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EFFECTS OF SELECTION FOR FERTILITY ON MILK PRODUCTION TRAITS

E.M. Strucken[1], G.A. Brockmann[2] and Y.C.S.M. Laurenson[1]

[1]School of Environmental and Rural Science, University of New England, Armidale, NSW, Australia
[2]Breeding Biology and Molecular Genetics, Humboldt-Universität zu Berlin, Berlin, Germany

SUMMARY

A previous study investigated the impact of selection for fertility upon milk yield in the first lactation. The current study extends this analysis to include the yield and content of fat and protein. Daughter test-day records were used to estimate Wilmink curve parameters of each trait for 2,405 sires. The sires also had breeding values for the production traits and their fertility index. Correlations and linear regression between curve parameters and breeding values were carried out with and without correction for environmental effects. Selection for fertility was found to negatively affect milk, fat and protein yield. Improved fertility was found to result in an increased initial fat and protein content, but also increased the rate of decline during early lactation causing a reduced nadir. The persistency of protein content reduced with increased fertility; whilst, fat content rebounded to a greater extent in fertile cows than those with lower fertility. Fat-to-protein ratio reached its maximum about 5 weeks before peak milk production and was higher for less fertile cows, coinciding with time of strongest energy imbalance. Correction for environmental effects resulted in overall lower production curves for yield traits and fat content, but higher protein content. After correction, cows with higher fertility produced more milk compared to lower fertile cows purely on their genetic merit. Similar patterns were found for fat and protein yield. Fat-to-protein ratio was lower for higher fertile cows throughout the entire lactation.

INTRODUCTION

With the advent of modern cattle breeding in the mid to late 20th century, milk production has seen a dramatic increase (Brotherstone and Goddard 2005). With modern breeding, a whole array of factors such as nutrition, health and fertility came into focus, and it was observed that fertility declined with increasing milk production (De Kruif and Mijten 1992; Crowe *et al.* 2018). Consequently, such factors have been included in breeding schemes which have incorporated weighted indices with health and fertility traits (Osteras *et al*. 2007, Boichard and Brochard 2012).

Strucken *et al.* (2015) concluded that the observed impact of milk production on fertility had both a functional (to provide optimal birth spacing) and causal (energy deficit) explanation. Other studies have shown the impact of milk fat and protein on fertility traits, with the fat-to-protein ratio being an accepted measure for energy balance. The fat-to-protein ratio was shown to affect days-open (Buckley *et al*. 2003, Puangdee *et al.* 2017); higher fat and protein yields were genetically correlated with longer calving intervals (Albarran-Portillo and Pollott 2013), and lower protein content was associated with an increased risk of delayed ovulation (Opsomer *et al.* 2000).

This study follows on from Strucken *et al.* (2015) and investigates whether selection for fertility has resulted in observable effects on the lactation curves for milk, fat and protein yield, and fat and protein content; or whether the application of indices allowed breeders to break the genetic link between milk production and fertility.

MATERIALS AND METHODS

Data. Estimated breeding values (EBVs) and the fertility index (RZR) were available for 2,405

Holstein Friesian sires as provided by VIT, Verden (Germany). EBVs for five milk production traits represented actual deviations from the population mean at 305 days in milk (DIM). The RZR summarizes pre-corrected breeding values for six fertility traits and is standardized to a mean of 100 with a standard deviation of 12. Additionally, test-day records of five milk production traits were available for 1,797,852 daughters (Table 1). Each sire had an average of 747 daughters (min=50, max=84.387), with a minimum of 386 and a maximum of 731,431 test-day records per sire.

Table 1. Test-day records of 1.8m cows in the first lactation for five milk production traits and the fertility index (RZR) for 2405 sires

	Milk yield (kg)	Fat yield (kg)	Protein yield (kg)	Fat content (%)	Protein content (%)	RZR
mean	25.57	1.04	0.87	4.14	3.42	101
min	2.00	0.04	0.05	1.60	2.00	62
max	98.80	5.48	3.84	10.50	7.97	136
SD	6.54	0.25	0.20	0.74	0.35	9.9
# test-days	14,862,232					

Analyses. Test-day records for each trait were used to fit 38 lactation curve models with a mechanistic or biological interpretation of curve parameters, and goodness of fit was assessed using 7 criteria. All selection criteria provided the same ranking of models except the Durbin-Watson coefficient. The Wilmink curve (Wilmink 1987) was among the top 10 models for all traits and was selected to allow for comparison of selection effects between traits.

The Wilmink curve was adjusted to allow for better interpretation of parameters, such that:

$$y = a + (b-a) * (1-exp^{-k*DIM}) - c * DIM$$

where y is the test-day record of yield (kg); a is the y-intercept (kg), i.e. starting yield; b is the potential maximum daily yield (kg); c is the gradient of the linear decay in yield (kg d^{-1}); k is the increase in yield prior to peak production; and *DIM* are the days in milk.

Pearson's correlation coefficients between production EBVs and the RZR, and between the curve parameters and the EBVs and RZR were calculated. A linear regression of EBVs and RZR on the curve parameters was used to further assess the impact of selection on the shape of the curve. To separate environmental from genetic effects, we estimated curve parameters per sire within a linear mixed model which required the fixation of parameter k based on estimates retrieved from the non-linear curve previously used. Fixed effects included *age at calving*, *year season*, and *milk recording system* nested within *farm*. These calculations were carried out across the top and bottom 9% of sires (216 sires) for the fertility index which showed significant differences based on an unpaired two-sided t-test assuming unequal variances.

RESULTS

The pseudo-genetic correlations between yield EBVs and RZR were significantly negative (milk yield = -0.282, fat yield = -0.231, protein yield = -0.305), whilst the content EBVs were significantly positively correlated with RZR (fat content = 0.077, protein content = 0.049), confirming previous reports (Oltenacu & Broom 2010).

Correlations between uncorrected curve parameters and RZR described a similar relationship as the linear regression of RZR on curve parameters (Table 2). Parameter a, determining the y-intercept, was not significantly affected by fertility for any of the analysed traits. Parameter b, describing the potential maximum, was strongly influenced by the level of RZR showing that a better fertility resulted in lower production for the yield traits (except fat yield), and an increase for the content traits (Table 2). Associations of fertility with parameters *k*, describing the production slope before the nadir, showed that better fertility resulted in a stronger increase and earlier peak for milk yield, and a lesser decrease in early lactation for fat and protein content. Parameter *c*, describing the slope after the nadir, showed that better fertility resulted in a stronger decrease in fat yield, stronger increase in fat content and a lesser increase in protein content (Table 2). Fat-to-protein ratio spiked at lactation day 12, after which it dropped and almost stabilized around lactation day 65. Cows with better fertility showed a lower fat-to-protein ratio at peak, and higher and slightly increasing ratio after lactation day 65 (Figure 1).

Table 2. Correlation/Regression coefficient for RZR on uncorrected lactation curve parameters in the first lactation

	Milk yield	Fat yield	Protein yield	Fat content	Protein content
a	-0.031/ -0.01	0.002/ 0.017	0.017/ 0.029	-0.017/ -0.023	-0.008/ -0.002
b	**-0.181***/** **-0.04*****	-0.048/ -0.0009	**-0.052†/** **-0.002***	**0.077**/** **0.002*****	**0.167***/** **0.001*****
c	-0.11/ -0.000006	**0.068†/** **0.000002***	0.012/ 0.0000006	**-0.054*/** **-0.000004****	**0.12***/** **0.000004*****
k	**0.064*/** **0.00017****	0.032/ 0.0008	-0.018/ -0.00006	0.036/ **0.0001†**	**0.05†/** **0.0003***

***P>0.0001, **P>0.001, *P>0.01, †P>0.05

Estimating curve parameters under the consideration of environmental effects showed that cows with a higher fertility also produced more milk (Figure 1), fat and protein yield, less fat content, and almost no difference for protein content. This being the inverse of the observed negative correlations between yield and fertility traits for uncorrected parameters. Correction for environmental effects showed that higher fertile cows have a strongly decreased peak and lower ratio throughout the entire lactation (Figure 1).

DISCUSSION

Reductions in fertility have been largely attributed to an increase in milk production and inadequate nutrition, which (especially at the beginning of the lactation) causes an energy deficit for the cow. This energy deficit forces the metabolism of the cow to shift energy partitioning in favour of milk production and results in the observed negative correlation with fertility traits. (Strucken *et al.* 2015). As such, it may be expected that breeding for better fertility slows milk production in early and peak lactation, unless the genetic link between these traits has been broken. We found that better fertility decreased milk production (especially around its peak), as seen by the significant effects on parameter *b* (parameter *a* in Strucken *et al.* (2015)); and moreover, similar effects were observed for fat and protein yield. Fat and protein content increased in early lactation with a better fertility, however, fat-to-protein ratio was lower for more fertile cows, all confirming the hypothesis of an energy deficit causing the negative trait correlation.

Correction for environmental effects revealed that highly fertile cows produced more milk, fat, and protein yield than less fertile cows, however, both high and low fertility cows profited from the environment. After correction for environmental effects, cows with a low fertility had a higher fat content, whilst protein content remained nearly unchanged. The fat-to-protein ratio strongly increased in early lactation around the time when the energy deficit can be expected to be most developed

(Negussie *et al.* 2013). After correction for environmental effects, cows with the highest fertility showed an overall decreased in fat-to-protein ratio, whilst the environment did not seem to affect cows with a poorer fertility (Figure 1).

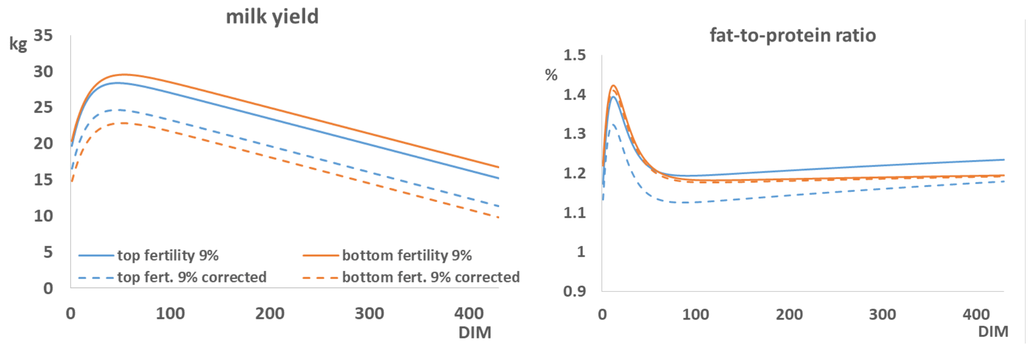

Figure 1. Lactation curves for milk yield and fat-to-protein ratio predicted with corrected and uncorrected Wilmink curve parameters for bulls ranking at the top and bottom of fertility

CONCLUSIONS

Highly fertile cows seem to be capable of producing more milk compared to low fertile cows purely based on the genetic merit. This suggests that the negative genetic link between high milk production and low fertility can be broken. The environment, i.e. favourable management, is not as optimal for high fertile cows and a limiting factor that can be overcome with better management, but sufficient for less fertile cows. This is also reflected in the fat-to-protein ratio as a measure of energy balance, which shows that especially highly fertile cows experience a strong energy deficit in early lactation.

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