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Skattning av heterosiseffekten och prestationsförmågan hos korsade svenska mjölkkor

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Abstract

The heterosis effect and breed group effect of crossbreds between Swedish Holstein (SH) and Swedish Red (SRB) was estimated in this study. Observations on cows born between 1990 and 2012 were used to estimate the heterosis effect and breed group effect for several traits included in the Nordic breeding goals: production, fertility, udder health, calving performance, survival and other diseases.

Breeding within the Holstein dairy breed has earlier been focused on increased milk production and conformation. This, combined with an intensive use of individual animals, has resulted in a radical increase of milk yield in the Holstein dairy cow population all over the world. However, this breeding strategy has resulted in increased inbreeding and several functional traits have impaired.

SH and SRB are the most common dairy breeds used in Sweden. The Nordic countries has for a long time included several functional traits in the breeding goals for both SH and SRB. SRB has been able to keep a high production level and still maintain a high performance of functional traits, such as fertility. However, SH has suffered similar problems as the Holstein breed abroad since the breeding has been influenced by international standards. Crossbreeding between SH and SRB has been used in order to increase the performance of functional traits and break the negative consequences of inbreeding at herd level. Several crossbreeding studies abroad have shown promising results but there is little knowledge about the effect of crossbreeding in Sweden.

The study showed that the crossbreds had a favourable heterosis effect in all lactations for all traits except for some health traits. The relative heterosis effect (RHE) for production traits in first lactation was favourable and significant ($P < 0.05$) and ranged from 1.9 % to 2.4 % for crossbreds with SRB as the paternal breed and SH as the maternal breed (SRB x SH), and from 3.4 % to 4.5 % for crossbreds with SH as the paternal breed and SRB as the maternal breed (SH x SRB). The RHE for the functional traits; fertility, calving performance and survival was favourable and significant ($P < 0.05$) in first lactation and ranged from 1.4 % to 13.0 % for SRB x SH and from 0.8 % to 12.3 % for SH x SRB. The greatest RHE was found for survival to 3rd lactation for both F1-crossbreds (13.0 % for SRB x SH and 12.3 % for SH x SRB). The smallest RHE was found for calving interval for both F1-crossbreds (1.4 % for SRB x SH and 0.8 % for SH x SRB). The RHE for udder health and other diseases ranged from 2.0 % to 26.8 % but few traits were significant. The breed group effect of crossbreds was higher than for purebred SH for fertility in all lactations and for calving performance in first and second lactation. Crossbreds also had a better survival rate and produced the same amount, or more, fat in 305-d lactation than purebred SH.

The results suggest that crossbreeding is a good method to improve functional traits at herd level while still having the potential to produce the same amount of milk fat. The crossbreds also have the potential to maintain, or even increase, the profitability in the dairy production since crossbreds have a high production, high fertility, small proportions of calving difficulties and stillbirths, and the survival is greater than for their purebred contemporaries.

Sammanfattning

I denna studie har heterosiseffekten och rasgruppseffekten skattats på mjölkraskorsningar mellan Svensk Holstein (SH) och Svensk röd och vit boskap (SRB). Observationer på kor födda mellan 1990 och 2012 användes för att skatta heterosiseffekten och rasgruppseffekten för flera egenskaper som inkluderas i de nordiska avelsmålen: produktion, fruktsamhet, juverhälsa, kalvningsförmåga, överlevnad och övriga sjukdomar.

Aveln inom mjölkkorasen Holstein har tidigare varit fokuserad på ökad mjölkproduktion och exteriör. I kombination med ett intensivt användande av ett fåtal individer har aveln resulterat i radikalt ökad mjölkmängd inom Holstein populationen världen över. Denna avelsstrategi har samtidigt lett till ökad inavelsgrad och att flera funktionella egenskaper har försämrats över tid.

SH och SRB är de vanligaste mjölkkoraserna som används för mjölkproduktion i Sverige. De nordiska länderna har länge inkluderat flera funktionella egenskaper i avelsmålen, utöver produktionsegenskaper, för både SH och SRB. För SRB har man med denna avelsstrategi lyckats öka produktionen och samtidigt behållit en hög nivå på de funktionella egenskaperna, såsom fruktsamhet. Avelsstrategin har dock inte fått samma genomslag för SH då ökad inavel och försämrad fruktsamhet har observerats trots de breda avelsmålen, eftersom aveln på SH till stor del har påverkats genom import av den avel som bedrivits internationellt. Korsningsavel mellan SH och SRB har därför använts som en metod för att höja de funktionella egenskaperna, samtidigt som inaveln bryts på besättningsnivå. Flertalet studier har utförts på korsningsavel utomlands men korsningseffekten är relativt outforskad under svenska förhållanden.

Studien visade att korsningarna hade fördelaktig heterosiseffekt i alla laktationer för alla egenskaper förutom några hälsoegenskaper. Den relativa heterosiseffekten (RHE) för produktionsegenskaper i första laktationen var fördelaktig och signifikant ($P < 0.05$). RHE för produktionsegenskaperna hade värden mellan 1.9% till 2.4 % för korsningar där fadern var SRB och modern var SH (SRB x SH), och mellan 3.4 % till 4.5 % för korsningar där fadern var SH och modern var SRB (SH x SRB). RHE för egenskaperna fertilitet, kalvningsförmåga och överlevnad var fördelaktig och signifikant ($P < 0.05$) i första laktationen. Värdena varierade mellan 1.4 % till 13.0 % för SRB x SH och 0.8 % till 12.3 % för SH x SRB. RHE var störst för egenskapen överlevnad till 3:e laktation för båda korsningsgrupperna (13.0 % för SRB x SH och 12.3 % för SH x SRB). RHE var lägst för egenskapen kalvningsintervall för båda korsningsgrupperna (1.4 % för SRB x SH och 0.8 % för SH x SRB). RHE för juverhälsa och övriga sjukdomar varierade från 2.0 % till 26.8 % men få egenskaper var signifikanta. Rasgruppseffekten var högre för korsningarna för fertilitet i alla laktationer, för kalvningsförmåga i första och andra laktationen och de hade högre överlevnadsgrad än renrasiga SH. De producerade samma mängd, eller mer, fett i 305-d laktation än renrasiga SH.

Resultaten tyder på att korsningsavel är en bra metod för att öka prestationen för de funktionella egenskaperna på besättningsnivå och samtidigt kunna producera samma mängd mjölkfett som renrasiga Svenska Holstein. Korsningarna visar även potential till att vara lika, eller till och med mer, lönsamma i mjölkproduktionen då de har en hög produktion, hög fruktsamhet, låg andel svåra kalvningar och dödfödslar, samt att de har bättre överlevnad än de renrasiga motsvarigheterna.

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Introduction

The breeding of dairy cows has earlier been focused on increasing the production traits and conformation where the US has been the leading Holstein breeders. The milk yield has radically increased and Holstein is today the breed that has the largest production potential per lactation. Thanks to modern reproductive techniques, semen from American Holstein sires has become available and spread intensively on the global market. This has led to an increased milk yield in the Holstein dairy cow population worldwide but functional traits such as fertility, health and calving performance have declined due to unfavourable genetic correlation between milk yield and functional traits (Butler, 1998; Meyer et al., 2001a; Washburn et al., 2002; Ettema & Santos, 2004; de Vries & Risco, 2005).

Crossbreeding has been implemented as a method in order to combat problems related to breeding for increased milk yield and the interest for crossbreeding has increased worldwide. Several studies have shown that crossbreds perform better than their purebred contemporaries concerning functional traits (Heins et al., 2006c; Dechow et al., 2007; Heins et al., 2011; Vance et al., 2013, Hazel et al., 2014), and may also contribute to a greater profitability at herd level (Lopez-Villalobos et al., 2000; Van Raden & Sanders, 2003).

Swedish Holstein (SH) and Swedish Red (SRB) are the dominating dairy breeds in Sweden. SRB has managed to compete with SH thanks to its high performance on functional traits but also the relatively high milk production compared with other dairy breeds in Sweden. SRB is economically comparable with SH since the functional traits compensate for the slightly lower milk production. This has been possible thanks to broad breeding goals where production has increased without declining functional traits (Berglund, 2008).

In Sweden, it would probably be most expected to crossbreed SH and SRB but the outcome from this combination is relatively unexplored. However, two breed crosses between Scandinavian Red (which includes SRB and Norwegian Red) and Holstein have been compared with purebred Holsteins in the US, and has shown promising results for fat and fat+protein production (Heins et al., 2006a), calving performance (Heins et al., 2006b), fertility traits (Heins et al., 2006c; Heins & Hansen, 2012) and survival (Heins et al., 2012).

The goal with this study was to analyse available data for SH, SRB and their crosses, and estimate the heterosis and breed group effect for several traits that are included in the Nordic breeding goals described in the Nordic Cattle Breeding Evaluation (Nordic EBV, 2014). More specifically, the traits production, fertility, udder health, calving performance, survival and other diseases were investigated.

The purpose was to evaluate the performance and increase the knowledge about the heterosis effect for crossbreds between SH and SRB in Sweden.

Literature Review

Holstein breeding

Breeding within the Holstein dairy breed has been focused on increasing the milk production, and nowadays Holstein is popular among dairy producers around the world because of this trait. Even though a high milk production is an important factor in dairy farming, negative consequences have been noticed while using this breeding strategy. For instance, when the production increased, so did the inbreeding level and several functional traits impaired within the breed. An evaluation of the Holstein population in Canada showed that inbreeding level has increased from 1.7 % to 5.2 % between 1980 and 2004 and is related to an increased risk for culling (Sewalem et al., 2006). Several studies have also paid attention to the unfavourable association between production yield and some functional traits. Butler (1998) described that the pregnancy rate has decreased from 65 % to 40 % between 1951 and 1996. Lucy (2001) reported that the calving interval and the number of services per conception increased at the same rate as the milk production. Roxström et al. (2001) also saw an unfavourable genetic correlation between milk yield and fertility and the unfavourable relationship increased with lactation number. Milk yield has also shown to be negatively correlated with other diseases such as milk fever, mastitis, retained placenta, ketosis and displaced abomasum (Fleischer et al., 2001).

Fertility problems

Several studies confirm the declining fertility in the Holstein population worldwide. The number of days open has increased from approximately 125 to 168 days and the number of services per conception has increased from approximately 1.9 to 3.0 between 1976 and 1999 when data from 532 Holstein herds were analysed (Washburn et al., 2002). The number of days from calving to first service has increased from 84.3 to 103.7 days and the conception rate has declined from 22 % to 12 % between 1976 and 2002 in Holstein herds in Florida and Georgia, US (de Vries & Risco, 2005). However, the conception rate might be underestimated in the study since only cows that got pregnant later than 70 days after calving was included in the study. A couple of years later, Norman et al. (2009a) observed the same declining trend concerning fertility but also noticed that the calving interval and the number of days between first and last service has stabilized, or even declined, from 2003. This is probably a consequence of implementing broader breeding goals within the Holstein breed.

Difficult calvings and stillbirths

Impaired calving performance has been observed within the Holstein breed and Meyer et al. (2001b) reported that the proportion of stillbirths was 11 % for primiparous and 5.7 % for multiparous cows in the US. Similar problems have been observed in Sweden. Steinbock et al. (2003) reported that primiparous SH cows had a stillbirth rate of 7.1 % whereas multiparous SH cows had a stillbirth rate of 2.7 %. The proportion of difficult calvings for primiparous SH cows were 8.3 % and 4.5 % for multiparous SH cows. The ratio of stillbirths and difficult calvings for SRB is considerably lower than for SH, which was reported by Steinbock et al. (2007). The stillbirth incidence for primiparous SRB cows were 3.6 % whereas multiparous SRB cows had a stillbirth rate of 2.5 %. The proportion of difficult calvings were 4.0 % for primiparous SRB cows and 1.9 % for multiparous SRB cows. According to recent data from the Swedish milk recording scheme, primiparous SH cows has a stillbirth rate of 9.0 % and the rate of difficult calvings is 4.5 % (Växa, 2014). The rates of stillbirths and calving difficulties for primiparous SRB were considerably lower (5.8 % and 3.7 % respectively). The rates of stillbirths and calving difficulties for multiparous SH and SRB were lower than for primiparous cows and the difference between multiparous SH and SRB were smaller.

Breeding of Swedish Red

The breeding goals for dairy cows in the Nordic countries has included functional traits for a relatively long time, both for the Nordic red Ayrshire breeds (including SRB) and Holsteins (Berglund, 2008). For instance, fertility was included in the breeding goal in 1972 and was not introduced in other countries until the 1990-ties. SRB has therefore kept its high reproductive ability and calving performance even though the milk production has increased. SH has not been able to keep the same level for functional traits as SRB since the breeding has been influences by international breeding goals that has been focused on production and conformation. The breeding goal has also contributed to a lower mortality rate for SRB compared with SH (Alvåsen, 2012).

Crossbreeding trials around the world

The majority of studies concerning crossbreeding with Holstein and other breeds have been conducted in the US. In most cases the first generation crossbreds (F1) has been evaluated. The traits that have been studied the most are to our knowledge production and fertility. Many of the publications about crossbreeding is made by a research team with Dr. Hansen and Dr. Heins from the Department of Animal Science at the University of Minnesota. The team has conducted several crossbreeding trials on different research farms in California to evaluate the crossbreeding effect between Holstein and one or two other breeds. Some of the publications are reviewed in the following paragraphs.

Production of milk and milk solids

In the studies summarised in this literature review, purebred Holsteins produced most milk per lactation, but some crossbreed combinations produced similar amount of milk solids as

Table 1. Difference in Least Square Means for 305-d production between first lactating F1-crosses and purebred Holsteins.

Breedgroup[1]	N	Milk (kg)	Fat (kg)	Protein (kg)	Fat + protein (kg)	Reference
Normande x H	245	– 1 227**	– 27**	– 28**	– 55**	Heins et al., 2006a
Montbeliarde x H	494	– 596**	– 12**	– 12**	– 24**	
SR x H	328	– 476**	– 6	– 8*	– 34	
Brown Swiss x H	274	– 195	+9	+14*		Dechow et al., 2007
Jersey x H	76	– 558**	– 3	– 15**	– 18*	Heins et al., 2008
Jersey x H	49	– 275**				Prendiville et al., 2010
Jersey x H	38	– 625**	+8	– 4	+4	Vance et al., 2013
Montbeliarde x H	59	– 340			– 9	Hazel et al., 2014

[1]H = Holstein; SR = Scandinavian Red. Breed of sire is mentioned first in the breed description.
*P < 0.05; **P < 0.01

purebred Holsteins (Table 1). A crossbreeding trial conducted by Heins et al. (2006a) between Scandinavian Red (SR; includes the breeds Swedish Red (SRB) and Norwegian Red) and Holstein showed no significant difference in fat and fat + protein production during the first lactation, and there were also no observed significant differences in fat production between Jersey x Holstein crossbreds (Heins et al., 2008). Also crossbreds between Brown Swiss x Holstein showed no significant differences in fat production and they even showed a significantly higher protein production compared with purebred Holstein (Dechow et al., 2007). Penasa et al. (2010) reported that crossbreds between Montbeliarde x Holstein produced less milk, fat and protein whereas crossbreds between Jersey x Holstein produced significantly less milk and protein but did not differ significantly in fat production compared with purebred Holsteins. Similar results were reported by Vance et al. (2013) where crossbreds between Jersey x Holstein produced less milk than purebred Holsteins, but the fat, protein and fat + protein production did not differ significantly. Also Prendiville et al. (2010) found a significantly lower milk production per day for crossbreds between Jersey x Holstein compared with purebred Holsteins.

Even though earlier mentioned studies have reported a significantly lower milk yield for crossbreds compared with purebred Holsteins, Heins et al. (2011) compared lifetime production for crossbreds between Jersey x Holstein with purebred Holsteins and found that lifetime production of milk, fat, protein and fat + protein for the crossbreds were lower but not significantly different from purebred Holsteins. Another study compared crossbreds between Normande x Holstein, Montbeliarde x Holstein and SR x Holstein with purebred Holsteins for production traits over five lactations (Heins & Hansen, 2012). The crossbreds produced significantly lower yields of milk, fat, protein and fat + protein over five lactations. However, Hazel et al. (2014) found that milk and fat + protein production for Montbeliarde x Holstein crossbreds were lower but not significantly different from purebred Holsteins from first to fifth lactation.

Udder health

Prendiville et al. (2010) found no significant differences for either mastitis or somatic cell score (SCS) when comparing purebred Holsteins with Jersey x Holstein crossbreds. Heins et al. (2011) found no differences in SCS and mastitis incidence during first and second lactation between Jersey x Holstein crossbreds and purebred Holsteins. However, mastitis incidence was significantly lower in third lactation for crossbreds even though SCS tended to be higher. Heins & Hansen (2012) compared crossbreds between Montbeliarde x Holstein and SR x Holstein and found that SCS was favourable and significantly different from purebred Holsteins.

Fertility and survival

The heterosis effect for fertility traits has been evaluated in different trials and the results for days open (DO) have been rather consequent among studies (Table 2). The number of days between calving and first service (CFS), and DO was significantly lower, and conception rate at first service (CRFS) was higher for first calving crossbreds between Normande x Holstein and Montbeliarde x Holstein compared with purebred Holsteins (Heins et al., 2006c). Only DO was significantly lower for first calving crossbreds between SR x Holstein.

Table 2. Difference in Least Square Means for fertility traits among F1-crosses compared with purebred Holsteins. CFS = days between calving and first service; DO = days open; CRFS = conception rate at first service; pp = percentage points.

Breed[1]	CFS (d)	DO (d)	CRFS (pp)	Reference
Normande x H	– 7**	– 27**	+13*	Heins et al., 2006c
Montbeliarde x H	– 4*	– 19**	+9**	
SR x H	– 3	– 21**	+8	
Brown Swiss x H		– 12*		Dechow et al. 2007
Jersey x H		– 23†		Heins et al., 2008
Normande x H[2]	– 4**	– 20**	+5†	Heins & Hansen, 2012
Montbeliarde x H[2]	– 7**	– 26**	+10**	
SR x H[2]	– 4**	– 12*	+6*	
Jersey x H		– 7	+23**	Vance et al., 2013
Montbeliarde x H		– 39*	+18*	Hazel et al., 2014

[1]H = Holstein; SR = Scandinavian Red. Breed of sire is mentioned first in the breed description.
[2]Difference in LSM for all traits across first five lactations.
†P < 0.10; *P < 0.05; **P < 0.01

Dechow et al. (2007) reported that crossbreds between Brown Swiss x Holstein had lower DO than purebred Holsteins. Penasa et al. (2010) observed a small but significant decline (P < 0.10) in calving interval (CI) for crossbreds between Jersey x Holstein compared with purebred Holsteins. Vance et al. (2013) compared crossbreds between Jersey x Holstein and found that DO did not differ significantly, but CRFS was significantly higher among crossbreds. Crossbreds between Normande x Holstein, Montbeliarde x Holstein and SR x Holstein have proven their superiority for fertility traits over first five lactations (Heins & Hansen, 2012). CFS, CRFS, pregnancy rate and DO were significant and favourably different from purebred Holsteins.

Crosses between Montbeliarde x Holstein had significantly fewer days open (DO) and both pregnancy rate and CRFS were significantly higher compared to purebred Holsteins (Hazel et al., 2014). The crossbreds had also significantly lower mortality rate, defined as the amount of cows euthanized or died divided by the total amount of cows, compared with purebred Holsteins (5.1 % for crossbreds vs. 17.7 % for purebred Holsteins) and the survival rate to subsequent calving was significantly higher for crosses from third to fifth lactation. The survival rate from first to second lactation was greater for crossbreds between Normande x Holstein, Montbeliarde x Holstein and SR x Holstein compared with purebred Holsteins (Heins et al., 2012). A significantly larger proportion of Normande x Holstein and SR x Holstein also survived to third lactation.

Calving performance

The heterosis effect for calving performance was evaluated in a crossbreeding trial conducted by Heins et al. (2006b) by comparing crossbreds of Normande x Holstein, Montbeliarde x Holstein and SR x Holstein with purebred Holsteins. The F1-crosses had significantly lower proportion of calving difficulties than purebred Holsteins at first calving. Crossbreds between Montbeliarde x Holstein and SR x Holstein also had a significantly lower proportion of stillbirths (6.2 % and 5.1 % compared with 14.0 % for purebred Holstein) at first calving. There were no significant differences between breed groups for calving difficulties and stillbirths at second calving.

Crossbreeding as a profitable breeding strategy

The majority of crossbreeding studies presented in this literature review showed that Holstein produced the most milk, but several crosses had the potential to produce the same amount of milk solids. The crosses were also superior in several functional traits and it also seems like crosses can be just as, or more, profitable than purebred Holsteins. In New Zealand, a two or three breed rotational crossbreeding system is the most profitable breeding strategy according to Lopez-Villalobos et al. (2000) and crossbreds also appeared to be more profitable than Holsteins in the US (Van Raden & Sanders, 2003).

Crossbreeding in Sweden

There are few studies published about the effect of crossbreeding under Swedish conditions. However, Ericson et al. (1988) compared the heterosis effect for production traits for crosses between SRB x Swedish Friesian (SLB), the breed that evolved to today's SH. Data from Swedish herds were compared and a small, but significant, heterosis effect was found. Both breeds have evolved since the study was conducted and these estimates of heterosis effect may not be fully applicable today mainly because semen from American Holsteins has been used on SLB to the extent that the breed has been renamed to SH. SRB has also evolved but the breeding has not been influenced by international breeding standards to the same extent as for SH, and has therefore kept a high capacity for functional traits.

Material & Methods

Data

Observations from the first three lactations from 8 522 505 cows born between 1990 and 2012 were collected from the Swedish milk recording scheme. All cows had given birth to at least one calf where the first calving occurred between 18 to 38 months of age. Observations that lacked information about dam, sire and maternal grandsire were deleted, and observations that remained were divided in different breed groups: SH, SRB, SRB x SH and SH x SRB, where the sire is mentioned first for the two crossbred groups (Table 3). If the breed of the observation was 100 % purebred SH, it was assigned to the SH breed group. If the breed of the cow was at least 93.75% of accepted red dairy cattle breed (RDC, including SRB, Norwegian Red, Finnish Ayrshire and Swedish Ayrshire) it was assigned to the SRB breed group. If the breed of the cow was a F1 crossbreed between SH and SRB it was assigned to either the SH x SRB or SRB x SH breed group, depending on the breed of the dam. Observations on cows that did not fit in one of these four breed groups were deleted. In order to minimize the influence of the environment, only herds with at least five purebred observations and at least five F1-observations were kept in the material. Herds with less than five F1-crosses were deleted.

In total, 5 325 herds and 2 676 286 observations fulfilled the criteria and were used for further analyses (Table 4). The majority of the cows used in the analyses were purebreds (1 452 440 purebred SRB, 1 094 947 purebred SH, 34 053 SRB x SH crossbreds and 94 846 SH x SRB crossbreds). The observations were divided into three datasets depending on lactation number. The analyses were made separately for each lactation.

Two approaches to estimate breed group and heterosis effect were used. The first way was by dividing observations into four breed groups described above. The second way was to include breed percentage in the analysis. Information about breed percentage was collected from the Nordic Cattle Genetic Evaluation (Nordic Cattle Genetic Evaluation, 2013). A coefficient for different breed combinations was made by using following model (Dickerson, 1973 cited by Lidauer et al., 2006):

$$h_{ij}^{k} = p_i^s p_j^d + p_j^s p_i^d$$

where h_{ij}^{k} is the estimated heterozygosity of breed i and breed j in the crossbred cow k. p_i^s and p_j^s are breed percentages from the sire, and p_j^d and p_i^d are breed percentages from the dam. The coefficient h_{ij}^{k} ranged from 0 to 1 where 0 equals that the animal is purebred and 1 equals that the animal is a F1 crossbred.

Breed group coefficients for the following breed group combinations were made: SH x SRB, SRB x Finnish Ayrshire (FAY), SRB x Canadian Ayrshire (CAY), SRB x SLB, SH x FAY, SH x CAY and SH x SLB.

Table 3. Description of the breed groups. SH = Swedish Holstein; SRB = Swedish Red.

Observation	Sire	Dam
SH	SH[1]	SH
SRB	SRB[2]	SRB
SH x SRB[3]	SH	SRB
SRB x SH[3]	SRB	SH

[1]100 % purebred Holstein
[2]At least 93.75 % accepted RDC breeds (SRB, Norwegian Red, Finnish Ayrshire, Swedish Ayrshire)
[3]F1-crosses between Holstein and SRB with 47-53% of each breed

Production traits & udder health

Production traits from test day observations of milk yield and percentages of fat and protein from milk recording were used to express production of milk, fat and protein in kg per 305-d lactation. The measurements are collected up to twelve times per year at herd level. At least two test days are required per observation to be registered. Values for production traits were only available from 2002 until today. Because of this, the data set used to analyse production traits was smaller than for other traits (Appendix 1). Values for milk, fat and protein production that were more extreme than three standard deviations from the mean value were deleted.

Mastitis was classified in two groups where 1 means that clinical mastitis was diagnosed between -10 to 150 days after parturition, mastitis was otherwise set to 0. Mastitis incidence was reported by veterinarians and data for SCS were collected at the same time as production traits. The value for SCS was converted to somatic cell count (SCC) in the results by using following formula: $10^{SCS} \cdot 10\,000$. SCC is measured as the amount of white blood cells per ml of milk.

Fertility & survival

There were four fertility traits analysed in the dataset: calving interval (CI), CFS, number of days from first to last service (FLS) and number of services per lactation (NINS). The data material was restricted to minimize bias in the analysis and values within a certain interval were included as follows: CI ranged from 280 to 700 days, CFS ranged from 21 to 290 days, FLS ranged from 0 to 250 days and NINS ranged from 1 to 7 number of services. Cows that did not fit in the mentioned criteria's were considered as culling candidates and were therefore not included in the analysis.

DO was calculated by summing the values of CFS and FLS. For observations where information about CFS and FLS was missing, DO was calculated by subtracting the estimated mean gestation length of 280 days (Norman et al., 2009b) from the CI. For observations where information about CI was missing and there was a subsequent calving, DO was set to 117 days (mean value of DO was obtained by using the PROC MEANS procedure of the edited data). For observations where information about CI was missing and there was no subsequent calving, DO was set to 397 by summing the mean gestation length with the mean DO (280 + 117).

Table 4. Number of observations fulfilling the criteria for further analysis for all traits divided in lactation number and breed group. SH = Swedish Holstein; SRB = Swedish Red.

Lactation	Number of herds	Number of observations	Number of SRB	Number of SH	Number of SRB x SH	Number of SH x SRB
1	5 325	1 237 941	663 138	515 529	15 442	43 832
2	5 325	883 783	481 242	360 073	11 234	31 234
3	5 309	554 562	308 060	219 345	7 377	19 780
Total	5 325	2 676 286	1 452 440	1 094 947	34 053	94 846

Two traits were analysed for survival: survival from first to second lactation and survival from first to third lactation. The value was set to 1 if the cow survived, otherwise the value was set to 0.

Calving performance & stillbirths

Calving performance was classified in two groups, where normal calving was set to 0 and difficult calving was set to 1. Stillbirth was classified in two groups where 1 equals dead at parturition or within 24 hours after, otherwise the value was set to 0. Observations with calves from embryo transfer, twins, abortions and early calvings were not included in the analysis.

Other diseases

Other diseases were divided in four different groups: early reproductive diseases (ERD), late reproductive diseases (LRD), metabolic diseases (MD) and feet and leg diseases (FLD). The reproductive disorders include hormonal, infective and other reproductive disorders. Reproductive disorders and retained placenta that occurred between 0 to 40 days after parturition were put in ERD and reproductive disorders that occurred between 40 to 305 days after parturition were put in LRD. MD included ketosis, milk fever, other metabolic diseases and other feed related disorders that occurred between −15 to 305 days after parturition. Information about FLD was included in the dataset if FLD occurred between −15 to 305 days after parturition. Observations that lacked information about other diseases were set to 0.

Nordic Total Merit

The Nordic Total Merit (NTM) values was used in the analyses in order to account for genetic differences in the breeding material since it can be assumed that semen from bulls with high NTM is used to a greater extent on purebred cows than on crossbreds. The breeding values for the NTM index for sire, dam and maternal grandsire of cows with observations in the material were collected from the Nordic Cattle Genetic Evaluation (Nordic EBV, 2014). All economically important traits are included in the breeding goal, NTM. The sub-indexes are milk yield, growth, fertility, udder health, other diseases, direct calving performance, maternal calving performance, survival, claw health, longevity, temperament, milkability and conformation (udder, body, feet and legs).

Statistical analysis

Statistical Analysis Software version 9.3 was used to obtain solutions and descriptive statistics (SAS Institute, 2011). The PROC MEANS and PROC FREQ procedures were used to obtain descriptive statistics (see Appendices).

The PROC GLM procedure was used to obtain solutions for fixed effects. Independent variables were the fixed factors of breed group, NTM of sire nested within the breed group of sire, NTM of maternal grandsire nested within breed group of maternal grandsire, herd and year, calving year and month, calving age (linear and quadratic). Days open was added as a fixed factor when analysing production traits. Sex of the calf and breed group of the sire of the calf were added as fixed factors when analysing calving performance traits.

Three dataset were created in order to get an overview of changes in means over time by dividing animals depending on birth year of the observation; 1990-2012, 1990-2002 and 2003-2012 (Appendix 5). These data were analysed with the PROC GLM procedure for the traits: survival to 2nd lactation and mastitis in first lactation in order to obtain solutions and observe if the estimated breed group differences changed over time.

The ESTIMATE statement was used to calculate differences between breed groups. The statement was also used to estimate the heterosis effect by comparing estimates of the F1-crosses with the mean of SH and SRB, illustrated in the following formula:

$$h_{F1} = \mu_{F1} - \frac{\mu_{SH} + \mu_{SRB}}{2}$$

The relative heterosis effect (RHE) was then calculated by dividing the estimated heterosis effect for the F1-crosses with the phenotypic mean value between SRB and SH:

$$RHE_{F1} = \frac{h_{F1}}{\left(\frac{\mu_{SH} + \mu_{SRB}}{2}\right)}$$

Different models were used to evaluate the regressions on NTM and decide what model fitted the traits best. This was done by adding and deleting regressions to see how important the regression was in the model. First, the NTM of the dam was set as a regression factor but it was changed to the NTM of the maternal grandsire. The final models used for analysis are described below.

<u>Fertility, survival, udder health and other diseases:</u>

$$Y_{ijklm} = \mu + B_i + HY_{jk} + YM_{kl} + A_m + A_m^2 + NTM^s(B_i^s) + NTM^g\left(B_i^g\right) + e_{ijklm}$$

<u>Production:</u>

$$Y_{ijklmn} = \mu + B_i + HY_{jk} + YM_{kl} + A_m + A_m^2 + NTM^s(B_i^s) + NTM^g\left(B_i^g\right) + O_n + e_{ijklmn}$$

<u>Calving performance:</u>

$$Y_{ijklmop} = \mu + B_i + HY_{jk} + YM_{kl} + A_m + A_m^2 + NTM^s(B_i^s) + NTM^g\left(B_i^g\right) + S_o + BS_p + e_{ijklmop}$$

where

Y = the observed value
μ = mean of the population
B_i = fixed class effect of breed group *i*; SH, SRB, SRB x SH or SH x SRB.
HY_{jk} = fixed class effect of calving herd *j*, and year *k*: 1990, …, 2012.
YM_{kl} = fixed class effect of calving year *k*: 1990, …, 2012 and month *l*: 01, …, 12.
A_m & A_m^2 = fixed regression of calving age *m*: 545, …, 1151 days.
$NTM^s(B_i^s)$ = fixed regression of NTM of sire nested within breed group of sire, *i*; SH, SRB, SRB x SH or SH x SRB.
$NTM^g\left(B_i^g\right)$ = fixed regression of NTM of maternal grandsire nested within breed group of maternal grandsire, *i*; SH, SRB, SRB x SH or SH x SRB.
O_n = fixed regression of days open *n*: 0, …, 397.
S_o = fixed class effect of sex of the calf *o*: bull or heifer.
BS_p = fixed class effect of the breed group of the sire of the calf. *p*: SRB, SH, beef breed, other milk breed or crossbreed.

The GLM procedure was used when analysing the heterosis effect where the breed coefficient and breed percentage was used instead of breed group. The model was:

$$Y_{ijklmnp} = \mu + h_{SH,SRB} + h_{SRB,FAY} + h_{SRB,CAY} + h_{SRB,SLB} + h_{SH,FAY} + h_{SH,CAY} + h_{SH,SLB} + B_q^{SH} + B_q^{SRB} + B_q^{FAY} + B_q^{CAY} + B_q^{SLB} + HY_{jk} + YM_{kl} + A_m + A_m^2 + NTM^s(B_i^s) + NTM^g\left(B_i^g\right) + O_n + e_{ijklmnq}$$

where

$h_{SH,SRB}$ was the breed coefficient for SH x SRB, *h*: 0, …, 1.
$h_{SRB,FAY}$ was the breed coefficient for SRB x FAY, *h*: 0, …, 1.
$h_{SRB,CAY}$ was the breed coefficient for SRB x CAY, *h*: 0, …, 1.
$h_{SRB,SLB}$ was the breed coefficient for SRB x SLB, *h*: 0, …, 1.
$h_{SH,FAY}$ was the breed coefficient for SH x FAY, *h*: 0, …, 1.
$h_{SH,CAY}$ was the breed coefficient for SH x CAY, *h*: 0, …, 1.
$h_{SH,SLB}$ was the breed coefficient for SH x SLB, *h*: 0, …, 1.
B_q^{SH} was the breed percentage for SH, *q*: 0, …, 1.
B_q^{SRB} was the breed percentage for SRB, *q*: 0, …, 1.
B_q^{FAY} was the breed percentage for FAY, *q*: 0, …, 1.
B_q^{CAY} was the breed percentage for CAY, *q*: 0, …, 1.
B_q^{SLB} was the breed percentage for SLB, *q*: 0, …, 1.

The remaining effects are as described above. The effect of herd and year was absorbed in all models.

Results

Production traits

The solutions for milk production were significantly lower for all other breed groups compared with purebred SH (Table 5). The estimates for milk, fat and protein over all lactations were lowest for SRB. The F1-crosses produced significantly more fat during first lactation (3.6 kg and 10.9 kg respectively) than purebred SH. SH x SRB produced significantly more fat during second lactation (4.4 kg) and there were no significant difference from purebred SH in fat production during third lactation. SH x SRB produced significantly more protein during first lactation (1.8 kg) compared with later lactations. The heterosis effect was significant and favourable for all production traits in all lactations.

Functional traits

Fertility

The estimated values for all other breed groups were significant and favourably different from purebred SH for all fertility traits in all lactations. SRB x SH had the shortest CI in first and third lactation while SRB had the shortest CI in second lactation (Table 6). The estimates for CFS were shortest for SRB during first and second lactation while SRB x SH had the shortest CFS in third lactation. SRB x SH had the shortest FLS interval in first and third lactation while SRB had the shortest FLS interval in second lactation. The heterosis effect was significant and favourable for all fertility traits in first lactation for both F1-crossbreds. In second lactation, CI, FLS and NINS were favourable but only significant for SH x SRB. In third lactation, CI, CFS and FLS were favourable but only significant for SRB x SH.

Table 5. Estimated breed group effects, relative to purebred Swedish Holstein (SH), and the estimated heterosis ($h_{SRB\times SH}$ and $h_{SH\times SRB}$) effect for production traits in three lactations. SRB = Swedish Red; SRB × SH = crossbred with SRB sire and SH dam; SH × SRB = crossbred with SH sire and SRB dam

Lactation	SRB	SRBxSH	SHxSRB	h_{SRBxSH}	h_{SHxSRB}
Milk (kg)					
1	– 835**	– 260**	– 113**	158**	305**
2	– 1315**	– 470**	– 299**	188**	358**
3	– 1399**	– 539**	– 366**	161*	334**
Fat (kg)					
1	– 9.65**	3.60*	10.90**	8.42**	15.72**
2	– 27.05**	– 4.59*	4.38**	8.94**	17.91**
3	– 33.02**	– 7.05*	1.40	9.46**	17.9**
Protein (kg)					
1	– 16.14**	– 2.44*	1.78**	5.62**	9.85**
2	– 29.50**	– 8.54**	– 3.19**	6.20**	11.55**
3	– 31.73**	– 11.31**	– 4.80**	4.55*	11.07**

*P < 0.05; **P < 0.01

Table 6. Estimated breed group effects, relative to purebred Swedish Holstein (SH), and the estimated heterosis ($h_{SRB\times SH}$ and $h_{SH\times SRB}$) effect for fertility traits in three lactations. SRB = Swedish Red; SRB × SH = crossbred with SRB sire and SH dam; SH × SRB = crossbred with SH sire and SRB dam; CI = calving interval; CFS = days from calving to first service; FLS = days from first to last service; NINS = number of services.

Lactation	SRB	SRBxSH	SHxSRB	h_{SRBxSH}	h_{SHxSRB}
CI (d)					
1	– 9.2**	– 10.2**	– 7.7**	– 5.6**	– 3.1**
2	– 14.8**	– 10.0**	– 9.6**	– 2.6	– 2.2*
3	– 14.1**	– 17.2**	– 8.8**	– 10.1**	– 1.8
CFS (d)					
1	– 5.4**	– 4.6**	– 3.9**	– 1.9**	– 1.2**
2	– 7.4**	– 4.4**	– 4.2**	– 0.7	– 0.5
3	– 6.4**	– 6.8**	– 3.3**	– 3.6**	– 0.1
FLS (d)					
1	– 4.0**	– 4.8**	– 4.0**	– 2.8**	– 2.0**
2	– 7.3**	– 5.1**	– 5.2**	– 1.4	– 1.5*
3	– 7.4**	– 7.5**	– 5.4**	– 3.8*	– 1.7
NINS (no)					
1	– 0.03**	– 0.08**	– 0.06**	– 0.06*	– 0.05**
2	– 0.11**	– 0.10**	– 0.09**	– 0.05	– 0.04*
3	– 0.10**	– 0.01*	– 0.10**	– 0.05	– 0.05

*P < 0.05; **P < 0.01

Survival

The F1 crossbreds were superior in survival as compared with both purebred SH and purebred SRB (Table 7). SRB had the lowest survival to 2nd lactation but was not significantly different from purebred SH in survival to 3rd lactation. The heterosis effect was favourable and significant for both F1-crossbreds.

Calving performance

Calving difficulties were significantly lower in first and second lactation for all other breed groups when comparing estimates with purebred SH (Table 8). No significant differences were observed in third lactation for calving difficulties between purebred SH and the other breed groups.

All other breed groups had a significantly lower incidence of stillbirths than purebred SH in first lactation. The estimates for purebred SRB and SH x SRB were significantly lower in second lactation but only purebred SRB differed significantly from purebred SH in third

Table 7. Estimated breed groups effects, relative to purebred Swedish Holstein (SH), and the estimated heterosis ($h_{SRB\times SH}$ and $h_{SH\times SRB}$) effect for survival traits in three lactations. SRB = Swedish Red; SRB × SH = crossbred with SRB sire and SH dam; SH × SRB = crossbred with SH sire and SRB dam; pp = percentage points.

Trait	SRB	SRBxSH	SHxSRB	h_{SRBxSH}	h_{SHxSRB}
Survival to 2nd lactation (pp)					
	– 1.1**	2.7**	2.6**	3.2**	3.2**
Survival to 3rd lactation (pp)					
	– 0.2	5.5**	5.2**	5.6**	5.3**

*P < 0.05; **P < 0.01

Table 8. Estimated breed groups effects, relative to purebred Swedish Holstein (SH), and the estimated heterosis ($h_{SRB×SH}$ and $h_{SH\ ×SRB}$) effect for udder health and calving performance traits in three lactations. SRB = Swedish Red; SRB × SH = crossbred with SRB sire and SH dam; SH × SRB = crossbred with SH sire and SRB dam; SCC = somatic cell count; pp = percentage points.

Lactation	SRB	SRBxSH	SHxSRB	h_{SRBxSH}	h_{SHxSRB}
Mastitis (pp)					
1	– 1.3**	– 0.2	– 0.8**	0.5	– 0.2
2	– 2.8**	– 0.6	– 2.1**	0.8	– 0.7*
3	– 4.4**	– 2.3**	– 3.2**	– 0.1	– 1.0
SCC (cells/ml milk)					
1	– 11 142*	– 10 185*	– 10 665	10 375*	– 10 092
2	– 12 022**	– 10 739**	– 11 428**	10 209	– 10 423**
3	– 12 445**	– 11 857**	– 11 168**	– 10 641	– 10 023
Calving difficulties (pp)					
1	– 1.8**	– 2.1**	– 1.9**	– 1.2**	– 1.0**
2	– 0.3*	– 0.8*	– 0.7**	– 0.6	– 0.5*
3	– 0.4	– 0.7	– 0.5	– 0.6	– 0.4
Stillbirth (pp)					
1	– 2.9**	– 2.4**	– 2.3**	– 0.9*	– 0.9**
2	– 0.4**	– 0.7	– 0.8**	– 0.4	– 0.6**
3	– 0.6**	– 0.8	– 0.5	– 0.5	– 0.2

*P < 0.05; **P < 0.01

lactation. The estimated heterosis effect was favourable and significant for stillbirth and calving difficulty, and F1-crossbreds in first lactation. SH x SRB-crossbreds had a significant and favourable heterosis effect in second lactation for both traits. No heterosis effects were observed in third lactation for F1-crossbreds for both traits.

Udder health

Purebred SRB and SH x SRB crossbreds had significantly lower mastitis incidence for all lactations compared to purebred SH. Lower mastitis incidence was also observed for SRB x SH, however only significant in third lactation (Table 8). The breed group effects for SCC were significantly lower for all other breed groups and all lactations except in first lactation where SH x SRB was not significantly different from purebred SH.

The heterosis effect for mastitis was however only significant and favourable for SH x SRB in second lactation. The heterosis effect for SCC was significant and unfavourable in lactation 1 for SRB x SH crosses but there was no significant heterosis effect for second and third lactation. The heterosis effect for SCC for SH x SRB was significant and favourable in second lactation but was not significant in first and third lactation.

Other diseases

When analysing other diseases, the estimates for ERD and MD were significantly lower than purebred SH for all other breed groups in first lactation (Table 9). Purebred SRB was the only breed group that had significantly lower occurrence of all other diseases in all lactations except FLD that were significantly higher in first lactation. The estimated value for SRB x SH

Table 9. Estimated breed groups effects, relative to purebred Swedish Holstein (SH), and the estimated heterosis ($h_{SRB \times SH}$ and $h_{SH \times SRB}$) effect for other diseases in three lactations. SRB = Swedish Red; SRB × SH = crossbred with SRB sire and SH dam; SH × SRB = crossbred with SH sire and SRB dam; ERD = early reproductive diseases; LRD = late reproductive diseases; MD = metabolic diseases; FLD = feet and leg diseases; pp = percentage points.

Lactation	SRB	SRBxSH	SHxSRB	h_{SRBxSH}	h_{SHxSRB}
ERD (pp)					
1	– 0.52**	– 0.61**	– 0.59**	– 0.35	– 0.33**
2	– 0.29**	– 0.58*	– 0.33	– 0.43	– 0.18
3	– 0.27*	– 0.15	0.05	– 0.02	0.19
LRD (pp)					
1	– 0.26**	– 0.17	– 0.16*	– 0.04	– 0.03
2	– 0.32**	– 0.30	– 0.41**	– 0.14	– 0.25**
3	– 0.32**	– 0.15	– 0.18	0.01	– 0.02
MD (pp)					
1	– 0.41**	– 0.67**	– 0.39**	– 0.47*	– 0.18
2	– 0.99**	– 0.55	– 0.57*	– 0.05	– 0.08
3	– 2.21**	0.63	– 0.41	1.73**	0.69
FLD (pp)					
1	0.46**	– 0.04	– 0.04	– 0.27	– 0.27
2	– 0.20**	0.14	– 0.23	0.24	– 0.13
3	– 0.25*	0.22	– 0.60**	0.34	– 0.48*

*P < 0.05; **P < 0.01

was significantly lower for MD in first lactation and ERD in first and second lactation but there were no difference from purebred SH in the remaining traits and lactations.

The estimated breed group effect for SH x SRB were significantly lower for ERD, LRD and MD in first lactation. In second lactation, the estimated breed groups effect for LRD and MD were significantly lower, and FLD were significantly lower in third lactation for SH x SRB.

The heterosis effect was significant and favourable for MD incidence for SRB x SH crosses in first lactation, however unfavourable and significant in the third lactation. The heterosis effect for ERD incidence was significant and favourable for SH x SRB in first lactation, the heterosis effect for LRD incidence was significant and favourable in second lactation and FLD were significant and favourable in third lactation for SH x SRB.

Relative heterosis effect (RHE)

The RHE for production traits ranged between 1.3 to 4.5 % and were favourable and significant for both F1-crosses in all lactations (Table 10). The RHE were favourable and significant for SH x SRB crosses in second lactation for both mastitis and SCS (7.1 and 2.0 % respectively) while the RHE for SRB x SH for SCC in first lactation were significant and unfavourable. The RHE ranged from 4.4 to 10.2 % for calving difficulties and from 4.4 to 14.5 % for stillbirths. The RHE for calving traits were favourably significant for SRB x SH in first lactation, and in first and second lactation for SH x SRB. No significant RHE was observed in third lactation.

Table 10. The relative heterosis effect presented in %. Favourable heterosis are marked in bold. SRB × SH = crossbred with Swedish Red (SRB) sire and Swedish Holstein (SH) dam; SH × SRB = crossbred with SH sire and SRB dam; CI = calving interval; CFS = days from calving to first service; FLS = day from first to last service; NS = number of services; SCC = somatic cell count; ERD = early reproductive diseases; LRD = late reproductive diseases; MD = metabolic diseases; FLD = feet and leg disorders.

	SRB x SH			SH x SRB		
Lactation	1	2	3	1	2	3
Production						
Milk	**1.9****	**2.0****	**1.6***	**3.7****	**3.7****	**3.4****
Fat	**2.4****	**2.2****	**2.3****	**4.5****	**4.5****	**4.3****
Protein	**2.0****	**1.9****	**1.3***	**3.4****	**3.5****	**3.3****
Fertility						
CI	**1.4****	**0.7**	**2.6****	**0.8****	**0.6***	**0.5**
CFS	**2.2****	**0.8**	**4.2****	**1.4****	**0.6**	**0.1**
FLS	**8.5****	**4.5**	**12.0***	**6.2****	**4.8***	**5.3**
NINS	**3.4***	**2.7**	**2.7**	**2.6****	**2.1***	**2.5**
Calving performance						
Calving difficulties	**10.2****	**7.0**	**6.7**	**8.5****	**5.9***	**4.4**
Stillbirths	**11.9***	**9.7**	**11.5**	**11.9****	**14.5****	**4.6**
Survival						
Survival to 2nd lactation	**4.6****			**4.5****		
Survival to 3rd lactation	**13.0****			**12.3****		
Udder health						
Mastitis	6.1	7.8	**0.5**	**2.6**	**7.1***	**7.4**
SCC	2.0*	1.1	**2.7**	**0.6**	**2.0****	**0.1**
Other diseases						
ERD	**20.5**	**18.9**	**0.7**	**19.3****	**7.9**	6.7
LRD	**8.8**	**19.4**	1.5	**6.6**	**34.7****	**3.1**
MD	**26.8***	**2.3**	20.9**	**10.3**	**3.7**	8.4
FLD	**9.8**	12.3	18.5	**9.8**	**6.7**	**26.2***

*P < 0.05; **P < 0,01

The RHE for fertility traits ranged between 0.1 and 12.0 % where the RHE were highest for FLS (ranged between 4.5 and 12.0 %). All fertility traits had a favourable RHE for both F1-crosses and all lactations. The RHE were significant for both F1-crosses in first lactation, and the RHE for CI, FLS and NINS were significant for SH x SRB crosses in second lactation. The RHE for CI, FLS and NINS were significant for SRB x SH crosses in third lactation.

The RHE for ERD were favourable and significant for SH x SRB crosses in first lactation (26.8%), for LRD favourable and significant for SH x SRB crosses in second lactation (34.7 %), and for MD favourable and significant for SRB x SH crosses in first lactation but unfavourable and significant in third lactation. Finally, RHE for FLD was favourable and significant for SH x SRB crosses in third lactation.

Table 11. The estimated heterosis effect (h_{F1}) for the breed groups Swedish Holstein (SH) x Swedish Red (SRB), SRB x Finnish Ayrshire (FAY), SRB x Canadian Ayrshire (CAY), SRB x Swedish Friesian (SLB), SH x FAY, SH x CAY and SH x SLB for 305-d production in three lactations obtained by using breed percentage coefficient in the analysis.

Lactation	$h_{SH,SRB}$	$h_{SRB,FAY}$	$h_{SRB,CAY}$	$h_{SRB,SLB}$	$h_{SH,FAY}$	$h_{SH,CAY}$	$h_{SH,SLB}$
Milk (kg)							
1	371.1**	243.8	– 49.6	963.9	395.4**	108.1	302.6
2	590.6**	568.9**	– 77.5	1 474.1	431.1**	– 65.8	184.9
3	451.1**	191.2	229.2	2 053.7*	280.9	106.2	392.8
Fat (kg)							
1	18.3**	7.8	– 3.5	– 2.0	22.5**	14.0*	15.0
2	31.8**	25.2**	3.8	31.7	18.4**	8.4	– 7.9
3	21.2**	13.9	– 0.6	103.4*	20.5*	16.0	11.5
Protein (kg)							
1	14.0**	7.6	– 5.4	– 30.9	13.3**	5.9	11.8
2	21.7**	13.7*	3.0	– 20.5	12.6**	– 1.0	0.4
3	13.9**	– 0.7	5.6	19.6	11.8	0.3	10.9

* P < 0.05; ** P < 0.01

The RHE for both survival traits were favourable and significant. Survival to 2nd lactation were 4.6 % for SRB x SH and 4.5 % for SH x SRB. Survival to 3rd lactation were 13.0 % for SRB x SH and 12.3 % for SH x SRB.

Estimating the heterosis effect by breed percentage

The estimated heterosis effect for the SH x SRB breed combination was significant and favourable for all production traits in all lactations (Table 11). The estimated heterosis effect was largest in second lactation for all traits. The estimated heterosis effect was smallest in first lactation for milk and fat production, and in third lactation for protein production.

The estimated heterosis effect for SRB x FAY breed combination was favourable and significant for all production traits in second lactation. No significant heterosis effect was observed for SRB x FAY in the other lactations. The estimated heterosis effect for SRB x SLB breed combination were favourable and significant for fat and protein production in third lactation while the heterosis effect for fat production was favourable and significant in first lactation for SH x CAY. The estimated heterosis effect was favourable and significant for SH x FAY breed combination in first and second lactation for milk and fat production. The estimated heterosis effect for fat production was also favourable and significant in third lactation. No significant heterosis effect was observed for SRB x CAY or SH x SLB for all production traits and all lactations.

The use of different regressions in the model

Herd-year was the parameter that had the largest impact on the outcome when trying out different factors in the model (Table 12). As soon as herd-year was added to the model, the estimated breed group effects changed and remained relatively constant when more factors were added. All factors in the models were significant (P < 0.05).

Table 12. Estimated breed group effects for Survival to 2nd lactation from different models. Values are presented in percentage units, relative to purebred Swedish Holsteins (SH). SRB = Swedish Red; SRB × SH = crossbred with SRB sire and SH dam; SH × SRB = crossbred with SH sire and SRB dam.

Model	SRB	SRB x SH	SH x SRB
B_i	2.6 ± 0.1	3.3 ± 0.4	2.1 ± 0.2
P-value	<0.01	<0.01	<0.01
$B_i + H_{jk}$	– 0.4 ± 0.1	2.7 ± 0.4	2.8 ± 0.3
P-value	<0.01	<0.01	<0.01
$B_i + H_{jk} + M_{kl}$	– 0.4 ± 0.1	2.7 ± 0.4	2.9 ± 0.3
P-value	<0.01	<0.01	<0.01
$B_i + H_{jk} + M_{kl} + A_m$	– 0.3 ± 0.1	2.6 ± 0.4	2.8 ± 0.3
P-value	0.03	<0.01	<0.01
$B_i + A_m$	2.7 ± 0.4	3.4 ± 0.1	2.2 ± 0.4
P-value	<0.01	<0.01	<0.01
$B_i + H_{jk} + A_m$	– 0.3 ± 0.1	2.6 ± 0.4	2.8 ± 0.3
P-value	0.02	<0.01	<0.01

Analysis for survival to 2nd lactation and mastitis using different datasets

There were differences in breed group effects over time for the traits survival to 2nd lactation and mastitis incidence in first lactation (Table 13). The largest favourable breed group effect for mastitis in first lactation was shown for SRB in dataset 1990-2012. There was a favourable but not significant breed group effect for mastitis incidence for SRB x SH in dataset 1990-2012 and 1990-2002. The breed group effect for mastitis incidence for SRB x SH was unfavourable but not significantly different from purebred SH in dataset 2003-2012. The breed group effect for mastitis incidence for SH x SRB was favourable in all datasets but only significantly different from purebred SH in dataset 1990-2012 and 2003-2012.

The largest favourable breed group effect for survival to 2nd lactation was shown for both F1-crossbreds in dataset 2003-2012. There was an unfavourable difference in estimated mean value for purebred SRB compared with purebred SH for survival to 2nd lactation in all datasets. However, the difference is smaller, but significantly different from purebred SH in dataset 2003-2012. The F1-crossbreds had a favourable breed group effect for survival to 2nd lactation in all datasets. All breed groups were significantly different from purebred SH in dataset 1990-2012 and 2003-2012 for Survival to 2nd lactation. The estimated values for survival to 2nd lactation for both F1-crossbreds were not significantly different from purebred SH in dataset 1990-2002. The difference in estimated mean values between F1-crossbreds and purebred SH for Survival to 2nd lactation are larger in dataset 2003-2012.

Table 13. Breed group effects, relative to purebred Swedish Holstein (SH), for mastitis occurrence in first lactation and survival to 2nd lactation estimated using three different datasets. SRB = Swedish Red; SRB × SH = crossbred with SRB sire and SH dam; SH × SRB = crossbred with SH sire and SRB dam; pp = percentage points.

	Dataset	SRB	SRB x SH	SH x SRB
Mastitis (pp)	1990-2012	– 1.3**	– 0.2	– 0.8**
	1990-2002	– 0.9**	– 0.5	– 0.9
	2003-2012	– 1.2**	0.3	– 0.8**
Survival to 2nd lactation (pp)	1990-2012	– 1.1**	2.7**	2.6**
	1990-2002	– 2.2**	1.3	1.3
	2003-2012	– 0.8**	3.1**	3.1**

* P < 0.05; ** P < 0.01

Discussion

The number of observations used in the analysis differed among traits. The smallest amount of observations was used for production traits, since data material was only available from cows born in 2002 to 2012. Lack of information for a certain trait is the main reason why observations are not included in the analysis. In addition, the use of NTM of sire and maternal grandsire reduced the amount of observations included in the analysis since a number of bulls lacked information about NTM. This might affect the results since there are different observations used in analysis for different traits.

Differences in datasets over time

The breed group effect between SH and the other breed groups were different between the datasets divided in different timespans. This indicates that there has been a progress in breeding since 1990 until today, especially for purebred SH and purebred SRB. This also affects the breed group effects for crossbreds. The breed group effects were generally larger and favourable in dataset 2003-2012 compared with dataset 1990-2002 for both traits.

Production traits

Estimating heterosis through breed groups

The differences in mean values for production traits compared with purebred SH showed that SH produced significantly more milk than SH x SRB and SRB x SH crossbreds. The results were consistent with the crossbreeding study performed by Heins et al. (2006a) who compared SR x Holstein crossbreds with purebred Holstein.

Even though few crossbreeding combinations produced the same amount of milk as purebred Holsteins in the literature, there were a number of crossbred combinations that has shown to be competitive with purebred Holsteins in production of milk solid (Heins et al., 2006a; Heins et al., 2008; Penasa et al., 2010; Prendiville et al., 2010; Vance et al., 2013; Hazel et al., 2014). This is consistent with the estimated breed group effect presented in this study, which even found a significantly higher milk solid production for the crossbreds.

There were considerably fewer observations in all studies presented in the literature review compared with this study. Despite this, the trends for production traits were similar. The SH is also somewhat genetically different from American Holstein for two reasons: SH originate from SLB and the breeding goals for Holstein are different in Sweden compared with USA. The weights in the breeding goal for American Holstein are 46 % on production traits, 28 % on health and fertility traits, and 26 % on conformation traits (Holstein Association USA, 2014). The weights in the breeding goal for SH are 31 % on production traits, 52 % on health and fertility traits, and 17 % on conformation, temperament and milk speed traits (Viking Genetics, 2014).

Estimating heterosis through breed percentage

The estimated heterosis effect was favourable and significant for both methods but the heterosis effect was greater for crossbreds between SH and SRB for production traits when breed percentage was used in the model instead of breed group. Few of the other crossbreed combinations had a significant heterosis effect for production traits, except for SH x FAY.

Only purebred SRB, purebred SH, and F1-crossbreds between those were kept in the data material. The amount of cows containing breed percentages of any other breeds were minimized. It is unknown why the size of the estimated heterosis effect differs between methods presented in this study. Further evaluation must be done in order to estimate the reliability of the methods. For instance, not only F1-crossbreds could be included in the data material. That will result in a much larger sample, but also include a large variety of breed combinations.

Functional traits

Fertility

Crossbreds have in several crossbreeding trials shown their superiority in fertility traits compared with purebred Holsteins (Heins et al., 2006c; Dechow et al., 2007; Heins et al., 2008; Heins et al., 2011; Vance et al., 2013; Hazel et al., 2014) and so were the breed group effect in this study as well. However, the breed group effect and the heterosis effect for fertility traits were most significant in first lactation. The breed group effect was still significant in second and third lactation but the heterosis effect was only significant for some fertility traits. These results are inconsistent with the results found by Heins et al. (2006b) who only found significantly fewer DO for SR x Holstein crosses compared with purebred Holsteins, but did not find any significant breed group difference in CFS and CRFS. However, they did see a significant difference over five lactations in DO, CRFS and DFS for SR x Holstein crossbreds compared with purebred Holsteins (Heins & Hansen, 2012).

Survival

The crossbreds showed a better longevity than purebred SH and the heterosis effect was favourably significant for both survival traits. Other studies have also shown a better longevity for crossbreds compared with purebred Holsteins (Heins et al., 2012; Hazel et al., 2014). This might be due to better health status and better fertility among crossbreds which leads to a lower culling rate. The results showed a lower proportion of ERD and MD in first lactation, and a lower mastitis occurrence in third lactation among F1-crosses. The fertility traits were also favourable for the crossbreds compared to purebred SH which indicates that there might be a fewer proportion of culling candidates among crossbreds because of health and/or fertility issues.

Udder health

No significant heterosis effect was found for udder health, except for mastitis occurrence for SH x SRB in second lactation. However, there were significant breed group differences between SH x SRB and purebred Holsteins in all lactations and between SRB x SH and purebred Holsteins in third lactations. No clear trend in mastitis and SCS occurrence has been observed in studies comparing Jersey x Holstein crosses with purebred Holsteins (Prendiville et al., 2010; Heins et al., 2011). One hypothesis might be that crossbreds are culled instead of treated when mastitis is detected and the mastitis will therefore not be reported to the Swedish milk recording scheme. However, this is doubtful since crossbreds had a better longevity than purebred Holsteins which indicates that they are not culled due to bad udder health status to a huge extent.

Another interesting observation was that the heterosis effect for SCC for SRB x SH in first lactation was significantly unfavourable, but the breed group effect was significantly favourable for SRB x SH crosses compared with purebred SH in all lactations. A favourable breed group effect was also found for SCS for SR x Holstein crosses compared with purebred Holsteins (Heins & Hansen, 2012).

Calving performance

The greatest breed group effect and heterosis effect for calving performance traits were found in first lactation. The breed group effect and heterosis effect were still favourable in second and third lactation, but significance was harder to find. The same trend has been found in crosses between Montbeliarde x Holstein, Normande x Holstein and SR x Holstein where a favourable breed group effect in first lactation for calving performance traits was observed (Heins et al., 2006b). The difference was not significant in second lactation. The results indicates that crossbreeding is most efficient for calving performance traits in first lactation where the breed group differences and the heterosis effect were larger and significant for all breed groups compared with second and third lactation. This could be expected since problems with calving performance are most common for first parity cows (Meyer et al., 2001b; Steinbock et al., 2003; Steinbock et al., 2007; Växa, 2014).

The relative heterosis effect

The RHE was significant and favourable in first lactation for most traits, excluding mastitis, SCC, ERD, LRD and FLD for both F1-crosses. MD was also not significant for SH x SRB in first lactation. This indicates that crossbreeding is most efficient for most traits in first lactation and the effect is not as clear in second and third lactation. One reason might be that many cows are culled after first lactation due to poor performance of either production or functional traits. The best performing cows remain in second and third lactation and there is therefore not a large difference in the RHE between crossbreds.

The RHE differed greatly for other disease traits and no systematic pattern could be found in the results. For most traits for other diseases, RHE were not significant and those who were ranged from 20.9 % unfavourable heterosis for SRB x SH for MD in third lactation to 34.7 % favourable heterosis for SH x SRB for LRD in second lactation. The results for other diseases might be false positive and more research has to be done to evaluate the heterosis effect for health traits.

Sex-linked differences

There was a difference in RHE between different F1-crossbreed combinations for production and fertility traits. The RHE for production traits were generally larger for F1-crosses where SRB was the paternal breed and SH the maternal breed. The opposite is shown for fertility traits where the RHE were larger for F1-crosses where SH is the paternal breed and SRB is the maternal breed.

One contributing reason to this difference may be due to epigenetic mechanisms, which means that inheritable changes occurs in the genome by chemical changes rather than changes in DNA (Singh 2012). The environment where the pregnant dam is housed can cause epigenetic effects on the fetus and that might be a part of the explanation why there were differences in the RHE depending on the maternal breed. Banos et al. (2007) saw that the dams' age at first calving and body condition score (BCS) had an impact on their daughters' performances. The daughters to dams with a low age at first calving produced more milk and had a higher BCS than daughters to dams with a high age at first calving. However, the daughters to dams with a low age at first calving had a higher number of services per pregnancy and a higher return rate.

Another possible explanation to the difference in RHE might be different management strategies. Since the amount of SH increases over time and SRB are relatively stable compared with SH, whereas the SH x SRB crossbreed combination increase over time (Appendix 6), it is most likely that a number of herds convert from a purebred SRB to SH by inseminating SRB cows and heifers with semen from Holstein bulls. The results in RHE might differ because of management reasons since a purebred SRB herd might be managed in a different way than a purebred SH herd. A large proportion of the SH x SRB crosses might presumably live in herds that convert from a purebred SRB herd to a SH herd and therefore contain a certain number of crossbreds during the transition period. The SRB x SH crosses are more likely in herds that use crossbreeding as a breeding strategy. There might be different management strategies in these type of herds that can affect the RHE and the breed effect.

The size of the heterosis effect is to some extent dependent on management, which was illustrated by Kargo et al., (2012) that noticed that herds with intermediate management level had a greater heterosis effect for milk production than herds with lower management levels. Management might therefore be one reason why the results are different between different crossbreed combinations.

Dairy producers' attitude to crossbreeding

The producers' attitude to crossbreeding is vaguely explored even though several traits are improved by the method. One can always speculate about the results from a producer's point of view, but since there are barely any studies that have done any research about it, it is hard to know the real reasons why crossbreeding is, or is not, implemented in the herd.

Weigel & Barlass (2003) evaluated answers from a survey sent to dairy producers in the US who were using crossbreeding in their herds. The respondents experienced improved fertility, calving ease, longevity and a larger milk component percentage. They also experienced some management problems due to the uniformity in the herd. However, the return rate of the survey was low (9.5 %) and the reliability of the survey is therefore low. More studies must be made in order to investigate the attitude to crossbreeding.

Managing crossbreeding

A continuous improvement on purebreds by breeding must be made in order to obtain positive effects of crossbreeding. To use purebred bulls on purebred cows with best genetic potential in the herd while use crossbreeding on the rest is a strategy that can be implemented at herd level. Lopez-Villalobos et al (2000) found that the most profitable breeding strategy in New Zealand was two or three breed rotational crossbreeding. Another strategy is to use semen from beef bulls on two or three breed crossbreds and thereby increase slaughter revenues.

Conclusions

There are differences in crossbreed combination depending on the breed of the sire and dam. This might be useful information when developing crossbreeding strategies. The level of the RHE tends to be higher for functional traits than for production traits and the RHE is also significant for more traits in first lactation. This might partly depend on management and/or epigenetic effects but also selection of the best cows after first lactation.

The results obtained for udder health and other diseases are hard to interpret and there is no obvious explanation why the results vary widely between lactations and breed groups. More studies have to be made in order to evaluate the heterosis effect for health traits.

Crossbreeding can be used as a favourable breeding strategy to improve functional traits at herd level, according to the results in this study. Crosses between SRB and SH produced less milk but the same amount, or more, fat than purebred SH. They also had a better longevity, calving performance and fertility which indicate that they are able to compete with purebred SH in lifetime profitability. A sustainable pure breeding strategy must be made to improve the performance of purebreds in order to maintain favourable effects of crossbreeding. Two or three breed rotational crossbreeding systems is one way to obtain the positive effects of crossbreeding.

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Appendices

Descriptive statistics

Appendix 1. Number of observations used in the analyses of three lactations. CI = calving interval; CFS = calving to first service; FLS = first to last service; NINS = number of services; SCC = somatic cell count; ERD = early reproductive disease; LRD = late reproductive disease; MD = metabolic disease; FLD = feet and leg disorder.

Lactation	1	2	3	Total
Production				
Milk	270 998	206 869	123 965	601 832
Fat	270 908	206 882	123 942	601 732
Protein	270 961	206 915	123 971	601 847
Fertility				
CI	524 706	325 134	170 593	1 020 433
CFS	516 915	317 453	165 519	999 887
FLS	516 915	317 453	165 519	999 887
NINS	516 915	317 453	165 519	999 887
Survival				
Survival to 2^{nd} lactation	792 094	.	.	792 094
Survival to 3^{rd} lactation	792 094	.	.	792 094
Calving performance				
Calving difficulties	748 350	515 949	313 623	1 577 922
Stillbirths	780 661	537 051	325 645	1 643 357
Udder health				
Mastitis	792 094	557 454	341 396	1 690 944
SCC	686 013	480 434	282 446	1 448 893
Other diseases				
ERD	792 204	557 475	341 404	1 691 083
LRD	792 204	557 475	341 404	1 691 083
MD	792 204	557 475	341 404	1 691 083
FLD	792 204	557 475	341 404	1 691 083

Appendix 2. Mean values for the studied traits for lactation numbers 1-3 for cows in herds with at least 5 purebreds and 5 F1-crossbreds. CI = calving interval; CFS = calving to first service; FLS = first to last service; NINS = number of services; SCC = somatic cell count; ERD = early reproductive disease; LRD = late reproductive disease; MD = metabolic disease; FLD = feet and leg disorder.

Lactation		1	2	3	Average 1-3
Production					
Milk	kg	8 359	9 630	9 876	9 107
Fat	kg	349	401	412	380
Protein	kg	288	332	337	313
Fertility					
CI	d	399	395	394	397
CFS	d	88	85	85	87
FLS	d	32	31	30	32
NINS	no	1.85	1.84	1.82	1.84
Survival					
Survival to 2nd lactation	%	70			
Survival to 3rd lactation	%	43			
Calving performance					
Calving difficulties	%	11.5	8.4	8.8	9.9
Stillbirths	%	7.2	4.1	4.3	5.6
Udder health					
Mastitis	%	7.6	9.8	13	9.4
SCC	cells/ml milk	56 624	73 621	98 175	69 023
Other diseases					
ERD	%	1.7	2.2	2.8	2.1
LRD	%	0.4	0.6	0.6	0.5
MD	%	1.7	3.7	8.1	3.7
FLD	%	2.7	1.7	1.8	2.2

Appendix 3. Mean values for the studied traits for lactation number 1 to 3 for cows in herds with at least 5 purebreds and 5 F1-crossbreds for the different breed groups. SH = Swedish Holstein; SRB = Swedish Red; SRB × SH = crossbred with SRB sire and SH dam; SH × SRB = crossbred with SH sire and SRB dam; CI = calving interval; CFS = calving to first service; FLS = first to last service; NINS = number of services; SCC = somatic cell count; ERD = early reproductive disease; LRD = late reproductive disease; MD = metabolic disease; FLD = feet and leg disorder.

	Lactation 1				Lactation 2				Lactation 3			
	SRB	SH	SRB x SH	SH x SRB	SRB	SH	SRB x SH	SH x SRB	SRB	SH	SRB x SH	SH x SRB
Production												
Milk, kg/305-d lactation	7 922	8 778	8 181	8 435	8 975	10 301	9 380	9 711	9 231	10 608	9 653	9 940
Fat, kg/305-d lactation	345	353	344	350	388	414	393	405	397	429	406	414
Protein, kg/305-d lactation	281	295	281	289	318	346	323	332	324	352	330	337
Fertility												
CI, d	395	405	397	398	389	403	393	395	389	402	392	394
CFS, d	85	92	90	89	83	90	86	87	82	90	87	87
FLS, d	31.0	34.7	30.5	30.8	28.2	35.2	29.4	30.4	27.8	34.5	27.8	29.2
NINS, no	1.85	1.85	1.79	1.77	1.81	1.88	1.77	1.79	1.80	1.87	1.76	1.78
Survival												
Survival to 2nd lactation, %	71.3	68.6	72.6	71.1								
Survival to 3rd lactation, %	44.8	41.1	47.7	45.1								
Calving performance												
Calving difficulties, %	9.3	14.4	11.0	12.4	7.2	9.9	9.6	8.7	7.9	10.2	10.7	9.0
Stillbirths, %	5.2	9.9	6.2	7.2	3.8	4.5	3.5	3.7	4.1	4.6	3.8	4.2
Udder health												
Mastitis, %	7.0	8.5	7.0	7.1	8.4	11.7	9.3	9.3	11.2	15.4	12.1	12.8
SCC, cells/ml milk	52 722	62 086	57 809	60 673	66 374	84 527	75 335	78 342	89 330	112 201	101 859	103 992
Other diseases												
ERD, %	1.5	2.0	1.3	1.4	2.3	2.3	1.6	1.9	2.9	2.8	2.3	2.6
LRD, %	0.3	0.6	0.4	0.4	0.7	0.7	0.5	0.5	0.5	0.8	0.5	0.6
MD, %	1.7	1.8	1.6	1.6	0.4	3.9	3.6	3.6	7.5	9.0	8.1	8.2
FLD, %	2.8	2.7	2.1	2.1	2.0	2.0	1.6	1.4	1.5	2.2	1.7	1.5

Appendix 4. The mean given by the PROC MEANS procedure subtracted from the mean for pure SH for all traits and all lactations for cows in herds with at least 5 purebreds and 5 F1-crossbreds. SH = Swedish Holstein; SRB = Swedish Red; SRB × SH = crossbred with SRB sire and SH dam; SH × SRB = crossbred with SH sire and SRB dam; CI = calving interval; CFS = calving to first service; FLS = first to last service; NINS = number of services; SCC = somatic cell count; ERD = early reproductive disease; LRD = late reproductive disease; MD = metabolic disease; FLD = feet and leg disorder; pp = percentage points.

	Lactation 1		Lactation 2		Lactation 3	
Breedgroup	SRB x SH	SH x SRB	SRB x SH	SH x SRB	SRB x SH	SH x SRB
Production						
Milk, kg	– 260	– 113	– 470	– 299	– 539	– 366
Fat, kg	4	11	– 5	4	– 7	1
Protein, kg	– 2	2	– 9	– 3	– 11	– 5
Fertility						
CI, d	– 10.2	– 7.7	– 10	– 9.6	– 17.2	– 8.8
CFS, d	– 4.6	– 3.9	– 4.4	– 4.2	– 6.8	– 3.3
FLS, d	– 4.8	– 4	– 5.1	– 5.2	– 7.5	– 5.4
NINS, no	– 0.08	– 0.06	– 0.1	– 0.09	– 0.01	– 0.1
Survival						
Survival to 2nd lactation, pp	2.7	2.6				
Survival to 3rd lactation, pp	5.5	5.2				
Calving performance						
Calving performance, pp	– 2.4	– 1.8	– 0.8	– 0.6	– 0.8	– 0.5
Stillbirths, pp	– 2.4	– 2.3	– 0.5	– 0.8	0.9	0.4
Udder health						
Mastitis, pp	– 0.2	– 0.8	– 0.6	– 2.1	– 2.3	– 3.2
SCC, cells / ml milk	– 10 185	– 10 665	– 10 739	– 11 428	– 11 857	– 11 168
Other diseases						
ERD, pp	– 0.6	– 0.6	– 0.6	– 0.3	– 0.2	– 0.1
LRD, pp	– 0.2	– 0.2	– 0.3	– 0.4	– 0.2	– 0.2
MD, pp	– 0.7	– 0.4	– 0.6	– 0.6	– 0.6	– 0.4
FLD, pp	– 0.04	– 0.04	0.14	– 0.2	– 0.2	– 0.6

Appendix 5. Means over different time spans in first lactation cows for all traits except for other diseases for cows in herds with at least 5 purebreds and 5 F1-crossbreds. SH = Swedish Holstein; SRB = Swedish Red; SRB × SH = crossbred with SRB sire and SH dam; SH × SRB = crossbred with SH sire and SRB dam; CI = calving interval; CFS = calving to first service; FLS = first to last service; NINS = number of services; SCC = somatic cell count.

	Dataset	SRB	SRB x SH	SH x SRB	SH
Production					
Milk (kg)	2003-2012	7 950	8 238	8 489	8 830
Fat (kg)	2003-2012	346	347	353	355
Protein (kg)	2003-2012	282	283	291	296
Fertility					
CI (d)	1990-2012	394	396	397	404
	1990-2002	393	395	394	402
	2003-2012	395	397	400	406
CFS (d)	1990-2012	84.8	89.5	89.1	91.5
	1990-2002	83.7	87.4	86.8	90.4
	2003-2012	85.8	90.8	90.9	92.1
FLS (d)	1990-2012	30.8	30.5	30.7	34.9
	1990-2002	29.4	28.6	28.6	32.5
	2003-2012	32.1	31.6	32.2	36.2
NINS (no)	1990-2012	1.84	1.78	1.77	1.85
	1990-2002	1.84	1.80	1.77	1.83
	2003-2012	1.84	1.78	1.77	1.86
Survival					
Survival to 2nd lactation (%)	1990-2012	71	72	71	69
	1990-2002	74	77	77	73
	2003-2012	49	54	53	48
Survival to 3rd lactation (%)	1990-2012	45	47	45	41
	1990-2002	68	69	67	66
	2003-2012	41	44	39	37
Calving performance					
Calving difficulties (%)	1990-2012	9.5	11.4	12.7	14.5
	1990-2002	5.1	4.9	6.7	9.9
	2003-2012	13.0	14.5	16.4	16.8
Stillbirths (%)	1990-2012	5.4	6.5	7.4	10.2
	1990-2002	4.8	5.3	6.8	9.9
	2003-2012	5.9	7.1	7.8	10.3
Udder health					
Mastitis (%)	1990-2012	6.8	6.9	7.0	8.4
	1990-2002	8.0	8.1	8.6	10.0
	2003-2012	5.8	6.3	6.0	7.6
SCC (cells/ml milk)	1990-2012	53 700	57 500	60 300	63 100
	1990-2002	52 500	57 500	61 700	64 600
	2003-2012	53 700	57 500	60 300	61 700

Appendix 6. Frequency of cows in herds with at least 5 purebreds and 5 F1-crossbreds divided by breed group and year of birth. SH = Swedish Holstein; SRB = Swedish Red; SRB × SH = crossbred with SRB sire and SH dam; SH × SRB = crossbred with SH sire and SRB dam.

Year of birth	SRB	SH	SRB x SH	SH x SRB
1990	62 089	23 668	1 313	2 353
1991	61 654	23 506	1 255	3 023
1992	63 719	26 593	1 058	4 432
1993	69 555	33 585	1 099	4 576
1994	70 256	37 378	1 042	4 790
1995	67 268	36 936	1 272	4 119
1996	70 715	41 619	1 255	3 612
1997	73 352	46 989	1 255	4 187
1998	72 725	53 046	1 436	4 100
1999	70 299	54 316	1 504	4 335
2000	72 117	57 411	1 475	4 709
2001	70 979	58 853	1 630	4 782
2002	70 592	60 116	1 730	4 462
2003	72 199	61 043	2 131	4 161
2004	75 253	64 232	2 233	4 093
2005	71 167	63 164	2 014	4 487
2006	71 119	65 029	2 126	4 862
2007	67 784	64 139	1 877	5 160
2008	67 603	68 019	2 207	5 754
2009	58 436	64 770	1 838	5 228
2010	44 015	52 197	1 401	4 365
2011	25 863	32 531	743	2 769
2012	3 681	5 807	159	487