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Crossbreeding in dairy cattle

Korsningsavel med mjölkkreatur

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Abstract

The aim of this literature review is to give an overview of the differences between pure- and crossbreeding systems. Crossbreeding is a mating system with individuals of different lines or breeds. It is one of several breeding strategies in dairy production used to increase the economic profit. The use of crossbreeding increases due to changes in the dairy market and an increase of inbreeding among purebred Holstein. The main benefit of crossbreeding is heterosis, which is the improvement in genetic level in a hybrid offspring above the average of the parent breeds. Results from several studies have shown that crossbreeding is the most profitable breeding strategy, with a high level of heterosis for traits associated with fertility, health and overall fitness along with only a slightly reduced milk production. Even if more research is needed to give accurate conclusions, the most profitable breeding system, according to this review, was the three way rotational crossbreeding system.

Sammanfattning

Syftet med denna litteratursammanfattning är att ge en översikt av skillnader mellan olika avelssystem med rena raser eller korsningar. Korsningsavel är ett avelssystem med individer av olika avelslinjer eller raser. Det är en av flera avelsstrategier som används inom mjölkproduktionen för att förbättra lönsamheten. Korsningsavel har ökat i omfattning på grund av förändringar i mejeribranschen och en ökad inavel i Holsteinrasen. Huvudorsaken till att korsningsavel kan vara lönsamt är heterosis, vilket innebär en förbättring av den genetiska nivån hos avkomman jämfört med medeltalet av föräldraraserna. Resultat från flera studier har visat att korsningsavel är den mest lönsamma avelsstrategin, med en hög nivå av heterosis för egenskaper associerade med fertilitet, hälsa och generell fitness samtidigt med en begränsad minskning av mjölkproduktion. Även om mer forskning behövs för att ge säkra slutsatser så var avelssystemet med den högsta lönsamheten, enligt denna forskning, rotationskorsning med tre raser.

Introduction

Benefits of crossbreeding have been known within many of the commercial livestock productions for many years (Hansen, 2006; Sørensen et al., 2008). In contrast, dairy production systems in most developed countries have almost exclusively consisted of purebreeding with a single breed, Holstein (Hansen, 2006). This domination was caused by its high production and good conformation traits (McAllister, 2002; Hansen, 2006). Today the interest in crossbreeding increases (Heins, 2007; Cassell & McAllister, 2009) due to changes in the dairy market towards broader breeding goals including functional traits and milk components, along with an increased level of inbreeding among purebred Holstein (Hansen, 2006). Other aspects such as increased consumer’s demands and higher awareness of welfare and sustainability may also effect the dairy production (Hallén Sandgren & Lindberg, 2007; Sørensen et al., 2008).

The reason for crossbreeding is to increase the dairy cattle production through new combinations of genes in different breeds, and one of the main benefits are caused by heterosis, or hybrid vigour (Simm 2000). Some dairy producers are trying to improve functional traits and production traits through crossbreeding between Holstein, with high milk production, and breeds with good fertility and health such as Scandinavian Red, Normande or Montbeliarde, and thereby increase the profitability of the dairy production (Hansen, 2006).

Several crossbreeding studies have been made and are under evaluation in several different countries (Heins, 2007; Cassell & McAllister, 2009) but this short literature review will only include breeds and crosses used in commercial milk production in industrial countries. The aim of this literature thesis is to present a short review about crossbreeding in dairy cattle. It will describe differences between various breeding systems and review results and conclusions regarding their profitability from several studies.

Crossbreeding

Crossbreeding is used for several different reasons. One is to increase the overall efficiency of a production system through crossing breeds which have their genetic merits in different traits. Another is to produce individual dairy cattle with intermediate performance between that of two more extreme parent breeds (Simm, 2000). This seems similar to the first reason but instead of matching different breeds with different roles in the breeding system it creates new individuals with intermediate performance. Crossbreeding can also be used for upgrading to a new breed or be used as an intermediate step when creating a new synthetic breed. It can be used to introduce new variation to numerically small breeds, or to introduce a favorable characteristic of a single gene to an existing breed. Finally, one of the most important reasons is to obtain benefits of heterosis (Simm, 2000).

Heterosis

Heterosis is an essential factor in crossbreeding strategies (Simm, 2000). It is defined as the improvement in genetic level and the advantage expressed for traits in a hybrid offspring above the average of the parent breeds. Heterosis is a result of the non-additive gene effect, dominance and epitasis along with differences in the frequencies of the different alleles at each locus. The total genetic makeup of crossbreds can include additive effects, dominance, maternal effects, maternal heterosis and recombination effects. Which effect that may be present is dependent of the particular kinds of crosses involved (McAllister, 2002).

The expected level of heterosis is difficult to predict and it differs depending on the type and number of breeds in the crossbreeding system (Sørensen et al., 2008). Usually it is larger for crosses between genetically diverse breeds, because the more distantly related the two breeds are, the greater the proportion of loci at which different alleles are fixed in the two parent breeds and hence the higher number of heterozygote loci in the offspring (Simm, 2000). The highest level of heterosis is most commonly seen in functional traits affecting reproduction, survival and overall fitness (Simm, 2000; Hansen, 2006). These traits often show at least 10% heterosis and low heritability (Hansen, 2006). Production traits affecting milk yield and growth show about 5% heterosis (Hansen, 2006; Heins, 2007; Heins et al., 2007) and a moderately high heritability (Hansen, 2006).

Recombination effects

Unfortunately, crossbreeding can also cause risks of negative effects and one of them is recombination loss (Pedersen & Christensen 1989; Cassell & McAllister, 2009). It is caused by separation of favorable gene combinations that are accumulated in the parental breeds. Recombination loss can be difficult to estimate although it has been seen to reduces the level of heterosis (Cassell & McAllister, 2009). The functional traits seem to have no recombination loss and instead sometimes even have a recombination gain (Sørensen et al., 2008).

Inbreeding

Through continuous use of highly effective selection and breeding programs without almost no concern of the risk of inbreeding, the genetic relationship within breeds has accumulated (Hansen, 2006). Inbreeding refers to mating of individuals with one or several ancestors in common (Falconer & Mackay, 1996; Simm, 2000) and the closer relationship, the larger the quantity of identical genes, and the higher the risk of inbreeding. Inbreeding can lead to a decline in performance of dairy cattle and it is known as inbreeding depression (Simm, 2000; Adamec et al., 2006). It is the opposite of heterosis (Falconer & Mackay, 1996; Simm, 2000) and is caused by a too high rate of homozygosity in loci (Falconer & Mackay, 1996) with genes which have a negative effect on traits connected with survival and overall fitness, e.g. reproductive rate, health and disease resistance. Hence, it increases the risk of recessive lethal diseases and defects, reduces the performance of the dairy cattle and also reduces the adaptability to future production environments (Simm, 2000).

With continuous use of genetic evaluation programs based on animal models, the genetic relationship within most dairy cattle breeds has increased. In particular, purebred Holstein has had a relatively constant increase of inbreeding with only a few sires dominating the pedigree of AI bulls. Purebred Jersey has also become more inbreed over time and because of a genetic improvement of those two breeds, they have largely replaced other breeds of dairy cattle in several countries. In contrast, European breeds such as Montbeliarde, Normande and the Scandinavian Red breeds have had a greater restraint in permitting accumulation of genetic relationships (Hansen, 2006).

New Techniques

Sexed semen

New reproductive and molecular genetic technologies may lead to more effective genetic improvement in breeding programmes (Simm, 2000; Powell & Norman, 2006). Through improvement in fertility and sorting capacity in reproduction techniques the use of commercial AI with sexed semen will increase (De Vries et al., 2008). Crossbreeding is sometimes impractical in the dairy production because of low reproduction rate in cattle, which makes a large number of purebreds needed for production of a regular supply of F1 cows (Simm, 2000). The use of sexed semen may increase the genetic progress and in combination with crossbreeding also the efficiency of the dairy breeding (De Vries et al., 2008). It will enable new possibilities to effectively create replacement cows for a purebred nucleus (Sørensen et al., 2008) and enable an increased supply of replacement heifers (De Vries et al., 2008). It will also reduce the frequency of stillbirth for cows (Norman et al., 2010) and the cost of embryo transfer and progeny testing programs (De Vries et al., 2008). The new techniques has also created an opportunity to exchange sexed semen between countries and because Nordic breeds have shown to perform well in combination with Holsteins, export of sexed semen from sires of Swedish Red has increased (Sørensen et al., 2008).

Genomic selection

Genomic selection is another new technology (Sørensen et al., 2008). It is used to predict breeding values from genetic data (Toosi et al., 2010) and it will decrease the importance of progeny testing and bull dam selection within the whole population (Sørensen et al., 2008). It will also support the genetic improvement and create an opportunity to combat poor fertility in dairy cattle (Veerkamp & Beerda, 2007).

Systems of crossbreeding

Traditionally, three different breeding strategies of livestock have been applied. These are selection between breeds or breeding lines, selection within breeds or breeding lines and crossbreeding (Simm, 2000). All breeding strategies for genetic improvement depend on genetic variation. Selection within breed exclusively creates the genetic improvement of dairy cattle (Simm, 2000; McAllister, 2002) and therefore are both the additive genetic merit of the pure breeds, as well as the non-additive bonus created when they are crossed, important in crossbreeding systems to increase the genetic gain (Simm, 2000) and achieve the maximum economic merit of the dairy production (McAllister, 2002). Crossbreeding also has to exploit the genetic gain created by pure breeding to gain maximum economic profit in the long-term (Sørensen et al., 2008) because unlike the improvement achieved by continuous within breed selection, the benefits of crossbreeding can only be achieved once (Simm, 2000). Choice of breeds or populations with large genetic differences in characteristics of economic importance will also create a greater genetic improvement leading to a higher overall efficiency and profitability, compared to similar populations (Simm, 2000).

There are several different models of crossbreeding and there are also several aspects to take into consideration when choosing the most competitive breed and crossbreeding system. Factors of importance are e.g. the number of available breeds with sufficiently high additive genetic merit for desirable traits, local market demands (Simm, 2000) and breeds suitable for the production specific conditions of the crossbreeding system (Hansen, 2006).

The simplest model of crossbreeding is the two way cross where two different breeds are crossed. The progeny are called F1and if the offspring from this cross is mated back to one of the original breeds, this is called a backcross. The highest level of individual heterosis is always seen in the F1 generation, but unfortunately the level always decreases in subsequent generations. If F1 cattle are crossed to produce the second generation, F2, heterosis is halved compared to the level in the F1. It continues to be halved in every following generation of backcrossing to the parent breeds (Simm, 2000).

An alternative to maintain the level of heterosis after creating a two way cross is to produce a three way cross because in the third generation (F3) or fourth generation (F4) there is no further decrease in heterosis, as long as no inbreeding exists. When a third new breed is introduced, it maintains a relatively high level of heterosis but it is still very important that this third breed holds a high additive genetic merit to be beneficial for the crossbreeding system (Simm, 2000).

Another alternative is rotational crossing which includes two, three or more breeds in rotation. It takes advantage of heterosis and gives relative consistent results. The two-breed rotational cross mate breed A and B to produce F1 offspring, AB, with 50% of genes from each breed. AB is then crossed with a sire of breed A to produce a second generation offspring, A(AB), with an average of $\frac{3}{4}$ genes from breed A and $\frac{1}{4}$ genes from breed B. A(AB) is then crossed to sires from breed B, producing an offspring with an average of $\frac{3}{8}$ breed A-genes and $\frac{5}{8}$ breed B-genes. The process will continue until the proportions of genes of the two breeds stabilizes in seven generations at an average of about $\frac{1}{3}$ for breed A and $\frac{2}{3}$ for breed B, or in successive generations, about $\frac{2}{3}$ for breed A and $\frac{1}{3}$ for breed B (Simm, 2000).

A three-breed rotational cross involves three different breeds. It will after a few generations produce crossbred cattle with an average of about 15%, 30% and 55% of genes from the three respective breeds, with the highest percentage of genes from the sire breed used in the most recent generation (Simm, 2000).

Two other crossbreeding systems can also be used to create a synthetic breed or a new breed. This is achieved either through combination of different breeds and recruitment of the progeny for breeding, or during creation of a new breed through successive shifting from one breed to another (Simm, 2000).

Heterosis through generations

As mentioned previously, the level of heterosis changes depending on the number of breeds in the cross (Hansen, 2006; Heins et al., 2007; Sørensen et al., 2008). Table 1 shows the extent of heterosis for each generation for rotational crossbreeding systems with unrelated breeds (Heins et al., 2007).

Table 1. Heterosis by generation for crossbreeding systems using 2, 3 and 4 unrelated breeds (Heins et al., 2007)

Generation	2 breeds	3 breeds	4 breeds
1	100	100	100
2	50	100	100
3	75	75	100
4	63	88	88
5	69	88	94
6	66	84	94
7	67	86	94
8	67	86	93
9	67	86	93

In the two-breed rotational cross, heterosis decreases from 100% in F1 to 50% in F2 and stabilizes at 67% from the seventh generation. The four-breed cross shows the highest heterosis of 94% after few generations (Heins et al., 2007). But the number of breeds might instead cause a decrease of extra high additive genetic levels for specific traits or reduce the influence of a breed which is extra well suited for the dairy production conditions. It is also often hard to find four unrelated and competitive breeds appropriate for the production system (Hansen, 2006; Heins et al., 2007). The three-breed crossing is often seen as the optimal crossbreeding system (Hansen, 2006). Today it is used by commercial semen companies and is also called Procross (Creative Genetics of California, 2011). It maintains 100% heterosis in the first two generations, 75% in the third, which is the lowest level possible in any generation with a three-breed cross, and it stabilizes at 86% heterosis after seven generations (Table 1) (Hansen, 2006). Three-breed crosses causes less dilution of the different breeds' traits compared to four breed cross (Hansen, 2006).

Choice of breeds

All modern dairy breeds have been applying highly effective selection programs. Which breeds that are truly dairy cattle are not uniformly accepted by everyone but the breeds with reasonably large (absolute) population size and highly effective selection programs are Holstein, Jersey, Brown Swiss, Normande, Montbeliarde and several Scandinavian Red breeds such as Swedish Red, Danish Red, Norwegian Red and Finnish Ayshire. They are sometimes collectively named Scandinavian Red because they have similar ancestry with the two breeds Shorthorn and Ayshire in the pedigree (Hansen, 2006).

The predominant breed in most developing and temperate dairy countries is purebred Holstein (Simm, 2000; Hansen, 2006) and over the last few decades, the North American Holstein has largely substituted the local strains of black and white cattle in Europe and several other countries. The Jersey breed is also a numerically important breed, especially in some countries with mainly pastoral production systems, as in New Zealand and Australia. In most countries there has been little use of crossbreeding in the past (Simm, 2000). One exception is New Zealand, where crossbreeding has been commonly used (Sørensen et al., 2008) and where export of dairy products is economically important (Lopez-Villalobos et al., 2000). The numerically most dominant breeds there are Holstein and Jersey (Harris & Kolver, 2001). In many European dairy industries, selling calves for beef production has traditionally been seen as an important by-product for many dairy industries (Simm, 2000) and therefore are dairy cows in some of these countries also inseminated with semen from beef cattle breeds (Sørensen et al., 2008).

In the Nordic countries of Sweden, Finland, Norway and Denmark, the breeding goal has for more than 25 years included both production and functional traits. In recent years, it has changed in most other western countries, from being primarily focused on milk production and conformation to be much broader, including functional traits such as health, calving ease, fertility and longevity (Sørensen et al., 2008). In Sweden there are currently about 350 000 cattle in milk production (Statistiska Centralbyrån, 2011).

Recording and Identification

To maintain a beneficial crossbreeding system, regardless of the number of breeds, it is essential to consistently follow systematic breeding strategies (Heins, 2007; Sørensen et al., 2008). It is important to only have unrelated and competitive breeds along with unique and permanent identification of all individual animals and their ancestry (Simm, 2000). It is also important to continuously use progeny tested and highly ranked AI bulls (Heins, 2007; Heins et al., 2007).

Crossbreeding studies

Several crossbreeding experiments have been made in the dairy industry. Unfortunately, most of them are several years old (Heins, 2007) and a lack of current crossbreeding projects has in recent years hindered the development of efficient crossbreeding systems in the dairy production (Weigel, 2007).

The first scientific crossbreeding experiment with dairy cattle is dating back to 1906 in Denmark, using the Jersey and Danish Red breed (Heins, 2007). Two recent crossbreeding studies have been made in North America (Weigel, 2007). One was made by Touchberry (1992) and indicated that purebred Holstein was superior to crossbreds for milk yield, but that crossbreds had an advantage regarding income per lactation and also income per cow per year. The other study was made by McAllister et al. (1994) and reported more than 20% heterosis in lifetime performances in crossbreds of Holstein and Ayrshire. Much of the data used in crossbreeding programs today comes from experiments in New Zealand (Weigel, 2007). One of these projects was conducted by Ahlborn-Breier & Hohenboken (1991) and it reported estimates of heterosis and showed an improvement in performance of first generation crossbreds. Another project by Lopez-Villalobos et al. (2000) evaluated the effects of selection on purebreeding and two- or three rotational crossbreeding systems with Holstein, Jersey and Ayrshire. The result generally favored selection of purebred Holstein or Jersey or a two-breed rotation of these breeds but also indicated that the result was highly dependent on the future cost and prices of dairy products. Currently, a number of crossbreeding studies have been and are under evaluation to determine differences between breeds, heterosis for economic important traits and crossbreeding systems (Weigel, 2007). In the following paragraph a few of the experiments and results are shown.

A crossbreeding research including purebred Holstein cows and heifers and crosses between purebred Holstein cows and Jersey AI sires was summarized by Weigel (2007). The result of average production of first lactation showed higher milk, fat and protein production for purebred Holstein compared to the crossbred (Table 2).

Table 2. Average production of first lactation Holstein and Jersey – Holstein cows (Weigel, 2007)

Breed of cow	N	Milk (kg)	Fat (kg)	Protein (kg)
Holstein	72	7,266	259	229
½ Jersey - ½ Holstein	77	6,693	258	214

(tests of significance were unavailable)

Measurements from the same experiment, summarized by Heins (2007), showed results of first service conception rate and days open during first lactation. It revealed significantly fewer days open for the crossbreds compared to purebreds, whereas the levels of first service conception rate did not differ (Table 3). The results are in agreement with most other recent experiments on fertility with purebred Holstein compared to F1 crossbreds involving Holstein (Heins et al., 2006b), which has reported two or three weeks fewer days open for crossbreds. The experiment also showed significantly higher body condition score for crossbreds but no significant difference in somatic cell score (Heins, 2007). In summary, overall result from the trial indicated only a modest loss in production, with a corresponding gain in calving performance and fertility for Holsteins crossbred with Jersey sires (Weigel, 2007).

Table 3. First service conception rate and days open during first lactation (Heins, 2007)

Breed	Number of cows	First service conception rate (%)	Number of cows	Days open
Holstein	71	41	67	150
Jersey-Holstein	74	39	70	127**

** Statistically significant difference of crossbreds from pure Holsteins (P<0.01)

Another Holstein-Jersey crossbreeding experiment compared first lactation purebred Jersey with purebred Holstein and reciprocal crosses of the two breeds. The result revealed a decrease in overall calving difficulty by adding genes from Jersey to the crossbreeding system compared with adding genes from Holstein. The Holstein-Jersey cross and purebred Jersey produced significant less milk than purebred Holstein whereas the Jersey-Holstein cross was not significantly different from purebred Holstein cows. Results of fat and protein yield were similar for Holstein and crossbreds (Cassell & McAllister, 2009). Purebred Jersey has shown a higher fat content in milk than Holstein (Paliviquist & Conrad, 1978), but because Holstein produce a higher amount of milk, Jersey was still the breed that produced the lowest yields of fat, protein and milk (Cassell & McAllister, 2009).

In a study purebred Holstein, Brown Swiss and Brown Swiss-Holstein crosses were compared for dairy production, days open, somatic cell score and effects of heterosis on traits (Dechow et al., 2007). The results summarized by Heins (2007) showed that the Brown Swiss-Holstein crossbreds had only a slightly reduced milk yield along with a significantly higher yield of milk components, compared to purebred Holstein. The study also showed significantly fewer days open and a low number of somatic cells for crossbreds (Table 4). Observations made by some producers in the experiment also showed difficulties in training Brown Swiss calves to drink from buckets, which may increases the labor devoted to weaning. Even if the overall results were positive for the Brown Swiss breed crosses it was concluded that more research is needed to determine if the breed is profitable in crossbreeding systems.

Table 4. Dairy production, days open, somatic cell score, and heterosis across lactation groups (Heins, 2007)

Breed	N	Milk (Ib)	Fat (Ib)	Protein (Ib)	Days open	Somatic cell score
Holstein	1773	74.3	2.7	2.2	156	2.75
Brown Swiss	805	62.1*	2.5*	2.1*	156	2.82
Brown Swiss-Holstein	132	73.2	2.9*	2.3*	145*	2.57
Heterosis (%)		6.7	10.4	7.1	7.3	7.8

*Statistically significant difference of crossbreds from pure Holsteins (P<0.05)

Another study, where Brown Swiss-sired calves were born from first-calf Holstein heifers, also showed promising result with significantly lower calving difficulties and numerically lower stillbirth rates for Brown Swiss crosses compared to Holstein-sired calves (Heins, 2007).

From year 2002 to 2005 a study on purebred, two-way and three-way crossbreeding systems was made in seven commercial herds in California. It compared purebred Holstein and crossbreds between Holstein, Normande, Montbeliarde, Brown Swiss and Scandinavian dairy breeds, including Swedish Red and Norwegian Red (Heins et al., 2006a; Heins et al., 2006c). From results by Heins et al. (2006b) which showed least squares means for fertility and survival of first lactation, it could be seen that all crosses had fewer days to first breeding, higher conception rate compared to purebred Holstein and that the most fertile crossbred was Normande-Holstein. The average number of days open was significantly lower for all crossbreds compared to Holstein and the data of survival to 305 days postpartum revealed that all three crossbreds had significantly higher survival than purebred Holstein (Table 5).

Table 5. Least squares means for fertility and survival of first lactation (Heins et al., 2006b)

Breed group	n	Days to first breeding	First service conception rate	n	Days open	Survival to 305 days postpartum (%)	Odds ratio
Pure Holstein	536	69±1.2	22±3.0	520	150±4.1	86	
Normande/Normande	379	62**±1.2	35*±3.0	375	123**±3.8	93*	2.70
Monbeliarde/Holstein	375	65*±1.3	31**±3.0	371	131**±4.4	92**	2.10
Scandinavian Red /Holstein	261	66±1.4	30±3.0	257	129**±4.6	93*	2.57

*P < 0.05 for contrast of difference from Holstein
**P < 0.01 for contrast of difference from Holstein

Least squares means for calving difficulty and stillbirths for breed of dam at first calving was evaluated by Heins et al. (2006c). All crossbreds had significantly lower calving difficulty than purebred Holstein and all crosses, except the cross with Normande, had significant lower levels of stillbirth. The Scandinavian Red cross showed the easiest calving and fewest stillbirths of all dairy breed combinationss in the study (Table 6).

Table 6. Least squares means for calving difficulty and stillbirths for breed of dam at first calving (Heins et al., 2006c)

Breed group of dam	n	Calving difficulty (%)	Stillbirths (%)
Pure Holstein	676	17.7	14.0
Normande/Holstein	262	11.6*	9.9
Montbeliarde/Holstein	370	7.2**	6.2**
Scandinavian Red/Holstein	264	3.7**	5.1**

*P < 0.05 for contrast of difference from pure Holstein
**P < 0.01 for contrast of difference from pure Holstein

Dairy production was compared by Heins et al. (2006a) and showed that purebred Holstein had a significant higher 305-day milk and protein production compared to all crossbred groups but that the purebred Holstein was not significantly different from Scandinavian Red crossbreds for fat production. Actual 305-day production during first lactation of specific breed combinations was summarized by Heins et al. (2007). The result in the two-breed crosses revealed that the Scandinavian Red-Holstein cross had the highest milk production and, together with the Montbeliarde-Holstein cross, the highest combined fat and protein yield. In the three-breed crossbreeding systems, the combination of Montbeliarde/(Scandinavian Red-Holstein) showed the highest production of milk, fat and protein among the crossbreds. The result also revealed no statistically significant difference in production between the various two-breed and three-breed combinations, except crossbreds containing Normande influence, which had lower production (Table 7). Still, conclusions based on preliminary results by both Heins (2007) and Heins et al. (2007) recommended that crossbreeding systems should make use of three breeds.

Table 7. Actual 305-day production during first lactation of specific breed combinations (Heins et al., 2007)

Breed	No of cows	No of sires	Milk (kg)	Fat (kg)	Protein (kg)
2-breed crossbreds					
Normande/Holstein	37	9	8865	345	288
Montbeliarde/Holstein	366	32	9432	351	302
Scandinavian Red/Holstein	162	15	9450	350	305
3-breed crossbreds					
Brown Swiss/(Montbeliarde-Holstein)	44	8	9297	349	302
Montbeliarde/(Scandinavian Red-Holstein)	43	9	9461	356	308
Scandinavian Red/(Normande-Holstein)	86	10	8809	331	620

Measurements from the experiment in California need to be interpreted with some caution. Even if more information are needed about European breeds under US management conditions (Cassell & McAllister, 2009), overall results indicate that crossbreeding will lead to a modest reduction in milk production, with a corresponding gain in female fertility, stillbirth rate, calving ease and cow survival (Weigel, 2007; Heins et al., 2007). Which therefore also eventually may lead to a higher lifetime net profit for the crossbreds compared to purebreds (Weigel, 2007). Particularly promising results from the experiment was seen for European breeds and especially for the Swedish Red (Cassell & McAllister, 2009). According to preliminary comparisons, it should also be noted that the superiority in production of Holsteins may be greater in later lactations that in the first (Weigel, 2007).

Attitudes of dairy farmers

The overall interest of crossbreeding among dairy farmers has increased (McAllister, 2002). Earlier, reproductive performance and survival rates have been overlooked by most dairy farmers in the dairy industry. Decline of fertility and survival of purebred Holstein in e.g. the US has led some dairy farmers to turn to crossbreeding to alleviate these problems (Cassell & McAllister, 2009). Many dairy producers in the US has also experienced improvement in fertility, calving easy and milk composition from the use of crossbred cattle (Weigel & Barlass, 2003; Heins et al., 2006a) and even if crossbreds in general have lower production yield than purebred Holstein it has often been shown to be compensated through other advantages in an overall perspective (Heins et al., 2006a). In Denmark a survey about different breed and production systems was conducted in 2004. It revealed differences in attitude depending on the breed in the herd but still showed a slightly more overall positive attitude towards crossbreeding compared to other breeding systems. Today several dairy farmers have recognized the value of crossbreeding and an increase in the use of different crossbreeding systems can therefore be expected (Sørensen et al., 2008).

Discussion

This thesis considers differences in various breeding systems and reviews results and conclusions from several studies that have evaluated the profitability of those. Crossbreeding is one of several breeding strategies which may increase the dairy cattle performance and thereby the profitability of the dairy production (Heins, 2007; Sørensen et al., 2008).

To determine the most beneficial breed and establish the most profitable crossbreeding system, several aspects have to be considered (McAllister, 2002; Hansen, 2006). It has been shown that crossbreeding systems should use three breeds because two breeds limit the long term impact of heterosis and four breeds instead limits the contribution of any single breed of especially high merit to the dairy herd composition (Heins et al., 2007). It has also been stated that individual dairy producers should choose breeds and production based on the current conditions of the dairy market (Simm, 2000) and at the same time are suited to the dairy production local conditions (Hansen, 2006).

Several crossbreeding projects have already been conducted in the past and more are currently under evaluation to compare differences between various breeds and breeding systems (Heins, 2007; Cassell & McAllister, 2009). According to experiments summarized by Heins (2007) Holstein-Brown Swiss crosses would be competitive with purebred Holsteins for several economically important production traits. Several different crossbreeding projects summarized by Weigel (2007), Heins (2007) and Cassell & McAllister (2009) all including purebred Holstein, Jersey and Jersey-Holstein crosses, revealed overall corresponding results indicating that Jersey-Holstein crosses would compete well with purebred Holstein in lifetime economic merit, especially in milk markets paying for milk components (Cassell & McAllister, 2009). According to a project with purebred, two-way and three-way rotational crossbreeding systems in California, summarized by Weigel (2007), Heins et al. (2006a), Heins et al. (2006b), Heins et al. (2006c), Heins et al. (2007) and Cassell & McAllister (2009) the results revealed a higher milk yield for purebred Holstein but an advantages in fertility health and survival of crossbreed cows which would compensate for their loss in production (Heins et al., 2006a). The results also suggested that dairy producers would improve fertility and survival of cows by crossing (Heins et al., 2006b) and reduce calving difficulties and stillbirths (Heins et al., 2006c). Further results summarized in (Weigel, 2007) also indicated that, in milk markets with adequate premiums for fat and protein content, first generation crosses of pure Holstein with three or four leading European and North American dairy breeds will exceed Holstein for lifetime net profit. Measurements summarized by Cassell & McAllister (2009) also revealed promising advantages for the use of European dairy breeds, particularly Scandinavian Red and Montbeliarde, and among them especially the Swedish Red, with reduced stillbirths and calving difficulty. Even if the preliminary result of production between two-breed and three-breed combinations showed no significant differences (Heins et al., 2007) both Heins et al. (2007) and Heins (2007) recommendations that crossbreeding strategies should make use of three breeds.

For dairy production to gain the maximum profit in the long-term, regardless of number of breeds, it has been concluded that crossbreeding has to be combined with a purebreeding system within each of the breeds used in the crossbreeding program (Sørensen et al., 2008). Selection within breed creates the genetic change of the dairy cattle which then is responsible for the economic merit of the dairy production (Simm, 2000; McAllister, 2002). How to deduce the most profitable proportions between breeding systems, and under what conditions each system are the most beneficial depend on several factors (McAllister, 2002*).* Today crossbreeding has been shown to be more appropriate in systems with large populations. A reason is because progeny testing schemes are important for the genetic improvement of dairy cattle in most counties, and it is dependent on access to a large population of milk recorded cows (Simm, 2000). A large amount of cattle also makes it easier to, simultaneous with crossbreeding systems, maintain purebreeding programs and thereby also support adequate numbers of purebred cattle for maintenance of different breeds and the genetic development (Sørensen et al., 2008). In numerically small breeds it can also be more difficult to find enough unrelated animals, of sufficient high genetic merit, to sustain an effective genetic improvement programme, at the same time as these problems also often can be exacerbated by a high level of inbreeding in the population (Simm, 2000).

Through changes and developments of new techniques in breeding, new possibilities are created (Sørensen et al., 2008). New reproduction techniques which have been shown to increase the efficiency of the breeding systems are sexed semen (Simm, 2000; De Vries et al., 2008) and genomic selection (Veerkamp & Beerda, 2007). Sexed semen has increased the efficiency of dairy breeding through a possibility for the dairy producers to produce a more effective and superior replacement of the nucleus and F1 production cows in crossbreeding systems. Offspring from the F1 production cows are then often used for meat production and are therefore inseminated with beef semen to increase the value of their offspring as beef animals (Sørensen et al., 2008). Sexed semen may also lead to an increased specialization if the dairy producers decide to either purchase replacements or specialize in producing genetically superior dairy replacement heifers for sale. If sexed semen will become less expensive in the future its economical benefits may eventually also be passed on to the consumers (De Vries et al., 2008). The new genetic technologies have also created an opportunity to exchange sexed semen between countries (Sørensen et al., 2008).

If crossbreeding is combined with purebreeding it presents many profitable options for the dairy production. Nevertheless further development of breeding strategies is needed, both for a continued increase of genetic gain and for the possibilities to maintain favorable breeds (Simm, 2000). The number of countries that are recording and evaluating different measures of health, reproduction, workability and longevity and associated traits has increased (Simm, 2000). Still, more information about performance in economically important traits along with measurements of heterosis for those traits are needed for dairy farmers (Cassell & McAllister, 2009) and to predict the future outcome of possible crossbreeding systems and breed combinations with certainty (Weigel, 2007). With a higher accuracy of breeding values a higher rate genetic improvement can be achieved (Simm, 2000). Research providing more information and new facts are in progress and promising results have already been shown (Weigel, 2007; Heins et al., 2007; Cassell & McAllister, 2009).

Conclusions

Crossbreeding in combination with purebreeding seems to increase the overall economic merit in dairy production. The conclusion of this review is that crossbreeding is the most profitable breeding strategy resulting in a high level of heterosis for traits associated with health and overall fitness, a decreased level of inbreeding problems along with only a slightly reduced milk production. According to the review, the breeding system with the highest economic profit seems to be the three-way rotational crossbreeding system. At present, too little research on comparisons of pure- and crossbreeding systems has been done to give reliable conclusions. Therefore further research is needed.

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