Estimation of crossbreeding effects on yields of dairy products and value of milk processed in different product portfolios

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Abstract

The international market requires milk products to meet specified minimum standards that define acceptable composition. This study used a deterministic simulation model to estimate milk products yields of individual cows for different export markets. Four milk product portfolios were analysed which included 100% of the milk to either whole-milk powder (WMP), skim-milk powder, cheese, or butter. Milk product potential was estimated for 4310 mixed-breed heifers from LIC Sire Proving Scheme herds based on total lactation production. Lactation lengths were 212, 214 and 213 days for Holstein Friesian (HF), Holstein Friesian-Jersey crossbreds (HFxJ), and Jerseys (J) respectively. Milk yields were significantly different between breeds averaging 3121 for HF, 2947 for HFxJ, and 2751 litres for J cows. Holstein Friesians had the lowest fat, protein and lactose concentrations, whereas J had the highest. Holstein Friesian had the greatest yields of WMP per 1000 litres of milk, whereas J had the least. For all scenarios, J milk was most valuable per litre. Crossbred cows provided greater total milk income for all scenarios except 100% butter. Positive heterosis effects were estimated for first-cross HFxJ animals for milk production and product yields. Crossbreeding produces cows with milk better suited to the processing requirements of the New Zealand dairy industry and returning greater value to the New Zealand dairy farmer.

Keywords: lactose; processing model; breed effects; heterosis effects

Introduction

Milk composition is well known to vary among breeds for milk fat and protein content (Cerbulis & Farrell 1975; Aikman et al. 2008; Bleck et al. 2009; Prendiville et al. 2010; Sneddon et al. 2014a), and lactose has also been found to vary among breeds (Cerbulis & Farrell 1975; Prendiville et al. 2010; Sneddon et al. 2014a). These breed differences in milk composition lead to differences in the simulated yields of products, for example, studies have shown that Jerseys can produce more cheese per 1000 litres of milk than Holstein Friesians (Auldist et al. 2004). However, breed effects on yields of whole-milk powder (WMP), skim-milk powder (SMP), and butter have not been reported. Only simulation studies (Garrick & Lopez-Villalobos 2000; Geary et al. 2010) have reported breed differences for yields of dairy products and value of milk using representative milk yields for each of the breeds. This study aimed to use records of individual cows to estimate breed and heterosis effects on yields of dairy products.

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 cows using the codex requirements for dairy products (codex standard 207-1999 WHO 2011). Four 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. With excess protein or fat being used for the production of "by-products" which, dependent on scenario were SMP, butter, butter-milk powder (BMP), casein, and whey powder (WP) determined by milk component availability and product value. Depending on the scenario, this could result in butter production in SMP and cheese scenarios, and SMP production in the cheese scenario, for example. Using the values of the products produced, the model calculated the value of milk per litre from each animal which was used to calculate milk value per lactation by multiplying value per litre by total milk yield for each animal.

Data

Herd-test records for milk, fat, protein and lactose (anhydrate) were available from 4310 mixed-breed Livestock Improvement Corporation Sire Proving Scheme heifers from the 2010-11 dairy season (Sneddon et al. 2014a). The data included records from 1067 Holstein Friesian (HF), 717 Jersey (J) and 2526 HFxJ crossbred cows. Lactation yields of milk (MY), fat (FY), protein (PY) and lactose (LY) were calculated from herd-test records. These estimates were obtained using a fifth-order Legendre polynomial with ASReml (Gilmour et al. 2009), fifth-order legendre polynomial was used as this produced an optimal Akaike information criterion for all investigated traits.

Milk product values ($US/Tonne) were averaged for the 2013-14 dairy season (4th June 2013 – 20th May 2014) (Global Dairy Trade 2014). The values were WMP $4,762, SMP $4,449, cheese $4,517, butter $3,972, BMP $4,630, casein $10,698 and WP $8,235.

Least squares means for breed average estimates were obtained using a mixed-model in SAS version 9.3 (SAS Institute Inc., Cary NC, USA) with fixed effects of breed, month of calving and herd. Heterosis effects were estimated using a mixed model with the fixed effects of month of calving and herd. Proportion of J, proportion of other breed (grouped as other, including Ayrshire, Shorthorn, Brown Swiss) and heterosis between HF and J were fitted as covariables, allowing estimation of breed and heterosis effects.

Results

Lactation yields of milk components are in Table 1. Lactation length was similar for the three breed groups. Holstein-Friesian cows had the greatest (P<0.05) MY and LY, whereas for PY and FY there was no difference (P>0.05) between HF and HFxJ. Jersey cows had the greatest fat, protein and lactose percentages. Holstein-Friesian cows had the lowest protein to protein-plus-lactose ratio, whilst J had the greatest (P<0.05). Somatic cell score (somatic cell count to the log base 2) was not different (P>0.05) among the breeds.

Table 1 Least square mean lactation yields of milk from Holstein-Friesian (HF), Jersey (J) and crossbred (HFxJ) first lactation heifers and standard errors of the mean.

	HF		HFxJ		J	
	Mean	SEM	Mean	SEM	Mean	SEM
Days in milk	212[b]	1.81	214[a]	1.71	213[ab]	1.94
Milk yield (kg)	3122[a]	48.3	2947[b]	45.7	2752[c]	51.7
Fat yield (kg)	143[c]	2.25	150[a]	2.13	147[b]	2.41
Protein yield (kg)	114[a]	1.69	112[a]	1.59	108[b]	1.80
Lactose yield (kg)	160[a]	2.47	152[b]	2.34	142[c]	2.64
Fat percentage	4.63[c]	0.05	5.11[b]	0.05	5.38[a]	0.06
Protein percentage	3.70[c]	0.02	3.86[b]	0.02	3.97[a]	0.02
Lactose percentage	4.86[c]	0.01	4.88[b]	0.01	4.89[a]	0.01
Protein to protein plus lactose	0.42[a]	0.002	0.43[b]	0.002	0.44[c]	0.002
Somatic cell score	5.89	0.09	5.92	0.09	5.87	0.11

[a,b,c] Means with different letters denote significant differences (P<0.05).

Product yields per 1000 litres of milk and per lactation are in Table 2. Under the WMP scenario HF cows produced the greatest yield of WMP both per 1000 litres milk and lactation with the least (P<0.05) by-products. This could be linked to the lower P:P+L of the HF cows. Jersey cows had the greatest (P<0.05) production of by-products, with the exception of WP per lactation which was similar to HFxJ animals. Jersey cows had the most valuable milk per litre (P<0.05), but milk value per lactation was not different to HF (P>0.05). Crossbred cows had the second most valuable milk per litre but the greatest milk value per lactation (P<0.05), due to the higher milk yield compared to J cows.

Under the SMP scenario, HF cows had the greatest yields of SMP both per 1000 litres of milk and per lactation (P<0.05). Jersey cows had the greatest yield of by-products per 1000 litres and the greatest milk value per litre of milk (P<0.05). Milk value from HFxJ cows was \$41-\$57 greater (P<0.05) than the milk value from HF or J respectively, which were similar to each other (P>0.05).

Under the cheese scenario, J cows had the greatest cheese yield per 1000 litres milk (127.8 kg) as well as the greatest yield of by-products (P<0.05), with the exception of SMP which was greater from HF and HFxJ cows. Per lactation HFxJ cows had the greatest yield of cheese (P<0.05), and J cows had the greatest yield of by-products (P<0.05). Jerseys had the most valuable milk per litre of milk but the lowest milk value per lactation (P<0.05); HF had the least valuable milk per litre (P<0.05) and no difference was found in the milk value per lactation between HF and HFxJ (P>0.05), which was \$136 more valuable than J milk per lactation.

Under the butter scenario, J cows had the greatest yields of butter and by-products per 1000 litres of milk, with the exception of WP which was not different (P>0.05) among breeds. Jersey cows also had the most valuable milk per litre of milk, but the lowest milk value per lactation (P<0.05). Crossbred and J cows had the greatest yield of butter and BMP per lactation (P<0.05). Holstein-Friesian cows had the greatest yields of casein and WP per lactation, as well as the greatest milk value (P<0.05) being \$58 and \$206 greater than HFxJ and J respectively.

Estimates of breed and heterosis effects are in Table 3. Breed differences between HF and J cows were estimated to be greatest for MY and LY (P<0.05), with no difference in FY. Jersey cows had lower MY, PY, LY but higher fat, protein, lactose percentages and P:P+L than the HF cows (P<0.05). Estimates of heterosis were positive for all traits except for days in milk, LP and SCS which were zero (P>0.05). Heterosis effects (as a proportion of parent average) were greatest for FY (8.26%) followed by PY (5.30%). Heterosis effects for MY and LY were similar when compared as a percentage of parent average.

Estimates of breed and heterosis effects for yields of dairy products are in Table 4. There was a small positive heterosis for butter and cheese yields per 1000 litres of milk (3.03 kg and 1.86 kg respectively) (P<0.05). There was a small positive heterosis value for milk value per litre under all scenarios (P<0.05) (\$0.014, \$0.014, \$0.017 and \$0.011 for WMP, SMP, cheese and butter scenarios respectively). Heterosis for product yield per lactation was significant only for cheese and butter production scenarios (P<0.05) (25.4 kg and 15.3 kg respectively). The heterosis for milk value per lactation was significantly different to zero (P>0.05), with the greatest heterosis effect found in the cheese scenario and the smallest in WMP and SMP.

Table 2 Least squares mean yields of dairy products per 1000 litres milk and per lactation of Holstein-Friesian (HF), Jersey (J) and crossbred (HFxJ) first-lactation heifers, and standard errors of the mean under four different milk processing scenarios, 100% whole milk powder, 100% skim milk powder, 100% cheese, 100% butter.

Scenario	Breed					
Products[1]	Yield per 1000 litres			Yield per lactation		
100% WMP	HF	HFxJ	J	HF	HFxJ	J
WMP	110.8^{a} ± 0.63	107.5^{b} ± 0.59	105.6^{c} ± 0.67	347.6^{x} ± 6.08	316.6^{y} ± 5.75	290.2^{z} ±6.51
SMP	-	-	-	-	-	-
Cheese	-	-	-	-	-	-
Butter	20.1^{c} ± 0.78	26.8^{b} ± 0.74	30.6^{a} ± 0.84	58.9^{z} ± 2.47	78.9^{y} ± 2.33	84.5^{x} ± 2.64
BMP	2.3^{c} ± 0.10	3.2^{b} ± 0.09	3.6^{a} ± 0.10	6.7^{z} ± 0.30	9.2^{y} ± 0.29	10.0^{x} ± 0.32
Casein	7.4^{c} ± 0.29	9.3^{b} ± 0.28	10.4^{a} ± 0.32	22.2^{z} ± 0.96	27.2^{y} ± 0.91	28.8^{x} ± 1.03
WP	5.0^{c} ± 0.20	6.3^{b} ± 0.19	7.1^{a} ± 0.22	14.9^{y} ±0.65	18.5^{x} ± 0.62	19.7^{x} ± 0.70
Milk value, $/L	0.67^{c} ± 0.01	0.72^{b} ± 0.01	0.75^{a} ± 0.01	-	-	-
Milk value, $/Lact	-	-	-	2075.5^{y} ± 31.7	2113.6^{x} ± 30.1	2053.2^{y} ± 34.0
100% SMP	HF	HFxJ	J	HF	HFxJ	J
WMP	-	-	-	-	-	-
SMP	73.9^{a} ± 0.44	71.6^{b} ± 0.41	70.3^{c} ± 0.47	232.0^{x} ± 4.09	210.9^{y} ± 3.87	193.1^{z} ± 4.38
Cheese	-	-	-	-	-	-
Butter	54.3^{c} ± 0.64	60.0^{b} ± 0.61	63.2^{a} ± 0.69	166.0^{y} ± 2.81	176.5^{x} ± 2.66	174.0^{x} ± 3.01
BMP	6.1^{c} ± 0.09	6.9^{b} ± 0.09	7.4^{a} ± 0.10	18.6^{y} ± 0.34	20.4^{x} ± 0.32	20.4^{x} ± 0.37
Casein	8.9^{c} ± 0.28	10.7^{b} ± 0.27	11.8^{a} ± 0.30	26.9^{z} ± 0.94	31.5^{y} ± 0.89	32.6^{x} ± 1.00
WP	6.0^{c} ± 0.19	7.3^{b} ± 0.18	8.1^{a} ± 0.21	18.1^{z} ± 0.63	21.4^{y} ± 0.60	22.3^{x} ± 0.68
Milk value, $/L	0.65^{c} ± 0.01	0.69^{b} ± 0.01	0.73^{a} ± 0.01	-	-	-
Milk value, $/Lact	-	-	-	2016.9^{y} ±31.0	2058.0^{x} ± 29.3	2001.1^{y} ± 33.2
100% cheese	HF	HFxJ	J	HF	HFxJ	J
WMP	-	-	-	-	-	-
SMP	3.4^{a} ± 0.35	1.3^{b} ± 0.34	0.8^{c} ± 0.38	12.3^{x} ± 1.37	3.8^{y} ± 1.29	2.3^{y} ± 1.46
Cheese	116.4^{c} ± 0.88	124.0^{b} ± 0.84	127.8^{a} ± 0.95	358.9^{y} ± 5.60	364.9^{x} ± 5.30	351.6^{y} ± 5.99
Butter	3.0^{c} ± 0.42	5.3^{b} ± 0.40	6.9^{a} ± 0.45	8.0^{z} ± 1.33	15.6^{y} ± 1.25	18.8^{x} ± 1.42
BMP	0.3^{c} ± 0.05	0.6^{b} ± 0.05	0.8^{a} ± 0.05	0.9^{z} ± 0.16	1.8^{y} ± 0.15	2.2^{x} ± 0.17
Casein	-	-	-	-	-	-
WP	62.9^{c} ± 0.26	64.6^{b} ± 0.25	65.2^{a} ± 0.28	195.1^{x} ± 3.03	190.2^{y} ± 2.87	179.1^{z} ± 3.25
Milk value, $/L	0.99^{c} ± 0.01	1.04^{b} ± 0.01	1.07^{a} ± 0.01	-	-	-
Milk value, $/Lact	-	-	-	3082.6^{x} ± 45.8	3075.7^{x} ± 43.3	2945.3^{y} ± 49.0
100% butter	HF	HFxJ	J	HF	HFxJ	J
WMP	-	-	-	-	-	-
SMP	-	-	-	-	-	-
Cheese	-	-	-	-	-	-
Butter	55.1^{c} ± 0.64	60.8^{b} ± 0.61	64.1^{a} ± 0.69	168.8^{y} ± 2.84	179.1^{x} ± 2.68	176.3^{x} ± 3.04
BMP	6.2^{c} ± 0.09	7.0^{b} ± 0.09	7.5^{a} ± 0.10	19.0^{y} ± 0.35	20.7^{x} ± 0.33	20.7^{x} ± 0.37
Casein	31.4^{c} ± 0.18	32.5^{b} ± 0.17	33.3^{a} ± 0.19	97.6^{x} ± 1.49	95.8^{y} ± 1.41	91.6^{z} ± 1.59
WP	61.4 ± 0.12	61.3 ± 0.11	61.4 ± 0.13	191.8^{x} ± 2.99	180.7^{y} ± 2.83	168.8^{z} ± 3.20
Milk value, $/L	1.06^{c} ± 0.01	1.10^{b} ± 0.01	1.12^{a} ± 0.01	-	-	-
Milk value, $/Lact	-	-	-	3294.1^{x} ± 48.6	3236.0^{y} ± 45.9	3088.1^{z} ± 52.0

[1]WMP = Whole milk powder, SMP = Skim milk Powder, WPC = Whey protein concentrate, BMP = Butter milk powder, HF = Holstein-Friesian, JE = Jersey, HFXJ = Crossbred. $/lact = value per lactation.

^{a,b,c,x,y,z} Means with different letters denote significant differences between breed groups ($P<0.05$).

Table 3 Estimated breed and heterosis effects for total lactation yields of milk, milk components, ratio of protein to protein-plus-lactose and somatic cell count from first-lactation dairy heifers.

	Breed effect			Heterosis		
Trait	HF-J	SEM	P	HFxJ	SEM	P
Days in milk	-1.78	1.58	0.264	1.97	1.30	0.130
Milk yield (kg)	633.3	41.46	<.001	93.6	34.19	0.006
Fat yield (kg)	-1.00	1.96	0.610	11.8	1.62	<.001
Protein yield (kg)	12.45	1.46	<.001	5.86	1.20	<.001
Lactose yield (kg)	30.86	2.12	<.001	5.06	1.75	0.004
Fat percentage	-1.09	0.04	<.001	0.16	0.04	<.001
Protein percentage	-0.39	0.02	<.001	0.05	0.02	0.002
Lactose percentage	-0.05	0.01	<.001	0.01	0.01	0.942
Protein to protein plus lactose	-0.02	0.001	<.001	0.003	0.001	0.002
Somatic cell score	-0.006	0.08	0.937	0.07	0.07	0.325

[1]WMP = Whole milk powder, SMP = Skim milk powder.
HF-J = Holstein-Friesian Jersey breed difference, Het HFxJ = heterosis effect for first-cross Holstein-Friesian x Jersey cows, SEM = standard error of the mean, P = P Value.

Table 4 Estimated breed and heterosis effects for yields of milk products per 1000 litres of milk and per lactation including milk value and lactation milk value from first-lactation dairy heifers.

		Yield per 1000 litres					
Scenario	Product[1]	HF-J	SEM	P	Het HFxJ	SEM	P
100% WMP	WMP (kg)	7.17	0.54	<.0001	-1.23	0.45	0.006
	Milk value ($/L)	-0.105	0.004	<.0001	0.014	0.003	0.0001
100%SMP	SMP (kg)	5.07	0.37	<.0001	-0.869	0.31	0.005
	Milk value ($/L)	-0.105	0.004	<.0001	0.014	0.003	0.0001
100% Cheese	Cheese (kg)	-15.6	0.75	<.0001	3.03	0.62	<.0001
	Milk value ($/L)	-0.105	0.004	<.0001	0.017	0.003	<.0001
100% Butter	Butter (kg)	-13.1	0.54	<.0001	1.86	0.45	<.0001
	Milk value ($/L)	-0.09	0.003	<.0001	0.01	0.002	0.0001
		Yield per lactation					
Scenario	Product[1]	HF-J	SEM	P	Het HFxJ	SEM	P
100% WMP	WMP (kg)	92.6	5.20	<.0001	4.74	4.29	0.26
	Milk value ($/Lact)	106.03	27.6	0.0001	139.54	22.8	<.0001
100%SMP	SMP (kg)	62.7	3.49	<.0001	2.94	2.88	0.308
	Milk value ($/Lact)	94.85	26.9	0.0004	137.67	22.2	<.0001
100% Cheese	Cheese (kg)	26.08	4.86	<.0001	25.4	4.01	<.0001
	Milk value ($/Lact)	311.7	39.7	<.0001	182.9	32.7	<.0001
100% Butter	Butter (kg)	-4.86	2.47	0.049	15.3	2.04	<.0001
	Milk value ($/Lact)	407.3	42.1	<.0001	162.6	34.7	<.0001

[1]WMP = Whole milk powder, SMP = Skim milk powder, ($/Lact) milk value per lactation.
HF-J = Holstein-Friesian Jersey breed difference, Het HFxJ = heterosis effect for first-cross Holstein-Friesian x Jersey cows.

Discussion

Whole milk powder is currently the largest export of the New Zealand dairy industry (Fonterra 2014) and made up nearly 70% of dairy exports in the 2013/2014 dairy season. This signifies a large change in the product portfolio of the industry over the past 11 years (Fonterra 2003; Fonterra 2014). As a consequence, changes in sale value or processing cost of WMP impact the dairy industry quickly, as occurred between 2013/2014 and 2014/2015 dairy seasons, when there was a 50% reduction in WMP prices in eight months, reducing payouts received by farmers from \$8.40 in 2013/2014 to a forecast \$4.50 for 2014/15 (Global Dairy Trade 2014; Fonterra 2015). One of the factors affecting the value of milk supplied by the farmer is the composition of that milk, and the composition is affected by the dairy breed used by the farmer (Lopez-Villalobos et al. 2000; Geary et al. 2010). In a previous study it was found that HFxJ cows could be the most profitable animals for the New Zealand dairy industry (Lopez-Villalobos et al. 2000). The present study only looked at milk value per lactation and not profit, however, milk value per lactation results indicate that similar levels could be achieved for all breeds under current processing systems. The milk values reported in this study are approximately three times greater than those reported by Lopez-Villalobos et al. (2000), which were \$NZ0.29/L, \$NZ0.36/L and \$NZ0.31/L for HF, J and HFxJ in the 1996/1997 dairy season. An analysis of costs associated with the production has not been undertaken in the present study to compare profitability.

The ratio of protein to protein-plus-lactose (P:P+L) can be used as a proxy predictor of a milk's suitability to produce WMP (Sneddon et al. 2014b). The ideal P:P+L for WMP is around 0.38 (Geary et al. 2010). As HF cows have P:P+L closer to ideal than J cows, more WMP can be made per 1000 litres of milk with fewer by-products (without addition of external milk components), whereas J cows with high P:P+L produce less WMP per 1000 litres of milk but more by-products. The same effects can be seen in the production SMP, with HF cows yielding more per 1000 litres, with less butter produced as a by-product. Crossbred animals allow for increased yields of products relative to J, while providing greater milk values than HF, due to the value of the by-products produced from milk components in excess of requirements for WMP production.

While none of these scenarios show a current industry snapshot, they indicate differences between the historic dairy industry and potential future markets if current trends in product portfolios are followed (Fonterra 2003, Fonterra 2014). When J cows were the dominant breed of the national herd (prior to the 1970s) the primary exports of the dairy industry were butter with a small amount of cheese. Under a primarily cheese or butter scenario, J cows will yield more product per 1000 litres of milk than HF or HFxJ cows.

Systematic crossbreeding could create New Zealand cows which can produce milk more suited to the dairy product portfolio along with beneficial heterosis for production, fertility and survivability that provides an overall benefit to the New Zealand dairy industry. It could be argued that systematic crossbreeding is already occurring, with HFxJ cows increasing from 19% of the national herd in 1998/1999 to just under 43% in the 2013/2014 dairy season (LIC 1999; LIC 2014). The differences between breeds in milk value per lactation may not be large enough to sway farmer opinion, however over time these differences may compound to give greater returns.

It should be considered that there are further options available such as incorporation of imported lactose, which allows for an artificial lowering of the P:P+L. This is the current strategy adopted by the New Zealand dairy industry. All scenarios used the same product values, however, it is possible that in situations where some products (such as casein) are supplied in great quantities their values would decrease.

Under WMP- or SMP-dominated portfolios the milk value per lactation was maximised using HFxJ cows. In a butter-dominated scenario, HF cows can provide the greatest returns, but there is no advantage to either breed under a cheese-production scenario for lactation milk value. Breed choice for greatest return is, therefore, dependent on product portfolio and the market for those products. Currently the New Zealand dairy industry can benefit from using HFxJ cows with current production dominated by both WMP and SMP. The development of lactation heterosis values for milk value could benefit the selection of crossbred sires for use in the industry, however, these values would represent the change in milk income not farm profit.

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