DETERMINING PREMIUM PAYMENTS FOR CONCENTRATION OF UNSATURATED FATTY ACIDS IN MILKFAT IN NEW ZEALAND BASED ON CHANGES IN FARM AND PROCESSOR PROFIT

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Dedicate to my wife and daughters, who supported me each step of the way

ABSTRACT

Niche markets have emerged for dairy products with a high concentration of unsaturated fatty acids (UFA) in milkfat. Several studies have indicated that although milkfat UFA concentration could be increased on-farm by manipulation of the diet and genetic selection, farm profit could be negatively affected in the absence of a premium for milkfat UFA concentration. The objective of this study was to estimate, via simulation, a premium for milkfat UFA concentration, for dairy farmers in New Zealand that segregate cows, or feed oilseed supplements to dairy cows, to produce milk high in UFA. Data from New Zealand Holstein-Friesian cows were used to develop a stochastic farm model that simulated the physical and financial performance of dairy farms under New Zealand conditions. The farm model was then used to simulate a population of 1,820,000 cows and 5,600 dairy farms. From the population simulated, the top 17,150 cows for milkfat UFA concentration were segregated and randomly distributed onto 50 farms (UFA farms). The farm model was also used to simulate a group of 50 farms on which an oilseed supplement was fed to dairy cows during lactation (OILSEED farms). The characteristics of UFA farms and OILSEED farms were compared with those of 50 average farms (AVE farms). A deterministic milk processing model was used to simulate a dairy processor that processed and marketed the milk produced by AVE farms, UFA farms and OILSEED farms. A milk payment system which paid dairy farmers for milkfat (\$/kg), protein (\$/kg) and milkfat UFA concentration (\$/kg milkfat), but penalised milk volume (\$/L), was developed using data corresponding to the physical and financial performance of the dairy processor and the three groups of dairy farms simulated. In the absence of a premium for milkfat UFA concentration, the operating profit (\$/ha) of UFA farms and OILSEED farms was significantly lower than that of AVE farms. For UFA farms, a premium of \$0.47 to \$0.51 /kg milkfat for each 0.1 g UFA/100 g milkfat increase (above 34.50 g UFA/100 g milkfat) equalled their operating profit (\$/ha) to that of AVE farms. For OILSEED farms, a premium of \$0.10 to \$0.14 /kg milkfat for each 0.1 g UFA/100 g milkfat increase (above 37.50 g UFA/100 g milkfat) equalled their operating profit (\$/ha) to that of AVE farms. These premiums for milfat UFA concentration could help New Zealand dairy companies to further evaluate whether it is economically viable producing and processing milk high in UFA.

Keywords: unsaturated fatty acids, stochastic farm model, milk processing, premium, milk payment.

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LIST OF ABBREVIATIONS

ALA	α-Linolenic acid
BMP	Butter milk powder
c9 t11 CLA	cis 9 trans 11 conjugated linoleic acid
CCC	Concordance correlation coefficient
CHD	Coronary heart disease
CLA	Conjugated linoleic acids
DGAT1	Diacylglycerol O-acyltransferase 1
DHA	Docosahexaenoic acid
DIM	Days in milk
DM	Dry matter
EPA	Eicosapentaenoic acid
F%	Milkfat percentage
FTIR	Fourier transform infrared spectroscopy
HDL	High-density lipoprotein
LDL	Low-density lipoprotein
LW	Live weight
ME	Metabolisable energy
ME_l	Metabolisable energy for lactation
ME_{lwc}	Metabolisable energy for live weight change
ME_m	Metabolisable energy for maintenance
ME_p	Metabolisable energy for pregancy
MIRS	Mid-infrared spectroscopy
MJ	Mega joules
MS	Milksolids (milkfat + protein)
MUFA	Monounsaturated fatty acids
MY	Milk yield
n-3 *and* **n-6**	Omega 3 (ω-3) and omega 6 (ω-6) polyunsaturated fatty acids, respectively
NIRS	Near-infrared spectroscopy
P%	Protein percentage
PUFA	Polyunsaturated fatty acids
RPE	Relative prediction error

SCD	Stearoyl-CoA esaturase
SFA	Saturated fatty acids
SMP	Skim milk powder
TFA	Trans fatty acids
UFA	Unsaturated fatty acids
WP	Whey powder

CHAPTER 1

General Introduction

Milkfat composition has acquired increasing importance due to its influence on the nutritional value and manufacturing characteristics of milk (Arsic et al., 2009; Bobe et al., 2007), greater health awareness and the demand for convenience among consumers. The attribution of health benefits to cis 9 trans 11 Conjugated Linoleic Acid (c9 t11 CLA) and n-3 fatty acids, both unsaturated fatty acids (UFA), has opened opportunities for the development of functional dairy products. Since the concentration of saturated fatty acids determines the hardness of butter at low temperature (Lubary et al., 2011), a reduction in their concentration could be advantageous for the manufacture of spreadable butter.

Historically, the modification of milk composition has contributed to market growth by increasing consumer's acceptance of dairy products (Henning et al., 2006; McMurray, 2010). An increase in milkfat UFA concentration could benefit consumers if it is associated with an increase in c9 t11 CLA, n-3 fatty acids (Diekman & Malcolm, 2009) and butter spreadability (Hurtaud et al., 2010). The New Zealand dairy industry could also benefit from an increase in milkfat UFA concentration if the manufacture and marketing of dairy products high in UFA designed for niche markets contributed to market share growth.

In other countries, the trend towards low-fat, functional and convenient dairy products (Sloan, 2010; Wiley, 2007) has motivated extensive research to increase milkfat UFA concentration at the farm level (DMGI, 2011; Shingfield et al., 2013). Several studies have indicated that milkfat UFA concentration can be increased on-farm by manipulation of the diet (Chilliard et al., 2001; Dewhurst et al., 2006; Thomson et al., 2002) and genetic selection (Arnould & Soyeurt, 2009; Mele, 2009; Shingfield et al., 2013). However, some studies have reported that the adoption of on-farm strategies for the production of milk high in UFA may negatively affect farm profit if the milk payment system does not include a premium for milkfat UFA concentration (Chilliard et al., 2001; Hurtaud & Peyraud, 2007; Stoop et al., 2008). In New Zealand, the milk payment system is based on the A + B – C system (LIC, 2011). Under this payment system, dairy farmers are paid for yields of milkfat and protein, and penalised for milk volume. However, this payment system does not reward the concentration of UFA in milkfat.

The modification of milkfat composition at the farm level through drastic changes to the genetic composition of the herd (segregation of cows) or dietary manipulation (oilseed supplementation) also impact other aspects of the productivity and cost structure of farms. Therefore, consideration of whole-farm performance, and dairy processor performance, is critical in evaluating the value of these strategies at an industry level. Currently, there is no information concerning the productivity and profitability of dairy farms that produce milk high in UFA or a dairy processor that processes milk high in UFA under New Zealand conditions. Considering that the above-mentioned information could help the New Zealand dairy industry to assess the benefits of increasing the milkfat UFA concentration at the farm level, the aim of the present PhD thesis was to fill this gap in knowledge.

The general objective of the present study was to develop a milk payment system that included a premium for the concentration of UFA in milkfat, for New Zealand dairy farmers that segregate cows, or use an oilseed supplement, to produce milk high in UFA. Specific objectives of this study were:

1) To determine the influence of breed and stage of lactation on the milkfat UFA concentration of New Zealand dairy cattle.

2) To determine the impact of increasing the milkfat UFA concentration through segregation of dairy cows or oilseed supplementation on farm production and profitability.

3) To determine the impact of increasing the milkfat UFA concentration on the manufacture of dairy products and dairy processor revenue.

4) To develop a milk payment system that included a premium for milkfat UFA concentration, for dairy farmers that practise the segregation of dairy cows, or use oilseed supplements, to produce milk high in UFA.

In order to achieve these objectives, it was necessary to review the current literature to understand both the issues concerning the increase of milkfat UFA concentration and the development of milk payment systems (Chapter 2).

Based on information about the factors that influenced the milkfat UFA concentration of New Zealand dairy cattle (Chapter 3), a stochastic farm model was developed to simulate dairy farms that produced milk with a specific milkfat UFA concentration, under New Zealand conditions (Chapter 4). The farm model developed was used to study the characteristics of dairy farms that segregated cows to produce milk with high milkfat UFA concentration (Chapter 5). Using the information from Chapter 5, a milk payment system with a premium for milkfat UFA concentration was developed for dairy farmers that practised the segregation of cows to produce milk high in UFA (Chapter 6). A payment system with a premium for mikfat UFA concentration was also developed for dairy farmers that used an oilseed supplement to increase the UFA concentration in milk (Chapter 7).

The information generated in the present research was analysed critically to extract sound conclusions and recommendations (Chapter 8).

CHAPTER 2

Benefits, options and challenges for increasing the concentration of unsaturated fatty acids in milkfat on-farm: A review

ABSTRACT

The properties of dairy products are determined to a substantial extent by the properties of the milk produced by the cow. Increasing the concentration of unsaturated fatty acids (UFA) in milkfat improves the spreadability of butter and may have health benefits. Milkfat composition can be altered on-farm by manipulation of the diet (grazing, feeding of plant oils, oilseeds and marine oils) and genetic selection. However, before establishing a programme to increase UFA concentration in milkfat several issues need to be considered. These include development of fast and economic methods to measure milkfat composition, understanding the effectiveness of diet manipulation to increase milkfat UFA concentration, the effects of genetic selection for UFA on other milk traits, the organisation of the dairy industry to collect and process the differentiated milk, the economic impact on farm and dairy processors, and the development of a payment system for UFA.

Keywords: milkfat composition; unsaturated fatty acids; genetic selection; diet manipulation

INTRODUCTION

As consumers pay more attention to the composition of food products, niche markets have emerged for dairy products with particular milk composition (Packaged Facts, 2012) to achieve functional benefits. Milkfat composition influences the processing characteristics (Glantz et al., 2009; MacGibbon et al., 2002; Smet et al., 2009) and the perceived nutritive value of milk (Arsic et al., 2009). Bovine milkfat composition has been extensively reviewed by Hillbrick & Augustine (2002), Jensen (2002) and MacGibbon & Taylor (2006). Milkfat is composed of about 70% saturated fatty acids (SFA) and 30% unsaturated fatty acids (UFA). Groups of UFA that are of interest in milkfat are monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), trans fatty acids (TFA), conjugated linoleic acids (CLA) and long chain omega 3 fatty acids (n-3). Of the more than 400 different types of fatty acids that have been identified in cow's milkfat, 16 fatty acids form 79% to 89% of milkfat, and only 12 are in quantities greater than 1% (Jensen, 2002). The concentrations (range) of the most abundant fatty acids in milkfat are C16:0 (22–35%, w/w), C18:1 cis 9 (20–30%, w/w), C18:0 (9–14%, w/w), C14:0 (8–14%, w/w), and C4:0 to C12:0 (each one with 1-5%, w/w) (Jensen, 2002).

Fatty acids present in cow's milkfat derive from *de novo* synthesis and the uptake of preformed fatty acids from the circulatory system. Short-chain (C4:0 – C10:0) and medium-chain (C12:0 – C14:0) fatty acids, and part of C16:0, are synthesised de novo in the mammary gland (Taylor & MacGibbon, 2011). The substrates for *de novo* synthesis of milk fatty acids are the acetate and β-hydroxybutyrate formed by rumen microbes during the fermentation of carbohydrates. Long-chain fatty acids (C18 and longer) and part of C16:0 in milkfat are absorbed by the mammary gland from the circulation, and come from the diet or the lipolysis of adipose tissue (MacGibbon & Taylor, 2006). Odd-carbon fatty acids (C15:0, C17:0) are synthesised by rumen bacteria (Antongiovanni et al., 2003) and are absorbed by the mammary gland from the circulation.

There is significant fluctuation in the concentrations of SFA and UFA fatty acids in milkfat of dairy cows. Several studies have found that factors such as stage of lactation, parity, energy balance, breed, strain within a breed, genetics, diet, season and geographical area influence the fatty acid composition of milkfat (Dewhurst et al., 2006; Stoop et al., 2009; Thomson et al., 2002; Wales et al., 2009). Table 1 shows the milkfat composition in different countries. However, it is difficult to compare the results from different countries due to the influence of the aforementioned animal and environmental factors on milkfat composition, and differences between studies in the way fatty acids were measured.

The manipulation of milk composition has contributed to the market growth of dairy processors by enabling the production of a range of products with different functionality aimed at different markets (Henning et al., 2006). For instance, while milk with more unsaturated fat may produce butter of a greater spreadability, more saturated fat may produce a better pastry fat.

Table 1 Mean and standard deviation (within brackets) for concentrations (g /100 g milkfat) of saturated (SFA), monounsaturated (MUFA) and polyunsaturated (PUFA) fatty acids in bovine milkfat in different countries.

Group of Fatty Acid	Bobe et al., (2008) (USA)[1]	Garnsworthy et al., (2010) (UK) [2]	Stoop et al., (2009) (The Netherlands)[3]	Alonso et al.,(2004) (Spain)[4]	Wales et al., (2009) (New Zealand)[5]
SFA	67.18 (4.20)	58.13 (5.69)	70.84 (2.74)	68.81	63.70
MUFA	29.67 (3.96)	30.99 (4.61)	25.74 (2.51)	31.18	28.10
PUFA	2.95 (0.50)	3.41 (0.77)			2.20
Total	99.8	92.53	96.58	99.99	94.00

[1] 233 American Holstein cows between 1 and 10 lactations.

[2] 2408 Holstein-Friesian cows (92% less than 3 lactations). The data excludes trans monounsaturated fatty acids.

[3] 1933 Holstein-Friesian cows between 63 - 282 days in milk of first lactation

[4] Average of 108 pooled samples from farms of Friesian cows.

[5] Average from 27 Holstein-Friesian cows.

The objectives of this review are to outline the experimental results regarding the example of increasing the UFA concentration of the milkfat on-farm: the benefits and options, and to use this information to present recommendations for the development of a payment system for concentration of UFA in milkfat.

BENEFITS OF INCREASING THE CONCENTRATION OF UFA IN MILKFAT

For the manufacture of butter

Increasing the concentration of UFA in milkfat can be advantageous for the manufacture of spreadable butter (Jensen, 2002). Since the 1970s, the per capita consumption of butter has remained constant in some countries, while in others it has declined (Kliem & Givens, 2011). Compared to other table spreads, butter has the inconvenience of being hard when taken out of the refrigerator. This has been one of the reasons for the decline in the use of butter as a table spread (Lubary et al., 2011).

It is possible that the consumption of butter in the future is affected by the availability in the market of table spreads that offer health benefits and are spreadable when taken out of the refrigerator. Examples of these products are Benecol® (Benecol, 2012) and Flora Pro-activ® (Unilever, 2012) which contain plant stanols and sterols, respectively. Plant stanols and sterols have been attributed cholesterol lowering properties (EFSA, 2008). Another example is the Balade™ range of butters marketed by Corman in Belgium (Corman, 2011), which comprises products that are spreadable when taken out of the refrigerator and have low cholesterol concentration, low fat concentration or are enriched with omega 3 fatty acids.

Traditionally, the combination of milkfat with vegetable oils (soybean oil, canola oil, coconut oil, sunflower oil, olive oil) or marine oils has been used to manufacture dairy blends which are higher in UFA and, therefore, more spreadable than butter (Mortensen, 2011). Other methods such as double churning and fat fractionation have also been used commercially for the manufacture of spreadable butter (Mortensen, 2011).

By increasing the concentration of UFA in milkfat, dairy farmers can supply dairy processors milk with a milkfat composition more suitable for the manufacture of spreadable butter. An example of this is observed in the Netherlands where the company FrieslandCampina uses milk with a higher concentration of UFA in milkfat for the manufacture of butter (FrieslandCampina, 2013). Furthermore, increasing the concentration of UFA in butter can result in direct benefits for dairy processors if some governments decide to approve taxes for the concentration of SFA in food products (The Washington Post, 2012).

Several studies have reported the effect of increasing the concentration of UFA in milkfat on butter rheological characteristics (Bobe et al., 2007; Couvreur et al., 2006; Hurtaud & Peyraud, 2007; MacGibbon et al., 2002;

Thomson et al., 2002). Overall, in these studies there were significant differences in butter texture and spreadability when the concentration of UFA was 6 to 15 g /100 g milkfat higher than in standard milkfat.

For the consumer and market growth

The consumer perception of milkfat is a complex area, in that the flavour characteristics have always being held in high regard but the high concentrations of saturated fatty acids have led to negative perceptions. What is clear is that the simplistic message of all saturated fats being bad and all unsaturated fats being good from a nutritional point of view has held sway in the past. This simplistic message has become much less clear with recent research on individual fatty acids, rather than saturated/unsaturated fats in general. In this review, the historical timeline will be followed to illustrate the reasons for the perceptions, followed by discussion of recent work on milkfat.

Milkfat, which is high in SFA, contributes significantly (27% to 57%) to dietary SFA intake in developed countries (Givens, 2009; O'Sullivan et al., 2011). In several studies, high intakes of SFA have been associated with obesity, elevated serum low-density lipoprotein (LDL) cholesterol levels, and increased risk of cardiovascular diseases, especially coronary heart disease (CHD) (Givens, 2009; Zyriax & Windler, 2000). This association is important given that in developed countries CHD is the leading cause of death (WHO, 2011). Based on this information, it has been suggested that consumer’s health and the nutritive value of milk and dairy products can be improved by reducing the concentration of SFA, and increasing the concentration of UFA in milkfat (Givens, 2008, 2009; Zyriax & Windler, 2000). In addition, replacing SFA for cis UFA may result in economic benefits for the dairy industry if the content of SFA in food products is taxed (Smed, 2012).

In contrast to SFA, in several studies UFA has been associated with reduced concentration of LDL cholesterol and reduced risk of cardiovascular diseases. In a study undertaken in New Zealand, consumption of a modified butter (54.4 g SFA and 42.5 g UFA /100 g milkfat) resulted in significant decrease of total cholesterol (-7.9%) and LDL cholesterol (-9.5%) levels (Poppitt et al., 2002). Noakes et al. (1996) reported a reduction in serum cholesterol levels (-4.3%) and risk of CHD (-9%) when the concentration of UFA in milkfat was increased (from 30 to 49 g /100 g milkfat), and the concentration of SFA was decreased (from 70 to 51 g /100 g milkfat). In another study, increasing the concentration of UFA in milkfat (from 28.52 to 36.93 g /100 g milkfat), and decreasing the concentration of SFA (from 59.6 to 52.7 g /100 g milkfat), decreased LDL cholesterol levels by -10.7% (Seidel et al., 2005). In a simulation study, Givens (2008) estimated that across eleven countries in Europe, reducing the concentration of SFA in milkfat (from 70 to 55 g /100 g milkfat), and increasing the concentration of MUFA (from 20 to 32 g /100g milkfat) would reduce total cholesterol levels by -0.8 to -2.43%, and the risk of a CHD event by -1.96 to -3.91%.

However, the association between SFA intake and CHD is controversial. In recent times, several epidemiological studies have indicated that, although SFA increased serum LDL cholesterol levels, there is no convincing evidence of a relationship between SFA and CHD (GDP, 2011; Kromhout et al., 2011; Parodi, 2009; Siri-Tarino et al., 2010). One study reported that a greater SFA intake was associated with less progression of coronary atherosclerosis in postmenopausal women with relatively low total fat intake (Mozaffarian et al., 2004). Furthermore, some studies reported that the milkfat and SFA concentration of dairy products were not associated with a higher risk of CHD but may be associated with a lower risk of CHD (Dalmeijer et al., 2012; de Oliveira Otto et al., 2012).

It is possible that differences in the biological effects of individual fatty acids could have played a role in the contradictory results between studies. C14:0 and C16:0 have been associated with high serum LDL cholesterol levels, while C18:0 does not seem to influence serum LDL cholesterol levels (Arsic et al., 2009; Hillbrick & Augustin, 2002). Some SFA (such as C12:0) also increase serum high-density lipoprotein (HDL) cholesterol levels, which have cardioprotective effects, and maintains the ratio between total cholesterol and HDL cholesterol in serum (Astrup, 2012; Kromhout et al., 2011). Several studies reported that replacing SFA for cis PUFA decreased the LDL:HDL cholesterol ratio and the risk of CHD (FAO, 2010; Jakobsen et al., 2009; Kromhout et al., 2011; Mozaffarian et al., 2010; Skeaff & Miller, 2009). However, there is no convincing evidence that the risk of CHD is reduced when SFA are replaced by cis MUFA (FAO, 2010; Jakobsen et al., 2009; Kromhout et al., 2011). Additionally, some recent studies reported that the benefitial effects of replacing SFA for PUFA were only observed when SFA were replaced by n-3 PUFA, and not when SFA were replaced by n-6 PUFA (Ramsden et al., 2013).

The increase in milkfat UFA concentration can benefit consumers if it is associated with increases in CLA and n-3 polyunsaturated fatty acids (n-3 PUFA). CLA are a class of PUFA formed by isomers of linoleic acid with conjugated double bonds. Several studies in animal models have reported that CLA have biological activity. However, the different physiological properties attributed to CLA seem to be specific to the cis 9 trans 11 C18:2 (c9 t11 CLA) and trans 10 cis 12 C18:2 (t10 c12 CLA) isomers (Pariza et al., 2001). Several studies reported that c9 t11 CLA may stimulate the immune system and help in the prevention of atherosclerosis, hypertension and different types of cancer (Bhattacharya et al., 2006; McGuire & McGuire, 2000). The t10 c12 CLA isomer has been found to inhibit lipogenesis and prevent certain types of cancer (McGuire & McGuire, 2000; Pariza et al., 2001). Cow’s milk is a good source of c9 t11 CLA for humans given that the concentration of CLA in ruminant milk and meat is higher than in other foods, and 75% to 90% of CLA in cow’s milkfat is c9 t11 CLA (Chin et al., 1992; Griinari & Bauman, 1999).

The concentration of n-3 PUFA in milkfat is low (0.5-2.92%, w/w) and corresponds mainly to α-linolenic acid (ALA) (Arsic et al., 2009; Jensen, 2002). Although the process is inefficient, ALA can be converted to C20:5 n−3 (EPA) and C22:6n−3 (DHA), which are essential for human development and function (Bauman & Lock, 2010). Several studies reported that EPA and DHA may contribute to the prevention of cardiovascular diseases (Delgado-Lista et al., 2012; FAO, 2010; Lopez-Huertas, 2010; Ramsden et al., 2010) and to cognitive function (Hooijmans et al., 2012). However, the role of EPA and DHA on cancer, inflammatory bowel disease and other diseases is still controversial (Cabre et al., 2012; Gerber, 2012).

Increasing the concentration of UFA in milkfat could benefit the dairy industry by perception of health-conscious consumers. However, to be beneficial for consumer's health the increase in UFA concentration should be associated with increases in cis PUFA, n-3 PUFA or c9 t11 CLA.

OPTIONS TO INCREASE THE MILKFAT UFA CONCENTRATION ON-FARM

Dietary manipulation

Dietary manipulation is the simplest way to increase the concentration of UFA in milkfat. Over the last three decades, several studies have investigated the effect of diet on the metabolism of nutrients in the rumen and milkfat composition. The rumen is a highly reductive environment where about 60-90% of dietary PUFA are hydrogenated to SFA during microbial fermentation (Antongiovanni et al., 2003). It is during the hydrogenation of c9 c12 C18:2 which c9 t11 CLA, and t11 C18:1 (a precursor of c9 t11 CLA), are formed (Griinari & Bauman, 1999).

The influence of cow diet on milkfat composition has been reviewed in detail by Dewhurst et al. (2006), Elgersma et al. (2006), Kalac & Samkova (2010), Walker et al. (2004), Antogiovanni et al., (2003) and Chilliard et al., (2007). Table 2 summarises the results of some studies on the influence of diet on milkfat composition. However, comparisons can only be made between treatments within a study given that there were differences in methodology and measurement of fatty acids between studies.

Table 2 Influence of diet on the bovine milkfat concentration (g /100 g milkfat) of saturated (SFA) and unsaturated (UFA) fatty acids.[1]

Author	Diet/Treatment [2]	SFA	Groups of UFA			
			MUFA	PUFA	CLA	n-3 PUFA
Chion et al. (2010)	Pasture + C (summer period 1)	58.1^{a}	30.5^{a}	5.77^{a}	2.34^{a}	1.17^{a}
(Italy)	Pasture + C (summer period 2)	57.2^{a}	31.6^{a}	5.32^{b}	1.84^{b}	1.14^{a}
	Pasture hay + C (winter period 1)	69.8^{b}	22.1^{b}	3.32^{c}	0.76^{c}	0.72^{b}
	Pasture hay + C (winter period 2)	67.2^{c}	24.6^{c}	3.28^{c}	0.85^{c}	0.67^{b}
Thomson et al.(2002)	Pasture (Ryegrass/white clover)					
(New Zealand)	10-day rotation	63.8^{b}	29.7^{b}	6.5^{ab}		
	20-day rotation	62.3^{c}	30.8^{c}	6.9^{b}		
	30-day rotation	66.3^{a}	27.7^{a}	6.1^{a}		
	Pasture (Timothy/white clover, 20-day rotation)	64.9^{b}	28.9^{b}	6.1^{a}		
Thomson et al.(2002)	Pasture (Ryegrass/white clover, control diet)	61.3^{a}	32.4^{a}	6.3^{a}		
(New Zealand)	Control + Canola (non-ruminally protected)	55.5^{b}	38.4^{b}	6.1^{a}		
	Control + Canola (ruminally protected, method 1)	51.0^{c}	42.0^{c}	6.8^{a}		
	Control + Canola (ruminally protected, method 2)	50.0^{c}	39.5^{b}	10.6^{b}		
Wales et al. (2009) [3]	Pasture (Perennial ryegrass dominant, control diet)	59.5	32.7	2.3	1.5^{a}	
(New Zealand)	Control + 3 kg C (barley grain + steam-flaked corn)	61.8	30.2	2.5	1.5^{a}	
	Control + 6 kg C (barley grain + steam-flaked corn)	62.9	29.0	2.4	1.3^{a}	
Frelich (2009)	Pasture	62.2^{a}	31.69^{a}	4.69^{a}	1.09^{a}	0.91^{a}
(Czech Republic)	Pasture silage + Pasture hay + C	67.2^{b}	27.55^{b}	4.16^{b}	0.74^{b}	0.99^{b}
Morales-Almaraz et al. (2010)	TMR + Pasture (12 hours grazing)	69.4^{a}	27.6^{a}	3.09^{a}	0.60^{a}	
(Spain)	TMR + Pasture (6 hours grazing)	70.5^{ab}	26.9^{ab}	2.75^{ab}	0.42^{b}	
	TMR	71.4^{b}	25.7^{b}	2.93^{b}	0.30^{c}	

Table 2 (Continued) Influence of diet on the bovine milkfat concentration (g/100 g milkfat) of saturated (SFA) and unsaturated (UFA) fatty acids.[1]

Ferlay et al. (2010)	MS + Pasture hay + C	74.94^{a}	19.84^{a}	2.47^{a}	0.38^{a}	0.29^{a}
(France)	MS + Pasture hay + EL	57.36^{bc}	34.03^{bc}	5.68^{b}	1.51^{b}	1.28^{b}
	MS + Pasture hay + EL + Vit E	59.33^{b}	32.25^{b}	5.24^{b}	1.61^{b}	0.99^{b}
	MS + Pasture hay + EL + Vit E + PERP	55.46^{c}	35.37^{c}	5.54^{b}	1.74^{b}	1.10^{b}
Potkanski et al. (2009) (trial II) [3]	Fresh alfalfa + MS + C (Control diet)	61.56^{a}	29.70^{a}	8.74^{a}	2.87^{a}	2.89
(Poland)	Control + FO + RO	56.61^{b}	34.23^{b}	9.16^{a}	4.96^{b}	2.71
Shingfield et al. (2003)	Grass silage + C	71.0^{a}	26.0^{a}	2.52^{a}	0.56^{a}	0.51^{a}
(Finland)	Grass silage + C + FO	67.5^{a}	23.3^{a}	7.99^{b}	1.85^{b}	1.89^{b}
Kraft et al. (2003) [3]	Pasture + C (Germany)	57.3	30.0	3.8	0.87^{a}	1.10
(Switzerland, Germany)	TMR (Germany)	60.6	25.7	2.6	2.28^{b}	0.48
	Pasture (Switzerland, Alps, different places)	51.9	34.0	3.5	2.29^{c}	1.45
	Pasture (Switzerland, Alps, L'Etivaz)	52.8	33.0	4.1	2.67^{c}	1.64
Schroeder et al. (2003)	TMR (week 1)	69.07	26.47	3.35	0.52	
(Argentina)	Pasture + C (week 1)	62.33	31.51	3.42	0.80	
	Pasture + C + Calcium salts of UFA (week 1)	55.42	34.27	6.98	1.29	
	TMR (week 2)	66.96	25.97	2.65	0.41	
	Pasture + C (week 2)	59.55	27.59	3.79	1.12	
	Pasture + C + Calcium salts of UFA (week 2)	52.06	32.59	7.31	1.91	
Lerch et al. (2012b) (year 1)	Pasture + C (control)	57.5^{a}	35.3^{c}	5.6^{b}	1.86^{a}	0.87
(France)	Control + EL	50.8^{c}	40.3^{b}	6.9^{a}	1.61^{b}	1.52
	Control + Extruded rapeseed	53.9^{b}	39.5^{b}	5.0^{cd}	1.35^{c}	0.93
	Control + Fat rich rapeseed meal	49.3^{c}	43.6^{a}	5.3^{c}	1.68^{ab}	0.82
	Control + Whole unprotected rapeseeds	57.6^{a}	36.2^{c}	4.7^{d}	1.22^{c}	0.93

Table 2 (Continued) Influence of diet on the bovine milkfat concentration (g/100 g milkfat) of saturated (SFA) and unsaturated (UFA) fatty acids.[1]

Lerch et al. (2012b) (year 1)	Grass silage + grass hay (control)	69.1^{a}	26.0^{d}	3.7^{c}	0.58^{c}	0.86
(France)	Control + EL	58.5^{c}	34.7^{b}	5.4^{a}	0.82^{a}	1.31
	Control + Extruded rapeseed	59.8^{c}	35.0^{b}	4.1^{b}	0.73^{b}	0.95
	Control + Fat rich rapeseed meal	56.4^{d}	38.2^{a}	4.2^{b}	0.81^{ab}	0.91
	Control + Whole unprotected rapeseeds	63.4^{b}	31.9^{c}	3.5^{c}	0.58^{c}	0.84
Frelich et al. (2012) [3]	Pasture + C (summer)	60.0	26.6	5.8		
(Czech Republic)	Grass silage + C (winter)	68.0	21.1	3.4		
	Grass silage + MS + C (all year round)	69.0	18.7	4.1		
Glover et al. (2012)	Pasture + C	60.21^{a}	33.48^{a}	5.20^{cb}	1.27^{ab}	0.80
(Canada)	Pasture + C + Rumen-protected microalgae	61.33^{a}	31.26^{a}	6.54^{a}	1.58^{a}	1.17
	TMR	66.87^{b}	27.39^{b}	4.58^{c}	1.01^{b}	0.54
	TMR + Rumen-protected microalgae	61.90^{a}	31.21^{a}	5.45^{b}	1.15^{b}	0.62

[1] The groups of UFA presented are: monounsaturated (MUFA), polyunsaturated (PUFA), cis 9 trans 11 conjugated linoleic acid (CLA), and omega 3 fatty acids (n-3 PUFA), with the total concentration of UFA = MUFA + PUFA. For each reference and within columns only, values for MUFA, PUFA, CLA and n-3 PUFA with different letter were statistically different.

[2] Abbreviations used: Pasture= grazed pasture (unless dominant species are specified, it refers to a mixture of grasses), TMR= total mixed ratio, MS= maize silage, C= concentrate, EL= extruded mixture of linseed and wheat, Vit E= Vitamin E, PERP= plant extracts rich in polyphenols, FO= fish oil, RO= rapeseed oil, FOSO= mixture of fish oil and sunflower oil.

[3] Some values for groups of UFA were obtained by summing individual fatty acids. No statistical comparison was made for groups of UFA.

The results of the studies in Table 2 indicate that the concentrations of different groups of UFA (MUFA, PUFA, c9 t11 CLA, n-3 PUFA) in milkfat were significantly higher, while the concentration of SFA was significantly lower, in pasture based diets than in diets based on hay, silage or total mixed rations. These results can be due to the high concentration of c9 c12 c15 C18:3 in pasture (50-75% of pasture lipids) (Elgersma et al., 2006). For this reason, it is possible that milkfat from cows in pasture-based dairy systems, such as in New Zealand or in Swiss Alpine localities, have a more beneficial fatty acid composition than the milkfat from cows raised in grain-based systems. The results shown in Table 2 also indicate that an increase in concentration of a specific group of UFA can also affect other groups of UFA. Nevertheless, the change in milkfat composition by manipulation of the diet varies significantly depending on animal factors (stage of lactation) and plant factors (maturity stage), which influence the rate of lipolysis and bio-hydrogenation of fatty acids in the rumen (Antongiovanni et al., 2003).

When fresh forage is fed, milkfat composition is influenced by the location, season, stage of maturity, grass species and method of feeding (Table 2). Thomson et al. (2002) reported that on a 20 day grazing rotation length, cows grazing ryegrass/white clover pasture had higher concentration of UFA in milkfat than cows grazing timothy/white clover pasture. In a Swiss study (Collomb et al., 2002), grasses of the Asteraceae and Rosaceae family were positively correlated with milkfat PUFA, CLA and TFA concentrations, but negatively correlated with SFA. The presence of condensed tannins in some plants, such as sulla (*Hedysarum coronarium* L.), also affects rumen fermentation and milkfat composition. In a study with dairy sheep, Cabiddu et al. (2009) reported that the presence of condensed tannins in sulla decreased the concentration of c9 t11 CLA, t11 C18:1, and TFA, but increased the concentration of n-3 PUFA, in milkfat. Avilez et al. (2012) and Thomson et al. (2002) reported that the concentration of UFA and CLA in milkfat decreased as the maturity stage of pasture increased.

When fresh pasture is not the only feed for dairy cattle, milkfat composition is influenced by the amount, type, form and mixture of the different forages, supplements or concentrates used in the diet. Since conserved forages (hay, pasture or legume silage) have a lower concentration of UFA than fresh pasture, its inclusion in the diet is associated with reductions in milkfat UFA concentration (Chilliard et al., 2007). Maize silage is a common supplement in New Zealand dairy farms. Some studies reported that replacing grass silage for maize silage in the diet decreased the concentration of n-3 PUFA, but increased the concentration of c9 t11 CLA, TFA, and the n-6/n-3 ratio (Chilliard et al., 2007; Kliem et al., 2008). This could be due to the higher concentration of c9 c12 C18:2 in maize silage than grass silage (Kliem et al., 2008).

The use of plant or fish lipid supplements high in UFA has been the most common strategy to increase the milkfat UFA concentration. Several studies have reported an increase in milkfat UFA concentration, but a decrease in SFA concentration, with the use of lipid supplements (Table 2). However, UFA in lipid supplements can be significantly hydrogenated in the rumen, unless they are protected. Lipid supplements can be protected chemically by forming calcium salts, by encapsulation with lipids, or by encapsulation within a layer of denatured protein in the presence of formaldehyde (Antongiovanni et al., 2003; Stamey et al., 2012). Feeding supplements as seeds instead of oils can also provide certain physical protection from rumen hydrogenation. Stamey et al. (2012) reported a greater efficiency in the transfer of DHA into milk of dairy cows when ruminally protected algae, rather than algal oil, was included in the diet.

The effect of lipid supplementation on milkfat composition is related to the composition of the basal diet, and the source, form (oil, seed, extruded, ruminally protected) and amount of the lipid supplement offered (Glover et al., 2012; Lerch et al., 2012b; Stamey et al., 2012; Sterk et al., 2012). The inclusion of lipid supplements can alter rumen fermentation and the concentration of individual UFA. Some studies reported a shift in rumen fermentation towards propionate, at the expense of acetate, when fish oil (250 g /day) (Shingfield et al., 2003) or large amounts of soybean oil (750 g /day) were used (Shingfield et al., 2008). This shift in rumen fermentation can negatively affect milkfat yield.

Common sources of lipid supplements that have been studied in detail are linseed, rapeseed, sunflower, soybean, fish oil, and marine algae. In a meta-analysis of 151 treatments from 50 experiments, protected rapeseed was associated with increased c9 c12 C18:2 concentration in cow milkfat, protected linseed was associated with increased c9 c12 c15 C18:3 concentration, while soybean and sunflower where associated with increased in both c9 c12 C18:2 and c9 c12 c15 C18:3 concentrations (Sterk et al., 2012). The use of lipid supplements high in c9 c12 C18:2 may increase milkfat c9 t11 CLA concentration by allowing an increased ruminal outflow of c9 t11 CLA and t11 C18:1 (Shingfield et al., 2008). Secchiari et al. (2003) reported a significant increase in PUFA and CLA when full fat soybean and full fat linseed were supplemented to dairy cows.

Fish oils and marine algae are rich in long chain PUFA (EPA, DHA) and may increase CLA and n-3 PUFA concentration in milkfat significantly (Antongiovanni et al., 2003; Stamey et al., 2012). Wright et al. (1999), patented a method for the production of DHA enriched milk which comprised feeding dairy cattle a feed additive that contained fishmeal. Although the inclusion of fish oil in the diet is associated with increases in EPA and DHA in milkfat, its use is inefficient since 95-96% of EPA and DHA in fish oil may be hydrogenated in the rumen and only a small proportion is transfer to milk (Shingfield et al., 2010).

Since the greatest changes in milkfat composition have been observed when lipid supplements are fed, the implementation of a plan to increase the milkfat UFA concentration on-farm should consider the inclusion of lipid supplements in the diet. Since the inclusion of fresh pasture can also contribute to increase the milkfat UFA concentration, New Zealand dairy farms have a competitive advantage given that their production system is based on pasture.

Genetic selection

In recent years greater attention has been given to the possibilities of using genetic selection to increase the milkfat UFA concentration on-farm. In Europe, the RobustMilk project (Veerkamp et al., 2011), the Dutch Milk

Genomics Initiative (DMGI, 2011) and the Phénofinlait programme (Phénofinlait, 2011) are also looking at opportunities to increase the concentration of UFA in milkfat through genetic selection.

In recent years, genetic manipulation to create transgenic animals that produce milk with high milkfat UFA concentration have also being investigated (Reh et al., 2004). In China, a transgenic cow that expresses a mammalianized version of the fat-1 gene from *Caenorhabditis elegans*, which codes for an n-3 fatty acid desaturase was created recently (Wu et al., 2012). The transgenic cow produced milk high in n-3 PUFA and with a fourfold reduction in milkfat n-6/n-3 ratio. However, concerns about animal welfare and the safety of transgenic products for human consumption suggest this technology is unlikely to be acceptable in the near future (Laible & Wells, 2007).

Genetic selection, which uses the natural genetic variation that exists between animals in milkfat UFA concentration, can be a slow but achievable and cumulative strategy to alter milkfat composition. Significant differences in milkfat composition between breeds of dairy cattle have been reported, with Jersey cows having a lower concentration of UFA, but a higher concentration of SFA, than Holstein-Friesian and other breeds (Maurice - Van Eijndhoven et al., 2010; Wales et al., 2009). Within a breed, significant differences in milkfat composition between strains have also been reported. Wales et al. (2009) and McParland et al. (2010) reported that North American Holstein-Friesian cows produced milkfat with lower concentrations of SFA (C12:0, C14:0, C16:0), and higher concentrations of UFA (c9 C18:1, c9 t11 CLA) than New Zealand Holstein-Friesian cows.

However, differences in milkfat composition between breeds and strains are not as large as differences between individual cows (Mackle et al., 1997; Mele et al., 2009). The ranges reported in the literature for concentration of MUFA in milkfat of Holstein-Friesian cows were 18.04 to 48.96 g /100 g milkfat (Garnsworthy et al., 2010), 11.40 to 41.41 g /100 g milkfat (Mele et al., 2009), and 16.20 to 27.86 g /100 g milkfat (Mackle et al., 1997).

Several studies have been undertaken on the heritability of milkfat composition (Arnould & Soyeurt, 2009; Bobe et al., 2008; Soyeurt et al., 2007). Low (0.0) to moderate (0.54) heritabilities have been reported in several countries for the concentration of individual fatty acids in milkfat (Arnould & Soyeurt, 2009; Bobe et al., 2008; Stoop et al., 2008). Lopez-Villalobos et al. (2011) reported heritabilities between 0.21 and 0.42 for the concentration of individual fatty acids in milkfat of New Zealand dairy cattle. Only a few studies reported heritability values for c9 t11 CLA in cow milkfat (Table 3). Low to moderate heritabilities for concentration of groups of fatty acids in milkfat (SFA, MUFA, PUFA) have also been reported in the literature (Table 3). However, it is difficult to compare the results from different studies due to differences in methodology (units of measurement, fatty acids analysed, statistical analysis) and the influence of other factors (e.g. stage of lactation, breed) on the heritability of milkfat composition (Soyeurt et al., 2008a).

Table 3 Heritability estimates of the concentration (g /100 g milkfat) of saturated (SFA), monounsaturated (MUFA) and polyunsaturated (PUFA) fatty acids in bovine milkfat.

	SFA	MUFA	PUFA	CLA
Arnould & Soyeurt (2009)	0.14	0.08-0.24	0.00	0.21
Garnsworthy et al. (2010)	0.14	0.09	0.03	
Mele et al. (2009)		0.14		0.12
Soyeurt et al. (2008a)	0.24	0.27		
Bobe et al. (2008) [1]	0.05	0.08	0.00	

[1] In this study the concentration of fatty acids was expressed as wt%.

The presence of genetic variation in milkfat composition between individual animals and the heritability of this trait provide the conditions to increase the concentration of UFA in milkfat by genetic selection. This can be achieved by selecting animals based on individual fatty acids, groups of fatty acids or specific genotypes.

The genetic correlations between the main individual UFA in milkfat are positive and vary from low to high (0.12-0.99) (Soyeurt et al., 2007; Stoop et al., 2008). Although there are positive genetic correlations between some individual UFA and some individual SFA (Stoop et al., 2008), the correlation between the groups of MUFA and SFA is moderate and negative (-0.44) (Soyeurt et al., 2007). Considering these correlations, selection for individual UFA may not only increase the concentration of other UFA, but also the concentration of some individual SFA. Therefore, the selection of animals based on total UFA concentration in milkfat may be more appropriate than the selection of animals based on an individual UFA.

The A293V and K232A polymorphisms in the genes that code for Stearoyl-CoA desaturase (SCD or Δ9 desaturase) and acyl CoA:diacylglycerol acyltransferase 1(DGAT1), respectively, influence the activity of these enzymes and partly explain the variation in milkfat composition between animals (Arnould & Soyeurt, 2009; Kgwatalala et al., 2009; Schennink et al., 2008; Spelman et al., 2002). The effect of the SCD and DGAT1 polymorphisms can be measured by the desaturation indices of milk fatty acids (Kelsey et al., 2003; Schennink et al., 2008). The C10, C12, C14, C16 and c9 t11 CLA indices are more related to the activity of SCD, and the C18 and total desaturation indices are more related to the activity of DGAT1 (Schennink et al., 2008). A high desaturation index indicates a high SCD and DGAT1 activity (active desaturation of fatty acids in the mammary gland) and a high concentration of MUFA in milkfat.

Since the SCD A293V and DGAT1 K232A polymorphisms explain a significant proportion of the genetic variance in milkfat composition (Bouwman et al., 2011; Schennink et al., 2007), they can be used in marker-assisted selection programmes to increase the concentration of UFA in milkfat, specifically MUFA (Kgwatalala et al., 2009; Schennink et al., 2008; Scotti et al., 2010). Selection for the V variant of SCD, and the A variant of DGAT1, can be implemented given that these genotypes have been associated with higher C16 (+9%), C18 (+6%) and c9t11 CLA (+14%) desaturation indices, and consequently higher milkfat UFA concentration, than their alternative alleles (Schennink et al., 2008). Since desaturation indices of milk fatty acids are also heritable (0.05 to 0.46), selection of animals based on their desaturation indices has also been suggested (Garnsworthy et al., 2010; Schennink et al., 2008).

CHALLENGES FOR INCREASING THE MILKFAT UFA CONCENTRATION ON-FARM

Although it is possible to increase the milkfat UFA concentration on-farm, there are several factors that need to be considered before implementing a programme to alter milkfat composition.

Manipulation of the diet

Although the milkfat UFA concentration in pasture-based dairy systems is higher than in intensive systems, the fatty acid composition of pasture can change significantly during senescence and storage (Elgersma et al., 2006). This makes it difficult to control the milkfat UFA concentration under grazing conditions. This is relevant to pasture-based dairy systems such as in New Zealand. Several studies have reported a significant influence of pasture allowance and pasture stage of maturity on milkfat composition (Alonso et al., 2004; Dewhurst et al., 2006; Thomson et al., 2002). As a consequence, changes in pasture quantity and quality during the year and from one year to another, together with other animal factors, can significantly affect the concentration of UFA in the milkfat supplied to dairy processors.

Several studies have indicated that feeding unprotected lipid supplements negatively affected the percentages of milkfat and protein, and in certain cases the yields of milkfat and protein (Hurtaud & Peyraud, 2007; Loor et al., 2005; Shingfield et al., 2003). Based on these results, the use of unprotected lipid supplements can negatively affect farm profit, especially under a payment system based on milkfat and protein yields.

The negative effects of feeding unprotected lipid supplements on milkfat percentage and/or yield is due in part to some CLA isomers (t10 c12 CLA, t9 c11 CLA, c10 t12 CLA, t10 18:1) formed during the incomplete hydrogenation of UFA in the rumen (Bauman et al., 2008; Shingfield et al., 2009). Of these isomers, t10 c12 CLA is the most potent of all and it specifically inhibits milkfat synthesis in the mammary gland in a dose depended manner. The presence of these isomers may reduce the mRNA coding for SCD and other key lipogenic enzymes in the mammary gland (Peterson et al., 2003).

Feeding protected lipid supplements can enable increasing the milkfat UFA concentration without affecting the yield of milk constituents significantly. In a meta-analysis of 145 oilseed experiments, cow milkfat percentage decreased linearly when linseed, rapeseed, sunflower or soybean were offered as oils, or when rapeseed or sunflower were offered as seed (Glasser et al., 2008). However, when oilseeds were ruminally-protected, milkfat percentage increased (soybean, sunflower) or was not significantly affected (linseed or rapeseed). Shingfield et al. (2008), showed that sunflower-seed oil supplementation of dairy cows increased milk yield significantly, but it did not significantly affect the yields of milkfat and protein due to reductions in the percentages of milkfat and protein. Nevertheless, there are also reports of reduced milkfat yield, fat percentage and protein percentage when protected fatty acids (Ca salts) were supplemented to dairy cattle (Schroeder et al., 2003).

Lerch, Ferlay, Pomies et al. (2012a) studied the effect on milk production and composition of oilseed supplementation during indoor (grass silage – hay based diet) and outdoor (pasture-based diet) periods and over two lactations. In the first year of study, when cows were outdoor, whole rapeseed increased milkfat percentage and rapeseed meal decreased protein percentage. However, when cows were indoor, oilseed supplementation decreased the percentage of milk protein but did not affect the percentage of milkfat. Although oil supplementation affected the percentages of milkfat and protein, it did not affect the daily yields of milk, milkfat, and protein significantly. However, in the second year of study, during the indoor period, extruded rapeseed increased the yields of milk and protein, and rapeseed meal increased the yields of milk, milkfat and protein. The effects of oilseed supplements during the outdoor period were similar to the first year.

More recent studies reported that supplementation with rumen-protected algae did not affect milk protein percentage and the yields of milk and milkfat, despite a significant decrease in milkfat percentage (Glover et al., 2012). In the study by Stamey et al. (2012), the supplementation of dairy cows with rumen-protected algae did not significantly affect the yields of milk, milkfat and protein, or the percentages of milkfat and protein.

However, more studies are needed to understand the factors that influence the milk production response to lipid supplements and the lipid supplement – basal diet – breed/strain interactions. Due to the number of factors involved, strategies to increase the milkfat UFA concentration by manipulation of the diet will need to be specific for each region and system, and will need to considered the milk payment system. Even if no losses in production are achieved, the extra costs and effort associated with lipid supplementation on farm will need to be rewarded through a higher milk payment.

The increase in milkfat TFA associated with supplementation with ruminally protected lipids indicates that UFA are still hydrogenated to some extent in the rumen. Several studies have reported a significant increase in TFA when lipid supplements were fed to dairy cows to increase the milkfat UFA concentration. Ferlay et al. (2010) reported a 3 to 4 fold increase in TFA when extruded linseed was supplemented to dairy cows. However, the increase in TFA varies depending on the lipid supplement. When dairy cows were supplemented with soybean, feeding full-fat extruded soybean significantly increased C18:1 TFA (1.80 vs 2.95 g /100 g) compared to soybean fed as a meal coated with palm oil soap (Secchiari et al., 2003).

In another study, the concentration of TFA (excluding t11 C18:1 and c9 t11 CLA) increased from 2.6 g /100 g milkfat to 5.3 and 4.2 g /100 g milkfat when dairy cows were supplemented with extruded linseed and cold pressed fat rich rapeseed meal, respectively (Lerch et al., 2012b). In the study by Stamey et al. (2012), feeding 112 g /day or 224 g /day of ruminally-protected marine algae biomass to dairy cows increased the concentration of C18:1 TFA (excluding t11 C18:1) by 46% to 66%, respectively. Sterk et al. (2012) reported a larger increase in milk C18:1 TFA when soybean and sunflower were fed as oil or seed than when they were offered as a ruminally-protected supplement.

Several studies have associated TFA intake with cardiovascular diseases, breast cancer, colon cancer, diabetes and allergies (Brouwer et al., 2010; Dhaka et al., 2011; Laake et al., 2012). Although there are studies indicating that trans fatty acids from industrial and ruminant sources vary in their effects on human health (Lock et al., 2004), this is still a controversial topic (Brouwer et al., 2010). The dietary guidelines for Americans (USDA-HHS, 2010) and the European Food Safety Authority (EFSA, 2010) indicate that studies on differences between TFA of industrial and ruminant origin are not conclusive and recommend to keep intake of TFA to a minimum. More studies are needed to clarify the effect of ruminant TFA on human health, especially when higher than average concentrations of TFA in milkfat increase TFA intake in humans. The increase in TFA associated to increases in milkfat UFA concentration should be considered cautiously since it may affect the perception of dairy products. Differences in the health effects of individual TFA have also been reported. It is possible that t11 C18:1, the main TFA in milkfat, may have positive health effects in humans, on its own and through its desaturation to c9 t11 CLA (Field et al., 2009). Similar views were expressed by Gebauer et al. (2011) in a review of epidemiological, clinical and mechanistic studies. In a review of the area, Brouwer et al. (2013) considered that while the detrimental effects of industrial trans fatty acids were beyond dispute, further research was required on ruminant trans fatty acids.

Genetic selection and herd segregation

Since the heritability of MUFA and PUFA in milkfat is moderate to low (Table 3), it will take several years to significantly increase the milkfat UFA concentration. Furthermore, the impact of selection on other milk constituents should be considered before the establishment of a programme to increase the milkfat UFA concentration. In a study with dairy ewes, high concentrations of MUFA, TFA and long chain fatty acids were associated with the AB phenotype of β-lactoglobulin (Mele et al., 2007). If this association also occurs in dairy cows, genetic selection which increases MUFA, TFA and long chain fatty acids will also alter the milk protein composition and increase the AB phenotype of β-lactoglobulin.

Several studies have reported negative genetic correlations between milkfat UFA concentration, milkfat yield and the percentages of milkfat and protein (Table 4). Likewise, a negative genetic correlation between some SCD desaturation indices and fat yield has also been reported. The negative correlations between milkfat UFA concentration and other traits are determined by the interactions between genes and the biochemical pathways that influence milk production. An example of this is t10, c12 CLA, an UFA which decreases the expression of genes encoding for enzymes involved in the synthesis of milkfat in the mammary gland, e.g. acetyl CoA carboxylase (Shingfield & Griinari, 2007).

Table 4 Genetic correlation between the concentration (g /100 g milkfat) of fatty acids in milkfat and milk yield (kg), fat yield (kg), protein yield (kg), fat percentage and protein percentage.

Source	Milk fatty acids	Milk yield	Fat yield	Protein yield	Fat %	Protein %
Soyeurt et al. (2007)	MUFA[1]	0.22			-0.22	-0.34
	C18:1	0.11			-0.78	-0.59
Stoop et al. (2008)	C18u	0.43	-0.35	0.38	-0.72	-0.35
	CLA[1]	0.33	-0.30	0.40	-0.58	-0.02
Mele et al. (2009)	MUFA[1]				0.01	-0.27
	CLA[1]				-0.55	-0.08
	DI[1]				0.08	-0.10
Schennink et al. (2008)	DI[1]	0.14	-0.43	0.09	-0.52	
	C14 index	-0.39	-0.13	-0.29	0.31	
	C16 index	-0.37	-0.21	-0.32	0.17	
	C18 index	0.01	-0.36	0.17	-0.35	
	CLA index	0.05	-0.44	0.10	-0.48	

[1] MUFA = monounsaturated fatty acids, CLA = cis-9 trans-11 conjugated linoleic acid, DI = Total desaturation index, C18u= cis unsaturated C18 fatty acids.

Selection for the A variant of DGAT1 and the V variant of SCD, which increase the concentration of UFA in milkfat, can also be associated with higher milk yield, lower milkfat yield and lower percentages of milkfat and protein

(Berry et al., 2010; Macciotta et al., 2008; Näslund et al., 2008; Schennink et al., 2008; Signorelli et al., 2009; Spelman et al., 2002). Therefore, under a payment system that focuses on milkfat yield, and not milkfat composition, genetic selection to increase the milkfat UFA concentration could negatively affect farm profitability.

The extent to which farm profitability can be affected by genetic selection for higher concentrations of UFA in milkfat depends on the impact of selection on other traits, the breed of dairy cattle, the economic value of each milk component and the payment system used. The importance of these factors can be observed in the study by Spelman et al. (2002), where the economic index of the K allele of DGAT1 was positive for the Holstein-Friesian breed (NZ$ +2.35), but negative for the Jersey breed (NZ$ -2.61). In Ireland, using current economic values, Berry et al. (2010) estimated that substituting an A allele of DGAT1 by a K allele was worth €5.43. This indicates that selection for the A allele of DGAT1 to increase the milkfat UFA concentration (Schennink et al., 2008) will be less profitable.

Since breeding companies control three of the four pathways of selection for dairy cattle, they have significant control over the industry genetic improvement programme (Garrick & Lopez-Villalobos, 2001; Harris, 2005). Therefore, artificial breeding companies must also be convinced there is a benefit from a selection programme to increase milkfat UFA concentration.

The segregation of animals within a herd can also be used to increase the concentration of UFA in milkfat supplied to the dairy factory (Garrick & Lopez-Villalobos, 2001). However, within a single herd, segregation may not be practical since it involves extra costs and organisation. A more practical option would be the segregation of cows to form herds (within a region) that produce milkfat with high UFA concentrations (Dooley et al., 2006; Garrick & Snell, 2005).

More studies are needed to examine the impact and cost-benefit of genetic selection to increase the milkfat UFA concentration. In 1991, Gibson (1991) concluded that genetic selection to increase the concentration of UFA in milkfat was not likely to be important in dairy cattle breeding. This conclusion considered the negative effects of selection on other traits, the length of time required and the extent to which the milkfat UFA concentration could be increased. However, these factors deserve further investigation. Given current consumer trends it is possible that increasing the milkfat UFA concentration through manipulation of the diet and genetic selection can be profitable for the dairy industry.

The dairy industry

For the success of a programme aimed at increasing milkfat UFA concentration, the participation of all contributors to the dairy chain is essential. This includes dairy farmers, dairy factories, research centres, breeding companies and feed manufacturers. In the Netherlands, milk for the Campina brand has 20% more UFA than standard milk and is supplied by about 400 dairy farmers who feed their cows pasture and supplements containing flax (FrieslandCampina, 2013). This is possible due to the willingness of dairy farmers to participate in this programme, the co-operation of feed manufacturers to supply the supplements needed and an economic incentive to encourage dairy farmers to supply milk with a higher milkfat UFA concentration.

Factors that need to be considered for the implementation of a programme to increase the milkfat UFA concentration are the routine measurement of milkfat composition, the legislation concerning the milkfat composition of dairy products and the influence of high milkfat UFA concentration on the rheological characteristics of dairy products. The routine measurement of milkfat composition is essential for segregating milk (at the dairy farm and at the dairy plant), to pay dairy farmers and to monitor changes in milkfat UFA concentration. Currently, the standard reference method for the measurement of milkfat composition requires the extraction of milk fatty acids by trans-esterification with methyl groups (in the presence of bases or acids) (ISO, 2002b); and their subsequent separation by capillary gas-liquid chromatography (GLC) (ISO, 2002a). However, the cost and complexity of this method does not make it suitable for large scale routine milk analysis.

In recent years, several studies have been undertaken to predict milkfat composition using near (NIRS) (Coppa et al., 2010), mid (MIRS) (IDF, 2010) and Fourier transform (FTIR) (Lopez-Villalobos et al., 2011; Rutten et al., 2009) infrared spectroscopy. Prediction equations with high validation coefficients of determination ($r^2 = 0.88 - 0.99$) have been reported in the literature for the main individual fatty acids (C14:0, C16:0, C18:0, C18:1 cis 9), SFA, MUFA and PUFA (Coppa et al., 2010; Ferrand et al., 2011; IDF, 2010; McParland et al., 2011b). Currently, the prediction of UFA concentration in milkfat using spectroscopy methods has allowed the possibility of genetic selection and the segregation of milk at the dairy factory. However, if the focus is on specific fatty acids with health benefits (c9 t11 CLA, n-3 PUFA) more progress needs to be made to accurately predict their concentration in milkfat. Presently, low validation coefficients of determination have been reported for prediction equations for c9 t11 CLA (0.35 - 0.70) and n-3 PUFA (0.20 - 0.79) (Coppa et al., 2010; Ferrand et al., 2011; IDF, 2010; McParland et al., 2011b).

Currently, there are large research projects focused on the development of calibration equations for the prediction of milkfat composition. These projects comprise the collection of spectra and milkfat composition data, and the development of better statistical methods for the derivation of calibration equations (Maurice - Van Eijndhoven et al., 2011; Soyeurt et al., 2011). In the future, it is expected that calibration equations will be developed for the prediction of milkfat composition for different breeds and production systems across countries.

It is also important that what is reported in the scientific literature concerning milkfat composition and health issues is reflected in the legislature. An example of this was the tax on SFA content of fatty foods in Denmark (Smed, 2012), which promoted the substitution of SFA for UFA without considering the type of UFA (MUFA or PUFA). However, studies indicate that the substitution of SFA for PUFA is more likely to have health benefits (FAO, 2010). Since claim regulations vary from country to country they must also be considered when developing dairy products with high UFA concentration. In the United States, the concentration of SFA should be reduced by 25% from the reference amount customarily consumed of a reference food (or -25% SFA /100 g) for a product to claim to be “reduced in saturated fat” (FDA, 2013a). The European Food Safety Authority indicates that for a food to claim to be high in UFA it needs to have at least 70% UFA (EFSA, 2005). Since claims can affect consumer’s perception of food products, the dairy industry can benefit if the increase in milkfat UFA is accompanied by a claim. However, claim requirements can be difficult to achieve unless substantial changes are made in milkfat composition.

Furthermore, the regulations for the labelling of milkfat content of food products should be considered in studies on milkfat composition. Chemically, SFA are straight carbon chains without double bonds and UFA are fatty acids with one (MUFA) or more (PUFA) double bonds (Kelly & Ching Kuang, 2007). Depending on the configuration of their double bonds UFA can be cis or trans. However, the classification of fatty acids for labelling purposes is slightly different. In New Zealand (NZFSA, 2009), The United States (FDA, 2011), Canada (CFIA, 2012), Europe (EFSA, 2005) and South America (MERCOSUR, 2003), for labelling purposes MUFA and PUFA only refer to cis MUFA and cis, cis-methylene-interrupted PUFA, respectively. In these countries, all TFA are classified as an independent group, and in New Zealand (NZFSA, 2009) and South America (MERCOSUR, 2003), CLA is included within the group of TFA.

Another factor that requires more study is the effect of high milkfat UFA concentrations on the rheological properties of the final dairy products, particularly butter, especially in ensuring that the products are tasty. Several studies have reported minor changes in flavour and aroma of butter and dairy products when the concentration of UFA in milkfat was increased by manipulation of the diet (Chen et al., 2004; Hurtaud et al., 2010). An increased susceptibility to lipid oxidation was reported in milk with high concentrations of UFA in milkfat, especially when exposed to light and with long storage times (Hedegaard et al., 2006; Juhlin, 2010; Smet et al., 2009). To control this problem, supplementation of the diet with antioxidants (α-tocopherol, β-carotene, ascorbic acid, lutein, and uric acid) has been attempted, though with variable results (Juhlin, 2010).

Other factors that dairy processors should consider are the cost of producing milkfat with high UFA concentration on-farm, the markets for milk with high milkfat UFA concentration, the consumer willingness to pay for this type of milk and the development of a payment system that includes milkfat UFA concentration. These factors will ultimately determine the profitability of dairy processors and dairy farmers.

DEVELOPMENT OF A PAYMENT SYSTEM FOR MILKFAT UFA CONCENTRATION

Dairy products that have been manufactured from milk high in UFA, c9 t11 CLA or n-3 PUFA are fluid milk, butter, different types of cheese, yogurt and ice cream (Khanal et al., 2005; Luna et al., 2007; Noakes et al., 1996; Poppitt et al., 2002). Several studies have reported that manufacturing processes did not significantly affect the transfer of UFA, c9 t11 CLA and n-3 PUFA from raw milk high in UFA to the end products (Gnadig et al., 2004; Luna et al., 2005). Therefore, when deciding on the dairy products to manufacture from milk high in UFA, dairy processors should consider the dairy products likely to generate the highest return..

Around the world, milk payment systems have changed over the years to better reflect the value of each milk component and to reward dairy farmers according to the quality/value of the milk they supply. In New Zealand, the milk payment system was initially based on milkfat only, but protein was included in the payment system by the late 1980s when its demand increased (LIC, 2000). Premiums and deductions are also included in a payment system to encourage or discourage deviations from a standard milk composition and for the production of certain types of milk, for example organic and winter milk (IDF, 2006).

The milk payment system influences all the players of the milk supply chain. For dairy farmers, the milk payment system determines the income from the sale of milk (about 90% of gross farm income) (DairyNZ, 2009). As a consequence, it influences management decisions (breed of dairy cattle, genetic selection, milk segregation and culling of animals), the farm system (feed input, calving pattern), farm profitability and milk supplied to dairy processors (quantity, quality and composition).

Through its influence on dairy farms, the payment system influences the quantity, quality and composition of dairy products manufactured by dairy processors (Emmons et al., 1990; Nightingale et al., 2008). This in turn influences dairy processors revenue and profitability. Similarly, the milk payment system also directs the selection decisions of breeding companies by its influence on the economic weight of milk production traits in the breeding objective (Banga et al., 2009; Wolfová et al., 2007).

In New Zealand, the milk payment system is based on the A+B-C system (payment for milkfat + payment for milk protein - milk volume costs) plus penalties and premiums for milk quality (LIC, 2010). However, each company adopts the payment system that best suits its product portfolio. This is the case of Synlait, a company specialised in the production of milk powder, which includes lactose within its payment system (Penno, 2009).

In New Zealand, dairy companies apply a penalty for bulk tank somatic cell count (BTSCC) above 400,000 cells /ml and, with the exception of Open Country Dairy and New Zealand Dairies, they do not offer a premium for BTSCC below 400,000 cells /ml (Cantley, 2008). Open Country Dairy and New Zealand Dairies have a premium system for BTSCC below 400,000 cells /ml. As of 2008, with an average payout = NZ $7.37 /kg milksolids (milkfat + protein) (DairyNZ, 2011), the highest premiums paid for milk quality were for BTSCC below 150,000 cells /ml, NZ $0.39 /kg milksolids for Open Country Dairy and +1% of standard payout for New Zealand Dairies(Cantley, 2008). Other premiums paid in New Zealand are for organic milk, winter milk and lactose. In 2007, when the average payout was NZ $4.13 /kg milksolids, the premium for winter milk was NZ $0.50-0.60 /kg milksolids (Waugh, 2007). In 2011, when the average payout was NZ $8.25 /kg milksolids (NBR, 2011), the premium for organic milk was NZ $1.05 /kg milksolids (NZFW, 2011). In 2007, the value of lactose was estimated at NZ $1.82 /kg MS (Lee, 2007).

Several studies have indicated that a critical factor for the success of a programme to increase the milkfat UFA concentration on-farm is the development of a payment system (Chilliard et al., 2001; Elgersma et al., 2006; Stoop et al., 2008). This is important since manipulation of the diet and genetic selection to alter milk composition can involve extra costs, risks, and losses in production of other milk components.

Strategies to increase the milkfat UFA concentration can have variable effects on milk production (Hurtaud & Peyraud, 2007; Schennink et al., 2008; Soyeurt et al., 2008a; Stamey et al., 2012). In view of this, funding for a premium system that rewards high milkfat UFA concentration is more likely to be associated with the manufacture of value-added dairy products than to increases in the yields of dairy products manufactured. As a consequence, and comparable to the case of organic milk, dairy products with high milkfat UFA concentration are likely to have a higher retail price. However, in the future, a direct economic benefit might arise from high milkfat UFA concentration if governments in some countries consider taxing the concentration of SFA in food products (The Washington Post, 2012). The marketing of dairy products based on specific groups of UFA (PUFA, c9 t11 CLA, n-3 PUFA), which have health benefits, may be more attractive to the customer than the marketing of dairy products as high in UFA concentration only. If dairy products sufficiently high in c9 t11 CLA or n-3 PUFA can be sold as functional foods, payment systems for specific groups of UFA may be considered rather than a payment system for total UFA.

Currently, there is no published information about a payment system that includes a premium for milkfat UFA concentration. However, in the Netherlands, FrieslandCampina compensates dairy farmers for extra costs associated with the production of milk with high milkfat UFA concentration (FrieslandCampina, 2013). A premium system for milkfat UFA concentration should meet the general objectives of a payment system. It must clearly transmit consumer’s demands to dairy processors, dairy farmers and breeding companies, it should contribute to improve the composition of dairy products, and it should distribute the payment to dairy farmers fairly. This premium should not only break even with the extra costs and losses in production, but contribute to increased farm profitability. A holistic approach of the milk supply chain has been proposed in the past to better suit market demands and to maximise profits for dairy processors and dairy farmers (Boland, 2002). For this reason, the development of a premium system for milkfat UFA concentration should consider all the players of the dairy supply chain, the market demand and consumer willingness to pay for dairy products with high UFA concentration in milkfat.

SUMMARY

Increasing the milkfat UFA concentration improves butter spreadability and may have health benefits (if it is associated with increases in c9 t11 CLA or n-3 PUFA). As a consequence, the dairy industry can benefit from developing dairy products with high concentrations of UFA in milkfat to target niche markets of consumers. Although it is possible to increase the milkfat UFA concentration on-farm, by manipulation of the diet and genetic selection, more studies are needed before a programme to increase the milkfat UFA concentration could be established. These studies should look at efficient methods to measure the milkfat UFA concentration, efficient methods to increase the milkfat UFA concentration on-farm, market demand and consumer willingness to pay for milk with high milkfat UFA concentration. An essential step is the development of a payment system that includes a premium for milkfat UFA concentration. Nevertheless, increasing the milkfat UFA concentration is likely to gain more attention in the future, especially if some countries establish taxes for the concentration of SFA in food products.

CHAPTER 3

Influence of breed, lactation stage, parity, calving month and herd on the concentration of unsaturated fatty acids in milkfat of New Zealand dairy cattle

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ABSTRACT

In recent years there has been an interest in increasing the concentration of unsaturated fatty acids (UFA) in milkfat. The objective of the present study was to determine the influence of breed, lactation stage, parity, calving month and herd on milkfat UFA concentration of New Zealand dairy cattle. Predicted milkfat UFA concentrations were obtained with a calibration equation derived using Fourier transform infrared spectroscopy. A mixed model, in which days in milk (DIM) were expressed as a third-order orthogonal polynomial, was used to analyse 21,952 test-day records of UFA. Milkfat UFA concentration was significantly ($P < 0.001$) influenced by DIM, breed, herd, and parity. Within each herd, cows were segregated in 2 groups (high or low) according to the average UFA concentration of their herd. Cows in the high UFA group had lower yields and percentages of milkfat and protein in milk ($P < 0.001$), but higher milk yield and milkfat UFA concentration, than cows in the low UFA group. This study demonstrates that segregation of animals can be used to form herds dedicated to the production of milk with a higher concentration of UFA in milkfat.

Keywords: milkfat; unsaturated fatty acids; breed; days in milk; milk segregation

INTRODUCTION

In New Zealand, the milk payment system is based on the A + B – C system (LIC, 2011). Under this payment system, dairy farmers are paid for yields of milkfat and protein, and penalised for milk volume. However, this payment system does not consider milkfat composition.

In recent years, greater health awareness and demand for convenience among consumers has resulted in a trend towards low-fat, functional and convenient dairy products (Sloan, 2010; Wiley, 2007). Milkfat composition is acquiring economic importance given that it influences the nutritional value and manufacturing characteristics of milk (Arsic et al., 2009; Bobe et al., 2007). Increasing the concentration of unsaturated fatty acids (UFA) in milkfat, and decreasing its concentration of saturated fatty acids (SFA), can improve butter spreadability and may have health benefits (Givens, 2008; MacGibbon et al., 2002; Poppitt et al., 2002).

Recently, greater attention has been given to the possibility of increasing the milkfat UFA concentration on-farm, by manipulation of the diet and genetic selection (Arnould & Soyeurt, 2009; Thomson et al., 2002). This may benefit New Zealand dairy processors if the spreadability of butter is improved and products to target health conscious consumers are developed. However, a sound knowledge of the factors that influence milkfat UFA concentration is essential before a programme to increase it on-farm is implemented.

Studies done in New Zealand and overseas have indicated that milkfat composition is influenced by season, diet, breed, strain, cow genetics, lactation stage and energy status of the cow (Arnould & Soyeurt, 2009; Auldist et al., 1998; MacGibbon, 1996; Palladino et al., 2010; Stoop et al., 2009; Thomson et al., 2002; Wales et al., 2009). However, no studies have been done comparing the change in milkfat UFA concentration, during the lactation, in the three main breeds of dairy cattle in New Zealand. Currently, there is no information about the effect of segregating animals within a herd according to their milkfat UFA concentration. The objectives of this study were therefore to 1) determine the influence of breed, lactation stage, parity, calving month and herd on the milkfat UFA concentration of New Zealand dairy cattle, and 2) determine the effect on milk production and composition of segregating cows within herds, according to their milkfat UFA concentration.

MATERIALS AND METHODS

Development of the equation for the prediction of milkfat UFA concentration

A detailed description of the calibration equations used for the prediction of milkfat UFA concentration in the present study was reported by (Lopez-Villalobos et al., 2014). A total of 848 milk samples were collected during the production season 2003–2004 from 348 second-parity crossbred Holstein-Friesian × Jersey cows in late lactation. These cows were part of a crossbreeding experiment designed for the identification of quantitative trait loci for traits of economic importance in New Zealand dairy cattle (Spelman et al., 2001). The herd was managed as a conventional spring-calving herd grazing ryegrass/white clover pastures and cows were milked twice a day in a rotary milking parlour.

Concentrations of UFA in the 848 milk samples were determined by gas chromatography. The same milk samples were analysed on a Foss MilkoScan FT6000 (Foss, Hillerød, Denmark) to provide the Fourier transform infrared spectroscopy (FTIR) spectrum. The calibration equation for UFA was determined using partial least squares (PLS; Haaland & Thomas, 1988) using SAS (SAS, 2009). The optimum number of PLS factors was determined by cross-validation from a maximum of 15 PLS factors allowed in the model. Half of the samples selected at random were used as the training data set and the other half was used as the validation data set.

Wavelengths related to water absorbance were removed from the spectra because these bands were found to interfere with the readings. Absorbance values at each wavelength were standardised with mean of 0 and standard deviation of 1. Measures of fitness used to select the best calibration equation were the coefficient of determination of the validation data set (R_V^2), relative prediction error (RPE; Fuentes-Pila et al., 1996) and the concordance correlation coefficient (CCC; Lin, 1989):

$$\text{RPE} = (\text{MPE}/\bar{\text{A}} \times 100) \tag{3.1}$$

$$\text{CCC} = \frac{2\text{S}_{\text{AP}}}{\text{S}_{\text{A}}^2 + \text{S}_{\text{P}}^2 + (\bar{\text{A}} - \bar{\text{P}})^2} \tag{3.2}$$

Where MPE is the mean prediction error calculated as:

$$\mathrm{MPE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(A_i - P_i)^2} \ , \qquad (3.3)$$

A_i is the ith actual concentration of an UFA in milkfat determined by gas chromatography, P_i is the ith concentration of the UFA in milkfat predicted by the calibration equation, and n is the number of samples studied. Means ($\bar{A}$,$\bar{P}$), variances (S^2), standard deviations (S) and covariance (S_{AP}) of A and P were calculated in the usual way.

The calibration equation developed for the estimation of UFA concentration in milkfat had a R_V^2 of 0.91, a RPE of 4.4% and a CCC of 0.95 (Lopez-Villalobos et al., 2014). These measures of fitness indicated that this calibration equation could accurately predict milkfat UFA concentration, according to the criteria stated by Fuentes-Pila et al. (1996). Studies based on predicted milkfat UFA concentration, using calibration equations with high cross-validation correlation coefficients, have been reported previously in the literature (Coppa et al., 2010; Rutten et al., 2009; Soyeurt et al., 2006). Therefore, this calibration equation can be used to study the concentration of UFA in milkfat of New Zealand dairy cattle.

Prediction of concentration of UFA in milkfat

The calibration equation developed previously was used to predict the milkfat UFA concentration of 21,952 milk samples (test-day records), taken during the 2007–2008 milk production season. The milk production season comprised 300 days, from 15 July 2007 to 10 May 2008. These milk samples, which corresponded to 2,015 Holstein-Friesian cows, 1,396 Jersey cows and 2,002 Holstein-Friesian × Jersey crossbred cows, were part of the herd-testing programme of cows participating in the sire proving scheme of Livestock Improvement Corporation (LIC). The cows sampled were of different parities (1 to 10), calved between 15 July and 10 October, and were distributed in 186 herds used for progeny testing of young bulls. On average, each cow was sampled 4 times, but some cows were sampled up to 6 times.

Data corresponding to milk yield (L/day) were obtained from the production records of each animal. The concentrations of milkfat and protein in milk were determined using a Foss MilkoScan FT6000 instrument (Foss, Hillerød, Denmark). The FTIR spectrum for each milk sample was provided by LIC. Statistics for the traits analysed in the present study are shown in Appendix 1.

Statistical analysis

A mixed model using restricted maximum likelihood procedures (Gilmour et al., 2006) was used to study the influence of lactation stage (days in milk, DIM), parity, calving month and herd on the milkfat UFA concentration of New Zealand Holstein-Friesian, Jersey and crossbred cows. The model included the fixed effects of breed, DIM, herd, parity and calving month, and the random effect of cow. For each breed, a 3rd order orthogonal polynomial was used to explain the influence of DIM on the milkfat UFA concentration.

Twenty nine herds, with more than 60 cows per herd, were selected to investigate the effect of segregating cows according to their milkfat UFA concentration on milk production and composition. Within each herd, cows were segregated into 2 groups according to the average milkfat UFA concentration of their herd. Cows with an average milkfat UFA concentration (lactation average) above their herd average formed the high UFA group, while cows with a milkfat UFA concentration below their herd average formed the low UFA group. The PROC GLM (Tukey-Kramer test) procedure of SAS (SAS, 2009) was used to compare the daily milkfat UFA concentration of the high and low UFA groups, with the following model:

$$y_{ijk} = H_i + U_j + D_k + UD_{jk} + e_{ijk} \tag{4}$$

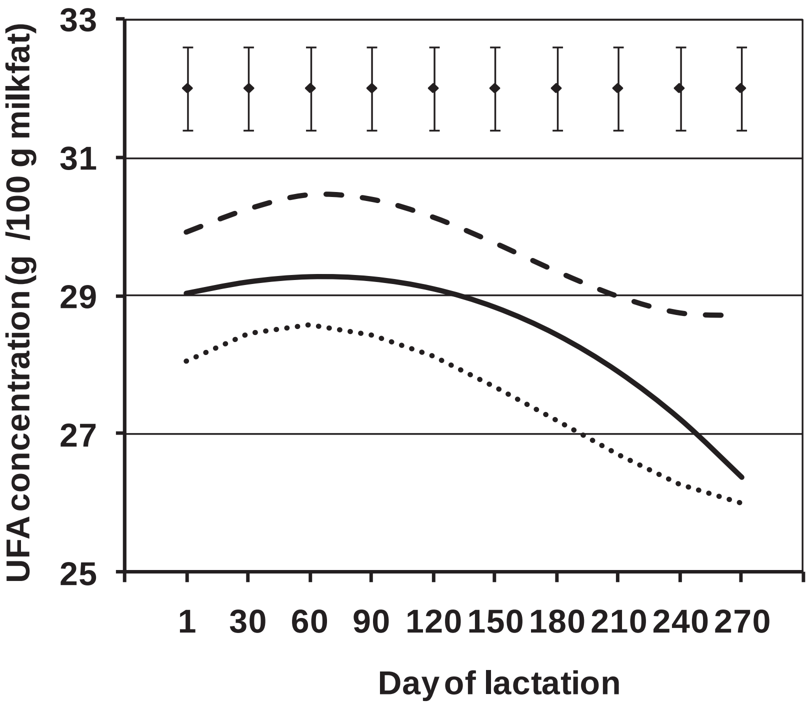
Where y_{ijk} is the UFA concentration (g /100 g milkfat) in milkfat produced by the j UFA group (high or low) of herd i, on day k of the milk production season (15 July 2007 to 10 May 2008). H_i is the random effect of herd i on milkfat UFA concentration, U_j is the fixed effect of the j UFA group, D_k is the fixed effect of the k day of the milk production season, UD_{jk} is the interaction between UFA group j and day k of the milk production season, and e_{ijk} is the random residual error.

Means (average of the milk production season) for milk production traits of the high and low UFA groups were compared using the PROC GLM (Tukey-Kramer test) procedure of SAS (SAS, 2009) with a model that included the fixed effect of UFA group and the random effect of herd.

RESULTS

There was a significant influence of breed (*P* < 0.001) on predicted milkfat UFA concentration. On average (lactation average), Holstein-Friesian cows had a higher milkfat UFA concentration (29.70 g /100 g milkfat, ± 0.04) than Jersey (27.61 g /100 g milkfat, ± 0.05) and Crossbred (28.56 g /100 g milkfat, ± 0.05) cows. During the lactation, Holstein-Friesian cows had higher milkfat UFA concentration than Jersey cows (Figure 1).

Figure 1 Mean and 95% confidence interval (Ⅰ) for concentration of unsaturated fatty acids (UFA) in milkfat of Holstein-Friesian (– – –), Jersey (·······) and Holstein-Friesian × Jersey crossbred (——) cows during the lactation.



Milkfat UFA concentration in Crossbred cows was intermediate to those of Holstein-Friesian and Jersey cows, but not significantly different from them in early and mid lactation (Figure 1). In late lactation, the UFA concentration in milkfat of Crossbred cows was significantly lower than that of Holstein-Friesian cows, but not significantly different from that of Jersey cows.

Milkfat UFA concentration was also significantly influenced by DIM ($P < 0.001$), and decreased steadily from the start to the end of lactation (Figure 1). There was a significant interaction ($P < 0.01$) between breed and DIM concerning milkfat UFA concentration, with milkfat UFA concentration decreasing at a faster rate in Jersey and Crossbred cows than in Holstein-Friesian cows. This interaction could also be appreciated in the 3rd-order orthogonal polynomial coefficients for each breed (Table 1).

Table 1 Third-degree orthogonal polynomial coefficients (based on 270 days in milk) for concentration (g /100 g milkfat) of unsaturated fatty acids in milkfat of Holstein-Friesian, Jersey and Holstein-Friesian × Jersey crossbred cows (Means ± SEM)[1].

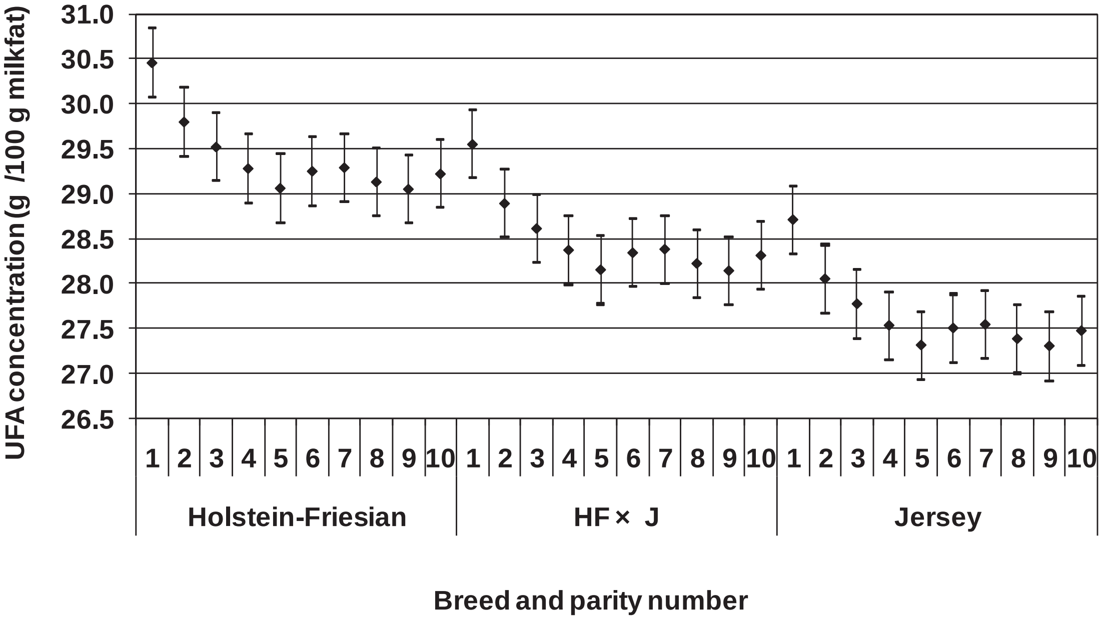
Coefficients	Holstein-Friesian (2015 cows)	Holstein-Friesian × Jersey (2002 cows)	Jersey (1396 cows)
α_0	$29.70^{a} \pm 0.35$	$28.56^{ab} \pm 0.35$	$27.61^{b} \pm 0.35$
α_1	$-0.97^{a} \pm 0.04$	$-1.28^{b} \pm 0.04$	$-1.41^{b} \pm 0.05$
α_2	$-0.48^{a} \pm 0.06$	$-0.85^{b} \pm 0.06$	$-0.59^{ab} \pm 0.08$
α_3	$0.47^{a} \pm 0.06$	$-0.05^{b} \pm 0.06$	$0.38^{a} \pm 0.07$

[1] Means within rows with different superscripts were significantly different ($P < 0.05$).

The intercept (α_0) and linear (α_1) coefficients used for the estimation of milkfat UFA concentration per DIM were higher for Holstein-Friesian cows than for Jersey cows, but the quadratic (α_2) and cubic (α_3) coefficients were not significantly different between these two breeds (Table 1). Crossbred cows had an intercept (α_0) coefficient intermediate to those of Holstein-Friesian cows and Jersey cows. The linear (α_1), quadratic (α_2) and cubic (α_3) coefficients of crossbred cows were significantly different from those of Holstein-Friesian cows. There were no significant differences between the quadratic (α_2) and cubic (α_3) coefficients of Crossbred and Jersey cows, but the cubic (α_3) coefficient of Crossbred cows was significantly different from that of Jersey cows (Table 1).

The milkfat UFA concentration was significantly influenced by parity ($P < 0.001$) in the three breeds studied. The average milkfat UFA concentration (lactation average) was higher in first parity cows than in cows with 3 or more parities (Figure 2).

Figure 2 Influence of parity (mean and 95% confidence interval) on the concentration of unsaturated fatty acids in milkfat of Holstein-Friesian, Jersey and Holstein-Friesian × Jersey crossbred (HF×J) cows.



The average milkfat UFA concentration (lactation average) was also significantly influenced ($P < 0.001$) by herd factors (Figure 3) and animal factors (mean=0 and standard deviation=0.83); but it was not significantly influenced by calving month ($P = 0.201$).

During the dairy season, the high UFA group had significantly higher concentrations of UFA in milkfat (4.0% to 8% more; $P < 0.001$) than the low

UFA group (Figure 4). There was a significant interaction between UFA group and day of dairy season, with larger differences between UFA groups observed in late lactation.

Figure 3 Influence of herd (mean and 95% confidence interval) on the concentration of unsaturated fatty acids in milkfat produced by a group of 29 herds with 60 or more cows per herd.

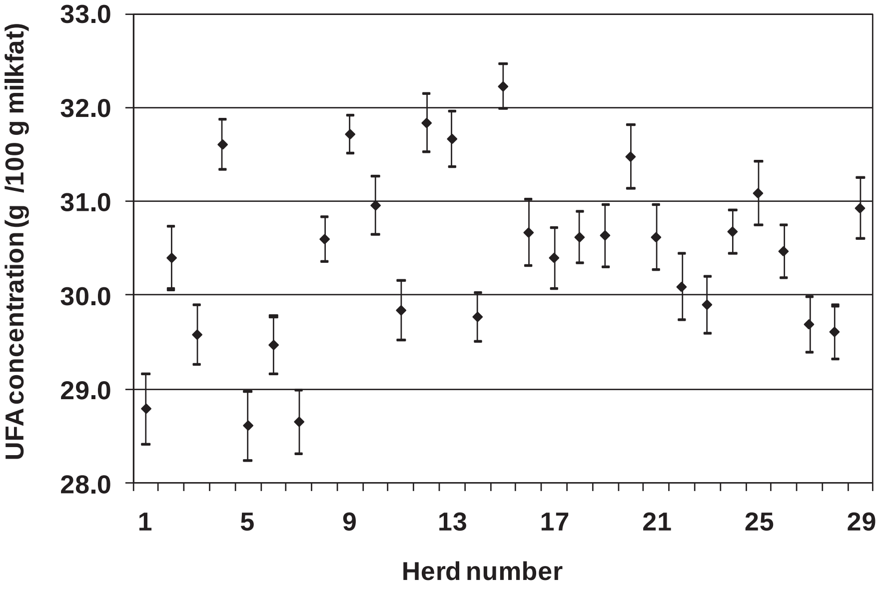
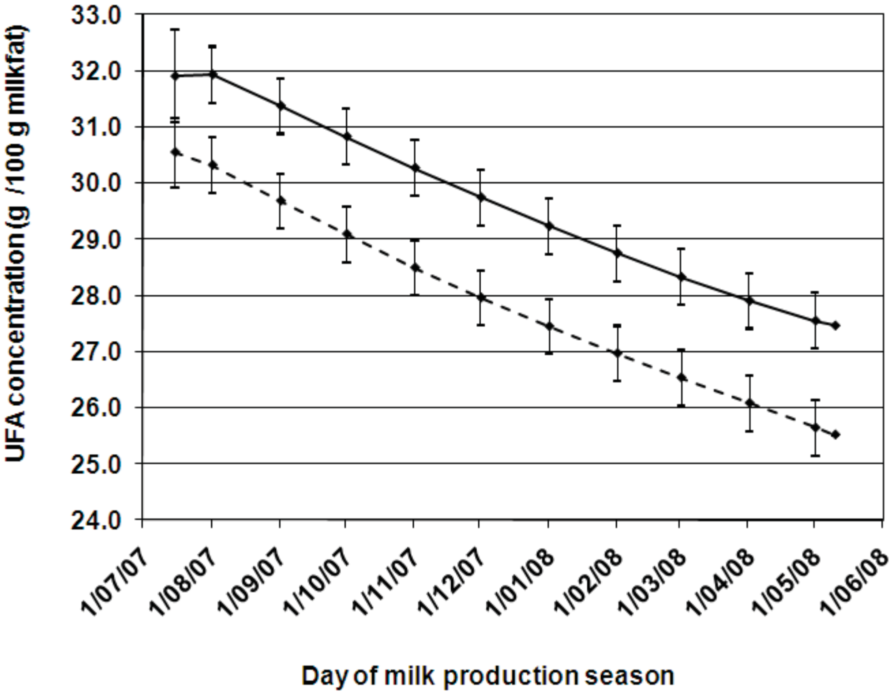


Figure 4 Mean and 95% confidence interval for concentration of unsaturated fatty acids (UFA) in milkfat produced by the high (——) and low (– – –) UFA groups during the milk production season.



On average (lactation average) and on a per day basis, cows in the high UFA group had significantly (*P* < 0.001) higher milk yields, but lower yields and percentages of milkfat and protein, than cows in the low UFA group (Table 2). The high UFA group had also a higher percentage of Holstein-Friesian cows than the low UFA groups.

Table 2 Average milk production and composition per day of cows in the high and low UFA groups of 29 herds (Means ± SEM)[1].

	High UFA Group	Low UFA Group
Test-day records	5892	5957
Number of cows	1438	1455
Milk yield (L/cow/day)	17.71^{a} ± 0.080	17.03^{b} ± 0.080
Fat yield (kg/cow/day)	0.800^{a} ± 0.003	0.879^{b} ± 0.003
Protein yield (kg/cow/day)	0.640^{a} ± 0.003	0.661^{b} ± 0.003
% Fat	4.69^{a} ± 0.010	5.31^{b} ± 0.010
% Protein	3.69^{a} ± 0.010	3.96^{b} ± 0.010
UFA (g /100 g milkfat)	29.88^{a} ± 0.030	27.46^{b} ± 0.030
% of Holstein-Friesian cows in the herd	40^{a} ± 1.830	25^{b} ± 1.830

[1] Means within rows with different superscripts are significantly different (P < 0.001)

DISCUSSION

The results of the present study concerning the differences in milkfat UFA concentration between Holstein-Friesian cows and Jersey cows are consistent with previous studies. Back & Thomson (2005) and MacGibbon (1996) reported a higher concentration of UFA in milkfat of Holstein-Friesian cows than in milkfat of Jersey cows. For crossbred cows, a milkfat UFA concentration intermediate to that of Holstein-Friesian cows and Jersey cows was reported by Back & Thomson (2005) in late lactation. However, it is difficult to compare values for milkfat UFA concentration between studies due to differences in methodology for the measurement of milkfat composition. The differences between breeds found in the present study also agreed with the results from overseas studies (Carroll et al., 2006; Palladino et al., 2010). However, caution is required when comparing the results of the present study with those of overseas studies due to differences in farming systems and the influence of breed strain on milkfat composition (Wales et al., 2009).

The difference in milkfat UFA concentration between breeds could be due in part to differences between breeds in the activity of Stearoyl-CoA desaturase 1 (SCD), an enzyme involved in the desaturation of fatty acids in the mammary gland. Soyeurt et al. (2008b) reported that the activity of SCD was influenced by stage of lactation and was lower in Jersey cows than in Holstein-Friesian cows. Another enzyme that influences the concentration of UFA in milkfat is Diacylglycerol Acyltransferase 1 (DGAT1), with its lysine (K) variant being associated with low milkfat UFA concentrations (Schennink et al., 2007). Given that DGAT1 polymorphism affects milkfat production in Holstein-Friesian and Jersey cows in different ways (Spelman et al., 2002; Suchocki et al., 2010), it is possible that differences in milkfat UFA concentration between these two breeds may also be influenced by DGAT1.

In the present study, the change in milkfat UFA concentration during the course of the lactation varied between breeds. This was reflected in the significant differences between breeds in the orthogonal polynomial coefficients for the prediction of milkfat UFA concentration (Table 1), and the significant interaction between breed and DIM for milkfat UFA concentration. As the lactation progressed, the milkfat UFA concentration of Holstein-Friesian cows decreased at a slower rate than in Jersey and crossbred cows.

In the present study the milkfat UFA concentration decreased steadily during the course of the lactation. This is contrary to the results of other studies done in New Zealand (Auldist et al., 1998; Back & Thomson, 2005; Thomson & Van-der-Poel, 2000) and overseas (Stoop et al., 2009), which reported that the concentration of UFA in milkfat was lower in mid lactation than in early and late lactation. Several studies have reported that nutritional factors influence milkfat composition significantly (Elgersma et al., 2006; Thomson et al., 2002). As pasture is the main feed for dairy cattle in New Zealand, it is possible that changes in pasture composition and stage of maturity could have also influenced the milkfat UFA concentration in the present study.

The influence of parity on the milkfat UFA concentration agreed with the study by Thomson & Van-der-Poel (2000). The influence of parity on milkfat UFA concentration may be associated to differences in energy balance between primiparous cows and multiparous cows. During early lactation primiparous cows are in a greater negative energy balance for a longer period than multiparous cows (Berry et al., 2006), and a negative energy balance has been associated with higher milkfat UFA concentrations (McParland et al., 2011a).

Herd management (planned start of calving date, feeding system) influences the type, quantity and quality of the feed supplied to the herd. It is possible that the differences in milkfat UFA concentration between herds in the present study could be associated with differences in management between herds. For New Zealand seasonal pastoral systems these factors are particularly important since the type, quantity and quality of pasture and supplements can vary significantly during the year, and between regions and farms.

The variance corresponding to animal factors in the mixed model is related to the genetic merit of the animal for milkfat UFA concentration. This is because the effects of other environmental and animal factors (breed, DIM, parity, calving month and herd) were already accounted for in the model. Since milkfat UFA concentration has a moderate heritability (0.09–0.28) (Garnsworthy et al., 2010; Lopez-Villalobos et al., 2011; Soyeurt et al., 2007), genetic selection could be used to increase the concentration of UFA in milkfat.

Some studies have suggested the manipulation of the diet, the use of genetic selection and the segregation of milk as alternatives to increase the milkfat UFA concentration of milk supplied to dairy processors, (Garrick & Lopez-Villalobos, 2001; Lock & Bauman, 2004; Soyeurt et al., 2007; Thomson et al., 2002). In a simulation study, Dooley *et al.* (2005) investigated the effect of segregating cows within herds to alter milkfat colour. In a similar way, the segregation of cows within a herd (cows with high milkfat UFA concentration), or the segregation of herds within a region (herds with high milkfat UFA concentration), may allow dairy farmers to supply dairy processors milk with high milkfat UFA concentration.

In the present study, a high milkfat UFA concentration was associated with high milk yield and low yields and percentages of milkfat and protein. With the exception of protein yield, similar results were reported in a previous study (Schennink et al., 2007). The lower milkfat yield and the lower percentages of milkfat and protein in milk produced by cows in the high UFA group could be due to negative genetic and phenotypic correlations between these traits and the concentration of UFA in milkfat. Several studies reported moderate to high negative genetic and phenotypic correlations between milkfat UFA concentration, milkfat yield and the percentages of milkfat and protein in milk (Schennink et al., 2008; Soyeurt et al., 2008b; Stoop et al., 2008). These studies also reported low to moderate positive genetic and phenotypic correlations between milkfat UFA concentration and the yields of milk and protein. However, protein yield was negatively associated with milkfat UFA concentration in the present study.

The negative correlation between milkfat UFA concentration and other milk production traits may be due to genetic (e.g. DGAT1 and SCD genotype) and environmental (nutrition) factors. The A variant of DGAT1, which is associated with higher concentrations of UFA in milkfat, has also been associated with higher yields of milk and protein, but lower milkfat yield and percentages of milkfat and protein (Schennink et al., 2007; Spelman et al., 2002). The presence of some trans fatty acids (in particular t10 c12 CLA) which are derived primarily from the incomplete biohydrogenation of dietary UFA in the rumen, can also inhibit lipogenic enzymes in the mammary gland (such as Acetyl-CoA carboxylase) and decreased milkfat yield (Piperova et al., 2000; Shingfield & Griinari, 2007; Wonsil et al., 1994). It is possible that a mixture of these factors could have been involved in the reductions in yields and percentages of milkfat and protein in the high UFA group.

Potential losses in production associated to increases in milkfat UFA concentration have also been highlighted in previous studies (Arnould & Soyeurt, 2009; Mele, 2009). In New Zealand, under the current payment system which rewards milkfat and protein yields and penalises milk volume, these losses in production would negatively affect farm profitability.

CONCLUSION

The concentration of UFA in milkfat is influenced by breed, DIM, parity, herd and animal factors. Understanding how each factor, and their interactions, influences milkfat UFA concentration is essential for the development of a programme to increase the milkfat UFA concentration on-farm. Although segregation of cows within a herd can be practised to harvest milk with high milkfat UFA concentration, more studies are needed before implementing such a programme. These studies should consider the costs and practicality of milk segregation and collection, and its cost-benefit. Furthermore, the development of a payment system for concentration of UFA in milkfat is essential to compensate dairy farmers for losses in production of milkfat, and for the extra costs involved with animal segregation.

CHAPTER 4

Development and application of a stochastic farm model for the simulation of dairy farms and the segregation of dairy cows that produce milkfat with different concentration of unsaturated fatty acids

ABSTRACT

The objective of this study was to develop a farm model for the simulation of milk production, milk composition (including milkfat UFA concentration), and the economic performance of dairy farms under New Zealand conditions. The model used the Cholesky decomposition algorithm of (co)variance matrices to simulate the performance of Holstein-Friesian cows for milk yield (MY), milkfat percentage (F%), protein percentage (P%), milkfat UFA concentration and live weight (LW). The mean performance of cows and farms simulated by the model were very close to national statistics of New Zealand dairy farms, suggesting that the model can simulate dairy farms with New Zealand characteristics satisfactory. The model was then used to simulate a group of 1,820,000 cows, distributed in 5,600 farms (325 cows/farm, average herd size in New Zealand), and to segregate into a herd the 325 cows with the highest milkfat UFA concentration ($UFA_{2.71}$ farm, 2.71 cows/ha). Given that cows in the $UFA_{2.71}$ farm had lower feed requirements than average cows, another scenario was simulated where the 353 cows with the highest milkfat UFA concentration were segregated from the group of 1,820,000 cows ($UFA_{2.94}$, 2.94 cows/ha). A herd size of 353 cows resulted in the $UFA_{2.94}$ farm utilising the same amount of feed per hectare as average farms. The simulations were repeated 1,000 times and a 95% confidence interval was estimated by bootstrapping methodology. On average, the $UFA_{2.71}$ and $UFA_{2.94}$ farms produced milk with 23.6% more UFA than average farms. However, cows on the $UFA_{2.71}$ and $UFA_{2.94}$ farms had significantly lower yields of milkfat (both -48 kg, $P<0.05$), protein (-24 and -23 kg, respectively, $P<0.05$) and milksolids (-73 and -72 kg, respectively, $P<0.05$) than cows on average farms. Under a milk payment system that pays for yields of milkfat ($5.59/kg) and protein ($10.62/kg), and penalises milk volume (-$0.04/litre), the $UFA_{2.71}$ and $UFA_{2.94}$ farms had significantly lower operating profit (-$1,163/ha and -$1,156/ha, respectively, $P<0.05$) than average farms. These results indicate that farm profit could be affected unless there is a premium for milkfat UFA concentration.

Keywords: unsaturated fatty acids, milk fat, stochastic farm model

INTRODUCTION

In recent years there has been a trend towards both healthy and convenient foods (Bermudez et al., 2010; IFICF, 2012). Several studies have indicated that increasing the concentration of unsaturated fatty acids (UFA) in milkfat improves the spreadability of butter (MacGibbon et al., 2002) and may have health benefits (Griinari & Bauman, 1999; Poppitt et al., 2002; Seidel et al., 2005). Therefore, the dairy industry may benefit from the increase in milkfat UFA concentration if this milk is processed into dairy products that target the niche markets of consumers searching for convenience and additional health benefits.

Milk fat composition can be altered at the farm level or during processing at the dairy plant. Since the late 1980s, several studies have examined the feasibility of increasing the milkfat UFA concentration at the farm level (Dewhurst et al., 2006; Garnsworthy et al., 2010; Gibson, 1991; Kalac & Samkova, 2010; Soyeurt & Gengler, 2008). However, before implementing a programme to increase the concentration of UFA in milkfat at the farm level it is necessary to determine its potential impact on farm production and profit. Some studies reported that increasing the milkfat UFA concentration at the farm level may negatively affect the production of other milk components and farm profit (Chilliard et al., 2001; Hurtaud & Peyraud, 2007; Stoop et al., 2008; Chapter 3). At present, there is no published information regarding the impact of increasing the milkfat UFA concentration on the physical and financial performance of dairy farms.

In the past, farm simulation models have been used to study the effects of altering milk composition on farm production and profit. Dooley et al. (2005) developed a deterministic farm simulation model to investigate the effect of breeding and segregating cows within herds to alter the colour of milkfat and the concentration of β-lactoglobulin in milk protein. Lopez-Villalobos (2002) used a deterministic farm model to study the effect of increasing the casein concentration of milk protein through genetic selection. A farm model with key physical and economic inputs can also be used to study the effect of increasing the milkfat UFA concentration on-farm production and profit.

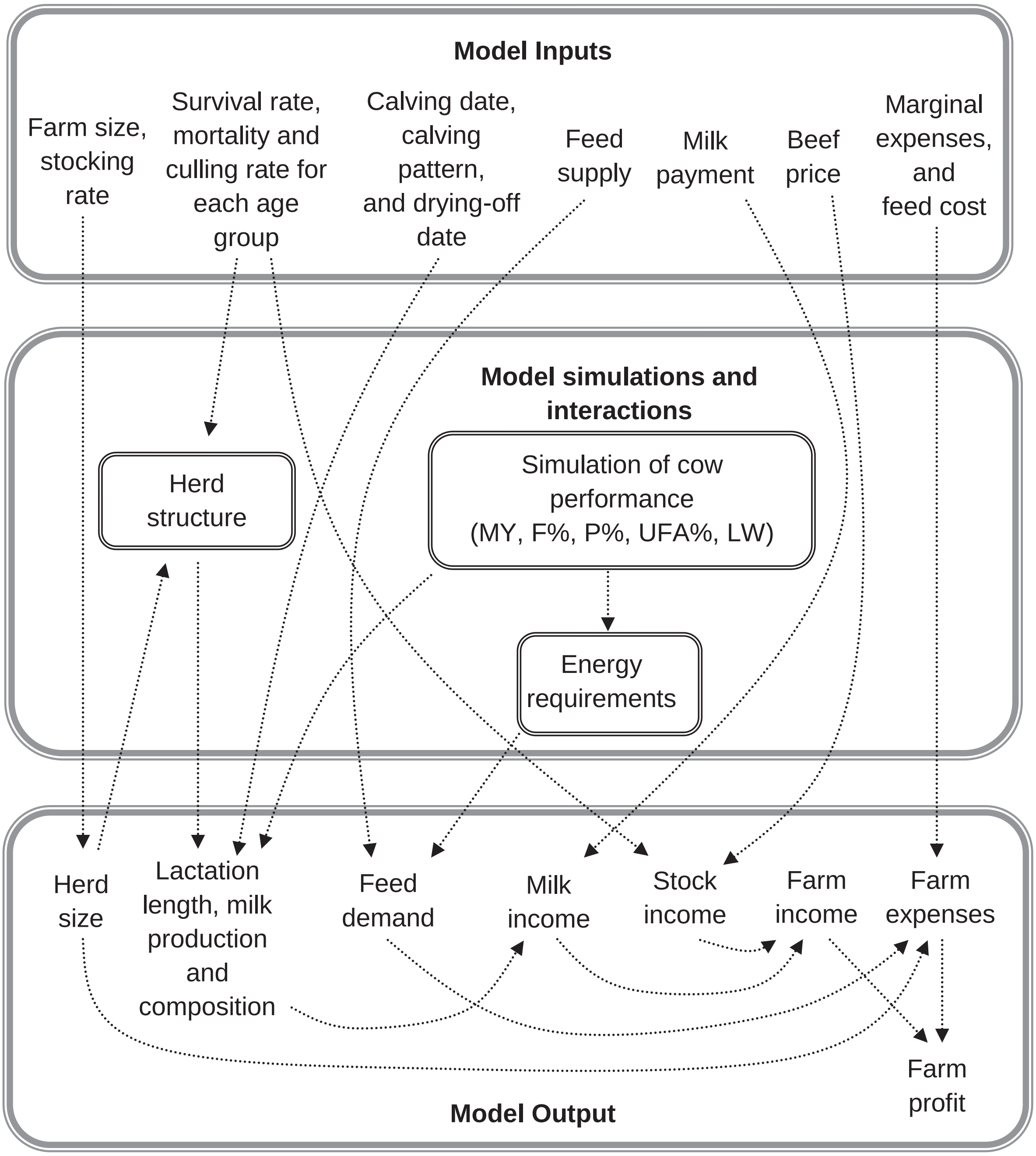
The objective of the present study was to develop a stochastic bio-economic farm model for the simulation of milk production, milk composition (including milkfat UFA concentration), and the economic performance of dairy farms under New Zealand conditions (seasonal pasture-based system). The farm model developed was used to examine the effect on farm production and profit of segregating cows according to their milkfat UFA concentration.

MATERIALS AND METHODS

Outline of the model

An empirical stochastic farm model that accounts for all the inputs and outputs in a typical New Zealand dairy farm was developed in SAS (SAS, 2009). Key model inputs are farm size (milking platform hectares, ha), start of calving date and calving pattern, drying-off date, replacement rate, herd structure, feed supply, milk payment, stock prices and farm expenses (Figure 1).

Figure 1 Diagram of the parameters considered in the farm model and their relationship.



The model simulates the daily and annual performance for milk yield (MY), milkfat percentage (F%), protein percentage (P%), milkfat UFA concentration and live weight (LW), of individual cows and farms. Key outputs of the model are data corresponding to milk production and composition, milkfat UFA concentration, cow live weight, feed demand, gross farm income and farm operating profit (per cow and per hectare).

Herd structure and replacement rate

The model considered 12 age classes: calves (female calves less than 2 months old), R1 (heifers less than 1 year old), R2 (heifers from 1 to less than 2 years old), and 2 to 10 years (cows in first to ninth lactation). The proportion of the herd in each age class was determined using the Leslie matrix model (Leslie, 1945), which takes into account the survival and fecundity (number of female offspring) rates for each age class. Survival rates used in the Leslie matrix for calves, R1, R2 and cows (age classes 2 to 10) were: 0.66 (percentage of female calves raised as replacement), 0.86, 0.86, 0.86, 0.87, 0.86, 0.81, 0.77, 0.71, 0.66, and 0.64, respectively. Survival rate values were obtained from the dairy statistics of Livestock Improvement Corporation (LIC, 2011). Since it was assumed that 50% of calves born were females, the fecundity rate for cows in each age class was 0.5.

Farms simulated by the model had a 12 week spring calving period. Calving dates and pattern were derived from data in Chapter 3, LIC (2011) and Holmes et al. (2002). The planned start of calving date was July 20. In each herd, 50% of the cows calved by August 11 (22 days after the start of calving), 90% of the cows calved by September 4, and the remaining cows calved between September 4 and October 10. All cows in each herd were dried off by May 10 the following year.

It was assumed that at the end of the mating period (October-December) 90% of the cows in the herd were pregnant and 94% of calves born survived to sale (Lopez-Villalobos et al., 2000b). R2 heifers were naturally mated at about 15 months of age, at the same time as older cows. Male calves, and female calves that were not used as herd replacements, were sold as bobby calves for veal.

Reasons considered in the model for culling of heifers and cows were age, death, disease, poor fertility and unsatisfactory performance. Culling rates for each category were obtained from Lopez-Villalobos et al. (2000b). Cows were culled from the herd at the end of their ninth lactation. Mortality rates for R1, R2 and cows (across age classes) were 4%, 3%, and 1.4%, respectively. Culling rates due to disease were 1%, 1% and 3.4% for R1, R2 and cows, respectively. The culling rate due to poor fertility (non-pregnant cows), for R2 and cows (across age classes), was 8%. For each age class, the culling rate for unsatisfactory performance (voluntary culling) was obtained by subtracting the sum of culling rates for age, death, disease and poor fertility from the total culling rate of each age class.

Simulation of cow performance

Daily cow performance for MY, F%, P%, milkfat UFA concentration and LW was simulated using regression coefficients developed in 3 stages as follows:

Stage 1: Data

Two datasets were used to derive regression coefficients for the simulation of cow performance (Appendix 2). This is because one dataset did not have data for milkfat UFA concentration and the other did not have data for LW. The first dataset (Dataset 1) had 3911 test day records corresponding to 109 Holstein-Friesian cows in their first lactation (Macdonald et al., 2008). Before the analysis of the data, milk production and live weight of cows in dataset 1 were adjusted to mature age by dividing it by an adjustment factor of 0.76 for milk production, and of 0.81 for live weight. These adjustments factors were estimated from age production averages reported in the New Zealand dairy statistics (LIC, 2011). Dataset 1 was used to derive the regression coefficients for MY, F%, P% and LW. The second dataset (Dataset 2) had 8635 test day records corresponding to 2146 Holstein-Friesian cows (4 or more test day records per cow) from the sire proving scheme of Livestock Improvement Corporation (Chapter 3). Dataset 2 was used to derive the regression coefficients for milkfat UFA concentration.

A univariate animal model with random regression on days in milk (DIM) was used in ASREML (Gilmour et al., 2006) to estimate regression coefficients for each cow in dataset 1 (MY, F%, P%, LW) and dataset 2 (milk fat UFA concentration) (Appendix 3). Five mathematical functions: Wood (1967), Wilmink (1987), Ali and Schaeffer (1987), and orthogonal polynomials of order 2 and 3 were fitted to the data. The goodness of fitness of the functions fitted was determined by their concordance correlation coefficient (Lin, 1989) and their relative prediction error (Fuentes-Pila et al., 1996). Based on their goodness of fitness, the Wilmink function (Wilmink, 1987) was selected to estimate MY, F%, P% and LW:

$$Y_{(ijt)} = a_{ij} + b_{ij}t + c_{ij}\exp^{-0.05t} \qquad (4.1)$$

Where i is the trait estimated: MY (L), F%, P% or LW (kg), $Y_{(ijt)}$ is the performance of cow j for trait i in the t DIM; and a_{ij}, b_{ij} and c_{ij} are the corresponding Wilmink regression coefficients of trait i for cow j. These coefficients described the level of production of each trait (a_j), and its change before (c_j) and after (b_j) the peak of lactation.

Also, based on their goodness of fitness, an orthogonal polynomial of order 3 was selected to estimate the regression coefficients for daily milkfat UFA concentration:

$$UFA_{(t,j)} = \alpha_{0j}\, p_{0j} + \alpha_{1j}\, p_{1j} + \alpha_{2j}\, p_{2j} + \alpha_{3j}\, p_{3j} \qquad (4.2)$$

Where $UFA_{(t,j)}$ refers to milkfat UFA concentration (g /100 g milkfat) for cow j on the t DIM; p_{0t}, p_{1t}, p_{2t} and p_{3t} are the orthogonal polynomial parameters corresponding to the intercept, linear, quadratic and cubic effects of the t DIM (in the range of 1 to 270), respectively; and α_{0j}, α_{1j}, α_{2j} and α_{3j} are the corresponding orthogonal polynomial regression coefficients for cow j.

The mean and phenotypic variance of the regression coefficients for MY, F%, P%, LW and milkfat UFA concentration are shown in Table 1. A 16 × 16 matrix was built with the phenotypic correlations between these regression coefficients (Table 2). The correlations for MY, F%, P% and LW were obtained from dataset 1, while the correlations for milkfat UFA concentration were obtained from dataset 2. A correlation of 0 was assumed between the regression coefficients for milkfat UFA concentration and LW, given that data for the correlation between these traits were not available. Since the matrix built was not positive definite, which is a requirement for Cholesky decomposition, a bending procedure was used to make it positive definite (Jorjani et al., 2003).

Table 1 Mean (mature equivalent, $\bar{X}$), phenotypic variance (σ^2_p) and estimated genetic (σ^2_g), herd (σ^2_{herd}) and residual (σ^2_e) variances for the Wilmink (a, b, c) and orthogonal polynomial of order 3 (α_0, α_1, α_2, α_3) regression coefficients for milk yield (MY), fat percentage (F%), protein percentage (P%), concentration of unsaturated fatty acids in milkfat (UFA) and live weight (LW).

Trait	Source[1]	N cows	$\bar{X}$	σ^2_p	σ^2_g	σ^2_{herd}	σ^2_e
MY a	DS1	109	26.79	14.42	4.32	3.60	6.49
MY b	DS1	109	-0.06	1×10^{-4}	4×10^{-5}	3×10^{-5}	6×10^{-5}
MY c	DS1	109	-10.30	10.93	3.28	2.73	4.92
F% a	DS1	109	3.36	0.17	0.08	0.04	0.04
F% b	DS1	109	0.01	2×10^{-6}	1×10^{-6}	6×10^{-7}	6×10^{-7}
F% c	DS1	109	2.57	0.31	0.16	0.08	0.08
P% a	DS1	109	3.14	0.04	0.02	0.01	0.01
P% b	DS1	109	3×10^{-3}	7×10^{-7}	4×10^{-7}	2×10^{-7}	2×10^{-7}
P% c	DS1	109	0.94	0.03	0.01	0.01	0.01
LW a	DS1	109	464.05	1239.37	433.78	247.87	557.71
LW b	DS1	109	0.36	0.01	3×10^{-3}	2×10^{-3}	3×10^{-3}
LW c	DS1	109	104.30	47.44	16.60	9.49	21.35
UFA α_0	DS2	1850	29.92	3.48	0.52	1.05	1.92
UFA α_1	DS2	1850	-1.90	0.35	0.05	0.11	0.19
UFA α_2	DS2	1850	0.27	0.26	0.04	0.08	0.14
UFA α_3	DS2	1850	0.15	0.18	0.03	0.06	0.10

[1] DS1= coefficients obtained from dataset 1 (Macdonald et al., 2008), DS2= coefficients obtained from dataset 2 (Sire proving scheme of Livestock Improvement Corporation).

Table 2 Bended phenotypic correlation matrix of the Wilmink (a, b, c) and orthogonal polynomial of order 3 (α_0, α_1, α_2, α_3) regression coefficients for milk yield (MY), fat percentage (F%), protein percentage (P%), milkfat UFA concentration (UFA) and live weight (LW).

	MY a	MY b	MY c	F% a	F% b	F% c	P% a	P% b	P% c	UFA α_0	UFA α_1	UFA α_2	UFA α_3	LW a	LW b	LW c
MY a	1.00	-0.59	-0.10	-0.33	-0.15	0.10	-0.21	-0.04	0.19	0.01	0.02	-0.04	0.09	0.22	-0.14	0.14
MY b		1.00	-0.31	0.43	-0.21	0.06	0.26	-0.16	-0.23	0.02	0.05	0.00	0.01	-0.14	0.39	-0.01
MY c			1.00	-0.18	0.34	-0.25	-0.17	0.27	0.06	-0.11	-0.09	0.05	0.05	0.06	-0.13	0.24
F% a				1.00	-0.17	0.04	0.50	0.05	-0.13	-0.54	-0.04	0.21	0.00	0.10	0.16	0.24
F% b					1.00	0.00	0.03	0.66	0.05	-0.52	-0.43	0.15	0.16	-0.04	0.01	-0.28
F% c						1.00	-0.28	0.10	0.15	0.01	0.14	-0.18	0.08	-0.29	0.14	0.18
P% a							1.00	-0.11	-0.15	-0.57	-0.12	0.10	0.09	0.25	0.20	-0.28
P% b								1.00	-0.07	-0.47	-0.46	0.09	0.15	0.07	0.26	0.07
P% c									1.00	-0.06	0.20	-0.20	0.16	0.00	-0.09	0.08
UFA α_0										1.00	0.26	-0.14	-0.15	-0.02	-0.01	0.01
UFA α_1											1.00	-0.06	-0.38	0.00	0.00	0.00
UFA α_2												1.00	-0.05	0.00	0.00	0.00
UFA α_3													1.00	0.00	0.00	0.00
LW a														1.00	0.02	0.01
LW b															1.00	0.10
LW c																1.00

Stage 2: Estimation of variance components

The phenotypic variance (σ_p^2) of the regression coefficients of the lactation curves for MY, F%, P%, milkfat UFA concentration and LW were divided into genetic and environmental (herd and residual) components (Table 1) as follows:

$$\sigma^2 = \sigma_p^2 \times \Phi \tag{4.3}$$

Where σ^2 is the variance due to genetic (σ_g^2), herd (σ_{herd}^2) or residual effects (σ_e^2), and Φ is the proportion of the phenotypic variance explained by genetic, herd or residual effects. The proportion of the phenotypic variance that was genetic in origin was determined assuming heritability values of 0.30, 0.50, 0.50, 0.15 and 0.35 for MY, F%, P%, milkfat UFA concentration and LW, respectively (Arnould & Soyeurt, 2009; Holmes et al., 2002; NZAEL, 2012b). The proportion of the phenotypic variance due to herd effects was assumed to be 0.25 for MY, F%, and P%, 0.30 for milkfat UFA concentration and 0.20 for LW (Stoop et al., 2008; Vanderick et al., 2009). The residual variance was obtained by subtracting the genetic and herd effects variances from the phenotypic variance.

The genetic (σ_g^2), herd (σ_{herd}^2) and residual (σ_r^2) variances of the regression coefficients for each trait (Table 1) were combined with their phenotypic correlation (Table 2) to build a 16 ×16 (co)variance matrix for genetic, herd and residual effects, respectively. The covariance between regression coefficients was estimated as follows:

$$\mathrm{Cov}_{ij} = \sqrt{\sigma_i^2} \times \mathrm{R}_{ij} \times \sqrt{\sigma_j^2} \tag{4.4}$$

Where Cov_{ij} is the covariance between regression coefficient i and j, $\sqrt{\sigma_i^2}$ and $\sqrt{\sigma_j^2}$ are the standard deviations of the regression coefficients i and j, respectively; and R_{ij} is the phenotypic correlation between the trait regression coefficients. The phenotypic correlation matrix was used to generate the three (co)variance matrices, given that no correlation data for genetic, herd and residual effects was available.

Stage 3: Simulation of vectors of coefficients

For each cow generated by the model, a vector of regression coefficients was simulated using the Cholesky decomposition algorithm of the (co)variance matrices for genetic, herd and residual effects (Van Vleck, 1994):

$$\mathbf{r_j = \mu + L_g\, q_1 + L_{herd}\, q_2 + L_e\, q_3} \tag{4.5}$$

Where:

$\mathbf{r_j}$ = vector of order 16, for cow j, with the Wilmink regression coefficients (a,b,c) for MY (L), F%, P% and LW (kg), and the orthogonal polynomial of order 3 regression coefficients (α_0, α_1, α_2, α_3) for milkfat UFA concentration,

$\boldsymbol{\mu}$ = vector of order 16 corresponding to the population mean (mature equivalent mean of each regression coefficient),

$\mathbf{L_g, L_{herd}, L_e}$ = 16 × 16 matrices corresponding to the lower triangular matrix (L) of the Cholesky decomposition of the matrices of genetic (g), herd (herd) and residual effects (e), respectively (such that covariance matrix = LL'), and

$\mathbf{q_1, q_2, q_3}$ = vectors of order 16, with their elements being random deviates with mean 0 and standard deviation of 1.

Daily cow performance for MY (L), F%, P% and LW (kg) was simulated as indicated in Eq. (4.1), using the corresponding regression coefficients for the Wilmink function in the $\mathbf{r_j}$ vector. Daily milkfat UFA concentration (g UFA /100 g milkfat) was simulated as indicated in Eq. (4.2), using the corresponding regression coefficients in the $\mathbf{r_j}$ vector.

Once daily MY, LW and milkfat UFA concentration were estimated, they were adjusted for the effect of age. Adjustment factors used for MY were 0.76, 0.88, 0.96, 1, 0.96 and 0.89, for lactations 1, 2, 3, 4 to 7, 8, and 9, respectively. Adjustment factors used for LW were 0.81, 0.92, 0.98, and 1, for lactations 1, 2, 3, and 4 to 9, respectively. Adjustments factors for MY and LW were estimated from age production averages reported in the New Zealand dairy statistics (LIC, 2011). Adjustment factors used for milkfat UFA concentration were 1.029, and 1, for lactations 1, and 2 to 9, respectively. Adjustment factors for milkfat UFA concentration were obtained from Chapter 3.

Since the simulated LW in mid- and late- lactation corresponded to pregnant cows, LW was adjusted from conception to drying-off, to remove the increase in weight associated with the conceptus, as follows:

$$LW_{np} = LW_t - (C_{bw} \times 0.01828 \times e^{0.02t - 0.0000143t \times t}) \tag{4.6}$$

Where LW_{np} is the non-pregnant LW, LW_t is the cow live weight (kg) at t day of pregnancy, $(C_{bw} \times 0.01828 \times e^{0.02t - 0.0000143t \times t})$ is the conceptus weight (kg) at t day of pregnancy (Fox et al., 1999), C_{bw} is the calf birth LW (assumed to be 35 ± 2 kg) (Clark & MacDonald, 2007), and *e* is the base of natural logarithms. After adjustment for pregnancy, it was assume that LW between drying-off and the next calving changed linearly.

Milk fat yield and protein yield were estimated from milk yield and the concentration of these components in milk. Milksolids production, a milk production trait in New Zealand, was estimated from the sum of milkfat yield and protein yield.

Cow's energy requirements and feed demand

Cow metabolisable energy (ME) requirement was estimated as indicated by Nicol and Brookes (2007). Total ME requirement (MJ/day) for each cow was determined by their ME requirements for maintenance (ME_m), LW change (ME_{lwc}), pregnancy (ME_p), and lactation (ME_l); and the efficiency (k) with which ME was used for maintenance (k_m), LW change (k_{lwc}), pregnancy (k_p) and lactation (k_l):

$$ME\ (MJ/day) = ME_m / k_m + ME_{lwc} / k_{lwc} + ME_p / k_p + ME_l / k_l \tag{4.7}$$

where $k_m=(ME_{feed}\times0.02)+0.5$, $k_l=(ME_{feed}\times0.02)+0.4$, and $kp=0.133$. ME_{feed} refers to the energy concentration of the feed dry matter (MJ ME/kg DM). During LW gain, $k_{lwc}=0.95\times k_l$ in lactating cows, and $k_{lwc}= (ME_{feed}\times0.42)+0.006$ in dry cows. During LW loss, $k_{lwc}=k_l$ in lactating cows, and $k_{lwc}= k_m$ in dry cows.

ME_m was the sum of the ME requirements for basal metabolism (Eq. (4.8)), chewing and walking during grazing (Eq. (4.9) and Eq. (4.10), respectively), and other activity (Eq. (4.11)):

$$ME_{m\ basal}\ (MJ/day) = 1.5 \times 0.28 \times e^{-0.03\times A} \times LW^{0.75} \tag{4.8}$$

$$ME_{m\ chewing}\ (MJ/day) = LW \times 0.0025 \times DMI \times (0.9 - Dig) \tag{4.9}$$

$$ME_{m\ walking}\ (MJ/day) = 0.026 \times LW \times 1 \times 0.07/(0.57 \times PM + 0.16) \tag{4.10}$$

$$ME_{m\ other}\ (MJ/day) = LW \times (0.0026 \times Hkm) \tag{4.11}$$

Where *e* is the base of natural logarithms, A is the age of the cow in years, LW is the cow LW (kg), DMI is dry matter intake (kg/d), Dig is the feed digestibility ($Dig=ME_{feed}/15.088$), PM is the pre-grazing pasture mass (assumed to be 2.5 t/ha), and Hkm is the daily horizontal distance walked by the cow when no grazing (assumed to be 3 km of flat land).

During periods of LW gain, ME_{lwc} corresponded to the ME requirement for LW gain and was estimated as indicated in Eq. (4.12):

$$ME_{lwc}(MJ/day) = 1.1\times(0.92\times LW_g\times((6.7\times R_g)+(20.3-R_g)/1-e^{-6x(LW/SRW-0.4)})) \quad (4.12)$$

Where LW_g is the amount of LW gain (kg), $R_g=(920\times LW_g)/(4\times SRW^{0.75})-1$ is an adjustment for the rate of LW gain, SRW is the standard reference LW. In 1st, 2nd, and 3rd, lactation cows LW_g also included the daily LW gain associated with growth: $LW_{growth} = (LW_l - LW_{l-1})/365$, where LW_l and LW_{l-1} are the average LW in the l lactation and the previous lactation, respectively.

During periods of LW loss, ME_{lwc} represented the dietary energy spared due to LW loss and was estimated as indicated in Eq. (4.13):

$$ME_{lwc}\ (MJ/day) = LW_{loss} \times GE_{lost} \times Eff_{use} \quad (4.13)$$

Where LW_{loss} is kg of LW lost (with a negative value), GE_{lost} is the gross energy associated with body tissue mobilisation (25 MJ/kg LW lost) and Eff_{use} is the efficiency with which that energy is used by the body (0.80 in dry cows and 0.84 in lactating cows).

The ME requirement for pregnancy was estimated assuming a pregnancy length of 282 days (LIC, 2011), as indicated in Eq. (4.14):

$$ME_p\ (MJ/day) = (C_{bw} / 40) \times (e^{349.222 - 349.164 \times \Psi} \times 0.0201 \times \Psi) \quad (4.14)$$

Where $(C_{bw}/40)$ is calf birth weight (assumed to be 35kg ± 2.3) scaled to 40 kg, the rest of the equation corresponds to the net energy requirements for growth of the foetus and associated tissue; $\Psi=e^{-0.0000576t}$, where t is the day of pregnancy.

ME_l was estimated based on daily MY and the net energy requirement to produce one litre of milk:

$$ME_l\ (MJ/day) = 1.1 \times MY \times ((0.376 \times F\%) + (0.209 \times P\%) + 0.976) \quad (4.15)$$

Total dry matter demand of the milking herd was estimated by dividing the ME requirement of all the cows by the energy concentration of the feed.

Feed supply and stocking rate

Cows simulated by the model were fed pasture (ryegrass-white clover) and supplements. The model assumed that on each farm, 14.5 t DM/ha of pasture were grown per year and 76% (11 t DM/ha) of the pasture produced was utilised (Holmes et al., 2002; MacDonald, 2011). From June to May of the following year the energy concentration of pasture was assumed to be 10.9, 11.0, 11.1, 11.5, 11.4, 11.3, 11.2, 10.7, 10.5, 10.3, 10.9, and 11.0 MJ ME/kg DM, respectively (Litherland & Lambert, 2007). The amount of supplementary feed (assumed to be conserved pasture) offered to the herd per year (t DM/ha) could be entered as a model input (fixed value) or determined by the model based on the feed demand of the herd (it was assumed that cows met their ME requirements at all times). The energy concentration of the supplements fed was assumed to be 10 MJ ME/kg DM. Herd size and stocking rate (cows/ha) were adjusted to match feed demand and feed supply on the farm.

Calves were fed milk (3.6 MJ ME/litre, 4 litres/day) and meal (12.5 MJ ME/kg DM, enough to meet their ME requirements) until 2 months of age. Heifers were sent to a runoff, where they were fed only pasture, and returned to the milking platform before calving.

Economic performance

Farm income

The economic performance of simulated farms was reported in New Zealand dollars (NZ $1 = US $0.7801, as of August 15, 2012; RBNZ, 2012). Milk income was estimated based on the New Zealand A+B-C payout system, which pays for milkfat and protein, and penalises milk volume. Gross farm income (GFI) was determined by the sale of milk (Milk_{inc}), stock ($\text{Stock}_{\text{inc}}$) and other miscellaneous dairy income ($\text{Other}_{\text{inc}}$), as indicated in Eq. (4.16):

$$\text{GFI (\$)} = \text{Milk}_{\text{inc}} + \text{Stock}_{\text{inc}} + \text{Other}_{\text{inc}} \qquad (4.16)$$

Milk income was estimated as indicated in Eq. (4.17):

$$\text{Milk}_{\text{inc}}\ (\$) = (\ (F_{kg} \times F_p) + (P_{kg} \times P_p) + (V_l \times V_p)\ ) \qquad (4.17)$$

Where F_{kg} and P_{kg} are milkfat and protein yields, respectively; F_p and P_p are milkfat and protein price (\$/kg), respectively, V_l is the volume of milk produced (litres), V_p is the penalty for volume of milk produced (\$/litre) and has a negative value.

Values for milk payout and fat to protein price ratio were obtained from New Zealand statistics (DairyNZ, 2012; NZAEL, 2012a). A milk payout of \$5.59/kg milkfat, \$10.62/kg protein and -\$0.04/litre of milk was used in the simulations, which corresponded to the 2010-2011 milk payout in New Zealand (\$7.36 /kg milksolids, milksolids= milkfat + protein).

Stock income was derived from the sale of culled cattle for beef (male calves, surplus female calves, surplus heifers and culled cows) as indicated in Eq. (4.18):

$$\text{Stock}_{\text{inc}}\ (\$) = \sum_{i=1}^{12} C_{kg} \times C_p \qquad (4.18)$$

Where i is the age group of the herd (12 groups: calves, R1 heifers, R2 heifers and cows from 2 to 10 years old), C_{kg} is the total carcass weight (kg) for sale of the i age group, and C_p is the carcass price (\$/kg) of the i age group.

LW of calves, R1 and R2 heifers at the time of culling were 8%, 40% and 70% of mature LW, respectively (Clark & MacDonald, 2007). For calves and heifers, carcass yield was assumed to be 50% and 53% of live weight, respectively (Lopez-Villalobos et al., 2000b). Carcass yield (CY%) of cows was estimated as indicated by McCall and Marshall (1991) in Eq. (4.19):

$$\text{CY\%} = 0.41 + 0.000208\ \text{LW} \qquad (4.19)$$

Beef prices used in the model were obtained from the Animal Evaluation economic value update (NZAEL, 2012a), and are shown in Table 3. Other miscellaneous dairy income ($Other_{inc}$, e.g. sale of hay) was assumed to be $46/ha (DairyNZ, 2012).

Table 3 Beef prices assumed in the model for disposed livestock (NZAEL, 2012a)

Type of animal and carcass weight	Value of beef (NZ $/kg carcass)
Male and female calves	
< 13.5 kg	0.73
13.5 - 18.5 kg	1.09
> 18.5 kg	2.54
Cows and Heifers	
< 145 kg	2.25
145 - 170 kg	2.52
170 - 195 kg	2.67
196 - 220 kg	2.74
> 220 kg	2.83

Farm expenses

Farm expenses were divided into marginal expenses and feed expenses. Marginal expenses comprised variable and fixed farm expenses, including rearing of replacement stock, but excluded expenses associated with feeding of the milking herd. Adjustments for labour, depreciation, runoff and livestock numbers were also included into marginal expenses (Table 4). Feed expenses were determined by the feed demand of the herd (kg DM) and feed price. Pasture and supplement prices used for the simulations were $0.10/kg DM and $0.25/kg DM, respectively (Holmes & Matthews, 2001),

Farm operating profit was estimated as the difference of gross farm income and farm expenses.

Table 4 Marginal costs (NZ$/cow) assumed in the simulations (DairyNZ, 2012).

Item	NZ $/cow
Wages	209
Animal health	81
Breeding, herd improvement	45
Farm dairy	20
Electricity	35
Young stock grazing	125
Runoff lease	22
Vehicles, Fuel	66
Repairs, maintenance	121
Freight	19
Administration	40
Insurance, ACC and rates	62
Depreciation	134
Labour	153
Runoff	28
Livestock	27
Total	1187

Application of the model

The model was used to simulate a group of 5600 farms, each of 120 ha and with 325 cows (2.71 cows/ha, average farms). This represents the average cow population (1,820,000 cows), and the average herd size and stocking rate of dairy farms, in the North Island of New Zealand (LIC, 2011). From all the cows simulated, the top 325 cows for milkfat UFA concentration were segregated to form a 120 ha farm (2.71 cows/ha) that produced milkfat with high UFA concentration ($UFA_{2.71}$ farm). As feed demand per hectare in the $UFA_{2.71}$ farm was lower than in average farms, another scenario was simulated where the top 353 cows for milkfat UFA concentration were segregated from a group of 5600 farms (1,820,000 cows) to form a 120 ha farm (2.94 cows/ha) that produced milkfat with high UFA concentration ($UFA_{2.94}$ farm). A stocking rate of 2.94 cows/ha was investigated because it was estimated that at this stocking rate feed demand per hectare in the high UFA farm was equivalent to that of average farms.

The physical and financial characteristics of the three groups of farms simulated (average, $UFA_{2.71}$, and $UFA_{2.94}$) were compared by bootstrapping methodology (Henderson, 2005). For this, the simulation of 5600 farms and the segregation of cows were repeated 1000 times. In each run, a value (θ^*_1 , θ^*_2 , … θ^*_{1000}) was obtained for each trait (θ), and the trait mean ($\overline{\theta}$) was estimated as: $\overline{\theta} = (\theta^*_1 + \theta^*_2 + \ldots + \theta^*_{1000})/1000$. The bootstrap percentile method was used to determine the confidence interval at the 95% level of confidence (α=0.05), as follows: 1) bootstrap values (θ^*_1 , θ^*_2 , … θ^*_{1000}) of a trait (θ) were sorted from smallest to largest (θ^*_{1st} , θ^*_{2nd} , … θ^*_{1000th}); 2) the lower (L_{th}) and upper (U_{th}) confidence intervals were estimated as: $L_{th}=(\alpha/2)\times 1000$ and $U_{th}=1000 - L_{th}$, respectively; 3) for 1000 iterations and α=0.05, the lower and upper confidence intervals of each trait (θ) corresponded to the 25th and 975th ordered elements [θ_{25th} , θ_{975th}], respectively.

RESULTS

During the milk production season, milkfat UFA concentration on farms simulated by the model was close to that of the original dataset from which the milkfat UFA concentration prediction equations for the model were developed (Figure 2). The mean values of key performance indicators for dairy farms simulated by the model were very close to published statistics for New Zealand dairy farms (Table 5).

Figure 2 Actual (——) and simulated (– – –) concentration (mean and 95% confidence interval) of unsaturated fatty acids (UFA) in milkfat during the milk production season. The actual milkfat UFA concentration corresponds to cows in the sire proving scheme of Livestock Improvement Corporation dataset (Source of UFA data for the model). The simulated milkfat UFA concentration corresponded to 5600 dairy farms simulated by the model.

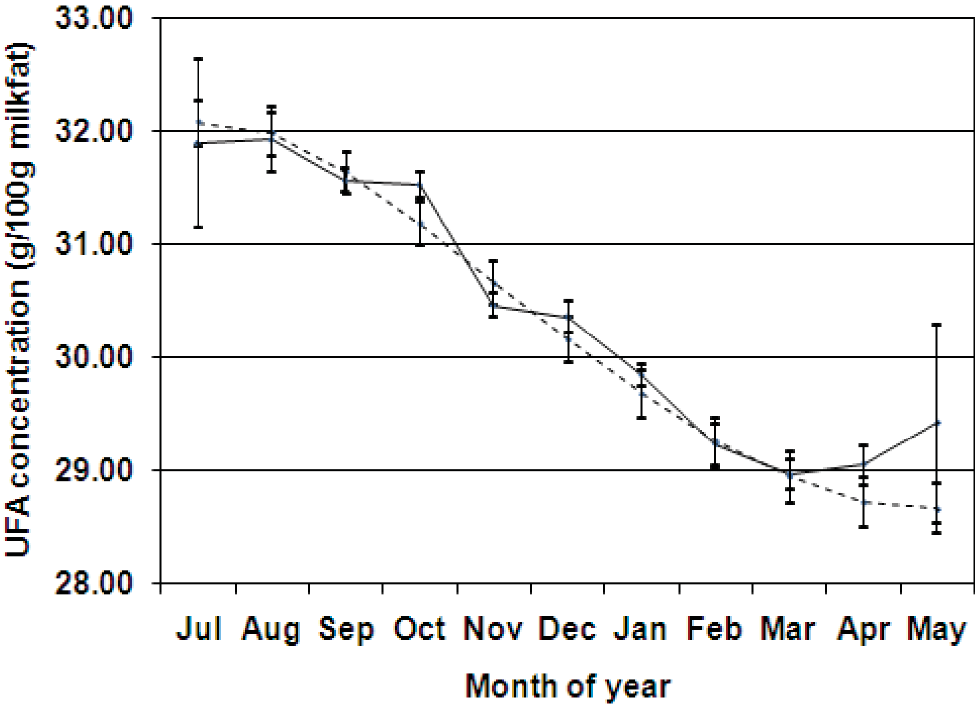


Table 5 Average production and financial characteristics of New Zealand dairy farms and simulated dairy farms [6].

	New Zealand	Simulated farms [6]	
Physical characteristics			
Per cow			
Lactation length (days)	268 [1]	267	(266 - 268)
Milk yield (Litres)	4,301 [1]	4,351	(4,267 - 4,425)
Milkfat yield (kg)	187 [1]	188	(184 - 191)
Protein yield (kg)	155 [1]	156	(153 - 160)
Milksolids yield (kg)	343 [1]	345	(337 - 350)
Fat %	4.35 [1]	4.33	(4.28 - 4.38)
Protein %	3.60 [1]	3.60	(3.57 - 3.63)
g UFA/100 g of milkfat	30.23 [2]	30.12	(29.92 - 30.32)
Live weight (kg)	491 [1]	491	(488 - 495)
Feed intake (kg DM)	4,319 - 4,784 [3]	4,574	(4,526 - 4,623)
Supplementary feed (kg DM)	329 - 404 [4]	516	(464 - 566)
Per hectare			
Milk yield (Litres)	10,554 [1]	11,788	(11,556 - 11,983)
Milkfat yield (kg)	524 [1]	510	(500 - 521)
Protein yield (kg)	399 [1]	423	(414 - 430)
Milksolids yield (kg)	923 [1]	935	(918 - 948)
Supplementary feed (kg DM)	905 - 1,082 [4]	1,389	(1,247 - 1,519)
Financial characteristics ($)			
Per cow			
Milk income	2,557 [5]	2,528	(2,483 - 2,568)
Gross farm income	2,708 [5]	2,729	(2,684 - 2,772)
Farm expenses	1,694 [5]	1,721	(1,709 - 1,733)
Operating profit	1,013 [5]	1,008	(975 - 1,038)
Per hectare			
Milk income	7,092 [5]	6,847	(6,725 - 6,956)
Gross farm income	7,509 [5]	7,392	(7,270 - 7,507)
Farm expenses	4,700 [5]	4,662	(4,629 - 4,695)
Operating profit	2,810 [5]	2,730	(2,639 - 2,812)

Source: [1] LIC, (2011); [2] milkfat UFA concentration in cows from the sire proving scheme of Livestock Improvement Corporation; [3] Values estimated from Holmes (2000) and DairyNZ (2013b) (eaten feed demand) for cows with equivalent live weight and production levels; [4] Silva-Villacorta et al., (2005); [5] DairyNZ, (2012), [5] Mean (and 95% confidence interval) of 5600 simulated dairy farms, replicated 1000 times, [6] DM= dry matter; Milksolids= milkfat + protein; UFA= unsaturated fatty acids.

The physical and financial characteristics of average, $UFA_{2.71}$, and $UFA_{2.94}$ farms are presented in Table 6 and Table 7.

Table 6 Physical characteristics (mean and 95% confidence interval) of 5600 simulated dairy farms (Average farms) and a farm formed by the segregation of the top 325 ($UFA_{2.71}$ farm) or 353 ($UFA_{2.94}$ farm) cows for concentration of unsaturated fatty acids in milkfat (DM = Dry matter, milksolids= milkfat + protein). Means within a row with different superscript letter are significantly different.

Trait	Average farms		$UFA_{2.71}$ farm		$UFA_{2.94}$ farm	
N	5600		1		1	
Farm size (Ha)	120		120		120	
Herd size (cows)	325		325		353	
Stocking rate (Cows/ha)	2.71		2.71		2.94	
Per cow production						
Lactation length (days)	267^{x}	(267 - 268)	267^{x}	(267 - 268)	268^{x}	(267 - 268)
Milk yield (Litres)	$4,349^{x}$	(4,267 - 4,425)	4392^{x}	(4,292 - 4,491)	$4,396^{x}$	(4,296 - 4,492)
Fat yield (kg)	188^{a}	(184 - 191)	140^{b}	(137 - 143)	140^{b}	(137 - 143)
Protein yield (kg)	156^{a}	(153 - 160)	132^{b}	(129 - 135)	133^{b}	(130 - 136)
Milksolids yield (kg)	345^{a}	(337 - 350)	272^{b}	(266 - 278)	273^{b}	(267 - 279)
Fat %	4.33^{a}	(4.28 - 4.38)	3.24^{b}	(3.20 - 3.28)	3.25^{b}	(3.21 - 3.28)
Protein %	3.60^{a}	(3.57 - 3.63)	3.04^{b}	(3.02 - 3.06)	3.04^{b}	(3.02 - 3.06)
g UFA/100 g of milkfat	30.12^{a}	(29.92 - 30.32)	37.27^{b}	(37.16 - 37.38)	37.23^{b}	(37.13 - 37.33)
Live weight (kg)	491^{x}	(488 - 495)	488^{x}	(484 - 492)	488^{x}	(484 - 493)
Feed demand (kg DM)	$4,574^{a}$	(4,526 - 4,623)	4218^{b}	(4,165 - 4,276)	4225^{b}	(4170 - 4277)
Supplement demand (kg)	516^{a}	(464 - 566)	156^{c}	(104 - 215)	485^{b}	(431 – 538)
Per hectare						
Milk yield (Litres)	11780^{a}	(11556 - 11983)	11894^{a}	(11,625 - 12,164)	12932^{b}	(12,638 - 13,213)
Fat yield (kg)	510^{a}	(500 - 521)	379^{c}	(370 - 387)	413^{b}	(403 - 422)
Protein yield (kg)	423^{a}	(414 - 430)	358^{c}	(350 - 367)	390^{b}	(381 - 399)
Milksolids yield (kg)	935^{a}	(918 - 948)	737^{c}	(721 - 753)	803^{b}	(785 - 820)
Pasture utilised (t DM)	11^{x}		11^{x}		11^{x}	
Supplement demand (kg DM)	$1,389^{a}$	(1,247 - 1519)	422^{b}	(281 - 581)	1428^{a}	(1268 - 1582)

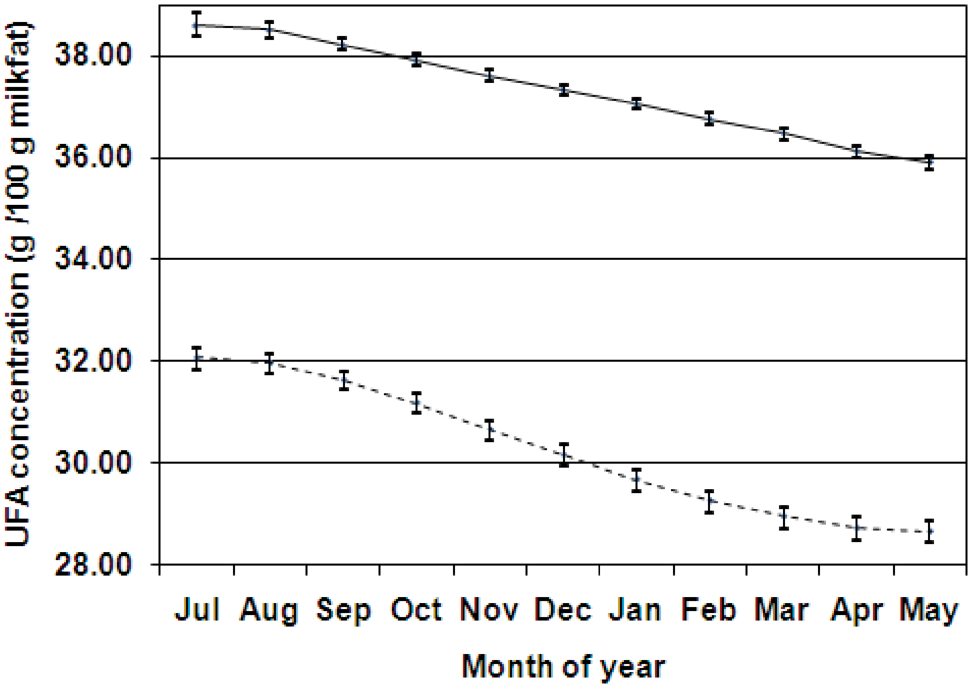
Table 7 Financial characteristics (mean and 95% confidence interval between brackets), of 5600 simulated dairy farms (Average farms) and a farm formed by the segregation of the top 325 ($UFA_{2.71}$ farm) or 353 ($UFA_{2.94}$ farm) cows for concentration of unsaturated fatty acids in milkfat (Values are in New Zealand dollars. Milk price: $5.59/kg milkfat, $10.62/kg protein and -$0.04/litre of milk). Means within a row with different superscript letter are significantly different.

Trait	Average farms		$UFA_{2.71}$ farm		$UFA_{2.94}$ farm	
Per cow ($)						
Milk income	2,528^{a}	(2,483 - 2,568)	2,011^{b}	(1,967 - 2,056)	2,017^{b}	(1,973 - 2,060)
Stock income	184^{x}	(182 - 187)	182^{x}	(178 - 187)	185^{x}	(180 - 189)
Other income	16.98^{x}		16.98^{x}		15.6^{x}	
Gross farm income	2,729^{a}	(2,684 - 2,772)	2,211^{b}	(2,166 - 2,256)	2,217^{b}	(2,172 - 2,261)
Marginal expenses	1,187^{x}		1187^{x}		1,187^{x}	
Feed expenses	534^{a}	(522 - 546)	445^{b}	(432 - 460)	495^{c}	(482 - 508)
Farm expenses	1,721^{a}	(1,709 - 1,733)	1,632^{b}	(1,619 - 1,647)	1,682^{c}	(1,669 - 1,695)
Operating profit	1,008^{a}	(975 - 1,038)	579^{b}	(546 - 611)	535^{b}	(502 - 568)
Per hectare ($)						
Milk income	6,847^{a}	(6,725 - 6,956)	5,447^{b}	(5,328 - 5,567)	5,933^{c}	(5,804 - 6,061)
Stock income	499^{a}	(493 - 506)	494^{a}	(482 - 507)	543^{b}	(531 - 556)
Other income	46^{x}		46^{x}		46^{x}	
Gross farm income	7,392^{a}	(7,270 - 7,507)	5,988^{b}	(5,866 - 6,111)	6,523^{c}	(6,390 - 6,652)
Marginal expenses	3,215^{a}		3,215^{b}		3,492^{c}	
Feed expenses	1,447^{a}	(1,414 - 1,480)	1,206^{b}	(1,170 - 1,245)	1,457^{a}	(1,417 - 1,496)
Farm expenses	4,662^{a}	(4,629 - 4,695)	4,420^{b}	(4,385 - 4,460)	4,949^{c}	(4,909 - 4,987)
Operating profit	2,730^{a}	(2,639 - 2,695)	1,567^{b}	(1,478 - 1,654)	1,574^{b}	(1,478 - 1,672)

Comparison between UFA farms and average farms

On average, UFA farms produced milkfat with significantly higher UFA concentration (+23.6%) than average farms (Table 6). The difference in milkfat UFA concentration between UFA farms and average farms was observed throughout the milk production season (July to May) and vary between +19% and +26% (Figure 3, $UFA_{2.71}$ farm not shown since its values were very close to that of the $UFA_{2.94}$ farm).

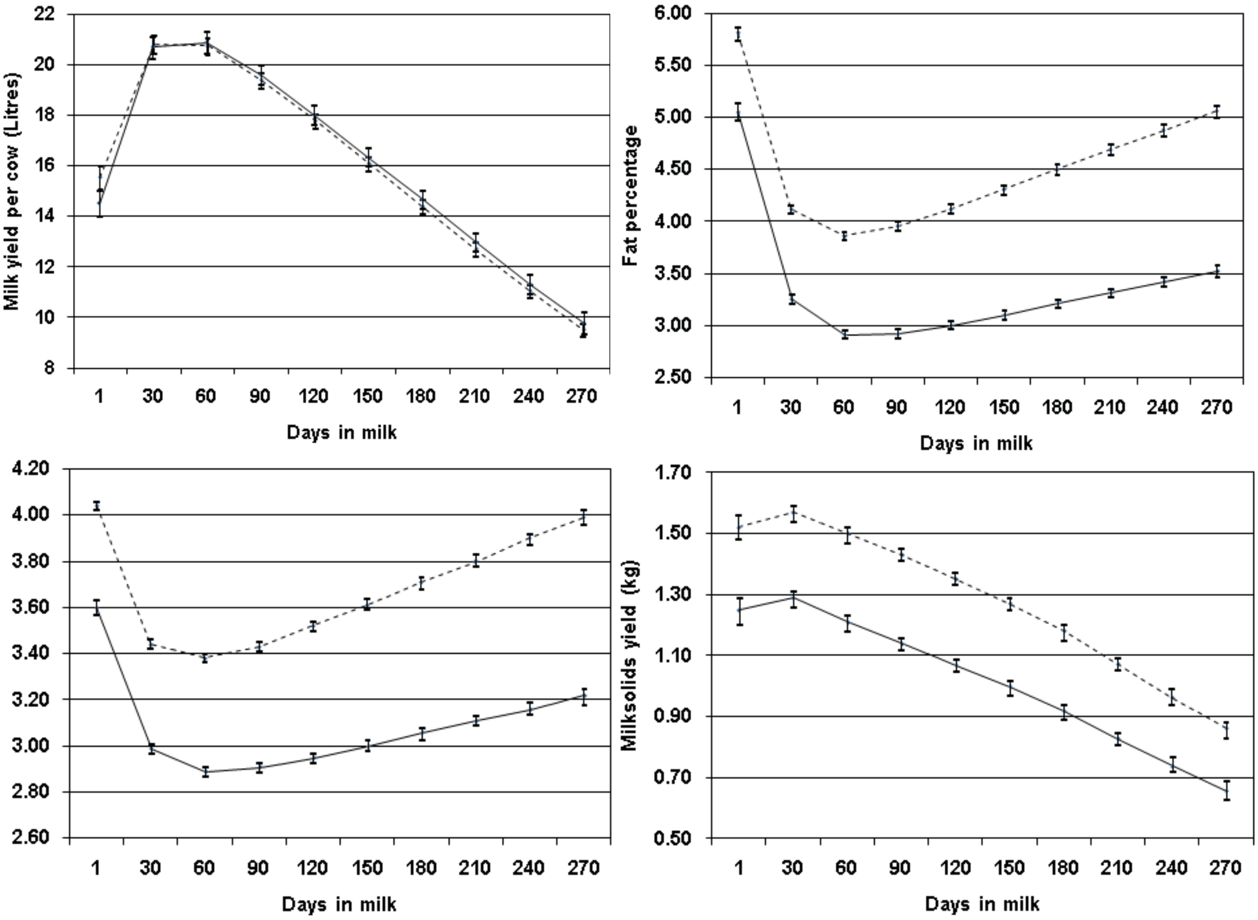
Figure 3 Concentration (mean and 95% confidence interval) of unsaturated fatty acids (UFA) in milkfat produced by average farms (– – –) and the $UFA_{2.94}$ farm (——) during the dairy season.



Per cow, there were no significant differences in lactation length, milk yield (Figure 4) and live weight between UFA farms and average farms, but feed demand per cow was significantly lower on UFA farms than on average farms (Table 6). For both, per cow and per hectare measures, UFA farms had significantly lower percentages of milkfat and protein, and lower yields of milk fat, protein and milksolids, than average farms. These differences were maintained during the lactation (Figure 4). Per hectare, the $UFA_{2.94}$ farm had significantly higher milk yield than average farms and the UFA$_{2.71}$ farm had significantly lower supplement demand than average farms.

UFA farms had significantly lower milk income, gross farm income and operating profit than average farms, both per cow and per hectare (Table 7). The UFA$_{2.71}$ farm had lower feed and farm expenses than average farms, both per cow and per hectare. Per hectare, feed expenses were not significantly different between the UFA$_{2.94}$ farm and the average farms, but farm expenses were significantly higher in the UFA$_{2.94}$ farm than in the average farms.

Figure 4 Milk yield, percentages of milkfat and protein, and milksolids (milk fat + protein) production per cow (mean and 95% confidence interval) for the average farms (**– – –**) and the UFA$_{2.94}$ farm (**——**)



Comparison between UFA$_{2.71}$ farm and UFA$_{2.94}$ farm

On a per cow basis, the UFA$_{2.94}$ farm had significantly higher supplement demand, feed expenses and farm expenses than the UFA$_{2.71}$ farm, but there were no significant differences in other physical and financial traits (Table 7).

On a per hectare basis, the UFA$_{2.94}$ farm had significantly higher yields of milk, milk fat, protein, and higher supplement demand than the UFA$_{2.71}$ farm (Table 7). Milk income, stock income, gross farm income, feed expenses and farm expenses were also higher in the UFA$_{2.94}$ farm than in the UFA$_{2.71}$ farm, but there were no significant differences in operating profit between the two UFA farms.

DISCUSSION

The present stochastic farm model was based on the Cholesky decomposition algorithm of (co)variance matrices. This method has been used previously in the development of stochastic farm models (Baudracco et al., 2013; Din et al., 2011; León-Velarde & Quiroz, 2001). The model was developed using published data for New Zealand Holstein-Friesian cows under grazing conditions. Therefore, data simulated by the model can only be extrapolated to individual cows or herds of Holstein-Friesian dairy cattle under grazing conditions. Furthermore, caution should be taken when interpreting the results of this study given that the application of the model developed is limited to the population it was developed from. In Chapter 3 it was found that the between-animal variation in milkfat UFA concentration is larger than the between-breed variation. Therefore, milkfat UFA concentration can also be increased in other breeds of dairy cattle (e.g. New Zealand crossbred cows). Knowledge of means, standard deviations, and correlations necessary for the estimation of parameters for the lactation curves of each trait is required to enable application of this model to other populations.

The model was evaluated by comparing simulated results with national statistics of New Zealand dairy farms (Table 5) and by asking an expert in dairy production for feedback on the assumptions and credibility of the model and the model output. These validation techniques (Sørensen, 1990), that have also being used in previous studies (Allen & Stewart, 1983; Congleton, 1984; Halasa et al., 2009), were selected because an external dataset with all input and output variables considered in the model was not available to conduct a validation of the model through goodness of fit tests.

When means of simulated performance traits were expressed per cow they were closer to national dairy statistics than when they were expressed per hectare (Table 5). These small differences were explained by differences in stocking rate between sources of dairy statistics, and the use of national averages when statistics specific for the Holstein-Friesian breed were not available. Although the values were close, the supplementary feed demand in simulated farms was higher than in the source of statistics for this trait. Since both, the source of statistics for supplementary feed demand and the farm model considered that 11 tonnes of pasture dry matter were eaten per hectare, the higher supplementary feed demand (per cow and per hectare) in the simulated farms is associated with their higher production levels than the source of statistics. As observed in Figure 2, the model was also able to simulate the milkfat UFA concentration from cows in the sire proving scheme of Livestock Improvement Corporation (original dataset). This indicates that the farm model developed was able to simulate dairy cows and farms with a milkfat UFA concentration characteristic of the population used in the development of the model.

The model was used to simulate the effect of altering milkfat UFA concentration by segregating cows with high milkfat UFA concentration to nominated farms. The segregation of dairy cows has been mentioned in the past as an option to harvest natural variation in milk composition (Garrick & Lopez-Villalobos, 2001; Thomson et al., 2003b). The present simulation study assumed that farms were under similar environmental conditions, based on pasture and without the manipulation of the diet to alter milkfat UFA concentration. The $UFA_{2.71}$ farm and $UFA_{2.94}$ farm had lower percentages of milkfat and protein and produced less milk fat, protein and milksolids than average farms, both per cow and per hectare (Table 6). These results are in agreement with other studies which reported a negative association between milkfat UFA concentration and other milk production traits (Hurtaud & Peyraud, 2007; Stoop et al., 2008; Chapter 3). Given that simulations made by the model were based on the correlations between milkfat UFA concentration and other milk production traits, the decrease in milk fat, protein and milksolids will be caused by the negative phenotypic and genetic correlations between these traits, (Schennink et al., 2008; Soyeurt et al., 2008b; Soyeurt et al., 2007; Stoop et al., 2008).

Since the $UFA_{2.71}$ farm and $UFA_{2.94}$ farm produced significantly less milksolids than average farms, their operating profit was significantly lower (-$1,163/ha and -$1,156/ha, respectively, $P<0.05$) than that of average farms (Table 7). The decrease in operating profit in the UFA farms was influenced by the milk payment system, which pays for yields of milkfat and protein only, and does not reward the milkfat UFA concentration. This highlights the need to modify the payment system before a programme to increase milkfat UFA concentration is established. Previous studies have also mentioned the need to alter the milk payment system so that farm operating profit is not negatively affected when milkfat UFA concentration is increased (Arnould & Soyeurt, 2009; Walker et al., 2004). Although the cost of establishment of high UFA farms was not considered in this study, it will also have to be evaluated before a programme to increase the milkfat UFA concentration is established.

As cows producing milkfat high in UFA ($UFA_{2.71}$ farm) produced less milkfat and protein than average cows, their feed demand was lower than that of average cows (Table 6). As a consequence, at the same stocking rate (2.71 cows/ha), the $UFA_{2.71}$ farm had lower feed demand per hectare than average farms. Since it has been reported that increasing feed utilisation by increasing stocking rate may increase total milksolids production and farm profit (MacDonald & Hedley, 2010), it was hypothesized that increasing the stocking rate in the UFA farm will maximise feed utilisation, and increase milksolids production and farm profit. In order to utilise the same amount of feed per hectare than average farms, the stocking rate in the UFA farm was increased to 2.94 cows per hectare ($UFA_{2.94}$ farm).

Although, the $UFA_{2.94}$ farm utilised more feed (kg DM/ha), and had higher milksolids production (kg/ha) than the $UFA_{2.71}$ farm, there were no significant differences in operating profit ($/ha) between the two UFA farms. Furthermore, the difference in operating profit ($/ha) between the $UFA_{2.94}$ farm and average farms (-$1,156/ha) was similar to the one between the $UFA_{2.71}$ farm and average farms (-$1,163/ha). This is because an increase in feed supply and stocking rate in the $UFA_{2.94}$ farm was associated with an increase milksolids production per hectare, but not with milksolids production per cow. Therefore, the higher stocking rate in the $UFA_{2.94}$ farm was not only associated with higher production and income per hectare, but also with higher farm expenses per hectare. In the past, it has also been reported that an increase in stocking rate and feed input was associated with increases in production, income and expenses per hectare, but without altering the farm operating profit per hectare significantly (Silva-Villacorta et al., 2005).

Most of the studies that focused on altering milkfat composition have been short-term and have not looked at the farm system as a whole. The farm model developed in this study can help to investigate the effects of altering the milkfat UFA concentration on farm. However, since this model does not consider the manipulation of the diet, caution should be taken when interpreting the results. In some studies it was reported that the feeding of protected oils increased milkfat UFA concentration without affecting milkfat yield per cow (Thomson et al., 2002). It is possible that different results would be obtained if segregation was combined with manipulation of the diet (feeding of protected oils) to increase milkfat UFA concentration. However, an additional model that includes the effect of feeding protected oils would be needed to study the effects of manipulation of the diet to increase milkfat UFA concentration.

CONCLUSION

The use of the farm bio-economic model developed in the present study helped to investigate the effects of segregating cows between farms to increase milkfat composition. Compared to average farms, the $UFA_{2.71}$ and $UFA_{2.94}$ farms had lower yields of milkfat, protein and milksolids. Under the current payment system, this reduction in production negatively affected the operating profit in the $UFA_{2.71}$ and $UFA_{2.94}$ farms. These results highlight the need to modify the milk payment system to include a premium for concentration of UFA in milkfat before a programme to increase the milkfat UFA concentration is established. In this study, the high UFA farms need an extra $1,156-1,163/ha to break even with average farms.

CHAPTER 5

Characteristics of a group of farms set up for the production and supply of milk with high concentration of unsaturated fatty acids in milkfat: A simulation study

ABSTRACT

The present study investigated, via simulation, the characteristics of farms that produce milkfat with a high concentration of unsaturated fatty acids (UFA) under a seasonal pastoral system. A stochastic model, based on a (co)variance matrix of milk traits and live weight was used to generate a population of 1,820,000 cows and 5,600 dairy farms. Simulated farms were, on average, 120 ha and had 325 cows (2.71 cows/ha) and had a spring calving pattern. In each farm, 11 t/ha/year of pasture dry matter were consumed, and supplements were used to cover feed deficits. From the population simulated, the top 17,150 cows for milkfat UFA concentration were segregated and randomly distributed onto 50 farms (UFA farms), each being 120 ha and with 343 cows (2.86 cows/ha). A higher stocking rate was chosen for UFA farms so that their feed demand per hectare was similar to that of average farms. The financial performance of the UFA farms was evaluated at a milksolids (milkfat + protein, MS) payout of \$5.21/kg MS and \$7.37/kg MS. The simulation was replicated 1,000 times and a 95% confidence interval for each trait was found using bootstrapping methodology. During the milk production season (July 20 – May 10) UFA farms produced significantly more milk (12,534 vs 11,788 litres/ha, $P<0.05$) than average dairy farms. Milk produced by the UFA farms had a higher concentration of UFA in milkfat (35.15 vs 30.12 g /100 g milkfat, $P<0.05$), but lower concentrations of milkfat (3.55 vs 4.33 %, $P<0.05$) and protein (3.19 vs 3.60 %, $P<0.05$), and lower yields of milkfat (445 vs 510 kg/ha, $P<0.05$) and protein (399 vs 423 kg/ha, $P<0.05$) than average dairy farms. At both milksolids payouts (\$5.21/kg MS and \$7.37/kg MS), UFA farms had lower milk income, gross farm income and farm operating profit, both per cow and per hectare, than average dairy farms. The difference in operating profit per hectare between UFA farms and average farms was larger at a milksolids payout of \$7.37/kg MS (-\$1434/ha) than at a milksolids payout of \$5.21/kg (-\$1242/ha). These results indicate that a premium for milkfat UFA concentration is necessary for dairy farmers that supply milk with high UFA concentration.

Keywords: unsaturated fatty acids, stochastic farm model, dairy cattle segregation

INTRODUCTION

There has been a growing interest in the manipulation of milkfat composition at the farm level, prompted by the trend in consumer demands toward food products with health benefits and convenience (Özer & Kirmaci, 2010). Milkfat composition affects the processability of milk, its nutritional value and the organoleptic characteristics of dairy products (Augustin et al., 2013; Smet et al., 2009). Increasing the concentration of unsaturated fatty acids (UFA) in milkfat can improve the spreadability of butter (Couvreur et al., 2006) and may have health benefits if it is associated with increases in cis 9 trans 11 C18:2 (c9 t11 CLA), cis polyunsaturated fatty acids (PUFA) or omega 3 fatty acids (n-3 PUFA) (Bhattacharya et al., 2006; FAO, 2010).

The concentration of UFA in milkfat is influenced by nutrition, cow genetics, stage of lactation, parity and the energy status of the cow (Auldist et al., 1998; Thomson & Van-der-Poel, 2000). Considering the different factors that influence milkfat composition, dairy farmers could implement strategies on-farm to increase the concentration of UFA in milkfat in order to supply dairy processors interested in this type of milk. Several studies have investigated the possibility of increasing milkfat UFA concentration through the manipulation of the diet (Oeffner et al., 2013; Sun et al., 2013) and genetic selection (Heck et al., 2012a; Marchitelli et al., 2013). The segregation of dairy cows has also been suggested as an option to alter the composition of milk supplied to dairy processors (Chen et al., 2004; Garrick & Lopez-Villalobos, 2001; Thomson et al., 2003b). Therefore, dairy cows that produce milkfat with high UFA concentration could be segregated to form herds that produce milk with high milkfat UFA concentration.

Previous studies have reported negative genetic and phenotypic correlations between milkfat UFA concentration and milkfat yield, and between milkfat UFA concentration and the percentages of milkfat and protein (Arnould &

Soyeurt, 2009; Schennink et al., 2008; Soyeurt et al., 2007; Stoop et al., 2008). Analysis of New Zealand data in Chapter 3 indicated that protein yield per cow could also be negatively affected in dairy cows that produce milkfat with a high UFA concentration. Under the current New Zealand milk payment system, which rewards milkfat and protein yields and penalises milk volume (LIC, 2012), these losses in production could negatively affect farm profit.

Before implementing a programme to increase the concentration of UFA in milkfat, it is necessary to be aware of its potential consequences. Currently little is known about how increasing the milkfat UFA concentration on-farm could affect farm production and profit. Also, there is little information about the effect on farm operating profit of segregating dairy cows between farms according to their milkfat UFA concentration. Given this gap in knowledge the objective of the present study was to investigate the physical and financial characteristics of a group of farms formed by the segregation of dairy cows that produce milk with high UFA concentration under New Zealand conditions.

MATERIALS AND METHODS

The bio-economic stochastic farm model developed in Chapter 4 was used to simulate the segregation of dairy cows into herds that produce milkfat with high UFA concentration. The model, which accounts for all the inputs and outputs of a typical New Zealand dairy farm, uses the Cholesky decomposition algorithm of (co)variance matrices to simulate the daily performance of individual cows for milk yield, the percentages of milkfat and protein, live weight and milkfat UFA concentration. The simulation assumed that there was a small dairy processor interested in collecting milk with high milkfat UFA concentration.

Model inputs: Simulation of the base population

A polulation of 1,820,000 cows distributed between 5,600 dairy farms was simulated for the present study, and assumed to be located in the North Island of New Zealand. This group of dairy farms constituted the base population from which some dairy cows were segregated. The number of dairy cows and dairy farms simulated corresponded to approximately 63% of the actual number of dairy cows and farms present in the North Island of New Zealand (LIC, 2011). Simulated dairy farms were 120 ha and had 325 cows, which are the average farm size and herd size of dairy farms in the North Island of New Zealand, respectively (LIC, 2011).

For each farm, a compact spring calving season (between July 20 and October 10) was simulated by determining that 50% of the herd calved within the first 22 days of the calving season (July 20 – August 11), and 90% of the herd calved within 46 days from the start of the calving season (July 20 – September 4). Calving dates and calving pattern were obtained from Chapter 3, LIC (2011) and Holmes et al. (2002). In each herd, all cows were dried off by May 10 the following year.

Herd structure and replacement rate

On each farm, herds were composed of 12 age classes: calves (<2months old), R1 heifers (<1 year old), R2 heifers (<2 years old), and 2- to 10- year-old cows (cows in their first to ninth lactation). On all farms, survival rates considered for each age class were 0.66 (percentage of female calves raised as replacement), 0.86, 0.86, 0.86, 0.87, 0.86, 0.81, 0.77, 0.71, 0.66, and 0.64, respectively. Survival rate values were obtained from the dairy statistics of Livestock Improvement Corporation (LIC, 2011), and determined a replacement rate of 20.6% for each farm.

Cows were culled from the herd due to age, death, disease, poor fertility (non-pregnant), and unsatisfactory performance (voluntary culling). Cows were culled due to age at the end of their ninth lactation. Culling rates due to death were 4%, 3% and 1.4% for R1, R2 and cows, respectively. Culling rates due to disease were 1%, 1% and 3.4% of R1, R2 and cows, respectively. The culling rate due to poor fertility was 8% for R2 and cows. The culling rate due to unsatisfactory performance was the difference between the culling rate of each age class minus the culling rates due to age, death, disease and poor fertility for the corresponding age class. Culling rates were obtained from Lopez-Villalobos et al. (2000b).

For each herd, it was assumed that 90% of cows (artificially inseminated) and R2 heifers (naturally mated) were pregnant at the end of the mating season (October – December). It was also assumed that 50% of calves born were females, that calf mortality rate was 6%, and that male calves and female calves not used as herd replacements were sold as bobby calves for veal (Lopez-Villalobos et al., 2000b).

Feed supply

On each farm, 14.5 t of pasture (ryegrass - white clover) dry matter (DM) was grown per hectare per year, of which 76% (11 t DM/ha/year) was eaten by the herd (Holmes et al., 2002; MacDonald, 2011). The energy concentration of pasture from June to May of the following year was 10.9, 11.0, 11.1, 11.5, 11.4, 11.3, 11.2, 10.7, 10.5, 10.3, 10.9, and 11.0 MJ ME/kg DM, respectively (Litherland & Lambert, 2007). It was assumed that cows met their ME requirements at all times and deficits in feed were filled with imported supplements made of conserved pasture (10 MJ ME/kg DM). Calves were fed 4 litres/day of milk (3.6 MJ ME/litre) and were offered enough meal (12.5 MJ ME/kg DM) to meet their ME requirements. Heifers went off-farm to a run-off post weaning were they were offered pasture only, and returned to the farm just prior to calving.

Economic inputs/performance

Income from the sale of milk was estimated using the New Zealand A + B - C milk pricing system, which pays for milkfat and protein, and penalises milk volume. Two milk payouts were evaluated: 1) a payout of $5.21/kg MS (MS = milksolids = milkfat + protein), which paid $3.34/kg milkfat, $8.86/kg protein and -$0.04/litre of milk and corresponded to the average milk payout in New Zealand over the last 10 years (DairyNZ, 2012; NZAEL, 2012a); and, 2) a payout of $7.37/kg MS, which paid $5.44/kg milkfat, $11.10/kg protein and

-$0.04/litre of milk and corresponded to the highest milk payout in New Zealand in the last 10 years (DairyNZ, 2012; NZAEL, 2012a).

The income from the sale of stock (male calves, culled cows and surplus female calves and heifers) was determined by the carcass weight of the cattle and the value of beef (Table 1). Carcass weight of calves and heifers was assumed to be 50% and 53% of live weight, respectively (Lopez-Villalobos et al., 2000b). Carcass weight of culled cows was estimated as indicated by McCall and Marshall (1991). Live weight of culled calves, R1 and R2 heifers was assumed to be 8%, 40% and 70% of mature live weight, respectively (Clark & MacDonald, 2007).

Table 1 Prices assumed for cattle culled for beef (NZAEL, 2012a)

Type of animal and carcass weight	Value of beef (NZ $/kg carcass)
Male and female calves	
< 13.5 kg	0.73
13.5 - 18.5 kg	1.09
> 18.5 kg	2.54
Cows and Heifers	
< 145 kg	2.25
145 - 170 kg	2.52
170 - 195 kg	2.67
196 - 220 kg	2.74
> 220 kg	2.83

Gross farm income was determined by the sale of milk, the sale of stock and the sale of other dairy-related products (assumed to be $46/ha, DairyNZ, 2012). Farm expenses were estimated as the sum of the marginal expenses (Table 2) and feed expenses incurred on each farm.

Table 2 Marginal expenses per cow (DairyNZ, 2012).

Item	NZ $/cow
Wages	209
Animal health	81
Breeding, herd improvement	45
Farm dairy	20
Electricity	35
Young stock grazing	125
Runoff lease	22
Vehicles, Fuel	66
Repairs, maintenance	121
Freight	19
Administration	40
Insurance, ACC and rates	62
Depreciation	134
Labour	153
Runoff	28
Livestock	27
Total	1187

Feed expenses were estimated from the feed dry matter demand of the herd (kg DM), assuming pasture and supplement prices of $0.10/kg DM and $0.25/kg DM, respectively. Feed prices were obtained from Holmes & Matthews (2001) and Clearwater & Wright (2003) given that there were no recent data available about the cost of pasture and supplements on dairy farms. However, the feed prices used in the present study may be good enough given that in a previous analysis (Chapter 4), the sum of marginal expenses per cow (DairyNZ, 2012) and feed expenses per cow (obtained using the above-mentioned feed prices) resulted in farm expenses per cow similar to that reported in the Economic Survey of New Zealand dairy farms (DairyNZ, 2012).

Farm operating profit was estimated as the difference of gross farm income minus farm expenses.

Model inputs: Segregation of dairy cows

The number of dairy cows to segregate, and the number of dairy farms needed, for the production of milk with high milkfat UFA concentration was determined taking into consideration the market for this type of milk and the examples of other dairy companies in New Zealand that manufacture speciality dairy products. The volume of milk supplied for the Campina brand of milk in the Netherlands was taken as an indication of the market size for milk high in UFA. In the Netherlands, about 500 dairy farms supplied over 200 million litres of milk annually for the Campina brand of milk, which, on an annual basis, has at least 20% more UFA than standard milk (Campina, 2007). In New Zealand, about 50 dairy farms currently supply organic milk to Fonterra for the manufacture of organic dairy products (DairyNews, 2011), and about 60 dairy farms supplied milk to Synlait when it started its operations in 2008 (Synlait, 2013). In Ontario (Canada), about 47 dairy farms feed their herds a special diet to supply milk (approximately 61.6 million litres) high in C22:6n−3 (DHA), an omega 3 fatty acid (DFO, 2013). Considering these examples and the average milk production of dairy farms in New Zealand, the present study assumed that there was a small cooperative (a small dairy processor + 50 milk suppliers) interested in the manufacture of dairy products with a higher than average concentration of UFA.

It was estimated that 17,150 cows were needed to form 50 farms (120 ha and 343 cows each) that produce milk with high milkfat UFA concentration (UFA farms). Since cows that produced milk with high milkfat UFA concentration have a lower feed demand than average cows (Chapter 4), a stocking rate of 2.86 cows/ha was selected for the UFA farms. Earlier analysis indicated that at this stocking rate feed demand per hectare in the UFA farms would be similar to that of average dairy farms. The 50 UFA farms formed would produce around 70 million litres of milk per year (about 35% of the total volume of milk supplied for the Campina brand in the Netherlands).

For the present study, it was assumed that UFA farm owners were willing to replace their whole milking herd by selling all their cows and buying cows that produced milk with high milkfat UFA concentration. From the 1,820,000 cows and 5,600 dairy farms simulated (base population), the top 17,150 cows for milkfat UFA concentration were segregated and randomly 'purchased' by the 50 UFA farms. It was assumed that the high milkfat UFA concentration in the segregated dairy cows was determined by genetic factors.

The cost of segregation ($220/purchased cow) was estimated assuming that each UFA farm spent an additional $200/purchased cow when replacing (sell/buy) its current herd by a herd of cows producing milkfat with high UFA concentration (Dooley et al., 2005), and that cattle freight costs were $20/segregated cow (DairyNZ, 2012). It was also assumed that milkfat UFA concentration, estimated by infrared spectrometry (Chapter 3), was part of routine milk testing and did not contribute additional costs to the segregation of cows.

Statistical analysis

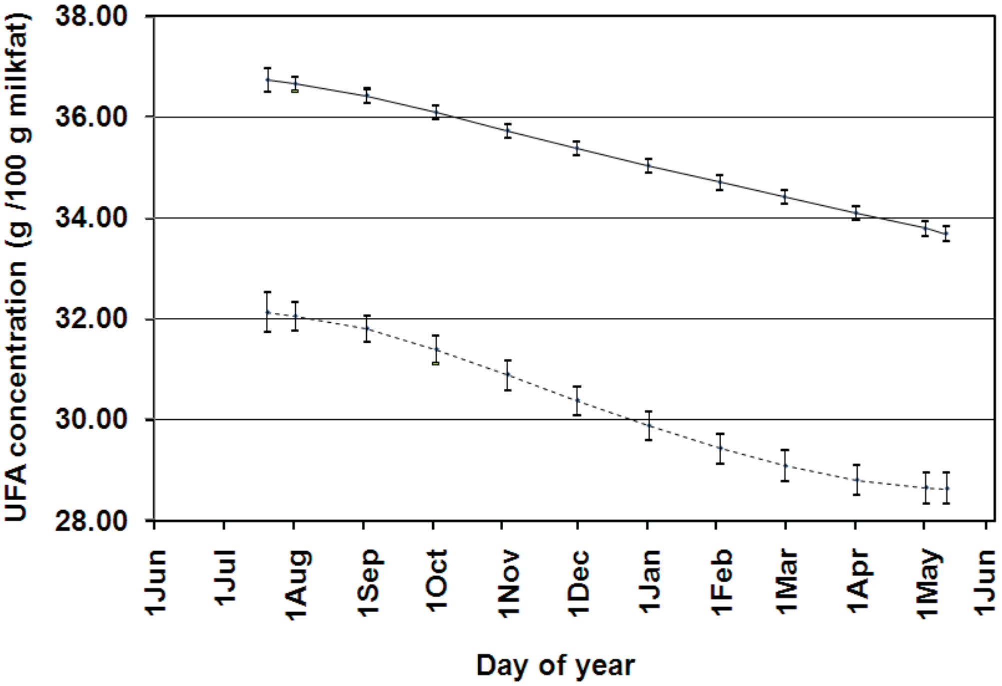
Traits of the UFA farms and farms in the base population (average farms) were compared by bootstrapping methodology (Henderson, 2005). The simulation of the base population and the segregation of dairy cows producing milk high in UFA was repeated 1,000 times. For each trait (θ), the mean ($\overline{\theta}$) was estimated as $\overline{\theta} = (\theta_1^* + \theta_2^* + \ldots + \theta_{1000}^*)/1000$. A 95% ($\alpha$=0.05) confidence interval was estimated using the percentile method: once bootstrap values (θ_1^*, θ_2^*, … θ_{1000}^*) of a trait (θ) were sorted from smallest to largest (θ_{1st}^*, θ_{2nd}^*, … θ_{1000th}^*), the lower and upper confidence intervals of each trait corresponded to the 25th and 975th ordered elements [θ_{25th} , θ_{975th}], respectively.

RESULTS

Physical characteristics of UFA farms

During the dairy production season (July 20 – May 10), milk produced and supplied to a dairy processor by the UFA farms had 15.0% to 18.4% (average 16.7%) more UFA (in milkfat) than the milk supplied by average dairy farms (Figure 1). On a per cow basis, there were no significant differences in lactation length, milk yield, live weight and supplementary feed demand between UFA farms and average dairy farms (Table 3). Cows in the UFA farms produced milk with significantly higher milkfat UFA concentration, but lower concentrations of milkfat and protein, than cows in average farms. As a consequence, cows in the UFA farms produced less millkfat, protein and milksolids than cows in average dairy farms.

Figure 1 Concentration (mean and 95% confidence interval) of unsaturated fatty acids (UFA) in milkfat produced by average farms (– – –) and UFA farms (——) during the dairy season.



Cows producing milk with high milkfat UFA concentration had lower feed demand than average cows, but the greater stocking rate (+0.15 cows/ha) on the UFA farms resulted in the UFA farms utilising a similar amount of feed (t DM/ha) to average farms (Table 3). Due to their greater stocking rate, UFA farms produced more milk per hectare (+746 L/ha/year), and could supply a dairy processor with more milk per farm (+28 to +394 L/day) during the dairy production season (Figure 2), than average farms. Although UFA farms had a greater stocking rate, they produced less milkfat (-65 kg/ha/year), protein (-24 kg/ha/year) and milksolids (-90 kg/ha/year) (Table 3), and supplied less milksolids (-5 to -45 kg/day) to a dairy processor (Figure 3), than average farms.

Table 3 Physical characteristics (mean and 95% confidence interval in brackets) of average farms and farms producing milk high in UFA (UFA farms).[1]

Trait[2]	Average farms (5600 farms)		UFA farms (50 farms)	
Farm size (Ha)[3]	120		120	
Herd size (cows)[3]	325		343	
Stocking rate (Cows/ha)[3]	2.71		2.86	
Per cow production				
Lactation length (days)	267^{a}	(266 - 268)	268^{a}	(267 - 268)
Milk yield (Litres)	4,351^{a}	(4,267 - 4,425)	4,385^{a}	(4,357 - 4,414)
Milkfat yield (kg)	188^{a}	(184 - 191)	156^{b}	(155 - 157)
Protein yield (kg)	156^{a}	(153 - 160)	140^{b}	(139 - 140)
Milksolids yield (kg)	345^{a}	(337 - 350)	296^{b}	(294 - 298)
Fat %	4.33^{a}	(4.28 - 4.38)	3.55^{b}	(3.53 - 3.57)
Protein %	3.60^{a}	(3.57 - 3.63)	3.19^{b}	(3.18 - 3.20)
g UFA/100 g of milk fat	30.12^{a}	(29.92 - 30.32)	35.15^{b}	(35.10 - 35.20)
Live weight (kg)	491	(488 - 495)	489	(488 - 491)
Feed demand (t DM)	4.58^{a}	(4.52 - 4.63)	4.34^{b}	(4.33 - 4.36)
Supplement demand (t DM)	0.52^{a}	(0.46 - 0.57)	0.49^{a}	(0.47 - 0.51)
Per hectare				
Milk yield (Litres)	11,788^{a}	(11,556 - 11,983)	12,534^{b}	(12,453 - 12,618)
Milkfat yield (kg)	510^{a}	(500 - 521)	445^{b}	(442 - 447)
Protein yield (kg)	423^{a}	(414 - 430)	399^{b}	(397 - 402)
Milksolids yield (kg)	935^{a}	(918 - 948)	845^{b}	(839 - 849)
Pasture utilised (t DM)[3]	11		11	
Supplement demand (t DM)	1.4	(1.2 - 1.5)	1.4	(1.3 - 1.5)
Total feed demand (t DM)	12.4	(12.2 - 12.5)	12.4	(12.3 - 12.5)

[1] Means within a row with different superscript letter are significantly different ($P<0.05$).

[2] DM = dry matter, milksolids= milkfat + protein.

[3] Model input

Figure 2 Daily milk production (mean and 95% confidence interval) for average farms (– – –) and farms producing milk high in (UFA farms, ——) during the dairy season.

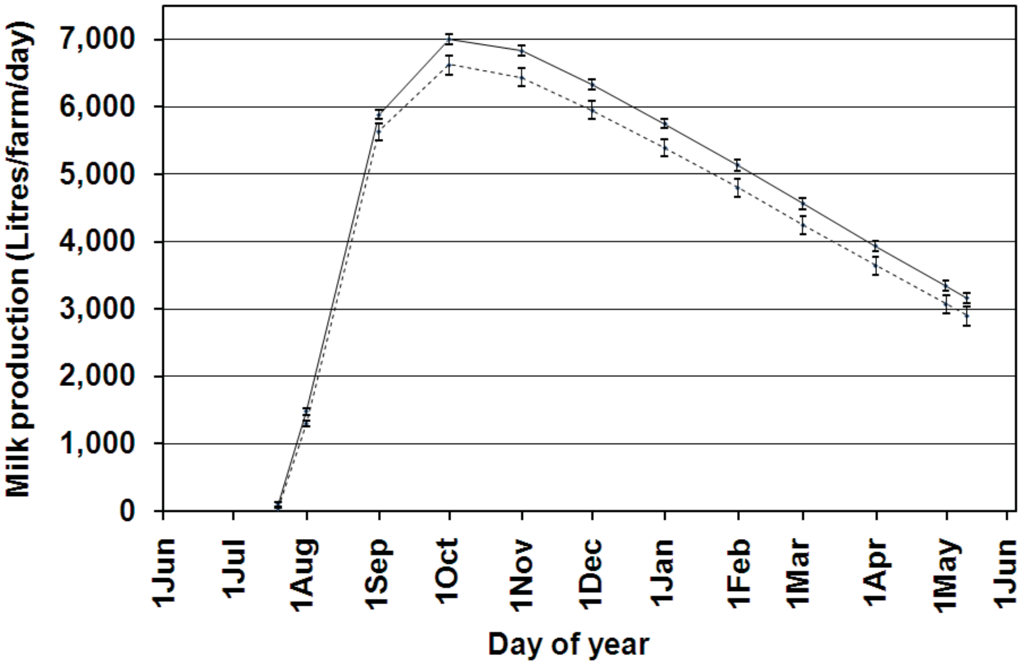
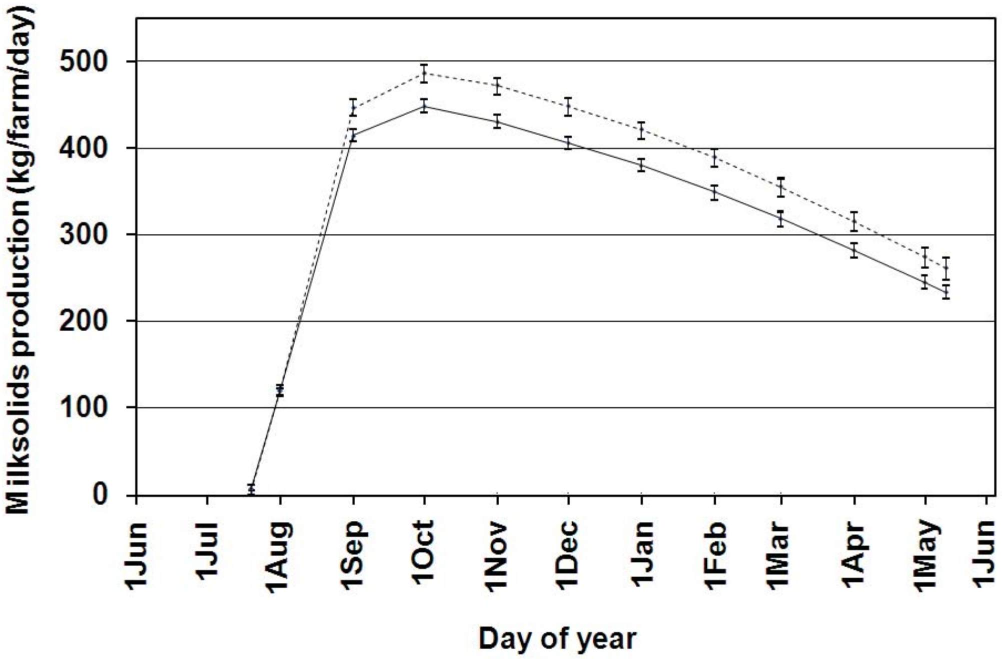


Figure 3 Daily milksolids production (mean and 95% confidence interval) of average farms (– – –) and farms producing milk high in UFA (UFA farms, ——) during the dairy season



Financial characteristics of UFA farms

Table 4 shows the financial performance of UFA farms. At the two milksolids payouts evaluated ($5.21 and $7.37 /kg MS), milk income and gross farm income were lower for UFA farms than for average farms, both per cow and per hectare. There were no significant differences in stock income per cow between UFA farms and average farms.

Per cow, UFA farms had significantly lower feed expenses than average farms, but per hectare there were no significant differences in feed expenses between UFA farms and average farms. Segregation costs significantly increased farm expenses in the UFA farms, both per cow and per hectare. The operating profit of UFA farms, per cow and per hectare, was significantly lower than that of average farms, being negative at a milksolids payout of $5.21/kg MS.

Milksolids payout significantly influenced milk income, gross farm income and farm operating profit on both UFA farms and average farms. The differences in milk income, gross farm income and operating profit between the UFA farms and average farms (per cow and per hectare) was larger at a milksolids payout of $7.37/kg MS than at a milksolids payout of $5.21/kg MS (Table 4).

DISCUSSION

The present study investigated, via simulation, the characteristics of a group of dairy farms formed by the segregation of dairy cows that produce milkfat with high UFA concentration. Bio-economic farm simulation models have also been used in the past to investigate the characteristics of dairy farms and herds that produce milk with a specific composition (da Cunha et al., 2010b; Dooley et al., 2005). The farm model used in the present study simulated the natural variation that exists in milk production, milk composition and milkfat UFA concentration in Holstein-Friesian dairy cows and farms under New Zealand conditions (Chapter 4). Therefore, the results of the present study could not be compared with or extrapolated to studies comprising other dairy breeds or studies in which milkfat composition was altered by dietary manipulation.

A holistic approach to consider the different components of the milk supply chain is necessary for the success of a programme aimed at increasing the milkfat UFA concentration (Augustin et al., 2013; Boland, 2002; Demeter et al., 2009). The scenario considered in the present study assumed that: 1) there was a dairy processor interested in sourcing milk with high milkfat UFA concentration, 2) there was a programme to measure the milkfat UFA concentration of cows on commercial farms, and 3) dairy farmers were motivated to buy/sell dairy cows that produce milk with high milkfat UFA concentration. These conditions, although not currently present in New Zealand, could develop in the future if dairy processors perceive that the international marketing of dairy products high in UFA could be profitable.

The base population in this study comprised 1,820,000 simulated dairy cows distributed in 5,600 dairy farms. This number of simulated dairy cows corresponds to the whole population of Holstein-Friesian cows in New Zealand, and represented 63% of dairy cows and farms present in the North Island of New Zealand (LIC, 2012). Therefore, the results from this study give an indication of the extent to which milkfat UFA concentration could be modified in New Zealand if all the Holstein-Friesian cows were included in a segregation programme to form 50 herds that produced milk with high milkfat UFA concentration.

The segregation of dairy cows has been practised in the past to alter milkfat composition. In a study conducted in New Zealand, Friesian cows were segregated according to their phenotype for solid fat content (Thomson et al., 2003a). As solid fat content is correlated to the concentration of UFA in milkfat (MacGibbon, 1996), the segregation of cows according to their phenotype for solid fat content resulted in herds that produced milkfat with high (soft milkfat) or low (hard milkfat) UFA concentration (Thomson et al., 2003a). Using segregation, the composition of milk produced by a farm could be changed within a year (Dooley et al., 2005). In the present study, UFA farms produced in

Table 4 Financial characteristics (mean and 95% confidence interval between brackets) of average farms and UFA farms at two milksolids payouts: \$5.21 and \$7.37 /kg milksolids.[1]

Trait	\$5.21 /kg Milksolids				\$7.37 /kg Milksolids			
	Average farms		UFA farms		Average farms		UFA farms	
Per cow (\$)								
Milk income	1834 ^{a}	(1788 - 1876)	1577 ^{c}	(1567 - 1586)	2576 ^{b}	(2511 - 2636)	2213 ^{d}	(2199 - 2227)
Stock income	184x	(181 - 188)	185x	(183 - 187)	184x	(181 - 188)	185x	(183 - 187)
Other income	16.98x		16.09x		16.98x		16.09x	
Gross farm income	2035 ^{a}	(1990 - 2078)	1778 ^{c}	(1767 - 1787)	2777 ^{b}	(2714 - 2837)	2414 ^{d}	(2400 - 2428)
Marginal expenses	1187x		1187x		1187x		1187x	
Feed expenses	534 ^{a}	(519 - 550)	508 ^{b}	(504 - 513)	534 ^{a}	(519 - 550)	508 ^{b}	(504 - 513)
Segregation expenses	0x		220x		0x		220x	
Farm expenses	1721 ^{a}	(1706 - 1737)	1915 ^{b}	(1911 - 1920)	1721 ^{a}	(1706 - 1737)	1915 ^{b}	(1911 - 1920)
Operating profit	314 ^{a}	(282 - 342)	-138 ^{c}	(-131 - -145)	1056 ^{b}	(1006 - 1101)	499 ^{d}	(489 - 509)
Per hectare (\$)								
Milk income	4966 ^{a}	(4842 - 5080)	4507 ^{c}	(4478 - 4534)	6977 ^{b}	(6801 - 7138)	6326 ^{d}	(6285 - 6364)
Stock income	499 ^{a}	(491 - 508)	529 ^{b}	(522 - 535)	499 ^{a}	(491 - 508)	529 ^{b}	(522 - 535)
Other income	46x		46x		46x		46x	
Gross farm income	5512 ^{a}	(5388 - 5627)	5081 ^{c}	(5051 - 5108)	7522 ^{b}	(7349 - 7682)	6901 ^{d}	(6960 - 6939)
Marginal expenses	3215x		3393x		3215x		3393x	
Feed expenses	1447x	(1405 - 1491)	1453x	(1441 - 1465)	1447x	(1405 - 1491)	1453x	(1441 - 1465)
Segregation expenses	0x		629x		0x		629x	
Farm expenses	4662 ^{a}	(4620 - 4705)	5475 ^{b}	(5462 - 5487)	4662 ^{a}	(4620 - 4705)	5475 ^{b}	(5462 - 5487)
Operating profit	849 ^{a}	(765 - 927)	-393 ^{c}	(-376 - -411)	2860 ^{b}	(2725 - 2983)	1426 ^{a}	(1396 - 1454)

[1] Milksolids payout (milkfat + protein - milk volume): \$5.21 /kg milksolids = \$3.34/kg milkfat, \$8.86/kg protein and -\$0.04/litre milk; \$7.37/kg milksolids = \$5.44/kg milkfat + \$11.10/kg protein and -\$0.04/litre milk. Means within a row with different superscript letter are significantly different ($P<0.05$)..

their first year milk with at least 15% more UFA than average farms. However, these results should be interpreted with caution given that in this study it was assumed that environmental effects remain constant and that the difference in milkfat UFA concentration between cows was exclusively due to genetic effects. Given that changes in grazing management and location could also influence milkfat UFA concentration significantly (Alonso et al., 2004; Frelich et al., 2012; Thomson et al., 2002), it is possible that cows that produce milkfat with high UFA concentration do not perform in the same way when segregated and relocated to another herd and region. Nevertheless, some studies reported that cows that produced milkfat with a high UFA concentration maintained this characteristic during the lactation and between seasons (Thomson et al., 2003b).

As cows on the UFA farms had a milk yield similar to that of average cows (Table 3), but with significantly higher milkfat UFA concentration (+5.03 g /100g milkfat) and significantly lower percentages of milkfat (-0.78 %) and protein (-0.41 %), their yields of milkfat, protein and milksolids were significantly reduced (-32 kg/cow, -16 kg/cow and -49 kg/cow, respectively). The differences in milkfat UFA concentration, milkfat percentage and milkfat yield between cows on UFA farms and average cows are consistent with the differences between cows that produced milkfat with high or low UFA concentration in the study by Thomson et al. (2003a): +3.48 g UFA/100g milkfat, -0.94 % milkfat and -23 kg milkfat, respectively (average of 3 trials and milkfat yield estimated to 270 days in milk). As in the present study, Thomson et al. (2003a) did not report a significant difference in milk yield between cows that produced milkfat with high or low UFA concentration. However, in the present study about 100 cows were screened for every cow segregated into a UFA farm, while in the study by Thomson et al. (2003a) about 30 cows were screened for every cow segregated into the soft milkfat (high UFA) herd.

The lowered production per cow on UFA farms could be due to a negative relationship between milkfat UFA concentration and other milk production traits. Several studies have reported negative genetic and phenotypic correlations (moderate to high) between milkfat UFA concentration and milkfat yield, milkfat percentage and protein percentage (Schennink et al., 2008; Soyeurt et al., 2008b; Soyeurt et al., 2007; Stoop et al., 2008). These studies also reported a low phenotypic correlation between milkfat UFA concentration and milk yield, which could be positive (Schennink et al., 2008) or negative (Soyeurt et al., 2007). In some studies, feeding lipid supplements to dairy cows, although increasing the milkfat UFA concentration, also tended to reduce milk protein yield (Gonthier et al., 2005; Hurtaud & Peyraud, 2007).

In the present study, the milk supplied to a dairy processor by the UFA farms had at least 15% more UFA in milkfat than the milk supplied by average dairy farms. Couvreur et al (2006) reported that significant changes in the sensorial properties of butter (melting score, firmness in mouth), but not spreadability, were achieved when the difference in milkfat UFA concentration between the control and modified milkfat were 11%. The percentage of difference in milkfat UFA concentration between UFA farms and average farms is lower than the 20% difference in milkfat UFA concentration between the Campina brand of milk and standard milk in the Netherlands (FrieslandCampina, 2013). However, in contrast to the scenario simulated in the present study (segregation of cows that produce milk with high milkfat UFA concentration), dairy farmers that supply milk for the Campina brand in the Netherlands increase the milkfat UFA concentration of milk by dietary manipulation (feeding of a rapeseed based supplement) (FrieslandCampina, 2013).

Milk income in the UFA farms was significantly lower than that of average farms (-$257/cow and -$459/ha at $5.21/kg MS and -$363/cow and -$651/ha at $7.37/kg MS). The lower milk income in the UFA farms was a consequence of their lesser milkfat and protein yields (per cow and per hectare), their greater milk yield per hectare, and a payment system that rewarded the yields of milkfat and protein, and penalised milk volume. As the income from the sale of milk represents more than 90% of gross farm income in a dairy farm (DairyNZ, 2012), the drop in milk income in the UFA farms significantly affected their gross farm income and operating profit, both per cow and per hectare.

Due to their higher stocking rates and the cost of segregation, UFA farms had significantly higher farm expenses than average farms. However, the cost of segregation could be different to the one assumed in this study ($220/segregated cow) if dairy farmers have to pay for the measurement of milkfat UFA concentration in milk. Also, it is possible that the value of dairy cows that produce milkfat with high UFA concentration is different from the one assumed in this study under a milk payment system that rewards the concentration of UFA in milkfat. However, it is also possible that segregation costs were overestimated considering that cows that produce milkfat with high UFA concentration could be selected to be culled due to their low milksolids production. If segregation costs were 0, the differences in operating profit per hectare between the UFA farms and average farms would be $614 at $5.21/kg MS and $805 at $7.37/kg MS. Although the present study investigated the annual establishment of UFA farms by the segregation of dairy cows only, once formed, genetic selection could be used to generate replacements that produce milkfat with high UFA concentration. With the use of genetic selection, segregation costs could be lower given that fewer cows that produce milkfat with high UFA concentration would need to be purchased.

Milksolids payout had a significant effect on the profitability of UFA farm. At a payout of $5.21 /kg MS (average of the last 10 years), the operating profit of UFA farms was negative, both per cow and per hectare (Table 4). The difference in operating profit between the UFA farms and average farms was larger at a milksolids payout of $7.37/kg MS than at a milksolids payout of $5.21/kg MS ($1,434/ha and $1,242/ha, respectively). This indicates that the premium necessary for UFA farms to break even with average farms was $1.48/kg MS (at a milksolids payout of $5.21/kg MS), and $1.71/kg MS (at a milksolids payout of $7.37/kg MS). These estimated premiums for the UFA farms are higher than the premium paid to organic dairy farmers ($1.05/kg) in New Zealand (LIC, 2012). However, the premium needed for UFA farms to break even with average farms should be better expressed per kg of milkfat given that the milk produced by UFA farms and average farms differ in milkfat composition only. Considering only milkfat, the premium needed for the UFA farms was $2.82/kg milkfat (at a milksolids payout of $5.21/kg MS), and $3.25/kg milkfat (at a milksolids payout of $7.37 /kg MS).

The effect on farm production and profit of segregating dairy cows that produce milkfat with high UFA concentration may vary depending on animal, environmental and financial factors. Therefore, more studies are necessary before a programme to form farms that produce milkfat with high UFA concentration is established. The economic performance of the UFA farms in the present study is an indication of what may happen if dairy cows were selected and segregated to form herds that produce milk with high milkfat UFA concentration. However, the limitations of this study should also be considered, especially with regard to the practicality of segregation, the cost of segregation and the effect of environmental factors on milkfat UFA concentration.

CONCLUSION

The concentration of UFA in milkfat could be increased by segregating cows with this characteristic. In the present study, high concentrations of UFA in milkfat were associated with lower yields and percentages of milkfat and protein, per cow and per hectare. In New Zealand, under the current payment system (milkfat + milk protein – milk volume), the operating profit per cow and per hectare was negatively affected on farms that produced milk with high concentrations of UFA in milkfat, especially at a high milksolids payout. This study highlights the importance of developing a payment system that includes a premium for concentration of UFA in milkfat. Such a premium would need to not only break even the operating profit of UFA farms with that of average farms, but also include an economic incentive to encourage dairy farmers to change their farm system. Further research is necessary before implementing a programme for increasing the concentration of UFA in milkfat at the farm level.

CHAPTER 6

Development of a milk payment system with a premium for concentration of unsaturated fatty acids (UFA) in New Zealand, when milkfat UFA concentration is increased through the segregation of dairy cows

ABSTRACT

The objective of the present study was to estimate a premium for the concentration of unsaturated fatty acids (UFA) in milkfat, for dairy farmers in New Zealand. A farm model was used to simulate 50 farms that produced milk with a high milkfat UFA concentration (each farm 120ha and 343 cows, UFA farms) and 50 average farms (each farm 120ha and 325 cows, AVE farms). UFA farms were formed by segregating the top 17,150 cows for milkfat UFA concentration from a population of 1,820,000 cows (on 5,600 average farms). The processing of milk supplied by UFA farms (UFA milk) and AVE farms (AVE milk) was simulated under three scenarios, Butter: all milk processed into butter, Butter-Cheese: 50% of milk processed into butter and 50% into cheese, and Cheese: all milk processed into cheese. For each milk-processing scenario, three premium scenarios for concentration of UFA above a threshold of 34.50 g UFA/100 g milkfat were evaluated: P_zero: no premium, P_breakeven: a premium which breaks even the operating profit ($/ha) of UFA farms with that of AVE farms, and, P_high: a premium which gives UFA farms a marginally higher operating profit ($/ha) than AVE farms. In the P_breakeven and P_high scenarios the market prices of butter and cheese manufactured from UFA milk were estimated using a premium pricing strategy. Milk suppliers were paid for milkfat and protein supplied, penalised for milk volume and paid a premium ($/kg milkfat) for each 0.1g UFA/100 g milkfat above the threshold. The simulation was replicated 1,000 times to estimate a 95% confidence interval for each trait by bootstrapping. In the three milk-processing scenarios, UFA milk produced a higher yield of SMP, but lower yields of cheese, butter, BMP, casein and WP, than AVE milk. Butter and cheese manufactured from UFA milk (value-added products) had a higher UFA concentration than those from AVE milk (35.15g vs 30.12 g UFA/100 g fat, $P<0.05$). The premium price of butter from UFA milk was 46% - 51% (P_breakeven) and 52% - 58% (P_high) higher than that from AVE milk, and the premium price of cheese was 22% - 24% (P_breakeven) and 25% - 27% (P_high) higher than that from AVE milk. Across processing scenarios, a premium of $0.47 - $0.51 /kg milkfat for each 0.1 g

UFA/100 g milkfat above the threshold, gave UFA farms an operating profit ($/ha) similar to that of AVE farms; and a premium of $0.53 - $0.57 /kg milkfat for each 0.1 g UFA/100 g milkfat gave UFA farms a higher ($P<0.05$) operating profit than AVE farms. The results from this study indicate to industry participants the level of premium needed to promote this speciality enterprise.

Keywords: milk payment system, unsaturated fatty acids, milk processing, farm model, premium

INTRODUCTION

Over the years, dairy processors have been able to expand the dairy food market by improving traditional dairy products and by introducing new dairy products (Blayney & Gehlhar, 2005; Henning et al., 2006). The trend in consumer demand for health and convenience have resulted in the emergence of niche markets for food products that offer health benefits, are low in saturated fat and offer convenience (Diekman & Malcolm, 2009; Sloan, 2011). A higher concentration of unsaturated fatty acids (UFA) in milkfat could improve the spreadability of butter (Chen et al., 2004) and could be preferred by consumers who want to reduce their intake of saturate fatty acids (Diekman & Malcolm, 2009; Eckel et al., 2009).

In recent years, several studies have investigated the possibility of increasing the concentration of unsaturated fatty acids (UFA) in milkfat by manipulation of the cow's diet (Oeffner et al., 2013; Shingfield et al., 2013), genetic selection (Bilal et al., 2012; Mele et al., 2009; Samkova et al., 2012) or the segregation of dairy cows (Thomson et al., 2003a). Several studies have also indicated that before the establishment of a programme aiming at increasing the milkfat UFA concentration it is necessary to develop a milk payment system that rewards the concentration of UFA in milkfat (Jenkins & McGuire, 2006; Mele, 2009; Palmquist et al., 2006; Stoop et al., 2008; Walker et al., 2004; Chapter 5). This is because increasing the milkfat UFA concentration at the farm level could be associated with losses in production and/or could involve additional costs (Arnould & Soyeurt, 2009; He & Armentano, 2011; Shingfield & Garnsworthy, 2012; Soyeurt et al., 2007; Chapter 5).

Since a milk payment system influences all the members of the dairy industry (Hillers et al., 1980; Ladd & Dunn, 1979; Wolfová et al., 2007), it should: 1) be equitable and pay dairy farmers according to the true value of their milk, 2) be easily understood by dairy farmers, 3) encourage desired changes in milk composition by contributing to farm profit, 4) encourage the growth of the dairy industry, and, 5) signal market trends clearly to dairy farmers and dairy processors (Bailey, 2003; Breen et al., 2001; Cook, 1954; Garrick & Lopez Villalobos, 2000). Therefore, a premium system for milkfat UFA concentration should clearly transmit market trends to dairy farmers and dairy processors, it should lead to an increase in milkfat UFA concentration, and it should fairly distribute the payment to dairy farmers.

The current milk payment system in New Zealand is based on the A + B - C system (LIC, 2012). Under this payment system dairy farmers are paid for the amount of milkfat and protein supplied to a dairy processor, with a penalty for milk volume. Some dairy farmers in New Zealand are also paid premiums for milk quality (Cantley, 2008), for the supply of milk during winter (Waugh, 2007) and for the supply of organic milk (NZFW, 2011). Some dairy companies in New Zealand have also modified the traditional milk payment system and have paid dairy farmers for the lactose (Penno, 2009) or casein (Boland & Hill, 2001) content of milk.

Although several studies have been published on the possibilities of increasing the milkfat UFA concentration at the farm level, currently there is no information about a potential premium for concentration of UFA in milkfat for dairy farms in New Zealand. Given this gap in knowledge, and since the development of a milk payment system is essential for the establishment of a programme aiming at increasing the milkfat UFA concentration, the objective of the present study was to develop a milk payment system which includes a premium for concentration of UFA, for dairy farms in New Zealand.

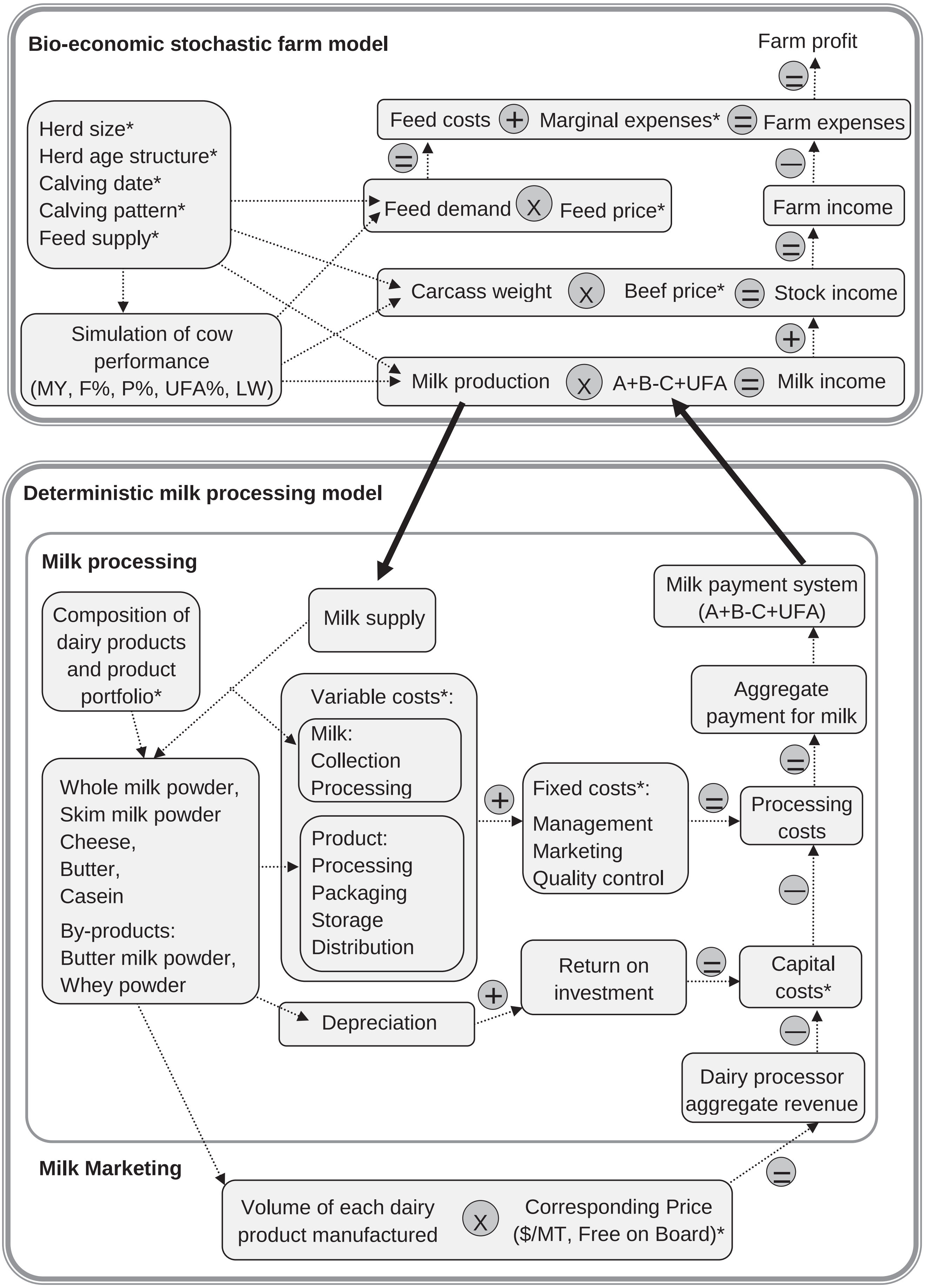
MATERIALS AND METHODS

Outline

A stochastic farm model (Chapter 4) and a deterministic milk processing model (Garrick & Lopez Villalobos, 2000) were used to simulate the production, processing and marketing of milk with a high concentration of UFA in milkfat. The farm model output corresponding to the quantity and the composition of the milk produced by simulated dairy farms was entered into the milk processing model to simulate the manufacture and marketing of dairy products. The milk processing model also estimated the farm gate milk price using a payment system that rewarded dairy farmers for the amount of milkfat and protein supplied, and the concentration of UFA in milkfat, but penalised milk volume. The main parameters for each model are presented in Figure 1.

For the present study, it was assumed that: 1) There was a dairy cooperative (50 dairy farms + a small dairy processor) interested in processing and marketing dairy products with a high concentration of UFA in milkfat; 2) Dairy farmer members of this cooperative were willing to increase the concentration of UFA in milkfat by selling cows in their current herds and buying cows that produce milk with a high UFA concentration in milkfat; and, 3) There was a programme to measure the milkfat UFA concentration of cows in commercial farms by infrared spectroscopy.

Figure 1: Diagram of the main parameters considered in the simulation of dairy farms and milk processing and their interaction (model inputs are marked with *).



Simulation of milk production and supply

Fifty dairy farms that produced milk with a high milkfat UFA concentration were simulated using the bio-economic stochastic farm model developed in Chapter 4, as follows: 1) a population of 1,820,000 cows distributed on 5,600 dairy farms was simulated; 2) from the population of dairy cows and farms simulated, the top 17,150 cows for milkfat UFA concentration were segregated and distributed (randomly and evenly) among 50 farms (UFA farms). The number of UFA farms (and cows) needed for the supply of milk high in UFA was determined considering the market for this type of milk and the examples of other dairy companies in New Zealand that manufacture speciality dairy products (Campina, 2007; DairyNews, 2011; DFO, 2008; Synlait, 2013). For comparative purposes, a group of 50 average farms (AVE farms) was also simulated to compare their production and economic performance with that of the 50 UFA farms.

The 5600 average farms simulated (120 ha and 325 cows each, 2.71 cows/ha) are representative of the population of Holstein-Friesian cows in New Zealand (LIC, 2011). A replacement rate of 20.6% was simulated for average farms using survival rates of 0.66 (percentage of female calves born raised as replacemens), 0.86, 0.86, 0.86, 0.87, 0.86, 0.81, 0.77, 0.71, 0.66, and 0.64, for calves (<2months old), R1 heifers (<1 year old), R2 heifers (<2 years old), and 2- to 10- year-old cows (cows in their first to ninth lactation), respectively (LIC, 2011). A compact spring calving, between July 20 and October 10, was simulated for each farm by determining that 50% of the herd calved within the first 22 days of the calving season, and 90% of the herd calved within 46 days from the start of the calving season (Holmes et al., 2002; LIC, 2011). Cows on each farm were dried off by May 10 the following year. On each farm, it was assumed that 90% of cows were pregnant at the end of the mating season (October-December), that 50% of calves born were females, that male calves and female calves not used for herd replacements were sold as bobby calves for veal, and that calf mortality rate was 6% (Lopez-Villalobos et al., 2000b).

For each farm, it was assumed that 11 tonnes (76% of pasture grown) of pasture (ryegrass - white clover) dry matter (DM) was eaten by the herd per hectare per year (Holmes et al., 2002; MacDonald, 2011). From June to May of the following year, the energy concentration of pasture was 10.9, 11.0, 11.1, 11.5, 11.4, 11.3, 11.2, 10.7, 10.5, 10.3, 10.9, and 11.0 MJ ME/kg DM, respectively (Litherland & Lambert, 2007). Feed deficits were filled with supplements (10 MJ ME/kg DM) made of imported conserved pasture. Calves were fed milk (4 litres/day, 3.6 MJ ME/litre) and were offered enough meal (12.5 MJ ME/kg DM) to meet their ME requirements. Heifers were raised off-farm and offered only pasture.

UFA farms were 120 ha and had 343 cows (2.86 cows/ha). A higher stocking rate was adopted for the UFA farms since an earlier analysis indicated that at this stocking rate feed demand per hectare in the UFA farms would be similar to that of average dairy farms. As the farm model did not simulate the concentrations of lactose, casein and minerals in milk, it was assumed that milk supplied by UFA farms and AVE farms had a standard composition of lactose (4.7%), casein (77 g/100 g of protein) and minerals (0.7%). Similar assumptions have also being used in previous studies (Garrick & Lopez Villalobos, 2000).

Estimation of dairy farm economic performance

Gross farm income was estimated as the sum of milk income, stock income and other dairy related income ($46/ha; DairyNZ, 2012). Milk income was estimated from milk sales and the milk payment system used by the dairy processor. Stock income was determined by beef price and the carcass weight of culled cows, surplus calves and surplus heifers. Prices ($/kg carcass) used for bobby calves were $0.73, $1.09, and $2.54 for carcass weights <13.5 kg, 13.5-18.5 kg and >18.5 kg, respectively (NZAEL, 2012a). Prices ($/kg carcass) used for culled heifers and cows were $2.25, $2.52, $2.67, $2.74 and $2.83 for carcass weights <145 kg, 145-170, 170-195, 195-220, and >220 kg respectively (NZAEL, 2012a). Live weight of culled calves, R1 heifers and R2 heifers was assumed to be 8%, 40% and 70% of mature live weight, respectively (Clark & MacDonald, 2007). The percentage of carcass yield (CY%) of culled cows was estimated as: $CY\% = 0.41 + 0.000208 \times$ kg Live weight (McCall & Marshall, 1991), while the carcass yields of calves and heifers were assumed to be 50% and 53% of mature live weight, respectively (Lopez-Villalobos et al., 2000b).

Farm expenses were estimated as the sum of feed expenses and marginal expenses. In the case of UFA farms, farm expenses also included segregation costs. Feed expenses were determined by feed price and the quantity of pasture and supplements eaten by the herd. The prices used for pasture and supplements in the present study were $0.10 and $0.25 /kg DM, respectively (Clearwater & Wright, 2003; Holmes & Matthews, 2001). Marginal expenses were assumed to be $1187/cow (DairyNZ, 2012), and included wages, animal health, breeding, herd improvement, farm dairy, electricity, young stock grazing, runoff lease, vehicles, fuel, repairs, maintenance, freight, administration, insurance, ACC, rates, and adjustments for depreciation, labour, runoff and livestock. Segregation costs of UFA farms ($220/segregated cow) comprised the cost of replacing the current cows on UFA farms by cows that produced milkfat with a high UFA concentration ($200/segregated cow) (Dooley et al., 2005), and the cost of transporting the segregated cattle ($20/segregated cow) (DairyNZ, 2012).

Farm operating profit was estimated by subtracting farm expenses from gross farm income.

Simulation of milk processing

Manufacture of dairy products

The daily processing of the milk supplied by the 50 UFA farms (UFA milk) and the 50 AVE farms (AVE milk), was simulated using the part of the processing model developed by Garrick and Lopez-Villalobos (2000) that simulates the yield of dairy products. This milk processing model, which has been modified, updated and used in other countries e.g. Ireland (Geary et al., 2010; Geary et al., 2013), is a mass balance processing model where all components of the milk processed were present in the dairy products manufactured or lost during processing (water). The daily concentrations of milkfat, protein, casein (as percentage of total protein), lactose and minerals in milk were the inputs of the milk processing model.

In previous studies (Chen et al., 2004; Lightfield et al., 1993; Oeffner et al., 2013) it was demonstrated that milk with a high concentration of UFA in milkfat can be used for the manufactured of butter and Cheddar cheese. In the present study, three milk-processing scenarios were evaluated to determine the sensitivity of milk price to product mix: 1) Butter: all milk was processed into butter and skim milk powder (SMP), 2) Butter-Cheese: 50% of milk was processed into butter and SMP, and 50% into Cheddar cheese, and 3) Cheese: all milk was processed into Cheddar cheese. The butter and cheese manufactured from UFA milk were the differentiated dairy products where a high concentration of UFA in milkfat added value to the final product. Depending on the milk-processing scenario, dairy by-products comprised butter, buttermilk powder (BMP), casein and whey powder (WP). The composition of the dairy products manufactured is shown in Table 1.

Table 1 Composition of butter, skim milk powder (SMP), cheese, buttermilk powder (BMP), casein and whey powder (WP) simulated by the processing model (Garrick & Lopez Villalobos, 2000; Geary et al., 2010).

Composition	Butter	SMP	Cheese[1]	BMP	Casein	WP
Fat %	84.00	1.00	35.00[1]	8.30	0	1.00
Protein %	0.59	33.00	24.50[1]	41.72	89.00	15.15
Lactose %	0.79	54.00	1.39[1]	40.32	0.56	77.15
Minerals %	0.12	8.00	3.85[1]	4.66	0.08	4.32
Water %	14.50	4.00	35.26[1]	5.00	10.35	2.38

[1] Minerals plus 1.7 g of salt added.

The volume of milk used for the manufacture of SMP and butter was separated into cream and skim milk (Garrick & Lopez Villalobos, 2000). Cream was standardised using skimmed milk. Yield of butter was estimated by dividing the volume of fat in the separated cream by the percentage of fat in butter (Lopez-Villalobos et al., 2000a). BMP was a by-product from the manufacture of butter, and its yield was estimated by dividing the volume of fat in buttermilk by the fat concentration of BMP (Table 1).

In the manufacture of SMP, skim milk was separated into permeate (lactose-rich) and retentate (protein-rich) fractions by ultrafiltration. Permeate and retentate fractions were recombined in variable ratios so that the SMP manufactured had a standard composition (Table 1). The reconstituted standardised skim milk was “evaporated and dried” to a moisture content of 2.7%. Surplus retentate from the manufacture of SMP was used for the manufacture of casein powder. Yield of casein powder was estimated by multiplying surplus protein times the concentration of casein in protein, and by dividing the result by the concentration of casein in casein powder (Lopez-Villalobos et al., 2000a). Surplus protein from the manufacture of casein and surplus permeate from the manufacture of SMP were recombined and used for the manufacture of whey powder (WP).

The volume of milk used for cheese manufacturing was standardised by separating the milk into cream, retentate and permeate, and by recombining these fractions in variable ratios to achieve a standard Cheddar cheese composition (Table 1). Surplus cream and whey were used for the manufacture of butter (and its by-product BMP) and WP, respectively.

Dairy processor revenue

The international marketing of dairy products manufactured from UFA milk and AVE milk was simulated taking as reference average market prices (average from 2010 to 2012). Market prices assumed in the simulation (in US dollars) were: US $3,450/t for SMP, US $4,050/t for cheese, US $3,641/t for butter, US $2,885/t for BMP, US $8,000/t for casein and US $1,177/t for WP. Market prices for SMP, butter and BMP were obtained from the Fonterra farm gate milk price statement (Fonterra, 2012b), market prices for cheese and WP were obtained from CLAL (CLAL, 2013a, 2013b), and the market price for casein was obtained from Global Dairy Trade (GlobalDairyTrade, 2013). With exception of the market prices of dairy products, which were given in US dollars, financial values reported in the present study corresponded to New Zealand dollars. The exchange rate used in the present simulation was NZ $1 = US $0.7184 (average exchange rate from 2010 to 2012) (Fonterra, 2012b).

Dairy products manufactured from AVE milk, and the SMP, BMP, casein and WP manufactured from UFA milk, were sold at their corresponding market price. The market prices of butter and cheese manufactured from UFA milk were estimated using a premium pricing strategy, in which a premium ($/tonne) was added to the market price of butter and cheese. The premium pricing strategy is widely used in the dairy industry to encourage changes in milk composition (Nightingale et al., 2008), to alter the pattern of milk supply to dairy processors (Byles, 1995) and in the marketing of differentiated dairy products (Armstrong et al., 2005; Fonterra, 2012b; OMSCO, 2006).

In each milk-processing scenario, three premium scenarios for milkfat UFA concentration above 34.50 g /100g milkfat were evaluated: P_zero: no premium for milkfat UFA concentration, P_breakeven: a premium scenario where the operating profit of UFA farms ($/ha) breakeven with that of average farms, and, P_high: a premium scenario where the operating profit of UFA farms ($/ha) is marginally higher than that of AVE farms. In each milk-processing scenario, the aggregate premium needed for milkfat UFA concentration in the P_breakeven (AP_b) and P_high (AP_h) scenarios were estimated as follows:

$$\mathrm{AP\_b} = (\mathrm{APM}_{\mathrm{mean\_ave}} - \mathrm{APM}_{\mathrm{mean\_ufa}}) + ((\mathrm{FE}_{\mathrm{mean\_ufa}} - \mathrm{FE}_{\mathrm{mean\_ave}})\times 50) \quad (6.1)$$

$$\mathrm{AP\_h} = (\mathrm{APM}_{\mathrm{max\_ave}} - \mathrm{APM}_{\mathrm{min\_ufa}}) + ((\mathrm{FE}_{\mathrm{max\_ufa}} - \mathrm{FE}_{\mathrm{min\_ave}})\times 50) \quad (6.2)$$

Where, $\mathrm{APM}_{\mathrm{mean}}$ is the average aggregate payment for milk (proportion of revenue used to pay dairy farmers) generated by AVE milk ($\mathrm{APM}_{\mathrm{mean\_ave}}$) and by UFA milk ($\mathrm{APM}_{\mathrm{mean\_ufa}}$) in the P_zero premium scenario. $\mathrm{APM}_{\mathrm{max\_ave}}$ is the maximum aggregate payment for milk generated by AVE milk, and $\mathrm{APM}_{\mathrm{min\_ufa}}$ is the minimum aggregate payment for milk generated by UFA milk in the P_zero premium scenario. $((\mathrm{FE}_{\mathrm{mean\_ufa}} - \mathrm{FE}_{\mathrm{mean\_ave}}) \times 50)$ is the average aggregate difference in farm expenses between the 50 UFA farms and the 50 AVE farms.

$((FE_{max\_ufa} - FE_{min\_ave}) \times 50)$ is the maximum aggregate difference in farm expenses between the 50 UFA farms and the 50 AVE farms. The parameters for Eq.(6.1) and Eq.(6.2) were estimated during the simulation of dairy farms and the simulation of milk processing, based on 1000 replicates.

The aggregate premium for milkfat UFA concentration (AP_b and AP_h) was divided between the tonnes of butter manufactured (Butter scenario), the tonnes of cheese manufactured (Cheese scenario) or between the tonnes of butter (50% of aggregate premium) and cheese (50% of aggregate premium) manufactured (Butter-Cheese scenario).

Dairy processor aggregate revenue was estimated by multiplying the volume of dairy products manufactured by their corresponding market value and the US$:NZ$ exchange rate.

Dairy processor costs

Dairy processor costs were divided into variable cash costs, fixed cash costs and capital costs (Fonterra, 2011). Variable cash costs associated with the processing of milk into SMP, butter, cheese and their by-products comprised: 1) milk collection costs (associated with on-farm cooling and storage, milk collection, milk testing and storage at the dairy factory), 2) milk processing costs (associated with milk separation, standardisation, pasteurisation and cooling), 3) product processing costs (associated with evaporation, drying, churning, curd manufacture, cheddaring), and 4) Product packaging, storage, and distribution costs. Variable cash costs assumed in the simulation varied depending on the product manufactured (Table 2) and corresponded to the average of the nominal processing costs reported by Geary et al. (2010) and Geary et al. (2013).

Table 2 Variable cash costs assumed in the simulation of milk processing.

	SMP	Butter	Cheese	BMP	Casein	WP
Volume costs						
Milk collection ($/L)[1]			0.0130			
Milk processing ($/L)[2]	0.0175	0.0115	0.0157	0.0144	0.0144	0.0117
Product costs						
Processing ($/t)	143	78	88	141	193	173
Packaging ($/t)	41	31	41	41	41	41
Storage ($/t)	8	80	47	28	6	8
Distribution ($/t)	77	73	65	78	65	78

[1] Milk collection cost per litre of milk was similar for all processing scenarios.

[2] includes standardisation costs ($0.0050/L).

Fixed cash costs, which comprised costs associated with management, marketing, quality control, and rents and rates; and were assumed to be $0.025/L milk processed by average farms (Geary et al., 2013). It was assumed that the total fixed cash costs from the processing of UFA milk was similar to the total fixed cash costs from the processing of AVE milk. Capital costs, which comprised costs associated with depreciation of processing plant and dairy processor return on investment, were assumed to be $0.07/L of milk processed. Capital costs per litre of milk processed were estimated by dividing the capital costs per kilogram of milksolids (milkfat + protein) estimated by Fonterra ($0.88/kg milksolids; Fonterra, 2012b), by the average litres of milk per kilogram of milksolids. The estimation of dairy processor capital costs was based on litres of milk processed to take into account differences in volume of milk processed from AVE farms and UFA farms.

The aggregate payment for milk was estimated by subtracting variable cash costs, fixed cash costs and capital costs from dairy processor aggregate revenue.

Milk payment system

The aggregate payment for milk determined the farm gate milk price. In each milk processing and premium scenario, milksolids payout for UFA milk and AVE milk was estimated by dividing the aggregate payment for milk by the kilograms of milksolids processed from UFA milk and AVE milk, respectively. UFA farms and AVE farms were paid using a multiple component payment system (A + B – C + UFA) which comprised milkfat (A), protein (B), milk volume (C) and milkfat UFA concentration (UFA). Milk volume was included in the payment system as a penalty charged to milk suppliers, and was determined by the variable costs associated with milk volume (Table 2). The values for milkfat, protein, milk volume and milkfat UFA concentration were estimated with the following multiple linear regression model:

$$\text{APM} = \text{Milkfat}_{\text{kg}} + \text{Protein}_{\text{kg}} + \text{Volume}_{\text{L}} + \text{UFA}_{0.1\text{g}} \qquad (6.3)$$

Where, APM is the contribution of each dairy product manufactured, total volume cost and aggregate UFA premium to the aggregate payment for milk. $\text{Milkfat}_{\text{kg}}$ and $\text{Protein}_{\text{kg}}$ are the kilograms of milkfat and protein, respectively, present in the total volume of each dairy product manufactured. Volume_{L} is the total volume of milk processed. $\text{UFA}_{0.1\text{g}}$ is the total 0.1g UFA/100g milkfat above a threshold of 34.50g UFA/100g milkfat, per kilogram of milkfat processed:

$$\text{UFA}_{0.1\text{g}} = ((\text{UFA}_{\text{FP}} - 34.50) \times 10) \times \text{kg FP} \qquad (6.4)$$

Where, UFA_{FP} is the UFA concentration (g/100 g milkfat) in milkfat processed, 34.50 refers to the threshold for milkfat UFA concentration, kg FP is the kilograms of milkfat processed, and 10 is a multiplication factor. A threshold for milkfat UFA concentration was established to ensure that milk supplied to the dairy processor had a minimum milkfat UFA concentration that enabled the manufactured of dairy products high in UFA. A concentration of 34.50 g UFA/100g milkfat was selected as the threshold because it was marginally below the lowest milkfat UFA concentration observed on individual UFA farms.

Statistical analysis

Confidence intervals for production and financial traits of simulated farms were determined by bootstrapping (Henderson, 2005). The segregation of dairy cows from the base population, to form 50 UFA farms, and the simulation of 50

AVE farms, was repeated 1000 times. The mean ($\bar{\theta}$) of each trait (θ) was estimated as the average of its 1000 bootstrap values (θ^*_1, θ^*_2, … θ^*_{1000}). The percentile method was used to estimate a 95% confidence interval, as follows: the 1000 bootstrap values of a trait (θ) were sorted from smallest to largest (θ^*_{1st}, θ^*_{2nd}, … θ^*_{1000th}), and the 25th and 975th ordered elements [θ_{25th}, θ_{975th}] were taken as the lower and upper confidence intervals of trait θ, respectively.

Since the simulation of UFA farms and AVE farms was replicated 1000 times, there were 1000 replicates of daily milk supply for both UFA farms and AVE farms. The simulation of milk processing, performed for each replicate of daily milk supply, resulted in dairy processors having 1000 replicates for each physical and financial trait. Means and confidence intervals for dairy processor traits were determined by bootstrapping methodology, as described in the previous paragraph.

RESULTS

Physical performance of dairy farms and volume of milk supply

The physical characteristics of dairy farms simulated by the farm model are presented in Table 3. Cows in the UFA farms were not significantly different from cows on AVE farms with regards to live weight and lactation length. In addition, UFA farms were not significantly different from AVE farms in feed demand and feed supply (t DM/farm/year). Per farm, UFA farms produced, and supplied a dairy processor, more ($P<0.05$) milk (+6%), lactose (+6%) and minerals (+6%), but less ($P<0.05$) milkfat (-13%), protein (-6%) and casein (-6%), than AVE farms (Table 3). On average, the milkfat produced by UFA farms had 16.7% (range: 15.0% - 18.4%) more UFA than the milkfat produced by AVE farms ($P<0.05$).

Although the volume of milk supplied was different, the profile of milk supplied by UFA farms during the production season was similar to that of AVE farms (Figure 2). The total volume of milk produced, and supplied to a dairy processor, by the 50 UFA farms increased from 9,807 L/day at the beginning of the lactation (July) to 353,098 L/day in October, after which it decreased steadily to 157,463 L/day at the end of the lactation (May). Based on their profile of milk supply, 14.4% of the annual milk supplied by the 50 UFA farms, and 14.6% of the annual milk supplied by AVE farms, was supplied in October (Figure 2). The volumes of milkfat, protein, casein, lactose and minerals supplied to a dairy processor by UFA farms and AVE farms followed the same profile as milk supply (Figure 2).

Table 3 Mean, and (95% confidence interval in brackets), for the physical characteristics of simulated dairy farms with their annual sales of milk, milkfat, protein, lactose, casein and minerals[1].

	AVE farms (50 farms)		UFA farms (50 farms)	
Farm physical characteristics				
Farm size (ha) [2]	120^{x}		120^{x}	
Herd size (cows) [2]	325^{x}		343^{x}	
Stocking rate (cows/ha) [2]	2. 71^{x}		2.86^{x}	
Lactation length (days/cow)	267^{x}	(266 - 268)	268^{x}	(267 - 268)
Live weight (kg/cow)	491^{x}	(488 - 495)	489^{x}	(488 - 490)
Feed demand (t DM/farm/year)	1,488^{x}	(1,464 - 1,500)	1,488^{x}	(1,476 - 1,500)
Pasture utilised (t DM/farm/year)[2]	1,320^{x}		1,320^{x}	
Supplement supply (t DM/farm/year)	168^{x}	(144 - 180)	168^{x}	(156 - 180)
Milk production [3]				
Milk (L/farm/year)	1,414,561^{a}	(1,379,561 - 1,448,273)	1,504,151^{b}	(1,494,371 - 1,514,112)
UFA (g/100 g milkfat) [4]	30.12^{a}	(29.84 - 30.38)	35.15^{b}	(35.10 - 35.20)
Milkfat (kg/farm/year)	61,260^{a}	(59,775 - 62,751)	53,366^{b}	(53,033 - 53,693)
Protein (kg/farm/year)	50,886^{a}	(49,608 - 52,061)	48,052^{b}	(47,742 - 48,339)
Casein (kg/farm/year)	39,182^{a}	(38,196 - 40,087)	37,004^{b}	(36,767 - 37,219)
Lactose (kg/farm/year)	66,484^{a}	(64,842 - 68,069)	70,695^{b}	(70,232 - 71,162)
Minerals (kg/farm/year)	9,901^{a}	(9,659 - 10,137)	10,524^{b}	(10,462 - 10,595)

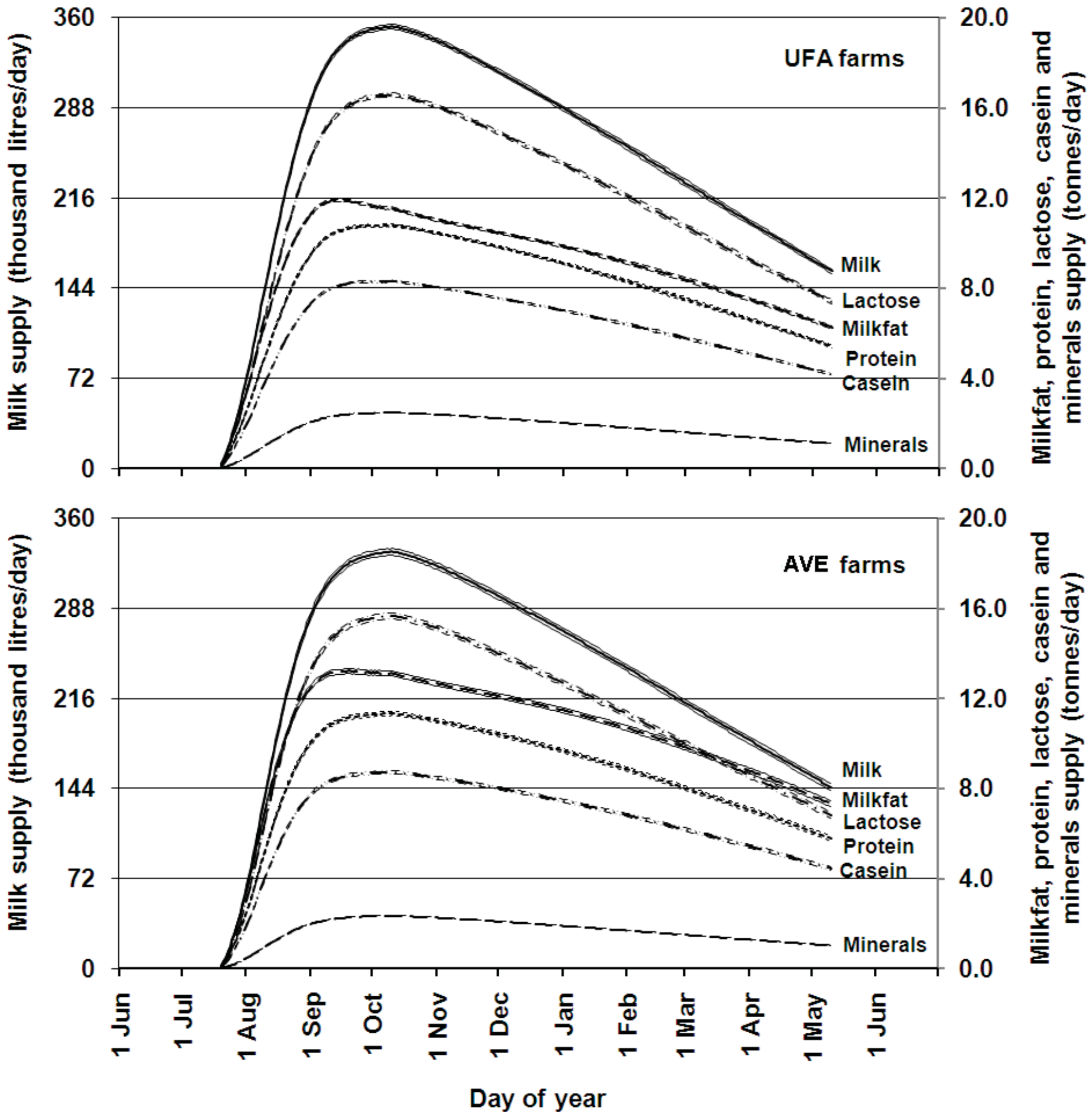
[1] Within a row, means with different letters are significantly different ($P<0.05$).

[2] Model input.

[3] Total volume sold/supplied to a dairy processor.

[4] UFA= concentration of unsaturated fatty acids.

Figure 2 Total volume (mean and 95% confidence interval) of milk, milkfat, protein, lactose, casein and minerals supplied to a dairy processor by the 50 UFA farms and the 50 AVE farms, during the milk production season.



Physical performance of dairy processor

In the three milk-processing scenarios, the processing of UFA milk produced a higher (P<0.05) yield of SMP, but lower (P<0.05) yields of cheese, butter, BMP, casein and WP, than the processing of AVE milk (Table 4). In the Cheese scenario, the by-products from the processing of UFA milk were SMP and WP, but the by-products from the processing of AVE milk were butter, BMP and WP (Table 4). A larger (P<0.05) volume of WP was manufactured in the Butter-Cheese and Cheese scenarios than in the Butter scenario.

On a daily basis, the volume of butter and cheese manufactured from UFA milk was lower (P<0.05) than the volume of butter and cheese manufactured from AVE milk (Figure 3). The concentration of UFA in fat of butter and cheese manufactured from UFA milk decreased steadily during the milk production season, from 36.75 (36.62 - 36.88) g /100 g fat to 33.69 (33.55 - 33.84) g /100 g fat (Figure 3). At all stages of lactation, UFA concentration in fat of butter and cheese manufactured from UFA milk was on average 16.7% (ranging from 15% to 18.4%) higher (P<0.05) than in fat of butter and cheese manufactured from AVE milk.

Table 4 Volume of dairy products manufactured from UFA milk and AVE milk, under three different processing scenarios[1].

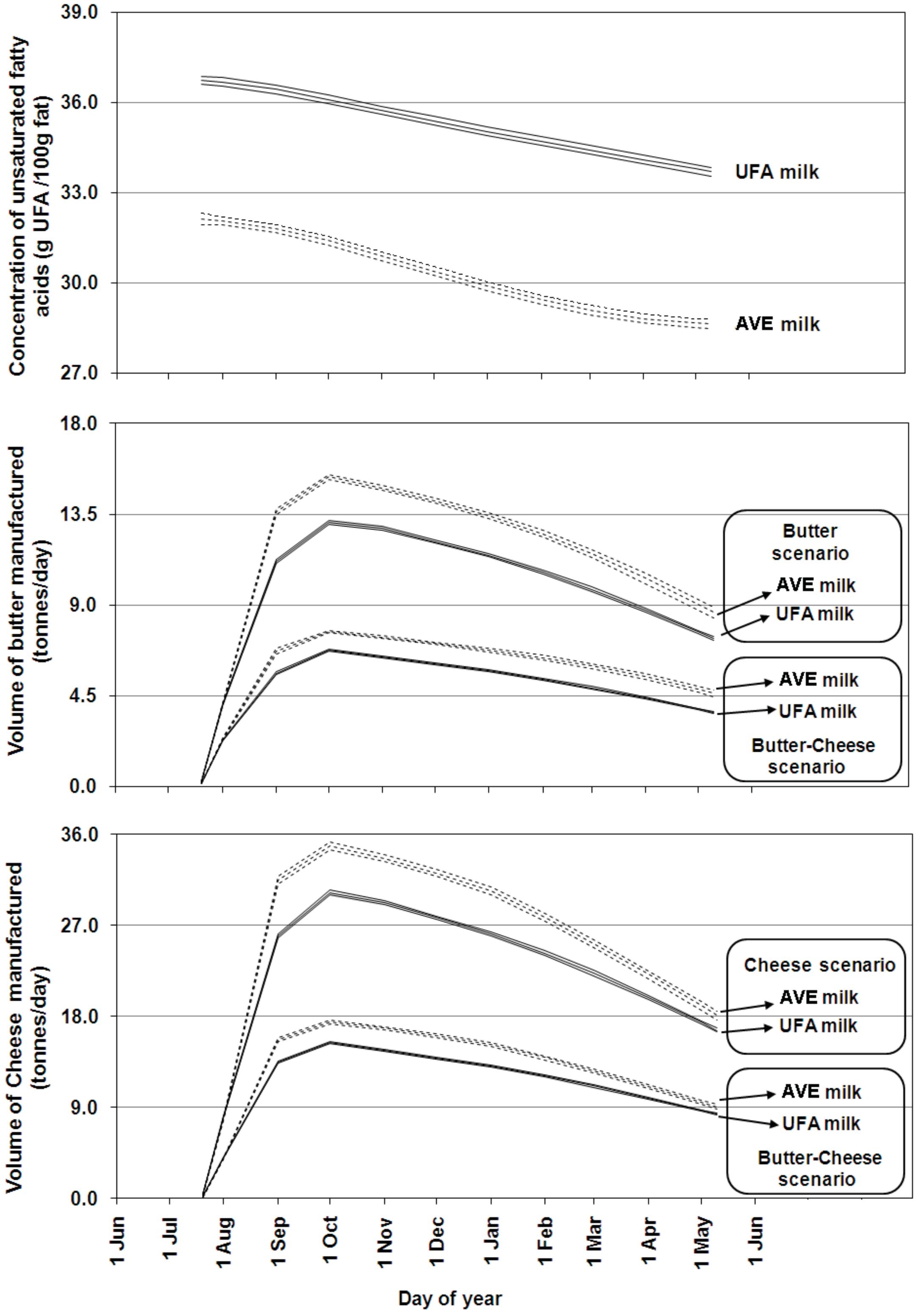
Processing scenario and dairy products[2]	Volume of products manufactured, kg /1,000 L	
	AVE milk	UFA milk
Butter		
SMP	71.8^{a} (71.4 - 72.3)	78.1^{b} (78.0 - 78.2)
Butter [3]	50.7^{a} (50.0 - 51.4)	41.3^{b} (41.2 - 41.5)
BMP	5.5^{a} (5.4 - 5.6)	4.2^{b} (4.2 - 4.3)
Casein	8.5^{a} (8.2 - 8.9)	3.8^{b} (3.8 - 3.9)
WP	6.2^{a} (5.9 - 6.4)	2.7^{b} (2.7 - 2.8)
Butter-Cheese		
SMP	35.9^{a} (35.7 - 36.1)	41.9^{b} (41.7 - 42.1)
Cheese [3]	56.6^{a} (56.1 - 57.1)	47.1^{b} (47.0 - 47.3)
Butter [3]	25.8^{a} (25.2 - 26.4)	20.7^{b} (20.6 - 20.7)
BMP	2.8^{a} (2.7 - 2.8)	2.1^{b} (2.1 - 2.1)
Casein	4.3^{a} (4.1 - 4.5)	1.9^{b} (1.8 - 1.9)
WP	35.4^{a} (35.3 - 35.6)	31.3^{b} (31.2 - 31.4)
Cheese		
SMP	0^{a}	5.7^{b} (5.3 - 6.1)
Cheese [3]	113^{a} (112 - 114)	94.3^{b} (94.1 - 94.6)
Butter [3]	0.8^{a} (0.3 - 1.5)	0^{b}
BMP	0.1^{a} (0.0 - 0.2)	0^{b}
Casein	0^{a}	0^{a}
WP	64.7^{a} (64.6 - 64.8)	59.9^{b} (59.7 - 60.2)

[1] Within a row, means with different letters are significantly different ($P<0.05$). UFA milk = milk with a high concentration of unsaturated fatty acids (UFA) in milkfat supplied by 50 farms (UFA farms). AVE milk = milk supplied by 50 average farms. Processing scenarios: Butter = milk processed into butter and SMP. Butter-Cheese = 50% of milk processed into butter and SMP, and 50% processed into cheese. Cheese = milk processed into cheese.

[2] SMP = skim milk powder, BMP = butter milk powder, WP = whey powder.

[3] Concentration of UFA in butter and cheese: UFA milk = 35.15 (35.10 - 35.20) g /100 g fat, AVE milk = 30.12 (29.84 - 30.38) g /100 g fat.

Figure 3 Simulated concentration of unsaturated fatty acids (UFA) and daily volume (mean and 95% confidence interval) of butter and cheese manufactured from milk supplied by the 50 UFA farms (UFA milk) and the 50 AVE farms (AVE milk), under three processing scenarios (Butter = milk processed into butter and SMP, Butter-Cheese = 50% of milk processed into butter and SMP, and 50% processed into cheese, Cheese = milk processed into cheese).



Financial performance of dairy processor

In the three milk-processing scenarios, when AVE milk was processed, dairy processor financial performance in the P_breakeven and P_high premium scenarios (data not shown) was similar to the one in the P_zero scenario. In the P_zero scenario, the processing of UFA milk was associated with higher ($P<0.05$) revenues from the sales of SMP, but lower ($P<0.05$) revenues from the sales of cheese, butter, BMP and casein, than the processing of AVE milk, in all three milk-processing scenarios (Table 5). With exception of the Cheese scenario, where there were no significant differences, the revenue from the sales of WP in the Butter and Butter-Cheese scenarios was significantly lower ($P<0.05$) for UFA milk than AVE milk (Table 5).

In the Butter scenario, the premium price of butter manufactured from UFA milk was US $5513/t in the P_breakeven scenario, and US $5749/t in the P_high premium scenario (51% and 58% higher than the market value of butter, respectively). In the Butter-Cheese scenario, the premium price of butter manufactured from UFA milk was US $5318/t (P_breakeven scenario) and US $5530/t (P_high scenario), 46% and 52% higher than its market value, respectively.

In the Butter-Cheese scenario, the premium price of cheese manufactured from UFA milk was US $5024/t and US $5147/t, for the P_breakeven and P_high scenarios, respectively (24% and 27% higher than its market value, respectively). In the Cheese scenario, the price of cheese manufactured from UFA milk was US $4939/t (P_breakeven scenario) and US $5047/t (P_high scenario), 22% and 25% higher than its market value, respectively. In the three milk-processing scenarios, the revenues from the sales of butter and cheese in the P_breakeven and P_high scenarios were higher ($P<0.05$) for UFA milk than for AVE milk, due to the higher market value butter and cheese manufactured from UFA milk (Table 5).

When UFA milk was processed, but not AVE milk, dairy processor total revenue was higher ($P<0.05$) when UFA milk was processed into cheese rather than into butter (deduced from confidence intervals for total revenue mean in different milk-processing scenarios, Table 5). In the Butter, Butter-Cheese and Cheese scenarios, the total revenue generated by UFA milk in the P_zero scenario was $48.76, $49.09 and $49.42 million, respectively (5.5%, 6.1% and 6.7% lower, respectively, than the total revenue generated by AVE milk) (Table 5). Across the three milk-processing scenarios, the total revenue generated by UFA milk in the P_breakeven and P_high premium scenarios was 8.4% - 8.7% and 10.4% - 10.7% higher ($P<0.05$), respectively, than the total revenue generated by AVE milk.

Dairy processor expenses were 3.3% higher ($P<0.05$) when UFA milk was processed in the cheese scenario rather than in the Butter scenario, but they were not significantly influenced by the milk-processing scenario when AVE milk was processed (deduced from confidence intervals of dairy processor expenses in different milk-processing scenarios, Table 5). In the three milk-processing scenarios, the processing of UFA milk was associated with 6.3% higher ($P<0.05$) volume costs and capital costs, but 3.6% - 4.3% lower ($P<0.05$) product manufacturing costs, than the processing of AVE milk (Table 5). Dairy processor total expenses were significantly higher ($P<0.05$) for UFA milk than for AVE milk in all three processing scenarios (Table 5).

The milk-processing scenario did not significantly influence the aggregate payment for milk (proportion of revenue used to pay milk suppliers) in the P_zero scenario. However, the aggregate payment for milk generated by UFA milk was significantly higher ($P<0.05$) when UFA milk was processed in the Cheese scenario rather than in the Butter scenario (deduced from confidence intervals for this trait in different milk-processing scenarios, Table 5).

In the Butter, Butter-Cheese and Cheese scenarios, the aggregate payment for milk generated by UFA milk in the P_zero scenario was 8%, 9% and 10% lower ($P<0.05$), respectively, than that of AVE milk. However, in the P_breakeven and P_high scenarios, the aggregate payment for milk generated by UFA milk was 12% and 15% higher ($P<0.05$), respectively, than that of AVE milk (Table 5).

In the P_breakeven scenario, the aggregate premium for milkfat UFA concentration (difference in aggregate payment for milk between the P_breakeven and P_zero scenarios for UFA milk) was \$8.1M, \$8.4M and \$8.8M, for the Butter, Butter-Cheese and Cheese scenarios, respectively. In the P_high premium scenario, the aggregate premium for milkfat UFA concentration (difference in aggregate payment for milk between the P_high and P_zero premium scenarios for UFA milk) was \$9.1M, \$9.5M and \$9.8M, for the Butter, Butter-Cheese and Cheese scenarios, respectively.

Table 5 Dairy processor financial characteristics (mean, with 95% confidence interval between brackets) when AVE milk and UFA milk were processed under three milk-processing scenarios (Butter, Butter-Cheese, Cheese), and under three premiums scenarios (P_zero, P_breakeven, P_high) for concentration of unsaturated fatty acids (UFA) in milkfat above 34.50 g UFA/100 g milkfat.[1]

Butter scenario	P_zero		P_breakeven	P_high
	AVE milk[3]	UFA milk	UFA milk	UFA milk
Butter market value (US $/tonne)	3641^{a}	3641^{a}	5513^{b} (5501 - 5525)	5749^{c} (5735 - 5763)
Dairy processor revenue (NZ $, millions)				
From sales of butter	18.17^{a} (17.73 - 18.62)	15.74^{b} (15.64 - 15.84)	23.84^{c} (23.73 - 23.94)	24.86^{d} (24.75 - 24.96)
From sales of SMP[2]	24.40^{a} (23.75 - 25.05)	28.21^{b} (28.03 - 28.41)		
From sales of BMP[2]	1.57^{a} (1.53 - 1.61)	1.29^{b} (1.28 - 1.30)		
From sales of casein[2]	6.72^{a} (6.42 - 7.01)	3.18^{b} (3.12 - 3.25)		
From sales of WP[2]	0.71^{a} (0.68 - 0.74)	0.34^{b} (0.33 - 0.34)		
Total revenue	51.57^{a} (50.79 - 52.35)	48.76^{b} (48.45 - 49.06)	56.86^{c} (56.54 - 57.15)	57.88^{d} (57.56 - 58.17)
Dairy processor expenses (NZ $, millions)				
Volume costs	2.97^{a} (2.90 - 3.04)	3.16^{b} (3.14 - 3.18)		
Product costs	2.73^{a} (2.67 - 2.80)	2.63^{b} (2.62 - 2.65)		
Fixed costs	1.77^{x} (1.72 - 1.81)	1.77^{x} (1.74 - 1.79)		
Capital costs	4.93^{a} (4.81 - 5.05)	5.25^{b} (5.21 - 5.28)		
Total expenses	12.41^{a} (12.10 - 12.70)	12.81^{b} (12.73 - 12.89)		
Aggregate payment for milk (NZ $, millions)	39.17^{a} (38.18 - 39.75)	35.95^{b} (35.71 - 36.17)	44.05^{c} (43.81 - 44.26)	45.07^{d} (44.83 - 45.28)

Table 5 (continued).

Butter-Cheese scenario	P_zero		P_breakeven	P_high
	AVE milk^3	UFA milk	UFA milk	UFA milk
Butter market value (US $/tonne)	3641^a	3641^a	5318^b (5307 - 5329)	5530^c (5518 - 5543)
Cheese market value (US $/tonne)	4050^a	4050^a	5024^b (5018 - 5030)	5147^c (5140 - 5155)
Dairy processor revenue (NZ $, millions)				
From sales of cheese	22.57^a (22.00 - 23.09)	19.98^b (19.85 - 20.11)	24.79^c (24.66 - 24.92)	25.40^d (25.27 - 25.53)
From sales of butter	9.24^a (8.97 - 9.51)	7.87^b (7.82 - 7.92)	11.50^c (11.45 - 11.55)	11.96^c (11.90 - 12.01)
From sales of SMP^2	12.20^a (11.88 - 12.53)	15.14^b (15.01 - 15.27)		
From sales of BMP^2	0.80^a (0.77 - 0.82)	0.64^b (0.64 - 0.65)		
From sales of casein^2	3.36^a (3.21 - 3.50)	1.59^b (1.56 - 1.62)		
From sales of WP^2	4.11^a (4.00 - 4.20)	3.86^b (3.83 - 3.88)		
Total revenue	52.27^a (50.96-53.45)	49.09^b (48.78 - 49.39)	57.52^b (57.21 - 57.82)	58.59^c (58.28 - 58.89)
Dairy processor expenses (NZ $, millions)				
Volume costs	2.91^a (2.84 - 2.98)	3.10^b (3.08 - 3.12)		
Product costs	3.03^a (2.95 - 3.09)	2.91^b (2.89 - 2.92)		
Fixed costs	1.77^x (1.72 - 1.81)	1.77^x (1.76 - 1.78)		
Capital costs	4.93^a (4.81 - 5.05)	5.25^b (5.21 - 5.28)		
Total expenses	12.64^a (12.33 - 12.93)	13.02^b (12.94 - 13.10)		
Aggregate payment for milk (NZ $, millions)	39.62^a (38.18 - 40.05)	36.07^b (35.83 - 36.29)	44.50^c (44.26 - 44.72)	45.57^b (45.33 - 45.79)

Table 5 (continued).

Cheese scenario	P_zero		P_breakeven	P_high
	AVE milk[3]	UFA milk	UFA milk	UFA milk
Cheese market value (US $/tonne)	4050^{a}	4050^{a}	4939^{b} (4933 - 4944)	5047^{c} (5041 - 5054)
Dairy processor revenue (NZ $, millions)				
From sales of cheese	45.13^{a} (44.01 - 46.19)	39.97^{b} (39.71 - 40.22)	48.74^{c} (48.47 - 48.99)	49.81^{d} (49.55 - 50.07)
From sales of butter	0.30^{a} (0.09 - 0.52)	0^{b}		
From sales of SMP[2]	0^{a}	2.07^{b} (1.92 - 2.19)		
From sales of BMP[2]	0.03^{a} (0.01 - 0.05)	0^{b}		
From sales of casein[2]	0^{x}	0^{x}		
From sales of WP[2]	7.50^{a} (7.31 - 7.67)	7.38^{a} (7.33 - 7.43)		
Total revenue	52.96^{a} (51.64 - 54.16)	49.42^{b} (49.10 - 49.72)	58.19^{c} (57.87 - 58.49)	59.26^{d} (58.94 - 59.56)
Dairy processor expenses (NZ $, millions)				
Volume costs	2.86^{a} (2.79 - 2.93)	3.04^{b} (3.02 - 3.06)		
Product costs	3.32^{a} (3.24 - 3.40)	3.18^{b} (3.16 - 3.2)		
Fixed costs	1.77^{x} (1.72 - 1.81)	1.77^{x} (1.76 - 1.78)		
Capital costs	4.93^{a} (4.81 - 5.05)	5.25^{b} (5.21 - 5.28)		
Total expenses	12.88^{a} (12.60 - 13.13)	13.23^{b} (13.14 - 13.31)		
Aggregate payment for milk (NZ $, millions)	40.08^{a} (39.08 - 40.99)	36.19^{b} (35.95 - 36.41)	44.96^{c} (44.72 - 45.18)	46.03^{d} (45.79 - 46.25)

[1] Within a row, means with different letters are significantly different ($P<0.05$). Milk-processing scenarios: Butter= all milk processed into butter and skim milk powder (SMP), Butter-Cheese= 50% of milk processed into butter and SMP, and 50% of milk processed into cheese, Cheese= all milk processed into cheese. UFA premium scenarios: P_zero= no premium for milkfat UFA concentration, P_breakeven= premium that breakevens the operating profit of UFA farms with that of AVE farms, P_high= premium in which UFA farms have a marginally higher operating profit than AVE farms. BMP= butter milk powder, WP= whey powder. UFA milk = milk high in UFA supplied by 50 dairy farms. AVE milk= milk supplied by 50 average farms.

[2] Market value of dairy products: US $3641/t for butter, US $3,450/t for SMP, US $2,885/t for BMP, US $8,000/t for casein and US $1,177/t for WP.

[3] Values for AVE milk in the P_breakeven and P_high scenarios were similar to the P_zero scenario.

Milk payment

Dairy processor payment to milk suppliers, expressed per kilogram of milksolids (milkfat + protein), was higher ($P<0.05$) when UFA milk and AVE milk were processed in the Cheese scenario rather than in the Butter scenario (deduced from confidence intervals for milksolids payout in different milk-processing scenarios, Table 6). Across milk processing and premium scenarios, milksolids payout was significantly higher ($P<0.05$) for UFA milk than for AVE milk, with an exception in the Cheese P_zero scenario, where there were no significant differences in milksolids payout between UFA milk and AVE milk (Table 6).

In the P_zero scenario, milksolids payout was higher ($P<0.05$) for UFA milk than for AVE milk, with exception of the Cheese scenario where there were no significant differences in milksolids payout between the two types of milk (Table 6). Across milk-processing scenarios, milksolids payout for UFA milk in the P_breakeven and P_high scenarios were 23% - 24% and 25% - 27% higher ($P<0.05$) than in the P_zero scenario, respectively. In the Butter scenario, the value of milkfat was higher ($P<0.05$) for UFA milk than AVE milk, but in the Butter-Cheese and Cheese scenarios it was higher ($P<0.05$) for AVE milk than UFA milk. In all processing scenarios the value of protein was higher ($P<0.05$) for UFA milk than AVE, but there were no significant differences in the value of milk volume between UFA milk and AVE milk (Table 6).

In the Butter, Butter-Cheese and Cheese scenarios, the premium for UFA concentration in the P_breakeven scenario was $0.47, $0.49 and $0.51 /kg milkfat, respectively, for each 0.1 g/100 g milkfat above 34.50 g UFA/100 g milkfat. In the P_high scenario, the premium for an increase in 0.1 g UFA/100 g milkfat (above 34.50 g UFA/100 g milkfat) was on average $0.53, $0.55 and $0.57 /kg milkfat, for the Butter, Butter-Cheese and Cheese scenarios, respectively (Table 6).

Table 6 Value of milkfat, protein, milk volume and concentration of unsaturated fatty acids (UFA) in milkfat, for AVE milk and UFA milk, under three milk-processing scenarios and under three premium scenarios for milkfat UFA concentration above 34.50 g UFA/100 g milkfat.[1]

	P_zero		P_breakeven	P_high
	AVE milk	UFA milk	UFA milk	UFA milk
Milk processed				
Milk processed (L, millions)	70.73^{a} (68.98 - 72.41)	75.21^{b} (74.72 - 75.71)		
Milkfat processed (kg, millions)	3.06^{a} (2.99 - 3.14)	2.67^{b} (2.65 - 2.68)		
Protein processed (kg, millions)	2.54^{a} (2.48 - 2.60)	2.40^{b} (2.39 - 2.42)		
Milksolids processed (kg, millions)	5.61^{a} (5.47 - 5.74)	5.07^{b} (5.04 - 5.10)		
$UFA_{0.1g}$ (0.1 g UFA, millions)[2]	0^{a}	17.34^{b} (16.18 - 18.60)		
Butter scenario				
APM ($, millions)[3]	39.17^{a} (38.19 - 39.75)	35.95^{b} (35.71 - 36.17)	44.05^{c} (43.81 - 44.26)	45.07^{d} (44.83 - 45.28)
Milksolids payout ($/kg MS)	6.99^{a} (6.97 - 7.00)	7.09^{b} (7.08 - 7.10)	8.69^{c} (8.67 - 8.70)	8.89^{d} (8.87 - 8.90)
Milkfat value ($/kg)	4.63^{a} (4.63 - 4.64)	4.69^{b} (4.68 - 4.69)		
Protein value ($/kg)	10.98^{a} (10.96 - 11.01)	11.07^{b} (11.05 - 11.09)		
Volume value ($/L)	-0.042^{x} (-0.042 - -0.042)	-0.042^{x} (-0.042 - -0.042)		
UFA value ($/0.1% UFA/kg milkfat)	0^{a}	0^{a}	0.47^{b} (0.45 - 0.48)	0.53^{c} (0.50 - 0.55)
Butter-Cheese scenario				
APM ($, millions)[3]	39.62^{a} (38.63 - 40.52)	36.07^{b} (35.83 - 36.29)	44.50^{c} (44.26 - 44.72)	45.57^{d} (45.33 - 45.79)
Milksolids payout ($/kg MS)	7.07^{a} (7.05 - 7.08)	7.11^{b} (7.10 - 7.12)	8.78^{c} (8.76 - 8.79)	8.99^{d} (8.97 - 9.00)
Milkfat value ($/kg)	4.72^{a} (4.71 - 4.73)	4.70^{b} (4.69 - 4.71)		
Protein value ($/kg)	11.03^{a} (11.01 - 11.06)	11.08^{b} (11.06 - 11.10)		
Volume value ($/L)	-0.041^{a} (-0.041 - -0.041)	-0.041^{x} (-0.041 - -0.041)		
UFA value ($/0.1% UFA/kg milkfat)	0^{a}	0^{a}	0.49^{b} (0.46 - 0.51)	0.55^{c} (0.52 - 0.57)

Table 6 (continued).

	P_zero		P_breakeven	P_high
	AVE milk	UFA milk	UFA milk	UFA milk
Cheese scenario				
APM ($, millions) [3]	40.08^{a} (39.08 - 40.99)	36.19^{b} (35.95 - 36.41)	44.96^{c} (44.72 - 45.18)	46.03^{d} (45.79 - 46.25)
Milksolids payout ($/kg MS)	7.15^{a} (7.13 - 7.16)	7.14^{a} (7.13 - 7.15)	8.87^{b} (8.85 - 8.88)	9.08^{c} (9.06 - 9.09)
Milkfat value ($/kg)	5.68^{a} (5.58 - 5.79)	4.49^{b} (4.44 - 4.55)		
Protein value ($/kg)	10.03^{a} (9.90 - 10.17)	11.34^{b} (11.26 - 11.42)		
Volume value ($/L)	-0.040^{x} (-0.040 - -0.040)	-0.040^{x} (-0.040 - -0.040)		
UFA value ($/0.1% UFA/kg milkfat)	0^{a}	0^{a}	0.51^{b} (0.48 - 0.53)	0.57^{d} (0.55 - 0.60)

[1] Within a row, means with different letters are significantly different ($P<0.05$). Milk-processing scenarios: Butter = all milk processed into butter and skim milk powder (SMP), Butter-Cheese= 50% of milk processed into butter and SMP, and 50% of milk processed into cheese, Cheese = all milk processed into cheese. UFA premium scenarios: P_zero= no premium for milkfat UFA concentration, P_breakeven= premium that breakevens the operating profit of UFA farms with that of AVE farms, P_high= premium in which UFA farms have a marginally higher operating profit than AVE farms. Milk payment system = (kg milkfat × milkfat value) + (kg protein × protein value) + (L milk × volume value) + ($UFA_{0.1g}$ × UFA value). Values for AVE milk in the P_breakeven and P_high scenarios were similar than for the P_zero scenario. AVE milk= milk supplied by 50 average farms. UFA milk = milk high in UFA supplied by 50 dairy farms.

[2] $UFA_{0.1g}$ = Total 0.1g UFA/100g milkfat above 34.50g UFA/100g in milkfat processed = (UFA concentration in milkfat processed - 34.50g/100g milkfat) × kg milkfat processed ×10.

[3] APM= aggregate payment for milk.

Financial performance of dairy farms

Milk income ($/ha) was estimated for each processing and premium scenario using the values for milkfat, protein, milk volume and milkfat UFA concentration reported in Table 6. Milk income ($/ha) was not significantly influenced by milk-processing scenario when UFA milk and AVE milk were processed in the P_zero scenario (deduced from the confidence intervals for milk income in different milk-processing scenarios, Table 7). In the P_breakeven and P_high premium scenarios, milk income ($/ha) was higher ($P<0.05$) when UFA milk was processed into cheese rather than into butter and SMP.

In all milk processing scenarios, in the P_zero scenario, the milk income ($/ha) of UFA farms was 8% to 10% lower ($P<0.05$) than that of AVE farms. In the P_breakeven and P_high scenarios, the milk income ($/ha) of UFA farms was 12% and 15% higher ($P<0.05$), respectively, than that of AVE farms, in all milk processing scenarios (Table 7). UFA farms had significantly higher ($P<0.05$) stock income than AVE farms (Table 7). The gross farm income ($/ha) of UFA farms in the P_zero scenario was significantly lower ($P<0.05$) than that of AVE farms (-7%, -8% and -9%, for the Butter, Butter-Cheese and Cheese scenarios, respectively). In the three milk-processing scenarios, the gross farm income per hectare of UFA farms in the P_breakeven and P_high premium scenarios was 12% and 14% higher ($P<0.05$), respectively, than that of AVE farms.

There were no significant differences in feed expenses per hectare between UFA farms and AVE farms, but UFA farms had significantly higher ($P<0.05$) marginal costs per hectare than AVE farms (Table 7). UFA farms spent $629/ha to replace their current herds with herds of cows that produce milkfat with high UFA concentration. On average, farm expenses per hectare were 17% higher ($P<0.05$) for UFA farms than for AVE farms.

In the P_zero premium scenario, the operating profit ($/ha) of UFA farms was significantly lower ($P<0.05$) than that of AVE farms (-55%, -56% and -57%, for the Butter, Butter-Cheese and Cheese scenarios, respectively) (Table 7). In the Butter, Butter-Cheese and Cheese scenarios, a premium of \$0.47, \$0.49, and \$0.51 /kg milkfat, respectively, for each 0.1 g/100 g milkfat increase in UFA concentration (above the threshold), resulted on UFA farms having an operating profit similar to that of AVE farms (Figure 4 and Table 7). A premium of \$0.53, \$0.55, and \$0.57 /kg milkfat for each 0.1 g/100 g milkfat increase in UFA concentration, for the Butter, Butter-Cheese and Cheese scenarios respectively, gave UFA farms a marginally higher ($P<0.05$) operating profit (\$/ha) than AVE farms (Figure 4 and Table 7).

Table 7 Financial characteristics of UFA farms and AVE farms under three milk-processing scenarios (Butter, Butter-Cheese, and Cheese) and under three premium scenarios (P_zero, P_breakeven, P_high) for concentration of unsaturated fatty acids (UFA) in milkfat above 34.50 g UFA/100 g milkfat .[1]

	P_zero		P_breakeven	P_high
	AVE farms	UFA farms	UFA farms	UFA farms
Farm income ($/ha)				
Milk income				
Butter scenario[2]	$6,496^{a}$ (6,333 - 6,645)	$5,985^{b}$ (5,919 - 5,995)	$7,295^{c}$ (7,255 - 7,331)	$7,463^{d}$ (7,423 - 7,499)
Butter-Cheese scenario[3]	$6,571^{a}$ (6,407 - 6,721)	$5,978^{b}$ (5,938 - 6,014)	$7,370^{c}$ (7,330 - 7,406)	$7,546^{d}$ (7,506 - 7,582)
Cheese scenario[4]	$6,645^{a}$ (6,479 - 6,798)	$5,998^{b}$ (5,958 - 6,035)	$7,446^{c}$ (7,405 - 7,482)	$7,623^{d}$ (7,582 - 7,660)
Stock income	499^{a} (491 - 508)	529^{b} (522 - 535)		
Other income	46^{b}	46^{b}		
Gross farm income				
Butter scenario	$7,041^{a}$ (6,878 - 7,190)	$6,533^{b}$ (6,493 - 6,570)	$7,870^{c}$ (7,829 - 7,906)	$8,038^{d}$ (7,998 - 8,074)
Butter-Cheese scenario	$7,116^{a}$ (6,952 - 7,268)	$6,553^{b}$ (6,512 - 6,590)	$7,945^{c}$ (7,904 - 7,982)	$8,121^{d}$ (8,081 - 8,158)
Cheese scenario	$7,190^{a}$ (7,022 - 7,344)	$6,573^{b}$ (6,532 - 6,610)	$8,021^{c}$ (7,980 - 8,058)	$8,198^{d}$ (8,157 - 8,235)
Farm expenses ($/ha)				
Marginal expenses	$3,215^{a}$	$3,393^{b}$		
Feed expenses	$1,447^{b}$ (1,405 - 1,491)	$1,453^{b}$ (1,441 - 1,465)		
Segregation expenses	0^{a}	629^{b} (629 - 629)		
Total expenses	$4,662^{a}$ (4,620 - 4,705)	$5,475^{b}$ (5,462 - 5,487)		

Table 7 (continued).

	P_zero		P_breakeven	P_high
	AVE farms	UFA farms	UFA farms	UFA farms
Operating profit ($/ha)				
Butter scenario	2,379^{a} (2,255 - 2,490)	1,059^{b} (1,030 - 1,086)	2,395^{a} (2,366 - 2,422)	2,563^{c} (2,535 - 2,590)
Butter-Cheese scenario	2,454^{a} (2,328 - 2,567)	1,078^{b} (1,049 - 1,105)	2,470^{a} (2,441 - 2,497)	2,647^{c} (2,618 - 2,674)
Cheese scenario	2,527^{a} (2,400 - 2,643)	1,099^{b} (1,069 - 1,126)	2,546^{a} (2,517 - 2,573)	2,724^{c} (2,694 - 2,751)

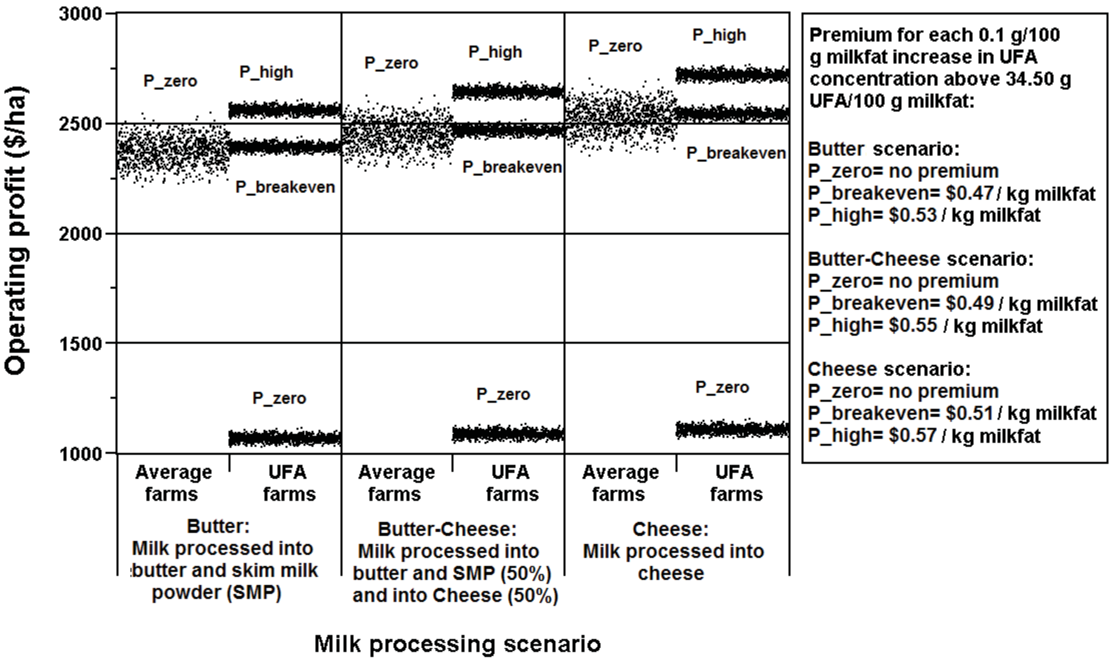
[1] Within a row, means with different letters are significantly different ($P<0.05$). Milk-processing scenarios: Butter = all milk processed into butter and skim milk powder (SMP), Butter-Cheese= 50% of milk processed into butter and SMP, and 50% of milk processed into cheese, Cheese = all milk processed into cheese.

[2] Milk payout: for AVE farms = $4.63/kg milkfat + $10.98/kg protein + -$0.042/L milk, for UFA farms = $4.69/kg milkfat + $11.07/kg protein + -$0.042/L milk + UFA premium. UFA premium ($ /kg milkfat for each 0.1 g UFA/100 g milkfat above 34.50 g/100 g milkfat): P_zero = 0, P_breakeven = $0.47 and P_high = $0.53.

[3] Milk payout: for AVE farms = $4.72/kg milkfat + $11.03/kg protein + -$0.041/L milk, for UFA farms = $4.70/kg milkfat + $11.08/kg protein + -$0.041/L milk + UFA premium. UFA premium ($ /kg milkfat for each 0.1 g UFA/100 g milkfat above 34.50 g/100 g milkfat: P_zero = 0, P_breakeven = $0.49 and P_high = $0.55.

[4] Milk payout: for AVE farms = $5.68/kg milkfat + $10.03/kg protein + -$0.040/L milk, for UFA farms = $4.40/kg milkfat + $11.34/kg protein + -$0.040/L milk + UFA premium. UFA premium ($ /kg milkfat for each 0.1 g UFA/100 g milkfat above 34.50 g/100 g milkfat: P_zero = 0, P_breakeven = $0.51 and P_high = $0.57.

Figure 4 Simulated (1000 replicates) operating profit of AVE farms and UFA farms, under three milk-processing scenarios (Butter, Butter-Cheese and Cheese) and three premium scenarios (P_zero, P_breakeven, P_high) for milkfat UFA concentration.



DISCUSSION

In the present study, the physical and financial characteristics of milk suppliers and dairy processors were considered in the development of a payment system with a premium for milkfat UFA concentration. This approach, which has been used in previous studies (Breen et al., 2001; Garrick & Lopez Villalobos, 2000), takes into account the effects, on dairy farms and dairy processors, of producing and processing milk with a high milkfat UFA concentration.

Although UFA farms were similar to AVE farms in size (ha/farm), pasture production (t DM/farm), supplement input (t DM/farm), feed demand (t DM/farm), cow live weight (kg) and lactation length (days), and despite UFA farms having larger herds and producing more milk (+6%, L/farm) than AVE farms, their yields (kg/farm) of milkfat, protein and casein were 13%, 6% and

6% lower, respectively, than AVE farms (Table 3). When milk production is expressed on a per cow basis (to eliminate differences due to herd size), there were no significant differences in milk yield (L) per cow between UFA farms and AVE farms, but cows on UFA farms produced milk with significantly lower percentages and yields (kg) of milkfat and protein, than cows on AVE farms.

As the simulation of cow performance was based on the correlations between milkfat UFA concentration and other milk production traits (Chapter 4), the decrease in yields of milkfat and protein was most likely due to the negative phenotypic and genetic correlations between these traits (Schennink et al., 2008; Soyeurt et al., 2008b; Soyeurt et al., 2007; Stoop et al., 2008). Similar differences in milk yield, fat yield and fat percentage, between cows that produced milkfat with high or average UFA concentration, were reported by Thomson et al. (2003a). The total volume of milksolids supplied by the 50 UFA farms and the 50 AVE farms were 5.07 and 5.61 million kilograms, respectively. These volumes were close to the volume of milksolids from organic milk (6.5 million kg) processed by Fonterra in 2010/2011 (DairyNews, 2011).

The total volumes of milk (L/year), lactose (kg/year) and minerals (kg/year) supplied to a dairy processor by the 50 UFA farms were 6% higher than those of AVE farms (Figure 2). The farm model estimated the yields of lactose and minerals as a percentage of milk yield. Therefore, the higher yields of lactose and minerals in UFA farms were due to their higher milk yields. This suggests that if milk suppliers changed from producing average milk to producing milk high in UFA, a dairy processor would need to increase its size to accommodate a larger volume of milk. The compact spring calving pattern simulated for UFA farms and AVE farms determined that the peak of milk supply occur in October (Figure 2). In the present study, the proportion of milk supplied by UFA farms and AVE farms in October (14.4% and 14.6% of the annual milk supply), was close to the proportion of milk supplied to Fonterra (14.2%) during the milk production season (July 20 - May 10) (Fonterra, 2012b).

During milk processing the yield of dairy products was influenced by the product mix manufactured and milk composition (Table 4). The influence of milk composition on yield of dairy products has been reported in several studies (Geary et al., 2010; Johnson et al., 2007; Lopez-Villalobos, 2002). Since the milkfat, protein, and consequently casein, content of UFA milk was lower than that of AVE milk, lower volumes of butter (84% milkfat) cheese (35% milkfat and 24.5% casein protein) and casein (89% casein) were manufactured from UFA milk than from AVE milk (Figure 3). As lactose is the major component of SMP (54% lactose), the higher volume of SMP manufactured from UFA milk was most likely due to the higher volume of lactose supplied with UFA milk. The daily volume of butter and cheese manufactured during the dairy season (Figure 3) followed the same pattern as milk supply (with a peak in October) and was similar to that observed in New Zealand (Fonterra, 2012b).

During the milk production season, the profile of UFA concentration in butter and cheese was similar to that of milkfat, and decreased during the milk production season. Previous studies have indicated that the milkfat UFA concentration of dairy products resembled that of the milk they were manufactured from (Bobe et al., 2003; Chion et al., 2010; Oeffner et al., 2013). Several studies reported that a high UFA concentration could affect the textural properties of butter and cheese, by decreasing butter hardness, increasing the spreadability of butter, decreasing the springiness of cheese and increasing the hardness, cohesiveness, chewiness of cheese (Baer et al., 2001; Bobe et al., 2007; Caroprese et al., 2013; Chen et al., 2004; Hurtaud & Peyraud, 2007; Oeffner et al., 2013).

In the study by Chen et al. (2004) an increase in milkfat UFA concentration of 18% yielded a significantly softer butter, but in other studies an increase of 22% to 35% in milkfat UFA concentration was necessary to improve butter spreadability (Baer et al., 2001; Bobe et al., 2007; Hurtaud & Peyraud, 2007; Oeffner et al., 2013). In the study by Couvreur et al. (2006), an increase in milkfat UFA concentration of 11% improved some sensorial properties of butter (melting score, firmness in mouth), but did not affect its spreadability. Based on previous studies, it is possible that the percentage of increase in milkfat UFA concentration achieved in the present study (from 15% to 18.4%) could improve the spreadability of butter. However, the milkfat UFA concentration is not the only factor that influences the spreadability of butter. A better measurement of the spreadability of butter is its solid fat content, which considers not only milkfat composition but also the physical characteristics of milkfat (organisation of triglycerides) and the influence of processing factors (reworking) (MacGibbon & McLennan, 1987).

When a premium was added to the price of butter or cheese manufactured from UFA milk, the price of butter increased more than the price of cheese. When butter was the only value-added product manufactured from UFA milk (Butter scenario), its premium price was 51% (P_breakeven) and 58% (P_high) higher than its market value (Table 5). However, when cheese was the only value-added product manufactured from UFA milk (Cheese scenario), its premium price was 22% (P_breakeven) and 25% (P_high) higher than its market value. When both, butter and cheese, were manufactured from UFA milk, the total premium was distributed between the volume of butter and cheese manufactured. As a consequence, the increase in the price of butter was smaller (46% - 52%), but the increase in the price of cheese was higher (24% - 27%), than when only butter or cheese was manufactured. The larger volume of value-added dairy product manufactured when UFA milk was processed into cheese (94.3 kg/1000 L milk) rather than butter (41.3 kg/1000 L milk) (Table 4) most likely contributed to dilute the premium price of cheese in the present study.

The percentage increase in the price of butter (46% to 58%) and cheese (22% to 27%) manufactured from UFA milk in the present study was higher than that of organic dairy products sold by Fonterra (15% to 25%) (NZFW, 2011). The premium price for butter and cheese estimated in the present study could escalate along the supply chain and be passed on to the end consumers, which may affect the consumer willingness to pay for these products. However, there are several examples where consumers pay a significant premium for a differentiated dairy product. In New Zealand, the retail price of the premium butter manufactured by Lewis Road Creamery is 100% higher than the price of standard butter (Brown, 2013). In some parts of the United States, the retail price of organic milk was 100% (or more) higher than the price of standard milk

(Dimitri & Venezia, 2007). Several factors influence consumer purchasing behaviour and willingness to pay for a differentiated product (Fearne & Bates, 2003). However, for consumers to be willing to pay, the perceived benefits of a high UFA concentration in butter and cheese should compensate the increase in price.

In the present study, in all premium scenarios, dairy processor revenue was significantly higher when UFA milk was processed into cheese (Cheese scenario), rather than butter (Butter scenario) (Table 5). The difference in total volume of dairy products manufactured from UFA milk between processing scenarios most likely contributed to the difference in dairy processor revenue between processing scenarios. In the Butter scenario, the total volume of dairy products manufactured from UFA milk (130 kg/1000 L milk, mainly butter and SMP) was lower than in the Butter-Cheese (145 kg/1000 L milk, mainly butter, SMP, cheese and WP) and Cheese scenarios (160 kg/1000 L milk, mainly cheese and WP) (Table 4). As total revenue is the main factor that influences the farm gate milk price (Fonterra, 2012b), it is important that a dairy processor determines the most profitable product mix into which UFA milk could be processed. Also, further studies are necessary to determine if the most profitable mix changes over the season when the quality of pasture and supplementary feed changes.

Dairy processor volume costs were higher for UFA milk than AVE milk due to the larger volume of UFA milk processed. However, the lower content of mikfat and protein in UFA milk caused lower product manufacturing costs for UFA milk than AVE milk. In the present study, the capital infrastructure needed to accommodate a larger volume of UFA milk was taken into account and the processing of UFA milk was associated with higher capital costs than AVE milk (Table 5). However, given that the estimation of capital costs is notional and based on litres of milk processed, caution should be taken when evaluating the capital costs associated with the processing of UFA milk in the present study. Due, in part, to the difference in capital costs, dairy processor total expenses were higher for UFA milk than AVE milk (Table 5). However, if capital costs of

UFA milk and AVE milk were similar, there would not be a significant difference in dairy processor total expenses.

In the absence of a premium for milkfat UFA concentration, the value of a kilogram of milksolids varied between \$6.99/kg and \$7.15/kg for AVE milk, and between \$7.09/kg and \$7.14/kg for UFA milk. The milksolids values obtained in the present study were close to the average milksolids payout in New Zealand between 2010 and 2012 (\$6.74 (\$6.16 - \$7.36) /kg milksolids) (DairyNZ, 2013a). This indicates that the results from the simulation of milk processing and marketing were close to those observed during those years. Several studies have indicated that a multiple component pricing system is the most efficient and equitable method to distribute the milk payment to dairy farmers (Breen et al., 2001; Emmons et al., 1990; Holmes et al., 2002). The range of values (\$/kg) reported for milkfat, protein and milk volume in the present study (\$4.49 - \$5.68 /kg, \$10.03 - \$11.34 /kg, and -\$0.042 - -\$0.040 /L, respectively) were close to those paid in New Zealand between 2010 and 2012: \$3.56 - \$4.97 /kg, \$10.14 - \$12.07 /kg, and -\$0.040 /L (DairyNZ, 2013a; NZAEL, 2012a).

The values (\$/kg) of milkfat, protein and milk volume were different for UFA milk and AVE milk, and varied between milk-processing scenarios (Table 6). Previous studies have also reported that the composition of milk, and the product mix manufactured, influenced the value of each milk component (Garrick & Lopez Villalobos, 2000; Geary et al., 2010).

Across processing scenarios, the aggregate premium for milkfat UFA concentration (\$8.1 million to \$8.8 million in the P_breakeven scenario and \$9.1 million to \$9.8 million in the P_high scenario) was higher than the aggregate premium for organic milk (about \$5 million) in New Zealand (NZFW, 2011). In the present study, the premium for milkfat UFA concentration varied between \$0.47 - \$0.51 /kg milkfat in the P_breakeven scenario, and between \$0.53 - \$0.57 /kg milkfat in P_high scenario, for each 0.1 g UFA/100 g milkfat (above 34.50 g UFA/100 g milkfat). In France, Valorex SAS and Danone pay a premium (€/1,000L milk) for milkfat composition (within established thresholds), according to a 0.1 g/100 g milkfat change in C18:3 n-3, 0.1 point change in C18:1/C16:0 ratio and 0.3 g or 1 g /100 g milkfat change in saturated fatty acids (Borreani et al., 2013). However, it is difficult to compare different premiums for milkfat composition given the differences in production systems, units of expression and fatty acids considered in the premium.

In the present study the premium for milkfat UFA concentration was expressed per kilogram of milkfat rather than milksolids given that the added value of dairy products manufactured from UFA milk was associated with the composition of milkfat and not of protein. However, the premiums estimated in the present study could also be converted and expressed in different units if necessary (e.g. $0.47 for each 0.1 g UFA/100 g milkfat is equivalent to $470 /kg UFA for milk with a milkfat UFA concentration above 34.50 g UFA/100 g milkfat). Nevertheless, the payment systems estimated in the present study were specific to the milk type (UFA milk and AVE milk) and the processing and premium scenarios they were derived from. When milk suppliers were paid using the payment system estimated for each processing and premium scenario, the total value distributed was similar to the aggregate payment for milk of the corresponding processing and premium scenario.

Since UFA farms produced more milk, but less milkfat and protein, than AVE farms, their milk income under a payment system that rewarded milkfat and protein yields, but penalised milk volume, was lower than that of AVE farms (-$537 to -$646 /ha across processing scenarios). As milk income determines about 90% of gross farm income (DairyNZ, 2013a), UFA farms had lower gross farm income ($/ha) than AVE farms, despite UFA farms having a higher stock income ($/ha) than AVE farms. The higher expenses of UFA farms (+ $813 /ha), when compared with AVE farms, were associated with their higher stocking rates and the costs associated with the segregation of cows that produce milkfat with high UFA concentration.

In the absence of a premium for milkfat UFA concentration, the combination of a lower gross farm income ($/ha) and higher farm expenses ($/ha) reduced the operating profit of UFA farms by $1,320 to $1,429 /ha (across processing scenarios). The potential negative effect of a high milkfat UFA concentration on farm profit has been mentioned in previous studies (Arnould & Soyeurt, 2009; Thomson et al., 2002; Chapter 5).

The premiums estimated for milkfat UFA concentration in the P_breakeven and P_high scenarios gave UFA farms an operating profit ($/ha) similar to, and marginaly higher than, AVE farms, respectively. The premiums estimated in the P_high scenario could meet the requirements of a payment system in the sense that it distributed the premium to dairy farmers fairly, according to the milkfat UFA concentration of the milk they supplied, and contributed to the economic growth of milk suppliers. However, more studies are needed to determine if these premiums could motivate dairy farmers to change their current herds for herds of cows that produce milkfat with high UFA concentration.

The present study provided information about the potential gains/losses that could occur (at the farm level and at the dairy processor level) if a small cooperative (50 farm members + dairy processor) focuses on the production and processing of UFA milk rather than average milk. However, considering the assumptions used in the simulation of dairy farms and milk processing, caution should be taken when interpreting the results of the present study given that those assumptions may not apply to other farm systems, and other processing and economic scenarios. Furthermore, more studies need to be done to better understand the effect of increasing the milkfat UFA concentration on the physical and rheological characteristics of dairy products. Some studies indicate that a higher concentration of UFA in milkfat could make dairy products more susceptible to oxidation and reduce their shelf life (Hedegaard et al., 2006; Mallia et al., 2008). More studies are also needed to determine the consumer willingness to pay for a higher UFA concentration in dairy products, the size of the premium that could be acceptable for consumers and dairy farmers, and consumer perception and knowledge concerning the role of UFA in dairy foods. if the premium price of butter and cheese high in UFA in the present study is justified

CONCLUSION

This study provided information about the physical and economic impact that increasing the milkfat UFA concentration could have on dairy farms and dairy processors. UFA farms produce significantly lower yields of milkfat, protein (casein), but significantly higher yields of milk, lactose and minerals than AVE farms. The difference in milk yield and composition between UFA farms and AVE farms determined that the milk from UFA farms produced less volumes of butter and cheese, but higher volumes of SMP. With a premium of \$0.47 - \$0.51 /kg milkfat for each 0.1 g UFA/100 g milkfat (above 34.50 g UFA/100 g milkfat), the operating profit of UFA farms was similar to that of AVE farms. A premium of \$0.53 - \$0.57 /kg milkfat for each 0.1 g UFA/100 g milkfat (above 34.50 g UFA/100 g milkfat) gave UFA farms a marginally higher operating profit (\$/ha) than AVE farms. More studies are needed to evaluate the perception of dairy products high in UFA and the consumer willingness to pay for them.

CHAPTER 7

Estimation of a premium for concentration of unsaturated fatty acids (UFA) in milkfat, for dairy farmers that use oilseed supplements on-farm in New Zealand: a simulation study

ABSTRACT

Currently, in New Zealand, little is known about the economic impact of using oilseed supplements on-farm to increase the concentration of unsaturated fatty acids (UFA) in milkfat. In addition, there are no payment systems in New Zealand that reward the concentration of UFA in milkfat. The objective of the present study was to estimate, via simulation, a premium for milkfat UFA concentration, for a group of dairy farms that feed oilseed supplements to dairy cows, under New Zealand conditions. A farm model was used to simulate a group of 50 average farms (AVE farms) and a group of 50 farms that feed oilseed supplements to dairy cows (OILSEED farms). Each simulated farm had 120 ha and 325 cows. The milk produced by each of the farm groups was processed into butter and skim milk powder (SMP). The prices of dairy products were simulated under 3 scenarios of premiums for milkfat UFA concentration (above 37.50 g UFA/100 g milkfat): Prem_0 (no premium for UFA), $\text{Prem}_{\text{breakeven}}$ (a premium to break even the operating profit ($/ha) of UFA farms with that of AVE farms) and $\text{Prem}_{\text{high}}$ (a premium that gives UFA farms a higher operating profit ($/ha) than AVE farms). Two price scenarios for oilseed supplements used on farm were also investigated: $\text{OP}_{\$1.0/\text{kgDM}}$ ($1.00/kg DM supplement) and $\text{OP}_{\$1.3/\text{kgDM}}$ ($1.30/kg DM supplement). OILSEED farms were not significantly different from AVE farms in yields of milk, milkfat and protein, and in energy conversion efficiency, both per cow and per hectare. In the $\text{Prem}_{\text{breakeven}}$ and $\text{Prem}_{\text{high}}$ scenarios, the price of OILSEED butter (28.8% higher in UFA than butter manufactured from AVE milk) was 24-32% and 36-44% higher, respectively, than the price of standard butter. In the absence of a premium for milkfat UFA concentration (Prem_0 scenario), the operating profit ($/ha) of OILSEED farms was 28% to 38% lower ($P<0.05$) than that of AVE farms. A premium (for each 0.1 g UFA/100 g milkfat increase) of $0.11 - $0.17/kg milkfat resulted on OILSEED farms having a similar operating profit ($/ha) than AVE farms ($\text{Prem}_{\text{breakeven}}$ scenario), but a premium of $0.15 - $0.21/kg milkfat resulted on OILSEED farms having a higher ($P<0.05$) operating profit ($/ha) than AVE farms ($\text{Prem}_{\text{high}}$ scenario). These results may be used to further

evaluate the impact of using oilseed supplements on-farm to increase the milkfat UFA concentration.

INTRODUCTION

Milkfat composition influences the nutritive value and the manufacturing characteristics of milk (Chen et al., 2004; Oeffner et al., 2013). In recent years, the emergence of niche markets, associated to greater health awareness and desire for convenience by some consumers, have prompted extensive interests in increasing the concentration of unsaturated fatty acids (UFA) in milkfat. An increase in milkfat UFA concentration may improve consumer perceptions of dairy products (especially if it is associated with increases in c9 t11 CLA and n-3 fatty acids) (Diekman & Malcolm, 2009) and could improve the spreadability of butter (Hurtaud et al., 2010).

Traditionally, lipid supplements have been used in pasture-based systems to increase the energy intake and milk production of dairy cows (Schroeder et al., 2004). Several studies have investigated the possibility of increasing the milkfat UFA concentration at the farm level, by feeding oilseed supplements to dairy cattle (Chilliard et al., 2007; Thomson & MacGibbon, 2000; Thomson et al., 2002). Some of the oilseed supplements that have been extensively studied are flaxseed (linseed) (Oeffner et al., 2013; Petit, 2010; Suksombat et al., 2013); rapeseed (canola) (Chichlowski et al., 2005; Lerch et al., 2012b; Thomson & MacGibbon, 2000; Thomson et al., 2002), soybean (Chouinard et al., 2001; Shingfield et al., 2013) and sunflower (Shingfield & Garnsworthy, 2012; Sterk et al., 2012). Due to their high C18:1, C18:2 and C18:3 concentrations (Chouinard et al., 2001; Shingfield & Garnsworthy, 2012), feeding of dairy cows with the above-mentioned oilseed supplements has been associated with increases in milkfat UFA concentration, particularly in the concentrations of c9 t11 CLA and C18:3 n-3 (Chouinard et al., 2001; Petit, 2010).

Numerous studies have examined the effect on milk production and composition of feeding different forms (whole, crushed, rolled, extruded, micronized, formaldehyde-treated, oil, calcium salts of oil) of oilseed supplements to dairy cows (Bork et al., 2010; Chilliard et al., 2007; Cortes et al., 2010; Flowers et al., 2008; Glasser et al., 2008; Gonthier et al., 2005; Petit, 2010; Shingfield & Garnsworthy, 2012; Sterk et al., 2012; Suksombat et al., 2013). These studies indicated that the response to oilseed supplements was influenced by factors such as the composition of the basal diet (pasture, supplements, concentrates, total mixed ration), and the amount, type, technological form (whole seed, ground seed, oil) and level of protection (susceptibility to hydrogenation in the rumen) of the oilseed supplement offered. Due to the influence of these factors, the feeding of oilseed supplements to dairy cows did not affect dry matter intake or the yields of milk, milkfat and protein in some studies (Bobe et al., 2007; Chichlowski et al., 2005; Flowers et al., 2008; Glasser et al., 2008; Lerch et al., 2012a; Oeffner et al., 2013; Schroeder et al., 2013). In others studies its use had a negative (Lerch et al., 2012a; Nicolae et al., 2011) or positive (Larsen et al., 2012; Lerch et al., 2012a; Thomson & MacGibbon, 2000) effect on dry matter intake and milk production.

If the yields of milk, milkfat and protein were not affected, feeding oilseed supplements to dairy cattle involves extra costs for the dairy farmer and could negatively affect farm profit if the concentration of UFA in milkfat is not rewarded. Several studies indicated that a payment system with a premium for milkfat UFA concentration is necessary to persuade dairy farmers to increase the UFA concentration of milk supplied to a dairy processor (Elgersma et al., 2006; Walker et al., 2004). Although some studies have investigated feeding oilseed supplements to dairy cattle in New Zealand (Thomson & MacGibbon, 2000; Thomson et al., 2002; Thomson et al., 2003b), currently there is no information about a potential premium for milkfat UFA concentration for dairy farmers in New Zealand. Therefore, the objective of the present study was to estimate, via simulation, a premium for milkfat UFA concentration, for a group of New Zealand dairy farmers that feed their cows an oilseed supplement to increase the milkfat UFA concentration.

MATERIALS AND METHODS

Simulation of milk production

For the present study, 2 groups of dairy farms were simulated using the bio-economic stochastic farm model developed in Chapter 4: 1) 50 farms with average characteristics of New Zealand dairy farms (AVE farms), 2) 50 farms in which the feeding of an oilseed supplement to dairy cows increased milkfat UFA concentration but did not affect milksolids (milkfat + protein) production per cow (OILSEED farms). The number of dairy farms in each group was determined by taking into account the approximate market for UFA milk (Campina, 2007), and the number of dairy farms that supply milk for the manufactured of other speciality dairy products in New Zealand (DairyNews, 2011; Synlait, 2013).

Simulation of AVE farms

Each AVE farm simulated had 120 ha with a herd of 325 cows (2.71 cows/ha), and a replacement rate of 20.6% (LIC, 2011). Survival rates for calves, R1 heifers (<1 year old), R2 heifers (<2 years old), and 2- to 10- year-old cows (cows in their first to ninth lactation) were 0.66, 0.86, 0.86, 0.86, 0.87, 0.86, 0.81, 0.77, 0.71, 0.66, and 0.64, respectively (LIC, 2011). In all AVE farms, milk production started on July 20, when calving started, and finished on May 10 of the following year, when cows were dried-off. To simulate a compact spring calving for each AVE farm, it was specified in the model that 50% of the herd calved within the first 22 days from the start of calving (July 20) and 90% of the herd calved within 46 days from the start of calving, with the last calving taking place by October 10 (Holmes et al., 2002; LIC, 2011). It was assumed that 90% of cows in each herd got pregnant during the mating season (October - December) and that 94% of calves born (50% of which were female) survived to be used as replacements (66% of female calves) or sold (male calves and female calves not used as replacements) as bobby calves for veal (Lopez-Villalobos et al., 2000b).

For each AVE farm, it was specified in the model that 11 t DM/ha/year (76% of pasture grown on-farm) of ryegrass-white clover pasture was eaten by the herd (Holmes et al., 2002; MacDonald, 2011). The energy concentration (MJ ME/kg DM) of pasture eaten was assumed to be 10.9, 11.0, 11.1, 11.5, 11.4, 11.3, 11.2, 10.7, 10.5, 10.3, 10.9, and 11.0, from June to May of the following year, respectively (Litherland & Lambert, 2007). Supplements (imported conserved pasture, 10 MJ ME/kg DM) were fed when the feed demand of the milking herd was not met by pasture grown on-farm. The energy requirements of calves were met by milk (3.6 MJ ME/litre, 4 litres/day) and meal (12.5 MJ ME/kg DM) sufficient to meet their ME requirement. The energy requirements of young stock (R1 and R2 heifers) were met by pasture alone (grazed off-farm).

Simulation of UFA farms

With exception of the characteristics of the supplementary feed offered to the herd, model inputs for OILSEED farms were similar to those of AVE farms. On OILSEED farms, it was assumed that, during the lactation, the herd was fed an oilseed based supplement (27% oilseed fat, 14 MJ ME/kg DM). The composition of the oilseed-based supplement assumed in the present study was within the range reported for some oilseed based supplements in previous studies (20% - 40% oilseed fat and 13.0 - 16.5 MJ ME/kg DM) (Bayourthe et al., 2000; Jacobs & Hargreaves, 2002; Lerch et al., 2012a; Shingfield & Garnsworthy, 2012; Ward et al., 2002; Woodward et al., 2006). The amount of oilseed supplement to be fed to each cow was estimated based on the fat content of the oilseed supplement, so that 2.5% of daily dry matter intake corresponded to fat from oilseed supplement. The rate of inclusion of the oilseed supplement in the diet was selected based on previous studies which indicated that milk production per cow was not negatively affected when fat from an oilseed supplement comprised 2% to 3% of feed dry matter (Bayourthe et al., 2000; Chichlowski et al., 2005; Kolver, 2000; Lerch et al., 2012a; Suksombat et al., 2013; Ward et al., 2002).

A (co)variance matrix (**C**), of order 5×5, corresponding to the percentage of change (percentage of difference between oilseed supplemented cows and cows without oilseed supplementation) in milk yield (MY), milkfat percentage (F%), protein percentage (P%), milkfat UFA concentration (UFA) and live weight (LW), was included in the farm model developed in Chapter 4 to simulate the effect of oilseed supplementation. The (co)variance matrix was constructed by entering into the model (inputs) the standard deviation of the percentage of change for each trait (effect of oilseed supplementation) and the correlations between them.

For the present study, the values used to simulate the effect of oilseed supplementation on MY, F%, P%, UFA and LW, and the associated covariance matrix, are presented in Table 1. The percentages of change (mean ± standard deviation) for MY, F%, P%, UFA and LW, and the correlations between them, were estimated from the differences observed between control (unsupplemented) groups and oilseed supplemented groups (ground/crushed canola, flaxseed or soybean) reported by Bayourthe et al. (2000), Bobe et al. (2007), Chichlowski et al. (2005), Lerch et al. (2012a), Lerch et al. (2012b), Oeffner et al. (2013), Schroeder et al. (2013), Ward et al. (2002) and Woodward et al. (2006), studies in which oilseed supplementation did not affect milk production per cow significantly.

Table 1 Percentages (% relative to unsupplemented cows) of change in milk yield (MY), milkfat percentage (F%), protein percentage (P%), milkfat UFA concentration (UFA) and live weight (LW), used to simulate the effect of oilseed supplementation, with their corresponding (co)variance matrix (**C** matrix).

		MY	F%	P%	UFA	LW
Mean (%)		+1.90	-4.21	-3.86	+28.72	-0.50
Standard deviation		1.21	1.13	1.12	3.56	1.07
Covariance matrix (**C** matrix)						
	MYx	1.46	-0.19	-0.11	0.77	-0.75
	F%x	-0.19	1.28	-0.05	0.26	0.15
	P%x	-0.11	-0.05	1.25	-0.52	0.90
	UFA	0.77	0.26	-0.52	13.00	-1.00
	LWx	-0.75	0.15	0.90	-1.00	1.14

The daily performance of cows on OILSEED farms was simulated as follows:

$$\mathbf{p}_{\mathrm{OILSEED(it)}} = \mathbf{p}_{\mathrm{it}} + (\mathbf{p}_{\mathrm{it}} \times \mathbf{k}_{\mathrm{i}}) \tag{7.1}$$

Where,

$p_{\mathrm{OILSEED(it)}}$ = a vector of order 5 with the performance for MY, F%, P%, UFA and LW, for cow i on day t in milk (DIM), and ($\mathbf{p}_{\mathrm{it}} \times \mathbf{k}_{\mathrm{i}}$) was the product (an element by element multiplication) of the p_{it} and k_{i} column vectors.

$\mathbf{p}_{\mathrm{it}}$ = a column vector of order 5 with the performance of cow i (for the corresponding traits) in the t DIM and in the absence of oilseed supplementation. $\mathbf{p}_{\mathrm{it}}$ was simulated using the Wilkmink function (MY, F%, P% and LW) and a 3$^{\mathrm{rd}}$ order orthogonal polynomial (UFA) as indicated in Chapter 4.

$\mathbf{k}_i$ = a vector of order 5 which contains the percentages of change in MY, F%, P%, UFA and LW (effect of oilseed supplementation) for cow i. $\mathbf{k}_i$ was assumed to be constant during the lactation and was estimated as indicated in Eq.(7.2):

$$\mathbf{k}_i = (\boldsymbol{\mu}_{\%change} + (\mathbf{L} \times \mathbf{q}_i)) \tag{7.2}$$

Where,

$\boldsymbol{\mu}_{\%change}$ = a vector of order 5 with the average change (%) in MY, F%, P%, UFA and LW due to oilseed supplementation (Table 1),

$\mathbf{L}$ = the Cholesky decomposition of the $\mathbf{C}$ (co)variance matrix (Table 1),

$\mathbf{q}_i$ = a vector (order 5) of random deviates for cow i, with mean 0 and standard deviation of 1.

For both AVE farms and OILSEED farms, it was assumed that the concentrations of lactose, casein and minerals in milk were 4.7%, 77% and 0.7%, respectively (Garrick & Lopez Villalobos, 2000). Previous studies reported that the feeding of oilseed supplements to dairy cows to increase milkfat UFA concentration did not significantly affect the concentrations of lactose, casein and solids-non-fat in milk (Chichlowski et al., 2005; Ferlay et al., 2010; Gonthier et al., 2005; Lerch et al., 2012b; Suksombat et al., 2013).

Simulation of the financial performance of dairy farms

For each dairy farm, the model estimated the farm operating profit as the difference between gross farm income and farm expenses.

Gross farm income was determined by the sum of milk income (milk supplied to the dairy processor × milk payment system used by the dairy processor), stock income (carcass weight × beef price) and other dairy income ($46/ha; DairyNZ, 2012). The formula developed by McCall and Marshall (1991) was used to estimate the carcass weight of culled cows. The carcass weight of culled calves, R1 heifers and R2 heifers were estimated as 50%, 53%, and 53% of their live weight, respectively (Lopez-Villalobos et al., 2000b), with their live weight assumed to be 8%, 40% and 70% of their mature live weight, respectively (Clark & MacDonald, 2007). Beef prices ($/kg) used for bobby calves carcass weights <13.5 kg, 13.5-18.5 kg and >18.5 kg were $0.73, $1.09, and $2.54, respectively (NZAEL, 2012a). For culled heifers and cows, beef prices ($/kg) used for carcass weights <145 kg, 145-170, 170-195, 195-220, and >220 kg were $2.25, $2.52, $2.67, $2.74 and $2.83, respectively (NZAEL, 2012a).

Farm expenses were estimated as the sum of marginal expenses (farm expenses excluding feed costs of milking herd), assumed to be $1,187/cow (DairyNZ, 2012), and feed expenses (kg feed eaten by the herd × feed cost). The price of pasture ($0.10/kg DM) and imported supplements made of conserved pasture ($0.25/kg DM) were obtained from Holmes & Matthews (2001). The financial performance of dairy farms was simulated at two oilseed supplement prices: $1.00/kg DM ($\mathrm{OP}_{\$1.0/\mathrm{kgDM}}$) and $1.30/kg DM ($\mathrm{OP}_{\$1.3/\mathrm{kgDM}}$), to determine the effect of oilseed price on farm profit and the premium needed for milkfat UFA concentration. The oilseed prices investigated in the present study represented a range around the price of the oilseed supplement used in the study by Thomson et al. (2002) ($0.90/kg, which was equivalent to $1.16/kg when adjusted for inflation; RBNZ, 2013).

Simulation of milk processing

Manufacture of dairy products

The milk processing model developed by Garrick and Lopez-Villalobos (2000) was used to simulate the daily processing of milk supplied by AVE farms (AVE milk) and OILSEED farms (OILSEED milk). Inputs for the milk processing model were the daily concentrations of milkfat, protein, casein (percentage of total protein), lactose and minerals in milk. In the present study, AVE milk and OILSEED milk were processed into butter and skim milk powder (SMP) (Table 2), with butter from OILSEED milk (OILSEED butter) being the value-added dairy product (characterised by a high UFA concentration). Previous studies reported that milk with a high milkfat UFA concentration could be processed into butter (Bobe et al., 2007; Chen et al., 2004; Oeffner et al., 2013). Dairy by-products from the manufacture of butter and SMP were buttermilk powder (BMP), casein and whey powder (WP) (Table 2).

Table 2 Composition of dairy products[1] simulated by the milk processing model (Garrick & Lopez Villalobos, 2000; Geary et al., 2010).

Composition	Butter	SMP	BMP	Casein	WP
Fat %	84.00	1.00	8.30	0	1.00
Protein %	0.59	33.00	41.72	89.00	15.15
Lactose %	0.79	54.00	40.32	0.56	77.15
Minerals %	0.12	8.00	4.66	0.08	4.32
Water %	14.50	4.00	5.00	10.35	2.38

[1] SMP = skim milk powder, BMP = buttermilk powder, WP = whey powder.

The milk processing model simulated the separation of milk into cream, permeate (lactose-rich) and retentate (protein-rich), and their recombination according to the composition of the dairy products manufactured (Garrick & Lopez Villalobos, 2000). The volume of fat in cream and in buttermilk (a by-product from the manufacture of butter) was divided by the percentage of fat in butter and BMP (Table 2), respectively, to estimate the yields of butter and BMP (Lopez-Villalobos et al., 2000a). For the manufacture of SMP, the permeate and retentate fractions were recombined (in ratios determined by the composition of SMP, Table 2), evaporated and dried to 2.7% moisture content. Surplus retentate was processed into casein powder, with the yield of casein powder determined by the volume of protein in surplus retentate, the percentage of casein in protein and the percentage of casein in casein powder (Lopez-Villalobos et al., 2000a). Whey protein from the manufacture of casein was manufactured into whey powder (WP).

Dairy processor revenue and costs

Dairy processor revenue was calculated as the product of the volume of each dairy product manufactured by their corresponding market price (in US dollars). Apart from the market prices of dairy products (given in US dollars), financial data reported in the present study referred to New Zealand dollars (NZ $1 = US $0.7184; Fonterra, 2012b). With the exception of OILSEED butter, the international marketing of dairy products was simulated assuming the following market prices: US $3,450/t for SMP, US $3,641/t for butter, US $2,885/t for BMP, US $8,000/t for casein and US $1,177/t for WP (CLAL, 2013b; Fonterra, 2012b; GlobalDairyTrade, 2013).

Based on the examples of other value-added dairy products (Armstrong et al., 2005; Fonterra, 2012b; OMSCO, 2006), the market price of OILSEED butter was determined by adding a premium to the market price of standard butter:

$$\mathbf{V}_{\text{OILSEED butter}} = \mathbf{V}_{\text{AVE butter}} + (\boldsymbol{\Psi} / \mathbf{t}_{\text{OILSEED butter}}) \tag{7.3}$$

Where,

$\mathbf{V}_{\text{OILSEED butter}}$ = market value of OILSEED butter

$\mathbf{V}_{\text{AVE butter}}$ = market value of standard (AVE) butter

$\boldsymbol{\Psi}$ = aggregate premium for milkfat UFA concentration

$\mathbf{t}_{\text{OILSEED butter}}$ = tonnes of OILSEED butter manufacture.

Three premium scenarios for milkfat UFA concentration above 37.50 g /100g milkfat were investigated: Prem_0 (a scenario without a premium for milkfat UFA concentration), $\text{Prem}_{\text{breakeven}}$ (a scenario where a premium for milkfat UFA concentration resulted on OILSEED farms having an operating profit per hectare similar to that of AVE farms), and $\text{Prem}_{\text{high}}$ (a scenario where a premium for milkfat UFA concentration resulted on OILSEED farms having a higher operating profit per hectare than AVE farms). $\boldsymbol{\Psi}$ in the Prem_0 scenario

($\boldsymbol{\Psi}_0$) was zero. $\boldsymbol{\Psi}$ in the $\text{Prem}_{\text{breakeven}}$ ($\boldsymbol{\Psi}_b$) and $\text{Prem}_{\text{high}}$ ($\boldsymbol{\Psi}_h$) scenarios was estimated as indicated in Eq.(7.4) and Eq.(7.5):

$$\boldsymbol{\Psi}_b = (\boldsymbol{\Omega}_{\text{ave\_mean}} - \boldsymbol{\Omega}_{\text{oilseed\_mean}}) + ((\boldsymbol{\delta}_{\text{oilseed\_mean}} - \boldsymbol{\delta}_{\text{ave\_mean}}) \times 50) \quad (7.4)$$

$$\boldsymbol{\Psi}_h = (\boldsymbol{\Omega}_{\text{ave\_max}} - \boldsymbol{\Omega}_{\text{oilseed\_min}}) + ((\boldsymbol{\delta}_{\text{oilseed\_max}} - \boldsymbol{\delta}_{\text{ave\_min}}) \times 50) \quad (7.5)$$

Where,

$\boldsymbol{\Omega}$ = aggregate payment for milk (profit used by dairy processor to pay dairy farmers) in the Prem_0 scenario

$\boldsymbol{\Omega}_{\text{ave\_mean}}$ = mean from 1000 replicates of $\boldsymbol{\Omega}$ generated by AVE milk

$\boldsymbol{\Omega}_{\text{oilseed\_mean}}$ = mean from 1000 replicates of $\boldsymbol{\Omega}$ generated by OILSEED milk

$\boldsymbol{\Omega}_{\text{ave\_max}}$ = maximum from 1000 replicates of $\boldsymbol{\Omega}$ generated by AVE milk

$\boldsymbol{\Omega}_{\text{oilseed\_min}}$ = minimum from 1000 replicates of $\boldsymbol{\Omega}$ generated by OILSEED milk

$\boldsymbol{\delta}$ = farm expenses ($/farm) in the Prem_0 scenario

$\boldsymbol{\delta}_{\text{ave\_mean}}$ = mean from 1000 replicates of $\boldsymbol{\delta}$ of AVE farms

$\boldsymbol{\delta}_{\text{oilseed\_mean}}$ = mean from 1000 replicates of $\boldsymbol{\delta}$ of OILSEED farms

$\boldsymbol{\delta}_{\text{ave\_min}}$ = minimum from 1000 replicates of $\boldsymbol{\delta}$ of AVE farms

$\boldsymbol{\delta}_{\text{oilseed\_max}}$ = maximum from 1000 replicates of $\boldsymbol{\delta}$ of OILSEED farms

$((\delta_{\text{oilseed\_mean}} - \delta_{\text{ave\_mean}}) \times 50)$ = average aggregate difference in farm expenses between OILSEED farms and AVE farms

$((\delta_{\text{oilseed\_max}} - \delta_{\text{ave\_min}}) \times 50)$ = maximum aggregate difference in farm expenses between OILSEED farms and AVE farms

The parameters for Eq.(7.4) and Eq.(7.5) were estimated from the financial performance (1000 replicates) of dairy farms and dairy processor in the

$Prem_0$ scenario. A concentration of 37.50 g UFA/100 g milkfat was selected as the threshold for a UFA premium because it was marginally lower than the lowest milkfat UFA concentration observed in individual OILSEED farms. This threshold also contributed to maintain a high milkfat UFA concentration in milk supplied to the dairy processor.

Dairy processor costs were estimated as the sum of variable costs, fixed costs and capital costs (Fonterra, 2011). Table 3 shows the dairy processor variable costs assumed in the present study for each dairy product manufacture (Geary et al., 2010; Geary et al., 2013).

Table 3 Dairy processor variable costs used in the simulation of milk processing.[1]

	SMP	Butter	BMP	Casein	WP
Volume related costs					
Milk collection ($/L)[2]		0.0130			
Milk processing ($/L)[3]	0.0175	0.0115	0.0144	0.0144	0.0117
Product related costs					
Processing ($/t)[4]	143	78	141	193	173
Packaging ($/t)	41	31	41	41	41
Storage ($/t)	8	80	28	6	8
Distribution ($/t)	77	73	78	65	78

[1] SMP = skim milk powder, BMP = butter milk powder, WP = whey powder.

[2] On farm cooling and storage, milk collection, milk testing, storage at the dairy factory.

[3] Milk separation, standardisation ($0.0050/L), pasteurisation and cooling.

[4] Costs associated with evaporation, drying or churning.

For both OILSEED milk and AVE milk, it was assumed that dairy processor fixed costs (management, marketing, quality control, rents and rates) were equivalent to $0.025/L of AVE milk processed (Geary et al., 2013). Dairy processor capital costs (depreciation, return on investment) were assumed to be $0.07/L of milk processed (estimated from Fonterra, 2012b).

The difference between dairy processor revenue and dairy processor costs represented the aggregate payment for milk, which determined the milksolids payout (milksolids payout = aggregate payment for milk / kg milksolids).

Milk payment system

A multiple component payment system (A + B – C + UFA) was used by the dairy processor to fairly distribute the aggregate payment for milk, and the variable costs associated with milk volume (Table 3). The distribution accounted for the volume and composition of the milk supplied by each AVE farm and OILSEED farm. Under this payment system, milk suppliers were paid according to the kilograms of milkfat (A) and protein (B) supplied to the dairy processor, penalised according to the volume of milk supplied (C), and paid a premium for a high UFA concentration in milkfat (UFA). The multiple linear regression model in Eq.(6.3) (Chapter 6) was modified to estimate the value of each component of the payment system:

$$\mathrm{APM} = \mathrm{Milkfat}_{kg} + \mathrm{Protein}_{kg} + \mathrm{Volume}_{L} + \mathrm{UFA}_{0.1g>37.50} \qquad (7.6)$$

Where,

APM = contribution of SMP, butter, BMP, casein, WP, volume related costs (Table 3) and aggregate premium for milkfat UFA concentration to the aggregate payment for milk,

$\mathrm{Milkfat}_{kg}$ = kilograms of milkfat in the total volume of each dairy product manufacture,

$\mathrm{Protein}_{kg}$ = kilograms of protein in the total volume of each dairy product manufacture, and

Volume_{L} = total volume of milk processed.

$\mathrm{UFA}_{0.1g>37.50}$ = total 0.1 g UFA/100 g milkfat above 37.50 g UFA/100 g milkfat, per kilogram of milkfat processed: $\mathrm{UFA}_{0.1g>37.50}$ = ((UFA concentration of milkfat processed - 37.50) × 10) × kg milkfat processed.

Statistical analysis

The simulation of AVE farms and OILSEED farms, and the simulation of milk processing, were replicated 1000 times, so that each trait (θ) studied had 1000 bootstrap values (θ_1^* , θ_2^* , … θ_{1000}^*), with mean: $\bar{\theta}$ =(θ_1^* + θ_2^* + … + θ_{1000}^*)/1000. A 95% confidence interval [θ_{25th} , θ_{975th}] for the mean of each trait was determined using the percentile method of bootstrapping (Henderson, 2005), which comprised sorting the bootstrap values of a trait from smallest to largest (θ_{1st}^* , θ_{2nd}^* , … θ_{1000th}^*), and identifying the 25th and 975th ordered bootstrap values.

RESULTS

Physical characteristics of dairy farms

Cows on OILSEED farms were not significantly different from cows on AVE farms in live weight (kg), lactation length (days), the yields of milk (L/year), milkfat (kg/year), protein (kg/year) and milksolids (kg/year), and energy (MJ ME/year) demand (Table 4). However, cows on OILSEED farms had lower feed demand (kg DM/year) and produced milk with lower ($P<0.05$) percentages of milkfat (-4.41%) and protein (-3.89%), but higher ($P<0.05$) UFA concentration in milkfat (+28.79%), than cows on AVE farms (Table 4). On average, cows on OILSEED farms consumed 303 kg DM of oilseed supplements during the lactation, but their total demand of supplements (kg/year) was significantly lower ($P<0.05$) than that of cows on AVE farms (Table 4).

Per hectare, OILSEED farms were not significantly different from AVE farms in yields of milk, milkfat, protein and milksolids, and in energy demand; but their supplement demand and total feed demand was significantly lower than on AVE farms (Table 4). In contrast to AVE farms, which did not use oilseed supplements, OILSEED farms used 0.82 t DM of oilseed supplement per hectare per year.

Per farm, there were no significant differences between AVE farms and OILSEED farms in the volume of milk, milkfat, protein, casein, lactose and minerals, supplied to a dairy processor (Table 5). However, milk supplied by OILSEED farms had 28.79% more UFA (38.78 g UFA/100 g milkfat) than milk supplied by AVE farms (30.11 g UFA/100 g milkfat).

Table 4 Physical characteristics of AVE farms and OILSEED farms (mean and (95% confidence interval between brackets)).[1]

Trait[2]	Average farms (50 farms)		OILSEED farms (50 farms)	
Farm size (Ha)	120		120	
Herd size (cows)	325		325	
Stocking rate (Cows/ha)	2.71		2.71	
Per cow (per year)				
Lactation length (days)	267^{a}	(266 - 268)	267^{a}	(266 - 268)
Milk yield (Litres)	$4,348^{a}$	(4,246 - 4,459)	$4,433^{a}$	(4,328 - 4,538)
Milkfat yield (kg)	187^{a}	(182 - 192)	182^{a}	(178 - 187)
Protein yield (kg)	156^{a}	(152 - 160)	153^{b}	(149 - 156)
Milksolids yield (kg)	343^{a}	(335 - 352)	335^{b}	(328 - 343)
Milkfat %	4.30^{a}	(4.24 - 4.36)	4.11^{b}	(4.06 – 4.17)
Protein %	3.59^{a}	(3.56 - 3.62)	3.45^{b}	(3.43 - 3.48)
g UFA/100 g of milk fat	30.11^{a}	(29.82 - 30.38)	38.78^{b}	(38.41 – 39.14)
Live weight (kg)	491^{a}	(487 - 496)	488^{a}	(484 - 493)
Feed demand (kg DM)	$4,574^{a}$	(4,509 - 4,643)	$4,434^{b}$	(4,373 - 4,497)
Energy demand (MJ ME)	$50,179^{a}$	(49,518 - 50,867)	$50,009^{a}$	(49,379 - 50,655)
Supplements demand(kg DM)	513^{a}	(447 - 581)	376^{b}	(313 - 438)
As oilseed (kg DM)	0^{a}		303^{b}	(298 - 307)
Conserved pasture (kg DM)[3]	513^{a}	(447 - 581)	72^{b}	(10 - 126)
Per hectare (per year)				
Milk yield (Litres)	$11,780^{a}$	(11,502 - 12,014)	$12,010^{b}$	(11,726 - 12,291)
Milkfat yield (kg)	506^{a}	(494 - 519)	494^{b}	(482 - 505)
Protein yield (kg)	422^{a}	(412 - 433)	414^{b}	(404 - 424)
Milksolids yield (kg)	929^{a}	(908 - 952)	908^{b}	(887 - 929)
Pasture utilised (t DM)[3]	11^{b}		11^{b}	
Supplements demand (t DM)	1.39^{a}	(1.24 - 1.58)	1.02^{b}	(0.92 - 1.12)
As oilseed (t DM)	0^{a}		0.82^{b}	(0.81 - 0.83)
Conserved pasture (t DM)[3]	1.39^{a}	(1.24 - 1.58)	0.20^{b}	(0.03 - 0.34)
Feed demand (t DM)	12.39^{a}	(12.24 - 12.58)	12.02^{b}	(11.93 - 12.13)
Energy demand (MJ ME, 10^{3})	136.0^{a}	(134.2 - 137.8)	135.5^{a}	(133.8 - 137.3)

[1] Within a row, means with different superscript letter are significantly different (P<0.05).

[2] DM = dry matter, milksolids = milkfat + protein, MJ ME = mega joules of metabolisable energy.

[3] Conserved pasture imported into the farm.

Table 5 Mean (and 95% confidence interval between brackets) volume of milk and milk components, and concentration of UFA in milkfat, supplied to a dairy processor by AVE farms and OILSEED farms (per farm per year).[1]

Milk Supply (/farm/year)	AVE farms (50 farms)		OILSEED farms (50 farms)	
Milk (L)	1,413,198^{a}	(1,379,916 - 1,449,042)	1,440,813^{b}	(1,406,589 - 1,474,903)
Milkfat (kg)	60,761^{a}	(59,293 - 62,333)	59,292^{b}	(57,879 - 60,641)
UFA[2]	30.11^{a}	(29.82 - 30.38)	38.78^{b}	(38.41 – 39.14)
Protein (kg)	50,698^{a}	(49,462 - 51,972)	49,669^{b}	(48,464 - 50,836)
Casein (kg)	39,037^{a}	(38,086 - 40,018)	38,245^{b}	(37,317 - 39,144)
Lactose (kg)	66,420^{a}	(64,856 - 68,105)	67,718^{b}	(66,110 - 69,320)
Minerals (kg)	9,892^{a}	(9,659 - 10,143)	10,086^{b}	(9,846 - 10,324)

[1] Within a row, means with different letters are significantly different ($P<0.05$).

[2] UFA= concentration of unsaturated fatty acids in milkfat (g UFA/100 g milkfat).

Physical characteristics of dairy processor

The volume of dairy products manufactured from AVE milk and OILSEED milk is presented in Table 6. There were no significant differences in the total volumes (kg/year) of butter and SMP manufactured from OILSEED milk and AVE milk. The concentration of UFA in butter fat was higher ($P<0.05$) when butter was manufactured from OILSEED milk (38.78 g UFA/100 g fat) rather than AVE milk (30.11 g UFA/100 g fat). There were no significant differences in the volume (kg/year) of BMP manufactured from OILSEED milk and AVE milk, but the volumes (kg/year) of casein and WP manufactured from OILSEED milk were lower (-17% and -19%, respectively, $P<0.05$) than those from AVE milk (Table 6). When the yield of dairy products was expressed per 1000 litres of milk, OILSEED milk produced more ($P<0.05$) SMP, but less ($P<0.05$) butter, BMP, casein and WP, than AVE milk (Table 6).

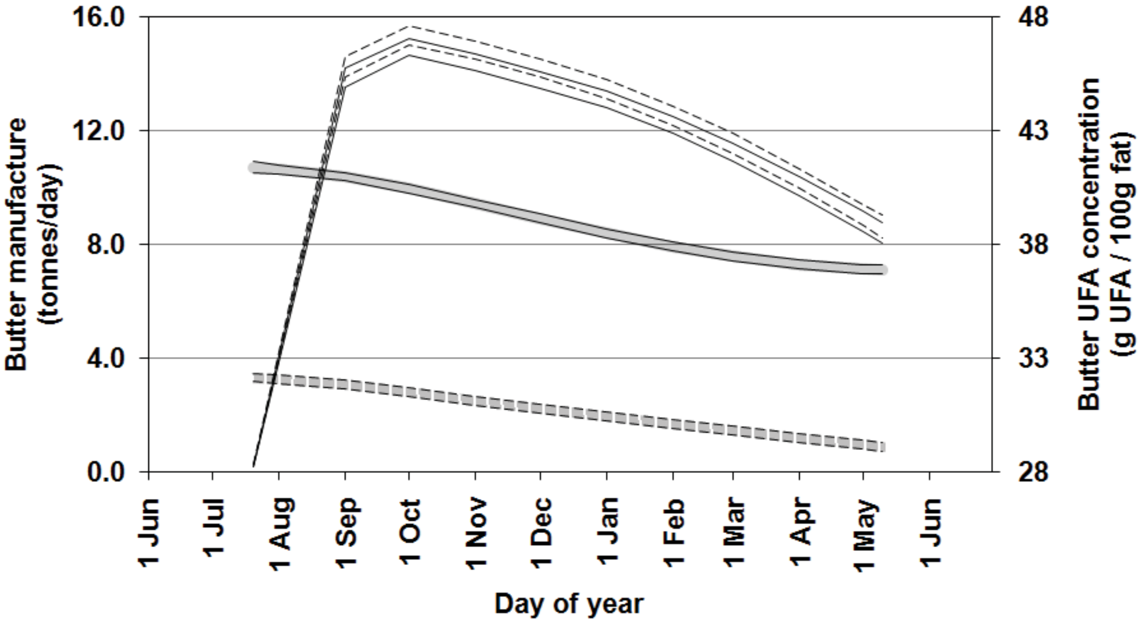
Table 6 Volume of dairy products manufactured from AVE milk and OILSEED milk, with the concentration of unsaturated fatty acids (UFA) in butter fat (mean (and 95% confidence interval between brackets)). [1]

	AVE milk		OILSEED milk	
Milk processed (L/year, millions)	70.66	(69.00 - 72.45)	72.04	(70.33 - 73.75)
Total (kg, millions)				
Skim milk powder	5.09^{a}	(4.95 - 5.23)	5.33^{b}	(5.20 - 5.46)
Butter	3.56^{a}	(3.47 - 3.65)	3.47^{b}	(3.38 3.55)
g UFA/100 g fat	30.11^{a}	(29.82 - 30.38)	38.78^{b}	(38.41 - 39.14)
Butter milk powder	0.39^{a}	(0.38 - 0.40)	0.37^{a}	(0.36 - 0.38)
Casein	0.59^{a}	(0.57 - 0.62)	0.49^{b}	(0.46 - 0.51)
Whey powder	0.43^{a}	(0.41 - 0.45)	0.35^{b}	(0.33 – 0.37)
Per 1000 litres of milk (kg/1000 L)				
Skim milk powder	72.0^{a}	(71.6 - 72.4)	74.0^{b}	(73.6 - 74.4)
Butter	50.3^{a}	(49.8 - 51.1)	48.1^{b}	(47.5 - 48.8)
Butter milk powder	5.5^{a}	(5.4 - 5.6)	5.1^{b}	(5.1 - 5.2)
Casein	8.4^{a}	(8.1 - 8.8)	6.8^{b}	(6.5 - 7.2)
Whey powder	6.1^{a}	(5.8 - 6.3)	4.9^{b}	(4.7 - 5.2)

[1] Within a row, means with different letters are significantly different ($P<0.05$). Milk was processed primarily into butter and skim milk powder, with butter milk powder, casein and whey powder being the by-products. AVE milk = milk supplied by 50 average farms. OILSEED milk = milk with a high concentration of unsaturated fatty acids (UFA) in milkfat, supplied by 50 farms that feed oilseed supplements to dairy cows.

On a daily basis, the volume (tonnes/day) of butter manufactured from OILSEED milk and AVE milk followed the profile of milk supplied (increasing from July to October, and decreasing steadily afterwards). However, there were no significant differences in the daily volume of butter manufactured per day between OILSEED milk and AVE milk (Figure 1). The concentration of UFA in fat of butter manufactured from OILSEED milk decreased steadily during the milk production season, from 41.36 (40.86 - 41.87) g /100 g fat to 36.88 (36.49 - 37.26) g /100 g fat (Figure 1). At all times, butter manufactured from OILSEED milk had 27.7% to 29.9% (average 28.79%) higher ($P<0.05$) UFA concentration in fat than butter manufactured from AVE milk.

Figure 1 Ninety five percent confidence interval for daily volume of butter manufactured from AVE milk (╌╌╌) and OILSEED milk (═══), and for daily concentration of unsaturated fatty acids (UFA) in fat of butter manufactured from AVE milk (▪▪▪▪▪) and OILSEED milk (▬▬).



Financial characteristics of dairy processor

When AVE milk was processed, dairy processor financial performance was similar in all UFA premium scenarios (Prem_0, $\text{Prem}_{\text{breakeven}}$ and P_{high}). In the Prem_0 scenario, where OILSEED butter was sold at the average market value, there were no significant differences in dairy processor revenue from the sales of butter, SMP and BMP between AVE milk and OILSEED milk (Table 7). Although dairy processor revenue from the sales of casein and WP was lower ($P<0.05$) when OILSEED milk was processed rather than AVE milk, dairy processor total revenue was not significantly affected by the type of milk processed (Table 7).

The market value of OILSEED butter was influenced by the UFA premium scenario and by the oilseed price scenario, being higher ($P<0.05$) in the $\text{Prem}_{\text{high}}$ scenario than in the $\text{Prem}_{\text{breakeven}}$ and Prem_0 scenarios, and in the $\text{OP}_{\$1.3/\text{kgDM}}$ scenario than in the $\text{OP}_{\$1.0/\text{kgDM}}$ scenario (Table 7). In the $\text{Prem}_{\text{breakeven}}$ scenario, the average premium price of OILSEED butter was US \$4,456/t ($\text{OP}_{\$1.0/\text{kgDM}}$) and US \$4,762/t ($\text{OP}_{\$1.3/\text{kgDM}}$), 22% and 31% higher, respectively, than the market value of standard butter. In the $\text{Prem}_{\text{high}}$ scenario, the average premium price of OILSEED butter in the $\text{OP}_{\$1.0/\text{kgDM}}$ and $\text{OP}_{\$1.3/\text{kgDM}}$ scenarios was 35% (US \$4,914/t) and 43% (US \$5,212/t) higher, respectively, than the price of standard butter.

In the $\text{Prem}_{\text{breakeven}}$ and $\text{Prem}_{\text{high}}$ scenarios, the processing of OILSEED milk resulted in both higher ($P<0.05$) revenue from the sales of butter (+19% to +27% and +31% to +39%, respectively) and higher ($P<0.05$) total revenue (+6% to +9% and +11% to +13%, respectively) than the processing of AVE milk (Table 7). In both the $\text{Prem}_{\text{breakeven}}$ and $\text{Prem}_{\text{high}}$ scenarios, the revenue from the sales of butter and dairy processor total revenue were higher ($P<0.05$) in the $\text{OP}_{\$1.3/\text{kgDM}}$ scenario than in the $\text{OP}_{\$1.0/\text{kgDM}}$ scenario. There were no significant differences in dairy processor expenses (volume costs, product costs, fixed costs, capital costs, total expenses) between OILSEED milk and AVE milk (Table 7).

In the Prem_0 scenario, the aggregate payment for milk (revenue used to pay dairy farmers) generated by OILSEED milk was not significantly different from that of AVE milk (Table 7). However, in the $\text{Prem}_{\text{breakeven}}$ and $\text{Prem}_{\text{high}}$ scenarios, OILSEED milk generated a higher ($P<0.05$) aggregate payment for milk than AVE milk (+8% to +12% and +14% to +17%, respectively). The aggregate payment for milk generated by OILSEED milk was higher ($P<0.05$) in in the $\text{OP}_{\$1.3/\text{kgDM}}$ scenario than in the $\text{OP}_{\$1.0/\text{kgDM}}$ scenario (Table 7).

In the $\text{Prem}_{\text{breakeven}}$ scenario, the aggregate premium needed for OILSEED milk, estimated as indicated in Eq.(7.4), was on average \$3.93M ($\text{OP}_{\$1.0/\text{kgDM}}$) and \$5.41M ($\text{OP}_{\$1.3/\text{kgDM}}$). In the $\text{Prem}_{\text{high}}$ scenario, the aggregate premium needed for OILSEED milk, estimated as indicated in Eq.(7.5), was on average \$6.14M ($\text{OP}_{\$1.0/\text{kgDM}}$) and \$7.58M ($\text{OP}_{\$1.3/\text{kgDM}}$).

Table 7 Dairy processor financial performance (mean (and 95% confidence interval between brackets)) when AVE milk and OILSEED milk were processed into butter and skim milk powder (SMP), under three premiums scenarios for concentration of unsaturated fatty acids (UFA) in milkfat above 37.50 g UFA/100 g milkfat ($Prem_0$, $Prem_{breakeven}$, $Prem_{high}$), and two price scenarios for oilseed supplements used on-farm ($OP_{\$1.0/kgDM}$ and $OP_{\$1.3/kgDM}$).[1]

	$Prem_0$		$Prem_{breakeven}$	$Prem_{high}$
	AVE milk[3]	OILSEED milk	OILSEED milk	OILSEED milk
Butter market value (US $/tonne) [2]				
$OP_{\$1.0/kgDM}$	3,641^a	3,641^a	4,456^b (4,436 - 4,477)	4,914^c (4,883 - 4,946)
$OP_{\$1.3/kgDM}$	3,641^a	3,641^a	4,762^b (4,735 - 4,790)	5,212^c (5,175 - 5,251)
Dairy processor revenue (NZ $, millions)				
From sales of butter				
$OP_{\$1.0/kgDM}$	18.10^a (17.70 - 18.60)	17.57^a (17.15 - 17.98)	21.50^b (21.08 - 21.91)	23.71^c (23.29 - 24.12)
$OP_{\$1.3/kgDM}$	18.10^a (17.70 - 18.60)	17.57^a (17.15 - 17.98)	22.97^b (22.55 - 23.39)	25.15^c (24.73 - 25.56)
From sales of SMP[2]	24.44^a (23.79 - 25.10)	25.60^a (24.96 - 26.33)		
From sales of BMP[2]	1.56^a (1.52 - 1.60)	1.49^a (1.45 - 1.53)		
From sales of casein[2]	6.70^a (6.40 - 6.99)	5.45^b (5.16 - 5.73)		
From sales of WP[2]	0.71^a (0.67 - 0.74)	0.58^b (0.55 - 0.61)		
Total revenue				
$OP_{\$1.0/kgDM}$	51.34^a (50.56 - 52.12)	50.68^a (50.02 - 51.34)	54.61^b (53.95 - 55.27)	56.82^c (56.16 - 57.48)
$OP_{\$1.3/kgDM}$	51.34^a (50.56 - 52.12)	50.68^a (50.02 - 51.34)	56.09^b (55.42 - 56.75)	58.26^c (57.60 - 58.92)

Table 7 (continued).

	$Prem_0$		$Prem_{breakeven}$	$Prem_{high}$
	AVE milk[3]	OILSEED milk	OILSEED milk	OILSEED milk
Dairy processor expenses (NZ $, millions)				
Volume costs	2.97^a (2.90 - 3.04)	3.03^a (2.95 - 3.10)		
Product costs	2.72^a (2.66 - 2.79)	2.70^a (2.64 - 2.77)		
Fixed costs	1.77^a (1.72 - 1.81)	1.77^a (1.73 - 1.81)		
Capital costs	4.93^a (4.81 - 5.05)	5.03^a (4.91 - 5.14)		
Total expenses	12.40^a (12.09 - 12.70)	12.52^a (12.23 - 12.82)		
Aggregate payment for milk (NZ $, millions)				
$OP_{\$1.0/kgDM}$	38.95^a (38.18 - 39.55)	38.16^a (37.47 - 38.84)	42.09^b (41.40 - 42.77)	44.30^c (43.61 - 44.98)
$OP_{\$1.3/kgDM}$	38.95^a (38.18 - 39.55)	38.16^a (37.47 - 38.84)	43.56^b (42.88 - 44.25)	45.74^c (45.05 - 46.42)

[1] Within a row, means with different letters are significantly different ($P<0.05$). UFA premium scenarios: $Prem_0$ = no premium for milkfat UFA concentration, $Prem_{breakeven}$ = premium scenario in which the operating profit of OILSEED farms was similar to that of AVE farms, $Prem_{high}$ = premium scenario in which the operating profit of OILSEED farms was higher than that of AVE farms. BMP= butter milk powder, WP= whey powder. AVE milk = milk supplied by 50 average farms (AVE farms). OILSEED milk = milk supplied by 50 farms (OILSEED farms) that feed oilseed supplements to dairy cows to increase milkfat UFA concentration. $OP_{\$1.0/kgDM}$ = \$1.00/kg DM oilseed supplement, $OP_{\$1.3/kgDM}$ = \$1.30/kg DM oilseed supplement.

[2] Market value of dairy products (NZ $1 = US $0.7184): US $3641/t for butter, US $3,450/t for SMP, US $2,885/t for BMP, US $8,000/t for casein and US $1,177/t for WP. The market value of butter manufacture from OILSEED milk (value-added dairy product high in UFA) was estimated using a premium pricing strategy.

[3] Values for AVE milk in the $Prem_{breakeven}$ and $Prem_{high}$ scenarios were similar to the $Prem_0$ scenario.

Premium for concentration of unsaturated fatty acids

In the Prem_0 scenario, there were no significant differences in milksolids payout between AVE milk and OILSEED milk, in both oilseed price scenarios (Table 8). However, in the $\text{Prem}_{\text{breakeven}}$ and $\text{Prem}_{\text{high}}$ scenarios, milksolids payout was higher ($P<0.05$) for OILSEED milk than for AVE milk (+11% to +14% and +16% to +20%, respectively). Within each UFA premium scenario, milksolids payout for OILSEED milk was higher ($P<0.05$) in the $\text{OP}_{\$1.3/\text{kgDM}}$ scenario than in the $\text{OP}_{\$1.0/\text{kgDM}}$ scenario (Table 8).

Across UFA premium scenarios and oilseed premium scenarios, there were no significant differences in the average value of milkfat and milk volume, between AVE milk ($4.63/kg and -$0.042/L, respectively) and OILSEED milk ($4.65/kg and -$0.042/L, respectively) (Table 8). The value of protein was significantly higher ($P<0.05$) for OILSEED milk ($11.04 (11.02 - 11.05) /kg) than for AVE milk ($10.98 (10.97 - 11.00) /kg), but it was not significantly affected by the UFA premium scenario or the oilseed price scenario (deduced by comparing confidence intervals for traits between oilseed price scenarios).

In the $\text{Prem}_{\text{breakeven}}$ ($\text{OP}_{\$1.0/\text{kgDM}}$) scenario, the premium for each 0.1 g UFA/100 g milkfat increase (above 37.50 g UFA/100 g milkfat) was $0.10(0.08-0.11)/kg milkfat, and in the $\text{Prem}_{\text{breakeven}}$ ($\text{OP}_{\$1.3/\text{kgDM}}$) scenario it was $0.14(0.12-0.15) /kg milkfat (Table 8). In the $\text{Prem}_{\text{high}}$ scenario, the premium for each 0.1 g UFA/100 g milkfat increase (above 37.50 g UFA/100 g milkfat) was $0.16(0.14-0.17)/kg milkfat ($\text{OP}_{\$1.0/\text{kgDM}}$) and $0.20(0.18-0.22)/kg milkfat ($\text{OP}_{\$1.3/\text{kgDM}}$) (Table 8).

Table 8 Value (mean (and 95% confidence interval between brackets)) of milkfat, protein, milk volume and concentration of unsaturated fatty acids (UFA) in milkfat, when AVE milk and OILSEED milk were processed into butter and skim milk powder, under three premium scenarios for milkfat UFA concentration above 37.50 g UFA/100 g milkfat ($Prem_0$, $Prem_{breakeven}$, $Prem_{high}$), and two price scenarios for oilseed supplements used on-farm ($OP_{\$1.0/kgDM}$ and $OP_{\$1.3/kgDM}$).[1]

	$Prem_0$		$Prem_{breakeven}$	$Prem_{high}$
	AVE milk	OILSEED milk	OILSEED milk	OILSEED milk
Milk processed				
Milk processed (L, millions)	70.66^a (69.00 - 72.43)	72.04^a (70.33 - 73.75)		
Milkfat processed (kg, millions)	3.04^a (2.97 - 3.13)	2.96^a (2.89 - 3.03)		
Protein processed (kg, millions)	2.53^a (2.47 - 2.60)	2.48^a (2.42 - 2.54)		
Milksolids processed (kg, millions)	5.57^a (5.46 - 5.72)	5.45^a (5.32 - 5.57)		
$UFA_{0.1g}$ (0.1 g UFA, millions)[2]	0^a	3.79^b (2.71 - 4.78)		
$OP_{\$1.0/kgDM}$				
APM ($, millions)[3]	38.95^a (38.18 - 39.55)	38.16^a (37.47 - 38.84)	42.09^b (41.40 - 42.77)	44.30^c (43.61 - 44.98)
Milksolids payout ($/kg)	6.99^a (6.98 - 7.01)	7.00^a (6.99 - 7.02)	7.73^b (7.71 - 7.75)	8.13^c (8.10 - 8.16)
Milkfat value ($/kg)	4.63^a (4.63 - 4.64)	4.65^a (4.64 - 4.65)		
Protein value ($/kg)	10.98^a (10.97 - 11.00)	11.04^b (11.02 - 11.05)		
Volume value ($/L)	-0.042^x (-0.042 - -0.042)	-0.042^x (-0.042 - -0.042)		
UFA value ($/0.1 g UFA/kg milkfat)	0^a	0^a	0.10^b (0.08 - 0.11)	0.16^c (0.14 - 0.17)

Table 8 (continued).

	$Prem_0$		$Prem_{breakeven}$	$Prem_{high}$
	AVE milk	OILSEED milk	OILSEED milk	OILSEED milk
$OP_{\$1.3/kgDM}$				
APM ($, millions) [3]	38.95^{a} (38.18 - 39.55)	38.16^{a} (37.47 - 38.84)	43.56^{b} (42.88 - 44.25)	45.74^{c} (45.05 - 46.42)
Milksolids payout ($/kg)	6.99^{a} (6.98 - 7.00)	7.00^{a} (6.99 - 7.02)	8.00^{b} (7.97 - 8.03)	8.40^{c} (8.37 - 8.43)
Milkfat value ($/kg)	4.63^{a} (4.63 - 4.64)	4.65^{a} (4.64 - 4.65)		
Protein value ($/kg)	10.98^{a} (10.97 - 11.00)	11.04^{b} (11.02 - 11.05)		
Volume value ($/L)	-0.042^{x} (-0.042 - -0.042)	-0.042^{x} (-0.042 - -0.042)		
UFA value ($/0.1 g UFA/kg milkfat)	0^{a}	0^{a}	0.14^{b} (0.12 - 0.15)	0.20^{c} (0.18 - 0.22)

[1] Within a row, means with different letters are significantly different ($P<0.05$). UFA premium scenarios: $Prem_0$ = no premium for milkfat UFA concentration, $Prem_{breakeven}$ = premium scenario in which the operating profit of UFA farms was similar to that of AVE farms, $Prem_{high}$ = premium scenario in which the operating profit of UFA farms was marginally higher than that of AVE farms. Milk payment system = (kg milkfat × milkfat value) + (kg protein × protein value) + (L milk × volume value) + ($UFA_{0.1g}$ × UFA value). Values for AVE milk in the $Prem_{breakeven}$ and $Prem_{high}$ scenarios were similar to that of the $Prem_0$ scenario. Unless other values are indicated, values for OILSEED milk in the $Prem_{breakeven}$ and $Prem_{high}$ scenarios were similar to those in the $Prem_0$ scenario. AVE milk = milk supplied by 50 average farms (AVE farms). OILSEED milk = milk supplied by 50 dairy farms (OILSEED farms) that feed oilseed supplements to dairy cows to increase milkfat UFA concentration. $OP_{\$1.0/kgDM}$ = \$1.00/kg DM oilseed supplement, $OP_{\$1.3/kgDM}$ = \$1.30/kg DM oilseed supplement.

[2] $UFA_{0.1g}$ = Total 0.1 g UFA/100 g milkfat (above 37.50 g UFA/100 g milkfat) in milkfat processed = (UFA concentration in milkfat processed - 37.50 g UFA/100 g milkfat) × kg milkfat processed ×10.

[3] APM= aggregate payment for milk.

Financial characteristics of dairy farms

Milk suppliers were paid using the payment system estimated (by the dairy processor) for each premium and oilseed price scenario (Table 8). In the Prem_0 scenario, per hectare, there were no significant differences in milk income, stock income, other income and gross farm income between OILSEED farms and AVE farms (Table 9).

In the $\text{Prem}_{\text{breakeven}}$ and $\text{Prem}_{\text{high}}$ scenarios, per hectare, OILSEED farms had a higher ($P<0.05$) milk income and gross farm income than AVE farms, but they were not significantly different from AVE farms in stock income and other income (Table 9). In the $\text{OP}_{\$1.0/\text{kgDM}}$ ($\text{Prem}_{\text{breakeven}}$) scenario, the milk income (\$/ha) and gross farm income (\$/ha) of OILSEED farms were 8% and 7% higher ($P<0.05$), respectively, than those of AVE farms, while in the $\text{OP}_{\$1.3/\text{kgDM}}$ ($\text{Prem}_{\text{breakeven}}$) scenario, they were 12% and 11% higher ($P<0.05$), respectively, than those of AVE farms (Table 9). In the $\text{Prem}_{\text{high}}$ scenario, OILSEED farms had 14% ($\text{OP}_{\$1.0/\text{kgDM}}$) to 17% ($\text{OP}_{\$1.3/\text{kgDM}}$) higher milk income per hectare, and 13% ($\text{OP}_{\$1.0/\text{kgDM}}$) to 16% ($\text{OP}_{\$1.3/\text{kgDM}}$) higher gross farm income per hectare, than AVE farms.

Farm expenses were not significantly influenced by UFA premium scenario, but in the case of OILSEED farms feed expenses and total farm expenses were influenced ($P<0.05$) by the price of the oilseed supplement used on farm (Table 9). Per hectare, there were no significant differences in marginal expenses between OILSEED farms and AVE farms, but OILSEED farms had 36% ($\text{OP}_{\$1.0/\text{kgDM}}$) to 53% ($\text{OP}_{\$1.3/\text{kgDM}}$) higher ($P<0.05$) feed expenses, and 11% ($\text{OP}_{\$1.0/\text{kgDM}}$) to 16% ($\text{OP}_{\$1.3/\text{kgDM}}$) higher ($P<0.05$) total farm expenses, than AVE farms.

The operating profit of OILSEED farms was significantly ($P<0.05$) influenced by UFA premium scenario and oilseed price scenario (Table 9). In the absence of a premium for milkfat UFA concentration (Prem_0 scenario), the operating profit (\$/ha) of OILSEED farms was 28% ($\text{OP}_{\$1.0/\text{kgDM}}$) and 38% ($\text{OP}_{\$1.3/\text{kgDM}}$) lower ($P<0.05$) than that of AVE farms (Figure 2). In the

$\text{Prem}_{\text{breakeven}}$ scenario there were no significant differences in operating profit ($/ha) between OILSEED farms and AVE farms, in both oilseed price scenarios (Figure 2). In the $\text{Prem}_{\text{high}}$ scenario, the operating profit ($/ha) of OILSEED farms was 15% higher than that of AVE farms, in both oilseed price scenarios (Table 9).

Table 9 Financial characteristics of OILSEED farms and AVE farms, when milk was processed into butter and skim milk powder under three premium scenarios (Prem_0, $\text{Prem}_{\text{breakeven}}$, $\text{Prem}_{\text{high}}$) for concentration of unsaturated fatty acids (UFA) in milkfat above 37.50 g UFA/100 g milkfat, and two price scenarios for oilseed supplements used on-farm ($\text{OP}_{\$1.0/\text{kgDM}}$ and $\text{OP}_{\$1.3/\text{kgDM}}$).[1]

	Prem_0		$\text{Prem}_{\text{breakeven}}$	$\text{Prem}_{\text{high}}$
	AVE farms	OILSEED farms	OILSEED farms	OILSEED farms
Farm income (\$/ha)				
Milk income				
$\text{OP}_{\$1.0/\text{kgDM}}$ [2]	$6,492^a$ (6,338 - 6,641)	$6,359^a$ (6,235 - 6,484)	$7,015^b$ (6,891 - 7,137)	$7,383^c$ (7,260 - 7,501)
$\text{OP}_{\$1.3/\text{kgDM}}$ [3]	$6,492^a$ (6,338 - 6,641)	$6,359^a$ (6,235 - 6,484)	$7,261^b$ (7,139 - 7,383)	$7,623^c$ (7,524 - 7,745)
Stock income	500^a (490 - 509)	495^a (486 - 504)		
Other income	46^b	46^b		
Gross farm income				
$\text{OP}_{\$1.0/\text{kgDM}}$	$7,037^a$ (6,886 - 7,184)	$6,901^a$ (6,775 - 7,026)	$7,556^b$ (7,430 - 7,680)	$7,924^c$ (7,801 - 8,042)
$\text{OP}_{\$1.3/\text{kgDM}}$	$7,037^a$ (6,886 - 7,184)	$6,901^a$ (6,775 - 7,026)	$7,802^b$ (7,682 - 7,924)	$8,164^c$ (8,045 - 8,286)
Farm expenses (\$/ha)				
Marginal expenses	$3,215^a$	$3,215^a$		
Feed expenses				
$\text{OP}_{\$1.0/\text{kgDM}}$	$1,447^a$ (1,403 - 1,493)	$1,970^b$ (1,920 - 2,021)		
$\text{OP}_{\$1.3/\text{kgDM}}$	$1,447^a$ (1,403 - 1,493)	$2,216^b$ (2,163 - 2,271)		
Total expenses				
$\text{OP}_{\$1.0/\text{kgDM}}$	$4,662^a$ (4,618 - 4,708)	$5,185^b$ (5,135 - 5,236)		
$\text{OP}_{\$1.3/\text{kgDM}}$	$4,662^a$ (4,618 - 4,708)	$5,431^b$ (5,377 - 5,486)		

Table 9 (continued).

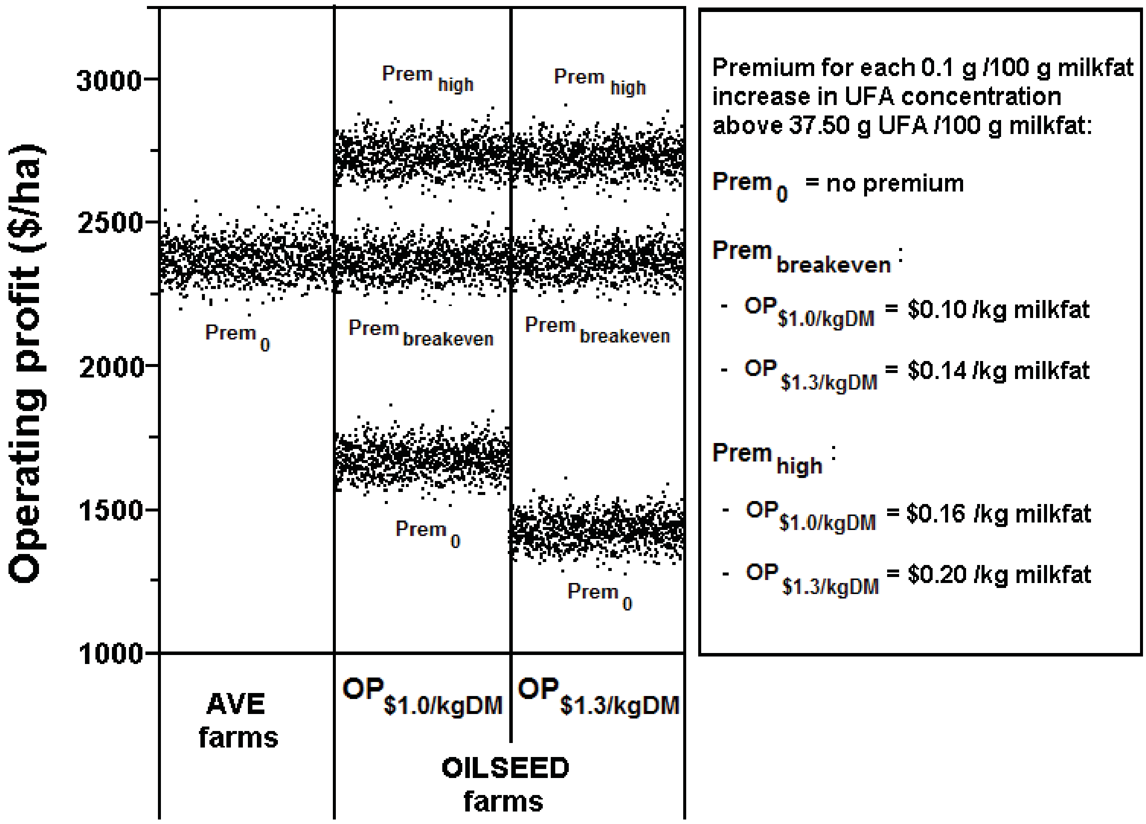
	Prem_{0}		$\text{Prem}_{\text{breakeven}}$	$\text{Prem}_{\text{high}}$
	AVE farms	OILSEED farms	OILSEED farms	OILSEED farms
Operating profit ($/ha)				
$\text{OP}_{\$1.0/\text{kgDM}}$	$2{,}375^{a}$ (2,270 - 2,496)	$1{,}716^{b}$ (1,618 - 1,815)	$2{,}371^{a}$ (2,273 - 2,470)	$2{,}739^{c}$ (2,641 - 2,838)
$\text{OP}_{\$1.3/\text{kgDM}}$	$2{,}375^{a}$ (2,270 - 2,496)	$1{,}470^{b}$ (1,377 - 1,560)	$2{,}370^{a}$ (2,277 - 2,466)	$2{,}733^{c}$ (2,639 - 2,828)

[1] Within a row, means with different letters are significantly different ($P<0.05$). OILSEED farms = dairy farms that feed oilseed supplements to dairy cows to increase milkfat UFA concentration. $\text{OP}_{\$1.0/\text{kgDM}}$ = $1.00/kg DM oilseed supplement, $\text{OP}_{\$1.3/\text{kgDM}}$ = $1.30/kg DM oilseed supplement. The performance of AVE farms in the $\text{Prem}_{\text{breakeven}}$ and $\text{Prem}_{\text{high}}$ scenarios was similar to that in the Prem_{0} scenario. Unless other values are indicated, the financial performance of OILSEED farms in the $\text{Prem}_{\text{breakeven}}$ and $\text{Prem}_{\text{high}}$ scenarios was similar to the Prem_{0} scenario.

[2] Milk payout for AVE farms = $4.63/kg milkfat + $10.98/kg protein + - $0.042/L milk + UFA premium. Milk payout for OILSEED farms = $4.65/kg milkfat + $11.04/kg protein + -$0.042/L milk + UFA premium. UFA premium ($/kg milkfat for each 0.1 g UFA/100 g milkfat above 37.50 g/100 g milkfat): $\text{Prem}_{0} = 0$, $\text{Prem}_{\text{breakeven}}$ = $0.10 and $\text{Prem}_{\text{high}}$ = $0.16.

[3] Milk payout for AVE farms = $4.63/kg milkfat + $10.98/kg protein + - $0.042/L milk + UFA premium. Milk payout for OILSEED farms = $4.65/kg milkfat + $11.04/kg protein + -$0.042/L milk + UFA premium. UFA premium ($/kg milkfat for each 0.1 g UFA/100 g milkfat above 37.50 g/100 g milkfat): $\text{Prem}_{0} = 0$, $\text{Prem}_{\text{breakeven}}$ = $0.14 and $\text{Prem}_{\text{high}}$ = $0.20.

Figure 2 Simulated (1000 replicates) operating profit of AVE farms and OILSEED farms, under three premium scenarios for milkfat UFA concentration (Prem_0, $\text{Prem}_{\text{breakeven}}$, $\text{Prem}_{\text{high}}$), and two price scenarios for oilseed supplements used on-farm: \$1.00 ($\text{OP}_{\$1.0/\text{kgDM}}$) and \$1.30 ($\text{OP}_{\$1.3/\text{kgDM}}$) /kg DM supplement.



DISCUSSION

The present simulation study evaluated the physical and financial characteristics of dairy farms and a dairy processor, when dairy cows were fed oilseed supplements to produce milk high in UFA. Many studies that investigated the feeding of oilseeds to dairy cows to alter milkfat composition have been short term and focused on the effects of oilseed feeding on milk production and composition at the cow level rather than at the farm level (Oeffner et al., 2013; Schroeder et al., 2013; Thomson & MacGibbon, 2000). In the present study, the use of a farm model and a milk processing model enabled the investigation of the potential effects of using oilseed supplements on farm productivity, yield of dairy products and farm profitability under the assumption that dairy farmers are integrated to control the production and processing of milk, and the marketing of dairy products. The development of a premium for milkfat UFA concentration taking as example farms that use an oilseed supplements to increase the milkfat UFA concentration was investigated in the present study because the feeding of oilseed supplements to alter milkfat composition has been researched extensively. However, other alternatives to increase the milkfat UFA concentration on-farm by dietary manipulation include the use of fish or marine oils and the combination of pasture-based diets with oilseed supplements.

Since several factors influence the response of dairy cows to oilseed supplements (Kennelly, 1996; Sterk et al., 2012), variable results have been published in the scientific literature concerning the effect of oilseed supplements on milk production (Shingfield et al., 2013). The percentages of change used for each trait in the present study were within the range reported in previous studies (Bobe et al., 2007; Lerch et al., 2012a; Lerch et al., 2012b; Oeffner et al., 2013; Schroeder et al., 2013; Woodward et al., 2006). As several factors influence the response to oilseed supplements (Grummer, 1991; Shingfield et al., 2013; Shingfield & Garnsworthy, 2012), caution should be taken when interpreting the results concerning the physical and financial performance of OILSEED farms because the change in milk production and composition associated to the use of an oilseed supplement may be different in other situations. Given that the source of oil supplement influences the milkfat UFA concentration (Vazirigohar et al., 2014), the involvement of cattle feed suppliers is important for the continuous supply of oil supplements that have been proved to increase the milkfat UFA concentration.

Apart from the percentages of milkfat and protein, the concentration of UFA in milkfat and the type of supplements fed to dairy cows, the physical performance indicators of OILSEED farms were not significantly different from AVE farms, both per cow and per hectare (Table 4). The results of the present study concerning milk production and composition per cow replicated the results of previous studies which reported that feeding oilseed supplements to dairy cows did not affect cow live weight and the yields of milk, milkfat and protein significantly, but reduced the percentages of milkfat and protein, and increased the concentration of UFA in milkfat (Bobe et al., 2007; Chichlowski et al., 2005; Flowers et al., 2008; Glasser et al., 2008; Lerch et al., 2012a; Oeffner et al., 2013; Schroeder et al., 2013). However, some studies have reported a significant increase (Caroprese et al., 2010; Larsen et al., 2012; Thomson & MacGibbon, 2000), or decrease (Gonthier et al., 2005; Nicolae et al., 2011), in milk, milkfat or protein yields, when dairy cows were fed oilseed supplements.

OILSEED farms produced milk with 28.79% more UFA than AVE milk (Table 4). Previous studies (Caroprese et al., 2010; Flowers et al., 2008; Oeffner et al., 2013; Suksombat et al., 2013) reported that milkfat c9 t11 CLA and n-3 fatty acids increased significantly (+47% to +135% and +45% to +191%, respectively) when oilseed supplements based on flaxseed or rapeseed were fed to dairy cows. Although individual UFA were not considered in the present study, the enrichment of milk with c9 t11 CLA and n-3 fatty acids, which have health benefits, could attract health conscious consumers and justify an increase in milk price.

The farm model used in the present study considered the live weight and milk production of dairy cows to estimate their energy demand. Since cows on OILSEED farms and cows on AVE farms were not significantly different in milk production and live weight, their annual energy demand was not significantly different (Table 4). Since the farm model matched the energy supply in the farm with the energy demand of the herd, the significant difference in total supplement demand and total feed demand between cows on OILSEED farms and cows on AVE farms was due to differences in energy content of the feed (14 MJ ME/kg DM oilseed supplement vs 10 MJ ME/kg DM conserved pasture supplements). However the difference in feed demand between cows on OILSEED farms and AVE farms disappeared when feed demand was expressed as energy demand (Table 4). Some studies reported that the use of oilseed supplements did not affect daily dry matter intake per cow (Cortes et al., 2010; Petit, 2010; Woodward et al., 2006), but in those studies the control and oilseed rations were made to be isoenergetic. However, caution should be exercised when interpreting these results because in the present study it was assumed that pasture substitution was nil, in both AVE farms and OILSEED farms.

During the lactation, 303 kg DM of oilseed supplement were offered per cow on OILSEED farms (Table 4). The amount of oilseed supplement offered per cow on OILSEED farms corresponded to 1.13 kg DM/day or 300 g oilseed fat/day, and was equivalent to 8% (as oilseed DM) or 2.5% (as oilseed fat) of daily dry matter intake during the lactation. Equivalent amounts of oilseed fat (oil) have also been fed to dairy cows in other studies (Caroprese et al., 2010; Flowers et al., 2008; Lerch et al., 2012b; Suksombat et al., 2013; Ward et al., 2002). The daily amount of oilseed fat offered to cows on OILSEED farms comprised less than 3% of the feed dry matter. Several studies have reported that fat from oilseed supplements could be included up to 3% of the feed dry matter without negatively affecting milk production (Kolver, 2000; Lerch et al., 2012a).

As there were no significant differences between OILSEED farms and AVE farms in the volume of milk and milk components supplied to a dairy processor, the volumes of SMP, butter and BMP manufactured from OILSEED milk were not significantly different from that of AVE milk (Table 6). Oeffner et al. (2013) reported that butter yield was not significantly affected when cows were fed oilseed supplements. However, the significant difference in volumes of casein and WP manufactured from OILSEED milk and AVE milk (Table 6) indicated that the manufacture of dairy by-products was more sensitive to small differences (although not significant) in the average volume of milk and milk components supplied to a dairy processor by OILSEED farms and AVE farms (Table 5).

The concentration of UFA in fat of butter manufactured from OILSEED milk or AVE milk corresponded to that of the milk it was manufactured from. Other studies have also reported that UFA concentration in butter fat resembled closely that of the milk it was manufactured from (Bobe et al., 2003; Chion et al., 2010; Oeffner et al., 2013). In previous studies in which oilseeds were fed to dairy cows to alter milkfat composition, an 18% to 32% increase in UFA concentration improved the spreadability of butter and its potential nutritional value (c9 t11 CLA, n-3 fatty acids) without affecting other rheological properties (Bobe et al., 2007; Hurtaud & Peyraud, 2007; Oeffner et al., 2013). Although UFA concentration is not the only factor that influences the spreadability of butter (MacGibbon & McLennan, 1987), a 28.79% increase in UFA concentration could improve the spreadability of OILSEED butter and its potential nutritional value (increased c9 t11 CLA and n-3 fatty acids concentrations).

Due to the higher market value of OILSEED butter in the $\text{Prem}_{\text{breakeven}}$ and $\text{Prem}_{\text{high}}$ scenarios, the processing of OILSEED milk in the presence of a premium for milkfat UFA concentration resulted in both higher revenue from the sales of butter and higher total revenue, than the processing of AVE milk (Table 7). The market value of OILSEED butter in the $\text{Prem}_{\text{breakeven}}$ and $\text{Prem}_{\text{high}}$ scenarios were 22% to 31% and 35% to 43% higher, respectively, than the standard market value of butter. The percentage increase in price of OILSEED butter was lower than that of UFA butter in Chapter 6 (butter scenario: 51% to 58%) and that of Lewis Road Creamery butter (100%; Brown, 2013), but higher than that of the organic dairy products sold by Fonterra (15% to 25%; NZFW, 2011).

In the case of OILSEED milk, the market value of butter, the revenue from the sales of butter and total revenue were also influenced by the premium needed to compensate dairy farmers for the cost of the oilseed supplements used on-farm. These results indicate that dairy processors should consider the economic impact of altering milk composition on-farm in the estimation of a premium for milkfat UFA concentration. In the present study, only the price of the oilseed supplement was considered. However, other expenses could also be involved when oilseed supplements are used on-farm (e.g. storage and feeding of the oilseed supplement).

Since significantly lower volumes of casein and WP were manufactured from OILSEED milk than AVE milk, the incomes from the sales of casein and WP were significantly lower for OILSEED milk than AVE milk, but it did not affect dairy processor total revenue (Table 7). The aggregate premium needed for OILSEED milk in the $\text{Prem}_{\text{breakeven}}$ (\$3.93 to \$5.41 million) and $\text{Prem}_{\text{high}}$ scenarios (\$6.14 to \$7.58 million) were comparable with, and higher than, respectively, the aggregate premium for organic milk paid by Fonterra in 2011 (\$5 million; NZFW, 2011).

In the present study (Prem_0 scenario, Table 8), the value of milksolids (\$6.99 to \$7.00/kg), milkfat (\$4.63 to \$4.65/kg), protein (\$10.98 to \$11.04/kg) and milk volume (-\$0.042/L) were within the range of values paid in New Zealand between 2010 and 2012: \$6.16 to \$7.36/kg milksolids, \$3.56 to \$4.97/kg milkfat, \$10.14 to \$12.07/kg protein, and -\$0.040/L milk (DairyNZ, 2013a; NZAEL, 2012a). The significant difference in the value of protein between OILSEED milk and AVE milk is most likely related to the significant differences in volume of casein and WP manufacture, and in revenue from the sales of casein and WP, between the two types of milk (Table 6 and Table 7). This indicates that the protein concentration of OILSEED milk affects the manufacturing of dairy products more than the protein concentration of AVE milk.

In the presence of a premium for milkfat UFA concentration, the values of milkfat, protein and volume were not affected, but the value of milksolids was significantly increased for OILSEED milk, in both premium and oilseed price scenarios (Table 8). The inclusion of a premium for each 0.1g/100g milkfat increase in UFA (above 37.50 g UFA/100 g milkfat) in the $\text{Prem}_{\text{breakeven}}$ (\$0.10 - \$0.14/kg milkfat) and $\text{Prem}_{\text{high}}$ (\$0.16 - \$0.20/kg milkfat) scenarios, resulted on OILSEED farms having significantly higher milk income (\$/ha) and gross farm income (\$/ha) than AVE farms (Table 9).

Although OILSEED farms and AVE farms were not significantly different in gross farm income (\$/ha) in the Prem_0 scenario, the use of oilseed supplements significantly increased feed expenses on OILSEED farms and reduced their operating profit by \$659/ha ($OP_{\$1.0/kgDM}$) and \$905/ha ($OP_{\$1.3/kgDM}$) compared to AVE farms. Previous studies mentioned that the use of oilseed supplements could significantly increase farm costs and affect farm profit in the absence of a premium for milkfat UFA concentration (Lerch et al., 2012a; Shingfield & Garnsworthy, 2012; Thomson et al., 2002). The present study enabled, via simulation, the quantification of the financial effects of the use of an oilseed supplement on-farm.

A premium of \$0.10 to \$0.14/kg milkfat ($Prem_{breakeven}$) and \$0.16 to \$0.20 /kg milkfat ($Prem_{high}$) for each 0.1g UFA/100 g milkfat increase resulted on OILSEED farms having a similar and higher, respectively, operating profit than AVE farms (Figure 2). However, a marginally higher operating profit than average farms may not be enough to motivate dairy farmers to use an oilseed supplement to increase the milkfat UFA concentration on-farm. Previous studies have indicated that the flexibility of the farm system and risks involved also influence farmers decisions (Finneran et al., 2012). Although the present study did not consider other factors related to oilseed supplementation (type of oilseed supplement, method of feeding, increase in milk trans fatty acids), the results contributed to a better understanding of the impact, on both farmer and dairy processor, of altering milkfat composition through the use of oilseed supplements on farm.

CONCLUSION

A farm model and a milk processing model were use to study the effects of increasing the milkfat UFA concentration on-farm through the use of oilseed supplements. In the present study, there were no significant differences in milk production per farm between OILSEED farms and AVE farms. The simulation of milk processing indicated that milk composition influenced the yield of dairy products. Therefore, the milk price would have to reflect the effect of milk composition on the yield of dairy products manufacture. However, dairy processor financial performance was influenced by the premium needed to compensate dairy farmers for the use of oilseed supplements. In the absence of a premium for milkfat UFA concentration, the operating profit ($/ha) of OILSEED farms was $659 to $905 /ha lower than that of AVE farms. A premium (for each 0.1 g UFA/100 g milkfat increase above 37.50 g UFA/100 g milkfat) of $0.10 to $0.14/kg milkfat resulted on OILSEED farms having a similar operating profit than AVE farms, and a premium of $0.16 to $0.20/kg milkfat resulted on OILSEED farms having a higher operating profit than AVE farms. Further studies are needed to determine the value of the premium for milkfat UFA concentration that could motivate dairy farmers to alter their farm system to produce milk high in UFA.

CHAPTER 8

General discussion and conclusions

INTRODUCTION

In recent years there has been an interest in increasing the concentration of unsaturated fatty acids (UFA) in milkfat. Although several studies have investigated the possibility of increasing the milkfat UFA concentration on farm, through genetic selection (Mele, 2009; Shingfield et al., 2013) and dietary manipulation (Shingfield & Garnsworthy, 2012; Thomson et al., 2002), little is known about the potential impact that this could have on farm production and profit. This PhD thesis investigated the effects of increasing the concentration of UFA in milkfat on farm productivity and profitability. The results provide a better understanding of the consequences of increasing the milkfat UFA concentration on New Zealand dairy farms.

The objectives of the present PhD thesis (Chapter 1) were accomplished in several stages. Chapter 2 provided the background necessary to evaluate the implications of increasing the milkfat UFA concentration on farm. In Chapter 3, it was shown that the milkfat UFA concentration of New Zealand dairy cattle was influenced ($P<0.001$) by days in milk (DIM), breed, herd, and parity. In addition, Chapter 3 showed that the segregation of dairy cows could be practised to form herds that produce milk with a high milkfat UFA concentration. Chapter 4 demonstrated that a stochastic farm model could be developed to study the characteristics of dairy farms that produce milk high in UFA under New Zealand conditions. Chapter 5 confirmed that, compared to average farms (AVE farms), the operating profit of farms that segregated dairy cows to produce milk high in UFA (UFA farms) was negatively affected, especially at a high milksolids (milkfat + protein, MS) payout (-$1434/ha at $7.37/kg MS vs -$1242/ha at $5.21/kg). In Chapter 6, the processing of milk produced by UFA farms was simulated. It was estimated that, across different processing scenarios, a premium (for each 0.1 g UFA/100 g milkfat above 34.50 g UFA/100 g milkfat) of $0.47 - $0.51 /kg milkfat, was needed for UFA farms to have an operating profit ($/ha) similar to that of AVE farms, and a premium of $0.53 - $0.57 /kg milkfat was needed for UFA farms to have a higher ($P<0.05$) operating profit than AVE farms. Chapter 7 studied the characteristics of farms that fed dairy cows an oilseed supplement to produce milk high in UFA (OILSEED farms). A premium (for each 0.1 g UFA/100 g milkfat increase above 37.50 g /100 g milkfat) of \$0.10 - \$0.16/kg milkfat was necessary for OILSEED farms to have an operating profit (\$/ha) similar to that of AVE farms, and a premium of \$0.14 - \$0.20/kg milkfat was necessary for OILSEED farms to have a higher ($P<0.05$) operating profit than AVE farms.

This chapter will discuss the main findings and implications of the present PhD thesis, its strength and weaknesses, and will suggest areas for future work.

IMPLICATIONS OF THE INCREASE OF THE MILKFAT UFA CONCENTRATION ON-FARM

Efforts to modify milkfat composition at the farm level are not new. Studies investigating the possibility of increasing the milkfat UFA concentration, by dietary manipulation (oilseed supplements), date back to the early 1960s (McDonald & Scott, 1977; Plowman et al., 1972; Scott et al., 1970; Storry, 1972). At that time, the demand to reduce the concentration of saturated fatty acids (SFA) in milkfat, and increase its UFA concentration, was associated with studies published during the 1950s and 1960s, which linked high intakes of SFA to the rise in the incidence of cardiovascular diseases in some industrialised countries (Carlsen, 1959; Jolliffe et al., 1961; Pyke, 1971). In addition to health concerns, the hardness of butter at low temperatures contributed to a decline in its consumption when margarine manufacturers emerged, and motivated dairy processors to investigate options to increase the spreadability of butter (Ashton, 1971; McDonald & Scott, 1977; Park & Bryant-Tebel, 1971).

Research to alter milkfat composition at the farm level has been intensified over the last four decades. In recent times, significant progress has been made in overseas countries regarding the factors that influence milkfat composition (Samkova et al., 2012; Stoop et al., 2009), the modification of milkfat composition through dietary manipulation (Kalac & Samkova, 2010; Schroeder et al., 2004; Shingfield & Garnsworthy, 2012) and genetic selection (Bilal et al., 2012; Gion et al., 2011; Shingfield et al., 2013; Stoop, 2009), the analysis of milkfat composition by infrared spectroscopy (Coppa et al., 2014; Ferrand-Calmels et al., 2014; IDF, 2010; Maurice-Van Eijndhoven et al., 2013; Soyeurt et al., 2011) and the manufacture of dairy products high in UFA (Bobe et al., 2003; Chen et al., 2004; Oeffner et al., 2013). Similar studies have also been done in New Zealand (Auldist et al., 1998; Cullen et al., 2012; MacGibbon et al., 2002; Mackle et al., 1997; Thomson et al., 2003b; Wales et al., 2009).

Over the decades in which milkfat composition has been researched, and despite some dairy companies in overseas countries offering economic incentives to farmers supplying milk high in UFA (Borreani et al., 2013; FrieslandCampina, 2013), few studies have investigated the economic impact of increasing the milkfat UFA concentration on-farm. To the knowledge of the writer, this is the first study that evaluates the economic impact of increasing the milkfat UFA concentration in New Zealand dairy farms. The present research corroborated what was reported in previous studies (Elgersma et al., 2006; McDonald & Scott, 1977; Mele, 2009; Walker et al., 2004). In the absence of a premium for milkfat UFA concentration, farm operating profit ($/ha) was significantly reduced when dairy farmers practised the segregation of cows (-$1,320 to -$1,429 /ha, Chapter 6), or the feeding of an oilseed supplement (-$659/ha to -$905/ha, Chapter 7), to produce milk high in UFA.

The information presented in this study may help dairy companies in New Zealand evaluate the potential economic impact of modifying the milkfat composition on-farm for the commercial manufacture of dairy products high in UFA. However, caution should be taken when interpreting its results because the assumptions taken in the simulations may not apply to other situations. Also, there are other issues around the modification of milkfat composition that were not considered in the present study, such as the measurement of milkfat composition, the marketing of dairy products high in UFA, the consumer willingness-to-pay for dairy products high in UFA, the change in concentration of trans fatty acids (TFA) associated to an increase in milkfat UFA concentration.

The results from the experimental chapters (Chapter 3 to Chapter 7) indicated that the segregation of dairy cows and oilseed supplementation could be practised to produce milk with a high milkfat UFA concentration. Although, in the short term, the segregation of dairy cows and oilseed supplementation could be used to achieve a rapid increase in milk-fat UFA concentration, further studies are needed to integrate those strategies into a long-term programme for the production of milk high in UFA. In the past, some studies reported that the segregation of dairy cows could be combined with oilseed supplementation to achieve a higher UFA concentration than that achieved by segregation or oilseed supplementation alone (Bobe et al., 2007; Thomson et al., 2003a).

A long-term programme for the production of milk high in UFA concentration may comprise the segregation of dairy cows combined with oilseed supplementation and a programme of genetic selection and breeding. Assuming a population base of 1,820,000 cows (the whole Holstein-Friesian population of New Zealand), the segregation of the top 17,150 cows for milkfat UFA concentration allowed the creation of 50 farms (UFA farms) that produced milk with a milkfat UFA concentration of 35.15 g /100 g milkfat (16.7% more UFA than AVE farms) (Chapter 5). An analysis, in which the group of 17,150 segregated cows was taken as the base for a four pathway of selection programme to increase milkfat UFA concentration, indicated that the annual rate of genetic gain for milkfat UFA concentration could be 0.05 g UFA /100 g milkfat (Appendix 4, Table A.4). At this rate, milkfat UFA concentration on UFA farms would increase to 36.22 g /100 g milkfat in 20 years (20.2% more than AVE farms) (Appendix 4, Table A.4). This is close to the milkfat UFA concentration obtained in Chapter 4 when the top 325 cows were segregated from a population base of 1,820,000 cows (37.27 g /100 g UFA, 23.6% more than AVE farms). In the present example, the change in milkfat UFA concentration after 20 years of genetic selection was small due to the small genetic variance for this trait in cows on UFA farms and the low heritability of milkfat UFA concentration. If genetic selection was practised on average dairy farms, the rate of genetic gain in milkfat UFA concentration may be larger due to a larger genetic variance for this trait in cows on average farms. However, the rate of genetic gain in milkfat UFA concentration may be lower if other milk production traits (which relate negatively with milkfat UFA concentration) are also included in the selection index.

Although genetic factors could contribute to increase milkfat UFA concentration, the success of a genetic selection programme to increase milkfat UFA concentration will require the involvement of breeding companies. Therefore, breeding companies must also benefit from a programme of genetic selection for UFA. Further studies are necessary to investigate the long-term consequences and cost-benefit of implementing a selection programme to increase the milkfat UFA concentration under New Zealand conditions. Some studies reported that a high C18:1 concentration, the most abundant UFA in milkfat, was associated with a negative energy balance and greater days from calving to conception (days open) in dairy cows (Bastin et al., 2012; McParland et al., 2011a). Since in New Zealand a compact seasonal calving pattern is important to maximise pasture utilisation, a decrease in cow fertility would be undesirable. It is possible that negative genetic correlations between milkfat UFA concentration and other milk production traits discourage the involvement of breeding companies in selection for milkfat UFA concentration, unless there are clear economic benefits.

In New Zealand, the availability of oilseed supplements for dairy cattle is limited and mainly in the form of oil. In the present study the availability of the oilseed supplement (Chapter 7) was not considered. However, the involvement of cattle feed suppliers is also important for the success of a programme aimed at increasing the milkfat UFA concentration through dietary manipulation. In some countries, a number of supplements to alter milkfat composition (based on plant or fish oils) have been designed, investigated, patented and are available commercially for dairy farmers that would like to use them and get a premium for a specific milkfat composition (DairyOh, 2013; FrieslandCampina, 2013; Strohmaier & Fredericksen, 2003; Wright et al., 1999). In the past, some studies in New Zealand investigated the use of oilseed supplements to alter milkfat composition (Thomson & MacGibbon, 2000; Thomson et al., 2002), but they have not been used in commercial dairy farms (due in part to the absence of a premium for milkfat UFA concentration).

The effect of oilseed supplements on dry matter intake, milk production and milk composition varies between studies (Glasser et al., 2008; Rabiee et al., 2012; Shingfield et al., 2013). This variation is due to the several factors that influence the cow's response to oilseed supplements, such as the composition of the base diet and the type, form and technical processing of the oilseed supplement (Chilliard et al., 2007; Dewhurst et al., 2006; Kennelly, 1996; Walker et al., 2004). However, of the several studies investigating the effects of oilseed supplements on milk production and composition, few have been done under grazing conditions.

In Chapter 7, it was assumed that the use of an oilseed supplement did not affect milk production per cow significantly. However, in the absence of a premium for milkfat UFA concentration, the high cost of the oilseed supplement resulted on OILSEED farms having a lower farm profit (-$659/ha to -$905/ha) than AVE farms. An approximate analysis (Appendix 5, Table A.5) indicated that the difference in operating profit between AVE farms and OILSEED farms may have been smaller (-$321/ha to -$567/ha) if the feeding of an oilseed supplement had increased the yields of milk and milksolids in proportions similar to the ones reported by Thomson & MacGibbon (2000).

Considering the advantages and disadvantages of segregation, genetic selection and oilseed supplementation, and the volatility of the dairy market, it is possible that oilseed supplementation is the first choice for dairy farmers wanting to participate in a programme to produce milk high in UFA. In contrast to the effects of segregation and genetic selection, the effects of feeding oilseed supplements on milkfat composition are observed rapidly and could easily be reversed in case the demand for dairy products high in UFA decreases.

Oilseed supplements that increase not only milkfat UFA concentration but also the yields of milk and milksolids would be ideal for a programme to increase the milkfat UFA concentration through dietary manipulation. If the demand for milk high in UFA develops in New Zealand, protocols for increasing the milkfat UFA concentration through dietary manipulation will need to be accessible to dairy farmers to help them avoid losses in production.

Several studies have reported that the addition of some oilseed supplements (linseed, canola) to dairy cow diets (2% - 3% of feed dry matter as oil from oilseed) reduced methane emissions (-11% to -18%) without significantly affecting milk production (Beauchemin et al., 2009; Brask et al., 2013; Grainger & Beauchemin, 2011; Martin et al., 2011; Shingfield & Garnsworthy, 2012). Although the effect of oilseed supplementation on methane emissions was not investigated in the present study, it is possible that dairy farms that use oilseed supplements for the production of milk high in UFA also have reduced methane emissions. However, the benefits of reduced methane emissions in dairy farms that use oilseed supplements to produce milk high in UFA still need to be determined.

Over a 12-month period, the UFA concentration in fat of butter and cheese manufactured from milk high in UFA was at least 15% (Chapter 6) to 28% (Chapter 7) higher than that of standard dairy products. In the Netherlands, FrieslandCampina indicated that, during the year, milk for the Campina brand had at least 20% more UFA than standard milk in the Netherlands (FrieslandCampina, 2013). Several studies have indicated that milk produced in pasture-based systems has more UFA than milk produced in intensive systems. However, differences in farm systems and measurement of fatty acids may also affect the difference in UFA concentration between dairy products high in UFA made in New Zealand and standard dairy products made in other countries. If dairy companies in New Zealand would like to draw attention to the UFA concentration of their products (high in UFA) for marketing purposes, it is important to determine the size of the difference, and how it changes during the year, in relation to standard dairy products made in other countries.

The physical and financial characteristics of a dairy processor are influenced by the product mix manufactured (Chapter 6). Therefore, dairy companies interested in the manufacture of dairy products high in UFA need to investigate the product mix that may result in the highest revenue. In Chapters 6 and 7 it was assumed that other milk components, the processing characteristics of milk and the rheological characteristics of dairy products were not affected by a high UFA concentration in milkfat (with the exception of butter hardness and spreadability). However, some studies reported that an increase in milkfat UFA concentration was associated with changes in the concentration of other milk components (lactose percentage; Caroprese et al., 2013; Palmquist et al., 1993, the manufacturing properties of milk (size of emulsion droplets, structural and thermal properties of milk triacylglycerols, rennet coagulation time, clot firmness; Augustin et al., 2013; Bugeat et al., 2011; Caroprese et al., 2013) and the composition and properties of dairy products (fat percentage, protein percentage, moisture, concentration of minerals, hardness and cohesiveness of cheese; Augustin et al., 2013; Caroprese et al., 2013; Oeffner et al., 2013). Further studies are necessary to determine the influence of a high milkfat UFA concentration on milk processing properties and the properties of dairy products. Dairy companies will probably need to modify some manufacturing processes and develop protocols for the manufacture of consistent dairy products high in UFA.

Although there is a trend in the population towards low intakes of SFA (Eckel et al., 2009; Kearney, 2010), currently the market for dairy foods high in UFA is small and mostly associated with functional dairy products (Özer & Kirmaci, 2010). In the present study, 50 dairy farms were considered to supply a small dairy processor with 72.04 to 75.21 million litres of milk high in UFA per year. However, for a company the size of Fonterra, which has small and large processing plants to process 17 billion litres milk/year (Fonterra, 2012a), the logistics and economics of segregating and processing a relatively small volume of milk (high in UFA) needs further evaluation. This is because changes in logistics may be necessary to manage a relatively small volume of milk separately to avoid the inefficient use of plant resources and losses in economy of scale. Some small dairy companies in New Zealand have focused on the manufacture of speciality dairy products. The manufacture of dairy products high in UFA may be an option for some of them to increase their market share.

A factor that was not covered in the present study was the consumer willingness-to-pay for dairy products high in UFA. Consumer's purchasing behaviour is complex and influenced by several factors, including income, subjective and objective knowledge and health status (Aertsens et al., 2011;

Armstrong et al., 2005). Further studies are needed to determine if international customers are willing to pay the premium prices for butter and cheese high in UFA reported in Chapter 6 and Chapter 7. The premium price (US $/tonne) of butter was 46% to 58% (Chapter 6) and 22% to 43% (Chapter 7) higher than its average market value. The premium price of cheese was 22% to 27% (Chapter 6) higher than its average market value. Several examples indicate that in some cases customers are willing to pay a premium of 100% to 150% at the retail level for dairy products with valued characteristics (Brown, 2013; Dimitri & Venezia, 2007).

However, the marketing of butter and cheese high in UFA could be challenging for dairy companies in New Zealand. For butter, a high UFA concentration in fat could improve its spreadability, an attribute which is valued by some consumers (Hillbrick & Augustin, 2002; Lubary et al., 2011; Mortensen, 2011). However, the health benefits of increasing the UFA concentration of butter and cheese are not clear.

In several countries, governments are encouraging the substitution of SFA for UFA through dietary guidelines and policies (Aranceta & Perez-Rodrigo, 2012; EC, 2014; EFSA, 2010; USDA-HHS, 2010). At the same time, policies regarding nutritional claims and labelling are becoming stricter in several countries (EFSA, 2005; FDA, 2013b; HC-SC, 2012). However, the health benefit of replacing SFA with UFA is still controversial. Some studies have reported that replacing SFA with UFA is beneficial to cardiovascular health (Gillingham et al., 2011; Rosqvist et al., 2014; Willett, 2012), while others have reported that there are no health benefits when SFA are replaced by UFA (DiNicolantonio, 2014; Huth & Park, 2012). Considering the above-mentioned factors, it is unlikely that dairy companies could legitimately claim health benefits in the marketing of butter and cheese high in UFA.

The marketing of butter and cheese high in UFA could also be based on specific UFA with demonstrated health benefits, rather than total UFA. This approach has been taken by some dairy companies in a few countries to sell dairy products enriched with n-3 fatty acids at a premium price (DairyOh, 2013;

Özer & Kirmaci, 2010). By focusing on the health benefits of some individual UFA, it is possible for dairy companies to make health claims to attract a premium price for their products.

The marketing of dairy products high in UFA could also be associated with economic benefits if governments taxed the SFA concentration of food products. In 2011, Denmark imposed a tax of 16 DKK (€ 2.15) per kilogram of SFA, for foods with a SFA content above 2.3 g/100 g fat (Smed, 2012). In a hypothetical scenario, it was assumed that an equivalent tax (€ 2.15/kg SFA, €1 = NZ $1.6415) was applied to the total volume of butter made in Chapter 6 (Butter scenario) and Chapter 7 (Appendix 6, Table A.6). Under this scenario, the sales of butter high in UFA would have saved $1.5 million (Chapter 6) and $1.1 million (Chapter 7) in taxes, compared to the sales of average butter. Although the tax on SFA in Denmark lasted a short time, it cannot be discarded that, in the future, governments in other countries may decide to tax the SFA of food products (CBCNews, 2011; Requillart, 2013; The Guardian, 2011; The Washington Post, 2012).

Rigorous regulations concerning the concentration of TFA in food products (FDA, 2013b) could make it difficult to market butter and cheese high in UFA, if they are also high in TFA. Industrial TFA have been associated with an increased risk of cardiovascular diseases (Givens, 2010). Although some studies reported that TFA from ruminant origin did not affect health negatively at typical consumption of dairy products, currently this issue still needs further explanation (Brouwer et al., 2010, 2013; Willett & Mozaffarian, 2008). The concentration of TFA in milkfat was not investigated in the present study. However, the high genetic and phenotypic correlations between individual UFA and TFA (Heck et al., 2012b; Shingfield et al., 2013; Stoop et al., 2008) suggests that the concentration of TFA in milkfat could also increase when dairy cows are segregated, or fed an oilseed supplement, to produce milk high in UFA. In several studies, the use of oilseed supplements increased the concentration of TFA in milkfat by 50% to 300% (Ferlay et al., 2010; Flowers et al., 2008; Lerch et al., 2012b; Shingfield et al., 2013). Therefore, changes in the concentration of TFA should also be considered when strategies are adopted on dairy farms to increase the milkfat UFA concentration.

IMPLICATIONS TO INCLUDE MILKFAT UFA CONCENTRATION ON THE MILK PAYMENT SYSTEM

The milk payment system has a significant impact on dairy farmer's decisions. If the right economic incentive exists, it is possible that a small dairy company contract some dairy farmers for the supply of milk high in UFA. However, it is necessary that both dairy processors and dairy farmers understand the desired composition of milk supplied, and the thresholds for milkfat UFA concentration for payment purposes. If a dairy company in New Zealand included into their payment system the premiums estimated for milkfat UFA concentration in this study, other elements of the dairy industry, in addition to dairy farmers and dairy processor, could also be influenced. In the presence of an economic incentive, some dairy farmers may decide to use oilseed supplements for the production of milk high in UFA. Demand for oilseed supplements could motivate some animal feed suppliers to invest in oilseed supplements. The interest of some dairy farmers in the segregation and selection of dairy cows for the production of milk high in UFA could encourage breeding companies to evaluate the cost-benefit of a selection programme to increase milkfat UFA concentration. Therefore, a dairy company interested in the manufacture of dairy products high in UFA will benefit from including dairy farmers, feed suppliers and/or breeding companies in the development of a programme to increase the milkfat UFA concentration.

The inclusion of a premium for milkfat UFA concentration into the milk payment system will impact on the economic value of milkfat UFA concentration in a genetic selection programme. An economic analysis (Appendix 7, Table A.7) showed that the economic benefit ($/ha) of increasing the milkfat UFA concentration in each kilogram of milkfat by 1 g /100 g milkfat was +$60, +$85, +$284 and +$308 for UFA premiums ($/kg milkfat for each 0.1 g /100 g milkfat above 37.50) of $0.10, $0.14, $0.47 and $0.51, respectively.

The premiums for milkfat UFA concentration estimated in the present study were specific for the scenarios they were derived from. The specificity of milk payment has also been indicated in the past (Garrick & Lopez Villalobos, 2000). Factors such as product portfolio, on-farm strategy to increase the milkfat UFA concentration, cost of oilseed supplement, cost of dairy cows and the level of economic incentive all influenced the size of the premium for milkfat UFA concentration (Chapter 6 and 7). This indicates that a dairy company will need to review its premiums for milkfat UFA concentration periodically. In Chapter 7, the premium needed for OILSEED farms to have an operating profit similar to that of AVERAGE farms was \$0.10 - \$0.14 /kg milkfat (for each 0.1 g UFA/100 g milkfat increase above 37.50 g UFA/100 g milkfat). However, if the oilseed supplement had increased the yields of milk and milksolids as reported in the study by Thomson & MacGibbon (2000), the premium needed for milkfat UFA concentration would have been smaller (about \$0.05 to \$0.08 /kg milkfat, estimated from Appendix 5, Table A.5).

A premium (for each 0.1 g UFA/100 g milkfat increase above the threshold) of \$0.53 to \$0.57 (Chapter 6) and \$0.16 to \$0.20 (Chapter 7) /kg milkfat resulted in farms producing milk high in UFA having a marginally higher operating profit than average farms. However, achieving a marginally higher operating profit than average farms may not be enough motivation for dairy farmers to get involved in a programme to produce milk high in UFA. This is because other non-cash factors, such as flexibility of the farm system and risks involved, may also influence farmers decisions (Finneran et al., 2012). Further studies are needed to determine the size of the premium that may motivate dairy farmers to get involved in a programme to increase the milkfat UFA concentration.

STRENGTHS AND WEAKNESSES OF THE PRESENT STUDY

The present study has provided important information concerning the economics of increasing the milkfat UFA concentration at the farm level. This information was obtained by using a stochastic farm model and a milk processing model. Simulation models are potentially powerful tools that could help to evaluate the effects of changes in variables of interest (León-Velarde & Quiroz, 2001). Several dairy farm models have been developed to study the effects of farm management (Baudracco et al., 2013; Congleton, 1984; da Cunha et al., 2010a), pasture growth (Romera et al., 2010), health status of the herd (Bruijnis et al., 2010; Van der Fels-Klerx et al., 2001), genetic selection (Zakizadeh et al., 2007), herd fertility (Hockey & Morton, 2010) and methane emissions of dairy cows (Crosson et al., 2011). However, a bio-economic farm model which simulates the milkfat UFA concentration has not been mentioned in the scientific literature before.

Studies investigating options to increase the milkfat UFA concentration at the farm level, both in New Zealand and overseas, have been short term, comprised a small number of animals and did not focus on the economic aspects of those strategies. Therefore, the farm model developed in Chapter 4 constitutes a powerful tool to investigate the effect of increasing the milkfat UFA concentration on dairy farms, under New Zealand conditions. The use of a milk processing model enabled the estimation of a premium for milkfat UFA concentration which considered both the cost of producing milk high in UFA and the cost of processing milk high in UFA. The scenarios investigated in Chapter 5, 6 and 7 would not have been possible to be investigated experimentally due to their high cost and complexity. The simulation of 50 average dairy farms and a dairy processor, and 50 dairy farms producing milk high in UFA and a dairy processor, enabled the determination of the opportunity costs of producing and processing milk high in UFA instead of average milk.

The premium for milkfat UFA concentration was estimated considering: 1) the market for milk of a modified composition, 2) the physical and financial characteristics of dairy farms producing milk with a modified composition, 3) the effect of milk composition on yield of dairy products manufacture, 4) the dairy product portfolio manufacture, 5) the market value of dairy products, and 6) the financial characteristics of the dairy processor. This methodology may also be applied in the development of premiums for other milk components.

In simulation studies, model inputs and assumptions are important. In the simulation of milk production and processing (Chapter 4 to Chapter 7), values for model inputs were not always available in the scientific literature. When input values were not available in the scientific literature they were estimated as accurately as possible based on results of available studies and expertise. Therefore, caution should be taken when extrapolating the results from this study to other situations. This is particularly important considering that milkfat composition is influenced by several factors.

The profile of milkfat UFA concentration simulated by the farm model decreased steadily during the course of lactation. Although similar results have been published in the past (Marchitelli et al., 2013), other studies reported an increase in milkfat UFA concentration at the end of the lactation. In addition, as the farm model could only simulate cows with characteristics of New Zealand Holstein-Friesian cows, simulation results may not apply to herds of different breeds. In Chapter 5 and Chapter 6, it was assumed that: 1) there was a dairy processor interested in sourcing milk with high milkfat UFA concentration, 2) there was a programme to measure the milkfat UFA concentration of cows in commercial farms and 3) dairy farmers were motivated to buy/sell dairy cows that produce milk with high milkfat UFA concentration. Although this is not currently the case in New Zealand, in the future these conditions may develop. In Chapter 7, factors concerning the availability of oilseed supplement, the storage of the oilseed supplements on farm, method of feeding of the oilseed supplement, and pasture substitution were not considered. Although the calibration equations for FTIR used in Chapter 3 could predict milkfat UFA concentration with high accuracy, more studies are needed before FTIR can be used as the basis to determine a payment scheme.

Nevertheless, the present study provides a model by which other desirable milk characteristics could be studied. The farm model developed in Chapter 4 is flexible and data corresponding to other breeds could be simulated if the corresponding covariance matrices were included in the model.

FUTURE WORK

Several studies need to be done before a programme to increase the milkfat UFA concentration could be implemented in New Zealand dairy farms. Future work following from the current research may comprise the simulation of the effects of increasing the milkfat UFA concentration by combining the segregation of dairy cows with the use of oilseed supplements. Also, the simulation of the effects of combining the segregation of dairy cows with oilseed supplementation and genetic selection for milkfat UFA concentration could provide valuable information for the New Zealand dairy industry.

The farm model developed in the present study could be improved to include other breed effects and to include pasture management (to evaluate the effect of pasture substitution due to oilseed supplementation). Further studies could be done using different oilseed composition, different sets of responses to oilseed supplementation and different prices for oilseed supplements. The effect of farm size on the physical and financial characteristics of herds producing milkfat high in UFA can also be investigated. For each new farm scenario simulated a premium for milkfat UFA concentration may be estimated by simulating the processing of milk high in UFA. Field trials could also be conducted to further investigate the scenarios simulated in the present PhD thesis.

The fertility of dairy cows is important to maintain a compact calving in New Zealand pasture-based dairy systems. Therefore, future studies should also investigate the effects of increasing the milkfat UFA concentration on other traits of the selection objective and the long-term performance of dairy cows. The economics of increasing the milkfat UFA concentration during milk processing at the dairy plant should also be investigated and compared against that at the farm level. Market research studies can also provide valuable information about consumer’s interest and willingness-to-pay for dairy products high in UFA.

FINAL CONCLUSIONS

The main conclusions from this PhD thesis are:

1. Significant progress has been made in recent years to increase the milkfat UFA concentration of milk at the farm level, but the health benefits of increasing the UFA concentration of milk and dairy products remain controversial.
2. The milkfat UFA concentration of New Zealand dairy cattle was influenced by breed, lactation stage, parity, and herd and animal factors.
3. Simulation models can be used to investigate the effects of altering milkfat UFA concentration on production and profit of dairy farms and dairy processors.
4. The segregation of dairy cows can be used to alter the milkfat UFA concentration in New Zealand dairy farms.
5. In the absence of a premium for milkfat UFA concentration, farm profit was negatively affected when dairy farms practised the segregation of dairy cows ($1,320 to $1,429 /ha) or the feeding of an oilseed supplement ($659 to $905/ha) to produce milk with a high milkfat UFA concentration.
6. The physical and financial performance of a dairy processor was influenced by milk composition and the type of dairy products manufactured from milk.
7. Dairy farms in which the segregation of dairy cows was practised for the production of milk high in UFA needed a premium of $0.47 to $0.51 /kg milkfat (for each 0.1 g UFA/100 g milkfat above 34.50 g UFA/100 g milkfat) to have an operating profit similar to that of average farms.
8. Dairy farms that produced milk high in UFA by feeding oilseed supplements to dairy cows needed a premium of $0.10 to $0.14/kg milkfat (for each 0.1 g UFA/100 g milkfat above 37.50 g UFA/100 g milkfat) to have an operating profit similar to that of average farms.

9. Several issues need further exploration and clarification before establishing a programme to increase the milkfat UFA concentration in New Zealand dairy farms. These include: long-term effects of selection to increase the milkfat UFA concentration, standardisation of the measurement of milkfat composition, role of SFA and UFA in human health, consumer willingness to pay for dairy products high in UFA, size of premium that may motivate dairy farmers to produce milk high in UFA, effects of ruminant trans fatty acids on human health.

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APPENDICES

Appendix 1

Table A.1 Mean, standard deviation (SD), coefficient of variation (CV), maximum (Max) and minimum (Min) values for milk production traits of cows in the sire proving scheme dataset of Livestock Improvement Corporation.

	N Cows	N samples	Mean	SD	Min	Max	CV
Holstein-Friesian							
Milk yield (L/day)	2015	8109	19.09	7.24	2.10	45.7	0.38
Fat yield (kg/day)	2015	8109	0.82	0.29	0.09	2.34	0.35
Protein yield (kg/day)	2015	8109	0.67	0.24	0.09	1.72	0.36
% Fat	2015	8109	4.42	0.74	2.43	7.55	0.17
% Protein	2015	8109	3.57	0.35	2.66	5.45	0.10
UFA[1]	2015	8109	30.23	2.24	20.05	37.62	0.07
Jersey							
Milk yield (L/day)	1396	5815	15.18	5.39	2.20	36.80	0.36
Fat yield (kg/day)	1396	5815	0.80	0.25	0.13	1.91	0.31
Protein yield (kg/day)	1396	5815	0.60	0.19	0.11	1.28	0.32
% Fat	1396	5815	5.42	0.88	2.69	8.09	0.16
% Protein	1396	5815	4.01	0.41	2.78	5.73	0.10
UFA[1]	1396	5815	27.70	2.64	19.12	37.39	0.10
Holstein-Friesian × Jersey							
Milk yield (L/day)	2002	8028	16.73	6.05	0.70	46.60	0.36
Fat yield (kg/day)	2002	8028	0.81	0.27	0.03	2.07	0.33
Protein yield (kg/day)	2002	8028	0.63	0.21	0.03	1.97	0.33
% Fat	2002	8028	4.95	0.82	2.47	7.80	0.17
% Protein	2002	8028	3.82	0.38	2.71	5.48	0.10
UFA[1]	2002	8028	28.82	2.51	19.17	36.86	0.09
All cows							
Milk yield (L/day)	5413	21952	17.19	6.55	0.70	46.60	0.38
Fat yield (kg/day)	5413	21952	0.81	0.27	0.03	2.34	0.33
Protein yield (kg/day)	5413	21952	0.64	0.22	0.03	1.97	0.34
% Fat	5413	21952	4.88	0.90	2.43	8.09	0.18
% Protein	5413	21952	3.78	0.42	2.66	5.73	0.11
UFA[1]	5413	21952	29.04	2.65	19.12	37.62	0.09

[1] Concentration (g /100 g milkfat) of unsaturated fatty acids in milkfat.

Appendix 2

Table A.2 Mean and standard deviation (SD) for milk production traits and live weight, for cows in the Macdonald et al. (2008) dataset (Dataset 1) and cows in the sire proving scheme of Livestock Improvement Corporation dataset (Dataset 2).

Trait	Dataset 1 (109 cows, 3911 test day records)		Dataset 2 (2015 cows, 8109 test day records)	
	Mean	SD	Mean	SD
Milk yield (L/day)	20.81	6.61	19.09	7.24
Fat yield (kg/day)	0.97	0.28	0.82	0.29
Protein yield (kg/day)	0.72	0.21	0.67	0.24
Fat %	4.77	0.78	4.42	0.74
Protein %	3.54	0.38	3.57	0.35
g UFA/100g milk fat			30.23	2.24
Live weight (kg)	534.63	53.26		

Appendix 3

Estimation of regression coefficients for milk traits and live weight, for cows in the Macdonald et al., 2008 dataset (Dataset 1) and cows in the sire proving scheme of Livestock Improvement Corporation dataset (Dataset 2).

Regression coefficients for each cow in dataset 1 (MY, F%, P%, LW) and dataset 2 (milk fat UFA concentration) were estimated in ASReml (Gilmour et al., 2006) using a univariate animal model with random regression on days in milk (DIM), as follows:

$$\mathbf{y = Xb + Zu + e} \qquad \text{Eq.(A3.1)}$$

Where **y** is a vector with the phenotype of each cow for a trait (MY, F%, P%, milkfat UFA concentration or LW), **X** and **Z** are design matrices of DIM transformed into the parameters of a mathematical function, for the fixed and random effects, respectively; **b** is a vector of fixed regression coefficients for a trait on days in milk (DIM), and **u** is a vector of random regression coefficients for a trait on DIM for each cow. This model enabled each cow to have a different shape of lactation curve for each trait.

Five mathematical functions: Wood (1967), Wilmink (1987), Ali and Schaeffer (1987), and orthogonal polynomials of order 2 and 3 were investigated. The goodness of fitness of the mathematical functions considered (Appendix 3, Table A.3) was determined by their concordance correlation coefficient (CCC; (Lin, 1989)) and relative prediction error (RPE; (Fuentes-Pila et al., 1996)), as indicated in Eq. (A3.2) and Eq. (A3.3), respectively:

$$\mathrm{CCC} = \frac{2S_{AP}}{S_A^2 + S_P^2 + (A_i - P_i)^2} \qquad \text{Eq. (A3.2)}$$

$$\mathrm{RPE} = (\mathrm{MPE}/\bar{A} \ \times 100) \qquad \text{Eq.(A3.3)}$$

where Ai is the ith actual value of a trait (MY, F%, P%, LW, UFA), Pi is the ith value of the same trait predicted by a mathematical function, n is the number of observations in the dataset. MPE is the mean prediction error, estimated as:

$$\mathrm{MPE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(A_i - P_i)^2} \quad \text{Eq. (A3.4)}$$

Means ($\overline{A}$, $\overline{P}$), variances (S_A^2, S_p^2) and covariance (S_{AP}) of actual (Ai) and predicted (Pi) values were estimated in the standard way (Eq. (A3.5) to Eq. (A3.11)):

$$\overline{A} = \frac{1}{n}\sum_{i=1}^{n} A_i \quad \text{Eq. (A3.5)}$$

$$\overline{P} = \frac{1}{n}\sum_{i=1}^{n} P_i \quad \text{Eq. (A3.6)}$$

$$S_A^2 = \frac{1}{n}\sum_{i=1}^{n}(A_i - \overline{A})^2 \quad \text{Eq. (A3.7)}$$

$$S_P^2 = \frac{1}{n}\sum_{i=1}^{n}(P_i - \overline{P})^2 \quad \text{Eq. (A3.8)}$$

$$S_{AP} = \frac{1}{n}\sum_{i=1}^{n}(A_i - \overline{A})(P_i - \overline{P}) \quad \text{Eq. (A3.9)}$$

$$S_A = \sqrt{S_A^2} \quad \text{Eq. (A3.10)}$$

$$S_P = \sqrt{S_P^2} \quad \text{Eq. (A3.11)}$$

The selection of the mathematical function to use in the estimation of regression coefficients for cows in Dataset 1 and 2 was based on their goodness of fitness (high CCC and low RPE) and their number of parameters (to reduce computational difficulties, functions with fewer parameters were preferred). Based on these criteria, the Wilmink function (Wilmink, 1987) was selected to estimate the regression coefficients for MY, FP, PP and LW, and an orthogonal polynomial of order 3 was selected to estimate the regression coefficients for daily milkfat UFA concentration.

Table A.3 Concordance correlation coefficient (CCC) and relative prediction error (RPE) of the mathematical functions fitted to data from Macdonald et al., 2008 (Dataset 1) and the sire proving scheme of Livestock Improvement Corporation (Dataset 2).

Model	Wood		Wilmink		Ali- Schaeffer		Orthogonal Polynomial (order 2)		Orthogonal Polynomial (order 3)	
Trait	CCC	RPE	CCC	RPE	CCC	RPE	CCC	RPE	CCC	RPE
Dataset 1										
Milk yield	0.85	3.31	0.92	2.60	0.92	2.87	0.90	2.83	0.91	2.59
Fat %	0.77	0.49	0.85	0.38	0.87	0.35	0.85	0.38	0.86	0.37
Protein %	0.82	0.21	0.88	0.17	0.90	0.16	0.87	0.17	0.89	0.16
Live weight	0.83	20.82	0.86	10.90	0.88	8.70	0.84	13.20	0.87	10.70
Dataset 2										
g UFA /100 g milkfat	0.62	1.59	0.82	1.16	0.83	1.13	0.90	0.89	0.91	0.83

Appendix 4

Table A.4 Values used in the estimation of the rate of genetic change in milkfat UFA concentration on UFA farms from Chapter 5, using four pathways of selection.[1]

Selection path	Population size	Number selected	Percentage selected	Selection intensity	Accuracy of selection [2]	Generation interval
Cow to cow	17,150	16,293	0.95	0.10	0.39	4.8
Cow to bull	1,544	57	0.04	2.19	0.39	3.5
Bull to cow	13	2	0.15	1.59	0.86	6.5
Bull to bull	13	2	0.15	1.59	0.68	6.0
				Total :	3.63	20.8

Rate of genetic gain [3] : 0.05 g UFA /100 g milkfat

Change in milkfat UFA concentration [4] :

Year 0. 35.15 g / 100 g milkfat (+16.7%)

Year 10. 35.68 g / 100 g milkfat (+18.5%)

Year 20. 36.22 g / 100 g milkfat (+20.2%)

[1] Assumptions (Dooley et al., 2006): 9% of cows were suitable for selection as bull dams, 2 bulls were used to breed cows (2 years in the bull team, 16,000 semen doses/year, 1.5 services/ conception). Number of bulls for progeny test (/year) = 13,

[2] Number of lactation records per cow = 1, repetability (t) = 0.75, number of bull daughters for progeny test = 75, heritability of milkfat UFA concentration = 0.15.

[3] Genetic standard deviation for milkfat UFA concentration = 0.31 (estimated from data in Chapter 4 and Chapter 5, considering the effect of segregation on the genetic variance of milkfat UFA concentration in cows of UFA farms).

[4] Percentage difference in milkfat UFA concentration with respect to the milkfat UFA concentration of average farms (30.12 g / 100 g milkfat).

Appendix 5

Table A.5 Approximate characteristics of a farm in which the use of a ruminally protected oilseed supplement (OILSEED$_{RP}$ farm) increased the yields of milk and milksolids. [1]

Trait	Average farms (50 farms)		OILSEED$_{RP}$ farm	
Stocking rate (Cows/ha) [2]	2.71		2.57	
Per cow (per year)				
Milk yield (Litres)	4,348^{a}	(4,246 - 4,459)	4,743	
Milkfat yield (kg)	187^{a}	(182 - 192)	212	
Protein yield (kg)	156^{a}	(152 - 160)	166	
Milksolids yield (kg)	343^{a}	(335 - 352)	378	
Milkfat %	4.30^{a}	(4.24 - 4.36)	4.48	
Protein %	3.59^{a}	(3.56 - 3.62)	3.50	
g UFA/100 g of milk fat	30.11^{a}	(29.82 - 30.38)	38.78	
Per hectare (per year)				
Milk yield (Litres)	11,780^{a}	(11,502 - 12,014)	12,190	
Milkfat yield (kg)	506^{a}	(494 - 519)	546	
Protein yield (kg)	422^{a}	(412 - 433)	426	
Milksolids yield (kg)	929^{a}	(908 - 952)	972	
Energy demand (MJ ME, 10^{3})	136.0^{a}	(134.2 - 137.8)	136.1	
Farm income ($)	7,037^{a}	(6,886 - 7,184)	7,239	
Oilseed Supplement price ($/kg DM)			1.0	1.3
Farm expenses ($)	4,662^{a}	(4,618 - 4,708)	4,917	5,150
Operating profit ($)	2,375^{a}	(2,270 - 2,496)	2,054	1,808
Difference in profit ($)			-321	-567

[1] The change (%) in milk yield, milkfat %, protein % and milksolids yield between the OILSEED$_{RP}$ farm and average farms was similar to those between the control group and the ruminally-protected oilseed supplement group in the study by Thomson & MacGibbon (2000): +9.1%, +4.2%, -2.6%, and +10.3%, respectively. Average farms = characteristics of average farms simulated in Chapter 7. Energy demand per cow in the OILSEED$_{RP}$ farm = MJME/cow in average farms + (79 MJ ME/kg milksolids × difference in milksolids yield per cow between the OILSEED$_{RP}$ farm and average farms).

[2] The stocking rate of the OILSEED$_{RP}$ farm was adjusted to match the energy demand per hectare of average farms.

[3] Milk payment system = $4.63/kg milkfat + $10.98/kg protein + -$0.042/L milk.

Appendix 6

Table A.6 Estimation of taxes paid by the sales of butter made in Chapter 6 (Butter scenario) and Chapter 7, under a scenario of taxation for saturated fatty acid content of food products.[1]

	Chapter 6		Chapter 7	
	AVE milk	UFA milk	AVE milk	OILSEED milk
kg butter (millions)	3.59	3.11	3.56	3.47
% fat	84	84	84	84
kg fat	3.01	2.61	2.99	2.91
g UFA/100 g fat	30.12	35.15	30.11	38.78
kg UFA (millions)	0.91	0.92	0.90	1.13
kg SFA (millions)	2.10	1.69	2.09	1.78
Tax (NZ$, millions)	7.4	6.0	7.4	6.3
Difference in tax paid		1.5		1.1

[1] Tax for SFA = €2.15/kg SFA (NZ $3.53/kg SFA). UFA= unsaturated fatty acids, SFA = saturated fatty acids.

Appendix 7

Table A.7 Estimation of the economic benefit of increasing the concentration (g /100 g milkfat) of unsaturated fatty acids (UFA) in milkfat by one unit.

Trait	Per cow	Per hectare (2.71 cows/ha)				
		UFA_$0.00	UFA_$0.10	UFA_$0.14	UFA_$0.47	UFA_$0.51
Physical performance						
Milk yield (Litres)	4,348	11,783				
Milkfat yield (kg)	187	507				
Protein yield (kg)	156	423				
Milkfat %	4.30					
Protein %	3.59					
UFA	30.12	**30.12**	**38.50**	**38.50**	**38.50**	**38.50**
Live weight (kg)	491	1,331				
t DM demand	4.58	12.4				
Financial performance ($)						
Milk income [1]		6,493	7,000	7,203	8,875	9,078
Stock income [2]		505	505	505	505	505
Gross farm income[3]		7,045	7,551	7,754	9,426	9,629
Farm expenses		4,662	4,662	4,662	4,662	4,662
Operating profit		2,383	2,889	3,092	4,764	4,967
UFA economic value						
For 8.38 UFA units[4]		0	507	709	2,382	2,585
For 1 UFA unit		0	60	85	284	308

[1] Milk payment system = ($4.63 × kg milkfat) + ($10.98 × kg protein) + (- $0.042 × L milk) + (UFA premium × UFApp). UFA premium ($/kg milkfat for each 0.1 g UFA/100 g milkfat above 37.50 g/100 g milkfat) = 0 (UFA_$0.00), $0.10 (UFA_$0.10), $0.14 (UFA_$0.14), $0.47 (UFA_$0.47), and $0.51 (UFA_$0.51). UFApp = g UFA/100g milkfat – 37.5.

2 Stock income = 0.49 × kg LW × $2.1/kg

3 Includes $46 related to other dairy income

4 Values corresponded to extra income associated with 8.38 units of UFA (38.50 g UFA/100 g milkfat - 30.12 g UFA/100 g milkfat). This estimation was necessary because it was considered that UFA premiums ($/kg milkfat) were given for each 0.1 g UFA/100 g milkfat above 37.50 g/100 g milkfat.

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