How does a beef x dairy calving affect the dairy cow's following lactation period?

Hur påverkar en kalvning med köttraskorsning mjölkkons fortsatta laktationsperiod?

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Abstract

In dairy x beef breeding, much of the research has focused on the performance of the crossbred calves, yet little focus has been given to the subsequent performance of the cow itself. This study aimed to evaluate the performance of dairy cows for milk yield, fertility, and survival traits after giving birth to crossbred calves, and to compare this to the performance of dairy cows after giving birth to purebred dairy calves. Phenotypic records from 4,980,886 calving events distributed in 4,509 herds from 1997 to 2020 were collected from the Swedish milk recording system from cows of the dairy breeds Swedish Red and Swedish Holstein. A total of 13 performance traits were defined and grouped in three large complexes as follows; cumulative and 305-day milk, fat, and protein yield as milk yield traits; calving to first insemination interval, calving to last insemination interval, first to last insemination interval, calving interval, and number of inseminations as fertility traits; and survival to next calving and last day in milk as survival traits. The data were analyzed for all traits for first and later parities separately using mixed linear models, with a focus on the estimates of sire breed by dam breed combinations. All traits were adjusted for previous milk yield for parities 2-3 based on the expectation that low-yielding cows would more likely be inseminated with beef semen. Overall, milk yield was lower after mating beef x dairy compared to the purebred matings. The largest decrease was about 400 kg for cumulative milk yield when breeding Charolais sires with purebred SR or SH dams. As for fertility traits, for most breed combinations, the effects were not large enough to be significant. Conversely, all sire-dam breed combinations showed significantly lower results for survival traits, suggesting that cows inseminated with beef semen have a lower probability to survive to the next lactation.

Table of contents

List of tables

List of figures

Abbreviations

ANG	Aberdeen Angus cattle
CFI	Calving to First Insemination interval
CHA	Charolais cattle
CINT	Calving Interval
CLI	Calving to Last Insemination interval
CUMMY	Cumulative milk yield over the lactation
DIM	Days in milk
FLI	First to last insemination interval
FY305	305-day yield of fat
GL	Gestation Length
HER	Hereford cattle
HYg	Herd-year group
HYS	Herd-year-season group
LASTDIM	Lactation length measured as Last Day in Milk or test-day
LIM	Limousin cattle
MY305	305-day yield of milk
NAV	Nordic Cattle Genetic Evaluation
NINS	Number of inseminations
P1	First parity
P2-3	Second and third parities
PROT305	305-day yield of protein
SCC	Somatic cell count
SH	Swedish Holstein cattle
SIM	Simmental cattle
SR	Swedish Red cattle
SURVNEXT	Survival to subsequent lactation
TDMY	Test-day milk yield

Introduction

The use of beef semen on dairy cows is increasing in popularity in many countries (Sørensen *et al.*, 2008; Berry and Ring, 2020b). The use of beef sires in combination with sexed semen facilitates the production of male and female crossbred calves in dairy cow herds, providing a potential increase in the economic incomes of the farms because the crossbred calves could be sold for slaughter at a higher price (Ettema *et al.*, 2017; Bittante *et al.*, 2020). Moreover, the use of sexed semen to produce female replacement dairy heifer calves enables the utilization of more beef semen in the herd. To date, about 60% of the beef produced in Sweden comes from culled dairy cows and their offspring (LRF, 2017). In turn, there has been a reported increase in calving difficulties in the past decades due to the heavier birth weight of the calves with a better carcass conformation (Steinbock *et al.*, 2003; Eriksson *et al.*, 2004, 2020).

The effects of beef x dairy crosses on the actual calving have been studied on Swedish material (Eriksson *et al.*, 2020). Moreover, many scientific studies on dairy x beef mating have focused on carcass traits and the benefits of heterosis in crossbred offspring. However, detailed studies about the effects of beef x dairy calvings on the cow's following lactation period in comparison with dairy x dairy or beef x beef breed crosses are still scarce (Berry and Ring, 2020b). The effects on the dairy cow's lactation period would be useful information for the farmers to understand the impact of crossbreeding on the cow's lactation period itself. The lactation period of a cow is defined in this study as a combination of milk production, fertility, i.e., its ability to become pregnant again after calving, and survival to the next calving.

In this study, a large dataset from routine production recording in the Swedish dairy industry is used to quantify the effect on the cow's lactation period after giving birth to a purebred or a beef x dairy calf. This research aims to evaluate the performance of dairy cows for milk yield, fertility, and survival traits after giving birth to crossbred calves and compare this to the performance of dairy cows after giving birth to purebred dairy calves, on a phenotypic level. The hypothesis is that milk yield and fertility in the coming lactation, as well as survival to next calving, are decreased.

Literature Review

Milk yield

305-day yield of milk (MY305) is a useful measurement in genetic evaluations of dairy cattle, where the milk yield from lactation records are standardized to a maximum number of 305 days of lactation (Dematawewa and Berger, 1997; Santos *et al.*, 2013; Berry and Ring, 2020b). Additionally, test-day milk yield (TDMY) is the measurement of the milk produced by a cow throughout 24 h (Schaeffer *et al.*, 2000; Santos *et al.*, 2013). TDMY is the base for calculating MY305 and in practice, monthly measurements can also possibly be referred to as TDMY. The very first attempt to estimate the MY305 and mathematically represent the lactation curve was done by Brody *et al.* (1923) and ever since several complex models were developed to estimate MY305, e.g., by applying a test-day model. A higher response to selection for MY305 was obtained by Santos *et al.* (2013) by using a test-day model and selecting for TDMY. In Scandinavian countries, to obtain MY305 breeding values, the Nordic Cattle Genetic Evaluation (2013) sums the estimated daily breeding values between 8-312 days in milk (DIM). Moreover, Schaeffer *et al.*, (2000) compared MY305 with TDMY models assuming that each cow in each lactation had a standard lactation curve where each lactation (within a cow) could have different shapes for each lactation curve, and described the benefits obtained from a TDMY model as persistency within and across lactations, better accounting for herd-test date environment, movement of cows between herds, more flexibility in milk recording schemes, and accurate genetic selection of bulls and cows. Furthermore, Tiezzi et al. (2012) indicated that the total lactation milk yield of a cow depends on the peak milk yield and lactation length. Lactation length is particularly important because the end of the lactation period is defined by the culling or the drying-off period (Clasen *et al.*, 2017), and the way the drying-off is done depends on the farm management.

Fertility

The importance of the fertility traits lies in the revenues and costs of the farm as changes in the overall fertility rate directly affect the net profit. To evaluate the cows' fertility on the farms, as well as survival traits, records of insemination, pregnancy diagnosis, calving, and disposal can be used. Fertility can be evaluated by considering it as the same trait over the parities of a given cow (Tiezzi *et al.*, 2012; Hazel, Heins and Hansen, 2017; Bittante *et al.*, 2020) or as separate traits. Over the first and second parities of the cows, a high genetic correlation of more than 0.92 has been established by Tiezzi *et al.* (2012). Moreover, fertility is significantly affected by the level of milk yield (López-Gatius, 2012; Bittante *et al.*, 2020). Milk yield and fertility traits have been demonstrated to have a general negative genetic correlation (Windig *et al.*, 2006; Tiezzi *et al.*, 2012). Depending on the objective of the study, there are many factors to take into account in order to avoid biases and misinterpretations derived from inaccurate modeling of fertility traits data. The statistical model has to include all related factors and evaluate them simultaneously (Bello *et al.*, 2012; Bittante *et al.*, 2020). The most important traits for Sweden can be found in the NAV female fertility evaluation (Muuttoranta *et al.*, 2018) where a multi-trait multi-lactation setting is used to analyze fertility traits in 3 clusters. The most relevant traits are the interval from calving to first insemination (CFI); interval from calving to last insemination (CLI); interval from first to last insemination (FLI); calving interval (CINT), and number of inseminations (NINS).

Survival

Survival to the subsequent calving is a complex trait that can be affected by previous calving problems as well as other factors such as management decisions, e.g., voluntary culling due to low production. Depending on the data, survival models where the time to the death of the cows is modeled might be suitable, yet is more computationally challenging. Moreover, Heins et al. (2012) compared the survival to subsequent calving of crossbred and purebred cows by using logistic regression analysis to obtain odds ratios. The results were expressed as a difference in means of the crossbreds compared to the purebreds, where the crossbreds showed higher odds ratios for survival to subsequent calving. However, a possible challenge with this method would be to include a random genetic effect. In a more recent study, Hazel et al., (2017) studied survival to subsequent lactation. Survival was recorded as a binary trait, i.e. if cows survived or not. Cows were analyzed for survival to 60 DIM and subsequent calving within 14 and 17 months. After the analyses, they obtained least-squares means and significance of contrasts and compared groups by calculating the differences in least-squares means.

Influence of environmental factors

The lactation performance of a cow can potentially be influenced by the sire breed of the calf, sex of the calf, calving performance, as well as other environmental factors. Berry & Ring (2020b) correlated the sire breed of the calf with milk yield traits (i.e., milk, protein, and fat yield), and somatic cell count (SCC). To estimate the effects of beef or dairy semen on the dams' subsequent milk yield, Berry & Ring (2020b) analyzed standardized 305-d milk yields for different breeds. Their model included the breed of the (calf's) sire, calf sex, cow parity, and the sire genetic merit for carcass weight; and mean gestation lengths were obtained and compared between beef x dairy crosses and purebred dairy or dairy x dairy crosses. Results suggested that the effect of the sire breed on the milk yield of the dam was related to the carcass conformation of the calf. Though the effect of calf conformation on the cow's milk yield is not yet known, it may be associated with the energetic cost while carrying a calf from a beef breed with greater musculature.

Regarding calf sex, it may have an effect on milk yield based on the biological justification that fetal hormones such as insulin-like peptide 3, which is expressed in different levels in male and female fetuses (Adham *et al.*, 2002) can cross the placenta of the dam, thus affect lactogenesis and ultimately milk yield. Hess et al. (2016) showed that the calf sex of the first parity may influence the lactation yield in the subsequent lactations; where dams with female calves could produce more milk than dams with male calves in the first parity. Moreover, cows that had calving difficulties showed a loss of milk yield, but the effects of calving performance will be discussed later for all traits.

Calving performance

While the focus of this study lies on milk yield, fertility, and survival traits on dairy cows, it is important to acknowledge the effect of difficult calving on the subsequent performance of the cows (i.e., milk yield and fertility), which has been well demonstrated (Coleman, Thayne and Dailey, 1985; Dematawewa and Berger, 1997; Bernoldi, Gens and Dick, 2016; Berry *et al.*, 2019). Calving difficulty has been associated with a decrease in daily milk production (Barrier and Haskell, 2011; Eaglen *et al.*, 2011) and a decrease in the reproductive efficiency of the herd due to a lower number of animals apt to reenter service (Dematawewa and Berger, 1997; Bernoldi, Gens and Dick, 2016). Eaglen *et al.* (2011) showed a loss of 710 kg in cumulative milk yield from 129 to 261 days in milk in veterinary-assisted calving. Moreover, calving difficulty has negative effects on the subsequent survival of the cows (Lombard *et al.*, 2007; Tenhagen, Helmbold and Heuwieser,

2007) and their offspring. Therefore, calving traits are importantly correlated to milk, fertility, and survival traits.

Calving difficulty is usually recorded by the farmers and the scoring systems to categorize such events can vary within countries and production systems. In the Nordic Cattle Genetic Evaluations (NAV, 2013), a scale of 1-4 is used, where score 1 refers to easy calving with no assistance; score 2 to easy calving with some assistance provided; score 3 to considerable calving difficulty with assistance provided, but without veterinary intervention; and score 4 to considerable calving difficulty resulting in a veterinary intervention (Eriksson *et al.*, 2020). Regarding the breed variations, the effect of beef-dairy calves on the cow's subsequent calving performance has not been studied to the same extent as dairy-dairy and beef-beef crosses (Fouz *et al.*, 2013; Berry and Ring, 2020b). Moreover, when using beef sires in Swedish dairy cows, Eriksson et al. (2020) found more difficult calvings but fewer stillbirths.

Material and Methods

Data collection

Data were obtained from the Swedish milk recording system provided by Växa Sverige. Ethical approval was not necessary given that the study was done entirely based on field data. Records were available for the two most common dairy breeds: Swedish Red (SR) and Swedish Holstein (SH). Records involved calving events, insemination information, and milk production. Calving records included unique animal identifications (of the calf, dam, and sire); calving date (birth date of calf); calving ease; calf sex; calving herd; and breed (of the calf, dam, and sire). Insemination records contained cow and sire id, and date of insemination. Cow production records included milk recording date; parity number; calving date; date of birth of cow; test-day milk, protein, and fat yield; somatic cell count, and days in milk. Only calvings of purebred SR and SH cows were used and calvings sired by either SR or SH bulls or beef breed bulls from Angus (ANG), Charolais (CHA), Hereford (HER), Limousin (LIM), and Simmental (SIM). Other beef breeds had too few calvings to be possible to study. Beef breeds were also categorized as Light (ANG, HER) or Heavy (CHA, LIM, SIM) breeds.

For all three types of traits (milk yield, fertility, and survival), we used the calving information and later performance records of the cow in the first to third lactations. To compare cows with calves sired by beef bulls to cows with calves sired by dairy bulls we first connected the calving to the right lactation by using the information on the date of birth of the calf and the identity of the dam and connecting these to the corresponding calving date for the cow.

Construction of traits

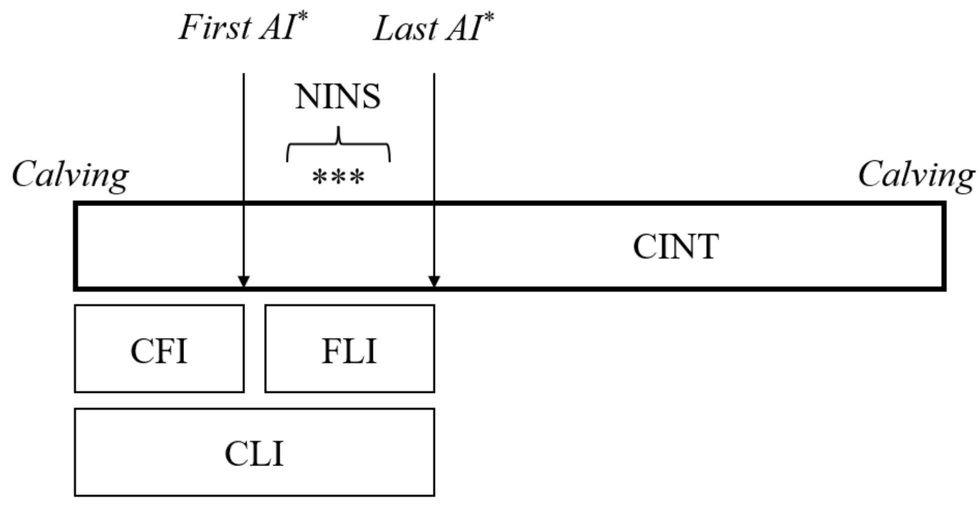
Milk yield

Cumulative milk yield over the whole lactation (CUMMY), along with 305-day milk yield (MY305), fat yield (FY305), and protein yield (PROT305) were created based on test-day (TD) milk yield. CUMMY (CUMFAT, CUMPROT) was defined as the cumulative sum of milk (fat, protein) yield during lactation. The yield was assumed to be the same from halfway from the previous TD to halfway to the next TD. For the first TD, the yield was calculated back until day 3 after calving. Similarly, fifteen days were added after the last TD. MY305 was defined as the sum of yield from day 3 to day 308 using the same approach as above. For cows that had shorter lactations than 305 days, the records were not considered.

Fertility

Five fertility traits were defined for use in this study similar to those used by Muuttoranta *et al.* (2018) and Berry and Ring (2020b). Limits were set for each trait as minimum and maximum expected values within observations. Observations with values outside the limits, i.e., fewer than or more than, were excluded from the dataset. The five fertility traits were: Calving to first insemination interval (CFI), defined as the number of days from calving to the first insemination, excluding observations with fewer than 20 or more than 230 days; Calving to last insemination interval (CLI), defined as the number of days from calving to the last insemination with limits set from 20 to 450 days; First to last insemination interval (FLI) defined as the difference between CLI and CFI with limits set from 0 to 365 days; Number of inseminations (NINS) defined as the number of inseminations per service with a limit set up to 8 inseminations; and Calving interval (CINT) for those cows who had a subsequent lactation, defined as the interval between calvings with limits set from 280 to 650 days. For a better illustration, Figure 1. Illustration of the fertility traits analyzed in this study.Figure 1 shows a timeline of the fertility traits analyzed in this study. The fertility traits were created for the subsequent lactation, after the birth of the calf resulting from the sire-dam breed combination.

Figure 1. Illustration of the fertility traits analyzed in this study.



*Artificial Insemination.

Survival

Survival to subsequent lactation was constructed as a binary trait, survival to subsequent lactation (SURVNEXT), defined as 1 for the cows that had subsequent calving, and 0 for those that did not. Owing to the structure of the data, SURVNEXT was only calculated for cows in their second parity as there was no information available for fourth parity calving dates. Additionally, lactation length, measured as the last TD (LASTDIM) was calculated and defined as an indicator of survival to subsequent lactation, with a maximum value of 365 days. There were no records available higher than 365 days.

Data structure

The original data consisted of a total of 4,980,886 calving events. The first and later parities were differentiated into two groups; parity 1 (P1) and parity 2-3 (P2-3). Calving age was grouped in month classes, with limits for P1 set from 22 months up to 34 months, P2-3 from 34 to 50 months for second parity, and 45 to 63 months for third parity. For those cows that were outside the limits, their calving age in months was combined with the younger and older limits within parities, e.g., a 35-month-old first parity cow was considered as 34 months old.

The number of sires available was 22,715 and 34,505 for SR and SH dairy breeds, respectively, while 7,677 and 6,342 for heavy and light beef breeds, respectively. Calving records were distributed from January 1997 to September 2020. Data were edited similarly to Eriksson et al. (2020) where herd-year groups (HYg) of four-year periods (e.g., 1997-2000, 2001-2004, …) were created and only herds with at least five crossbred calves from beef breed sires and at least 10 calving events in total were retained, to focus on herds that regularly used insemination with beef semen. The calving records were distributed in 4,509 herds and 2,114 and 5,389 HYg were created for P1 and P2-3, respectively. Calving ease scores were considered according to NAV (2013) but to facilitate computation they were reclassified as easy (original scores 1 and 2), difficult (original scores 3 and 4), or missing (all other scores or missing score). Moreover, calving records with abortion (<215 d) and premature calving (215-240 d) were removed from the dataset (<5%). The distribution of records per parity and the distribution of beef x dairy calving per year-group are shown in Table 1. After all edits, a total of 867,178 calving events were used for further analysis.

Table 1. Distribution of calving events per parity

	Records	Dairy x dairy	Beef x dairy
Parity 1	200,403	170,123 (84.9%)	30,280 (15.15%)
Parity 2-3	666,775	589,348 (88.4%)	77,427 (11.6%)

The number of crossbred calvings for the most common beef breeds is represented in Table 2. The number of calvings with beef breeds in first and second lactation for SRB and SH was similar. The main difference in the distribution of calvings with beef sire breeds between P1 and P2-3 was the overall increase in the use of heavy breeds such as CHA, LIM, SIM in P2-3 compared to the relatively constant use of light breeds such as ANG, HER in both parities.

Table 2. Distribution of crossbred calvings with beef breeds in first and later parities

	Parity 1		Parity 2-3	
Sire breed	SR	SH	SR	SH
ANG	4,007 (28.2%)	5,687 (35.4%)	4,085 (11.4%)	4,659 (11.2%)
CHA	341 (2.4%)	610 (3.8%)	8,706 (24.3%)	11,009 (26.5%)
HER	7,323 (51.6%)	5,976 (37.1%)	8,481 (23.6%)	6,316 (15.2%)
LIM	1,584 (11.2%)	2,038 (12.7%)	5,621 (15.7%)	5,913 (14.3%)
SIM	939 (6.6%)	1,775 (11%)	9,002 (25%)	13,635 (32.8%)
Total	14,194 (100%)	16,086 (100%)	35,895 (100%)	41,532 (100%)

Statistical analysis

Data were analyzed independently for each trait with P1 and P2-3 separately but both dam dairy breeds simultaneously. The main difference between P1 and P2-3 was the adjustment in P2-3 using the linear regression on previous lactation yield (MY305) expressed as a deviation from the average yield of 9,600 kg. For those records lacking previous MY305 information, i.e., cows with shorter previous lactation length than 305 days, the deviation was set to 0 to have them included in the analyses, but without adjusting the next lactation performance. After the analyses, least-squares means and significance of contrasts between all the breed combinations were obtained. The model was:

$$\boldsymbol{y}_{ijklmnp} = \boldsymbol{\mu} + \mathbf{SD}_{ij} + \mathbf{P}_k + \mathbf{S}_l + \mathbf{C}_m + \mathbf{HYg}_n + \boldsymbol{HY}_o + \mathbf{b}_p MY305 + \mathbf{e}_{ijklmnop}$$

where,

y = observed value (for yield, fertility, or survival)

μ = population mean

SD_{ij} = fixed effect of breed combination (sire breed *i* nested with dam breed *j*)

P_k = fixed effect of parity *k* (2, 3 for later parities)

S_l = fixed effect of calf sex *l* (bull, heifer)

C_m = fixed effect of calving performance *m* (easy, difficult, missing)

HYg_n = fixed effect of herd-year group combination *n* (e.g. 1997-2000)

HY_o = random effect of herd and calving year combination *o*, IND(0,σ^2_{HY})

b_p = fixed regression coefficient of the trait on previous 305-d milk yield, MY_{305} (for later parities)

$e_{ijklmnop}$ = random residual effect, IND(0,σ^2_e)

In a separate analysis, a second model was created – Model 2 – where the SD_{ij} effect was replaced by an effect of sire breed group (Dairy, Light, or Heavy beef breeds) by dam breed combination (SGD_{ij}). Furthermore, in a third analysis, a third model was created – Model 3 – where an interaction between the C_m effect and the sire breed group by dam combination was included to test whether the calving ease had the same effect over all types of calvings, i.e., breed combinations. Table 3 shows a summary of the three models.

Table 3. Overview of statistical models for first and later parities

Model 1	P1	$\boldsymbol{y}_{ijklmnp} = \boldsymbol{\mu} + \mathbf{SD}_{ij} + \mathbf{S}_l + \mathbf{C}_m + \mathbf{HYg}_n + \boldsymbol{HY}_o + \mathbf{e}_{ijklmnop}$
	P2-3	$\boldsymbol{y}_{ijklmnp} = \boldsymbol{\mu} + \mathbf{SD}_{ij} + \mathbf{P}_k + \mathbf{S}_l + \mathbf{C}_m + \mathbf{HYg}_n + \boldsymbol{HY}_o + \mathbf{b}_p MY305 + \mathbf{e}_{ijklmnop}$
Model 2	P1	$\boldsymbol{y}_{ijklmnp} = \boldsymbol{\mu} + \mathbf{SGD}_{ij} + \mathbf{S}_l + \mathbf{C}_m + \mathbf{HYg}_n + \boldsymbol{HY}_o + \mathbf{e}_{ijklmnop}$
	P2-3	$\boldsymbol{y}_{ijklmnp} = \boldsymbol{\mu} + \mathbf{SGD}_{ij} + \mathbf{P}_k + \mathbf{S}_l + \mathbf{C}_m + \mathbf{HYg}_n + \boldsymbol{HY}_o + \mathbf{b}_p MY305 + \mathbf{e}_{ijklmnop}$
Model 3	P1	$\boldsymbol{y}_{ijklmnp} = \boldsymbol{\mu} + \mathbf{SGD}_{ij} + \mathbf{S}_l + \mathbf{C}_m(\mathbf{SGD})_{ij} + \mathbf{HYg}_n + \boldsymbol{HY}_o + \mathbf{e}_{ijklmnop}$
	P2-3	$\boldsymbol{y}_{ijklmnp} = \boldsymbol{\mu} + \mathbf{SGD}_{ij} + \mathbf{P}_k + \mathbf{S}_l + \mathbf{C}_m(\mathbf{SGD})_{ij} + \mathbf{HYg}_n + \boldsymbol{HY}_o + \mathbf{b}_p MY305 + \mathbf{e}_{ijklmnop}$

R statistical software (R Core Team, 2020) was used to edit the data and compute descriptive statistics. For the linear mixed model shown above, SAS (SAS Institute, 2012), PROC HPMIXED was used.

Results

Data summary statistics

The overall raw mean values for each trait after final edits considering all sire-dam breed combinations over time for P1 and P2-3 are presented in Table 4. The phenotypic standard deviation of the traits was calculated as the square root of the sum of the variance components, i.e., herd-year season (HY) and residual, following the adjustment for fixed effects in Model 1. All traits, except CFI, LASTDIM, and SURVNEXT showed a higher mean value in P2-3 compared with in P1.

Table 4. Means and phenotypic standard deviations for all traits

Trait[1]	Parity 1		Parity 2-3	
	Mean	σ_p	Mean	σ_p
CUMMY	8,510	2,541	9,782	2,931
MY305	9,005	1,261	10,768	1,374
CUMFAT	351	104	401	123
FAT305	368	50	439	59
CUMPROT	293	87	335	101
PROT305	309	40	368	44
CFI	82	31	82	30
CLI	121	65	122	62
FLI	35	53	38	52
CINT	391	55	392	53
NINS	1.96	1.27	2.02	1.27
LASTDIM	283	71	275	75
SURVNEXT	0.65	0.45	0.34	0.37

[1]For explanation, see list of abbreviations on page 10.

Adjustment for previous milk yield regression

All traits were adjusted for previous milk yield for parities 2-3 because, e.g., a low previous 305-day milk yield would also give an expected lower next lactation yield. There was an expectation that low-yielding cows would more likely be inseminated with beef semen. The regression coefficient of each trait on the previous 305-d milk yield is shown in Table 5. All the regressions are positive for the milk traits. Indeed, cows with a low previous 305-day milk yield would also have a lower next milk yield. All the coefficients were significantly different from 0 with a p-value <0.0001.

Table 5. Estimates of the regression coefficient for each trait on previous 305-day milk yield and SE for parities 2-3

Trait[1]		Estimate	SE
Milk yield	CUMMY	0.533	0.003
	MY305	0.422	0.002
	CUMFAT	0.015	0.000
	FAT305	0.009	0.000
	CUMPROT	0.016	0.000
	PROT305	0.011	0.000
Fertility	CFI	0.001	0.000
	CLI	0.004	0.000
	FLI	0.003	0.000
	CINT	0.004	0.000
	NINS	0.000	1.49E-06
Surv.	LASTDIM	0.005	0.000
	SURVNEXT	2.26E-06	1.10E-08

[1]For explanation, see list of abbreviations on page 10.

Effects of sire x dam breed combinations

Results below are reported as three large trait complexes: milk, fertility, and survival traits. The graphs are expressed in the absolute values of each trait, i.e., kg for yield traits, days for fertility and LASTDIM, number of inseminations for NINS, and proportion for SURVNEXT. The stars in the bars indicate that the effect is statistically significantly different from zero, i.e. the corresponding purebred calving. The estimated differences in breed combinations' least-squares means can be found in Appendix 1, 2, and 3 for yield, fertility, and survival, respectively.

Milk yield

Overall, the general tendency was that milk yield was lower after beef x dairy calvings compared to the purebred calvings, aligning with the initial research hypothesis. Figure 2-Figure 5 show the effect of the sire x dam breed combination on cumulative milk yield and 305-day milk yield for Models 1 and 2, respectively.

The effect of the breed combinations seen in CUMMY was much larger than that in MY305. The largest decrease in Model 1 for CUMMY was seen when breeding SR and SH with CHA bulls, with a decrease of over 400 kg, corresponding to about 0.14 SD-units of the trait (P2-3), followed by SR x ANG and SH x HER. In general, the decrease in CUMMY was larger in P2-3 than in P1.

The largest decreases observed for CUMMY and MY305 in Model 2 were when breeding SR dams with heavy breed bulls (SR x HEAVY), with a deviation of -337.5 kg for CUMMY in P2-3, corresponding to 0.11 SD-units of the trait, and a deviation of -72.3 kg for MY305 in P1-2, corresponding to 0.06 SD-units of the trait. There was an overall significant improvement of over 100 kg in MY305 of SR cows in P2-3 when breeding with SH bulls (SR x SH).

Figure 2. Effect of sire x dam breed combination on cumulative milk yield for Model 1

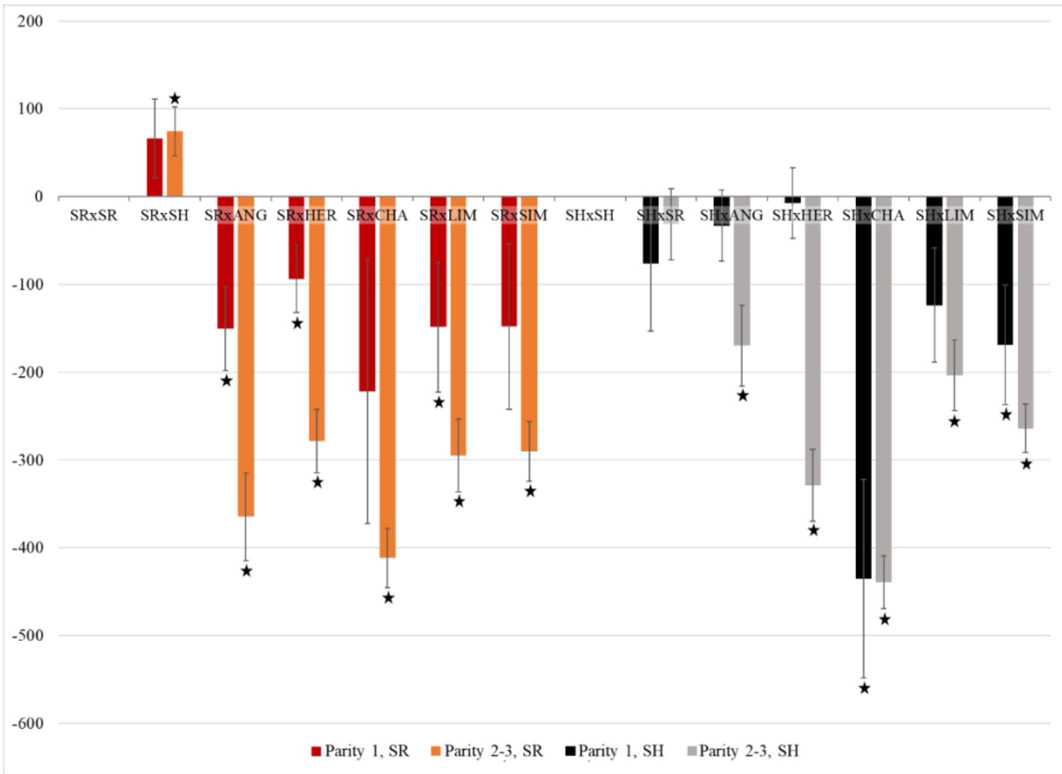


Figure 3. Effect of sire x dam breed combination on 305-d milk yield for Model 1

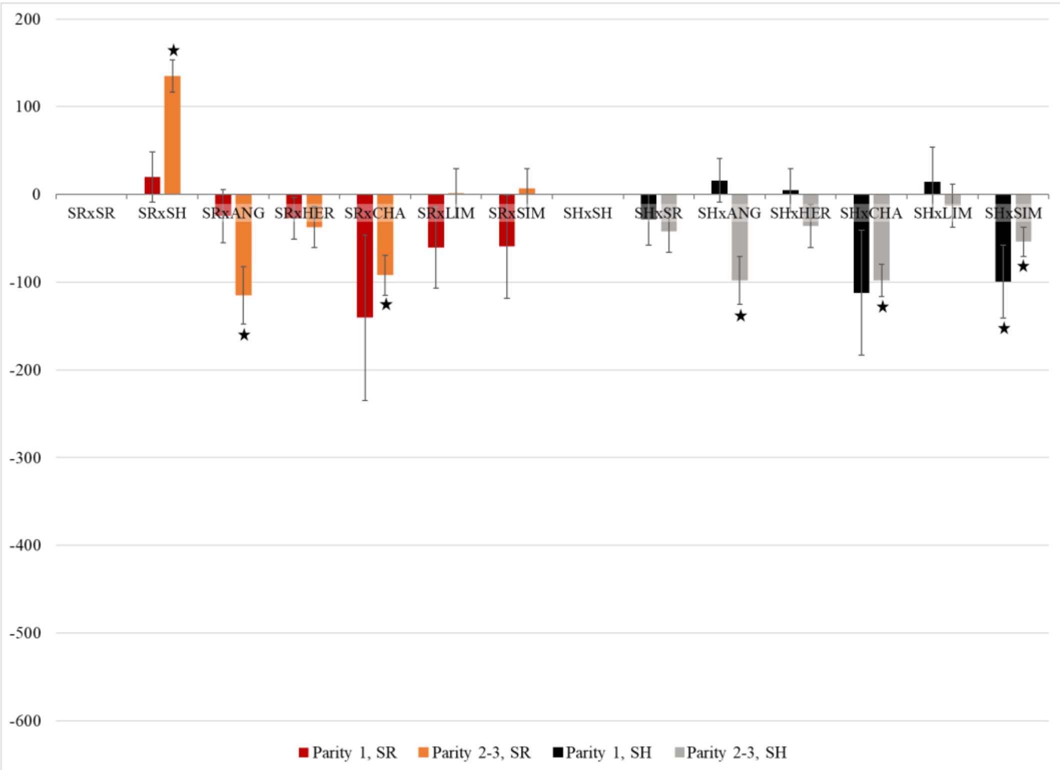


Figure 4. Effect of sire x dam breed combination on cumulative milk yield for Model 2

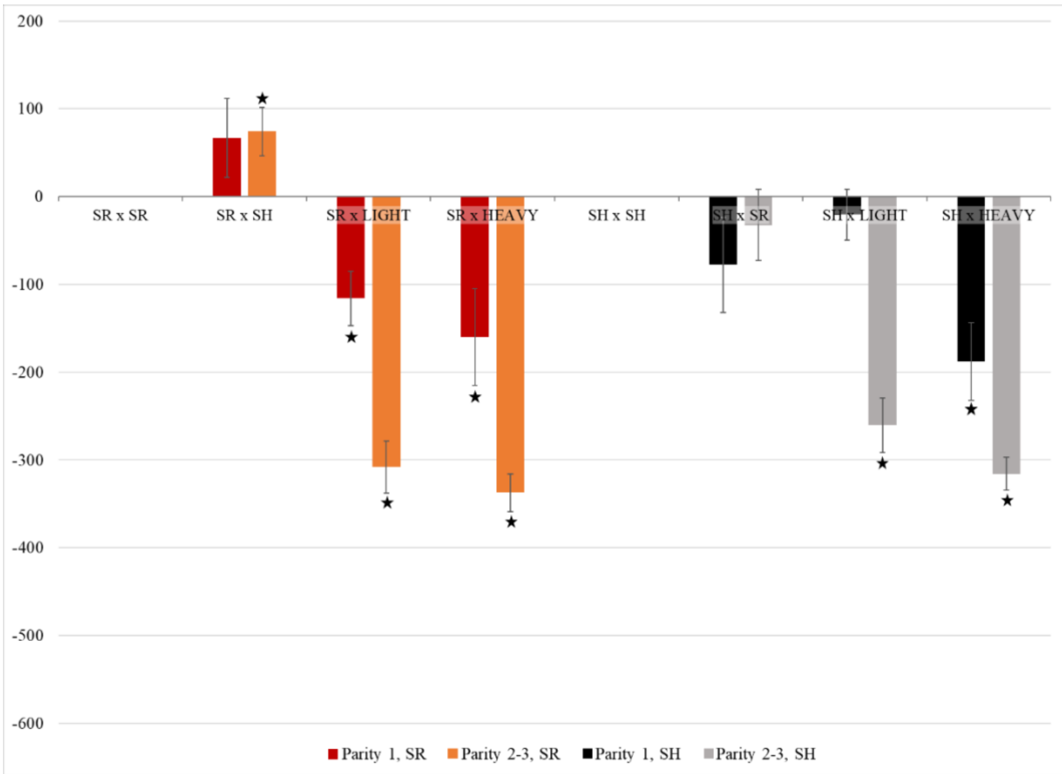
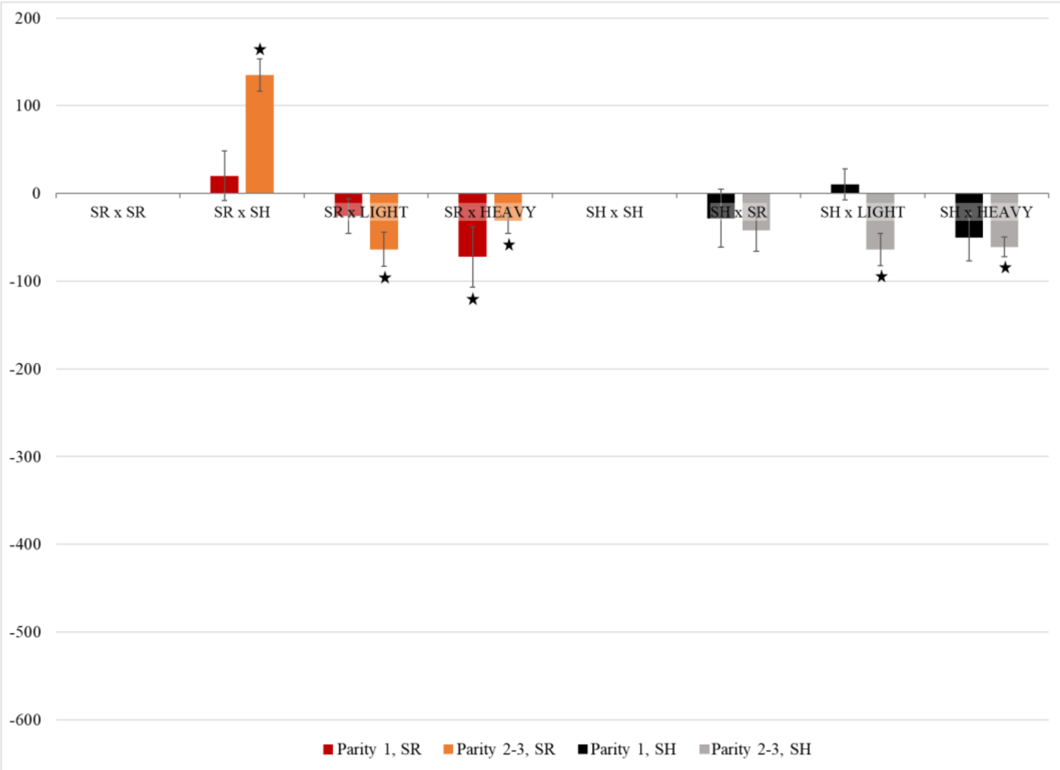


Figure 5. Effect of sire x dam breed combination on 305-d milk yield for Model 2



Regarding fat and protein yields, the effects on cumulative and 305-d yield are shown in Figure 6-Figure 9 for Model 2 only as there were no large differences between Models 1 and 2 and the patterns seemed to emerge more clearly when looking at fewer groups, i.e., Light and Heavy. Overall, the behaviour for both fat and protein followed the same pattern as the above-presented results for milk yield with a downward trend for the beef cross calvings. The largest effect for fat and protein yields corresponded to 0.14 SD-units for both traits.

Figure 6. Effect of sire x dam breed combination on cumulative fat yield for Model 2

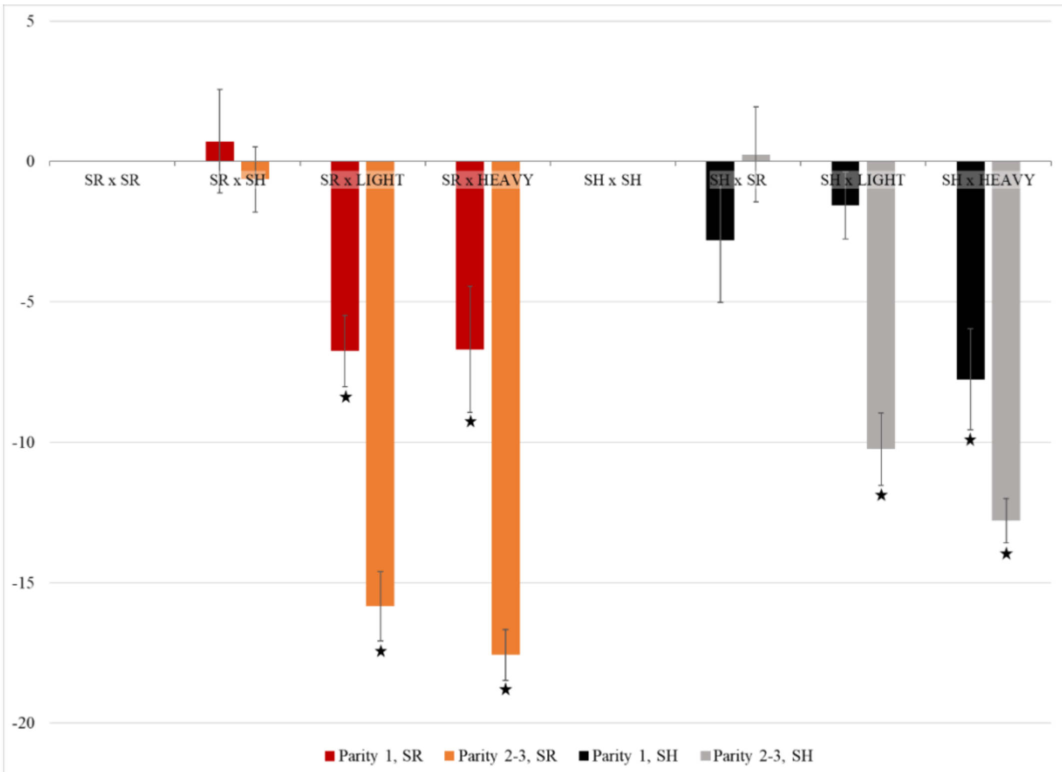


Figure 7. Effect of sire x dam breed combination on 305-d fat yield for Model 2

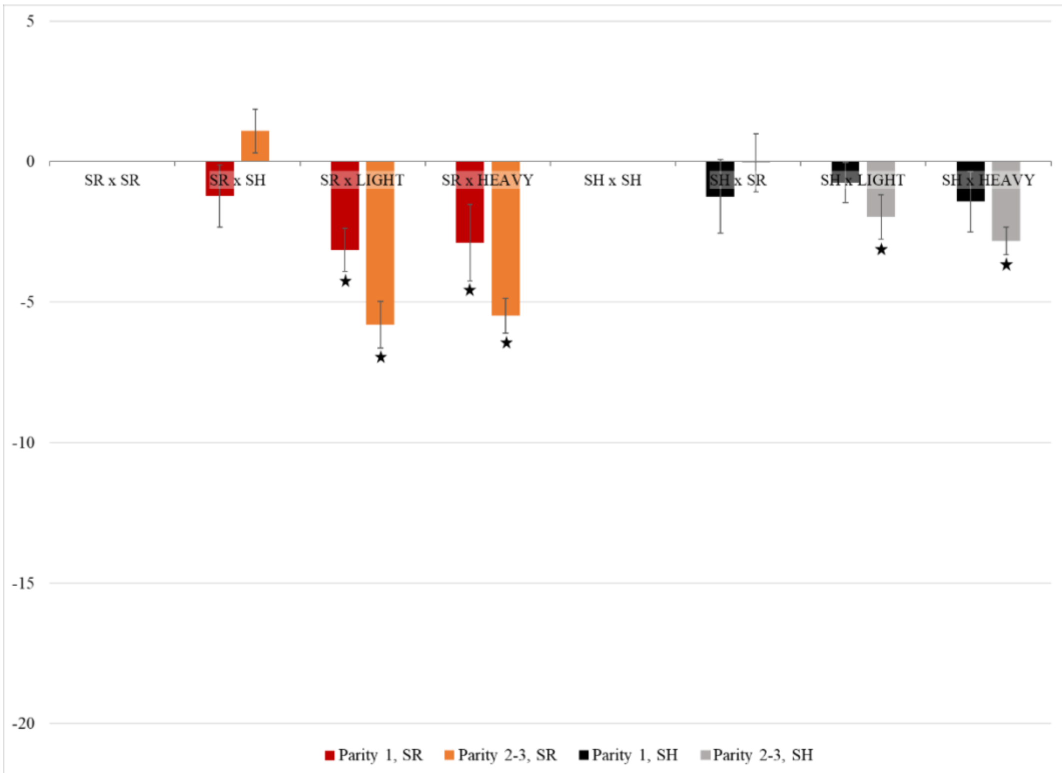


Figure 8. Effect of sire x dam breed combination on cumulative protein yield for Model 2

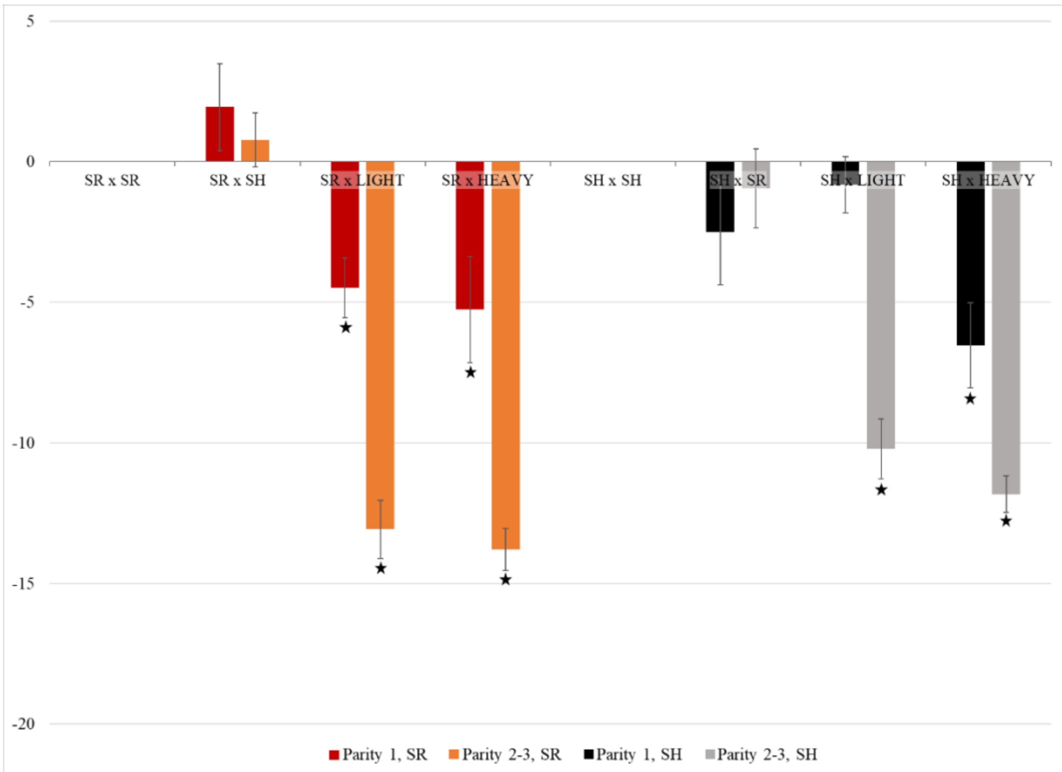
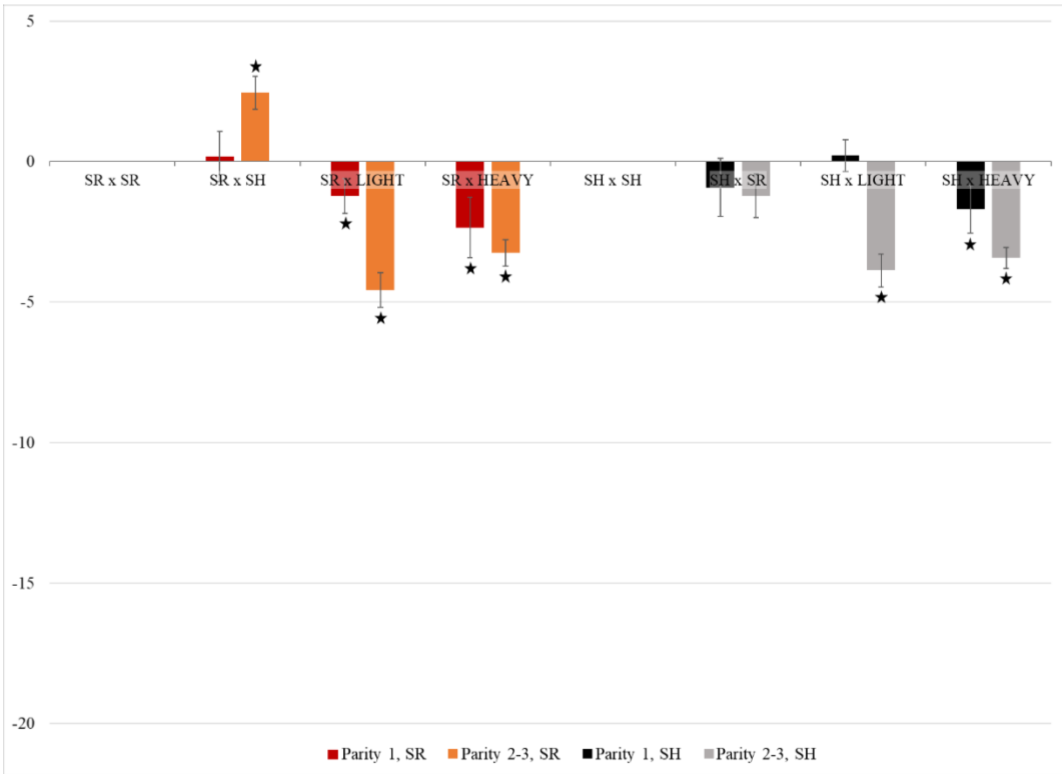


Figure 9. Effect of sire x dam breed combination on 305-d protein yield for Model 2



Fertility

For most breed combinations, the effect on fertility traits was not large enough to be significant. Figure 10-Figure 19 show the effect of the sire x dam combination on fertility traits for Models 1 and 2. In general, it was difficult to observe a clear pattern and the differences in days for most traits was about 1-2 days, except for CHA. The fertility of dairy cows bred with CHA bulls stand out with a shorter CLI, FLI, and CINT, and fewer NINS, and mostly for first parity SR cows.

Figure 10. Effect of sire x dam combination on calving to first insemination interval (CFI) interval for Model 1

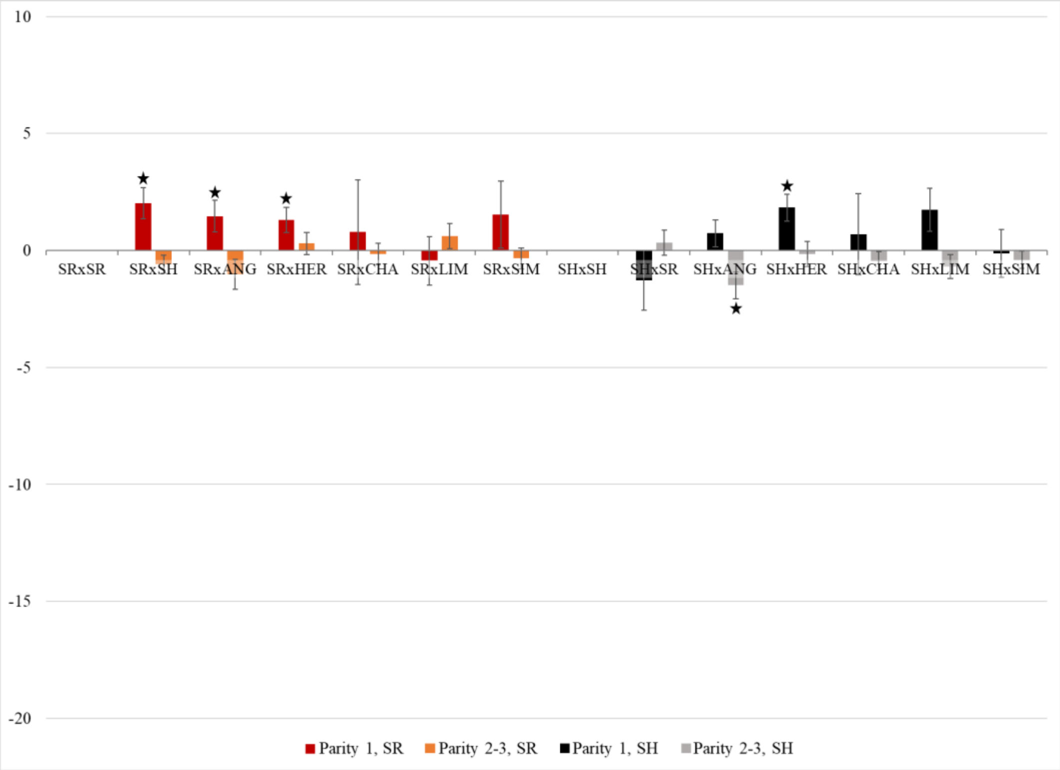


Figure 11. Effect of sire x dam combination on calving to first insemination (CFI) interval for Model 2

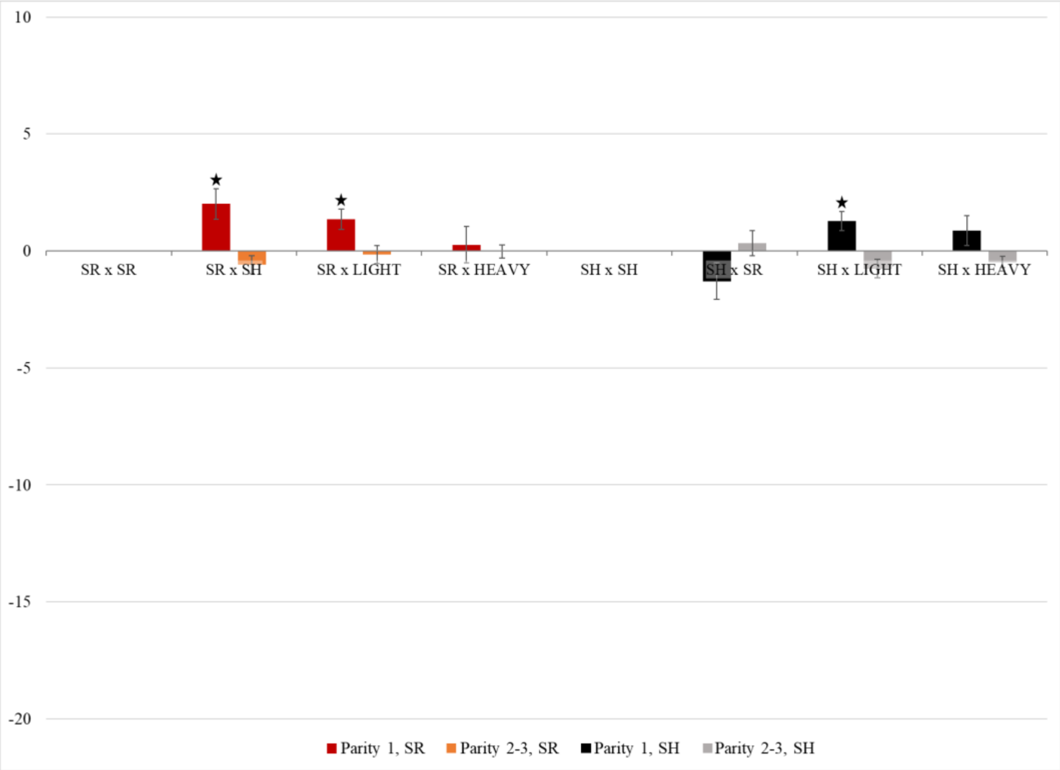


Figure 12. Effect of sire x dam combination on calving to last insemination (CLI) interval for Model 1

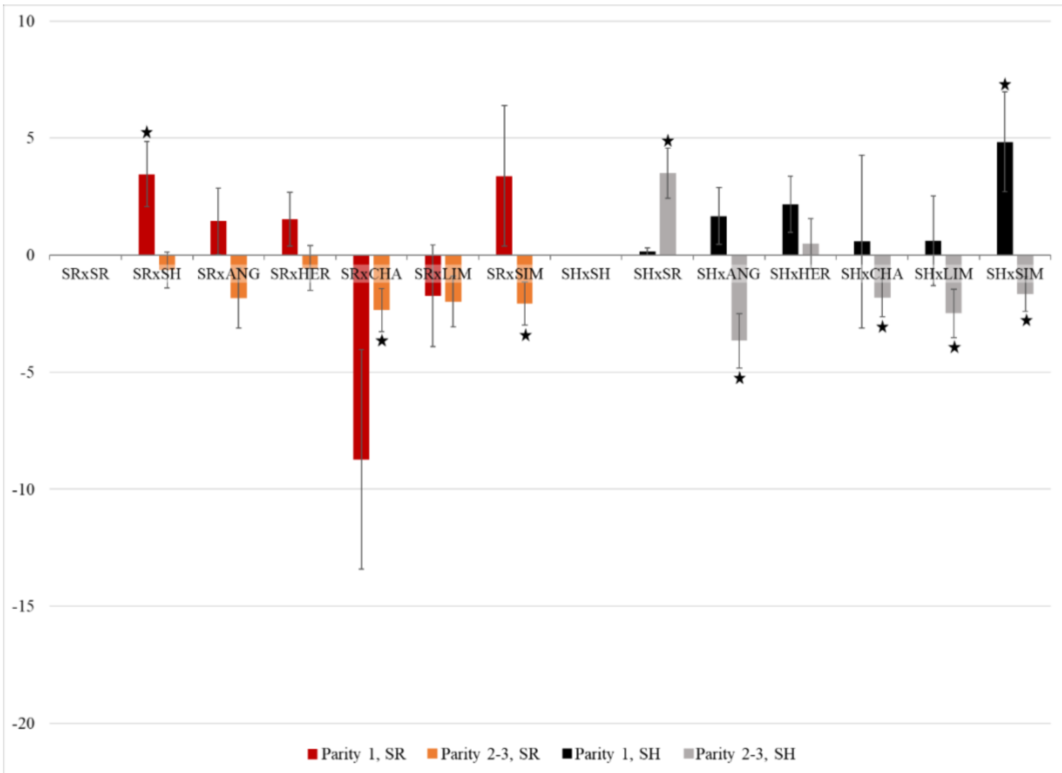


Figure 13. Effect of sire x dam combination on calving to last insemination (CLI) interval for Model 2

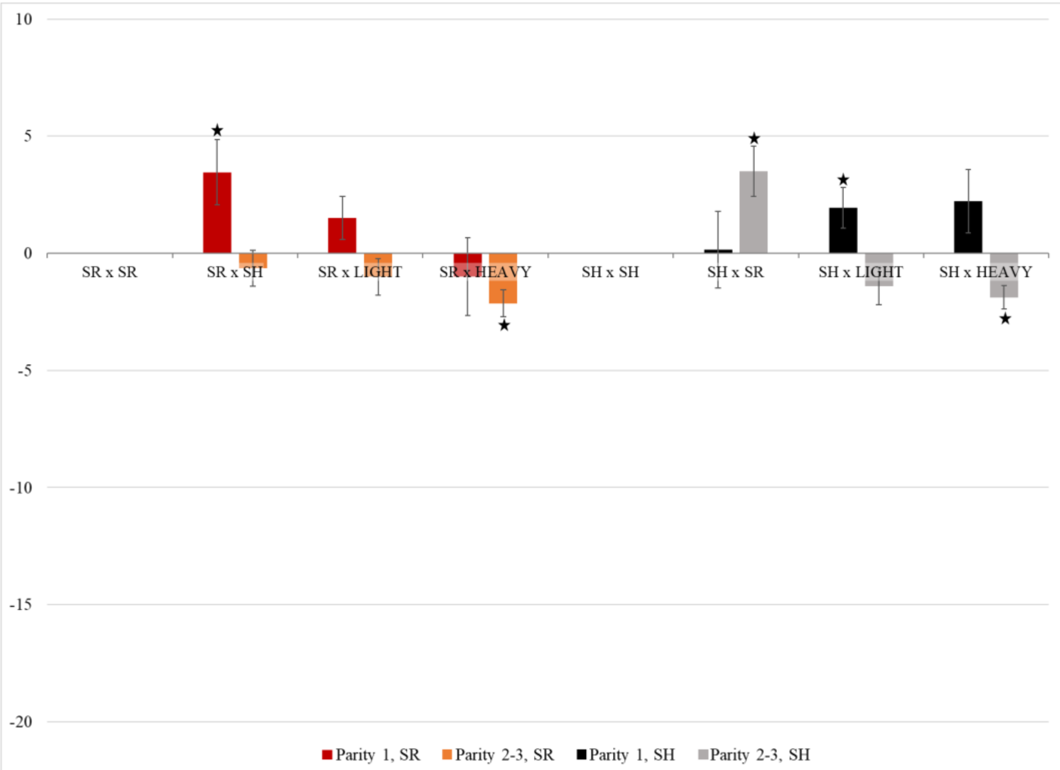


Figure 14. Effect of sire x dam combination on first to last insemination (FLI) interval for Model 1

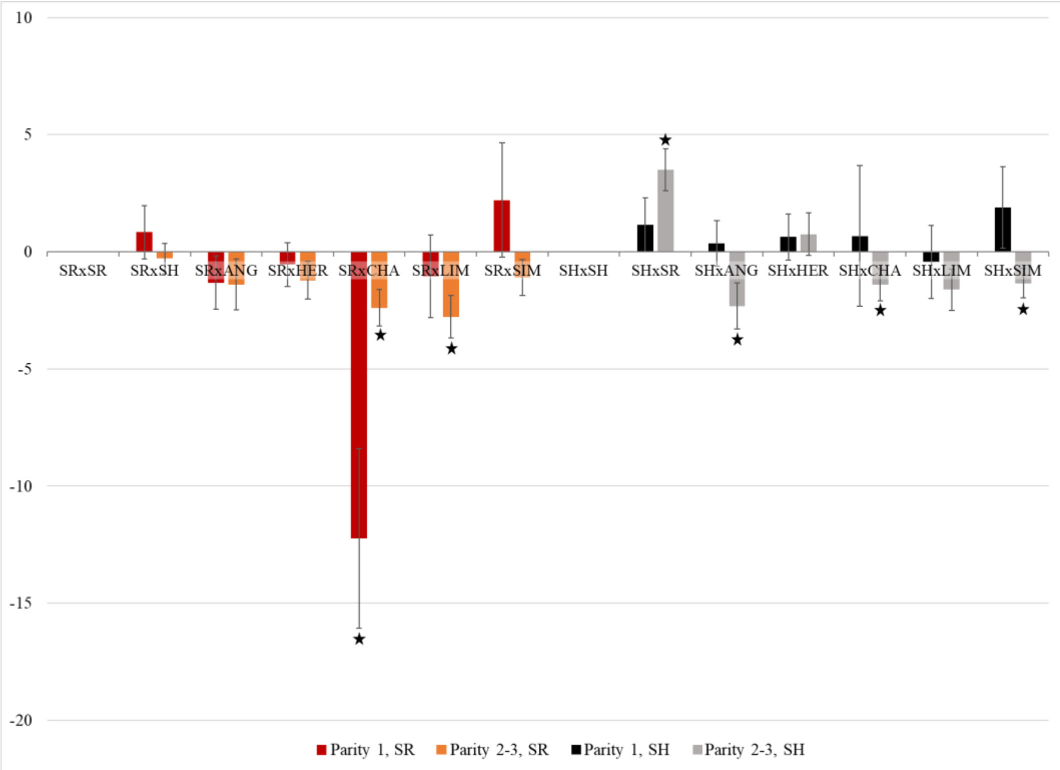


Figure 15. Effect of sire x dam combination on first to last insemination (FLI) interval for Model 2

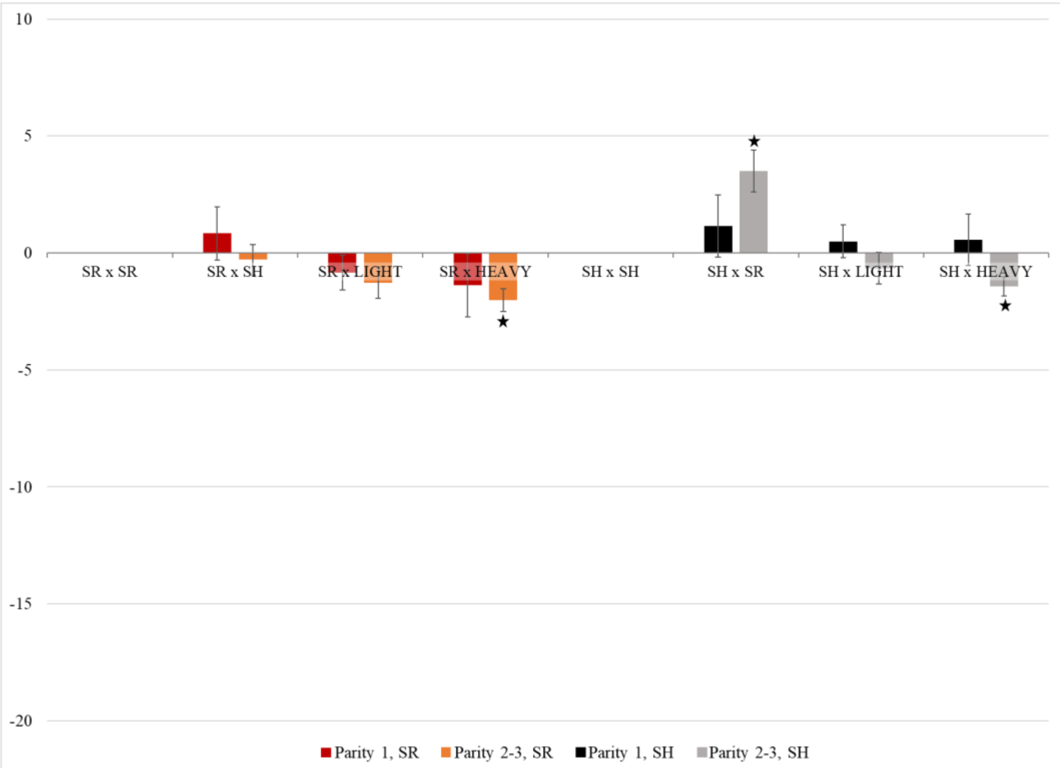


Figure 16. Effect of sire x dam combination on calving interval (CINT) for Model 1

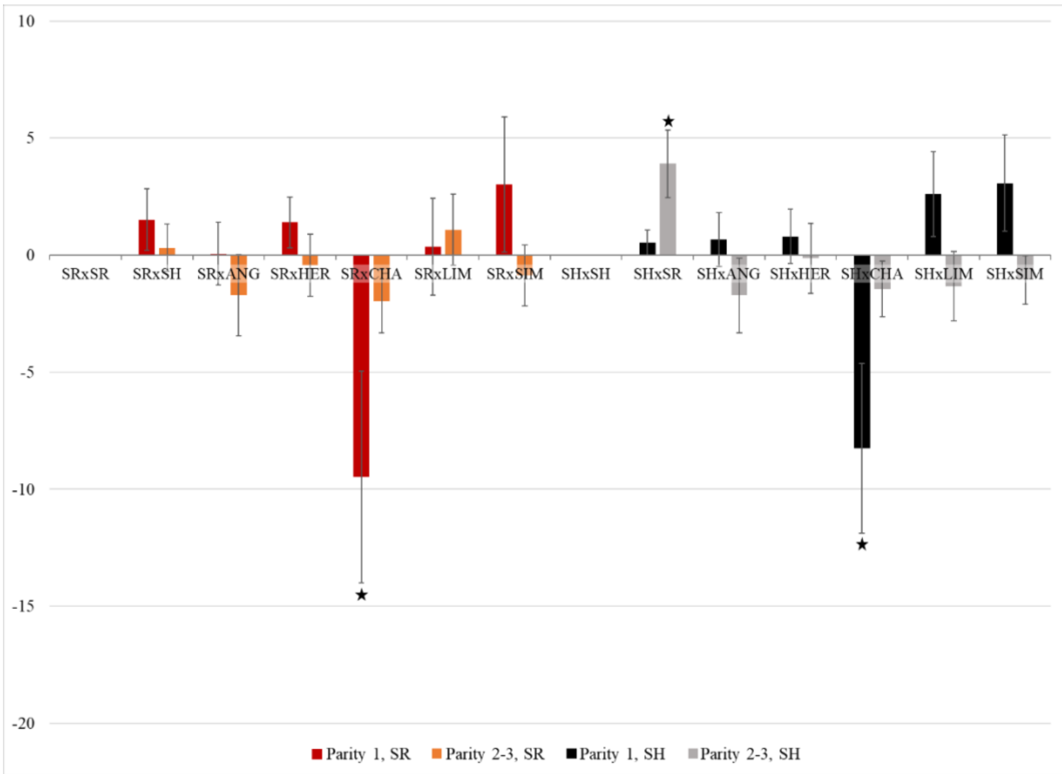


Figure 17. Effect of sire x dam combination on calving interval (CINT) for Model 2

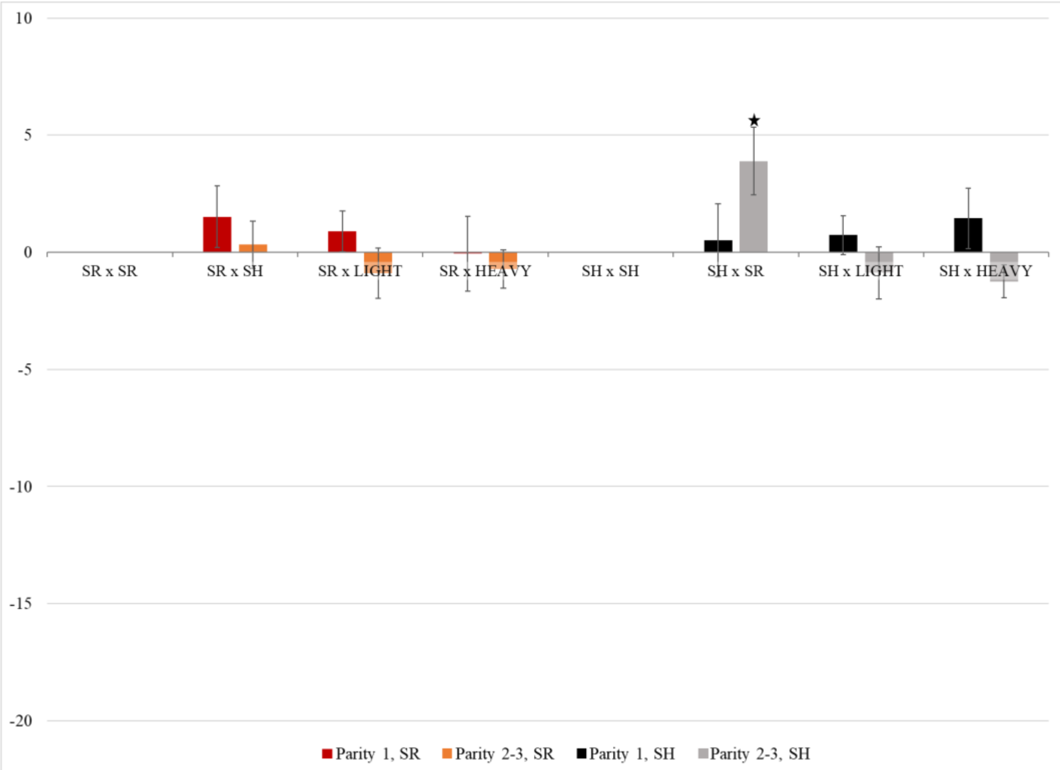


Figure 18. Effect of sire x dam combination on the number of inseminations (NINS) for Model 1

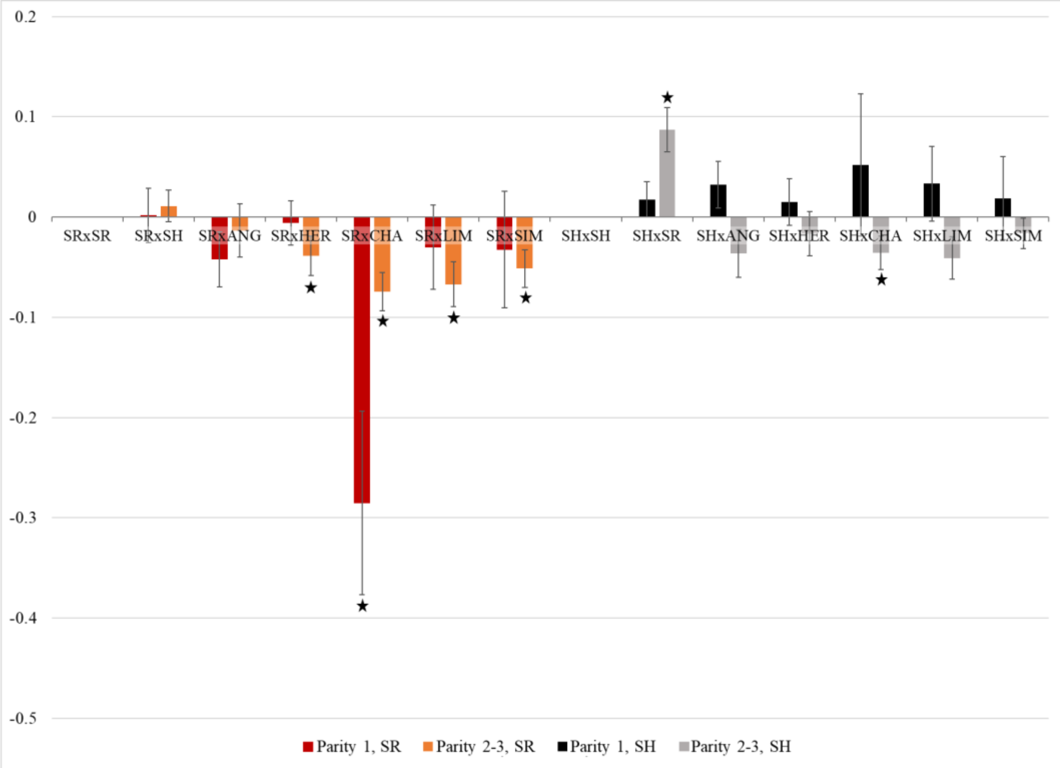
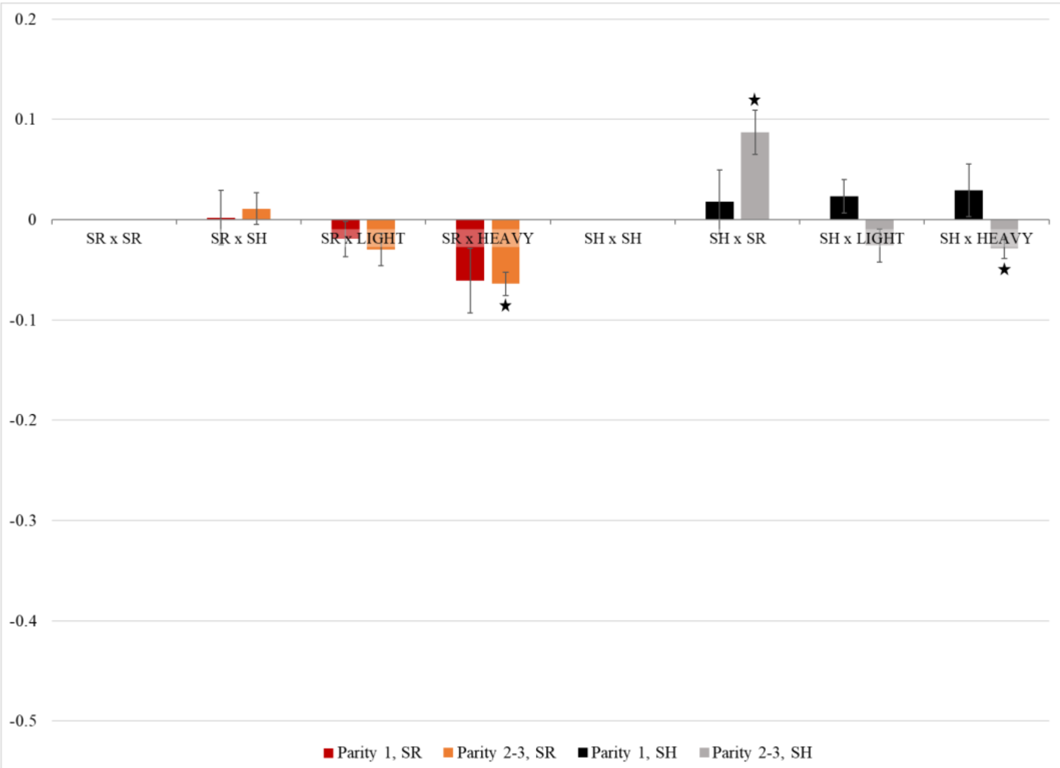


Figure 19. Effect of sire x dam combination on the number of inseminations (NINS) for Model 2



Survival

All sire beef breed combinations showed significantly lower results for LASTDIM and survival to next lactation (SURVNEXT), suggesting that cows inseminated with beef semen have a lower probability to survive to the next lactation (Figure 20-Figure 23). The decrease in LASTDIM records suggested an earlier culling. The mean LASTDIM across parities was 279 days. Whereas SURVNEXT was of special interest due to the large decrease in survival probability for Model 1 of 5.9% and 5.1% on average across beef-sired calvings in P1 and P2-3 compared to the purebred calvings, respectively. Moreover, even the dairy-crossbred cows showed a decrease in SURVNEXT of 3.4% and 4.9% for SR x SH in P1 and P2-3, and 3.8% and 4.3% for SH x SR in P1 and P2-3, respectively. It is worth noting again that due to the structure of the data, the results of survival to next lactation are only valid for parity 2, and not also for parity 3 as for the other traits.

Figure 20. Effect of sire x dam breed combination on lactation length (LASTDIM) for Model 1

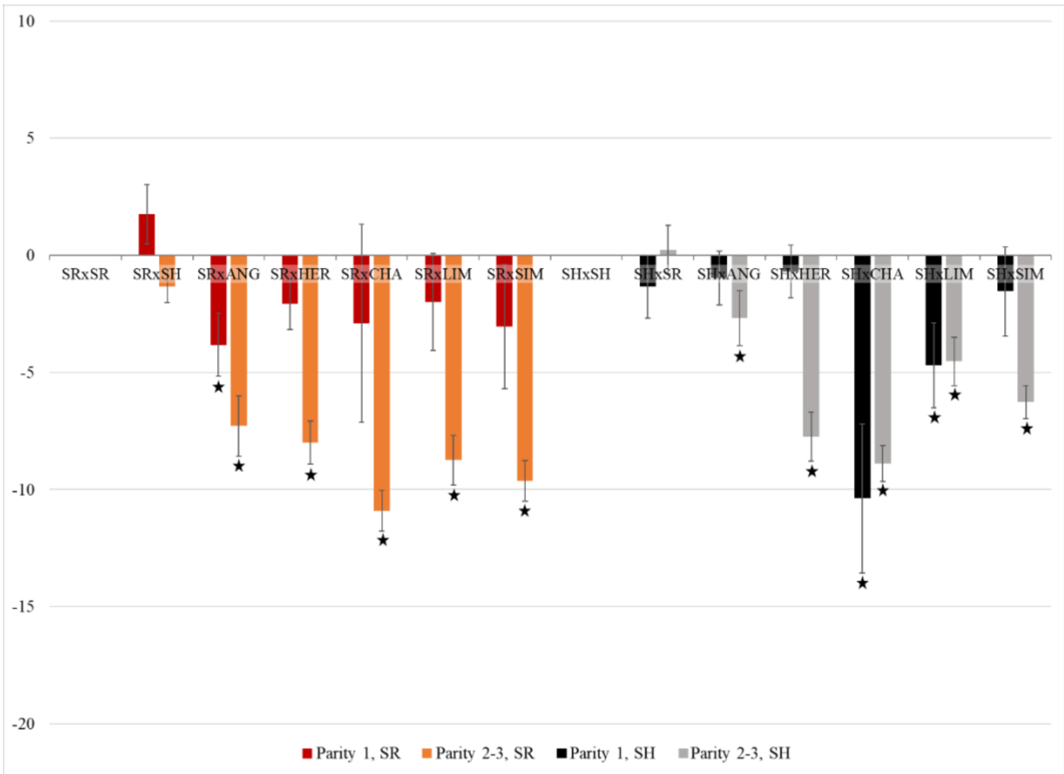


Figure 21. Effect of sire x dam breed combination on lactation length (LASTDIM) for Model 2

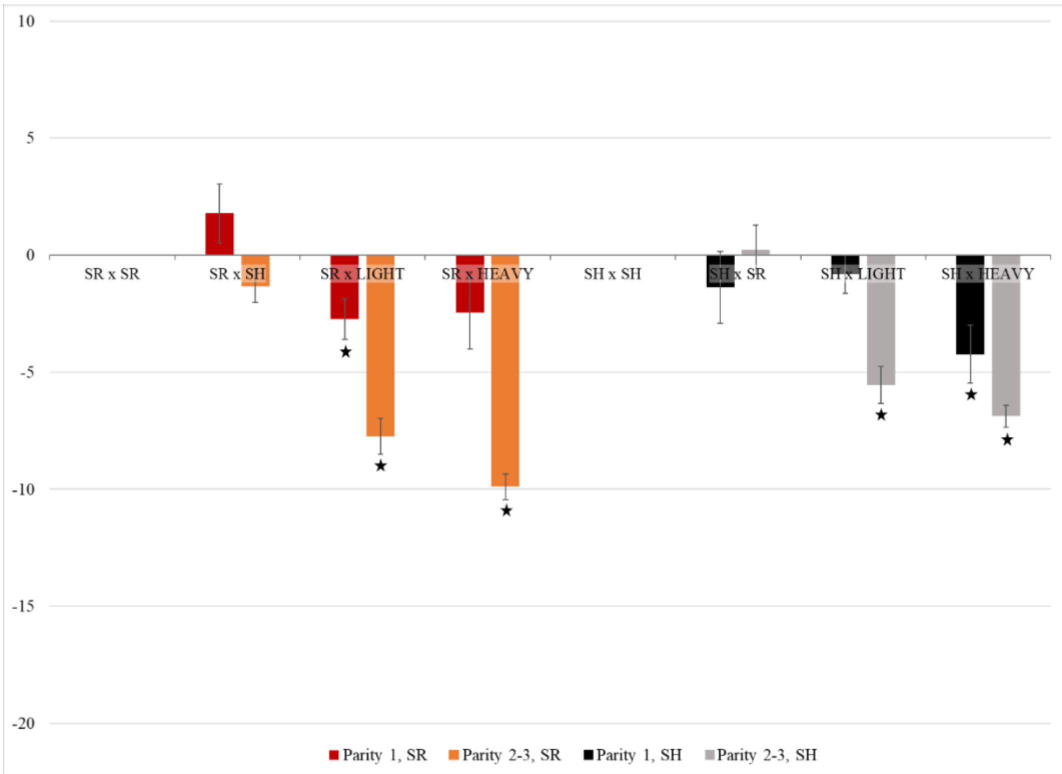


Figure 22. Effect of sire x dam breed combination on survival to next lactation (SURVNEXT) for Model 1

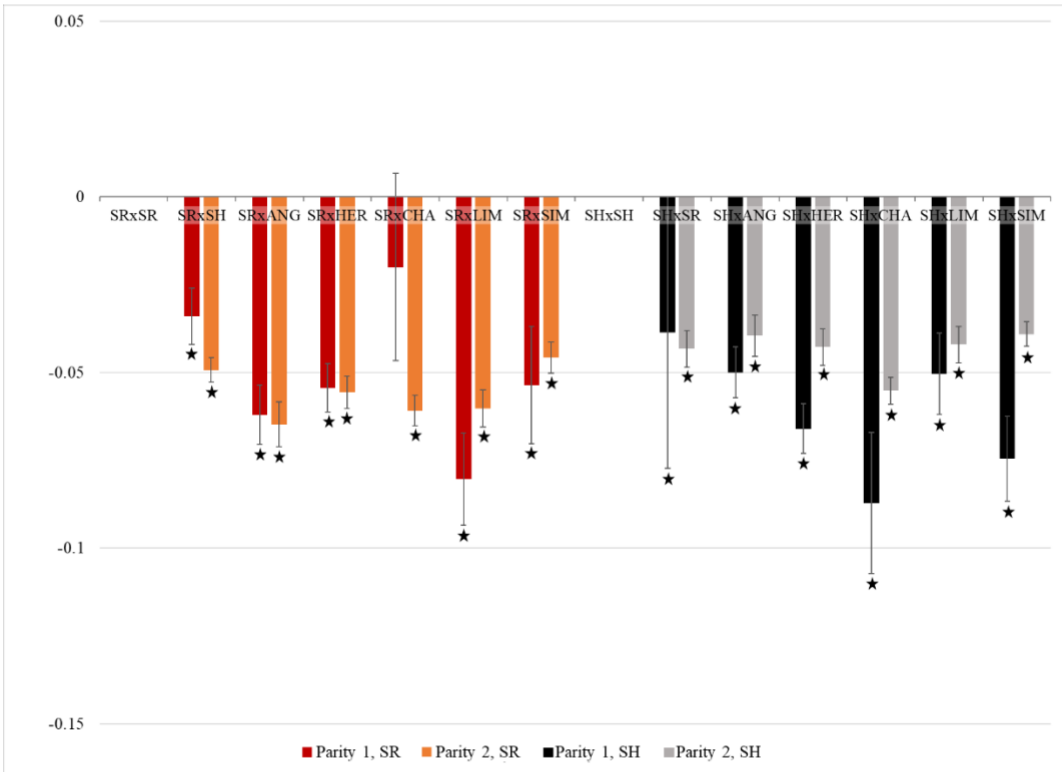
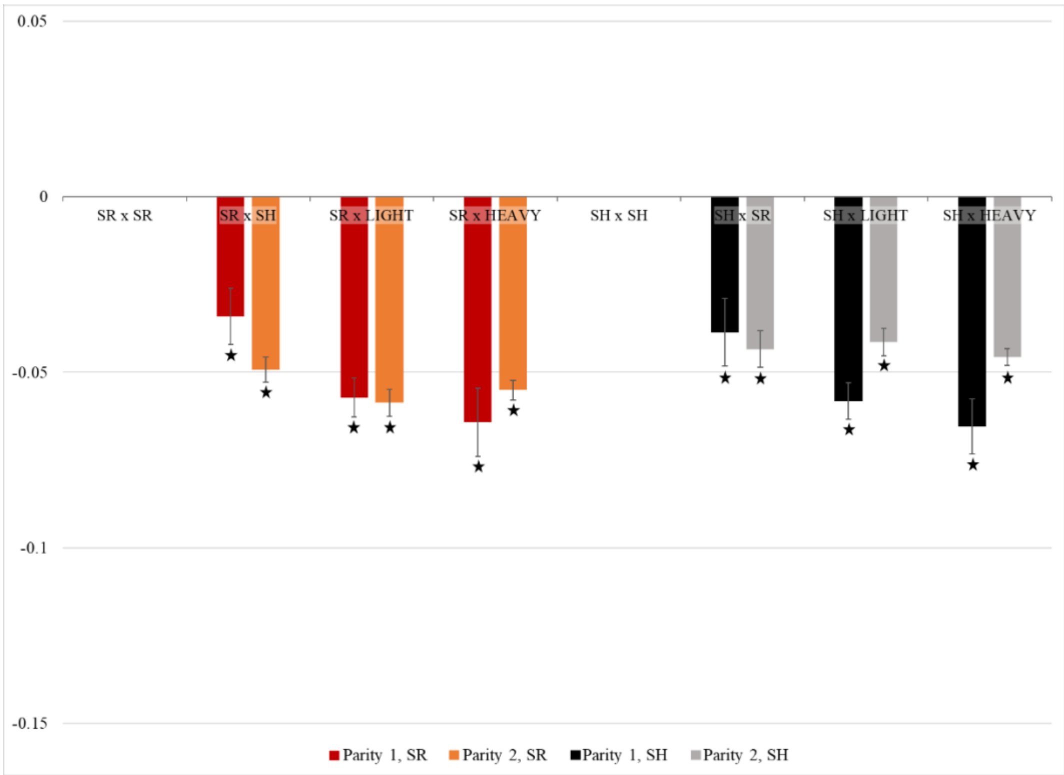


Figure 23. Effect of sire x dam breed combination on survival to next lactation (SURVNEXT) for Model 2



Effects of calving ease on subsequent lactation

The aim of Model 3 was to test whether the calving ease had the same effect over all types of calvings. The interaction effects between calving ease score and sire breed group by dam breed combination were not significant for P1. However, the interaction effects were more substantial for most of the traits in P2-3. Table 6 shows a summary of the effect over the traits for P2-3. All the numerator DF were 14.

Table 6. Summary of calving ease and breed combination interaction effect across traits for P2-3

	Trait	Den DF	F Value	Pr > F
Milk yield	CUMMY	661000	2.5	0.00
	MY305	383000	1.81	0.03
	CUMFAT	661000	1.93	0.02
	FAT305	383000	1.17	0.29
	CUMPROT	661000	2.12	0.01
	PROT305	383000	1.39	0.15
Fertility	CFI	488000	2.32	0.00
	CLI	487000	2.19	0.01
	FLI	486000	2.99	0.00
	CINT	222000	1.36	0.16
	NINS	491000	2.02	0.01
Surv.	LASTDIM	661000	1.14	0.31
	SURVNEXT	661000	1.49	0.10

Discussion

This study aimed to evaluate the performance of dairy cows for milk yield, fertility, and survival traits after giving birth to crossbred calves and compare this to the performance of dairy cows after giving birth to purebred dairy calves. Cows giving birth to beef breed crosses were shown to have lower overall performance in yield and survival traits.

Cumulative and 305-d milk yield were lower when breeding with beef bulls than when breeding with dairy bulls. These results were in accordance with previous reports (Berry and Ring, 2020b; Bittante *et al.*, 2020). Berry and Ring (2020b) reported a decrease in MY305 (in kg) of 45.22, 36.7, 101.1, 51.5, and 43.3 kg for ANG, HER, CHA, LIM, and SIM-sired calvings, respectively, compared to a pure dairy Holstein-Friesian calving. In this study, a larger effect was observed in CUMMY than MY305. Part of the explanation on a lower overall milk yield could be explained by a shorter lactation length (LASTDIM), i.e., cows being fewer days in production, which would affect CUMMY but not MY305 as the cows with a LASTDIM lower than 305 days were not included in the analyses. The effect on MY305 can be interpreted as a result of decreasing the average milk production during the first period. Moreover, any effect on MY305 was included in the CUMMY decrease, together with the effect of a shorter lactation length. Therefore, when not including an effect of lactation length in the model for MY305, the solutions can be expected to be smaller. The same pattern of decrease in yield was observed for fat and protein cumulative and 305-days milk yield.

Adjustment for previous lactation 305-d in the models was done for P2-3 to account for the potential association between milk yield and the farmers' decision to breed with beef semen. This study assumed that farmers would choose whether to inseminate with beef semen or not mainly based on known yield, however, that previous yield might be correlated with other traits in the next lactation. The regression coefficients of CUMMY, MY305, CUMFAT, FAT305, CUMPROT, and PROT305 on previous 305-day milk yield were 0.533, 0.422, 0.015, 0.009, 0.016, and 0.011, respectively. All the positive regressions for the milk traits indicate that cows with a low previous 305-day milk yield would also have a lower next milk yield. (Berry and Ring, 2020a) also reported a similar association between milk yield in the previous lactation and the likelihood of a dairy cow being mated to a beef or dairy sire. The linear regressions of fertility on previous 305-day milk yield however gave a less clear picture, with slightly positive estimates that are statistically different from zero. Although fertility per se is assumed to decrease in subsequent lactations (Bittante *et al.*, 2020), the previous lactation yield has only been shown to be moderately associated with fertility traits (Tiezzi *et al.*, 2012). Based on the correlation of the traits, low-yielding cows in the previous lactation are expected to have better fertility, i.e., shorter intervals in the next lactation. However, these differences in interval days are biologically insignificant (<3 d). The aforementioned hypothesis was confirmed by looking at previous milk yield deviation within groups that later had purebred or crossbred calves. SR and SH cows that later gave birth to beef crossbreds in P2-3 showed a significantly lower previous 305-day milk yield of 345 kg and 365 kg compared with cows that had purebred calves.

For fertility traits crossbred calvings had small effects on all fertility traits for most breed combinations, except for cows bred with CHA, an effect that did not show up anymore in Model 2 when grouping CHA with other heavy breeds. The effect was also largest for SR cows in parity 1. Cows bred with CHA were expected to calve earlier in the next lactation, thus also dry-off earlier. The last DIM of these groups of cows would be expected to be shorter as well, however, this was not seen. A possible explanation was that previous gestation length might affect the next lactation and there was no adjustment made in the model for it. The effect of gestation length was not included because of the systematic differences between the sire breeds with respect to gestation length. Therefore, adjusting for this would potentially mask some of the differences between the beef sire breeds and ultimately the effects of having giving birth to a dairy x beef calf.

Regarding the correlation between fertility in later lactations and calving age, previous studies of milk yield (Hansen *et al.*, 2006) have shown that the calving age seems to have a smaller effect than the parity effect. Parity effect can serve as an adjustment for milk yield within breeds but still, it is not simple to get an expected value for fertility traits (Tiezzi *et al.*, 2012). In that study, for example, the number of inseminations (NINS) in previous lactation insemination showed that beef x dairy inseminations were more likely to be successful than dairy x dairy inseminations.

As for survival traits, the decrease in the probability of surviving to the next lactation was overall large for cows with beef cross calvings. The average SURVNEXT for P1 was 65%, then an average decrease of 5.9% across beef-sired calvings in P1 turns into a probability of 59.1% to survive to the next lactation. While the average SURVNEXT for P2 was 34% which with a decrease of 5.1% in beef-sired calvings reduces the probability to survive to 28.9%. SURVNEXT was the only trait with the particularity that also the dairy breeds crosses had an almost as large decrease of survival probability as the crossbreds. Moreover, the effect of P1 lactation yield on P2 survival (LASTDIM), where a low-yielding first lactation cow would have had a shorter LASTDIM, is observable as a decrease of 1,000 kg would give 4.5 days shorter lactation length. The effect of P1 MY305 on P2 survival was small, where a 1,000 kg lower yield would give 0.02% lower survival. However, it is questionable if this regression should be linear, as it has been shown that high-yielding cows are not protected from being culled, whereas having very low yields is increasing the risk of culling substantially (Barrier and Haskell, 2011; Berry *et al.*, 2019).

About the effects of calving ease by sire group interaction on subsequent lactation, it has not been shown that the interaction would significantly affect the next lactation period. While in first parity the effect was not significant at all, opposite to the general expectation of having more difficult calvings in primiparous cows, for second parity it was barely significant considering all the other highly significant factors and the F values were much lower. Because the estimated effects of beef cross calvings were obtained after adjusting for calving difficulties, a possible hypothesis could be that the total effect would be larger. However, preliminary results without the CE effect in the model (results not shown) showed very similar results, probably because the differences are so small and there were few difficult calvings.

Conclusion

This study evaluated the performance of dairy cows for milk yield, fertility, and survival traits after giving birth to crossbred calves and compared this to the performance of dairy cows after giving birth to purebred dairy calves. Differences in breed combinations' least-squares means were computed for first and later parities from three different models, independently for each trait but with both SR and SH dam dairy breeds simultaneously. Of the evaluated traits, milk yield and survival showed the largest effect of the beef breed by dam combinations. The cows that gave birth to calves sired by CHA showed the largest decrease (>400kg) in cumulative milk yield when being bred to SR and SH. Moreover, cows inseminated with beef semen and dairy semen from different dairy breeds, i.e., those with crossbred calves, showed to have a shorter lactation length and lower probabilities to survive to the next lactation, compared to the purebreds. The interaction effects between calving ease and sire breed group by dam breed combination were significant for most of the traits in P2-3, but not in P1. More research is needed to understand the impact of the calf breed combination on the subsequent cow performance, particularly on fertility traits. Nevertheless, all three evaluated trait complexes are important for farm profit and should therefore be considered together when combining sire and dam breeds in dairy herds.

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Popular Science Summary

For the past decades, the dairy industry has reported an increase in mating beef bulls to dairy cows to produce calves with a better musculature that could be sold for meat production at a higher price. As a consequence, much of the research has focused on improving the carcass traits of these newborn calves. However, how this combination of beef by dairy affects the subsequent performance of the dairy cows after calving is not well-known. After giving birth, the milk production of the cow during the lactation period is assumed to influence the farmers' decision to inseminate them with beef or dairy semen, as a high-yielding cow would likely be selected to be mated to dairy bulls to improve the next generation, while a low-yielding cow would more likely be inseminated with beef semen with the aim of culling.

Besides milk production, other important traits to evaluate during the lactation period of the cow are its fertility, or its ability to get pregnant again, and its survival to the next lactation. Because Swedish farmers might lack useful information to understand the impact of combining beef x dairy on the cow’s next lactation period, this study evaluated the performance of dairy cows for milk yield, fertility, and survival traits after giving birth to crossbred calves, and compared this to the performance of dairy cows after giving birth to purebred dairy calves.

The performance of the two most common dairy breeds, Swedish Red (SR) and Swedish Holstein (SH), were analysed after breeding with purebred SR and SH bulls, as well as purebred beef bulls Angus, Hereford, Charolais, Limousin, and Simmental. The study revealed that the milk production was lower after mating beef x dairy compared to the purebred matings, especially when using Charolais sires with purebred SR or SH dams. As for fertility, the breed combination did not show to affect the cows’ performance. In addition, all cows inseminated with beef semen showed a lower probability to survive to the next lactation.

More research is needed to understand the impact of the calf breed combination on the subsequent cow performance. Nevertheless, all three evaluated traits are important for the profit of the farms and should therefore be considered together when combining sire and dam breeds in dairy herds.

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Appendices

Appendix 1. Estimated differences in breed combinations' LS Means for milk traits

Appendix Table 7. Estimated differences of breed combinations least-squares means in cumulative milk yield (CUMMY) in first and later parities from different models

		Parity 1			Parity 2-3		
Sire breed	Dam breed	Estimate	SE	P-value	Estimate	SE	P-value
Model 1							
SR	SR	0			0		
	SH	66.32	45.07	0.14	74.21	27.74	0.01
	ANG	-150.64	47.68	0.00	-364.48	50.09	<.0001
	HER	-93.74	38.61	0.02	-278.80	36.03	<.0001
	CHA	-222.21	150.68	0.14	-411.65	33.76	<.0001
	LIM	-148.74	73.84	0.04	-295.14	41.57	<.0001
	SIM	-147.91	94.26	0.12	-290.23	34.09	<.0001
SH	SH	0			0		
	SR	-76.51	54.30	0.16	-31.45	40.64	0.44
	ANG	-33.10	40.68	0.42	-169.88	45.89	0.00
	HER	-7.66	40.14	0.85	-329.09	40.75	<.0001
	CHA	-435.28	113.18	0.00	-439.49	30.15	<.0001
	LIM	-123.78	65.08	0.06	-203.54	40.34	<.0001
	SIM	-168.82	68.01	0.01	-263.96	27.67	<.0001
Model 2							
SR	SR	0			0		
	SH	66.85	45.07	0.14	74.07	27.74	0.01
	LIGHT	-115.80	30.99	0.00	-307.99	29.77	<.0001
	HEAVY	-159.94	54.97	0.00	-337.48	21.59	<.0001
SH	SH	0			0		
	SR	-77.84	54.29	0.15	-32.35	40.64	0.43
	LIGHT	-20.55	29.12	0.48	-260.41	30.82	<.0001
	HEAVY	-187.73	44.18	<.0001	-315.97	18.73	<.0001

Appendix Table 8. Estimated differences of breed combinations least-squares means in 305-day milk yield (MY305) in first and later parities from different models

		Parity 1			Parity 2-3		
Sire breed	Dam breed	Estimate	SE	P-value	Estimate	SE	P-value
Model 1							
SR	SR	0			0		
	SH	19.77	28.40	0.49	134.98	18.20	<.0001
	ANG	-24.58	30.41	0.42	-114.89	32.63	0.00
	HER	-27.07	24.04	0.26	-37.16	23.49	0.11
	CHA	-140.55	94.63	0.14	-92.14	22.86	<.0001
	LIM	-60.55	46.11	0.19	1.54	27.68	0.96
	SIM	-59.33	58.97	0.31	6.62	22.51	0.77
SH	SH	0			0		
	SR	-28.85	33.15	0.38	-41.75	24.16	0.08
	ANG	16.05	24.92	0.52	-98.45	27.33	0.00
	HER	4.62	24.70	0.85	-35.64	24.50	0.15
	CHA	-111.98	71.19	0.12	-98.29	18.40	<.0001
	LIM	14.34	39.87	0.72	-13.13	24.43	0.59
	SIM	-99.30	41.66	0.02	-53.65	16.71	0.00
Model 2							
SR	SR	0			0		
	SH	20.10	28.40	0.48	135.08	18.20	<.0001
	LIGHT	-25.78	19.44	0.18	-63.80	19.39	0.00
	HEAVY	-72.31	34.39	0.04	-30.93	14.39	0.03
SH	SH	0			0		
	SR	-28.35	33.15	0.39	-42.23	24.16	0.08
	LIGHT	10.32	17.90	0.56	-64.03	18.46	0.00
	HEAVY	-50.02	27.17	0.07	-61.63	11.36	<.0001

Appendix Table 9. Estimated differences of breed combinations least-squares means in cumulative fat yield (CUMFAT) in first and later parities from different models

		Parity 1			Parity 2-3		
Sire breed	Dam breed	Estimate	SE	P-value	Estimate	SE	P-value
Model 1							
SR	SR	0			0		
	SH	0.69	1.84	0.71	-0.64	1.16	0.58
	ANG	-9.05	1.95	<.0001	-18.18	2.09	<.0001
	HER	-5.34	1.58	0.00	-14.62	1.51	<.0001
	CHA	-11.95	6.16	0.05	-20.54	1.41	<.0001
	LIM	-4.87	3.02	0.11	-15.89	1.74	<.0001
	SIM	-7.55	3.86	0.05	-15.65	1.42	<.0001
SH	SH	0			0		
	SR	-2.76	2.22	0.21	0.29	1.70	0.87
	ANG	-1.15	1.66	0.49	-6.86	1.92	0.00
	HER	-1.94	1.64	0.24	-12.81	1.70	<.0001
	CHA	-16.98	4.63	0.00	-16.99	1.26	<.0001
	LIM	-6.05	2.66	0.02	-9.26	1.69	<.0001
	SIM	-6.32	2.78	0.02	-10.87	1.16	<.0001
Model 2							
SR	SR	0			0		
	SH	0.72	1.84	0.69	-0.64	1.16	0.58
	LIGHT	-6.75	1.27	<.0001	-15.83	1.24	<.0001
	HEAVY	-6.70	2.25	0.00	-17.57	0.90	<.0001
SH	SH	0			0		
	SR	-2.80	2.22	0.21	0.25	1.70	0.88
	LIGHT	-1.58	1.19	0.19	-10.24	1.29	<.0001
	HEAVY	-7.77	1.81	<.0001	-12.78	0.78	<.0001

Appendix Table 10. Estimated differences of breed combinations least-squares means in 305-day fat yield (FAT305) in first and later parities from different models

Sire breed	Dam breed	Parity 1			Parity 2-3		
		Estimate	SE	P-value	Estimate	SE	P-value
Model 1							
SR	SR	0			0		
	SH	-1.25	1.12	0.26	1.09	0.78	0.16
	ANG	-3.74	1.20	0.00	-8.44	1.40	<.0001
	HER	-2.91	0.95	0.00	-4.43	1.01	<.0001
	CHA	-9.02	3.72	0.02	-7.70	0.98	<.0001
	LIM	-0.90	1.81	0.62	-4.30	1.19	0.00
	SIM	-3.73	2.32	0.11	-4.12	0.96	<.0001
SH	SH	0			0		
	SR	-1.29	1.30	0.32	-0.03	1.04	0.98
	ANG	1.05	0.98	0.28	-3.02	1.17	0.01
	HER	-2.50	0.97	0.01	-1.14	1.05	0.28
	CHA	-3.15	2.80	0.26	-3.57	0.79	<.0001
	LIM	-0.01	1.57	1.00	-2.12	1.05	0.04
	SIM	-2.38	1.64	0.15	-2.53	0.72	0.00
Model 2							
SR	SR	0			0		
	SH	-1.23	1.12	0.27	1.10	0.78	0.16
	LIGHT	-3.15	0.76	<.0001	-5.80	0.83	<.0001
	HEAVY	-2.89	1.35	0.03	-5.48	0.62	<.0001
SH	SH	0			0		
	SR	-1.24	1.30	0.34	-0.04	1.04	0.97
	LIGHT	-0.75	0.70	0.29	-1.98	0.79	0.01
	HEAVY	-1.43	1.07	0.18	-2.83	0.49	<.0001

Appendix Table 11. Estimated differences of breed combinations least-squares means in cumulative protein yield (CUMPROT) in first and later parities from different models

		Parity 1			Parity 2-3		
Sire breed	Dam breed	Estimate	SE	P-value	Estimate	SE	P-value
Model 1							
SR	SR	0			0		
	SH	1.92	1.54	0.21	0.78	0.96	0.42
	ANG	-5.82	1.63	0.00	-14.84	1.73	<.0001
	HER	-3.65	1.32	0.01	-12.18	1.24	<.0001
	CHA	-7.12	5.17	0.17	-15.97	1.17	<.0001
	LIM	-4.56	2.53	0.07	-12.99	1.44	<.0001
	SIM	-5.53	3.23	0.09	-12.12	1.18	<.0001
SH	SH	0			0		
	SR	2.47	1.86	0.19	0.93	1.40	0.51
	ANG	-1.06	1.39	0.45	-7.09	1.58	<.0001
	HER	-0.58	1.38	0.67	-12.63	1.41	<.0001
	CHA	-14.50	3.88	0.00	-15.75	1.04	<.0001
	LIM	-5.02	2.23	0.02	-8.95	1.39	<.0001
	SIM	-5.31	2.33	0.02	-9.86	0.96	<.0001
Model 2							
SR	SR	0			0		
	SH	1.94	1.54	0.21	0.77	0.96	0.42
	LIGHT	-4.48	1.06	<.0001	-13.08	1.03	<.0001
	HEAVY	-5.26	1.89	0.01	-13.80	0.75	<.0001
SH	SH	0			0		
	SR	-2.51	1.86	0.18	-0.96	1.40	0.50
	LIGHT	-0.83	1.00	0.41	-10.23	1.06	<.0001
	HEAVY	-6.52	1.51	<.0001	-11.83	0.65	<.0001

Appendix Table 12. Estimated differences of breed combinations least-squares means in 305-day protein yield (PROT305) in first and later parities from different models

		Parity 1			Parity 2-3		
Sire breed	Dam breed	Estimate	SE	P-value	Estimate	SE	P-value
Model 1							
SR	SR	0			0		
	SH	0.17	0.89	0.85	2.45	0.59	<.0001
	ANG	-1.21	0.95	0.20	-5.90	1.05	<.0001
	HER	-1.28	0.76	0.09	-3.87	0.76	<.0001
	CHA	-3.80	2.97	0.20	-5.04	0.74	<.0001
	LIM	-1.78	1.45	0.22	-2.53	0.89	0.00
	SIM	-2.58	1.85	0.16	-1.98	0.73	0.01
SH	SH	0			0		
	SR	-0.94	1.04	0.36	-1.21	0.78	0.12
	ANG	0.69	0.78	0.38	-4.69	0.88	<.0001
	HER	-0.27	0.78	0.73	-3.22	0.79	<.0001
	CHA	-3.40	2.24	0.13	-4.44	0.59	<.0001
	LIM	-0.37	1.25	0.77	-2.95	0.79	0.00
	SIM	-2.59	1.31	0.05	-2.81	0.54	<.0001
Model 2							
SR	SR	0			0		
	SH	0.18	0.89	0.84	2.45	0.59	<.0001
	LIGHT	-1.23	0.61	0.04	-4.57	0.62	<.0001
	HEAVY	-2.34	1.08	0.03	-3.25	0.46	<.0001
SH	SH	0			0		
	SR	-0.92	1.04	0.37	-1.23	0.78	0.12
	LIGHT	0.21	0.56	0.71	-3.88	0.59	<.0001
	HEAVY	-1.70	0.85	0.05	-3.43	0.37	<.0001

Appendix 2. Estimated differences in breed combinations' LS Means for fertility traits

Appendix Table 13. Estimated differences of breed combinations least-squares means in calving to first insemination (CFI) interval in first and later parities from different models

Sire breed	Dam breed	Parity 1 Estimate	SE	P-value	Parity 2-3 Estimate	SE	P-value
Model 1							
SR	SR	0			0		
	SH	2.01	0.66	0.00	-0.59	0.38	0.12
	ANG	1.47	0.67	0.03	-1.01	0.63	0.11
	HER	1.31	0.55	0.02	0.30	0.47	0.52
	CHA	0.78	2.24	0.73	-0.15	0.45	0.74
	LIM	-0.44	1.03	0.67	0.61	0.54	0.25
	SIM	1.53	1.43	0.28	-0.34	0.45	0.45
SH	SH	0			0		
	SR	-1.28	0.78	0.10	0.33	0.53	0.53
	ANG	0.73	0.57	0.20	-1.49	0.57	0.01
	HER	1.83	0.57	0.00	-0.15	0.53	0.77
	CHA	0.69	1.73	0.69	-0.45	0.40	0.26
	LIM	1.73	0.91	0.06	-0.68	0.51	0.18
	SIM	-0.12	1.02	0.90	-0.40	0.36	0.27
Model 2							
SR	SR	0			0		
	SH	2.01	0.66	0.00	-0.59	0.38	0.12
	LIGHT	1.35	0.44	0.00	-0.16	0.38	0.68
	HEAVY	0.27	0.79	0.74	-0.02	0.28	0.94
SH	SH	0			0		
	SR	-1.29	0.78	0.10	0.33	0.53	0.53
	LIGHT	1.28	0.41	0.00	-0.76	0.39	0.05
	HEAVY	0.88	0.64	0.17	-0.48	0.24	0.05

Appendix Table 14. Estimated differences of breed combinations least-squares means in calving to last insemination (CLI) interval in first and later parities from different models

		Parity 1			Parity 2-3		
Sire breed	Dam breed	Estimate	SE	P-value	Estimate	SE	P-value
Model 1							
SR	SR	0			0		
	SH	3.46	1.39	0.01	-0.64	0.77	0.41
	ANG	1.45	1.41	0.31	-1.84	1.29	0.15
	HER	1.54	1.15	0.18	-0.55	0.95	0.57
	CHA	-8.72	4.69	0.06	-2.35	0.92	0.01
	LIM	-1.74	2.17	0.42	-1.99	1.09	0.07
	SIM	3.38	3.00	0.26	-2.06	0.91	0.02
SH	SH	0			0		
	SR	0.16	1.63	0.92	3.50	1.07	0.00
	ANG	1.67	1.21	0.17	-3.66	1.16	0.00
	HER	2.17	1.20	0.07	0.49	1.08	0.65
	CHA	0.57	3.69	0.88	-1.82	0.81	0.02
	LIM	0.62	1.92	0.75	-2.49	1.04	0.02
	SIM	4.84	2.14	0.02	-1.64	0.74	0.03
Model 2							
SR	SR	0			0		
	SH	3.45	1.39	0.01	-0.64	0.77	0.41
	LIGHT	1.50	0.92	0.10	-1.00	0.78	0.20
	HEAVY	-1.01	1.67	0.55	-2.15	0.57	0.00
SH	SH	0			0		
	SR	0.15	1.63	0.93	3.50	1.07	0.00
	LIGHT	1.92	0.87	0.03	-1.41	0.80	0.08
	HEAVY	2.23	1.35	0.10	-1.89	0.50	0.00

Appendix Table 15. Estimated differences of breed combinations least-squares means in first to last insemination (FLI) interval in first and later parities from different models

Sire breed	Dam breed	Parity 1 Estimate	SE	P-value	Parity 2-3 Estimate	SE	P-value
Model 1							
SR	SR	0			0		
	SH	0.84	1.14	0.46	-0.28	0.65	0.66
	ANG	-1.32	1.15	0.25	-1.40	1.09	0.20
	HER	-0.55	0.93	0.55	-1.22	0.81	0.13
	CHA	-12.24	3.82	0.00	-2.40	0.77	0.00
	LIM	-1.05	1.76	0.55	-2.77	0.92	0.00
	SIM	2.21	2.44	0.37	-1.09	0.77	0.16
SH	SH	0			0		
	SR	1.16	1.33	0.39	3.50	0.90	0.00
	ANG	0.36	0.98	0.71	-2.32	0.99	0.02
	HER	0.63	0.98	0.52	0.75	0.91	0.41
	CHA	0.67	3.00	0.82	-1.40	0.68	0.04
	LIM	-0.44	1.56	0.78	-1.62	0.88	0.07
	SIM	1.89	1.74	0.28	-1.35	0.63	0.03
Model 2							
SR	SR	0			0		
	SH	0.83	1.14	0.46	-0.29	0.65	0.66
	LIGHT	-0.84	0.74	0.26	-1.29	0.66	0.05
	HEAVY	-1.39	1.35	0.30	-2.01	0.48	<.0001
SH	SH	0			0		
	SR	1.15	1.33	0.39	3.50	0.90	0.00
	LIGHT	0.49	0.70	0.48	-0.66	0.68	0.33
	HEAVY	0.56	1.10	0.61	-1.43	0.42	0.00

Appendix Table 16. Estimated differences of breed combinations least-squares means in calving interval (CINT) in first and later parities from different models

		Parity 1			Parity 2-3		
Sire breed	Dam breed	Estimate	SE	P-value	Estimate	SE	P-value
Model 1							
SR	SR	0			0		
	SH	1.51	1.32	0.25	0.32	1.01	0.75
	ANG	0.06	1.34	0.96	-1.71	1.75	0.33
	HER	1.40	1.09	0.20	-0.43	1.33	0.75
	CHA	-9.48	4.53	0.04	-1.95	1.35	0.15
	LIM	0.35	2.06	0.86	1.09	1.51	0.47
	SIM	3.02	2.89	0.30	-0.88	1.30	0.50
SH	SH	0			0		
	SR	0.54	1.56	0.73	3.90	1.44	0.01
	ANG	0.66	1.15	0.56	-1.72	1.59	0.28
	HER	0.80	1.16	0.49	-0.14	1.50	0.93
	CHA	-8.26	3.63	0.02	-1.45	1.19	0.22
	LIM	2.61	1.82	0.15	-1.33	1.48	0.37
	SIM	3.07	2.06	0.14	-1.06	1.04	0.31
Model 2							
SR	SR	0			0		
	SH	1.51	1.32	0.25	0.32	1.01	0.75
	LIGHT	0.89	0.87	0.31	-0.90	1.07	0.40
	HEAVY	-0.06	1.59	0.97	-0.71	0.82	0.39
SH	SH	0			0		
	SR	0.52	1.56	0.74	3.89	1.44	0.01
	LIGHT	0.73	0.83	0.38	-0.88	1.10	0.42
	HEAVY	1.45	1.29	0.26	-1.24	0.71	0.08

Appendix Table 17. Estimated differences of breed combinations least-squares means in the number of inseminations (NINS) in first and later parities from different models

		Parity 1			Parity 2-3		
Sire breed	Dam breed	Estimate	SE	P-value	Estimate	SE	P-value
Model 1							
SR	SR	0			0		
	SH	0.002	0.027	0.947	0.011	0.016	0.489
	ANG	-0.042	0.027	0.126	-0.013	0.027	0.614
	HER	-0.006	0.022	0.791	-0.039	0.020	0.048
	CHA	-0.285	0.092	0.002	-0.075	0.019	<.0001
	LIM	-0.030	0.042	0.475	-0.067	0.022	0.003
	SIM	-0.032	0.058	0.576	-0.051	0.019	0.006
SH	SH	0			0		
	SR	0.017	0.032	0.583	0.087	0.022	<.0001
	ANG	0.032	0.023	0.168	-0.036	0.024	0.129
	HER	0.015	0.023	0.514	-0.017	0.022	0.448
	CHA	0.052	0.071	0.463	-0.035	0.017	0.033
	LIM	0.033	0.037	0.370	-0.041	0.021	0.056
	SIM	0.019	0.041	0.648	-0.016	0.015	0.290
Model 2							
SR	SR	0			0		
	SH	0.002	0.027	0.940	0.011	0.016	0.493
	LIGHT	-0.019	0.018	0.274	-0.030	0.016	0.061
	HEAVY	-0.061	0.032	0.058	-0.064	0.012	<.0001
SH	SH	0			0		
	SR	0.018	0.032	0.581	0.087	0.022	<.0001
	LIGHT	0.023	0.017	0.163	-0.026	0.016	0.116
	HEAVY	0.029	0.026	0.265	-0.028	0.010	0.005

Appendix 3. Estimated differences in breed combinations' LS Means for survival traits

Appendix Table 18. Estimated differences of breed combinations least-squares means in last day in milk (LASTDIM) in first and later parities from different models

		Parity 1			Parity 2-3		
Sire breed	Dam breed	Estimate	SE	P-value	Estimate	SE	P-value
Model 1							
SR	SR	0			0		
	SH	1.77	1.26	0.16	-1.32	0.71	0.06
	ANG	-3.82	1.34	0.00	-7.29	1.28	<.0001
	HER	-2.07	1.09	0.06	-7.99	0.92	<.0001
	CHA	-2.89	4.23	0.49	-10.91	0.86	<.0001
	LIM	-2.00	2.07	0.34	-8.75	1.06	<.0001
	SIM	-3.04	2.65	0.25	-9.63	0.87	<.0001
SH	SH	0			0		
	SR	-1.34	1.52	0.38	0.25	1.04	0.81
	ANG	-0.96	1.14	0.40	-2.68	1.17	0.02
	HER	-0.69	1.13	0.54	-7.75	1.04	<.0001
	CHA	-10.38	3.18	0.00	-8.88	0.77	<.0001
	LIM	-4.70	1.83	0.01	-4.53	1.03	<.0001
	SIM	-1.53	1.91	0.42	-6.27	0.71	<.0001
Model 2							
SR	SR	0			0		
	SH	1.78	1.26	0.16	-1.32	0.71	0.06
	LIGHT	-2.46	1.54	0.11	-9.90	0.55	<.0001
	HEAVY	-2.75	0.87	0.00	-7.75	0.76	<.0001
SH	SH	0			0		
	SR	-1.38	1.52	0.36	0.24	1.04	0.82
	LIGHT	-0.83	0.82	0.31	-5.54	0.79	<.0001
	HEAVY	-4.23	1.24	0.00	-6.87	0.48	<.0001

Appendix Table 19. Estimated differences of breed combinations least-squares means in survival to next lactation (SURVNEXT) in first and later parities from different models

		Parity 1			Parity 2-3		
Sire breed	Dam breed	Estimate	SE	P-value	Estimate	SE	P-value
Model 1							
SR	SR	0			0		
	SH	-0.034	0.008	<.0001	-0.049	0.004	<.0001
	ANG	-0.062	0.008	<.0001	-0.065	0.006	<.0001
	HER	-0.054	0.007	<.0001	-0.056	0.005	<.0001
	CHA	-0.020	0.027	0.455	-0.061	0.004	<.0001
	LIM	-0.080	0.013	<.0001	-0.060	0.005	<.0001
	SIM	-0.054	0.017	0.001	-0.046	0.004	<.0001
SH	SH	0			0		
	SR	-0.039	0.010	<.0001	-0.043	0.005	<.0001
	ANG	-0.050	0.007	<.0001	-0.039	0.006	<.0001
	HER	-0.066	0.007	<.0001	-0.043	0.005	<.0001
	CHA	-0.087	0.020	<.0001	-0.055	0.004	<.0001
	LIM	-0.050	0.012	<.0001	-0.042	0.005	<.0001
	SIM	-0.075	0.012	<.0001	-0.039	0.004	<.0001
Model 2							
SR	SR	0			0		
	SH	-0.034	0.008	<.0001	-0.049	0.004	<.0001
	LIGHT	-0.057	0.005	<.0001	-0.059	0.004	<.0001
	HEAVY	-0.064	0.010	<.0001	-0.055	0.003	<.0001
SH	SH	0			0		
	SR	-0.039	0.010	<.0001	-0.043	0.005	<.0001
	LIGHT	-0.058	0.005	<.0001	-0.041	0.004	<.0001
	HEAVY	-0.065	0.008	<.0001	-0.046	0.002	<.0001