture adjusted yield.

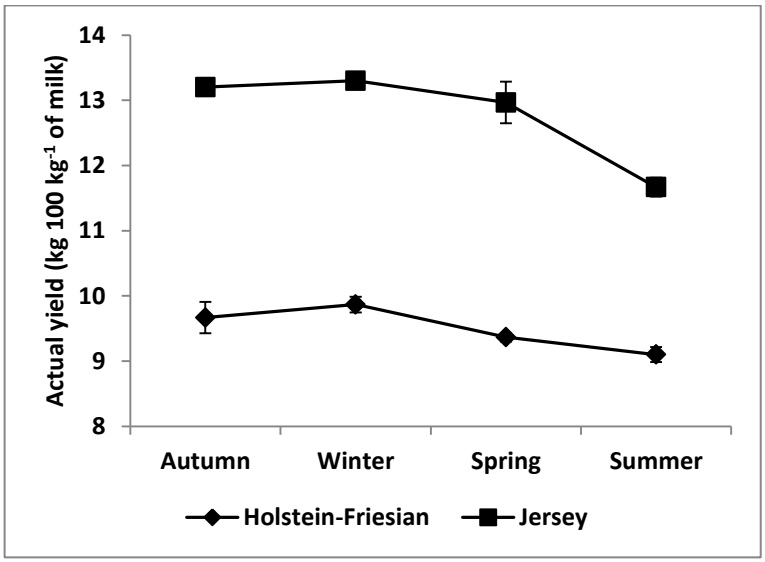

Figure 4.1 Seasonal variation in actual cheese yield of Holstein-Friesian and Jersey milk (Mean ± SEM).

Yield of whey was decreased when J milk was added to H-F milk at rate of 50 % or over, with the exception of summer where no difference in whey quantity was found. This is consistent with Whitehead (1948) who found J curd to have improved syneresis compared to H-F. Following the same cheese-making process, J curd retained 25 % more whey. This is in accordance with a higher casein content improving syneresis. However, the higher content of fat and larger MFG would be expected to decrease syneresis rate (Guinee et al., 2007). This indicates that protein concentration and CMS compensate for the higher fat content and larger MFG found for J milk.

Composition of whey was modified by a high inclusion of J milk with protein decreasing and lactose and solid increasing with inclusion of J milk. However, there was some seasonal variation in the phenomenon, in particular, the level of protein was found not to be different in spring and summer, while the level of lactose was not significantly different

in autumn and winter and level of solids not different in autumn and summer. The concentration of fat in whey was not affected by inclusion of J milk overall, but was found to be higher in autumn and winter.

The recovery rate of protein and fat was improved when J milk was used solely, but this was highly affected by season, in agreement with the study of Banks et al. (1984a) for fat, but not for protein. This study also found higher recovery value than in the present study which is believed to be due to a lower efficiency on small scale production. No differences in recoveries were found in autumn and in winter.

The time to cutting was lower when J milk was added at 50 % or higher throughout the year. This is in accordance with the shorter coagulation time and higher curd firming rate of J milk reported in several other studies (Okigbo et al., 1985; Barlowska et al., 2006; Kielczewska et al., 2008; Frederiksen et al., 2011a; Jensen et al., 2012). The time from cutting to milling was increased for 100 % J milk due to a lower acidity development, which was also reported by Whitehead (1948) who advised the use of more starter to overcome this problem. However, this only occurred in the summer, which is in agreement with Banks et al. (1984a). Overall, the total cheese making time was not different between inclusions rates, the faster coagulation time with J milk compensating for the longer acidification time.

The mass balance percentages for total weight and weight of fat plus protein (**Table 4.3**) were lower than previously found (Guinee et al., 2007) and can be linked to the white whey not being collected and thus some output not being accounted for. The differences between fat and protein recoveries and losses were higher than previously found (Guinee et al., 2007) which can again be linked to the white whey not being collected.

Including J milk significantly modified the Cheddar cheese process. The increase in

Cheddar cheese yield was linear and was at its maximum when J milk was used solely. The fat and protein recoveries were also improved but no statistical differences were found when more than 25 % of J milk was used. Whey quantity and composition were modified by J milk inclusion as were the cutting and acidification time, but this was not deemed to affect negatively the cheese making process. From these results the use of J milk solely seemed to be the most efficient way of producing Cheddar cheese.

4.3.3. Cheese composition

The cheeses were analysed for fat, protein, moisture, salt and pH, and only fat and moisture were modified by the inclusion of J milk (**Table 4.4**). This is in agreement with the study of Auldist et al. (2004) which found little difference in cheese composition, however, changes in pH and salt were observed, which were not seen in the current study.

Table 4.4 Effect of different inclusion of Jersey milk in Holstein-Friesian milks on Cheddar cheese composition (Mean ± SEM)

	Jersey milk inclusion (%)				
Cheese composition	**0% n = 12**	**25% n = 6**	**50% n = 12**	**75% n = 6**	**100% n = 12**
Fat (%)	31.41 ± 0.39^{a}	33.45 ± 0.83^{b}	34.47 ± 0.55^{c}	35.32 ± 0.30^{d}	37.15 ± 0.27^{e}
FDM (%)	51.59 ± 0.52^{a}	54.98 ± 1.47^{b}	54.81 ± 0.88^{b}	55.71 ± 0.43^{b}	58.21 ± 0.54^{c}
Protein (%)	23.48 ± 0.84^{a}	24.10 ± 1.10^{a}	23.58 ± 0.77^{a}	22. 92 ± 1.03^{a}	23.21 ± 0.80^{a}
Moisture (%)	39.12 ± 0.34^{a}	39.14 ± 0.71^{a}	37.11 ± 0.32^{b}	36.61 ± 0.20^{c}	36.17 ± 0.44^{c}
MNFS (%)	57.04 ± 0.40^{a}	58.85 ±1.25^{a}	56.66 ± 0.64^{a}	56.60 ± 0.33^{a}	57.54 ± 0.70^{a}
Salt (%)	1.80 ± 0.08^{a}	1.90 ± 0.07^{a}	1.74 ± 0.07^{a}	1.90 ± 0.05^{a}	1.86 ± 0.06^{a}
pH	5.43 ± 0.05^{a}	5.39 ± 0.14^{a}	5.50 ± 0.05^{a}	5.62 ± 0.03^{a}	5.56 ± 0.05^{a}

$^{a-e}$ Means within a row with different superscripts differ ($P < 0.05$)

All cheeses were above the legal minimum standard for fat content and however some cheese made of 0 % and 25 % J milk were slightly above the legal maximum standard for

moisture content however this could not be linked to the addition of J milk. The fat in dry matter was also always above the recommended 50 % for good quality Cheddar cheese (Lawrence and Gilles, 1980). However at 100 % J milk, the fat in dry matter (58.21 ± 0.54 %) was slightly above the recommended range 50 - 57 %, which could increase the chance of downgrading (O'Riordan and Delahunty, 2003).

Fat increased with the inclusion of J milk in autumn, winter and spring (**Figure 4.2**). This is consistent with a higher level of casein and larger MFG improving fat retention as well as seasonal effects (Banks et al., 1984b, 1986).

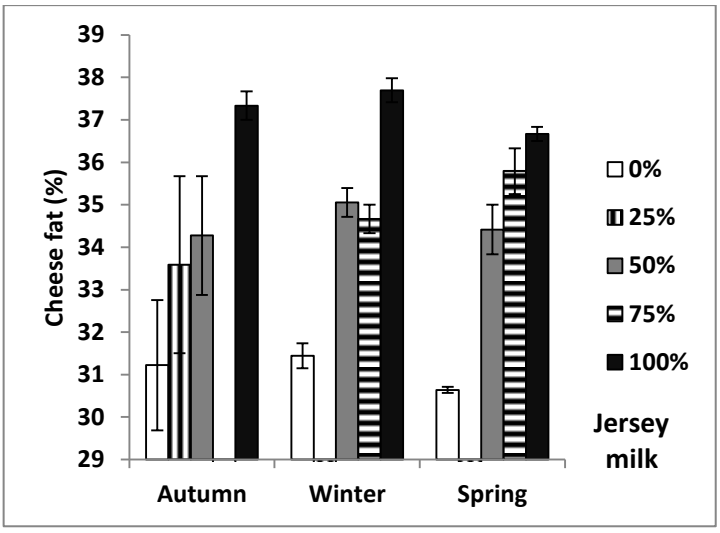

Figure 4.2 Effect of inclusion of Jersey milk on Cheddar cheese fat at different seasons (Mean ± SEM).

Moisture was reduced when J milk was used in spring and summer (**Figure 4.3**). Whitehead (1948) also found moisture to be decreased when J milk was used, due to higher syneresis, and noted that similar moisture could readily be achieved through the adaptation of the scalding temperature. The moisture in non-fat substance was not found to be different between inclusion rates, but the levels were slightly higher than that considered as optimal for Cheddar cheese (50 - 56 %) by Banks et al. (1984b).

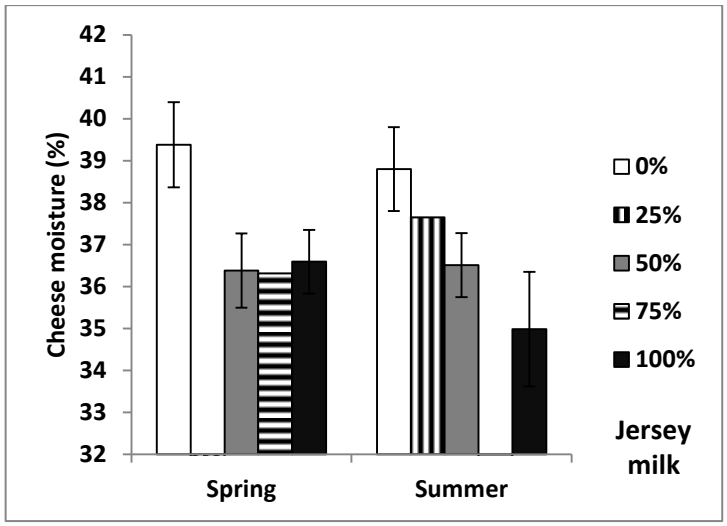

Figure 4.3 Effect of inclusion of Jersey milk on Cheddar cheese moisture in spring and summer (Mean ± SEM).

4.3.4. Cheese quality attributes

From all the quality attributes studied, including texture, colour and professional grading (**Table 4.5**), only the colour and total grading scores were modified by the inclusion of J milk. This lack of difference in quality attributes is supported by Whitehead (1948), except that the latter study found firmness to be greater in J cheese which was not the case in our study. The lack of effect of J milk on texture is surprising as the increase in fat in dry matter (**Table 4.4**) should have decreased cheese firmness (Martin et al., 2000). Still, as texture was both monitored instrumentally (TPA) and through grading, it can be concluded that in our study this was not the case.

Table 4.5 Effect of different inclusion of Jersey milk in Holstein-Friesian milks on Cheddar cheese quality (Mean ± SEM).

Cheese quality	Jersey milk inclusion (%)				
	0% **n = 12**	**25%** **n = 6**	**50%** **n = 12**	**75%** **n = 6**	**100%** **n = 12**
Hardness (N)	22.30 ± 0.94[a]	22.69 ± 2.35[a]	23.86 ± 1.12[a]	21.88 ± 1.78[a]	23.79 ± 0.99[a]
Springiness	0.79 ± 0.19[a]	0.80 ± 0.01 [a]	0.78 ± 0.03[a]	0.73 ± 0.06[a]	0.75 ± 0.04[a]
Cohesiveness	0.51 ± 0.01[a]	0.50± 0.00[a]	0.50 ± 0.01[a]	0.51 ± 0.01[a]	0.50 ± 0.01[a]
Resilience	0.34 ± 0.01[a]	0.31 ± 0.01[a]	0.31 ± 0.01[a]	0.32 ± 0.02[a]	0.30 ± 0.02[a]
Yellowness (*b)	25.18 ± 1.44[a]	25.89 ±1.71[a]	27.78 ± 1.11 [b]	28.20± 0.33[b]	28.72 ± 1.54[c]
Grading at 3 month					
Flavour and aroma (/45)	34.5 ± 1.0[a]	34.9 ± 1.6[a]	35.7 ± 0.5[a]	33.3 ± 1.1[a]	35.4 ± 1.0[a]
Body and texture (/40)	33.2 ± 0.8[a]	32.1 ± 1.0[a]	33.6 ± 0.8[a]	31.6 ± 1.3[a]	34.0 ± 1.0[a]
Colour (/5)	3.8 ± 0.1[a]	3.8 ± 0.1[a]	3.9 ± 0.1[a]	3.8 ± 0.2[a]	3.9 ± 0.1[a]
Appearance (/10)	8.0 ± 0.1[a]	8.1 ± 0.2[a]	8.0 ± 0.1[a]	8.0 ± 0.1[a]	8.0 ± 0.1[a]
Total grading (/100)	74.4 ± 2.8[a]	72.7 ± 5.5[a]	76.1 ± 2.9[b]	73.4 ± 3.6[ab]	76.1 ± 3.1[b]
Grading at 8 month					
Flavour and aroma (/45)	31.9 ± 1.0[a]	33.02 ± 1.3[a]	32.8 ± 1.6[a]	31.7 ± 1.1[a]	33.4 ± 1.7[a]
Body and texture (/40)	27.4 ± 0.96[a]	29.1 ± 1.0[a]	28.3 ± 1.8[a]	26.5 ± 2.1[a]	30.8 ± 1.7[a]
Colour (/5)	3.8 ± 0.1[a]	3.7 ± 0.2[a]	4.0 ± 0.1[a]	4.0 ± 0.1[a]	4.0 ± 0.1[a]
Appearance (/10)	7.6 ± 0.1[a]	7.7 ± 0.16[a]	8.0 ± 0.1[a]	7.8 ± 0.1[a]	7.9 ± 0.1[a]
Total grading (/100)	71.2 ± 1.4[a]	74.5 ± 1.6[a]	73.0 ± 3.1[a]	69.6 ± 2.6[a]	75.5 ± 3.0[a]

[a-e] Means within a row with different superscripts differ ($P < 0.05$)

Figure 4.4 presents the b* value in summer, which corresponds to the colour yellow, and showed that when J milk was included the cheese was more yellow. However, the colour differences (ΔE*ab) were not different ($P < 0.05$) and the ranges were lower than the normal eye tolerances, which require a difference of 2.8 to 5.6 ΔE*ab (Fernández-Vázquez et al., 2011) to be noticeable by consumers. This was demonstrated by no difference being found in the grading for colour.

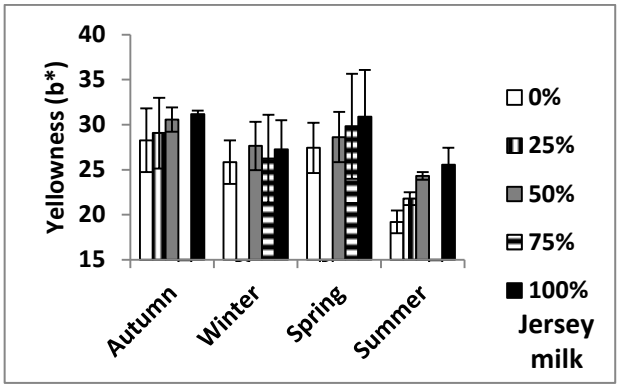

Figure 4.4 Effect of inclusion of Jersey milk on the yellow colour of Cheddar cheese according to season (yellowness expressed in CIELAB) (Mean ± SEM).

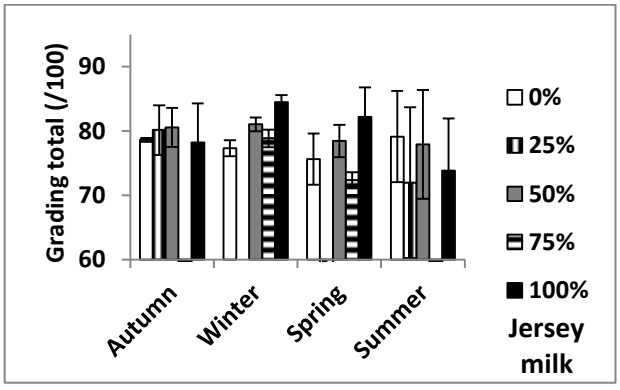

Figure 4.5- Effect of inclusion of Jersey milk on the total grading score of Cheddar cheese according to season (Mean ± SEM).

The total grading scores in winter increased with the inclusion of J milk (**Figure 4.5**), however this difference was not sustained at 8 months and no significant difference in

graded flavour, texture, appearance and colour was detected at either 3 or 8 months. This is in contradiction with the belief of a negative effect of J milk on cheese quality. Not standardizing, while increasing cheese fat, fat in dry matter and moisture in non-fat substance, did not affect cheese quality, and is thus a viable way of producing Cheddar cheese with J milk. Further research should investigate the effect of J milk on the grading of cheese, after 8 months as the larger MFG could still lead to lipolysis and thus bitter taste (Cooper et al., 1911).

4.4. CONCLUSIONS

This study showed that including J milk improved the yield of non-standardized Cheddar cheese in direct proportion to the rate of inclusion, the cheese composition was significantly different for fat, FDM, moisture however this did not affect negatively the sensory quality of the cheese and the differences were not detected by the professional cheese graders. In addition the change in the cheese making process and cheese composition does not hinder its use. Therefore using J milk is a valid way of improving the yield of Cheddar cheese with the optimal inclusion rate being 100 % J milk.

CHAPTER 5

5. ESTIMATION OF THE FINANCIAL BENEFIT OF USING JERSEY MILK AT DIFFERENT INCLUSION RATES FOR CHEDDAR CHEESE PRODUCTION USING PARTIAL BUDGETING

5.1. INTRODUCTION

An important factor influencing revenue in a cheese making plant is the yield of cheese from a set quantity of milk. Improving milk suitability for cheese-making has been shown to be a valid way of improving cheese yield and thus revenue (Storry et al., 1983; Lucey and Kelly, 1994; Sundekilde et al., 2011). Jersey (J) milk especially has been shown to be better suited for Cheddar cheese making than Holstein-Friesian (H-F) milk by improving cheese yield (Lundstedt, 1979; Geary et al., 2010) and reducing greenhouse gases and the environmental impact of Cheddar cheese production (Capper & Cady, 2012). However, its use commercially has been hindered by a presumed negative effect on cheese quality (Bliss, 1988) and the lack of information on the financial benefits of this method. The study presented in **Chapter 4**, has shown that when J milk was included at different rates into H-F milk, the improvement in Cheddar cheese yield was not accompanied by detrimental changes in cheese quality. Cheese quality was evaluated through instrumental texture analysis and professional grading scores at 3 and 8 months and it was found that including J milk did not significantly affect those parameters. Still, due to the higher price of J milk compared to H-F milk and the difficulties of changing milk supply, the economic benefit needs to be determined before cheese makers will be confident in using J milk more actively.

To determine the profitability of including J milk in H-F milk supply for Cheddar cheese production, the increase in cheese yield must be weighed against increased milk costs. To explore these questions, partial budgeting was used in conjunction with sensitivity and break-even analysis. These methods are regularly used to compare alternative production practices in agriculture with limited data (Roth and Hyde, 2002). In addition, due to the influence of J milk on whey production (**Chapter 4, section 4.3.2**), the financial effect on the co-products of cheese making was evaluated.

5.2. MATERIALS AND METHODS

5.2.1. Assumptions

Partial budgeting is a method of comparing costs and benefits of alternatives methods of production, in this case using different rates of inclusion of J milk. The specific underlying assumption of our partial budgeting is that J milk can significantly improve yield but would cost more to purchase. The model only encompasses the production stage and does not take into account the costs of transportation of milk and packaging and transportation of cheese. The fixed costs were also not included in the model as they are incurred regardless of the level of output. Furthermore, the model being based on a set quantity of milk, starter and enzyme quantity were not modified by the addition of J milk. Salt quantity was modified: however, it did not significantly influence the model and thus, with the aim of simplification, it is not presented in this study. In addition the revenue from whey products was not included in the partial budgeting due to the numerous uses of whey in the UK and the lack of available market prices for most of these products. Thus the only changes seen in the partial budget were in cheese quantity and milk price.

Using J milk was deemed more profitable than H-F if total positive impacts were higher than total negative impacts (**Table 5.1**). Total positive impact was calculated as increased

incomes plus reduced costs. Total negative impact was calculated as increased costs plus reduced incomes. The Additional Profit (AP) was given on a kilo of milk basis and expressed in Pounds Sterling and in brackets US Dollars using an one year exchange rate average of £1 = $1.6290 from the Website Oanda.com.

Table 5.1 Partial budget of the use of Jersey milk for Cheddar cheese making.

Positive impacts		**Negative impacts**	
Increased incomes	£	***Increased costs***	£
J[1] Cheese yield × Cheese price		J[1] milk quantity × J[1] milk price	
Reduced costs	£	***Reduced incomes***	£
H-F[2] milk quantity × H-F[2] milk price		H-F[2] cheese yield × Cheese price	
Total positive impacts		**Total negative impacts**	
		Additional profit per kilo of milk:	

[1] Jersey, [2]Holstein-Friesian.

5.2.2. Experimental Data

The partial budgeting was performed using the data from **Chapter 4** (**Table 5.2**), based on one vat production of 100 kg of milk. In this study H-F cheese making was compared to different inclusion rates of J milk (25, 50, 75 and 100 %) every month, over a year. The inclusions 25 % and 75 % were done on alternate months due to time constraints. The data set contained milk composition, cheese composition and actual cheese yield. The average cheese composition was 34.3 ± 0.3 %, 23.4 ± 0.4 % and 37.6 ± 0.3 % for fat, protein and moisture content respectively. Actual yield was calculated from the weight of milk placed in the vat, and the weight of cheese after pressing and vacuum packing and expressed as kg of cheese per 100 kg of milk. Milk price was calculated from the milk contract offered by the commercial Cheddar cheese maker on which the cheese making process was based on (Alvis Bros Ltd, Bristol, UK). The determination of the milk price was based on season, somatic cell count and milk protein and fat content as commonly carried out in the UK.

Table 5.2 Input variables and partial budgeting, sensitivity and break-even analysis of the use of Jersey for Cheddar cheese making (Mean ± SEM).

Items	Percentage of Jersey milk in Holstein-Friesian (%)				
	0 **n = 12**	**25** **n = 6**	**50** **n = 12**	**75** **n = 6**	**100** **n = 12**
Milk fat content (%)	3.94 ± 0.07	4.19 ± 0.09	4.70 ± 0.05	5.12 ± 0.12	5.43 ± 0.10
Milk protein content (%)	3.15 ± 0.02	3.26 ± 0.03	3.44 ± 0.03	3.58 ± 0.06	3.74 ± 0.05
Milk casein content (%)	2.31± 0.02	2.39 ± 0.03	2.55 ±0.03	2.66 ± 0.05	2.79 ± 0.04
Pence per kg of milk (p£)	30.43 ± 0.40 (49.57 ¢)	32.22 ± 0.52 (52.49¢)	34.39 ± 0.33 (56.02¢)	35.96 ± 0.86 (58.58¢)	38.16 ± 0.39 (62.16¢)
Cheese yield (kg100 kg^{-1} of milk)	9.5 ± 0.1	10.3 ± 0.2	11.3 ± 0.2	12.0 ± 0.2	12.8 ± 0.2
Cheese price (£ kg^{-1})	5.76 ± 0.01 ($9.38)	5.76 ± 0.01 ($9.38)	5.76 ± 0.01 ($9.38)	5.77 ± 0.01 ($9.40)	5.76 ± 0.01 ($9.38)
Additional profit					
Per kilo of milk (p£)		3.41 ± 0.72[a] (5.55¢)	6.44 ± 0.77[b] (10.49¢)	8.57 ± 0.71[c] (13.98¢)	11.18 ± 0.75[c] (18.24¢)
Sensitivity analysis [1]					
Cheese yield decrease (%)		-17.38	-10.24	-8.04	-6.51
Cheese price decrease (%)		-1.42	-1.66	-1.59	-1.65
Milk fat price increase (%)		-0.28	-0.45	-0.34	-0.35
Milk protein price increase (%)		-0.28	-0.30	-0.23	-0.26
Break-even point					
Cheese yield (kg 100 kg^{-1} of milk)		9.8 ± 0.7[a]	10.2 ± 0.1[ab]	10.6 ± 0.2[bc]	10.8 ± 0.2[c]

[a-c] Means within a row with different superscripts differ ($P < 0.05$),[1] Effect of 1 % change in input on additional profit.

Cheese price was based on the average monthly wholesale price for mild Cheddar cheese on the UK market, over the period of the study as reported by the study of the Kantar World Panel (2013). The data used are presented in **Table 5.2** showing mean and SEM for each inclusion rate. In total 36 scenarios were analysed.

5.2.3. Sensitivity Analysis

Sensitivity analysis was used to test which input variables had the greatest influence on the AP. The model inputs were defined as cheese price, cheese yield, and price for milk protein and milk fat. For the 36 scenarios, the impact of a fixed change (1 %) on the AP was calculated, one input at a time and expressed as percentage change in AP.

5.2.4. Break-even Analysis

The break-even analysis was carried out on the inputs which were found by the sensitivity analysis to have the most significant effect on the profitability of using J milk. Using the Solver add-in (Frontline Systems, Inc., Incline Village, NV) in Excel (Microsoft, Seattle, WA), the level of inputs which would give zero AP was calculated for all 36 scenarios.

5.2.5. Whey revenue

The evaluation of whey revenue was based on the production of whey butter and whey powder for which UK market prices are available. Conversion of whey fat into whey butter and whey non-fat solids into whey powder were calculated using the mass balance approach of DairyCo (2014b). Prices were determined using the average monthly UK wholesale price for whey butter and whey powder over the period of the study as reported by DairyCo (2014a).

5.2.6. Statistical Analysis

Data were subject to ANOVA and Tuckey analysis using SPSS PASW Statistics 21.0 (IBM, Hampshire, UK) to detect any statistical differences in AP and whey revenue between inclusion rates. Seasonal variation effects were tested the same way. Differences were considered significant at $P < 0.05$.

5.3. RESULTS AND DISCUSSION

5.3.1. Partial Budgeting

A positive AP per vat and per kilo of milk was found for each inclusion rate (**Table 5.2**). This indicates that the improvement in cheese yield resulting from the use of J milk compensates for its higher milk price, and therefore J milk was more profitable than H-F milk. In addition, a positive quadratic trend was found between AP and percentage of J milk ($R^2 = 0.998$, $P < 0.001$). Thus, to maximize Cheddar cheese making profit, the largest amount of J milk possible should be used. This held true throughout the year as no difference in AP was observed between seasons ($P < 0.01$).

5.3.2. Sensitivity Analysis

The results of the sensitivity analysis, presented in **Table 5.2**, showed that cheese yield had the most important impact on AP. A negative trend was found between J milk inclusion rate and the percentage decrease in AP resulting from a lower cheese yield ($R^2 = 0.983$, $P < 0.001$). Thus, at high J milk inclusion rates AP was less impacted than at a lower inclusion rates, again supporting the point that a high level of J milk should be used for Cheddar cheese making.

The second most important variable was cheese price. However, it did not put profit at risk, as volatility month to month is low (0.00 % over the period of the study) and even when

the lowest cheese price seen since January 2010 was used for the partial budgeting, £5.18 ($8.44) per kilo (Kantar World Panel, 2013), the AP was still positive: 2.86 ± 0.64 (4.66¢), 5.38 ± 0.70 (8.76¢),7.16 ± 0.69 (11.66¢) and 9.27 ± 0.66 (15.10¢) pence per kilo of milk for 25, 50, 75 and 100 % J milk respectively. Similarly, price for milk fat and protein had a small impact on AP.

5.3.3. Break-even analysis

The break-even analysis was carried out on cheese yield as it was the input which had the most important effect on profitability. The level of cheese yield which would give zero AP, meaning the profit would be equal to using only H-F milk, is given in **Table 5.2**. The use of J milk would result in a loss of profit only if the increase in cheese yield was less than 2.63, 7.28, 9.95 and 12.36 % for each J milk inclusion rate respectively. Past research has found, using the Van Slyke yield equation, that 100 % J milk would improve Cheddar cheese yield by 17.74 to 36 % (Lundstedt, 1979; Geary et al., 2010; Capper and Cady, 2012, **Chapter 4, section 4.3.2**), which is higher than the break-even point, thus it is unlikely that using J milk would result in a loss of profit.

5.3.4. Whey revenue

Including J milk did not influence whey composition overall and the reduction in whey quantity (**Table 5.3**) did not impact the quantity of whey butter and whey powder produced, thus no difference in revenue was found. However, due to the higher price of J milk this would cause a reduction in total AP, to 2.53 ± 0.73 (4.12¢), 5.04 ± 0.76 (8.20¢), 6.76 ± 0.64 (11.01¢) and 8.96 ± 0.74 (14.59¢) pence per kilo of milk for 25, 50, 75 and 100 % J milk respectively.

Table 5.3 Effect of Jersey milk on whey products revenue (Mean ± SEM).

Whey	Percentage of Jersey milk in Holstein-Friesian (%)				
	0 **n = 12**	**25** **n = 6**	**50** **n = 12**	**75** **n = 6**	**100** **n = 12**
Yield (kg100 kg^{-1} of milk)	87.5 ± 0.28^{a}	87.5 ± 0.56^{b}	85.93 ± 0.27^{c}	84.91 ± 0.38^{d}	84.33 ± 0.35^{e}
Fat (%)	0.70 ± 0.03^{a}	0.60 ± 0.03^{a}	0.60 ± 0.02^{a}	0.62 ± 0.02^{a}	0.65 ± 0.02^{a}
Solids non-fat (%)	7.14 ± 0.03^{a}	7.12 ± 0.02^{a}	6.63 ± 0.07^{a}	7.42 ± 0.03^{a}	7.52 ± 0.04^{a}
Butter (kg100 kg^{-1} of milk)	0.008 ± 0.000^{a}	0.007 ± 0.000^{a}	0.007 ± 0.000^{a}	0.007 ± 0.000^{a}	0.007 ± 0.000^{a}
Powder (kg 100 kg^{-1} of milk)	6.32 ± 0.04^{a}	6.31 ± 0.05^{a}	6.33 ± 0.03^{a}	6.34 ± 0.04^{a}	6.40 ± 0.04^{a}
Price (£ kg^{-1})					
Butter	3.01 ± 0.11 ($4.90)	2.95 ± 0.20 ($4.80)	3.01 ± 0.11 ($4.90)	2.98 ± 0.16 ($4.85)	2.96 ± 0.23 ($4.82)
Powder	0.82 ± 0.00 ($1.33)	0.83 ± 0.00 ($1.35)	0.82 ± 0.00 ($1.34)	0.82 ± 0.01 ($1.34)	0.82 ± 0.01 ($1.33)
Revenue(£ 100 kg^{-1} of milk)					
Butter	2.05 ± 0.17^{a} ($3.34)	1.87 ± 0.17^{a} ($3.05)	1.80 ± 0.07^{a} ($3.04)	1.75 ± 0.12^{a} ($2.85)	1.78 ± 0.08^{a} ($2.90)
Powder	5.19 ± 0.7^{a} ($8.45)	5.21 ± 0.09^{a} ($8.48)	5.23 ± 0.05^{a} ($8.52)	5.18 ± 0.09^{a} ($8.43)	5.26 ± 0.06^{a} ($8.56)
Total	7.24 ± 0.23^{a} ($11.79)	7.09 ± 0.2^{a} ($11.55)	7.02 ± 0.12^{a} ($11.44)	6.93 ± 0.19^{a} ($11.29)	7.04 ± 0.13^{a} ($11.46)

[a-c] Means within a row with different superscripts differ ($P < 0.05$).

5.4. CONCLUSIONS

Including J milk in H-F milk for Cheddar cheese production was shown through partial budgeting to increase profit. The level of AP was increased when a high percentage of J milk was used, and was also shown to be less sensitive to a decrease in cheese yield. Cheese yield had the most important impact on the level of AP, but the cheese yields would have to be significantly lower than those found in this study and previous reports for J milk not to be profitable. Change in cheese and milk price had only a small impact on AP and were deemed not to put the profitability of using J milk at risk.

When the revenue from whey butter and powder was included in the partial budgeting, the AP remained positive but was reduced as J milk did not influence the production of whey products, but was more expensive.

Additional studies on the effect of J milk on Cheddar cheese yield, especially on a commercial scale where production efficiency is higher, would bring higher certainty regarding the amount of AP which could be expected by cheese makers from the use of J milk.

CHAPTER 6

6. EFFECT OF JERSEY MILK ON THE PRODUCTION OF CHEDDAR CHEESE ON A COMMERCIAL SCALE

6.1. INTRODUCTION

Pilot scale studies are commonly used for cheese research and development in order to minimize cost and the risk to commercial production. In addition, it enables greater control over experimental design and process variables. However, reducing the scale was found to influence the process due to lower efficiency of production (Chiavari et al., 1993) and the milk and cheese produced may not be fully representative of commercial production (Barbano and Joseph Yun, 1993). It is therefore important to validate the findings of pilot scale studies under commercial production.

In **Chapter 4**, Jersey (J) milk was found to improve cheese yield without impacting cheese quality. The study was carried out at pilot scale (100 L) and while the experimental procedures were selected to mimic commercial production by using the recipe of a commercial cheese maker (Alvis Bros Ltd., Bristol, UK) it is necessary to validate these findings at a commercial scale before recommendations for commercial implementation are made.

Therefore to insure the results of the pilot plant study are representative of commercial production, commercial trials were performed at the commercial cheese makers (Alvis Bros Ltd., Bristol, UK) on which the pilot plant study was based.

6.2. MATERIALS AND METHODS

6.2.1. Experimental Design

The commercial experiment was carried out four times over a year. The number of repeats

was dictated by capacity and commercial considerations of the cheese plant. Bulk milk from a Jersey herd (220 cows) was transported via milk tanker to the cheese making plant facility. J milk was blended with H-F milk in the vat on a volume basis, after pasteurization, at three different rates up to 28 % J milk. The choice of including up to 28 % J milk was based on Jersey milk availability. In total 12 observations were made which were compared to the data presented in **Chapter 4**.

6.2.2. Milk Composition

Milk analysis for fat, protein, lactose, casein, urea content and Somatic Cell Count (SCC) was performed using a combine flow cytometry and infrared milk analyser as done in **Chapter 4**. The ratio of protein to fat (P/F) and casein to protein (C/P) were calculated from this data.

6.2.3. Cheese making process

Cheese making was carried out according to standard operating procedures of the cheese plant. Bulk milk was pasteurized, but not standardized. Approximately 1,800 L of milk was placed into each vat. Yield was calculated from the weight of milk placed in the vat, and the weight of cheese after pressing and vacuum packing (± 0.02 kg). This was expressed as actual yield of cheese (kg) per 100 kg of milk. Additionally, fat and protein recoveries were calculated as done in **Chapter 4**.

6.2.4. Cheese composition and quality attributes

Cheese was analysed for fat, protein, moisture, pH and salt 1 month after production as presented in **Chapter 4**. The cheese quality attributes, texture, colour and professional gradings were evaluated after 3 months of ageing as done in **Chapter 4**.

In addition, triangle tests were performed at 4 month. The sensory panel was comprised of

70 non-trained members of the department of Food and Nutritional Sciences. The study took place in the Sensory booth at the University of Reading (UK) in partitioned booths under red lights to limit colour comparison. Data were collected using a self-completion questionnaire presented on a computer screen in each booth using the Compusence Five software (Compusence Inc., Ontario, Canada). Three samples of 5 g each were presented simultaneously to the panelists (random three digit coded, balanced presentation order); two samples of the same type of cheese and one from the other type of cheese. In each case cheese made using solely Holstein-Friesian was presented as control against two inclusions rate of J milk. The subjects had to indicate which sample was the odd sample. No carrier was given but crackers and water at room temperature were given as a palate-cleansing method between each sample. This was used to test if no perceptible difference between the types of cheese could be detected.

6.2.5. Statistical analysis

Data of the commercial trial were subject to ANOVA using SPSS PASW Statistics 21.0 (IBM, Hampshire, UK) to detect any statistical differences between inclusion rates and milk composition. Data from the Pilot Plant (PP) and Commercial Trial (CT) were then subject to Ancova to detect any statistical differences between regression slopes and intercepts. Differences were considered significant at $P < 0.05$.

Results for the sensory test were also considered statistically significant at $P < 0.05$ and were analysed using the Binomial 1-tailed test.

6.3. RESULTS AND DISCUSSION

6.3.1. Milk composition

Statistical analysis found no significant effect of J milk on CT milk components with the exception of milk protein content (**Table 6.1**). This is in disagreement with the result of the

PP study presented in **Chapter 4**, **Table 4.1**, which found that, with the exception of lactose and urea, there was a high regression coefficient between milk components and percentage J milk ($R^2 > 0.568$; $P < 0.05$). The reason behind this lack of correlation for the CT trial can be linked to high variability in milk composition between trials and the smaller range of inclusion rates used.

Table 6.1 Mean (± SEM) and range of commercial trial milk composition and regression coefficient of the effect of including Jersey milk on milk composition (n = 12).

Milk composition	Mean	Range	R^2	*P*
Fat (g/100 g)	3.83 ± 0.10	3.45 - 4.54	0.080	NS
Protein (g/100 g)	3.28 ± 0.04	3.13 - 3.55	0.359	*
Protein : fat	0.863 ± 0.022	0.780 - 0.970	0.000	NS
Casein (g/100 g)	2.45 ± 0.03	2.31 - 2.62	0.270	NS
Casein : protein	0.744 ± 0.006	0.720 - 0.780	0.011	NS
Lactose (g/100 g)	4.47 ± 0.02	4.31 - 4.57	0.002	NS
Urea (mg/100 g)	0.029 ± 0.001	0.024 - 0.033	0.146	NS
SCC[1] (1,000 cells mL^{-1})	172 ± 13	105 - 241	0.157	NS

[1]SCC: Somatic cell count, *$P < 0.05$, NS: Non-significant.

Figure 6.1 presents the effect of J milk on milk fat concentration for each trial (CT1 first trial done in winter, CT2 second trial done in summer, CT3 third trial done in autumn and CT4 fourth trial done in summer) and the average PP result. In each case J milk increases fat concentration which is consistent with past studies (Auldist et al., 2004; Czerniewicz et al., 2006; **Chapter 4**).

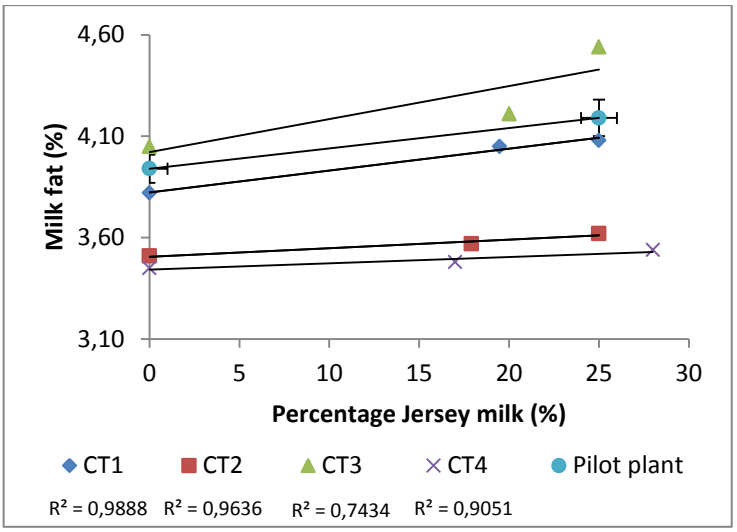

Figure 6.1 Effect of Jersey milk on milk fat for the four commercial trials and pilot plant study.

It can be seen that both winter (CT1) and autumn (CT3) trials showed higher fat content than summer trials (CT2 and CT4). This is consistent with the seasonal milk composition variation as described by Heck et al. (2009). In addition, the increase in fat concentration brought by the use of J milk is higher in winter (CT1) and autumn (CT3) than in summer (CT2 and CT4) demonstrating that J milk experience higher variation in fat concentration than H-F milk with season. The average PP fat concentration for 0 % and 25 % was similar to what was seen in winter and autumn but had lower variation with season than the CT trials.

It can be noted that no trial was carried out during the spring period due to the limited extra capacity of the cheese maker during this season. Therefore it is not possible to fully study seasonal variation, however both the study of Heck et al. (2009) and **Chapter 4**, **section 4.3.1** found autumn and spring milk composition to be similar.

There was less variation in protein concentration (**Figure 6.2**). However, a sharp increase in protein content can be seen for J milk in CT3 autumn and CT2 summer trial which could

not be explained by seasonal variation. The ANCOVA test showed a significant difference between the effect of J milk on milk protein concentration in the CT and PP study ($P > 0.05$).

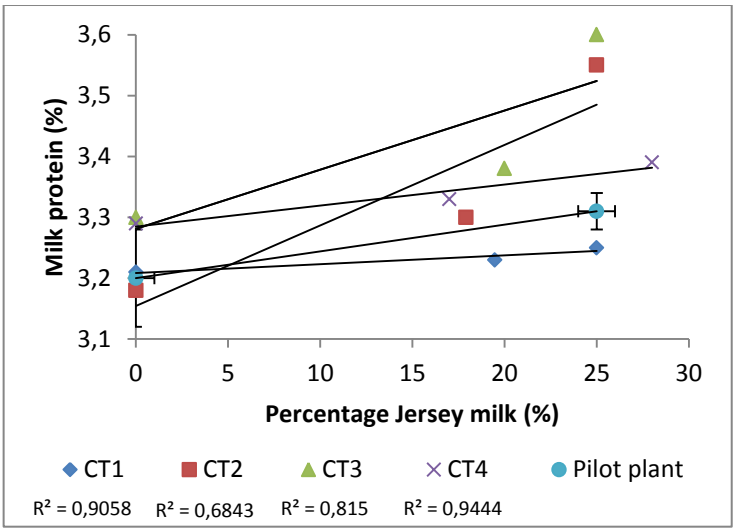

Figure 6.2 Effect of Jersey milk on milk protein content for the four commercial trials and pilot plant study.

The CT2 and CT3 can be seen in both **Figure 6.1** and **Figure 6.2** to have a lower regression coefficient than the other commercial trials, due to the data of the 20 % inclusion rate milk fat and protein content not being in line with the two other rates in the same trials. This could be due to a problem of milk sampling by the cheese maker in the vat.

In terms of the other milk components CT and PP range were similar with PP 0 % and 25 % inclusion rates showing however a slightly lower protein to fat ratio (0.712 - 0.907), casein content (2.16 - 2.47 %), somatic cell count (79 - 257 1,000 cells mL^{-1}) and higher urea concentration (0.017 - 0.050 mg/100 g).

The variation in the effect of J milk between trials was higher than expected and additional trials would have been warranted for the effect of J milk on milk composition to be

investigated fully. Still, the average milk composition of CT was found to be similar to the PP results (0 % and 25 % inclusion rates average milk composition) which should assist in the comparison of the cheese making data.

6.3.2. Cheese making process

The cheese making variables also displayed high variation making regression for percentage of Jersey milk (**Table 6.2**) difficult. This was not the case in the PP study where all cheese making variables with the exception of coagulation to milling time were correlated to percentage Jersey milk ($P < 0.05$). When cheese making variables were regressed with milk protein and fat concentration the only significant effect found was for fat on actual yield. This is different to the results of the PP study where fat and protein were correlated to all variables with the exception of rennet to milling time and coagulation to milling time. This can again be linked to lack of repeats not allowing to distinguish the effect of J milk and natural cheese making variability.

The difference in range of cheese making variables was important with lower fat recovery found in the PP study (66.40 - 89.80 %) which can be explained by lower efficiency of production at a smaller scale of production (Chiavari et al., 1993). The cutting time and acidification time range was also wider in the PP study (38 - 54 and 213 - 285 min respectively). Those differences could be explained by higher mechanisation and automation at the commercial cheese making leading to higher efficiency of recoveries but less flexibility in cheese making time due to use of recommended cutting time (40 min) at the cheese making plant.

Table 6.2 Mean (± SEM) and range of cheese making process variables and regression coefficient of the effect of Jersey milk percentage on cheese making variables (n = 12).

Cheese making variables	Mean	Range	R^2	*P*
Actual yield (kg 100 kg^{-1} of milk)	10.6 ± 0.1	9.5 - 11.4	0.280	NS
Yield increase (%)	3.6 ± 1.2	0.0 - 11.5	0.399	*
Fat recovery (%)	90.40 ± 1.77	81.17 - 98.8	0.108	NS
Protein recovery (%)	75.48 ± 1.69	63.38 - 83.64	0.016	NS
Coagulation time (min)	42.8 ± 0.3	41.0 - 46.0	0.029	NS
Acidification time (min)	227.9 ± 2.5	220.0 - 248.0	0.002	NS
Total cheese making time (min)	185.1 ± 2.4	177.0 - 202.0	0.005	NS

*P< 0.05, NS: Non-significant.

The individual CT trials, however, showed a strong effect of J milk on cheese yield (**Figure 6.3**). The PP average cheese yield was lower than the CT trials which is consistent with a lower efficiency of production at a smaller scale of production (Chiavari et al., 1993). The slopes of the regression line of the CT trials were different which can be seen in more details in **Figure 6.4** presenting the effect of J milk on yield increase.

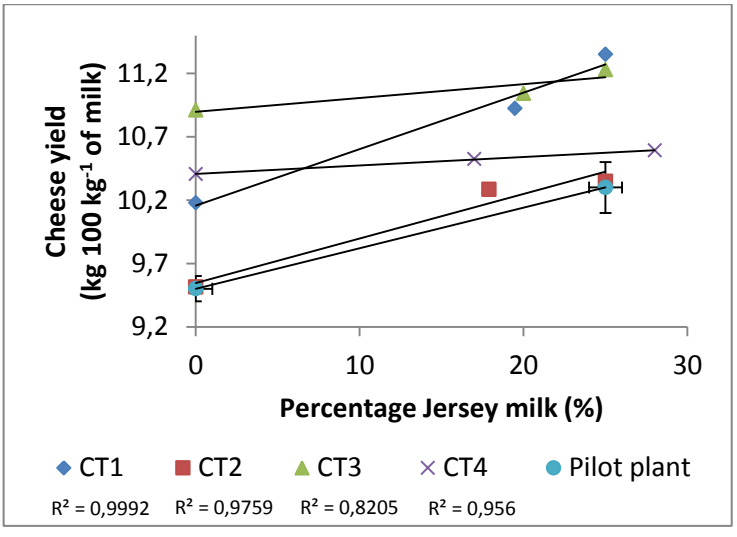

Figure 6.3 Effect of Jersey milk on cheese yield for the four commercial trials and pilot plant study.

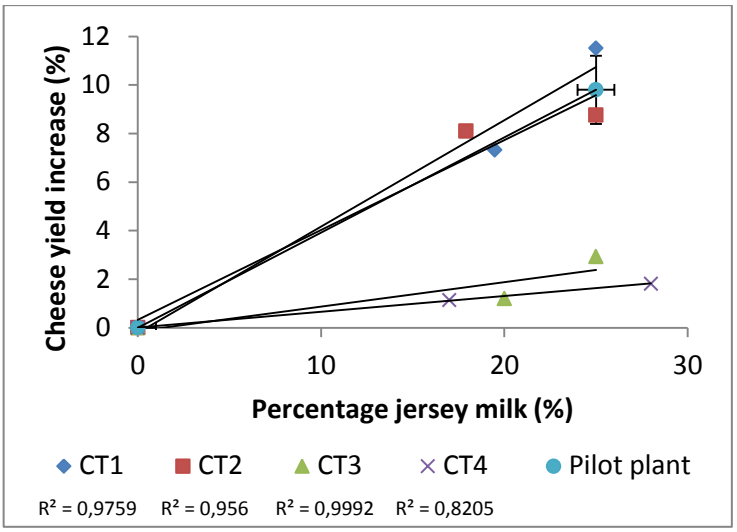

Figure 6.4 Effect of Jersey milk on cheese yield increase for the four commercial trials and pilot plant study.

The CT1 (winter) and CT2 (summer) trials showed an increase in yield of 8.0 % and 11.5 % respectively at 25% inclusion rate which is similar to that found in the PP study. However in CT3 (autumn) and CT4 (summer) the increase was much lower (1.5 - 2.0 %). This difference in increase in yield could not be explained by fat and protein (**Figure 6.5**) or the other cheese making variables ($P > 0.05$). The regression slope and intercept of the effect of J milk on yield increase was not found to be significantly different between CT and PP ($P < 0.05$).

The CT2 and CT3 trials again had lower correlation (**Figure 6.3** and **6.4**) tending to show that the problem in regressing milk composition over J milk inclusion was not due to a sampling error but could be an inaccuracy in blending.

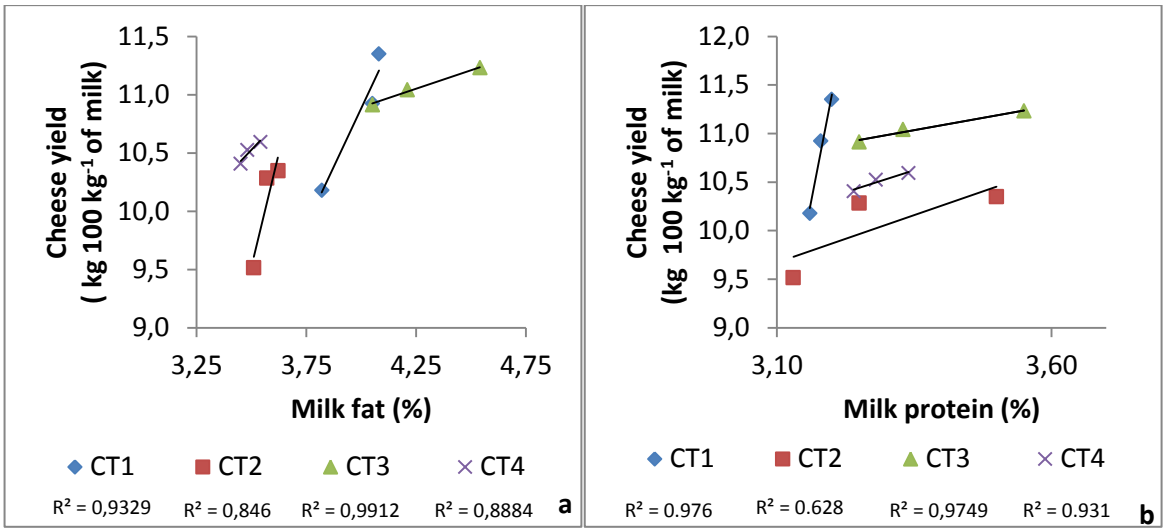

Figure 6.5 Effect of milk fat (a) and protein (b) on cheese yield for the four commercial trials.

While the effect of including Jersey on cheese yield was always positive, it was also highly variable, ranging from 1.50 to 11.51 % at 25 % inclusion rate. Surprisingly this variability could not be directly explained by the level of milk component or other cheese making process variables analysed in this study. A possible explanation is that there is a natural variability in yield at the cheese making plant, which was not expected. Still these results indicate that J milk does indeed improve Cheddar cheese yield.

6.3.3. Cheese composition

The cheese composition was found not to be affected by the inclusion of J milk (**Table 6.3**) and the level of protein in milk ($P > 0.05$) however level of fat in milk was correlated to cheese fat content ($R^2 = 0.348$; $P = 0.03$). In the case of the PP study, only cheese fat and moisture were significantly affected by the inclusion of J milk and milk protein and fat was only found to affect fat in cheese. The lack of correlation between milk fat and protein content and cheese composition could again be due to variability in the cheese making.

Table 6.3 Mean (± SEM) and range of cheese composition and regression coefficient for the effect of Jersey milk percentage, milk fat and milk protein on cheese composition (n = 12).

Cheese composition	Mean	Range	R^2	*P*
Fat (%)	32.99 ± 0.53	30.67 - 35.50	0.241	NS
Protein (%)	23.63 ± 0.53	19.80 - 26.68	0.039	NS
Moisture (%)	38.32 ± 0.86	34.82 - 44.55	0.008	NS
Salt (%)	1.75 ± 0.09	1.33 - 2.28	0.219	NS
pH	5.59 ± 0.05	5.45 - 5.97	0.009	NS

NS: Non-significant

However, when considered on a per trial basis, percentage J milk appeared to be correlated to fat concentration **(Figure 6.6**). The CT results showed an increase in fat concentration for all trials with the exception of one of the summer trials CT2. This is partly in contradiction with the PP results which showed an increase in fat content only in autumn, winter and spring.

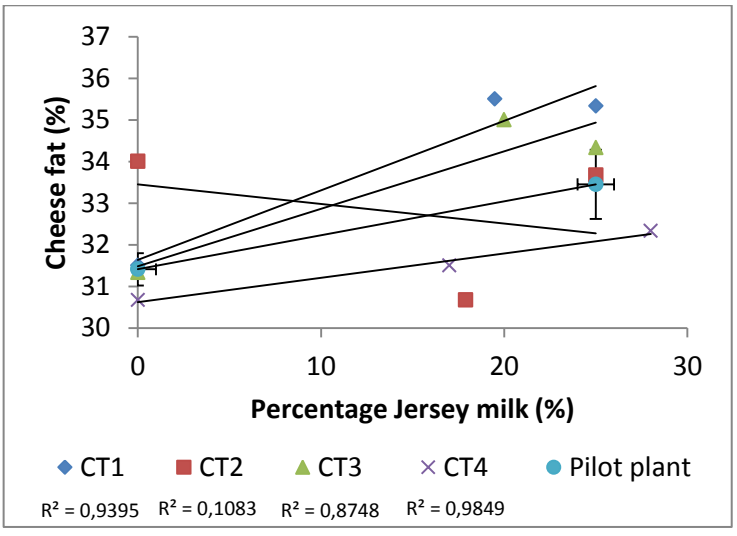

Figure 6.6 Effect of Jersey milk on cheese fat for the four commercial trials and pilot plant study.

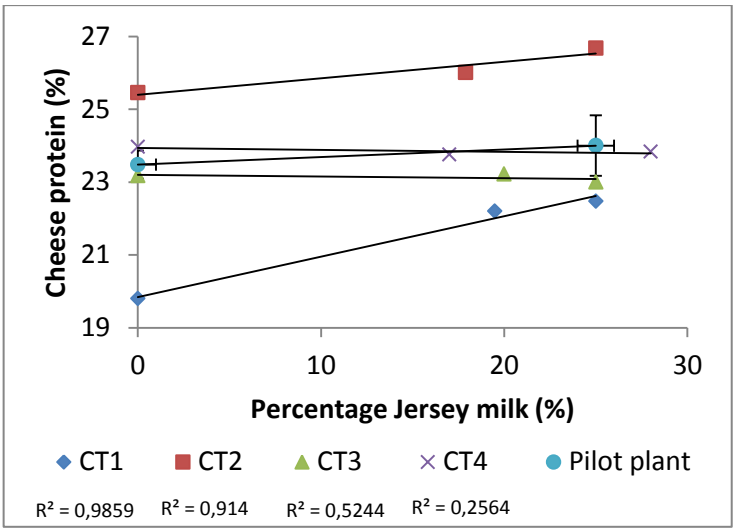

Figure 6.7 Effect of Jersey milk on cheese protein for the four commercial trials and pilot plant study.

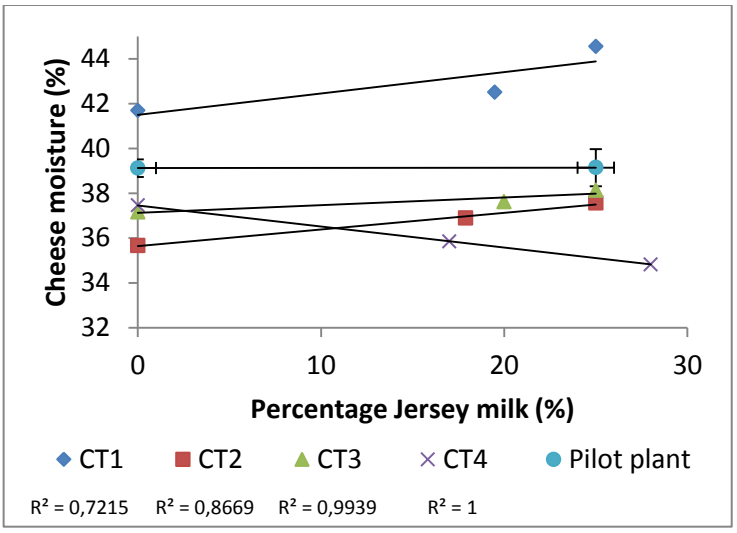

Figure 6.8 Effect of Jersey milk on cheese moisture for the four commercial trials and pilot plant study.

In the case of cheese protein content, the PP study found no difference between inclusion rates while the CT study showed two trials with an increase (CT1 and CT2), a decrease (CT4) and no difference (CT3) (**Figure 6.7**). Those results again highlight the difficulty of judging the effect of J milk with a small number of repeats. But, nonetheless, the cheese protein level found in the CT trials was in line with the one found in the PP study.

In the PP study, while moisture in cheese decreases with the addition of J milk, statistically no differences were found between the 0 % and 25 % inclusion rates. In the case of the CT study, moisture in cheese increases in the case of CT1, CT2 and CT3, while CT4 showed a decrease (**Figure 6.8**). Overall, the variability in moisture content of the cheese was much higher in the CT study than for PP.

Still, it can be observed that the results of the PP study are in line with those of the CT results (**Figure 6.6**, **6.7** and **6.8**) demonstrating that the cheese produced for the PP study was representative of commercial production. This was also the case for salt concentration (1.25 - 2.16 %), while pH was slightly lower in the PP study (5.35 - 5.63).

6.3.4. Cheese quality attributes

No relation was found between the inclusion of J milk, milk fat and protein concentration and the different factors for cheese quality attributes in agreement with the PP study (**Table 6.4**). In addition, the PP ranges were similar with the CT trials for hardness (16.41 - 30.43 N), springiness (0.76 - 0.85), cohesiveness (0.48 - 0.54), resilience (0.31 - 0.39) but yellowness was lower (18.50 - 33.15).

The grading was in this case only done at 3 months in comparison with the PP study at 3 and 8 months due to time constraints. Still, all the cheese produced using J milk in the commercial study was sold as mature cheese (> 10 months), which confirmed that, under the inclusion rate studied, there was no negative influence of J milk on Cheddar cheese quality. The total grading score of the CT trials was found higher than the PP trials (69.33 - 87.33) which could be due to the lower pH level witnessed in the PP trials leading to faster ageing and the cheese having to be sold younger.

Table 6.4 Mean (± SEM) and range of cheese quality attributes and regression coefficient for the effect of Jersey milk percentage (n = 12).

Cheese quality attributes	Mean	Range	R^2	*P*
TPA[1] Hardness (N)	21.99 ± 1.58	13.91 - 29.73	0.295	NS
TPA[1] Springiness	0.80 ± 0.01	0.76 - 0.84	0.117	NS
TPA[1] Cohesiveness	0.50 ± 0.00	0.49 - 0.52	0.007	NS
TPA[1] Resilience	0.32 ± 0.01	0.26 - 0.36	0.006	NS
Yellowness (*b)	25.75 ± 1.02	20.12 - 32.07	0.058	NS
Flavour and aroma (/45)	37.56 ± 0.62	35.00 - 40.67	0.008	NS
Body and texture (/40)	35.61± 0.48	32.33 - 37.33	0.280	NS
Colour (/5)	4.00 ± 0.00	4.00 - 4.00	0.000	NS
Appearance (/10)	8.00 ± 0.00	8.00 - 8.00	0.000	NS
Total grading (/100)	85.26 ± 0.88	81.50 – 90.33	0.102	NS

[1]TPA: Texture Profile Analysis (unitless), NS: Non-significant.

The cheese was also tested by consumers using a triangle test analysis and in only one of the four trials (CT4) did consumers find a difference between cheeses (*P* = 0.004). The CT4 cheeses made with J milk were found to have a different texture than H-F cheese (*P* = 0.03). This can be linked to the increase in hardness (**Figure 6.9**) and explained the higher grading score for texture found (**Figure 6.10**). This increase in firmness is in disagreement with the result found for the PP study (**Chapter 4**, **section 4.3.4**) and the belief that an increase in fat in cheese would lead to a softer cheese (Martin, 2000). However, it is in accordance with the findings of Whitehead (1948) and it can be hypothesize that the decrease in moisture (**Figure 6.8**) and the smaller casein micelle size found for the J breed (**Chapter 4**, **Table 4.1**) could have compensated for the effect of fat on texture (Lucey et al., 2003). However, it is surprising the decrease hardness found for CT2 and CT3 (**Figure 6.9**) was not detected during the grading (**Figure 6.10**) or sensory test.

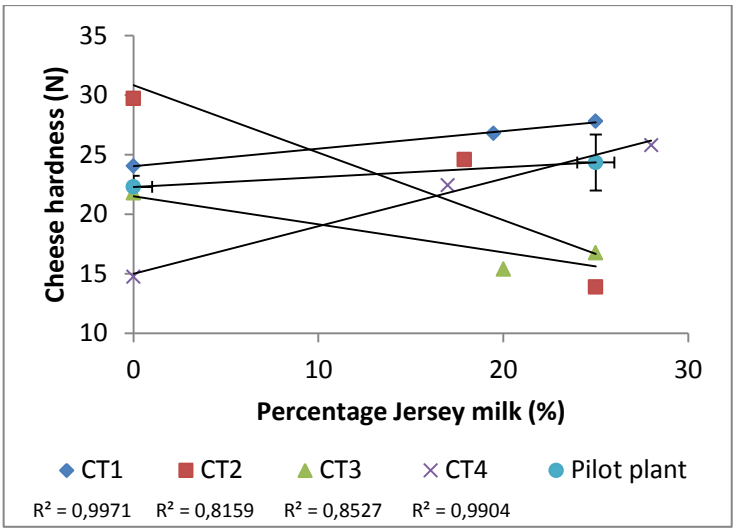

Figure 6.9 Effect of Jersey milk on cheese hardness for the four commercial trials and pilot plant study.

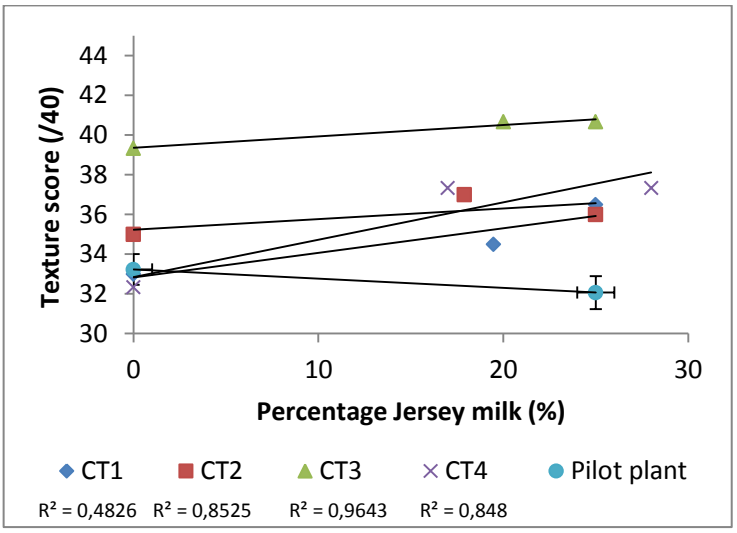

Figure 6.10 Effect of Jersey milk on cheese body and texture grading score for the four commercial trials and pilot plant study.

6.4. CONCLUSIONS

The commercial trial suffered from limitations due to a lack of repeats and inaccuracy in blending and milk sampling which could have affected the investigation of the effect of J on the cheese making process. This highlights the difficulty in performing commercial

trials where the production process and sampling are not under strict control of the researchers.

Nonetheless, this study confirmed that the milk used and cheeses produced in the PP study were within the normal range of composition and properties witnessed at a commercial scale of production. In addition, this study did find a significant increase in cheese quantity and no decrease in cheese quality in accordance with the PP study. This suggests that the influence of J milk, with the exception of increase in cheese yield, would not be higher than the expected variability between cheese batches. More research on a commercial scale using different cheese making plant and more numerous repeats would enable to study in more details the effect of J milk on Cheddar cheese making.

CHAPTER 7

7. EVALUATION OF MILK COMPOSITIONAL VARIABLES ON COAGULATION PROPERTIES USING PARTIAL LEAST SQUARES

7.1. INTRODUCTION

Improving the suitability of milk for cheese making, and thus the efficiency of production, is of paramount importance to the cheese industry (Pretto et al., 2013). Widely used indicators of milk suitability for cheese making are Milk Coagulation Properties (MCP) (Pretto et al., 2013) which have a determinant effect on the cheese making process and the yield of cheese (O'Callaghan et al., 2000). MCP are mainly defined as Rennet Coagulation Time (RCT), Curd Firmness (CF), while the rate of development of the coagulum is also a useful additional indicator (Curd Firmness Rate: CFR) (Frederiksen et al., 2011b). Milk that exhibits a short RCT and a high CF and CFR has commonly been linked to higher cheese making suitability, however the optimal MCP will be dependent on the cheese varieties and cheese making production methods (Pretto et al., 2013).

Studies on the effect of milk composition on MCP have typically focused on casein and protein content as they form the basis of the gel matrix and are associated with positive MCP traits (Ekstrand et al., 1980). A high level of Titratable Acidity (TA) and calcium ions, and a low pH and somatic cell count have also been shown to improve MCP (Pretto et al., 2013). The effect of fat content has been subject to less research due to the common practice of standardization of fat content by cheese makers and the findings of these studies were contradictory. On one hand Milk Fat Globules (MFG) were found to weaken the coagulum structure thus reducing CF (Green et al., 1983). Alternatively fat was found to restrict the movement of gel strands and thus increase rigidity and CF (Chapman, 1974).

These contradictory findings could be due to differences in study design and whether the level of protein was kept constant, and so diluted by the increase in fat content, or alternatively whether the protein to fat ratio was kept constant (Guinee et al., 2007). This problem is seen in many studies where the effect of a single variable or small group of compositional variables was being examined and changes in other variables were not accounted for. For example, O'Mahony et al. (2005) reported that larger MFG were associated with increased RCT and lowered CF, but warned that varying protein levels could have affected the results. The precise relationship between milk composition and cheese making properties is thus still unclear due to the number of compositional variables which could impact MCP, and their interrelationships, which makes it difficult to determine which factors are causal and which are secondary to other relationships (Storry et al., 1983; Coulon et al., 2004; Macciotta et al., 2012). This has been seen particularly when standard regression or ANOVA techniques were used as they are not appropriate for elucidating the relationship between large numbers of collinear variables (Ikonen et al., 2004; Vallas et al., 2010). Hence, other, more sophisticated statistical techniques such as Principal Component Analysis (Auldist et al., 2004), Multivariate Factor Analysis (Macciotta et al., 2012), Survival Analysis (Cecchinato, 2013) and Partial Least Squares (PLS) (Lawlor et al., 2001 and De Marchi et al., 2009) have been employed recently. In the present study, PLS regression was used as it can analyse data with strong colinearities and with numerous predictors against fewer observations. In addition, PLS forms new variables, termed "Latent Variables (LV)", which reduces the dimensionality of the data, making it easier to interpret and reduce over fitting compared to generalized linear models (Wold & Sjostrom, 2001).

The present study builds on previous studies by evaluating the effect of a larger number of milk compositional variables than previously carried out on RCT, CF and CFR using PLS.

Holstein-Friesian (H-F) and Jersey (J) milk was used as they display significantly different milk composition and MCP (Storry et al., 1983; Czerniewicz et al., 2006; Kielczewska et al., 2008) which will facilitate the modelling.

The study objectives were to determine whether using a wider range of compositional variables would improve the modelling of MCP and deepen the understanding of the effect of milk composition on RCT, CF and CFR. This could help improve predictive functions of MCP such as those used for predictions of the cutting time in automated or semi-automated systems of cheese production (Fagan et al., 2007; Sundekilde et al., 2011) by using additional variables which have been shown to have an important influence. In addition, a better understanding of which milk components improve MCP could guide cheese makers on selecting milk with higher suitability for cheese making.

7.2. MATERIALS AND METHODS

7.2.1. Experimental Design and Milk Composition

The experiment was carried out 5 times over a 12 month period spaced at regular intervals through the seasons. Milk samples from J and H-F herds were used at different ratios (0 to 100 % at 10 % intervals). Thus, 11 samples were analysed for milk composition as described in **Chapter 3**, **section 3.2.1**.

7.2.2. Milk Coagulation Properties

Coagulation properties were measured using a C-VOR controlled stress rheometer (Bohlin Instruments Ltd., Gloucestershire, UK) as described in **Chapter 3**, **section 3.2.2**.

The following MCP parameters were obtained from the storage modulus: RCT the time in minutes at which the curd attained 0.5 Pa (O'Callaghan et al., 2000), CF the firmness of

the curd (Pa), 10 min after RCT and CFR the increase in firmness (Pa min^{-1}) calculated from the time for the gel to firm from 0.5 to 2 Pa.

7.2.3. Statistical Analysis

Statistical analysis was carried out using PLS using statistical package XLStat (Addinsoft SARL, Anglesey, UK). The technique uses the method of least squares to fit a quadratic response surface regression where data is projected onto a small number of underlying LV and was based on the method of Wold & Sjostrom (2001). All data were standardized (auto-scaled, centered $\mu = 0$ and normalized: 1/SD). The CFR results were non-linear and thus were expressed as $\log_{10}$. Each model was pruned; milk composition variables with the smallest coefficient were removed one by one and the model recalculated. Outliers were also removed when high dModY (distance to Y response model) values were found. The model was confirmed using full cross and random cross-validation with 9 segments and between 6 or 7 samples per segment. All prediction residuals were then combined to compute the Root Mean Squares Error of Cross-Validation (RMSECV). Several criteria were used to determine the proficiency of the predictive models: lowest RMSECV value, greatest R^2 and Q^2 value and lowest component as done by De Marchi et al. (2009).

The practical utility of the models was assessed using the Range Error Ratio (RER). Values for this ratio were calculated by dividing the range of a parameter by the RMSECV for that parameter (Hubert & Vanden Branden, 2003). Models with RER < 3 are of little practical utility, 3 to 10 indicate good practical utility and > 10 high utility value (Hubert & Vanden Branden, 2003). A model with Q^2 lower than 0.66 was assumed to have no predictive ability, between 0.66 to 0.82 approximate predictions, between 0.82 and 0.90 good prediction and higher than 0.90 excellent prediction (Hubert & Vanden Branden, 2003). The standardized coefficients for each model were compared using T-test.

7.3. RESULTS AND DISCUSSION

7.3.1. Descriptive statistics

Table 7.1 Mean and range of milk composition studied (n = 55).

Milk component	Mean	Min	Max	SEM
Fat (g 100 g^{-1})	4.68	3.45	5.93	0.07
Protein (g 100 g^{-1})	3.54	3.12	3.97	0.03
Protein: fat	0.76	0.67	0.93	0.00
Casein (g 100 g^{-1})	2.65	2.29	3	0.03
Casein: protein	0.75	0.73	0.77	0.00
Lactose (g 100 g^{-1})	4.51	4.44	4.63	0.00
Urea (mg 100 g^{-1})	0.0249	0.0100	0.0452	0.0010
SCC[1] (1,000 cells mL^{-1})	200	41	319	9
Calcium ions (mg 100 g^{-1})	8.43	5.56	11.99	0.22
D(4.3) (µm)	4.16	2.88	5.57	0.09
D(3.2) (µm)	1.12	0.64	1.43	0.02
D(0.5) (µm)	3.90	2.71	4.75	0.07
MFG[2] Span (µm)	1.925	1.672	2.168	0.016
CMS[3] (d. nm)	168	154	187	1
pH	6.81	6.69	6.96	0.00
Titratable acidity (°D)	0.156	0.139	0.183	0.001
Rennet Coagulation Time (min)	38.52	20.61	62.92	1.60
Curd Firmness (Pa)	5.98	1.46	17.02	0.50
Curd Firmness Rate (Pa min^{-1})	0.30	0.10	0.67	0.02

[1]SCC: Somatic Cell Count, [2]MFG : Milk fat globules, [3]CMS :Casein Micelle Size.

Milk composition and MCP variables mean and range are reported in **Table 7.1**. The milk composition is representative of average national milk (Centre for Dairy Information, 2010) with an increased range due to the use of J and H-F. The values for RCT, CF and CFR could not be compared to past findings due to the heavy influences of method of analysis and operational setup. The variability in RCT (Coefficient of Variation CV = 30

%), CF (CV = 62 %) and CFR (CV = 50 %) values facilitated the development of the model.

7.3.2. Rennet Coagulation Time model

The most accurate model for RCT (R^2 = 0.825; Q^2 = 0.811; n = 55) had 1 component, a RMSECV of 4.93 min and RER of 8.59. The model had higher R^2, Q^2 and RER than found in other studies (Auldist et al., 2004; Wedholm et al., 2006; De Marchi et al., 2009). The model thus demonstrates that using a larger array of compositional variables improve the prediction of RCT. However, the current model RMSECV would be too high to be used commercially (**Figure 7.1**).

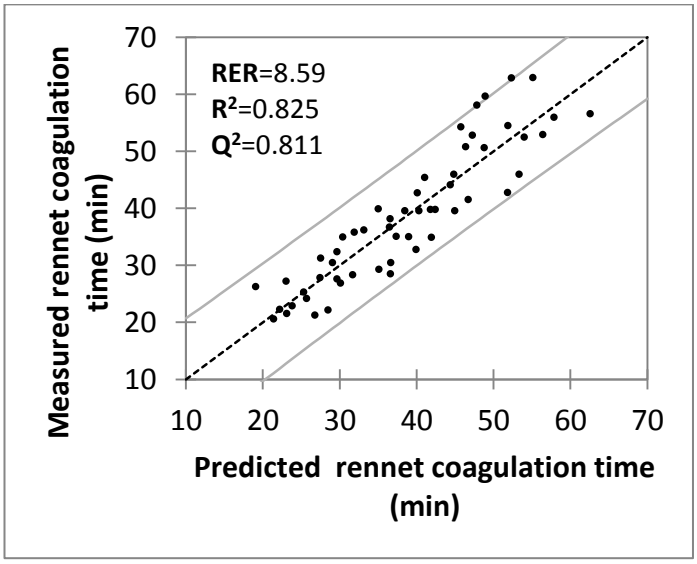

Figure 7.1 Measured vs. predicted rennet coagulation time using a PLS model (n = 55).

All compositional variables, except urea concentration, were found to have a significant effect on RCT and their standardized coefficients are shown in **Table 7.2**.

As expected from past research and the kinetics of milk coagulation, casein, casein to protein ratio and protein were the key drivers of RCT (Chiofalo et al., 2000; Marchini et

al., 2010). However, CMS and D(0.5) were shown to be equally important in determining RCT.

Table 7.2 Standardized coefficients and SEM for coagulation time, curd firmness and curd firmness rate.

Standardized Coefficient					
Coagulation time		**Curd firmness**		**Curd firmness rate**	
Casein	-0.114 ± 0.000^{a}	**C:P^{2}**	0.177 ± 0.003^{a}	**C:P^{2}**	0.415 ± 0.008^{a}
CMS^{1}	0.108 ± 0.000^{ab}	**Lactose**	0.171 ± 0.003^{a}	**Urea**	0.345 ± 0.008^{ab}
Protein	-0.108 ± 0.000^{ab}	**CMS^{1}**	-0.157 ± 0.004^{ab}	**Lactose**	0.261 ± 0.011^{bc}
D(0.5)	-0.105 ± 0.000^{ab}	**SCC^{6}**	0.137 ± 0.004^{abc}	**Casein**	0.232 ± 0.001^{bc}
C:P^{2}	-0.100 ± 0.000^{bc}	**Casein**	0.134 ± 0.002^{abc}	**TA^{3}**	-0.227 ± 0.011^{bcd}
D(4.3)	-0.097 ± 0.000^{bc}	**Fat**	0.118 ± 0.006^{abc}	**Protein**	0.168 ± 0.007^{bcde}
Fat	-0.094 ± 0.000^{c}	**Protein**	0.110 ± 0.003^{bc}	**CMS^{1}**	-0.141 ± 0.008^{cde}
TA^{3}	-0.088 ± 0.000^{cd}	**Urea**	0.101 ± 0.007^{bc}	**D(4.3)**	0.079 ± 0.009^{de}
Lactose	-0.083 ± 0.001^{cde}	**D(0.5)**	0.098 ± 0.003^{c}	**D(0.5)**	-0.074 ± 0.005^{e}
D(3.2)	-0.071 ± 0.001^{def}	**TA^{3}**	0.085 ± 0.006^{c}	**Fat**	-0.026 ± 0.007^{e}
Span^{4}	0.061 ± 0.002^{efg}	**D(4.3)**	0.070 ± 0.005^{c}	**Ca^{2+}**	0.003 ± 0.001^{e}
P:F^{5}	0.053 ± 0.002^{fg}				
SCC^{6}	-0.051 ± 0.002^{fg}				
pH	0.036 ± 0.001^{g}				
Ca^{2+}	-0.036 ± 0.003^{g}				

^{a,g} Numbers in a row with different superscript are significantly different, ^{1}CMS: Casein micelle size, ^{2}C:P: casein to protein ratio, ^{3}TA: Titratable acidity, ^{4}Span: Span of fat globules, ^{5}P:F: protein to fat ratio,^{6}SCC: Somatic cell count.

The negative relationship between CMS and RCT is in agreement with larger CMS having lower amount of κ-casein and thus forming a gel more slowly (Grimley et al., 2009; Marchini et al., 2010). On the contrary the positive effect of D(0.5), but also fat content, D(4.3) and D(3.2), is in disagreement with the common assumption of the MFG hindering the process of coagulation. Nevertheless, the findings of O'Mahony et al. (2005), Martini

et al. (2008) and Grimley et al. (2009) were in agreement with the current findings, indicating that the effect of fat on MCP warrants further investigation. The important effect of CMS and D(0.5) could explain why casein and protein level are not always good predictors of RCT as was found by Frederiksen et al. (2011a) where a J milk with lower casein content and C/P had a shorter RCT than a H-F milk with a higher casein and C/P. The effect of P/F, SCC, pH and Ca^{2+} on RCT was small and would, in this case, not be a good indicator of RCT. This model suggests that a higher SCC reduces RCT which contradict past research (Politis & Ng-Kwai-Hang, 1988). However, the range examined in this study was much smaller and did not correspond to udder health problems as compared to the latter study.

Modifying Ca^{2+} concentrations or pH level is widely used to improve RCT, however, a weak correlation of Ca^{2+} and pH with RCT was found, in agreement with Grimley et al. (2009) and Nian et al. (2012). Titratable acidity had a stronger correlation with RCT than pH, which was also found in the study of Formaggioni et al. (2001), and presumably relates to the fact that TA measurement incorporates the buffering capacity of the milk. This suggests a switch from using pH to TA as an indicator of milk suitability for cheese making. Lactose was linked negatively to RCT which was also reported by Amenu and Deeth (2007) and Glantz et al. (2010) without explanation of the mechanism.

7.3.3. Curd Firmness Model

The preferred model for log CF (R^2 = 0.935; Q^2 = 0.914; n = 52) had 2 components, a RMSECV of 0.066 Pa and RER of 15.40 which, as for RCT, give a good prediction of the current data (**Figure 7.2**). Protein to fat ratio, D(3.2), span, pH and Ca^{2+} did not influence CF. Protein to fat ratio was already found not to influence CF in the study of Guinee et al. (2007).

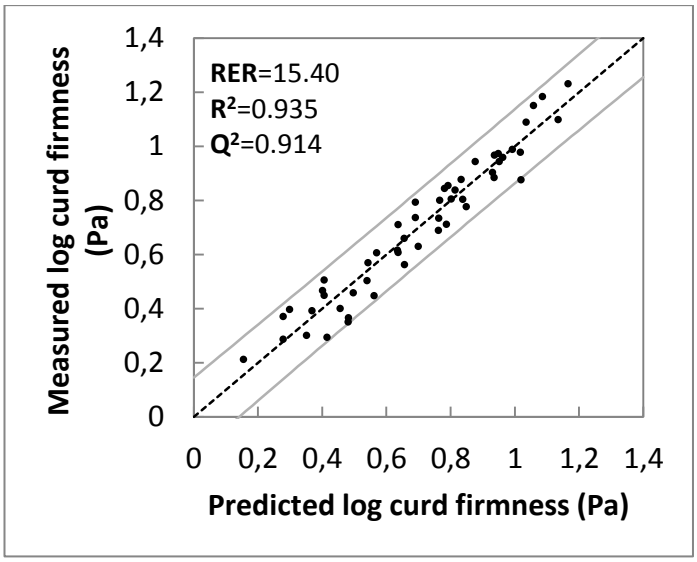

Figure 7.2 Measured vs. predicted log curd firmness using a PLS model (n = 52).

The standardized coefficients for log CF are presented in **Table 7.2** and represent the importance of each compositional factor for the models. The C/P and casein content had the expected major influence on log CF in agreement with Chiofalo et al. (2000) and Storry et al. (1983). However, lactose, CMS, SCC and fat were found to be equally important to CF development. The strong effect of lactose content was unexpected, although it has been noted previously, and the mechanism is unclear (Amenu & Deeth 2007; Grandison et al., 1984; Glantz et al., 2010). The positive effect of small CMS, SCC and fat was again shown in the CF model in agreement with Grimley et al. (2009) and Marchini et al. (2010) for CMS and Martini et al. (2008) for fat. However in contrast to RCT, the fat content had a stronger effect than D(0.5) and D(4.3) which had a secondary effect on Log CF.

Protein, urea and TA were also secondary contributors to the determination of CF. Urea concentration was positively correlated with log CF in agreement with the findings of Marziali and Ng-Kwai-Hang (1986) but it did not influence CF as much as protein.

7.3.4. Curd Firmness Rate Model

The most proficient model for CFR model (R^2 = 0.940; Q^2 = 0.858; n = 51) had 3 components, a RMSECV of 0.045 Pa min^{-1} and RER of 12.02. Again, the model showed that using a large array of compositional values increased the fit and predictive abilities of the model (**Figure 7.3**). The factors excluded from the model due to non-significant effect were P/F, D(3.2), span of MFG, pH and SCC, demonstrating that these parameters should not be used for the prediction of MCP having a small impact on RCT and no effect on CF and CFR. **Figure 7.3** indicates a better predictive power at low CFR which was also seen for CF (**Figure 7.2**), this could be linked to high CFR and CF being related to J milk which displayed a stronger variation in milk composition than H-F (**Figure 3.2**).

Standardized coefficients for the predictive equation of CFR are presented in **Table 7.2**. Casein to protein ratio, urea concentration, lactose, casein and TA were the most important factors governing CFR. The importance of C/P, protein and casein was again expected (Storry et al., 1983, Frederiksen et al., 2011b).

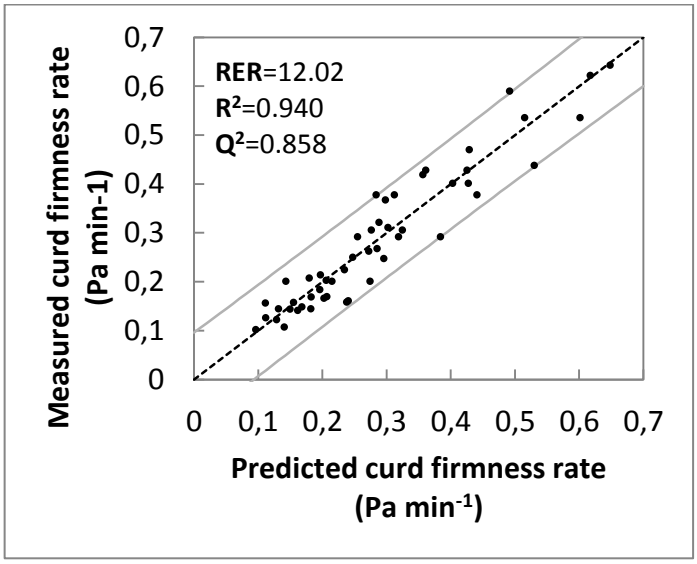

Figure 7.3 Measured vs. predicted curd firmness rate using a PLS model (n = 51).

The strong positive effect of urea concentration on CFR was however not expected and is in conflict with the study of Martin et al. (1997a) which found a negative effect and the study of Marziali and Ng-Kwai-Hang (1986) which found no effect. Similarly lactose was again found to have a larger impact than expected. Again, the mechanisms behind the effect of urea and lactose on CFR are not understood and more research on their effect is needed. Fat content and D(0.5) had a small negative effect on CFR which is consistent with larger and more numerous MFG hindering the development of the matrix (Chiofalo et al., 2000). Again, D(4.3) was found to have a positive effect and more research is needed to understand the difference between the effect of D(0.5) representing the volume median diameter and D(4.3) representing the volume moment mean. In addition, a negative relationship between TA and CFR was found in accordance with Macciotta et al. (2012) study. There was also a negative influence of CMS on CFR although to a lower extent than for RCT and CF.

7.4. CONCLUSIONS

The importance of considering a number of compositional variables was demonstrated through the modelling of the MCP. The models obtained in this study had greater predictive power than those previously developed, and having $R^2 > 0.825$ and $Q^2 > 0.811$ would indicate that most variation in MCP could be explained by the milk components examined. Moreover, the findings challenge the standard understanding that the milk casein and protein fractions are the main factors responsible for MCP. While they are clearly determinants, other factors were shown to play a key role such as CMS and MFG sizes. In addition, this study indicates a strong influence of urea and lactose on MCP, although the mechanisms are not yet understood. Some established indicators of MCP such as P/F, pH and Ca^{2+}, were shown not to be very significant due to their relatively small influence. This knowledge could assist both the cheese industry to select milk with better

MCP and the associations involved in animal selection to improve milk suitability. However, future research is needed if these models were to be used commercially: by using a higher number of samples and using different breeds. In addition faster and cheaper methods of milk analysis should be developed if certain milk compositional variables such as MFG size and CMS were to be analysed routinely.

CHAPTER 8
8. EFFECT OF MILK COMPOSITION ON CHEDDAR CHEESE MANUFACTURE, YIELD AND QUALITY

8.1. INTRODUCTION

Optimization of cheese yield, composition and sensory properties has become increasingly important for the cheese industry, due to pressure for lower price and increased competition (Pretto et al., 2013). A way of optimizing the cheese making process is to improve the milk suitability prior to the cheese making process.

To improve milk suitability, the effect of milk composition on the cheese making process, cheese yield, composition and sensory properties needs to be better understood. While several studies have investigated the effect of milk composition on the cheese making process, they have mainly focused on the effect of protein and fat content and their ratio (Lou and Ng-Kwai-Hang, 1992; Guinee et al., 2007). Other properties such as pH, Titratable Acidity (TA) and calcium ions (Ca^{2+}) have also been extensively studied and were found to affect the cheese making process, and thus have been used as indicators of milk suitability (Lucey and Fox, 1993; De Marchi et al., 2009). However, when compared to the effect of protein, fat and casein their effects were found to be less important (Grandison et al., 1985; **Chapter 7**). Other factors, such as Milk Fat Globules (MFG) size and Casein Micelle Size (CMS), while having been subject to less research were found to have important effects on the structure of cheese curd (Michalski et al., 2003; O'Mahony et al., 2005) but their relative importance on the cheese making process, in comparison to the level of protein and fat, is still unclear. The lack of understanding of the relative importance of each component is an important limitation for the determination of the optimal cheese milk. Evaluating the relative importance of each component is, however,

difficult due to the number of intercorrelated components. The statistical analysis used thus needs to take the complexity of the milk system into account. For example, the widely used Pearson correlation is of limited use if not linked with partial correlations to help spot spurious correlations. The compositional variables found significant through those analyses could then be used in a linear regression without the risk of overfitting due to excessive numbers of variables and multicolinearity.

In addition to looking at only a limited number of compositional factors, past research has mainly focused on component recoveries, cheese yield, and composition. However, with whey now becoming a core product of cheese making with a significant financial value, and with higher expectations of the retail sector for high-quality cheese, more information is needed on the effect of milk composition on the yield and composition of whey and cheese sensory properties.

The objective of this study was, thus, to advance the knowledge of the effect of milk composition on the cheese making process, whey production, cheese composition and sensory properties by using a larger array of compositional variables than previously considered to detect which are the most important. This knowledge would assist cheese makers in selecting milk more suitable to their production aims.

8.2. MATERIALS AND METHODS

8.2.1. Experimental design

The experiment was carried out three times each season between September 2012 and November 2013 as described in **Chapter 4**, **section 4.2.1**. J milk was blended with H-F milk at 0, 25, 50, 75 and 100 % J. Due to time limits, the ratios 25 % and 75 % were performed on alternate repeats. Thus, 4 samples were analysed on each repeat, giving a total of 48 observations.

8.2.2. Milk composition

Analysis of all milk compositional variables was performed as described in **Chapter 4**, **section 4.2.2**.

8.2.3. Cheese making process

Bulk milk was pasteurized, but not standardized, and the cheese making process was performed as described in **Chapter 4**, **section 4.2.3**.

8.2.4. Cheese quality

Cheese was analysed for fat, protein, moisture, pH and salt 1 month after production and texture, colour and grading were evaluated after 3 months of ageing as described in **Chapter 4**, **section 4.2.5**.

8.2.5. Statistical analysis

Data were first subjected to Pearson correlation followed by a partial correlation to select the variables to include in the linear regression. Linear regression was done using backward selection using SPSS PASW Statistics 21.0 (IBM, Hampshire, UK). Seasonal and herd variation effects were tested the same way. Differences were considered significant at $P < 0.05$.

8.3. RESULTS AND DISCUSSION

8.3.1. Descriptive statistics

Milk composition variables are reported in **Table 8.1**. The milk composition is representative of average national milk records (Centre for Dairy Information, 2010) with an increased range due to the use of J and H-F and the non-standardization of milk. The use of non-standardized milk enabled the effect of a range of Protein-to-Fat Ratio (P/F) to be evaluated. The values for the cheese making process could not be compared to past

findings due to the heavy influences of method of cheese making (**Table 8.2**). Cheese composition was in accordance with the legislation on Cheddar cheese composition (International Food Standards, 2003).

Table 8.1 Mean (± SEM) and range of milk composition variables (n = 48).

Milk composition	Mean	Range
Fat (g 100 g^{-1})	4.68 ± 0.09	3.44 - 6.06
Protein (g 100 g^{-1})	3.44 ± 0.04	2.99 - 4.07
Protein: fat	0.742 ± 0.009	0.637 - 0.907
Casein (g 100 g^{-1})	2.54 ± 0.03	2.16 - 3.05
Casein: protein	0.739 ± 0.002	0.717 - 0.758
Lactose (g 100 g^{-1})	4.45 ± 0.009	4.28 - 4.54
Urea (mg 100 g^{-1})	0.02 ± 0.00	0.01 - 0.05
SCC[1] (1,000 cells mL^{-1})	181 ± 6	79 - 257
Ca^{2+} (mg 100 g^{-1})	7.43 ± 0.09	6.18 - 8.74
D(4.3) (µm)	4.05 ± 0.08	2.91 - 5.36
D(3.2) (µm)	1.2433 ± 0.04	0.63 - 2.15
D(0.5) (µm)	3.99 ± 0.08	2.74 - 5.37
MFG[2] Span (µm)	1.79 ± 0.01	1.55 - 1.95
CMS[3] (d. nm)	166 ± 2	146 - 193
pH	6.77 ± 0.01	6.56 - 6.93
TA[4] (°D)	16.01 ± 0.21	12.67 - 19.00

[1]SCC: Somatic cell count, [2]MFG: Milk fat globules, [3]CMS: Casein micelle size, [4]TA: Titratable acidity.

8.3.2. Cheese making process

Cheese yield is often predicted using the Van Slyke equation (**Chapter 4, section 4.2.3**) based on milk fat and casein content, and cheese moisture content (Van Slyke and Price, 1949). Cheese moisture has a significant impact on yield but can be easily influenced by the cheese making process. Thus moisture-adjusted yield was modelled and the model was compared to the actual yield model and Van Slyke model.

Table 8.2 Mean (± SEM) and range of cheese making process, cheese composition and quality attributes variables (n = 48).

Cheese making properties	Mean	Range
Cheese-making process		
Actual yield (kg 100 kg^{-1} of milk)	11.2 ± 0.2	8.9 - 13.5
Theoretical yield (kg 100 kg^{-1} of milk)	11.5 ± 0.2	9.9 - 14.1
Yield MA[1] (kg 100 kg^{-1} of milk)	10.9 ± 0.2	7.3 - 13.7
Yield whey (kg 100 kg^{-1} of milk)	86.0 ± 0.2	82.9 - 89.6
Fat whey (g 100 g^{-1})	0.66 ± 0.01	0.55 - 0.90
Protein whey (g 100 g^{-1})	0.83 ± 0.01	0.62 - 0.95
Lactose whey (g 100 g^{-1})	4.58 ± 0.02	4.32 - 4.81
Solid whey (g 100 g^{-1})	7.91 ± 0.03	7.49 - 8.47
Fat recovery (%)	86.6 ± 1.1	66.4 - 97.5
Protein recovery (%)	77.5 ± 1.2	59.3 - 95.4
Cutting time (min)	36 ± 1	20 - 54
Acidification time (min)	206 ± 3	159 - 271
Cheese composition		
Cheese fat (g 100 g^{-1})	34.35 ± 0.36	28.17 - 39.00
Cheese protein (g 100 g^{-1})	23.44 ± 0.38	18.01 - 29.17
Cheese moisture (g 100 g^{-1})	37.57 ± 0.25	34.41 - 41.35
Cheese salt (g 100 g^{-1})	1.82 ± 0.03	1.15 - 2.16
Cheese pH	5.55 ± 0.01	5.35 - 5.80
Instrumental cheese texture and cheese grading		
TPA[2] Hardness (N)	23.47 ± 0.58	14.97 - 31.77
TPA[2] Springiness	0.80 ± 0.01	0.69 - 0.87
TPA[2] Cohesiveness	0.50 ± 0.00	0.47 - 0.54
TPA[2] Resilience	0.31 ± 0.00	0.23 - 0.39
Flavour and aroma (/45)	34.94 ± 0.44	27.67 - 39.00
Body and texture (/40)	33.15 ± 0.43	25.75 - 37.50
Colour (/5)	3.85 ± 0.06	3.25 - 4.33
Appearance (/10)	7.98 ± 0.05	7.25 - 8.75

[1]MA: moisture adjusted, [2]TPA: Texture profile analysis.

Table 8.3 Beta regression coefficient (β) and coefficient of determination (R^2) between milk composition variables and cheese making process (n = 48).

	Fat	P^2	P/F [3]	C [4]	C/P [5]	Lactose	SCC	D(4.3)	CMS [6]	pH	Season	R^2	SEE [7]	*P*
Yield MA [1]			-0.385 ***	0.887 ***								0.850	0.645	***
Actual yield		0.751 ***	-0.293 ***									0.919	0.402	***
Fat recovery					0.596 ***			0.761 ***	0.435 **			0.704	1.755	***
Protein recovery		0.881 ***							-0.243 **		-0.422 ***	0.881	1.247	***
Cutting time		-0.327 **	0.265 *			-0.322 ***		-0.368 **				0.784	1.672	***
Acidification time	0.800 **	1.246 ***				-0.368 **	-0.386 **			0.434 **		0.510	2.632	***

[1]MA: Moisture Adjusted, [2]P: protein, [3]P/F: Protein to fat ratio, [4]C: Casein, [5]C/P: Casein to protein ratio, [6]CMS: Casein micelle size, [7] SEE: Standard error of the estimate, ***, $P < 0.001$.

The cheese making process variables models are presented in **Table 8.3**. The factors predicting moisture-adjusted yield were milk casein, P/F and C/P ratio. The importance of milk casein is consistent with the Van Slyke formula and with the fact that it is the main constituent of the gel matrix. The negative relationship between P/F was found previously (Grandison and Ford, 1986; Guinee et al., 2007) and is in contradiction with the common belief of a high P/F being an indicator of cheese making suitability. In contrast, actual yield was best predicted using milk protein and P/F and it also had a higher coefficient of determination than moisture-adjusted yield. The coefficients of determination for the two models were similar or higher than found in previous studies (Martin et al., 1997b; Melilli et al., 2002; Zeng et al., 2007). In the case of actual yield, protein had a higher importance than casein as found previously (Zeng et al., 2007; Frederiksen et al., 2011b). This difference between the two models indicates that protein encompasses the difference in moisture better than casein. The model based on the Van Slyke equation had a much lower prediction power ($R^2 = 0.507$, $P > 0.001$).

The main difference between the models developed in this study for yield moisture-adjusted yield and actual yields and the standard Van Slyke model was the use of ratio rather than only content. Indicating that the use of ratio between components, rather than the level of individual components, would result in a better prediction of cheese yield.

8.3.3. Recoveries

Recoveries of fat and protein are important factors for the evaluation of cheese making efficiency.

Fat recovery was linked to D(4.3), C/P, and CMS (**Table 8.3**). The influence of D(4.3), which represent the MFG volume moment mean, on fat recovery is consistent with larger MFG becoming trapped into the curd matrix more easily than smaller ones (Michalski et

al., 2003). Similarly, the relationship with C/P may be caused by an increase in curd firmness and thus greater fat retention. On the other hand, the effect of larger CMS increasing fat recoveries is in disagreement with past research, showing weaker curd with larger CMS (Marchini et al., 2010; **Chapter 7**).

Protein recovery was related to milk protein, season and CMS (**Table 8.3**). The higher amount of protein in milk increasing protein recovery is consistent with higher curd firmness (Chiofalo et al., 2000). The effect of CMS in this case consistent with larger CMS reducing curd firmness and thus retention capacities (Marchini et al., 2010).

Thus, to increase recovery, cheese makers should select milk with high C/P and high protein concentration and higher D(4.3). It is not suggested to increase CMS as large CMS has been shown to be detrimental to milk gelation and protein recovery (Glantz et al., 2010). In addition, the improvement in fat recoveries would be better achieved by modifying D(4.3). The relative importance of each compositional variable is to be taken into account when judging the suitability of milk for cheese making.

8.3.4. Cutting and acidification time

The time for cutting and acidification affect the cheese making time and also cheese quality (Martin et al., 1997b; Pretto et al., 2013).

Cutting time was linked to D(4.3), milk lactose, milk protein and P/F in equal measure (**Table 8.3**). The negative relationship with D(4.3) and protein content and the positive relationship with lactose was also found in **Chapter 7** on rennet coagulation time.

Acidification time was defined as the time for the curd, after cutting, to reach the TA for drainage (0.20 ± 0.05 °D). The acidification time was linked to milk protein, milk fat, milk pH, Somatic Cell Count (SCC) and milk lactose. However, the coefficient of determination

was lower than for cutting time (**Table 8.3**). Milk protein is linked to an increase in buffering capacity of milk thus an increase in acidification time with milk with high protein content (Salaün et al., 2005). The similar effect of fat was surprising as it was found previously to decrease the buffering capacity of milk due to softer curd leading to a higher loss of matter in the whey (Salaün et al., 2005). However, in the study presented in **Chapter 7**, **section 7.3.3** fat content increased curd firmness which could lead to higher recovery of buffering components such as protein. The negative effect of pH and positive effect of lactose are in agreement with past research (Waldron and Fox, 2004). The positive effect of SCC on acidification time is in contradiction to the common understanding of SCC increasing pH (Grandison et al., 1984; Król et al., 2010), but is in agreement with the study presented in **Chapter 7** who also using J and H-F milk found SCC, in a range not representing udder health problem, to have a beneficial effect on coagulation properties.

To reduce cheese making time, milk with a higher level of protein, lactose, D(4.3) and lower level of P/F and pH should be chosen. A lower level of fat and protein and higher level of SCC was also shown to improve cheese making time; however selecting milk with this composition could negatively affect the rest of the cheese making process.

8.3.5. Whey production

As mentioned previously, whey is now an important product of cheese production and is used for many applications. In addition, the most important step in estimating the efficiency of the cheese-making process is to measure the residual protein and fat in whey. Surprisingly, little research has been undertaken to understand how milk composition affects the quantity and composition of whey produced.

Table 8.4 Beta regression coefficient (β) and coefficient of determination (R^2) between milk composition variables and the yield and composition of whey (n = 48).

Whey	Fat	Protein	P/F [1]	Casein	Lactose	TA[2]	Season	R^2	SEE[3]	*P*
Yield			0.314 **	-0.764 ***			0.274 **	0.786	0.820	***
Fat					-0.413 **	-0.397 **	0.481 **	0.390	0.062	***
Protein		-0.621 ***					0.535 **	0.803	0.044	***
Lactose	0.550 ***	0.366 ***					0.417 ***	0.723	0.067	***

[1]P/F: Protein to fat ratio, [2] TA: Titratable acidity, [3] SEE: Standard error of the estimate, *** $P < 0.01$.

Whey quantity was affected by milk casein, P/F, and season (**Table 8.4**). The components involved are, as expected, similar to those found for the prediction of cheese yield, with a higher level of casein and lower P/F increasing component recovery and thus decreasing yield.

Fat in whey was linked to season, lactose and TA. The model had, however, a low predictability (**Table 8.4**). The negative effect of lactose and TA is consistent with a higher acidification rate creating a firmer curd and thus a higher retention of fat (Formaggioni et al., 2005). The fact that season had the most important effect and the model had low predictability suggests fat in whey is dependent on variables which were not evaluated in the current study.

Protein in whey was linked to milk protein and season. The regression coefficient was higher than for fat in whey (**Table 8.4**). The negative relationship with milk protein might seem contradictory, but is coherent with an increase in milk protein leading to a stronger curd thus a higher protein retention (Chiofalo et al., 2000). Again seasonal variation could be the expression of non-evaluated variables.

Whey lactose was related to milk fat, season and milk protein (**Table 8.4**). Unexpectedly, lactose in whey was not directly dependent on lactose, suggesting the amount of lactose in whey is linked to the rate of acidification rather than the amount of preexisting lactose. In this way this model is coherent with the model on acidification time where fat and protein had a negative effect on acidification.

To decrease the quantity of whey, cheese makers should select milks with a high level of casein and low P/F. However, due to variability in the use of the whey components it is not possible to indicate the most appropriate milk composition, especially as the most important product remains cheese.

8.3.6. Cheese quality

Cheese composition is a key factor in cheese quality. Firstly, the cheese to be called Cheddar must follow the legal requirement in moisture and fat content (International Food Standards, 2003). Secondly cheese composition impacts on the quality attributes of the cheese. Thus several researchers have studied the influence of milk composition, especially through the study of the effect of breed and diet.

Cheese fat was linked to D(0.5) and P/F (**Table 8.5**). The strong effect of D(0.5), which represents the MFG volume median diameter, is consistent with the idea of large MFG getting trapped in the curd matrix thus increasing fat retention (O'Mahony et al., 2005). Surprisingly, the MFG parameter found significant in this case, D(0.5), was not the same as for fat recovery which found D(4.3) to be significant. The negative impact of P/F on cheese fat is in agreement with the study of Guinee et al. (2007).

Cheese protein was linked to P/F, CMS and season (**Table 8.5**). The positive impact of P/F is consistent with the study of Guinee et al. (2007). The negative effect of CMS was

coherent with smaller CMS creating a stronger matrix thus reducing leaking of protein (Marchini et al., 2010). Season would again be the expression of the effect of a compositional variable not evaluated in this study.

Table 8.5 Beta regression coefficient (β) and coefficient of determination (R^2) between milk composition variables and cheese composition (n = 48).

Cheese composition	P:F[1]	Urea	D(4.3)	D(0.5)	CMS[2]	pH	Season	R^2	SEE	*P*
Fat	-0.576 ***			1.830 ***				0.718	1.208	***
Protein	0.558 ***				-0.432 ***		0.510 ***	0.707	1.551	***
Moisture	0.300 **		-0.381 ***					0.724	0.972	***
Salt		-0.494 ***						0.344	0.200	*
pH		0.425 **	0.553 ***			0.319 **		0.506	0.070	***

[1] P/F: Protein to fat ratio, [2] CMS: Casein micelle size, *** $P < 0.001$, ** $P < 0.01$, ** $P < 0.05$.

Cheese moisture was linked to SCC, D(4.3) and P/F (**Table 8.5**). The important negative effect of SCC on moisture was in disagreement with past study (Grandison et al., 1984), but the levels in this study were not representative of udder health problem. Research should be undertaken on understanding the effect of different healthy levels of SCC on the cheese making process. The negative effect of D(4.3) on cheese moisture is in agreement with larger MFG binding water to a lesser extent than small MFG (Martini et al., 2008). Protein to fat ratio is positively related to cheese moisture in accordance with Guinee et al. (2007).

Cheese salt was found to be only related to urea with a low model predictability (**Table 8.5**). No previous research has shown urea as a predictor of cheese salt and it is probable that the correlation is spurious.

Cheese pH was linked to D(4.3), urea and pH (**Table 8.5**). The positive effect of urea and pH on cheese pH is in agreement with past research (Martin et al., 1997b). However, D(4.3) was not found to affect cheese pH previously (O'Mahony et al., 2005) and so could be linked to its effect on cheese moisture, affecting the salt to moisture ratio and thus cheese pH (Upreti and Metzger, 2007).

The findings support the use of standardization to control cheese composition, due to the importance of the P/F on cheese composition. In addition, it was found that the CMS and MFG size are better indicators of cheese fat and protein content, than levels of fat and protein in milk.

8.3.7. Cheese quality attributes

Hardness was defined as the maximum force encountered when cheese is deformed to a certain point, and was related to P/F, cheese protein, cheese moisture and CMS, however the regression coefficient was low (**Table 8.6**). The positive effect of milk P/F and level of protein in cheese on cheese hardness is consistent with an increase in curd firmness, while larger CMS and higher cheese moisture would reduce curd firmness (Lucey et al., 2003).

Springiness was defined as the degree to which a sample returns to its original size after compression. It was related to D(4.3), cheese protein and urea but again the regression coefficient was low (**Table 8.6**). The negative effect of D(4.3) is consistent with larger MFG increasing the rigidity of cheese curd (Michalski et al., 2003). The positive effect of cheese protein is in accordance with Lucey et al. (2003). The positive effect of pH with springiness is consistent with low pH producing more brittle and compact cheeses (Lucey et al., 2003) .

Table 8.6 Beta regression coefficient (β) and coefficient of determination (R^2) between milk and cheese composition variables and cheese texture and grading scores (n = 48).

Quality attributes	Milk component					Cheese component				R^2	SEE	*P*
	Protein	P:F[1]	pH	D(4.3)	CMS[2]	Fat	Protein	Moisture				
Hardness		0.883 ***			-0.438 *		0.851 ***	-0.450 *		0.413	0.450	***
Springiness			0.412 ***	-0.599 ***			0.488 **			0.45	0.023	***
Cohesiveness	-2.907 ***			1.540 ***		4.402 **				0.707	0.009	***
Resilience				-0.368 **			0.627 ***			0.501	0.024	***
Flavour and taste												NS
Texture and body		0.500 **		-0.397 *	-0.490 **		0.366 **			0.384	2.637	**
Colour												NS
Appearance		0.514 **		-0.399 **						0.664	0.219	***

[1]P:F: Protein to fat ratio, [2]CMS: Casein micelle size, [3]SEE: Standard error of the estimate, *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

Cohesiveness was the resistance of the sample to be separated into parts and was related to cheese fat, milk protein and D(4.3) for a higher regression coefficient than the other parameters of cheese texture (**Table 8.6**). Cheese fat and D(4.3) were positively correlated to cohesiveness due to their effect on the firmness of the cheese (Michalski et al., 2003). Milk protein was negatively correlated to cohesiveness which could not be explained.

Resilience corresponds to the instantaneous recoverable springiness and was related to cheese protein and D(4.3) with a regression coefficient higher than springiness (**Table 8.6**). Due to the similarity between resilience and springiness it is not surprising the cheese protein content and D(4.3) were related in the same manner than for springiness.

The cheese was graded for taste and flavour, texture and body, colour and appearance. The scores reflect the cheese conformity to retailer requirements. The cheese grading score for taste and flavour, and colour could not be significantly correlated to the milk compositional variables studied (**Table 8.6**). Taste and flavour have already been previously found hard to model (O'Riordan and Delahunty, 2003) and cheese colour can be mainly linked to the β-carotene content of the milk which was not evaluated (Verdier-Metz et al., 2000). In addition the difficulty in correlating grading scores could also be due to their low coefficient of variation (8.9 % and 9.9 % for flavour and colour respectively).

Body and texture score was linked to P/F, CMS, D(4.3) and cheese protein, however the regression coefficient was low (**Table 8.6**). The effect of P/F, CMS and cheese protein on texture and body score was similar to the one found for hardness, which is consistent with hardness being a desired body attribute for Cheddar cheese (Banks et al., 1984b). While the negative effect of D(4.3) is possibly linked to its effect on springiness and cohesiveness.

Appearance was related to P/F and D(4.3) (**Table 8.6**). The effect of P/F and D(4.3) on appearance can be linked to their impacts on cheese texture which would affect the appearance of cheese.

To produce cheese with a high grading score and thus the desired hardness, springiness, cohesiveness, resilience and appearance, a milk with a high P/F and small CMS and D(4.3) is important.

8.4. CONCLUSIONS

The study demonstrated the importance of evaluating the effect of a large array of milk compositional variables on the cheese making process, cheese composition and quality. While most findings were in accordance with past research, some components were more important than had previously been understood, such as MFG and CMS which were shown, in most cases, to be more correlated to the cheese making than level of fat and protein. In addition, the difficulty in determining the optimal milk composition for Cheddar cheese making was seen with, for example, a high P/F having a positive effect on cheese protein and moisture content and the grading of scores but having a negative effect on cheese yield and fat content. Thus, a balance needs to be found between improving yield and maintaining high cheese quality and each cheese maker should select milk whose composition would help achieve their specific production aims such as improving cheese yield or modifying cheese quality. To ensure the universality of these results, further research would benefit from using different breeds of cows than those used in this study.

CHAPTER 9

9. OVERALL CONCLUSIONS AND RECOMMENDATIONS

9.1. OVERALL CONCLUSIONS

The present thesis aimed to improve milk suitability for Cheddar cheese making by including Jersey milk into Holstein-Friesian milk and, secondly, deepening our understanding of the effects of several milk components on the cheese making process.

The review of the literature justified the research topic and approach. Jersey milk was found by past studies to have a milk composition with the potential to improve the cheese making process. However, the higher level of fat leading to a lower protein to fat ratio and the larger fat globules had the potential to negatively affect the cheese making process. In addition important differences were found for each breed between countries and with year confirming the importance of studying the suitability of the Jersey breed for cheese making in the UK.

Blending Jersey and Holstein-Friesian milk led to non-additional (quadratic) effect on casein micelle size which was decreased at a lower rate at high percentage of Jersey milk. Fat globules size D(4.3) was quadratically increased when Jersey milk was added and again the rate of increase was lower at high percentage of Jersey milk. Milk coagulation properties also demonstrated non-additional effects with coagulation time decreasing at a higher rate between 0 and 50 % Jersey milk. Curd firmness was quadratically increased with a higher rate of increase occurring when over 50 % Jersey milk was included. The non-additional trends were strongly affected by season. However, when a limited number of inclusion rates were used, non-additional effects were not observed on the cheese making process, suggesting the effects are negligible and should not be a concern for the industry.

Including Jersey milk in Holstein-Friesian milk improved the efficiency and profitability of cheese making by increasing yield linearly without negatively impacting cheese quality. These results were supported on a commercial scale albeit less consistently than at pilot scale. This was to be expected due to the challenges in scaling up the process in a commercial environment. In addition, the commercial trial confirmed that the Cheddar cheese produced in the pilot plant was representative of commercial production.

The approach chosen in this thesis not to standardize, while not representative of all commercial cheese production, demonstrated that the effect of varying milk protein to fat ratio and fat concentration, although impacting cheese fat, fat in dry matter and moisture, did not influence cheese texture or grading scores.

The importance of considering a number of compositional variables when modelling the effect of milk composition on the cheese making process was demonstrated as it led for most models to a greater predictive power due to more variation being explained. It also demonstrated the use of both PLS and partial correlations to overcome the problem of multicolinearity. Furthermore it allowed the study of the relative importance of the different milk components, challenging the general understanding of milk fat, casein and protein fractions being the main factors responsible for the cheese making process. While they were clearly determinants, other factors were shown to play a key role, suggesting that more complex models taking into account factors such as titratable acidity, casein micelle size, and the milk fat globules size could lead to more precise predictive equation and understanding of the effect of milk composition. Considering the effect of these other factors can already help explain why the higher milk fat content of the Jersey milk did not lead to a softer cheese as the larger fat globules and smaller casein micelle size would have increased curd firmness and thus compensated for higher fat levels.

This work has thus provided a straightforward way of improving the efficiency and profitability of Cheddar cheese making by including Jersey milk in the standard cheese milk supply. In addition it supports the idea that optimising milk quality for dairy processing is an effective way of improving the efficiency and profitability of the dairy sector.

It also demonstrated the importance of considering the effect of a wider range of compositional variables on the cheese making process than is current practice. Viewing milk as a complex system where several components have direct and indirect effects rather than using a simplistic view of protein and fat being the main contributors to the cheese making process would greatly assist both scientists and cheese makers through a better understanding of the effect of milk composition. However, faster and cheaper methods of milk analysis should be developed if certain milk compositional variables were to be analysed routinely.

9.2. RECOMMENDATIONS

Blending

Research should be carried out to further elucidate the cause of non-additional effects occurring when milk is blended as while it was shown not to have a significant effect on the cheese making process it could deepen our understanding of interaction between milk components.

Jersey milk

In future studies on the use of Jersey milk, the effect of standardization should be evaluated as it is now common practice. Standardization could reduce the increase in yield due to the lower level of fat and influence cheese quality due to changes in the balance between

protein and fat. In addition, the mechanical stress placed on the fat globules during standardisation could lead to damage and potential off-flavours. This should be linked to several well controlled commercial trials at different cheese making plants.

Another interesting avenue for further research would be to evaluate the effect of milk from Jersey and Holstein-Friesian cross breeds as cross-breeding is increasing worldwide and could yield additional benefit in terms of higher animal vigour.

Additional research should be undertaken on the financial impact of using of Jersey milk commercially by using commercial data and also by looking at the potential for the increase in profitability to be translated into higher price for Jersey farmers. This information could support dairy farmers in switching to Jersey cows which would solve the problem of low availability.

Milk modelling

Although the model developed in this study revealed new information on the effect of milk components on Cheddar cheese making, further work is needed to improve and validate it. To do this a variety of breeds could be used under different cheese making condition and more components could be evaluated such as protein variants and minerals balance. Moreover, the modelling of texture and grading could be improved using data showing more variation in those parameters.

In addition, the models revealed the role of a number of components on the cheese making process however the mechanisms are not yet understood and further research should be performed on the effects of: lactose, urea and a healthy range of somatic cell count on milk coagulation properties, a healthy range of somatic cell count on milk acidification and cheese moisture and milk fat on acidification time.

CHAPTER 10
10. REFERENCES

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APPENDICES

1. Cheddar cheese recipe: Pilot plant

1. Add the starter Hansen RSF 638 at 0.0269 g kg^{-1} to 80 kg of pasteurized milk at 33 °C. Allow the milk to “ripen" for 35 min.
2. Coagulant Marzyme 15 PF should be added at 0.2566 mL kg^{-1} (and then diluted 1:5 with deionize water). Stir for 2 min then remove the paddle.
3. After 30 to 55 min a firm coagulum should be formed. Cut with vertical and horizontal knives.
4. Replace the paddle and start stirring 5 min after cutting. Begin the scald (≈ 10 °C per hour) to reach 39.3 ± 0.2 °C in 45 min.
5. Hold at 39.3 ± 0.2 °C for 50 min. Remove the paddle and allow the curd to settle (pitch), then move the curd away from the drain and place the sieve plate. Take samples of curd, strain off the whey and check the acidity. Drain off the whey using a sieve in the whey stream to recover curd particles to a TA of 0.20 ± 0.05 °D.
6. Cut a centre channel through the curd then cut across the curd. After 10 min turn the blocks over.
7. The blocks are turned at intervals of 10 ± 5 min; the faster the rate of acid development the more frequent the turning.
8. Cheddaring (which should take around 30 ± 5 min) is continued till a “chicken breast” texture is achieved (TA 0.30 ± 0.01 °D). The curd (36.3 °C) should then be milled, salt added at 24 g kg^{-1} and mixed thoroughly with the curd for 5 min.
9. Leave the salted curd on the curd cooling table for at least 15 min, turning every 5 min to ensure mixing of the salt and even cooling of the curd to a temperature less than 30 °C before filling into moulds.
10. Curd from 80 kg of milk fill two 5 kg block mould lined with disposable cheese cloth. Fill carefully to give an even packing density then transfer to the large press.
11. Prepress at 3 kPa till whey stops running then increase the pressure over approximately an hour to 7 kPa and leave overnight.
12. In the morning, block cheese should be demoulded, the cheese vacuum packed and placed in store at 8 °C for ripening.

2. Inputs and outputs for each vat:

Table 1 Inputs and outputs quantity for all 48 vats.

Code	**PP1**	**PP1**	**PP1**	**PP1**	**PP2**	**PP2**	**PP2**	**PP2**	**PP3**	**PP3**	**PP3**	**PP3**
Rate of Jersey milk (%)	0	25	50	100	0	50	75	100	0	25	50	100
Inputs (kg)												
Pasteurized milk	78.4	83.6	83.4	83	81.6	89.9	81.2	94.864	79.20	79.80	79.60	89.20
Starter (g)	2.11	2.25	2.24	2.23	2.20	2.42	2.18	2.55	2.13	2.15	2.14	2.40
Rennet solution (g)	100.59	107.26	107.00	106.49	104.69	115.34	104.18	121.63	101.61	102.38	102.13	114.44
Salt	208.8	220.8	235.2	302.4	225.6	292.8	264.0	316.8	235.2	259.2	249.6	316.8
Fat in cheese milk	2.70	3.25	3.63	4.39	3.51	4.37	4.42	5.22	3.33	3.56	3.84	4.54
Protein in cheese milk	2.45	2.73	2.87	3.09	2.64	3.27	3.07	3.86	2.37	2.54	2.69	3.35
Total weight of inputs	78.71	83.93	83.74	83.41	81.93	90.31	81.57	95.24	79.54	80.16	79.95	89.63
Weight of fat + protein	5.14	5.99	6.50	7.48	6.15	7.64	7.49	9.08	5.69	6.10	6.53	7.89
Outputs (kg)												
Curd	8.7	9.2	9.8	12.6	9.4	12.2	11	13.2	9.8	10.8	10.4	13.2
Cheese	7.2	8.4	8.8	11	8.2	11.4	10.1	12.4	7.80	8.80	9.40	11.80
Bulk whey	68.6	72.8	71.6	68.8	70.2	76.3	67.8	78.8	69.0	68.6	67.2	74.4
Fat in cheese	2.03	2.65	2.80	4.07	2.71	3.91	3.54	4.59	2.54	3.14	3.45	4.48
Fat in bulk whey	0.42	0.55	0.54	0.42	0.45	0.50	0.41	0.55	0.48	0.45	0.42	0.48
Protein in cheese	1.84	2.09	2.23	2.38	1.80	2.36	1.91	2.71	1.40	1.87	1.92	2.67
Protein in bulk whey	0.54	0.54	0.47	0.45	0.58	0.66	0.42	0.52	0.61	0.59	0.56	0.58
Total outputs	75.8	81.2	80.4	79.8	78.4	87.7	77.9	91.2	76.8	77.4	76.6	86.2
Weight of fat + protein	4.83	5.82	6.05	7.32	5.54	6.28	6.28	8.37	3.94	5.00	5.37	7.16

Table 1 Inputs and outputs quantity for all 48 vats (continues).

Code	**PP4**	**PP4**	**PP4**	**PP4**	**PP5**	**PP5**	**PP5**	**PP5**	**PP6**	**PP6**	**PP6**	**PP6**
Rate of Jersey milk (%)	0	50	75	100	0	25	50	100	0	50	75	100
Inputs (kg)												
Pasteurized milk	79.00	80.60	79.80	85.60	80.80	79.00	78.60	71.00	80.20	81.60	81.20	79.00
Starter (g)	2.13	2.17	2.15	2.30	2.17	2.13	2.11	1.91	2.16	2.20	2.18	2.13
Rennet solution (g)	101.36	103.41	102.38	109.82	103.67	101.36	100.84	91.09	102.90	104.69	104.18	101.36
Salt (g)	225.60	254.40	268.80	307.20	211.20	230.40	220.80	249.60	211.20	244.80	273.60	269.76
Fat in cheese milk	3.33	3.87	4.17	4.92	3.19	3.49	3.90	4.30	3.31	3.99	4.24	4.47
Protein in cheese milk	2.53	2.81	2.89	3.22	2.55	2.64	2.81	2.82	2.48	2.78	2.87	2.97
Total weight of inputs	79.33	80.96	80.17	86.02	81.12	79.33	78.92	71.34	80.52	81.95	81.58	79.37
Weight of fat + protein	5.85	6.68	7.06	8.14	5.74	6.13	6.70	7.12	5.79	6.77	7.11	7.44
Outputs (kg)												
Curd	9.4	10.6	11.2	12.8	8.8	9.6	9.2	10.4	8.8	10.2	11.4	11.24
Cheese	8.00	9.60	10.00	11.40	7.80	8.60	9.20	9.60	7.60	9.20	9.80	10.24
Bulk whey	68.4	68.8	67.4	71.0	70.2	68.2	67.2	59.2	71.1	70.9	70.1	67.6
Fat in cheese	2.56	3.31	3.43	4.36	2.44	3.01	3.28	3.60	2.34	3.06	3.45	3.74
Fat in bulk whey	0.43	0.43	0.40	0.46	0.39	0.38	0.39	0.38	0.58	0.47	0.47	0.46
Protein in cheese	1.71	1.97	2.11	2.32	1.73	1.89	2.06	1.80	1.66	2.09	2.26	2.41
Protein in bulk whey	0.59	0.56	0.49	0.51	0.63	0.62	0.55	0.44	0.65	0.61	0.57	0.51
Total weight of outputs	76.4	78.4	77.4	82.4	78	76.8	76.4	68.8	78.66	80.08	79.94	77.8
Weight of fat + protein	5.30	6.27	6.44	7.65	5.19	5.90	6.28	6.22	5.23	6.23	6.75	7.11

Table 1 Inputs and outputs quantity for all 48 vats (continues).

Code	**PP7**	**PP7**	**PP7**	**PP7**	**PP8**	**PP8**	**PP8**	**PP8**	**PP9**	**PP9**	**PP9**	**PP9**
Rate of Jersey milk (%)	0	25	50	100	0	50	75	100	0	25	50	100
Inputs (kg)												
Pasteurized milk	81.80	80.00	81.60	81.20	81.60	73.00	79.00	88.40	88.20	72.30	77.00	89.60
Starter (g)	2.20	2.15	2.20	2.18	2.20	1.96	2.13	2.38	2.37	1.94	2.07	2.41
Rennet solution (g)	104.95	102.64	104.69	104.18	104.69	93.66	101.36	113.42	113.16	92.76	98.79	114.96
Salt (g)	216.00	225.60	246.24	288.00	206.40	218.40	256.80	292.80	223.20	194.40	232.80	295.20
Fat in cheese milk	3.13	3.34	3.88	4.43	3.25	3.36	3.61	4.99	3.26	2.92	3.50	4.35
Protein in cheese milk	2.58	2.66	2.80	3.09	2.59	2.48	2.71	3.17	2.73	2.31	2.55	3.16
Total weight of inputs	82.12	80.33	81.95	81.59	81.91	73.31	79.36	88.81	88.54	72.59	77.33	90.01
Weight of fat + protein	5.72	5.99	6.67	7.52	5.83	5.85	6.32	8.16	5.99	5.23	6.04	7.51
Outputs (kg)												
Curd	9	9.4	10.26	12	8.6	9.1	10.7	12.2	9.3	8.1	9.7	12.3
Cheese	7.60	8.40	9.40	11.00	7.60	8.20	9.40	11.00	8.20	7.00	7.80	10.20
Bulk whey	64.5	71.7	71.1	71.9	71.8	62.8	67.2	75.2	77.9	63.2	65.7	77.0
Fat in cheese	2.32	2.73	3.29	4.02	2.33	2.87	3.42	4.07	2.62	2.17	2.73	3.64
Fat in bulk whey	0.45	0.42	0.44	0.47	0.56	0.39	0.43	0.46	0.58	0.44	0.41	0.47
Protein in cheese	1.74	1.88	2.21	2.59	1.81	1.89	2.24	2.56	2.18	1.97	2.12	2.93
Protein in bulk whey	0.57	0.62	0.60	0.56	0.62	0.53	0.59	0.63	0.73	0.59	0.59	0.69
Total weight of outputs	72.08	80.06	80.48	82.86	79.4	71	76.6	86.2	86.1	70.2	73.5	87.2
Weight of fat + protein	5.08	5.65	6.54	7.63	5.32	5.68	6.67	7.73	6.11	5.17	5.85	7.72

Table 1 Inputs and outputs quantity for all 48 vats (continues).

Code	**PP10**	**PP10**	**PP10**	**PP10**	**PP11**	**PP11**	**PP11**	**PP11**	**PP12**	**PP12**	**PP12**	**PP12**
Rate Jersey milk (%)	0	50	75	100	0	25	50	100	0	50	75	100
Inputs (kg)												
Pasteurized milk	85.20	80.40	73.20	78.80	83.60	81.80	76.80	89.00	88.20	80.20	81.40	78.00
Starter (g)	2.29	2.16	1.97	2.12	2.25	2.20	2.07	2.39	2.37	2.16	2.19	2.10
Rennet solution (g)	109.31	103.15	93.92	101.10	107.26	104.95	98.53	114.19	113.16	102.90	104.44	100.07
Salt (g)	215.52	234.72	216.00	244.80	213.60	215.52	223.20	288.00	230.40	240.00	264.00	268.80
Fat in cheese milk	3.35	3.63	3.82	3.98	3.22	3.40	3.53	4.68	3.32	3.76	4.10	4.29
Protein in cheese milk	2.68	2.69	2.52	2.78	2.65	2.67	2.58	3.15	2.91	2.86	3.00	3.00
Total weight of inputs	85.53	80.74	73.51	79.15	83.92	82.12	77.12	89.40	88.55	80.55	81.77	78.37
Weight of fat + protein	6.03	6.31	6.34	6.76	5.87	6.08	6.11	7.83	6.23	6.62	7.10	7.29
Outputs (kg)												
Curd	8.98	9.78	9	10.2	8.9	8.98	9.3	12	9.6	10	11	11.2
Cheese	7.60	8.60	8.20	9.20	7.60	8.00	8.40	10.60	8.60	9.00	9.80	10.20
Bulk whey	74.0	69.2	62.2	67.0	74.7	72.5	67.4	76.6	77.0	69.0	69.3	66.3
Fat in cheese	2.51	2.61	2.95	3.31	2.43	2.80	3.11	3.98	2.67	3.15	3.43	3.81
Fat in bulk whey	0.66	0.42	0.38	0.40	0.57	0.50	0.44	0.49	0.47	0.39	0.44	0.50
Protein in cheese	2.03	2.51	2.13	2.56	1.68	2.08	1.96	2.45	2.46	2.21	2.40	2.37
Protein in bulk whey	0.68	0.63	0.54	0.57	0.65	0.64	0.60	0.68	0.73	0.60	0.57	0.51
Total weight of outputs	81.58	77.8	70.4	76.2	82.3	80.5	75.8	87.2	85.58	77.98	79.08	76.48
Weight of fat + protein	5.88	6.17	6.01	6.84	5.34	6.01	6.11	7.76	6.32	6.35	6.85	7.18

3. Cheese composition, texture, colour and grading analysis

Moisture

The moisture content was determined by weighing 10 ± 0.005 g of ground cheese from a sample of 30 g of cheese sampled as fat and protein concentration into a dish with 20 ± 0.5 g of sand, along with lid and rod, which had been previously dried for an hour at 105 °C and then pre-weighed (± 0.0001 g). The sample was then put into an oven to dry for 19 h at 105 °C. The weight was then recorded and the sample was put back for an hour until any change in weight was smaller than 0.0005 g. Analysis was done in triplicate and results were expressed as g of moisture per 100 g of cheese.

Salt

A Tritralab automatic titrator (Radiometer Analytical, Villeurbanne, France) was used to assess salt concentration in cheese. A sample (5 ± 0.001 g) of ground cheese was mixed with 100 mL of water at 40 °C and a 50 mL aliquot was sampled. To this aliquot 5 mL of nitric acid 1 M was added to make it acid and then it was titrated using a combined silver / mercurous sulphate metal probe MC609/Ag (Radiometer Analytical, Villeurbanne, FR) with silver nitrate 0.1 M to an endpoint of -100 Mv. Analysis was performed in triplicate and results expressed as g NaCL per 100 g fresh weight of cheese.

pH

The pH of cheese samples was measured with a Thermo Orion star A111 benchtop pH meter (Thermo Fisher Scientific Ltd, Loughborough, UK) using a specially designed cheese FoodCare pH combination pH probe FC240B (Hanna Instruments Ltd, Leighton Buzzard, UK). Standard solutions of pH 4.00 and 7.00 were used prior to the analyses to

calibrate the pH probe. Analyses were carried out in triplicate at room temperature (20 ± 0.5 °C).

Colour

Colour was analysed using a ColorQuest II spectrophotometer (HunterLab, Virgina, US) which measures the transmitted colour.

Three samples for each inclusion rate were taken and cut flat in a squared shape of 5x5x3 cm and vacuum packed in a S303 pack (Grays Packaging Ltd, Essex, UK). Each was placed, still in the pack, in front of the reader after initialization and calibration of the ColorQuest II, using the Commission on Illumination Standard (CIE) Illuminant D65 lamp representing midday Northern Europe daylight.

Results are given as a CIE L*a*b colour scale:

- L* going from 0 to 100, 100 representing a perfect reflecting diffuser.
- a* has no numerical limits, positive a is red, negative a is green.
- b* has no numerical limits, positive b is yellow and a is blue.

NACEPE UK cheese grading sheet

Cheese grading

Based on NACEPE UK grading scheme

Name:

Date:

Experiment number:

Sample number:	
Flavour and aroma	/45
Body and texture	/40
Colour	/5
Appearance	/10
Total	/100
Comments:	

Sample number:	
Flavour and aroma	/45
Body and texture	/40
Colour	/5
Appearance	/10
Total	/100
Comments:	

Sample number:	
Flavour and aroma	/45
Body and texture	/40
Colour	/5
Appearance	/10
Total	/100
Comments:	

Sample number:	
Flavour and aroma	/45
Body and texture	/40
Colour	/5
Appearance	/10
Total	/100
Comments:	

4. Dissemination of the results to the dairy industry

- **Publications**

Bland, J.H. 2012. The use of Jersey milk for cheese-making in the USA. April 2012 J*ersey Q*, UK.

UK Jerseys, The Royal Bath and West of England Society, Dartington Cattle Breeding Trust, Pocock Memorial Trust and J.H. Bland. 2014. Jersey Milk: An effective way of improving Cheddar cheese yield and profitability.

- **Poster presentations**

Bland, J.H., A.S. Grandison and C.C. Fagan. 2012. Effect of Jersey milk inclusion on Cheddar yield and quality. Presented at The Science of Artisan Cheese Conference, 27-28 August 2012, North Cadbury Court, UK.

- **Oral presentations**

Bland, J.H., A.S. Grandison and C.C. Fagan. 2014. Benefits of using Jersey milk for Cheddar cheese production. Presented at The Royal Bath and West of England Society Dairy Show, 1 October 2014, Shepton Mallet, UK.

Bland, J.H., A.S. Grandison and C.C. Fagan. 2014. Benefits of using Jersey milk for Cheddar cheese production. Presented at Jersey Milk for Cheese Making Briefing, 23 October 2014, Taunton, UK.

Constant Cheese Quality

- Cheese composition fully met food quality standards
- Cheese fat increased in autumn, winter and spring (maximum increase 18%)
- Cheese moisture decreased in spring and summer (maximum decrease 8%)
- Cheese protein, salt or pH levels were not modified
- Cheese colour was yellower in a few batches of cheese, still overall no noticeable difference was found either by graders or instrumental colour analysis
- Cheese texture was not affected by the inclusion of Jersey milk as determined both by instrumental analysis and grading
- Cheese grading scores both at 3 & 8 months were not affected by the inclusion of Jersey milk and the cheese produced on a commercial scale was sold between 8 & 15 months
- Consumers who tried mild Cheddar cheese made with up to 25% Jersey milk were not able to detect any differences

Financial Benefit

- Profit was increased when Jersey milk was included. The higher cheese yield always outweighing the higher milk price
- Cheese yield was the most important factor determining the level of additional profits while change in cheese price and milk price had a small impact, thus not putting the profitability by using Jersey milk at risk
- Using high inclusion of Jersey milk reduces fluctuations in additional profit due to change in cheese yield

Ease of Blending and Processing

- The recommended blending amount is the highest possible level of Jersey milk due to the important increase in yield and profitability and the lack of detrimental effect on cheese quality
- No change in processing was found to be necessary

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For more information:

- *Jersey Milk for Cheddar Cheese Production Project scientific articles*

J.H. Bland, C.C. Fagan & A.S. Grandison. Effect of blending Jersey and Holstein-Friesian milk on Cheddar Cheese Processing, Composition and Quality. Journal of Dairy Science. Under review.

J.H. Bland, C.C. Fagan & A.S. Grandison. Estimation of the Financial Benefit of using Jersey milk at Different Inclusion Rate for Cheddar Cheese production using Partial Budgeting. Under review

Reference

(1) Capper, J. L.; Cady, R. A. J. Dairy Sci. 2012, 95, 165–176.
(2) International Food Standards. Codex Alimentarius Standard for Cheddar cheese 263-1966 A-6- 1978, Rev.1-1999, Amended 2003 www.codexalimentarius.net/web/standard_list (accessed Apr 24, 2014).

Jersey Milk

An effective way of improving Cheddar cheese yield and profitability

"...up to 35% increase in cheese yield with no noticeable impact on quality, leading to a significant increase in manufacturing profitability"

The Jersey breed has a lower milk yield than Holstein-Friesians cows however, the milk has a higher fat, protein and casein content. In addition, this breed is well known for its increased longevity, higher fertility and lower feed and water requirements per unit of body weight.

Hilmar Cheese Company, an inspiration to the Jersey breed, worldwide.

Hilmar is one of the biggest producers of Cheddar cheese in the world, processing over 9.5 million litres of milk per day; and using 30% Jersey milk in their California site and 55% Jersey milk at their Texas site.

The Jersey Milk for Cheddar Cheese Project

This study should remove any concerns about the effect which Jersey milk could have on Cheddar cheese texture or flavour – also demonstrating the Jersey milk attributes in a mature product.

In addition to the beneficial effect on cheese yield, using Jersey milk was also shown to reduce the carbon footprint and environmental impact of Cheddar cheese production.

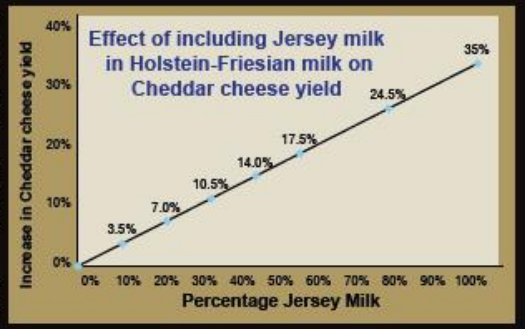
An in-depth review of the compositional qualities of Jersey and Holstein milk was completed. This led to a better understanding of the effects of inclusion of Jersey milk into the standard milk supply to different levels on Cheddar cheese production, the process can be optimized, leading to benefits and financial gains to both cheese makers by increasing cheese yield and Jersey farmers by increasing milk demand.

The project has been carried out by the University of Reading and sponsored by the following organisations:

DCBT · Lye Cross Farm · Pocock Memorial Trust · The Royal Bath & West of England Society · UK Jerseys

Julie Bland, Reading University
PhD student who completed the study

From the base research Cheddar cheese was produced using a wide range of inclusion rates of Jersey into Holstein-Friesian every month over a one year period in the University pilot plant.



The cheese making process mirrored that of Lye Cross Farm by using non-standardized milk, starter cultures.

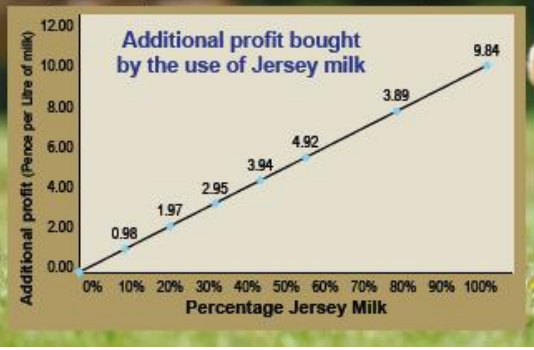
Additional commercial trials were performed at Lye Cross Farm to ensure the result from the pilot scale conformed to what would be found commercially.

All cheeses were analysed for yield, composition and sensory quality - the latter was evaluated by instrumental analysis of colour and texture, professional graders and sensory test using 280 consumers in total.

Higher Cheddar Cheese Yield*

- Increased yield throughout the year (up to 35%)
- Constant increase throughout the year
- Increased fat recovery (up to 30%)
- Increased protein recovery (up to 13%)

*Based on both pilot and commercial trial using unstandardized milk with an average Holstein-Friesian milk composition of 3.94% fat and 3.15% protein and Jersey milk composition of 5.43% fat and 3.74% protein.



5. Scientific publications

- **Journal publications**

Bland, J.H., C.C. Fagan, and A.S. Grandison. 2014. Effect of blending Jersey and Holstein-Friesian milk on Cheddar Cheese Processing, Composition and Quality. *J. Dairy Sci*. 98:1-8.

Bland, J.H., C.C. Fagan, and A.S. Grandison. 2014. Modelling the Effect of Milk Composition on Coagulation Properties using a combination of Jersey and Holstein-Friesian milk. *J. Dairy Res*. 82:8-14.

Bland, J.H., A.P. Bailey, C.C. Fagan, and A.S. Grandison. 2014. Estimation of the Financial Benefit of using Jersey milk at Different Inclusion Rate for Cheddar Cheese production using Partial Budgeting. *J. Dairy Sci.* 98: 1661-1665.

Bland, J.H., C.C. Fagan, and A.S. Grandison.. (2014). Non-additive effects of blending Jersey and Holstein-Friesian milk on composition and coagulation properties. *Int. J. Dairy Technol*. (in press).

Bland, J.H., C.C. Fagan, and A.S. Grandison.. (2014). Effect of Milk Composition on Cheddar Cheese Manufacture, Yield and Quality. *J. Dairy Res*. (under review).

- **Poster presentation**

Bland, J.H., C.C. Fagan, and A.S. Grandison. 2014. Blending Jersey and Holstein-Friesian milk: Effect on milk composition and coagulation properties. Presented at 2014 Joint Annual Meeting of ADSA®, ASAS and CSAS: Meeting the global demands of 2050, 20-24 July 2014, Kansas City, United States.

- **Oral presentation**

Bland, J.H., C.C. Fagan, and A.S. Grandison. 2014. Comparison of the effect of Holstein-Friesian and Jersey milk on Cheddar cheese production. Presented at 2014 Joint Annual Meeting of ADSA®, ASAS and CSAS: Meeting the global demands of 2050, 20-24 July 2014, Kansas City, United States.