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Fertility traits of purebred Holsteins and 2- and 3-breed crossbred heifers and cows obtained from Swedish Red, Montbéliarde, and Brown Swiss sires

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ABSTRACT

The objective of this study was to compare fertility traits of heifers and primiparous cows from Swedish Red × Holstein (SR × HO; n = 634 and 581, respectively), Montbéliarde × Holstein (MO × HO; n = 126 and 114, respectively), Brown Swiss × Holstein (BS × HO; n = 59 and 50, respectively), and MO × (SR × HO) (n = 241 and 139, respectively) crossbreds, versus those of Holstein heifers and cows (HO; n = 3,483 and 2,549, respectively). Animals were born between 2007 and 2011, and belonged to 4 herds located in northern Italy. Heifers were compared for age at first service (AFS), age at first conception (AFC), interval between first service and conception (IFC), nonreturn rate at 56 d after first service (NR56), conception rate at first service (CR), and number of inseminations required for conception (INS). The same traits were evaluated in primiparous cows, except that AFS and AFC were replaced with days at first service (DFS) and days open (DO). The AFS, AFC, IFC, DFS, and DO traits were continuous variables and were thus analyzed under a proportional hazards Cox model that properly accounted for censoring among cows that were culled or failed to conceive. The NR56, CR, and INS traits were analyzed as binary traits using logistic regression. Our results indicated that, among heifers, SR × HO crossbreds had a better chance of having an earlier first service and conceiving earlier than HO, with hazard ratios (HR) of 1.31 for AFS and 1.34 for AFC. Similarly, MO × (SR × HO) crossbreds differed from HO heifers in this regard (HR = 1.18 and 1.24, respectively). For the primiparous cows, all crossbreds showed significant differences for DFS, DO, and IFC relative to purebred HO, with the exception of the BS × HO crossbreds. The MO × HO, SR × HO, and MO × (SR × HO) crossbred cows showed increased chances of having fewer DFS (HR = 1.40, 1.30, and 1.27, respectively), fewer DO (HR = 1.59, 1.43, and 1.58, respectively), and fewer IFC (HR = 1.52, 1.26, and 1.39, respectively) than HO cows. All crossbred genotypes, including BS × HO cows, showed higher probabilities for higher NR56, higher CR, and lower INS than purebred HO cows. Together, these findings indicate that the studied crossbred cows have higher reproductive potential than Holsteins.

Key words: crossbreeding, fertility, survival analysis, Swedish Red, Montbéliarde

INTRODUCTION

Reproductive efficiency in dairy cows has declined worldwide (Lucy, 2001), and Norman et al. (2007) reported unsatisfactory reproductive performance as the primary reason for culling cows during the first 3 lactations. To overcome this problem, many of the leading dairy countries have incorporated fertility traits into their national genetic evaluation systems (VanRaden et al., 2004; Miglior et al., 2005). Many studies have reported a negative correlation between milk production and fertility traits (Pryce et al., 2002, 2004; Tiezzi et al., 2011), indicating that intensive selection of animals for milk production in the past decades may have affected fertility negatively, especially through worsening of body condition (Tiezzi et al., 2013). However, other factors may be associated with reduced fertility over time, including increasing herd size, greater use of confinement housing, labor shortages, and higher inbreeding coefficient (Lucy, 2001). Crossbreeding programs appear to offer a viable strategy for alleviating such problems in the dairy industry, because crossbreeding decreases the homozygosis that arises from the intensive selection of pure breeds. Weigel and Barlass (2003) comprehensively analyzed the experiences of US dairy producers who were using crossbreeding programs and found that most of the respondents cited the need to improve cow fertility, health, and survival as the reasons for their interest in crossbreeding. Heins and Hansen (2012) reported the results of a 5-lactation study on the production and fertility traits of pure Holstein (**HO**), Montbéliarde (**MO**) × HO, Scandinavian Red (**SCR**) × HO, and Normande (**NO**) × HO. Crossbred cows showed fewer days open (**DO**) compared

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with HO, and the groups differed in their changes in DO with increased lactation number. The DO of NO × HO crossbreds was consistent across lactations; MO × HO crossbreds tended to have fewer DO as the lactation number increased, and SCR × HO crossbreds tended to show an increase in DO as the lactation number increased. However, similar to other studies with crossbred cows, the DO data were truncated at 250 d (Heins et al., 2006; Bjelland et al., 2011; Blöttner et al., 2011). This is the approach used by the Animal Improvement Programs Laboratory (Beltsville, MD) of the USDA for routine genetic evaluations in the United States (VanRaden et al., 2004); however, it might result differences in reduced fertility between breed groups (Heins et al., 2006). Other fertility measures commonly used to evaluate reproductive performance are the number of days between calving and first service (**DFS**) and the interval between first service and conception (**IFC**). Some authors reported differences in DFS between HO and crossbred cows, with a lower DFS for crossbreds (Heins et al., 2006; Walsh et al., 2008; Blöttner et al., 2011). However, DFS does not exactly correspond to a cow's ability to resume cyclic activity after calving; instead, it includes both the interval between calving and first heat and the voluntary waiting period during which cows are intentionally not inseminated. The voluntary waiting period reflects management decisions related to cow health postpartum and is also typically influenced by season, parity, and milk yield during early lactation (DeJarnette et al., 2007). The availability of data for these time-related variables is influenced by the times of culling and data collection. Data are missed from cows that have not undergone insemination or conception by the time of culling or data recording (censored records), introducing bias into the fertility parameters. Several methods have been proposed to deal with the analysis of censored data. Linear Gaussian models for handling right-censored data were developed by Sorensen et al. (1998), who used the technique of data augmentation under a Bayesian framework (Tanner and Wong, 1987). This approach, which provides all posterior conditional distributions in a standard form after the censored records are updated with values sampled from a left-truncated density, has been used successfully to analyze fertility traits in dairy cattle (Chang et al., 2006; González-Recio et al., 2006; Hou et al., 2009). Variations among non-Gaussian censored variables can be investigated using survival analysis techniques (Cox, 1972; Prentice and Gloeckler, 1978; Ducrocq et al., 1988), which can properly account for censored and uncensored records and use all available information (Vargas et al., 1998; Allore et al., 2001; Schneider et al., 2005).

The reproductive ability of cows can also be expressed in terms of success traits, such as the number of inseminations required for conception (**INS**), conception at first service (**CR**), and nonreturn to first service (i.e., whether another service follows within a given period, usually 56 or 90 d). Such traits may also be computed for heifers, allowing comparison between cows and heifers. However, the estimates of those traits may be biased by culling or incomplete data.

The objective of the present study was to investigate the effect of crossbreeding on fertility traits by comparing data from HO primiparous cows and heifers against 2- and 3-way crossbred heifers and cows obtained from Swedish Red (**SR**), Montbéliarde, and Brown Swiss (**BS**) sires and HO dams, using an approach that accounts for censored information.

MATERIALS AND METHODS

Data Collection

Fertility records for the heifers and primiparous cows from 4 herds in northern Italy were collected using the Afifarm management software (version 3.06; SAE Afikim, Afikim, Israel). All animals were born between 2007 and 2011. All farms used the same 3-way rotational crossbreeding program, in which HO, SR, and MO stocks were used to obtain 2-breed SR × HO and 3-breed MO × (SR × HO) crossbred cows. The farmers also had MO × HO and BS × HO crossbreds, which were included in the analysis. The milk yields and milk compositions of these cows were previously described by Malchiodi et al. (2011). Briefly, the average milk yield was 34.3 ± 7.8 kg, fat content was 4.1 ± 0.8%, and protein content was 3.4 ± 0.3%. Relative to HO cows, SR × HO, and MO × (SR × HO) crossbreds produced less milk (−8.2 and −4.6%, respectively) but had slightly higher protein content (+2.6 and +3.2%, respectively). In contrast, those traits did not differ significantly between HO and MO × HO.

Editing Procedure and Trait Definition

Fertility traits for heifers were age at first service (**AFS**), age at first conception (**AFC**), IFC, CR, nonreturn rate at 56 d after first service (**NR56**), and INS. For primiparous cows, the same traits were evaluated, except that AFS and AFC were omitted, and DFS and DO were evaluated. The CR and NR56 traits were coded as binary variables (0, 1), where 1 was assigned when pregnancy at first service was confirmed (for CR) and when a second insemination did not occur within 56 d from the first service (for NR56).

Pregnancy was confirmed by a subsequent calving or (when the former information was not available) with a pregnancy diagnosis by a veterinarian. If information on the first insemination was not available or the first insemination and data collection were less than 56 d apart, the insemination event was considered a missing record. If data were available for a subsequent calving, the pregnancy was required to be within 30 d of the average of pregnancy days calculated for each breed group. If the pregnancy time was outside this limit, the data were considered missing. Inseminations occurring within 6 d of each other were considered to be a single service, and only the information from the last breeding was included. The trait INS was considered an ordinal categorical variable with 5 classes, the last of which was an open class of 5 or more inseminations. Cows without a diagnosis of pregnancy or a subsequent calving after the last service were penalized by the addition of a penalty insemination, as previously described by Hou et al. (2009).

All time variables (AFC, AFS, DFS, DO, and IFC) were subjected to survival analysis, which allowed us to use censored records. The AFS and AFC of heifers were required to be <650 and <750 d, respectively, and IFC was restricted to between 0 and 356 d for both heifers and cows; DFS was required to be between 0 and 250 d, and DO had to be between 20 and 365 d. Data below the lower limits were excluded from the analysis. Data above the upper limits were replaced with the value of the upper limit and considered to be censored records. Cows that were in the herds but had not been inseminated by the time of the data collection were considered censored for DFS if more than 20 d had passed between calving and data collection. In such a case, the first service was replaced with the last day available. If 20 or fewer days had passed, the record was deleted. Heifers and cows not present in the herd at the moment of sampling were considered censored if the culling occurred after an age of 450 d for heifers and after 65 d postcalving for primiparous cows (these were the approximate averages for AFS and DFS, respectively); in such cases, AFS and DFS were replaced with the culling date. Heifers and cows culled before this point were not included in the analysis. For animals in which no pregnancy test had been performed or that had an abortion after a pregnancy diagnosis, the data were considered censored and DO, AFC, and IFC were calculated from the data of the last insemination event. For those cows that had not yet received a first insemination, IFC was considered a missing value and was not used in the analysis. After editing, a total of 3,483 HO heifers were compared with 634 SR × HO, 241 MO × (SR × HO), 126 MO × HO, and 59 BS × HO crossbred heifers, and a total of 2,549 HO primiparous cows were compared with 581 SR × HO, 139 MO × (SR × HO), 114 MO × HO, and 50 BS × HO crossbred cows.

Statistical Analyses

The fertility interval traits (AFS, AFC, DFS, DO, and IFC) were subjected to survival analysis. Beforehand, the survivor function for the general population was estimated by the Kaplan-Meier method (Kaplan and Meier, 1958). The linear regression of $\ln\{-\ln[S(t)]\}$ on $\ln(t)$, where $S(t)$ is the Kaplan-Meier estimated survivor function, was used to check the suitability of the assumption of a Weibull baseline hazard (Ducrocq et al., 1988). Because the relationship between $\ln\{-\ln[S(t)]\}$ and $\ln(t)$ was not linear, the assumption of a Weibull distribution function for the baseline was rejected and the fertility interval traits were modeled using a proportional hazard model (Cox, 1972) of the general form

$$h(t) = h_0(t)\exp\{\mathbf{x}'\boldsymbol{\beta}\},$$

where $h(t)$ is the hazard of either receiving the first service at time t for AFS, becoming pregnant at time t for AFC, receiving the first service after calving at time t for DFS, becoming pregnant after calving at time t for DO, or becoming pregnant after first insemination at time t for IFC; $h_0(t)$ is the baseline hazard function; $\boldsymbol{\beta}$ is an unknown vector of fixed regression coefficients for a set of systematic effects; and $\mathbf{x}'$ is a vector of indicator variables for systematic effects. Because the distribution function for the baseline $h_0(t)$ was left completely unspecified, the resulting model was a semiparametric proportional hazard model (i.e., a Cox model). The survival models included the systematic effects of herd, breed group, and the season-year of birth or season-year of calving, for heifers and cows, respectively. The IFC was analyzed using the same model but considering the systematic effect of the season-year of first insemination. All analyses were carried out using the PHREG procedure of SAS (SAS Institute, 2011).

Logistic regression was used to investigate the influence of a set of explanatory variables on CR, NR56, and INS. The effect of the investigated set of explanatory variables on the outcome of the aforementioned traits has been evaluated using estimates and confidence intervals of odds ratio (**OR**), a multiplicative measure of probability that ranges from 0 to infinity. Values of OR >1 or OR <1 indicate an increased or decreased probability of conceiving at the first insemination, not receiving an insemination after 56 d from the first insemination, or having a lower number of inseminations to conception, respectively, compared with a "reference condition" given by the intercept of the logistic regression model. To estimate OR, logistic regression analysis was performed using the LOGISTIC procedure of SAS, considering the fixed effects of herd, breed group, and season-year of first insemination.

RESULTS AND DISCUSSION

Descriptive Statistics

Descriptive statistics for the time-related reproductive traits for each breed group are reported in Table 1 and those for the studied success traits are shown in Table 2. On average, uncensored heifers received the first insemination at the age of approximately 14 to 15 mo and became pregnant at about 15 to 16 mo, with an IFC that ranged from 21 to 28 d between different breed groups. Censored records showed higher values and greater variation than uncensored records for all breed groups. In a previous study, Vargas et al. (1998) reported a censorship rate of 23% for AFC. In our study, however, this rate ranged from 1.42% (for SR × HO cows) to only 11.86% (for BS × HO cows). Importantly, in the study by Vargas et al. (1998), only heifers with a confirmed date of calving were considered as having a failure date, and those authors suggested that the high proportion of censored data could be the result of the large variation and the high mean for age at first calving. The censored data represented a greater proportion of all animals in the case of primiparous cows, reflecting the higher culling rate of cows and the greater bias that may affect fertility estimates when these data are excluded. The higher proportion of censored cow data suggests that survival analysis may be more useful for studying reproductive performance in cows than in heifers. The proportion of censored records was different between breed groups, suggesting a possible difference in culling rate of cows. However, this difference may also be due to the different numbers of animals for each group. The HO cows showed a mean DFS of 64 d and a mean DO of 109 d, with an IFC of 42 d. Among crossbred cows, BS × HO showed the highest means for DFS, DO, and IFC (65 d, 73 d, and 60 d, respectively). In contrast, MO × HO had the lowest means for both DFS and DO (56 d and 70 d, respectively), and also had the lowest mean for IFC, with conception occurring an average of only 20 d after first insemination. Similar to that in heifers, the variation among primiparous cows was higher for censored than for uncensored records.

Regarding success traits (Table 2), on average, HO heifers needed 1.8 inseminations to conceive. Conception rate at first service and NR56 showed similar values (52 and 58%, respectively). In HO primiparous cows, average INS was 2.5 and CR and NR56 were 34% and 40%, respectively. Norman et al. (2009) reported the same values for CR and INS when considering 2006 data from first-lactation HO cows. However, in the same study, the average for DFS and DO (85 d and 142 d, respectively) were higher than that in our study for HO primiparous cows. Compared with HO, all crossbreds showed improved fertility measures, in both heifers and primiparous cows. Crossbred heifers had a CR ranging from 55 to 61%, whereas primiparous cows had a CR in the range of 45 to 55%. Considering INS, crossbred heifers needed between 1.65 and 1.73 inseminations, and crossbred primiparous cows between 1.93 and 2.22 inseminations to conceive.

The Kaplan-Meier survival curves for AFS and AFC (Figure 1a, 1b) differed among the breed groups. At 15 mo of age, more than 80% of the BS × HO and SR × HO crossbreds, 70% of the MO × (SR × HO) crossbreds, 64% of the MO × HO crossbreds, and only 54% of the pure HO heifers had received the first insemination. At the same age, less than 40% of the pure HO heifers were pregnant, versus more than 60% of the BS × HO and SR × HO crossbreds heifers and around 50% of the MO × HO and MO × (SR × HO) heifers. About 50% of the HO heifers and 60% of the SR × HO crossbred heifers were pregnant after the first service (Figure 1c). The other crosses showed intermediate values.

The differences among breed groups were not pronounced in terms of DFS (Figure 2a), probably because a common voluntary waiting period was used. Importantly, because both AFS and DFS can be affected by this type of on-farm management decision, the use of these parameters as absolute measures of cow fertility must be considered carefully. The proportion of animals that became pregnant at first insemination was lower in primiparous cows than in heifers (Figure 2c). In fact, only 33% of the purebred HO cows and around 50% of the crossbred cows became pregnant from the first service. Kaplan-Meier survival curves for DO (Figure 2b) showed that, at 100 d postpartum, the proportion of pregnant cows was 49% for pure HO, around 65% for BS × HO and SR × HO crossbred cows, and around 75% for MO × HO and MO × (SR × HO) crossbred cows. Heins et al. (2008) found a positive effect of crossbreeding but a lower proportion of pregnant cows before 100 d postpartum for both purebred HO and crossbred Jersey (**JE**) × HO cows (31 and 41%, respectively). In another study, Olson et al. (2011) reported a similar frequency of pregnant cows at 150 d after calving for first-lactation pure HO and JE × HO crossbreds cows (56 and 66%, respectively).

Table 1. Descriptive statistics of time traits: age at first service (AFS), age at first conception (AFC), interval between first service and conception (IFC), days to first service (DFS), and days open (DO) for heifers and primiparous cows

			Uncensored records		Censored records	
Trait[1]	No.	Censored, %	Mean	SD	Mean	SD
Heifers						
AFS, d						
HO	3,483	1.09	446.6	35.7	589.6	64.6
BS × HO	59	1.69	428.2	29.5	513	—
MO × HO	126	0.79	439.1	36.0	650	—
SR × HO	634	0.32	427.8	30.2	528	8.5
MO × (SR × HO)	241	1.24	439.8	39.9	609.3	70.4
AFC, d						
HO	3,483	7.87	474.8	58.9	518.4	88.4
BS × HO	59	11.86	456.4	77.7	504.6	18
MO × HO	126	3.17	463.5	58.2	515.8	99.4
SR × HO	634	1.42	453.0	53.6	494.3	88.4
MO × (SR × HO)	241	9.13	459.9	54.0	500	104.9
IFC, d						
HO	3,445	6.97	28.1	45.3	57.9	73.4
BS × HO	58	12.07	25.2	56.8	93	113
MO × HO	125	2.40	24.1	44.9	45.7	58.8
SR × HO	632	1.11	25.3	45.0	49.7	94.9
MO × (SR × HO)	238	7.98	21.0	37.1	32.7	54.8
Primiparous cows						
DFS, d						
HO	2,549	7.49	64.2	20.1	85.2	74.6
BS × HO	50	—	65.6	17.6	—	—
MO × HO	114	0.88	60.0	15.7	96.4	60.9
SR × HO	581	2.07	63.8	16.7	49.9	23.4
MO × (SR × HO)	139	11.51	56.0	16.1	85.2	74.6
DO, d						
HO	2,549	24.83	109.1	64.4	129.0	95.4
BS × HO	50	8.00	107.8	73.6	198.5	139.0
MO × HO	114	11.40	83.7	37.8	132.9	99.6
SR × HO	581	9.12	95.6	50.6	102.0	96.2
MO × (SR × HO)	139	28.78	70.4	34.5	164.0	87.5
IFC, d						
HO	2,358	18.70	42.1	68.4	133.8	130.0
BS × HO	50	8.00	46.1	60.7	74.4	86.1
MO × HO	113	10.62	20.0	45.5	65.7	110.6
SR × HO	569	7.21	24.0	35.5	50.8	75.7
MO × (SR × HO)	123	18.70	32.4	46.5	110.3	80.0

[1]HO = Holstein; BS = Brown Swiss; MO = Montbéliarde; SR = Swedish Red.

Effect of Breed Combination on Fertility Traits

The differences in the reproduction time interval traits between crossbreds and purebred HO were greater in primiparous cows than in heifers (Table 3). However, differences were also found among heifers. The SR × HO and MO × (SR × HO) crossbred heifers showed a better chance of being inseminated (HR = 1.31 and HR = 1.18, respectively) and becoming pregnant (HR = 1.34 and HR = 1.24, respectively) with time, compared with pure HO heifers ($P < 0.05$). However, the HR of IFC was close to 1.00 for all crossbred combinations and different only for SR × HO crossbred heifers compared with HO heifers ($P < 0.05$). With the exception of BS × HO, the crossbred heifers tended to have a better chance of becoming pregnant following the first insemination compared with HO. In agreement with these results, all crossbred heifers showed numerically higher probabilities for NR56, becoming pregnant after the first insemination, and having fewer inseminations required for conception, compared with HO (Table 4). However, only SR × HO crossbred heifers were significantly different from purebreds for these traits, with a 45% higher probability of NR56, a 54% higher probability of conception at first service, and a 50% higher probability of having a lower INS compared with HO heifers.

Crossbred primiparous cows were significantly different from HO ($P < 0.05$) for all traits (Tables 3 and 4), except for BS × HO, which were not significantly different from HO cows for DFS, DO, or IFC (Table 3). Blöttner et al. (2011) also failed to find any difference in DFS and DO when comparing HO cows with BS ×

Table 2. Mean and number of observations (N) for success traits [nonreturn at 56 d after the first insemination (NR56) and conception rate at first service (CR)], and for number of insemination to conception (INS) for heifers and primiparous cows

	Heifers		Primiparous cows	
Trait[1]	N	Mean	N	Mean
NR56				
HO	3,339	0.58	2,204	0.40
BS × HO	57	0.61	50	0.62
MO × HO	125	0.62	108	0.53
SR × HO	630	0.64	562	0.51
MO × (SR × HO)	224	0.61	107	0.54
CR				
HO	3,358	0.52	2,213	0.34
BS × HO	57	0.56	49	0.55
MO × HO	124	0.55	107	0.49
SR × HO	629	0.61	562	0.45
MO × (SR × HO)	228	0.60	112	0.54
INS				
HO	3,445	1.83	2,358	2.53
BS × HO	58	1.72	50	2.22
MO × HO	125	1.73	113	2.02
SR × HO	632	1.71	569	2.14
MO × (SR × HO)	238	1.65	123	1.93

[1]HO = Holstein; BS = Brown Swiss; MO = Montbéliarde; SR = Swedish Red.

HO primiparous cows, but they did observe a difference between these 2 breed groups (in favor of crossbred cows) in terms of DFS during the second and third lactations. In a study examining records from 5 lactations, Dechow et al. (2007) found that DO was 21 d longer for pure HO compared with BS × HO, but found no difference for age at first calving. These results suggest that the reproductive potential of these crossbreeds may increase with parity. In our study, however, BS × HO showed higher probabilities for NR56, CR, and INS than purebred HO, with OR = 2.26, 2.17 and 1.80, respectively (Table 4). This is in contrast to the findings of Blöttner et al. (2011), who observed no significant difference in the number of inseminations across the first 3 calvings in these crossbreds compared with HO cows.

The MO × HO, SR × HO, and MO × (SR × HO) cows had a better chance of being inseminated early after calving (HR = 1.40, 1.30, and 1.27, respectively) and conceiving after calving (HR = 1.59, 1.43, and 1.58, respectively) compared with HO cows (Table 3). In contrast to our findings in heifers, IFC also differed for all crossbreds compared with HO cows ($P < 0.05$). The MO × HO, SR × HO, and MO × (SR × HO) cows had 52, 26, and 39% higher risks, respectively, of conceiving after the first service, compared with HO cows. Previously, Heins et al. (2006) reported lower DFS and DO for NO × HO and MO × HO primiparous cows versus HO cows, but found no difference in DFS between SCR × HO cows and pure HO cows. Walsh et al. (2008) reported a higher DFS for HO cows compared with MO × HO cows (73 and 68 d, respectively), but no difference in DFS between NO × HO and HO, or in DO or INS between HO and crossbred cows. However, their analysis imposed a 13-wk breeding season, which limited the maximum value of DO and may have decreased potential differences between breed groups. Furthermore, the strain of HO (Irish Holstein-Friesian) used in the study of Walsh et al. (2008) might differ from other strains of HO, based on historical differences in selection. Consistent with this notion, a study comparing JE × HO with HO (Heins et al. 2008) found no difference in the proportion of cows that were pregnant within 120 d of lactation, but they found differences when comparing those pregnant within 150 and 180 d of lactation (59 and 61%, respectively, for HO cows; and 75 and 77%, respectively, for JE × HO cows). In the same study, DO was lower for JE × HO than for HO cows (−23 d), but the conception rate after 6 inseminations did not differ between the 2 breed groups.

In accordance with our observations for time-related reproductive traits, MO × HO, SR × HO, and MO × (SR × HO) primiparous cows showed higher probabilities for NR56 (OR = 1.69, 1.37, and 2.03, respectively) and CR (OR = 1.76, 1.44, and 2.26, respectively) than HO cows. Previously, Heins et al. (2006) reported a higher CR for MO × HO and NO × HO cows compared with pure HO cows, and a tendency for SCR × HO cows to have a higher CR than HO cows. Contrary to these results, Walsh et al. (2008) found no difference between HO cows and MO × HO and NO × HO crossbred cows in terms of CR and INS. In the present study, CR and INS showed favorable values for crossbred cows, with MO × HO, SR × HO, and MO × (SR × HO) having

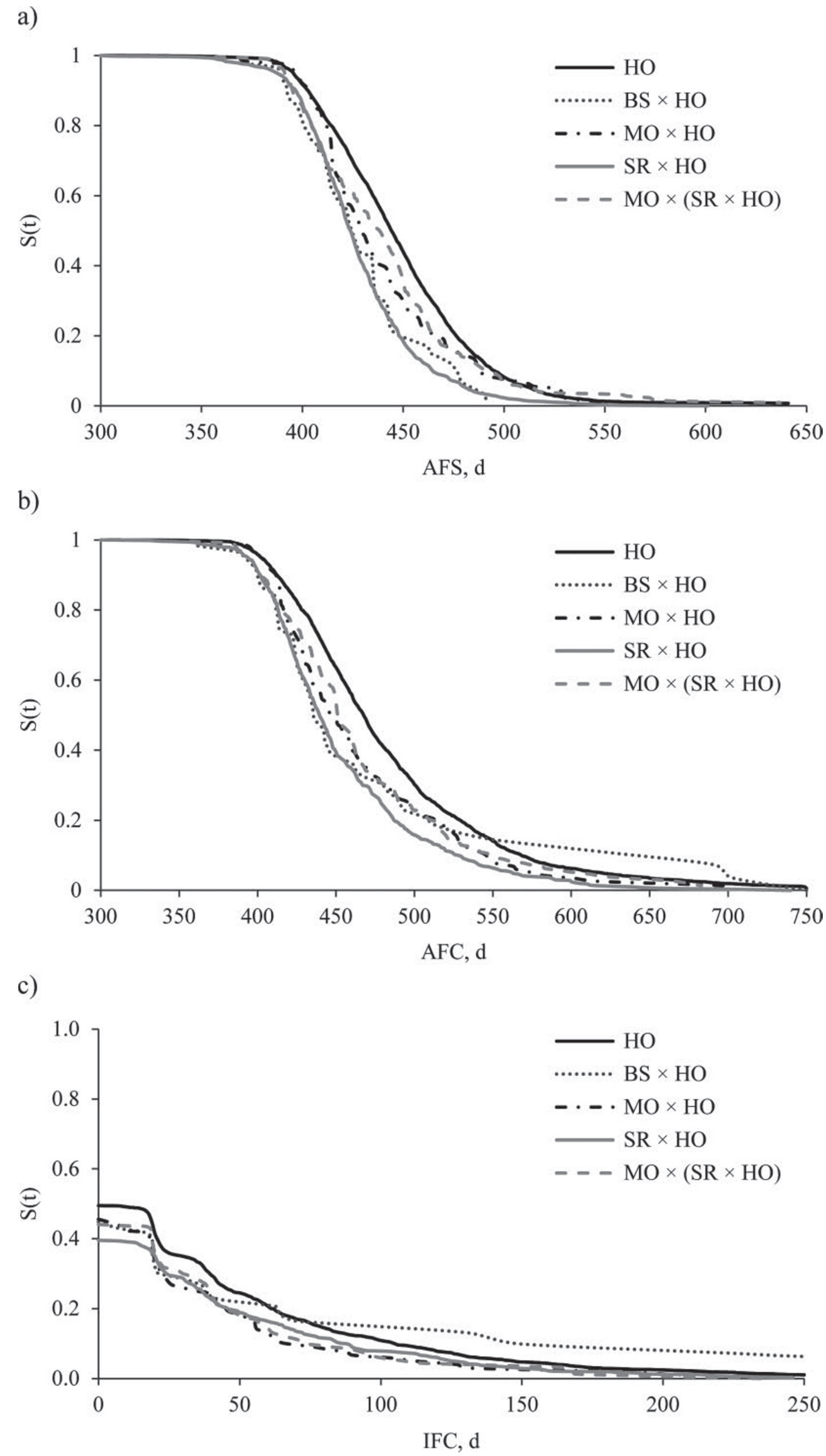

Figure 1. Kaplan-Meier survival curves for age at first service (AFS; a), age at first conception (AFC; b), and interval between first insemination and conception (IFC; c) for Holsteins (HO), and for Brown Swiss × HO (BS × HO), Montbéliarde × HO (MO × HO), Swedish Red × HO (SR × HO) and MO × (SR × HO) crossbred heifers.

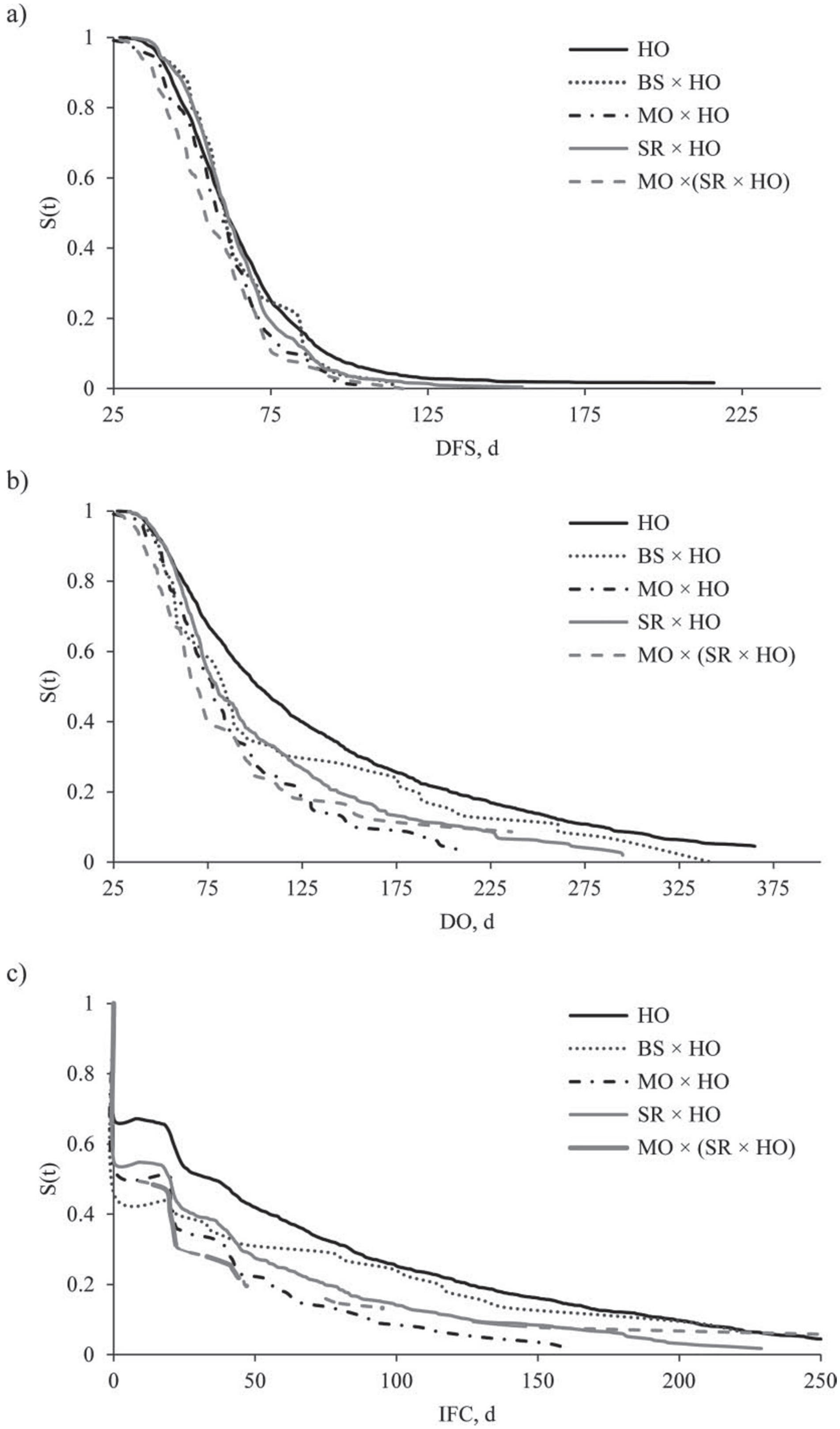

Figure 2. Kaplan-Meier survival curves for days at first service (DFS; a), days open (DO; b) and interval between first insemination and conception (IFC; c) for Holsteins (HO), and for Brown Swiss × HO crossbreds (BS × HO), Montbéliarde × HO (MO × HO), Swedish Red × HO (SR × HO) and MO × (SR × HO) crossbred primiparous cows.

Table 3. Estimated hazard ratio (HR) and 95% CI of breed group effects for reproduction time interval traits of heifers [age at first service (AFS), age at first conception (AFC), and interval between first service and conception IFC)] and of primiparous cows [(days to first service (DFS), days to conception (DO), and IFC]

	Heifers		Primiparous cows	
Trait[1]	HR[2]	95%CI	HR[2]	95%CI
AFS/DFS[3]				
HO	1		1	
BS × HO	0.90	0.69–2.03	1.17	0.88–1.56
MO × HO	0.93	0.80–1.69	1.40	1.15–1.69
SR × HO	1.31	1.21–1.76	1.30	1.15–1.43
MO × (SR × HO)	1.18	0.79–1.38	1.27	1.05–1.53
AFC/DO[4]				
HO	1		1	
BS × HO	0.90	0.75–2.20	1.23	0.91–1.64
MO × HO	1.11	0.77–1.60	1.59	1.30–1.94
SR × HO	1.34	1.28–1.86	1.43	1.29–1.58
MO × (SR × HO)	1.24	0.92–1.60	1.58	1.28–1.94
IFC				
HO	1		1	
BS × HO	0.91	0.77–2.16	1.09	0.81–1.47
MO × HO	1.12	0.82–1.64	1.52	1.24–1.86
SR × HO	1.12	1.26–1.80	1.26	1.14–1.39
MO × (SR × HO)	1.10	0.94–1.60	1.39	1.13–1.72

[1]HO = Holstein; BS = Brown Swiss; MO = Montbéliarde; SR = Swedish Red.

[2]HR >1 (HR <1) means a higher (lower) risk of being inseminated/becoming pregnant at given time t compared with HO.

[3]AFS refers to heifers; DFS refers to primiparous cows.

[4]AC refers to heifers; DO refers to primiparous cows.

higher probabilities for a lower INS compared with HO cows (OR = 1.85, 1.59, and 2.02).

Finally, although significant, differences in reproductive performance between HO and the crossbreeds were smaller in heifers than in primiparous cows (Tables 3 and 4). Other studies using pure breeds reported moderate genetic relationships for fertility traits between heifers and lactating cows, suggesting

Table 4. Estimated odds ratio (OR) and 95% CI of breed group effects for success traits [nonreturn after 56 d from first service (NR56), conception rate at first service (CR)] and for number of inseminations to conception (INS)

	Heifers		Primiparous cows	
Trait[1]	OR[2]	95%CI	OR[2]	95%CI
NR56				
HO	1		1	
BS × HO	1.21	0.70–2.09	2.26	1.25–4.07
MO × HO	1.14	0.80–1.66	1.69	1.13–2.51
SR × HO	1.45	1.20–1.75	1.37	1.12–1.67
MO × (SR × HO)	1.05	0.79–1.40	2.03	1.35–3.05
CR				
HO	1		1	
BS × HO	1.29	0.75–2.20	2.17	1.21–3.90
MO × HO	1.11	0.77–1.60	1.76	1.18–2.62
SR × HO	1.54	1.28–1.86	1.44	1.18–1.76
MO × (SR × HO)	1.22	0.92–1.60	2.26	1.52–3.36
INS				
HO	1		1	
BS × HO	1.29	0.77–2.16	1.80	1.06–3.04
MO × HO	1.16	0.82–1.64	1.85	1.30–2.65
SR × HO	1.50	1.26–1.80	1.59	1.33–1.89
MO × (SR × HO)	1.22	0.94–1.60	2.02	1.42–2.85

[1]HO = Holstein; BS = Brown Swiss; MO = Montbéliarde; SR = Swedish Red.

[2]OR >1 (OR <1) means a higher (lower) probability of becoming pregnant or of having fewer (more) inseminations than HO.

that gene expression (and potentially related fertility traits) does, indeed, differ when evaluated in heifers versus lactating cows (Tiezzi et al., 2012). Because the reproductive performance of heifers is not affected by milk production, the fertility of lactating cows might, on the other hand, also reflect the ability of the cow to conceive when milk yield hinders reproductive physiology. Several studies have reported that HO purebreds have a higher milk yield but lower reproductive performance compared with crossbred cows (Dechow et al., 2007; Heins et al., 2008; Heins and Hansen, 2012). This suggests that HO purebreds are at a reproductive disadvantage that may be due in part to the effect of increased nutrient demands to support greater milk yield during early lactation. However, Walsh et al. (2008) reported no difference between NO × HO, MO × HO, and purebred HO cows in terms of milk yield, but found favorable DFS values for crossbred cows. This suggests that reproductive physiology may differ between HO purebreds and crossbreds, and that the latter may respond better to the high metabolic demands of milk production. In addition, hybrid vigor of crossbreds is likely to explain their improved fertility compared with Holstein. Because inbreeding-related depression of fertility is expected to occur in Holstein animals subject to intensive selection, the reduction of homozygosis by crossbreeding could also help explain why crossbreds showed improved reproductive performance in the present study.

CONCLUSIONS

As evidenced by their advantage for most of the reproductive traits evaluated, our results indicate that crossbred cows have a greater reproductive potential than Holsteins, even when censored records are considered (e.g., culled animals, incomplete data). The superiority of crossbreds over Holstein was more evident in primiparous cows than in heifers, indicating that the effects of breed on fertility may depend on the physiological state of the animals. Future studies that explore the effects of milk production on fertility of crossbred and Holsteins may help us understand whether improved fertility of primiparous crossbred cows is due to lower milk production or to an inherently better response of these animals to the demands of milk production. The present results from both cows and heifers suggest that crossbreeding could improve the fertility of Holstein dairy herds.

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