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Supply curves for yields of dairy products from first-lactation Holstein Friesian, Jersey and Holstein Friesian-Jersey crossbred cows accounting for seasonality of milk composition and production.

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Abstract

The economic efficiency of a milk-processing system is influenced by seasonality of the milk supply, and changes to milk composition, influences the product potential of that milk. Lactation curves for milk yield and composition for seasonal calving first-lactation Holstein Friesian (F), Jersey (J) and Holstein Friesian-Jersey crossbred (FxJ) cows were used as inputs in a deterministic simulation model to produce seasonal curves for daily yields of dairy products. The dairy products were whole milk powder, skim milk powder, cheese, or butter. Dairy product potential was estimated for each animal from a population of 4333 mixed-breed, first-lactation cows. Lactation lengths differed ($P < 0.0001$), among F, FxJ, and J, which averaged 219, 222 and 221 days respectively. Total-lactation milk yield was different ($P < 0.0001$) among breeds and averaged 3257, 3092 and 2902 litres for F, FxJ and J cows, respectively. Whole-milk powder potential (yield per 1000 L of milk) was greatest at the start of the season and least at the end of the season, whereas cheese-production potential (yield per 1000 L of milk) followed the opposite pattern. Total-lactation whole-milk powder yield was different among breeds ($P < 0.0001$) at 366, 338 and 312 kg of whole-milk powder for F, FxJ and J cows, respectively. Total-lactation cheese yield was also different among breeds ($P < 0.0001$), and was 371, 375 and 361 kg for F, FxJ and J cows, respectively. The supply curves indicate that milk is best processed into whole or skim milk powder during peak season, and cheese and butter at the end of lactation. However, seasonal production of specific products would limit the use of by-product lactose from cheese manufacture in the production of milk powders, and thus negate the efficiency gains from changes to processing priorities.

Keywords: Lactation curves; New Zealand; dairy cattle; dairy products; lactose

Introduction

It is important to know the potential supply of milk over the season (Geary et al. 2012), and the products that can be made most efficiently from this milk at various stages of the season in order to increase the efficiency at which existing infrastructure is utilised for milk processing. The ratio of protein to protein-plus-lactose (P:P+L) can be used as a proxy for a milks suitability for producing whole-milk powder (WMP) (Geary et al. 2010; Sneddon et al. 2014a, b), however, to the authors' knowledge, there have been no studies characterising P:P+L or WMP potential over a lactation. Lactation curves for milk (MY), fat (FY) and protein (PY) yields have previously been published (Mackle et al. 1996; Holmes et al. 2007; Lembeye et al. 2014). However, there is less published information for milk component concentrations such as fat (FP), protein (PP) and lactose (LP) percentages over the lactation. Information is scarcest for lactation curves for LP (Holmes et al. 2007; Nishiura et al. 2015), and there has been no publication of supply curves for WMP, skim-milk powder (SMP), cheese or butter yields or their potentials across the season based on the productivity of New Zealand cows. This study reports 270-day lactation curves for MY, FY, PY, lactose yield (LY), FP, PP, LP, P:P+L, and supply curves for WMP, SMP, cheese and butter yields and WMP, SMP, cheese and butter product potentials from milk records of first-lactation cows grazing in New Zealand.

Materials and methods

A mass-balance milk-processing model developed at Massey University (Garrick & Lopez-Villalobos 2000), which balanced product outputs on available fat, protein and lactose, was used to estimate yields of milk products for individual first-lactation cows on herd-test days using the codex requirements for dairy products (codex standard 207-1999 WHO 2011). Four processing scenarios were investigated; these were 100% of milk produced by the cow processed into; either WMP, SMP, cheese, or butter. The model produced the maximal amount of the desired product with available components at that stage of lactation.

Data and statistical analysis

Herd-test records for milk, fat, protein, lactose and somatic cell count were available from 4333 first-lactation mixed-breed cows in the Livestock Improvement Corporation Sire Proving Scheme from the 2010-11 dairy season (Sneddon et al. 2014a) giving a total of 15,310 individual herd-test days. The data included records from 1073 Holstein Friesian (F), 726 Jersey (J) and 2534 FxJ crossbred first-lactation cows. Milk yield, FY, PY, LY, and potential supply of WMP, SMP, cheese and butter yield over the lactation were calculated from these herd-test records. The lactation curves were obtained for individual animals using a fifth-order Legendre polynomial with ASReml (Gilmour et al. 2009). A fifth-order Legendre polynomial was used as this produced an optimal Akaike information

criterion for all investigated traits. The polynomial included the fixed effects of days in milk (as a polynomial effect of the 5th order), and the random effect of cow by days in milk. Each cow had its individual lactation curve fitted and the area under the curve summed to estimate total lactation yields (to the last day of its lactation). Somatic cell score (SCS) for each herd test was calculated as Log_2 (somatic cell count).

The least square means for total yields of milk and components and dairy products for each breed were obtained from the summed areas under the curve using the GLM procedure in SAS version 9.3 (SAS Institute Inc., Cary, NC, USA, 2012) from a linear model that included the fixed effects of herd-year as a contemporary group, deviation from mean calving date (within-herd) and covariate effects of proportion F, proportion J and FxJ heterosis effect.

Results

The least squares means and standard errors of the mean of the variables for each breed are presented in Table 1. The mean lactation lengths of 219, 220, and 222 for first-

Table 1 Least squares means and standard errors of the mean (SEM) for lactation yields of milk, milk components, dairy products, and product potentials from first-lactation Holstein-Friesian (F), Jersey (J) and crossbred (FxJ) cows in New Zealand dairy herds in the 2010-11 dairy season.

Trait ¹	F		J		FxJ	
	Mean	SEM	Mean	SEM	Mean	SEM
DIM	219 ^b	0.7	220 ^{ab}	0.9	222 ^a	0.4
MY	3257 ^a	19.1	2902 ^c	25.1	3092 ^b	11.0
FY	148 ^c	0.9	152 ^b	1.2	155 ^a	0.5
PY	120 ^a	0.7	114 ^b	0.9	118 ^a	0.4
LY	167 ^a	1.0	150 ^c	1.3	159 ^b	0.6
FP	4.61 ^c	0.0002	5.28 ^a	0.0003	5.03 ^b	0.0001
PP	3.70 ^c	0.0001	3.94 ^a	0.0001	3.84 ^b	0.00005
LP	5.14 ^c	0.00005	5.18 ^a	0.0001	5.16 ^b	0.00003
P:P+L	0.418 ^c	0.0006	0.432 ^a	0.0008	0.427 ^b	0.0003
SCS	5.66	0.04	5.67	0.05	5.71	0.02*
WMP total	366 ^a	2.4	312 ^c	3.2	338 ^b	1.4
SMP total	245 ^a	1.6	208 ^c	2.1	225 ^b	0.9
Cheese total	371 ^a	2.1	361 ^b	2.7	375 ^a	1.2
Butter total	368 ^c	1.4	373 ^b	1.8	378 ^a	0.8
WMP potential kg/1000 L	109 ^a	0.2	104 ^c	0.3	106 ^b	0.1
SMP potential kg/1000 L	73 ^a	0.2	70 ^c	0.2	71 ^b	0.1
Cheese potential kg/1000 L	113 ^c	0.3	124 ^a	0.4	120 ^b	0.2
Butter potential kg/1000 L	54 ^c	0.3	62 ^a	0.3	59 ^b	0.1

¹DIM, days in milk; MY, milk yield; FY, fat yield; PY, protein yield; LY, lactose yield; MSY, milk solids yield (fat plus protein); FP, fat percentage; PP, protein percentage; LP, lactose percentage; P:P + L, protein to protein-plus-lactose ratio; SCS, somatic cell score (Log_2 somatic cell count); WMP, Whole milk powder; SMP, Skim milk powder.

lactation F, J and FxJ cows respectively, were significantly different ($P < 0.001$). Milk and LY were significantly higher from F cows compared with J or FxJ cows, with FxJ greater than J cows. Jersey cows had higher, and F cows lower, fat, protein and lactose percentages and higher protein-to-protein-plus-lactose ratio than FxJ cows. Crossbred cows had the highest and F cows the least FY. Protein yield was similar between F and FxJ and least for J cows.

First-lactation F cows produced the greatest yields of WMP and SMP, and the least butter. Cheese production was similar between F and FxJ cows. Jersey cows produced the least WMP, SMP and cheese yields but were intermediate for butter yield. A similar trend was seen in the product potentials for WMP and SMP, however, J cows had the greatest cheese and butter potentials compared with F and FxJ. No significant differences were found for SCS between the breeds.

The estimated 270-day lactation curves for MY, FY, PY and LY are in Figure 1. First-lactation F and FxJ cows had similar lactation curves for MY and LY. Crossbred cows had the highest peak for FY. The FY lactation curve from FxJ was then higher than that for F or J cows for the entire lactation. At the start of the lactation, J cows had the lowest PY. Lactation curves for PY were similar among all breeds after day 200 of lactation. Overall the Lactation curves for MY and LY were similar, and less variable than curves for FY and PY. Jersey cows had the lowest peak for MY, PY and LY, while FY was similar to F cows. By the end of lactation FY was similar between F and J cows.

Lactation curves for daily percentages of fat, protein, lactose and P:P+L are in Figure 2. Lactose percentage declined over the lactation, after peaking at approximately 50 days, whereas fat and protein percentages and P:P+L increased as lactation progressed. Jersey cows had the highest curve for FP, PP, and P:P+L with F cows least and FxJ intermediate. Jersey and FxJ cows had similar lactation curves for LP and were higher than F cows.

The supply curves for predicted daily yields of WMP, SMP, cheese and butter over the lactation period are in Figure 3. Whole and skim milk powders had a more-pronounced decline in production over the lactation compared with cheese or butter. Holstein-Friesian and FxJ cows had similar peaks and curves for WMP and SMP, while J cows had the lowest curve.

Lactation curves for predicted milk-product potentials (kg of product per 1000 litres of milk) for WMP, SMP, cheese and butter are in Figure 4. WMP and SMP reached peak potential in the first 100 days of lactation then declined over the remainder of the lactation. However, cheese and butter had the lowest product potential up to day 100, after which the potential started to increase.

Discussion

Total yields of milk, fat and protein from first-lactation F and J cows in this study were slightly lower than those for first-lactation cows as reported in the New Zealand dairy industry season 2010-11 (LIC & DairyNZ 2011), although

Figure 1 270-day lactation curves for milk (a), fat (b), protein (c) and lactose (d) yields for first-lactation Holstein-Friesian (F: —), Jersey (J; ···) and FxJ (- - -) crossbred cows in New Zealand dairy herds in the 2010-11 dairy season.

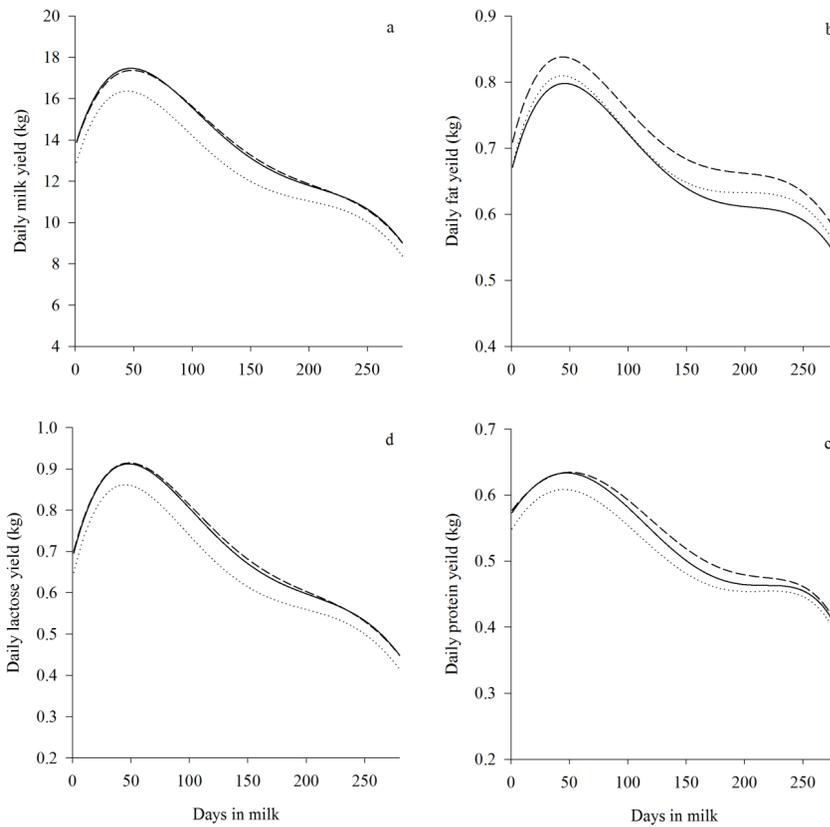
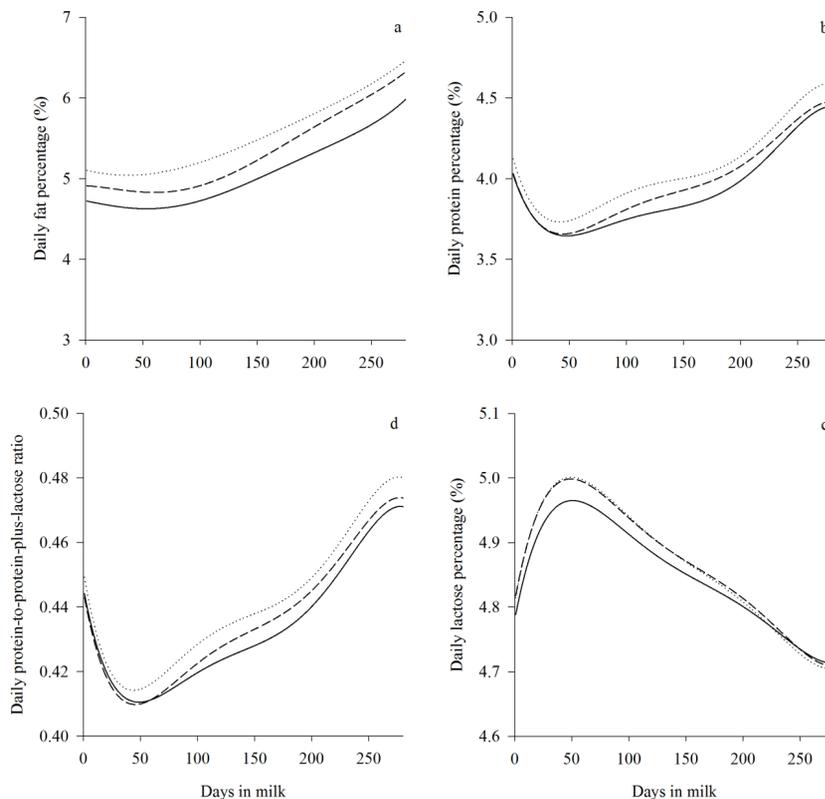


Figure 2 270-day lactation curves for fat (a), protein (b), lactose (c) percentages and protein-to-protein-plus-lactose ratio (d) for first-lactation Holstein-Friesian (F: —), Jersey (J; ···) and FxJ (- - -) crossbred cows in New Zealand dairy herds in the 2010-11 dairy season.



lactation length was similar. Total yields from FxJ cows were similar to those in industry (LIC & DairyNZ 2011). This likely reflects that the FxJ records in the dairy statistics are obtained from progeny-test herds, as are those in this study, while the F and J records include those from the wider industry as well as the progeny-test herds. The F cows had greater MY than J or FxJ cows. While this was not associated with greater FY or PY there was a greater WMP and SMP yield.

The MY lactation curve was similar to that of the national milk supply (DCANZ 2016), indicating the value of modelling industry production to establish efficient milk processing. While this study used first-lactation cows, previous studies have indicated that the shape of the lactation curve is largely unaffected by lactation only the magnitude changes as milk production increases across parity (Horan et al. 2005). Efficiency gains can come through matching peak milk processing capacity to peak milk production (Geary et al. 2012) and reducing excess idle capacity in the factory.

In this study, contrary to current practice of producing WMP and SMP year round (Fonterra 2014), milk was found to provide the highest WMP and SMP potential at the start of the lactation, and declined over the lactation. As the lactation continues the potential yield of cheese and butter per 1000 L of milk also increases, a trend supported by research results of Auldust et al. (1996). However, the increase in SCS over the lactation means this milk becomes less suitable for producing high quality cheese (Auldust et al. 1996). The change in WMP and SMP potential over the lactation appears to be due to declining LP, which is the limiting component in the production of these milk products. The effect of declining LP and increasing PP results in increasing

Figure 3 270-day lactation curves for daily whole milk powder (a), skim milk powder (b), cheese (c) and butter (d) yields for first-lactation Holstein-Friesian (F —), Jersey (J; ···) and FxJ (- - -) crossbred cows in New Zealand dairy herds in the 2010-11 dairy season.

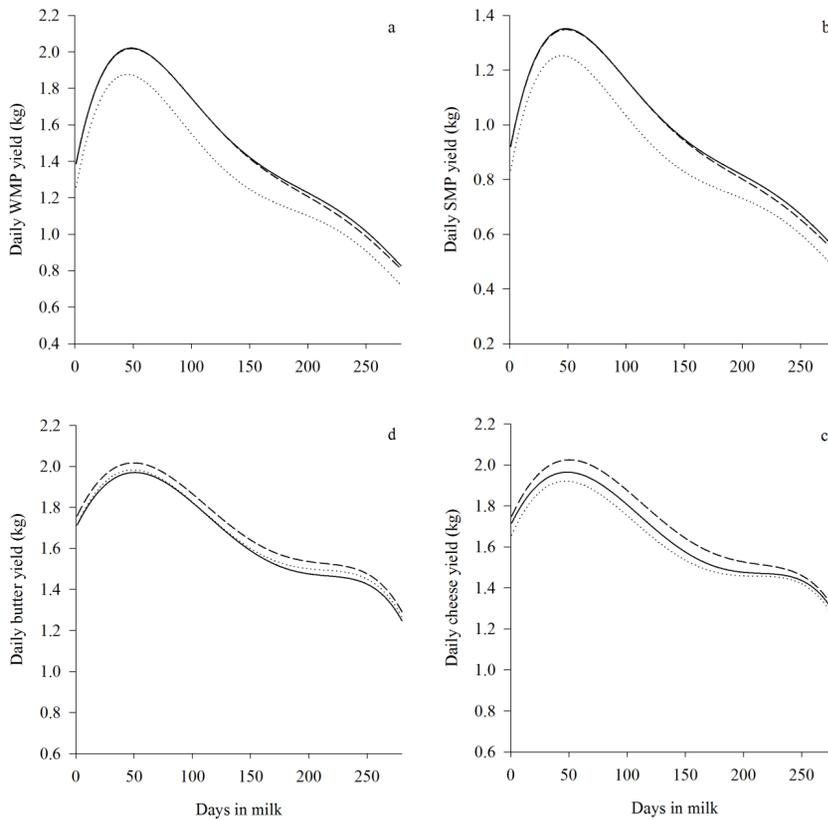
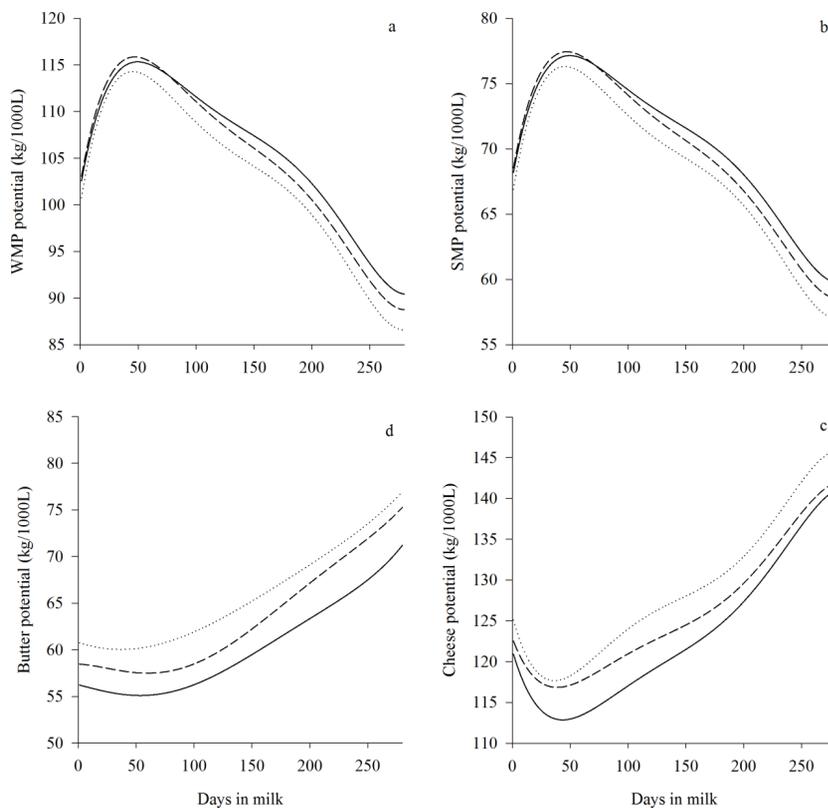


Figure 4 270-day lactation curves for milk product potentials (kg/1000 L) per day of lactation for whole-milk powder (a), skim-milk powder (b), cheese (c) and butter (d) yields for first-lactation Holstein-Friesian (F: —), Jersey (J; ···) and FxJ (- - -) crossbred cows in New Zealand dairy herds in the 2010-11 dairy season.



P:P+L which is associated with reduced suitability of milk to make powders (Geary et al. 2010; Sneddon et al. 2014a, b).

Somatic cell count may have an effect in reducing the LP (Auld et al. 1995; Bleck et al. 2009), however, there was no significant differences between breeds for SCS, and the curve for SCS was flat (unpublished data), while the curves for LP differed between breeds.

Matching milk processing with milk production and quality would require milk processors to build greater capacity for all products than is currently required during peak lactation, as currently milk can be spread over multiple products and factories instead of specialising products to particular stages of the lactation period. Further investigation of the effect of end-of-season-milk characteristics (protein profile and quality) on the yield of milk products is required if cheese was to be produced from end-of-season-milk. Specialisation in processing would also reduce the ability to move surplus milk components e.g. lactose between products to meet limitations in supply of certain components for certain products. For example, movement of lactose as a by-product of cheese into WMP and SMP production where it is in deficit, with excess fat from all products being used to produce butter. Despite potential benefits, specialisation of production on a seasonal basis may reduce the efficiency and profitability of the system as well as the ability of the system to quickly react to pricing signals.

This study indicates the value in modelling milk product yields during the lactation in order to predict required milk-processing capacity. Powder capacity could be built to utilise peak spring production to maximise WMP and SMP production efficiency, whereas cheese and butter

production can be met by building autumn capacity to utilise the higher product potentials at this time.

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