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Fertility and survival of Swedish Red and White × Holstein crossbred cows and purebred Holstein cows

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ABSTRACT

Swedish Red and White × Holstein (S×H) cows were compared with pure Holstein (HOL) cows for fertility and survival traits in 2 commercial dairy farms in central-southern Córdoba province, Argentina, over 6 years (2008–2013). The following traits were evaluated: first service conception rate (FSCR), overall conception rate (CR), number of services per conception (SC), days open (DO), mortality rate, culling rate, survival to subsequent calvings, and length of productive life (LPL). The data set consisted of 506 lactations from 240 S×H crossbred cows and 1,331 lactations from 576 HOL cows. The FSCR and CR were analyzed using logistic regression, DO and LPL were analyzed using a Cox's proportional hazards regression model, and differences of proportions were calculated for mortality rate, culling rate, and survival to subsequent calvings. The S×H cows were superior to HOL cows in overall lactations for all the fertility traits (+10.5% FSCR, +7.7% CR, −0.5 SC, and 35 fewer DO). During the first lactation, S×H cows were superior to HOL cows for all fertility traits (+12.8% FSCR, +8.0% CR, −0.4 SC, and 34 fewer DO). In the second lactation, S×H cows exhibited lower SC (−0.5) and 21 fewer DO than HOL cows. In the third or greater lactations, S×H cows showed higher FSCR (+11.0%) and CR (+12.2%), lower SC (−0.8), and 44 fewer DO than pure HOL cows. In addition, S×H cows had a lower mortality rate (−4.7%) and a lower culling rate (−13.7%) than HOL cows. Due to the higher fertility and lower mortality and culling rates, the S×H cows had higher survival to the second (+9.2%), third (+16.9%), and fourth (+18.7%) calvings than HOL cows. Because of these results, S×H cows had longer LPL (+10.3 mo) than HOL cows. These results indicate that S×H cows had higher fertility and survival than HOL cows on commercial dairy farms in Argentina.

Key words: crossbreeding, fertility, survival

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INTRODUCTION

Selection strategies have led to a fast increase of milk production for Holstein (**HOL**) dairy cows (Cole and VanRaden, 2018). At present, HOL cows are the dominant breed in most of the temperate regions worldwide (Oltenacu and Broom, 2010). However, simultaneous selection for increased body size and greater angularity, along with selection for milk production (Hansen, 2000; Shook, 2006; Henderson et al., 2011), have contributed to a decrease in fertility, health, and survival (Lucy, 2001; Hare et al., 2006; Berry, 2018), and the increase in mortality of HOL cows (Miller et al., 2008) in several production systems (Walsh et al., 2011).

From an economic standpoint, high culling rates in HOL cows pose a great problem to dairy producers (Weigel and Barlass, 2003). Pinedo et al. (2010) indicated that factors contributing to the low survival rate in HOL cows included increases in inbreeding, calving difficulty, death rate, and health disorders, and a decrease in fertility. Dallago et al. (2021) reported low fertility as the main reason for culling of dairy cattle in high milk-producing countries. Deterioration of the functional and health traits of HOL cows may also be due to increased inbreeding (Sørensen et al., 2005; Bjelland et al., 2013). In addition, considering that heritability of fertility traits is low compared with production traits and given the relatively few years that fertility has been included in selection goals, because of the low selection emphasis on fertility in many countries, the dairy sector should not expect rapid genetic improvement for fertility of HOL cows (Fleming et al., 2019).

Concern about the reduction in fertility (Heins et al., 2006a; Auldist et al., 2007), health, and survival of HOL cows has raised interest in crossbreeding (Weigel and Barlass, 2003; Buckley et al., 2014). Estimates of heterosis is about 6% for production traits and about 10% for fertility traits, resistance to diseases, and productive life in dairy cows (Hansen et al., 2005). Sørensen et al. (2008) reported significant heterosis (more than 18%) for productive life of crossbred cows compared with the average of the parental purebred cows. Studies by Kargo et al. (2012) and Buckley et al. (2014) illustrate greater fertility and survival for crossbred cows than for pure HOL cows, using a variety of modern breeds, both in high-input environments (confinement production) and low-cost (grazing-based) systems. Thus, there is interest in crossbreeding HOL cows as a means of improving fertility, longevity (Harris et al., 1996; Clasen et al., 2019), yield (Coffey et al., 2016; Shonka-Martin et al., 2019) and farm profitability (Lopez-Villalobos et al., 2000) in commercial dairy herds. Production and functional traits should be analyzed together so as to evaluate the total economic merit of dairy cows rather than measuring only milk production (Heins and Hansen, 2012; Lopez-Villalobos et al., 2000).

This study was conducted using the crossing between H, the dominant breed in commercial dairy farms in Argentina (Demarco, 2010; Lazzarini et al., 2019), and Swedish Red and White (**SRW**) breed. The SRW breed originated from the Nordic selection system, which focuses not only on productive traits but also on selection for health, fertility, and conformation traits (Miglior et al., 2005; Sørensen et al., 2008). Therefore, SRW may complement HOL breed in crossbreeding, because the selection goal of HOL breed focused more on production at the expense of fertility and health (Hazel et al., 2017).

The objective of this study was to compare SRW × HOL crossbred (**S×H**) cows and HOL cows for fertility and survival traits in commercial dairy farms of central-southern Córdoba province, Argentina. The following traits were compared: first service conception rate (**FSCR**), overall conception rate (**CR**), number of services per conception (**SC**), days open (**DO**), mortality rate, culling rates, survival to second, third, and fourth calving, and longevity.

MATERIALS AND METHODS

Data Collection

This was an observational study and did not involve direct work with animals or persons and therefore did not require an animal ethics approval. The study included purebred HOL cows and S×H crossbred cows that had their first calving since January 1, 2008. The data set consisted of 506 lactations from 240 S×H crossbred cows and 1,331 lactations from 576 HOL cows (Table 1). Records were collected in 2 commercial dairy farms located in Ucacha, central-southern Córdoba, Argentina, between January 1, 2008 to December 31, 2013 (6 yr). Dairy farm 1, El Arroyo, had 180 dairy cows, and dairy farm 2, Tambo JE, had 350 dairy cows. For survival to subsequent calving analysis, the data set was restricted to cows that had their first calving between January 1, 2008, to December 31, 2010, to consider only cows that had the opportunity to calve at least 4 times: 228 HOL cows and 56 S×H crossbred cows.

Table 1. Number of lactations and cows (in parentheses) in the study population for each breed group and herd

	Breed group	
Herd	Holstein	Swedish Red and White × Holstein
1	387 (186)	220 (110)
2	944 (390)	286 (130)
Total	1,331 (576)	506 (240)

For more than 20 yr, the farms have bred cow replacements through AI using cryopreserved semen and the genetics implemented came from the United States. The 2 herds had general satisfaction with most of their herd statistics, including mean level of production and overall management; however, the dairy farmers chose to venture into crossbreeding because they sought to improve the health, fertility, longevity, and profitability of dairy cows. Furthermore, the dairy producers had no previous experience with milking crossbred cows in their herds, so elected to explore crossbreeding with only a percentage of dairy cows in their herds. On each farm, 2 daily milkings were performed within a semi-stalled feeding system with cows outside grazing alfalfa during the hot summer months and oats or barley in the winter. The diet was systematically supplemented with maize silage and regional by-products, expeller, and flours, depending on the time of year. Throughout the years of the study, the dairy producers managed cows in the breed groups the same in all ways. They comingled heifers and cows without regard to breed group and used identical protocols within herd for insemination, health treatment, and culling. Heifers and cows were grouped by age, stage of lactation, or reproductive status across breed groups. The herds had a weighted mean production level of 6,205 kg of milk, 226 kg of fat, and 220 kg of protein for HOL breed, and 5,505 kg of milk, 213 kg of fat, and 201 kg of protein for S×H breed. The descriptions of herds and cows enrolled, and results from the lactation curves for production of milk, fat, and protein, percentage of fat and protein, and SCS were previously reported by Pipino et al. (2019).

Reproductive Management of Dairy Farms

In each commercial dairy farm, HOL heifers and HOL cows were randomly assigned to be mated by AI with semen from SRW or HOL bulls. Every year, at least 20% of the purebred HOL females in each herd annually were mated to SRW bulls, and the remaining purebred HOL females in each herd were mated with HOL bulls. For the crossbred group, in the subsequent generation, the resulting crossbreed progeny (S×H crossbreds) were mated by AI to the HOL breed. All matings were with conventional, unsexed semen for both heifers and cows. The HOL bulls were proven AI sires and the genetics implemented came from the United States (CIALE S.A.). The HOL bulls were selected mainly by ranking AI bulls for the net merit index in the United States available in Argentina at the time of selection. The cryopreserved semen from the SRW bulls was imported from Sweden (VikingGenetics). The SRW bulls were selected mainly for functional traits, with the objective of reducing body size, improving calving ease, fertility, milk quality, udder health, and survival based on the selection indices developed for this breed. The SRW breed is part of the programs by Viking Red (**VR**) breed resulted from combining the previously separate genetic improvement programs of the SRW, Finnish Ayrshire, and Danish Red breeds, and these 3 breeds historically shared genetic material and applied similar selection goals (Hazel et al., 2017). The Nordic dairy cattle breeding programs combine production, health, fertility, and longevity traits optimally combined in a total merit index (Oltenacu and Broom, 2010). The same 3 SRW bulls were selected annually for use in both herds. Likewise, 4 HOL bulls were selected annually for use in both herds. In total, 18 SRW AI bulls and 24 HOL AI bulls were selected over 6 yr. Proven HOL and SRW bulls were selected by the dairy producers with consultation by the 2 genetic advisors.

The 2 dairy farms used only AI for breeding throughout the year, except for a period of 45 d (March 16 to April 30 to avoid calving in the summer, the season of the greatest heat stress). The AI was performed on the day that the cow was detected in estrus by a dairy farm worker. Cows were monitored twice daily for 40 min each time for signs of estrus, and tail paint (CE-Lamark) was applied to the tailhead to assist with identifying cows in estrus.

As a routine protocol, every 14 d all the lactating cows were considered by a veterinarian. Cows with assisted calvings, those with reproductive diseases (i.e., retained fetal membranes, endometritis), and cows with normal calving and more than 30 d postpartum were examined. Cows more than 60 d postpartum, which had not been subjected to AI and with presence of corpus luteum (greater than 20 mm in diameter) were treated with $PGF_{2\alpha}$ (analogs of different trade marks). Pregnancy was diagnosed by ultrasound, 30 d after AI, and each cow was examined at drying-off to confirm pregnancy status (Chison D600VET ultrasound, transrectal transducer, 5.0 MHz).

Additionally, 2 fixed-time artificial insemination (**FTAI**) blocks were performed, to avoid extension of the period of days to first service. Cows that were subjected to the FTAI protocols were at a minimum of 70 d postpartum, had a minimum BCS of 2.75, and did not have reproductive problems. The first FTAI block was performed in May and the second block in July to August. Protocols for ovulation synchronization to perform FTAI consisted of the insertion of a device that released 0.5 g progesterone (DIB 0.5; Syntex) and the administration of 2 mg estradiol benzoate (estradiol benzoate, Syntex; d 0, Monday afternoon). On Tuesday morning of the following week (d 7.5), the intravaginal device was removed (DIB 0.5; Syntex), and 2 mL of cloprostenol sodium (Ciclase LD, Syntex), and 400 UI equine chorionic gonadotropin (Novormon 5000, Syntex) were administered. On Wednesday morning (8.5 d), cows received a dose (1 mg) of estradiol benzoate (Syntex). On Thursday afternoon (10 d), 54 to 56 h after device removal, FTAI was performed.

Trait Descriptions

Fertility. The FSCR was the proportion of first inseminations that resulted in pregnancy divided by all first inseminations within a lactation. The overall CR was the proportion of successful inseminations divided by all inseminations within a lactation. The SC was defined as the total number of inseminations per lactation divided by the number of cows that got pregnant. The final fertility trait was DO, which was defined as the number of days from calving to conception. For all the fertility traits, pregnancy was confirmed by ultrasound or palpation; when possible, it was verified by a subsequent calving. The herd imposed a voluntary waiting period of 60 d postpartum before cows were inseminated. No limits were established for DIM or number of services. The calving season was defined as warm for spring and summer or cold for autumn and winter, for further analysis.

Mortality and Culling Rates. Mortality rate was defined as the number of cows that died after the first calving to the end of this study divided by the total number of cows included in the analysis. Culling rate was defined as the total number of cows that were culled after the first calving to the end of this study divided by the total number of cows included in the analysis.

Survival to Subsequent Calving. Survival to subsequent calving was defined as the percentage of cows that calved a second, third, and fourth time divided by the total number of cows that calved for the first time.

Longevity. Length of productive life (**LPL**) was defined as the time a cow was in the herd and was calculated as the number of days between first calving and culling or death.

Statistical Analysis

Fertility. The number of cows analyzed within each generation of S×H crossbred cows and their HOL herdmates, as well as within the lactation number, differed for each of the 4 fertility traits because the exclusions described in the trait descriptions were applied independently for each trait. First, an exploratory statistical analysis of all the fertility indicators was performed for each breed group and for all the lactations and as a function of 2 factors: calving season (warm or cold) and lactation number (first, second, third or greater). Also, all the fertility indicators were analyzed for overall lactations (accumulated lactations).

To estimate the relative contribution of factors affecting the probability of first service conception and overall conception, multiple linear regressions were fitted, and the odds ratios (**OR**) were obtained using the software JMP version 14.2.0 (SAS Institute Inc.). The independent variables included in the model were breed, calving season, and lactation number. The output of this model consisted of the coefficients of regression and the OR, which indicate how the independent variables introduce changes in the probability of occurrence of an event, in this case, conception.

The variable SC was analyzed with a linear model that included the fixed effect of breed group and calving season using the software JMP version 14.2.0 (SAS Institute Inc.).

For the variable DO, a Cox's proportional hazards regression model (Cox, 1972) was fitted, and the hazard ratios (**HR**) were obtained using PROC PHREG in SAS (version 9.4; SAS Institute Inc.) to compare breed groups with respect to DO as a function of calving season and by lactation number. The assumption that the hazards are proportional over time was tested using PROC LIFEREG in SAS. In addition, Kaplan-Meier curves (Kaplan and Meier, 1958) were obtained for each breed within each lactation number to compare the percentage of pregnant cows over days in lactation at time t. The similarity of 2 or more survival curves was compared using the statistic log rank (Kaplan and Meier, 1958). A high value of log rank corresponded to a small P-value (probability that the curves are different only by chance); differences in survival curves were considered statistically significant at $P \leq 0.05$.

Both for the survival analysis and the Cox proportional hazards model, the animals included in this study were at risk of becoming pregnant after calving. Data were collected for analysis until December 31, 2013 (defined as time t). If a cow became pregnant during the data collection period and no abortion was recorded before December 31, 2013, it was not censored. Therefore, a censored observation refers to a cow that did not get pregnant before time t (December 31, 2013) or that was no longer observed because data collection ended. Other reasons for interrupting observation of a cow during the study were animals that were no longer included in list of eligibility for services, animals that died during the study and animals that were culled and sold. Thus, DO was measured as days from calving to the moment the cow was censored or when the cow became pregnant and did not have an abortion recorded during the observation or data collection period (January 1, 2008 to December 31, 2013). For all the analyses performed, statistical significance was considered at $P \leq 0.05$.

Survival. For the dependent variables mortality rate, culling rate, and survival to subsequent calving, the differences in proportions were calculated and the significance levels were tested using the Chi-squared test ($\alpha \leq 0.05$).

For the variable LPL, a Cox's proportional hazards regression model (Cox, 1972) was fitted, and the HR were obtained using the PHREG procedure of SAS version 9.4 (SAS Institute Inc.) to compare breed groups with respect to LPL as a function of calving season and lactation number category (primiparous and multiparous). The assumption that the hazards are proportional over time was tested using the LIFEREG procedure of SAS version 9.4 (SAS Institute Inc.). In addition, Kaplan-Meier curves (Kaplan and Meier, 1958) were obtained for each breed group to compare percentage of culled or dead animals at time t over the months after the first calving. The similarity of 2 or more survival curves was compared using the log rank statistic (Kaplan and Meier, 1958). A high log rank value corresponds to a small P-value (probability that the curves are different only by chance); differences in survival curves were considered statistically significant at $P \leq 0.05$.

RESULTS

Fertility

The analysis considering all the lactations showed that S×H cows were superior for all the fertility traits,

Table 2. First service conception rate (FSCR), overall conception rate (CR), number of services per conception (SC), and days open (DO) in first, second, third or greater, and overall lactations, for Holstein cows and Swedish Red and White × Holstein crossbred cows

Trait	Number of lactations	Holstein	Number of lactations	Swedish Red and White × Holstein	*P*-value
First lactation					
FSCR (%)	515	36.5	211	49.3	<0.001
CR (%)	1,313	36.1	440	44.1	0.004
SC[1]	462	2.4 ± 0.08	193	2.0 ± 0.12	0.004
DO[2] (d)	576	139	240	105	<0.001
Second lactation					
FSCR (%)	325	33.5	125	39.2	0.239
CR (%)	892	33.0	300	37.7	0.636
SC[1]	288	2.6 ± 0.10	103	2.1 ± 0.17	0.014
DO[2] (d)	359	137	136	116	0.011
Third lactation or greater					
FSCR (%)	340	32.1	116	43.1	0.032
CR (%)	1,040	27.3	253	39.5	<0.001
SC[1]	276	2.8 ± 0.13	99	2.0 ± 0.21	<0.001
DO[2] (d)	396	145	130	101	<0.001
Overall lactations					
FSCR (%)	1,180	34.4	452	44.9	<0.001
CR (%)	3,245	32.4	993	40.1	<0.001
SC[1]	1,341	2.6 ± 0.06	498	2.0 ± 0.09	<0.001
DO[2] (d)	1,331	140	506	105	<0.001

[1]SC expressed as mean ± SE.

[2]DO expressed as median (equal to the 50th percentile).

with 10.5% higher FSCR, 7.7% higher CR, and lower SC (−0.5) than HOL cows (Table 2, $P < 0.001$). In general, better reproductive performance of S×H cows was observed across the lactations. No significant differences in calving season were found for these 3 variables in any of the lactations analyzed.

Estimations of the OR for FSCR and CR are presented in Table 3. The analysis considering all the lactations showed that the OR for FSCR and CR of S×H cows were 1.6 and 1.4 compared with HOL cows ($P < 0.001$). The analyses performed within each lactation showed that the S×H cows had higher OR for these 2 traits than HOL cows, except in the second lactation, in which the differences were not significant.

Table 4 presents the parameters estimated for each explanatory variable of the Cox's proportional hazards regression model proposed for the DO trait. Effects of breed and calving season were significant, but the lactation number was not significant. Regarding DO, the HR for overall the lactations of S×H cows was 1.4 rela-

Table 3. Odds ratio (OR), hazard ratio (HR), 95% CI, and *P*-value for first service conception rate (FSCR), overall conception rate (CR) in the first, second, third or greater, and overall lactations, and days open (DO) in all lactations, for Holstein cows and Swedish Red and White × Holstein cows

Trait	Holstein OR or HR	Swedish Red and White × Holstein OR or HR	95% CI	*P*-value
First lactation				
FSCR[1]	1	1.7	1.22–2.33	0.002
CR[2]	1	1.4	1.11–1.73	0.004
Second lactation				
FSCR[1]	1	1.3	0.84–1.98	0.239
CR[2]	1	1.0	0.81–1.41	0.637
Third lactation or greater				
FSCR[1]	1	1.6	1.04–2.48	0.032
CR[2]	1	1.7	1.25–2.24	<0.001
Overall lactations				
FSCR[1]	1	1.6	1.25–1.94	<0.001
CR[2]	1	1.4	1.21–1.62	<0.001
DO[3]	1	1.4	1.27–1.61	<0.001

[1]Odds ratio for FSCR.

[2]Odds ratio for CR.

[3]Hazard ratio for DO.

tive to HOL cows, indicating that S×H cows had 1.4 times greater hazards of conception at a given moment than HOL cows (Table 3, $P < 0.001$). In turn, the HR was 1.2 times higher for those cows that calved in the cold season than those that calved in the warm season ($P < 0.005$). No significant differences were found in lactation number ($P = 0.294$). The time when 50% of cows became pregnant, considering overall lactations, calculated with the Kaplan-Meier method (Figure 1), was 140 d (CI 95% = 131 to 187 d) for HOL cows and 105 d (CI 95% = 98 to 115 d) for S×H cows, indicating a delay of 35 d in HOL cows to achieve the same percentage of pregnant cows as that of S×H cows ($P < 0.001$). For first, second, and third or greater lactation cows, the detected delay to achieve the same percentage of pregnant animals (50%) in HOL cows as that of S×H cows was 34 ($P < 0.001$), 21 ($P = 0.011$), and 44 d ($P < 0.001$), respectively (Table 2).

Mortality and Culling Rates

Mortality rate of S×H cows was 4.7% lower than that of HOL cows (Table 5, $P = 0.026$). Culling rate was 13.7% higher in HOL cows than in S×H crossbred cows (Table 5, $P < 0.001$).

Survival to Subsequent Calving

Survival to subsequent calving was higher in S×H crossbred cows than in pure HOL cows in all lactations (Table 6, $P < 0.05$). The S×H crossbred cows had higher survival to the second (+9.2%, $P = 0.036$), third (+16.9%, $P = 0.009$), and fourth (+18.7%, $P = 0.016$) calving than pure HOL cows. After the fourth calving, the difference was more pronounced, because 69.6% of the S×H crossbred cows versus 50.9% of the pure HOL cows remained in the herd ($P = 0.016$).

Longevity

The HR of LPL for HOL cows with respect to S×H cows was 1.4 (CI 95% = 1.03–1.95), indicating that HOL cows have 1.4 greater hazard of culling (deaths or sales) at a given moment than S×H cows ($P = 0.031$). In turn, the hazard risk was 21 (CI 95% = 14–32) greater for primiparous than for multiparous cows ($P < 0.001$). No significant differences with respect to calving season were detected ($P = 0.610$). The results of the Kaplan-Meier survival curves as a function of the breed group for LPL were different ($P = 0.017$). Median of time in which 50% of the animals were culled was 47.5 mo for HOL cows and 57.8 mo for S×H cows, indicating a greater LPL for S×H cows (+10.3 mo) to reach the same percentage of culled animals (Figure 2).

Table 4. Estimated parameters, SE, and P-value for each explanatory variable of the Cox's proportional hazards regression model for the indicator days open

Explanatory variable	Coefficient	SE	P-value
Breed	−0.179	±0.029	<0.001
Calving season	−0.077	±0.027	0.005
Lactation number category[1]	−0.028	±0.026	0.294

[1]Lactation number category included 2 groups: primiparous and multiparous cows.

In turn, the median of the time during which 75% of the pure HOL cows were culled was 64.3 mo. Interestingly, by the end of our study, it was not possible to estimate that median for S×H crossbred cows because they remained in the herd, indicating a higher LPL in S×H cows (at least +7.7 mo, $P = 0.017$) to reach 75% of culling.

DISCUSSION

The objective of this study was to compare S×H crossbred cows and HOL cows for fertility and survival traits on commercial dairy farms in central-southern Córdoba province, Argentina.

Fertility

Differences in FSCR between crossbred S×H and purebred HOL cows found in the current study were similar to those reported for first lactation cows in the United States by Hazel et al. (2017), who reported a FSCR of 38% for purebred HOL cows compared with 47% for crossbred VR × HOL cows. The same authors reported a smaller difference in DO between HOL cows (125 d) and VR × HOL cows (117 d) than was observed between HOL and S×H cows in the present study.

Recently, Hazel et al. (2020) reported results of 3 generations of crossbred cows from a 3-breed rotation of the VR, Montbéliarde, and HOL breeds compared with HOL herdmates in 7 high-performance, commercial dairy herds in Minnesota. For first lactation cows, the authors reported better values of FSCR (+8%), CR (+4%), and SC (−0.2) for VR × HOL crossbred cows than for HOL cows, and in second lactation cows, found advantages for VR × HOL crossbred cows in all the fertility traits, with 7% higher FSCR, 1% higher CR, lower SC (−0.3) and 11 fewer DO. In both, Hazel et al. (2020) and the current study, the crossbred cows had advantages from both the heterosis of the cows and the heterosis of their embryos compared with the pure HOL cows and their pure HOL embryos. In this study the S×H cows had on average 35 less DO than HOL cows, which is consistent with the results reported by Piccardi et al. (2014), who observed an advantage

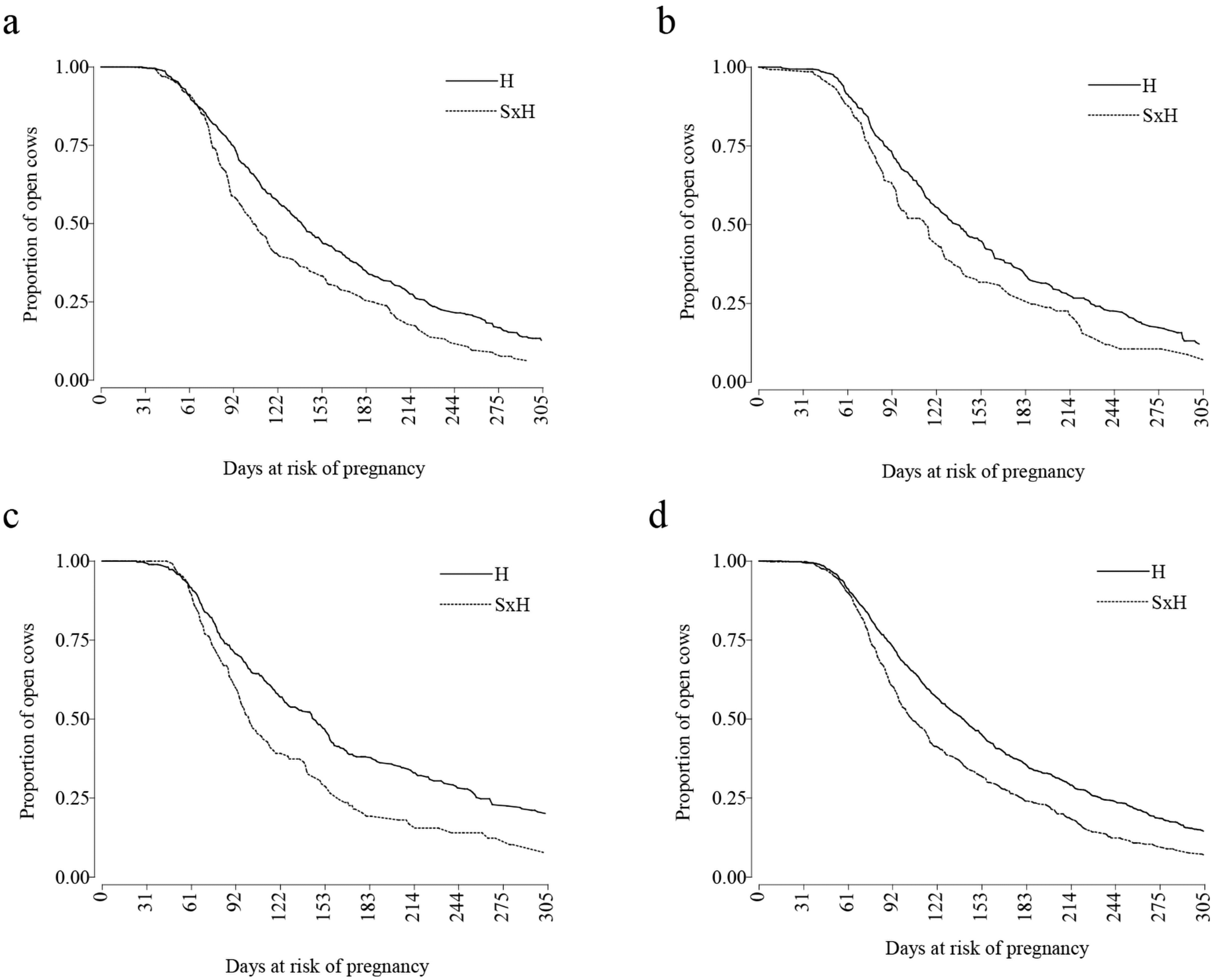

Figure 1. Kaplan-Meier survival curves for days open for the first lactation (a; $P < 0.001$), second lactation (b; $P < 0.011$), third lactation or greater (c; $P < 0.001$), and overall lactations (d; $P < 0.001$) for Holstein (H) and Swedish Red and White × Holstein (S × H) cows.

of 30 fewer DO for S×H cows compared with HOL cows in the first lactation. The advantage in DO for the crossbred cows may provide an economic advantage during first lactation over HOL cows (Groenendaal et al., 2004; De Vries, 2006; Cole et al., 2009). The difference in economic advantage may result from less

Table 5. Mortality[1] and culling[2] rates for Holstein cows and Swedish Red and White × Holstein crossbred cows

	Holstein (cows = 576)		Swedish Red and White × Holstein (cows = 240)		
Trait	n	Percentage	n	Percentage	*P*-value
Mortality rate	56	9.7	12	5.0	0.026
Culling rate	162	28.3	35	14.6	<0.001

[1]Mortality rate = number of cows that died after the first calving to the end of this study divided by the total number of cows included in the analysis.

[2]Culling rate = number of cows that were culled after the first calving to the end of this study divided by the total number of cows included in the analysis.

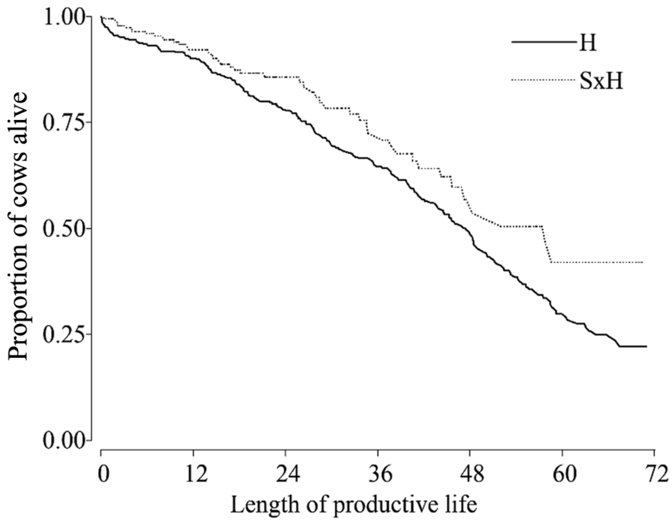

Figure 2. Kaplan-Meier survival curves for length of productive life in month of Holstein (H) and Swedish Red and White × Holstein (S × H) cows. ($P = 0.017$).

culling for fertility, and a faster return to peak production at second calving (Hazel et al., 2017). Our results also agree with those of Heins and Hansen (2012) and of Jönsson (2015), who reported an improvement in fertility in Scandinavian Red × HOL cows and in Swedish Red × Swedish Holstein cows, respectively, with respect to pure HOL cows. Other studies have reported smaller differences in DO between crossbred and purebred cows. A study conducted in Denmark by Clasen et al. (2019) reported that Nordic Red × HOL crossbred cows had on average 10 fewer DO than purebred HOL cows in the first and second lactation. Similarly, Malchiodi et al. (2014) in Italy reported that S×H crossbred cows had 13 fewer DO than pure HOL cows in the first lactation.

The effect of heterosis on fertility traits may explain the better reproductive performance of crossbred cows compared with purebred HOL cows (Sørensen et al., 2008). Another factor that could explain the superior fertility of S×H cows is the contribution of additive genetic effects of the SRW breed, which has been selected for fertility performance for several decades, with greater emphasis than the HOL breed (Hazel et al., 2020). Improvements in fertility are often a primary reason stated by dairy producers for crossbreeding (Weigel and Barlass, 2003), and high-input dairy herds benefit from crossbreeding at least as much for fertility as their lower-input counterparts (Clasen et al., 2019).

Lower fertility of HOL cows compared with S×H cows is likely to be partially explained by the greater milk yield of the HOL cows, with higher yielding cows more likely to be in negative energy balance in early lactation (Bauman and Currie, 1980; Lucy, 2001). Extended periods of negative energy balance increases DO and reduces FSCR (Butler, 2000; Lucy, 2003). Differences in milk production between HOL and S×H cows of this study were reported by Pipino et al. (2019), who found that the crossbred S×H cows produced 11 to 14% less milk than the purebred HOL cows. Studies in Minnesota have also reported that S×H cows produced 4 to 7% less milk than HOL cows (Heins and Hansen 2012; Hazel et al., 2020). Farmers are likely to accept a reduction in milk production in exchange for better fertility of their cows.

Mortality and Culling

The mortality rate of 9.7% found for pure HOL cows in this study is lower than the 16.5% reported by Dechow and Goodling (2008) and 17.7% reported by Hazel et al. (2014). Differences between these studies and our research was greater although for US national data, cow deaths are likely underreported because some herds do not report cows that die before the first day of testing (Heins et al., 2012). However, seasonal pasture herds typically have reduced death loss compared with other housing systems (Burow et al., 2011; Dechow et al., 2012; Mee, 2012), and this may be because exercise improves the general health of cows (Gustafson, 1993). Heins et al. (2012) analyzed mortality during the first 305 d of first lactation cows and, as in our work, they

Table 6. Survival to subsequent calvings[1] for Holstein cows and Swedish Red and White × Holstein crossbred cows

	Holstein		Swedish Red and White × Holstein		
Trait	n	Percentage	n	Percentage	P-value
Survival to subsequent calving					
First	228	—	56	—	
Second	203	89.0	55	98.2	0.036
Third	165	72.4	50	89.3	0.009
Fourth	116	50.9	39	69.6	0.016

[1]Survival to subsequent calving = percentage of cows that calved for second, third, and fourth time divided by the total number of cows that calved for the first time.

found lower values for crossbred cows (1.7%) than for purebred HOL cows (5.3%); in addition, 7.4% of the crossbred cows versus 15.9% of pure HOL cows were culled during the 305 d of the first lactation. In other words, in the present study, crossbred cows were half as likely to die compared with purebred HOL cows in these herds, and cow mortality represents a significant loss of income for dairy farmers because they lose salvage value and future production, and might not recover the costs of heifer replacement (Heins et al., 2012; Pritchard et al., 2013).

The culling rate of 28.3% of purebred HOL cows found in this study is comparable with the 27.7% reported by Dechow and Goodling (2008) and the 25.1% reported by Pinedo et al. (2010). The results in the present study for pure HOL cows for mortality rate and culling rate is comparable with the reported in Argentina by Gastaldi et al. (2016). In the present study, more crossbred cows remained in the herds than did pure HOL cows, with only 50% of crossbred cows removed compared with pure HOL cows. The difference in results between crossbreed cows and HOL cows in our study, might be attributed to poor reproductive performance of HOL cows, which often leads to premature culling and decreased longevity of dairy cows (Oltenacu and Broom, 2010). Improvements in health, conformation and fertility reduce involuntary culling and allow better decision making about culling of functional healthy cows (De Vries and Marcondes, 2020). Increasing cow longevity by reducing involuntary culling would cut health costs, increase cow lifetime profitability, improve animal welfare, and could contribute toward a more sustainable dairy industry while optimizing dairy farmers' efficiency in the overall use of resources available (Dallago et al., 2021).

Survival to Subsequent Calving

The differences in rates of survival to second, third, and fourth calving between purebred HOL and S×H crossbred cows found in this study are comparable to those reported by Heins et al. (2012), who found higher values for S×H crossbred cows than HOL cows (+10.1, +20.1, and +21.4%, respectively). Similarly, Clasen et al. (2019) reported 15% higher survival of Nordic Red × Holstein crossbred cows compared with HOL cows between first and third calving. Also, Heins et al. (2006b) reported greater survival of Scandinavian Red × HOL crossbred cows than pure HOL cows in first lactation and Norman et al. (2016) reported that 77% of the crossbred cows had a second calving during the first lactation compared with 74% of pure HOL cows in data from the United States. In contrast, Hazel et al. (2017) did not find significant differences in survival to second calving between pure HOL cows and S×H crossbred cows in commercial dairy farms in Minnesota but did find that a higher number of S×H crossbred cows (+7%) had a calving within 14 mo after the first calving.

The results of the present investigation, as well as numerous studies, have documented that more crossbred cows had a subsequent calving compared with the HOL cows. In the present study, only 2% of crossbred cows did not calve a second time, whereas 11% of pure HOL cows failed to calve a second time. Also, a greater percentage of crossbred cows (19%) than pure HOL cows calved a fourth time. Traits such as survival to subsequent calving revealed the more rapid speed at which the crossbreds returned to peak production compared with the HOL cows (Hazel et al., 2017). The reduced survival of pure HOL cows in the seasonal pasture herd appeared to be heavily influenced by the poor fertility of pure HOL cows (Hazel et al., 2014). Washburn (2009) suggested that the poor survival of pure HOL cows in pasture herds may be the driving factor for the increased use of crossbreeding among pasture herds in the United States. An explanation for the superior survival of crossbred cows compared with the HOL cows in this study could be the due to the higher fertility and lower mortality and culling rates of S×H cows.

Longevity

The main aim of studying longevity has been to develop the best management and genetic selection strategies based on a clearer understanding of the multiple factors that may affect this parameter (Schuster et al., 2020; Dallago et al., 2021). Therefore, it is difficult to suggest a single definition of longevity for academic discussions, because the result of interest varies among studies (Fetrow et al., 2006). However, the terminology used can be standardized (Schuster et al., 2020). In this study, longevity was defined as LPL following Ducrocq et al. (1988), which is a different definition of productive life for genetic evaluation of US dairy cattle (VanRaden and Klasskate, 1993).

Longevity of cows is a determining factor affecting farm profitability, since growing replacement heifers involves a high cost for dairy farms (Hazel et al., 2014). Our results agree with those of Heins et al. (2012), who reported a longevity of 1,092 d for S×H crossbred cows compared with 937 d for purebred HOL cows in an analysis of a maximum of 4 yr after the first calving. Kaplan-Meier survival curves reported by Ferris et al. (2014) showed that the estimated time to culling 50 and 75% pure HOL cows was 1,133 and 1,824 d, respectively; our longevity values were higher than those results. De Vries, (2013) reported that dairy cattle in the United States had a productive life of 31.6 mo; therefore, mean longevity is about 57.1 mo. According to data from the USDA, productive life has decreased by approximately 40% compared with cows born in 1960 and in 2000 (Dallago et al., 2021), with a great part of the reduction in longevity of dairy cows being related to the involuntary culling of cows due to health or fertility problems (Rushen and de Passillé, 2013). Increasing dairy cow longevity would imply that an animal has a long and profitable productive life (Dallago et al., 2021). It is clear that when we look for long-term consequences of selection for high milk production we find that the increase in milk yield has generally been accompanied by declining ability to reproduce, increasing incidence of health problems, and declining longevity in modern dairy cows, all of which are indicative of reduced animal welfare (Oltenacu and Broom, 2010).

The production achieved by the cows considered in this study (Pipino et al., 2019) was similar to the average for Argentina (OCLA, 2018). Similarly, reproductive traits, mortality rate, and culling rate of the HOL cows in this study were comparable with those reported in Argentina by Gastaldi et al. (2016). Therefore, the differences in performance between S×H cows and HOL cows reported here are likely to indicate the potential outcomes if SRW bulls were used more widely in Argentina.

The HOL cows produced 700 more liters of milk and 32 more kilograms of fat plus protein per cow per lactation compared to S×H cows (Pipino et al., 2019), yet the S×H cows were superior for both fertility and survival traits, indicating a greater LPL for S×H cows of 10.3 mo, which is equivalent to one more lactation. These results highlight the importance of including all relevant traits in the evaluation of cows to determine the most profitable cows for a dairy system. For commercial dairy farms, where financial sustainability is important, production, and functional traits should be analyzed together (Heins and Hansen, 2012; Lopez-Villalobos et al., 2000). It is likely that a herd with S×H cows, that have greater fertility and longevity, would have an age structure with more mature cows producing more milk and lower replacement rate. This would not only mean higher milk income (milk and fat plus protein), but also lower replacement costs. Also, early age at culling is a growing concern among consumers, especially because cow longevity is a global indicator of animal welfare because higher cow longevity indicates that the animal biological functions and health are not impairing the LPL (Bruijnis et al., 2013; Berry, 2015). In this way, our results showed that crossbreeding with the SRW improved fertility and survival in low-input production systems (grazing-based). Research has been initiated around the world to compare crossbred cows to pure HOL cows for profitability. For crossbreeding, complete recording of production, survival, fertility, and health is essential to assess the profitability of crossbred versus purebred cows (Heins et al., 2012). Testimonials from the owners of these 2 herds indicated that crossbreds had fewer health problems and fewer metabolic disorders throughout their lifetimes, and increased health cost of pure HOL cows over time is a major justification provided by dairy producers for deciding to use crossbreeding. Quantification of health traits more specific than LPL would be worthwhile in future studies to better enable quantification of the profitability of crossbred versus HOL cows.

The results of our study and Pipino et al. (2019) are of importance to the region of Córdoba and Argentina, as well as for other countries because the study used commercial herds in semipastoral production systems, rather than experimental herds. The quantification of improved fertility and survival of the crossbred cows is important, and it contrasts with the loss of production per lactation, and comprehensive measures of performance are needed to best evaluate the cows for farming systems.

CONCLUSIONS

This study found that S×H cows were superior to HOL cows in overall lactations for all the fertility traits, had lower mortality and culling rates, and higher survival to subsequent lactations; therefore, they lived longer than HOL cows. The results suggest that dairy farmers can implement crossbreeding between HOL cows with SRW bulls as a tool to improve cow fertility and survival.

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