

# **Crossbreeding – An Important Part of Sustainable Breeding in Dairy Cattle and Possibilities for Implementation**

Morten Kargo Sørensen  
Danish Cattle Federation and Faculty of Agricultural Sciences,  
Aarhus University, Denmark

Crossbreeding can improve the profit for most dairy producers if economically similar breeds are used. However, it is important to stress that crossbreeding cannot replace pure breeding. Pure breeding is a prerequisite for crossbreeding. The heterosis obtained from crossbreeding is an added bonus on top of the genetic gain created by pure breeding. The size of the bonus depends on the number and types of breeds involved in the breeding program. Most studies report at least a 10% increase in total economic gain per cow among F1 crosses between “unrelated” breeds.

## **Introduction**

During the last century, dairy cattle breeding improved markedly. From initially being based on phenotypic selection with very few measurements, dairy cattle breeding now involves high-tech breeding schemes based on extremely large data files. These data files, in combination with optimized breeding schemes based on systematic progeny testing, have increased genetic gain with ever increasing speed.

The breeding goal, however, has changed from being primarily focused on milk production and conformation, just a few years ago, to a much broader breeding goal that includes functional traits, such as fertility, health, and calving ease, in most of the western dairy countries. The reason for this change is mostly because of the deterioration of functional traits of cows, which results from the antagonistic genetic correlations between functional and production traits (Rauw et al., 1998; Miglior et al., 2005; Mark, 2004). At the same time, rate of inbreeding has increased within most breeds. Because of the increased need for robust cows in dairy herds with increasing herd sizes, crossbreeding seems very appealing to many.

## **Sustainable breeding**

The genetic level for numerous functional traits has been reduced within many dairy breeds. Therefore, animal welfare of cows and economics of dairying have been adversely impacted. Long term, the genetic change for the functional traits is not sustainable in regard to economic loss or to animal welfare, because dairy producers are unable to adequately compensate via improved management for the decreased genetic level for the functional traits. Breeding goals and definition of breeding goals are, therefore, very important parts of sustainability for all species of livestock.

If the breeding goals for a breed are not defined based on future economic circumstances, then commercial dairy producers will avoid that breed, and the breed will diminish in importance. Therefore, if the aim of a breed is survival, then an economically sustainable breeding goal is essential. In addition to an economic component, the definition of a sustainable breeding goal can include an animal welfare component. The reasons for considering animal welfare are not only based on moral grounds, but also on the assumption that consumers, in the future, will pay more attention to animal welfare issues related to dairy production. Selling products from breeds with sustainable breeding goals will eventually become easier. The extra weight that can be placed on top of purely economic values for some traits is called “non-market” economic weights (Olesen et al., 2000).

Another important issue related to sustainable breeding is inbreeding. The breeding programs of dairy breeds have been successful in improving production. The cost has been high rates of inbreeding. With existing pedigree information in the Danish cattle database, the level of inbreeding in Danish Holstein

was 3.9% for calves born in 2003 with pedigree completeness in five generations greater than 90% (Sørensen et al., 2005). This level of inbreeding is slightly below corresponding estimates for U.S. Holsteins (VanRaden, 2005). Inbreeding leads to inbreeding depression, to reduced genetic variation, and to higher frequencies of recessive lethal diseases (Kristensen and Sørensen, 2005).

For dairy cattle, inbreeding depression has been reported for production traits in several populations (Miglior et al., 1995); however, inbreeding depression also occurs for the functional traits (Smidt et al., 1998; Sørensen et al., 2006). For recessive lethal diseases such as BLAD and CVM of Holsteins, inbreeding increases the negative consequences of these diseases. Reduced genetic variation from inbreeding will result in a future reduction in genetic gain even with the same breeding scheme. Results from simulation analyses show a reduction in genetic gain of 20% over a 25 year period due to reduced genetic variation from increased inbreeding (Sørensen et al., 1999). Therefore, managing the rate of inbreeding clearly is an important part of sustainable breeding.

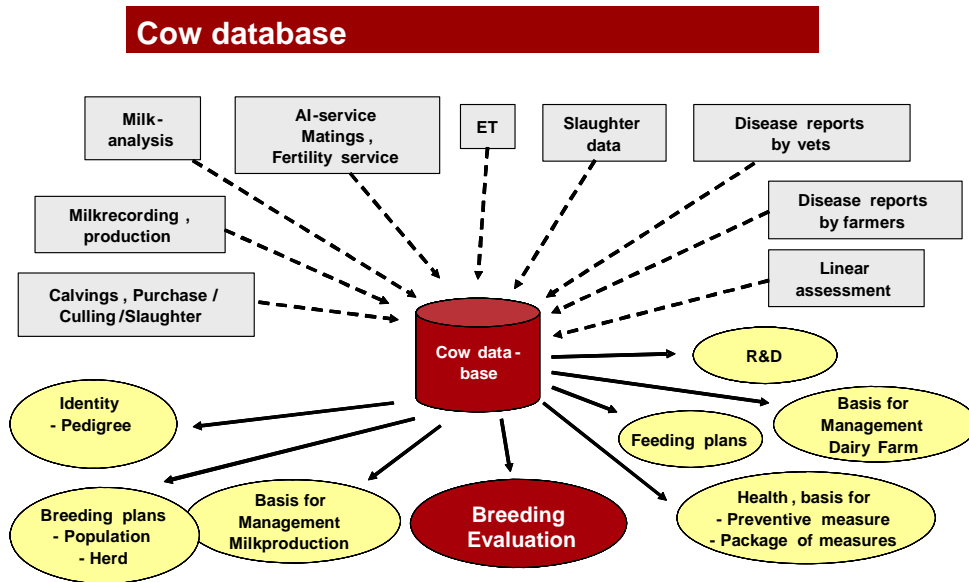
## **Requirements**

For sustainable breeding goals, data recording for the traits of interest is required. Within the Nordic countries, data recording for the functional traits, such as veterinary treatments, reproduction, calving ease, and calf size, has been done for the past 25 years (Heringstad et al., 2000). To be usable for calculation of PTA, easy access to the data is essential; therefore, storage of data in a common database is very valuable. In Denmark, recorded data are collected in the Danish cattle database as shown in Figure 1 (Bundgård and Høj, 2000).

Quality of data is even more important for calculation of PTA. Dairy producers must appreciate the importance of high quality data. Making dairy producers and veterinarians, who are responsible for data recording, aware of the importance of high-quality data has been a long process in Denmark. For many years, the percentage of Danish herds with valid data recorded for health by veterinarians was approximately 70%; however, within the past few years, this has increased to more than 90% of herds for all breeds. A high percentage of health data must be recorded to achieve acceptable accuracy for PTA.

Two methods exist to obtain adequate amounts of data for the functional traits – either deliberate data recording or contracting a large number of herds to do the data recording. The first method is the most efficient, but cooperative thinking among the dairy producers is required. The second method is more expensive, because many dairy producers must be under contract to provide enough data – especially when functional traits are included in the breeding goal. To date, the Nordic countries have used deliberate data recording, and we hope to be able to continue this approach into the future; therefore, improved online forms for data recording have been developed. Data recording for the functional traits is, in itself, not enough. The breeding scheme needs to be optimized in accordance with the breeding goal, which under most circumstances means larger daughter groups than exist today (Christensen, 1998).

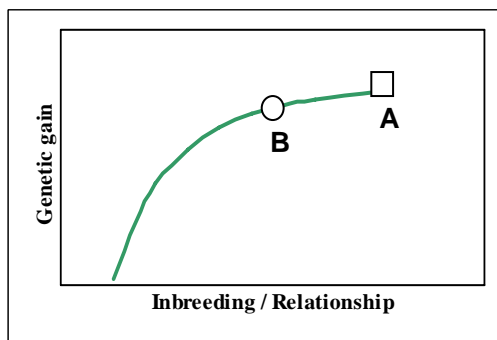
Another requirement for sustainable breeding schemes is appropriate control of the increase in rate of inbreeding. The rate of inbreeding is greater than 1% per generation in many populations, which has increased the need to monitor the actual rate of inbreeding. Also, tools are needed to control future rates of inbreeding, such as optimal genetic contribution selection within populations (Meuwissen, 1997; Grundy et al., 2000). With dynamic tools for maximising genetic gain, while constraining the future rate of inbreeding (Meuwissen, 1997; Grundy et al., 1998; Meuwissen and Sonesson, 1998; Grundy et al., 2000), the rate of inbreeding can be kept under control by assuring that the parents of future breeding animals are not too closely related. Such methods have been tested in large dairy cattle populations (Weigel and Lin, 2002; Kearney et al., 2004; Sørensen et al., 2007). In Denmark, the computer program referred to as “EVA” (Berg et al., 2006) is used for inbreeding control (Sørensen et al., 2006).



**Figure 1.** Illustration of the Danish Cattle data base.

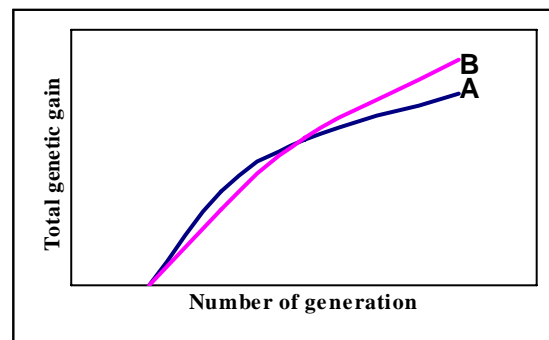
When genetic gain is the major focus for selection of sires of sons and bull dams, the result should be substantial genetic gain in the next generation; however, an increase in the genetic relationship between the selected young bulls will also likely result. Closer relationships results in more inbreeding in future generations. If a small decrease in genetic gain can be accepted among the selected bulls, then the degree of relationship will be reduced in the next generation. Figure 2 shows the schematic connection between genetic relationship and maximum genetic gain in the next generation.

In the short term, a little genetic gain is lost when genetic relationship in the next generation is considered – for example, by choosing strategy B instead of strategy A (Figure 2). By choosing strategy B, more sires of sons will be used, leading to less of an increase in average relationship and to maintenance of more genetic variation. In the long term, it pays to choose strategy B rather than strategy A (Figure 3). Furthermore, a population using strategy A will suffer more inbreeding depression than the population using strategy B. The time when the two lines intersect depends on where B is placed on the curve in Figure 2 – the further to the left B is placed, the later the curves will intersect. Therefore, as more weight is placed on relationship, more time is needed to obtain the genetic gain lost in the short term.



**Figure 2.** Schematic connection between average genetic relationship and genetic gain.

- A Focus only on genetic gain
- B Focus on both genetic gain and average relationship in next generation



**Figure 3.** Genetic gain with the two different selection strategies in Figure 2.

## Possibilities

Crossbreeding is another way to increase sustainability for dairy cattle breeding. Inbreeding problems are removed by use of crossbreeding strategies within herds. As mentioned in other presentations in this symposium by Brad Heins and by Kevin Prins, heterosis has substantial impact in dairy cattle. The scientific literature also has many reports on the meaningful influence of heterosis in dairy cattle. For dairy producers who focus on functional traits, crossbreeding is of special interest, because heterosis effects tend to be greater for functional traits, which have low heritability compared to production traits.

In addition to heterosis, the degree to which breeds compliment one another needs to be considered to evaluate crossbreeding systems. By choosing breeds for crossbreeding with higher genetic levels for traits of importance than the original breed, rapid improvement might result for these traits. For example, when Nordic Red breeds are used for crossbreeding with Holstein cows, the Nordic Red breeds contribute a higher genetic level for the functional traits. More or less economically equal breeds must be used for crossbreeding; however, with respect to this, the Nordic Red breeds probably are a good fit with Holsteins. A new Swedish investigation, based on economic information from dairy herds, has shown that total economic gain for Swedish Red and Swedish Holstein is equal using Swedish economic values (Lidfeldt, 2006) – Swedish Holsteins had a slightly higher income, and Swedish Reds had slightly lower costs.

## Genetic gain

Many studies on the effects of various breeding schemes have been done, but few with more than a single trait. Therefore, the Ph.D. project, “Stochastic simulation of breeding schemes for dairy cattle”, studied all traits within the Danish breeding goal for dairy cattle (Sørensen et al., 1999). Given Danish circumstances, the simulation study clearly showed the importance of selecting for total merit compared with selection for yield alone (Table 1). Results are in agreement with an Austrian study (Willam et al., 2002).

Denmark has used a total merit index since the early 1980s; although, in the early 1990s, the total merit index was expanded to include udder health. Therefore, functional traits of dairy cattle have been genetically improved in Denmark, as well as in the other Nordic countries. Progress for the functional traits has not been as substantial as it could have been in Denmark, and the major reason for this was the use of sire of sons from countries without PTA for the functional traits. The genetic trends for female fertility are in Figures 4 and 5 for the Nordic Holstein and Nordic Red populations in Finland, Denmark and Sweden. The standard error for the index is 10, and 10 index units approximately correspond to 14 days open.

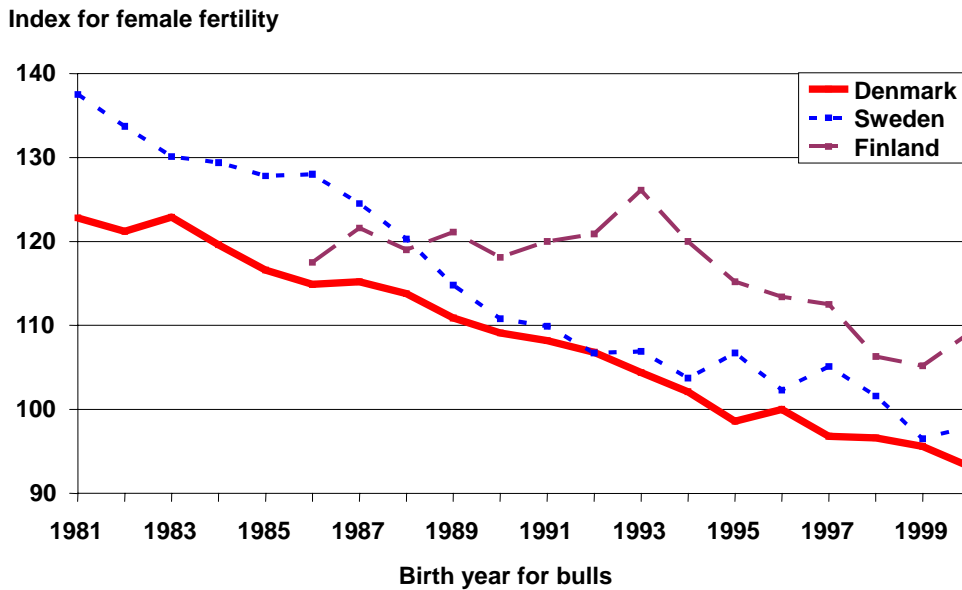
**Table 1.** Genetic gain (\$ per cow per year) by selection for total merit and yield respectively (Sørensen, 1999).

|                                 | <b>Selection for total merit</b> | <b>Selection for yield</b> |
|---------------------------------|----------------------------------|----------------------------|
| Production traits               | 20.0                             | 28.0                       |
| Conformation                    | 6.5                              | -1.0                       |
| Functional traits <sup>1)</sup> | 1.5                              | -9.0                       |
| <b>Total economic gain</b>      | <b>28.0</b>                      | <b>18.0</b>                |

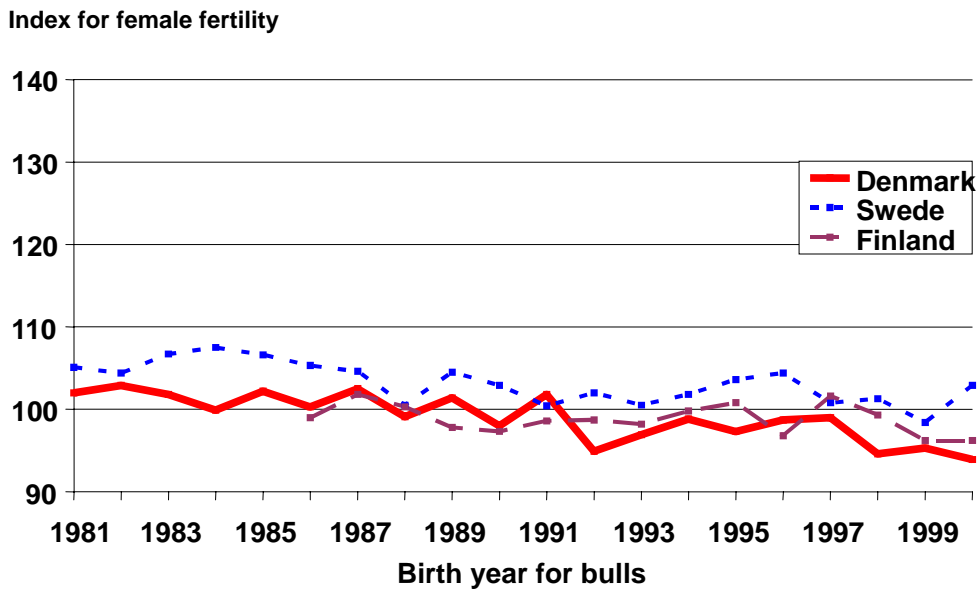
<sup>1)</sup> Female fertility, calving ease and health resistance.

For Holsteins, additive genetic level drops substantially for female fertility, which is similar to other Holstein populations. For the Nordic Red populations, additive genetic level has been very stable for female fertility, which is impressive compared to most dairy cattle breeds. The reason for the breed difference is because the Nordic Red breeds actually followed the breeding goals for the “Nordic breeding

profile” and used only sires of sons with known genetic level for female fertility. Also, undue emphasis on type traits in Holsteins has been a problem according to Shook (2006). Because of changes in the selection strategy, sires of sons and bull dams within Nordic Holsteins are now selected more in accordance with the total merit index. Therefore, the trend for genetic progress in the future is expected to be more like those in Table 1.



**Figure 4.** Genetic trend for female fertility among Holstein AI bulls in Denmark, Sweden, and Finland (Nordic breeding value estimation, 2006).



**Figure 5.** Genetic trend for female fertility among Red AI bulls in Denmark, Sweden, and Finland (Nordic breeding value estimation, 2006).

## “EVA” results

Accounting for inbreeding in breeding schemes results in lower average genetic relationship within the population, which leads to a reduction in future rate of increase in inbreeding. Somewhat more weight on average relationship and somewhat less on genetic merit will result in more dispersion of sires of sons and maternal grandsires. Table 2 has the distribution of sires of sons for Danish Holsteins with different weights on genetic relationship versus genetic merit. Twenty potential sires, 2167 potential dams, 1421 A.I. sires, 754 contract matings, and all pedigrees were analyzed (Sørensen et al., 2006).

**Table 2.** Total merit index for potential sires of sons, their relationship with the populations, and the distribution of sires of sons given different weights on average genetic relationship compared to merit.

| Sire      | Total merit index | Average relationship with population | Distribution of sires with low (L), high (H) and only (O) cost on average relation |    |    |
|-----------|-------------------|--------------------------------------|--|----|----|
|           |                   |                                      | L  | H  | O  |
| V Groovy  | 139               | 0.095                                | 100  | 22 | 4  |
| F Halvor  | 136               | 0.101                                | 6  | 6  | 3  |
| V Gottorp | 136               | 0.087                                | 59   | 28 | 2  |
| T Krarup  | 135               | 0.093                                | -  | 4  | 4  |
| L Martin* | 135               | 0.085                                | 10   | 14 | 11 |
| D Stilst* | 134               | 0.074                                | 25   | 38 | 27 |
| V Eron    | 134               | 0.108                                | -  | 2  | 3  |
| R Murphy* | 132               | 0.105                                | -  | 3  | 4  |
| Alves*    | 131               | 0.073                                | -  | 29 | 40 |
| T Kargo   | 130               | 0.101                                | -  | 10 | 4  |
| RGK Esne  | 129               | 0.089                                | -  | 6  | 9  |
| T Katborg | 129               | 0.090                                | -  | 1  | 4  |
| T Audi    | 129               | 0.089                                | -  | 5  | 4  |
| Amador*   | 129               | 0.096                                | -  | 3  | 5  |
| V Ejlif   | 128               | 0.073                                | -  | 8  | 37 |
| Var Gress | 128               | 0.079                                | -  | 8  | 28 |
| K Potter* | 128               | 0.113                                | -  | 1  | 2  |
| Burt*     | 128               | 0.102                                | -  | 4  | 3  |
| V Force   | 128               | 0.139                                | -  | 2  | 3  |
| H Bo*     | 127               | 0.084                                | -  | 6  | 3  |

\* Imported sires of sons.

Use of sires of sons is more diverse with less weight on merit compared to average relationship in next generation, and bulls less related to the population are used to a larger extent.

## Crossbreeding

The reason for inclusion of sustainable breeding, including breeding goals and inbreeding, in a paper on crossbreeding is because “healthy” breeding programs within the pure lines are a prerequisite for crossbreeding. If crossbreeding is used in a population at the expense of genetic gain in the pure breeds then, in the long run, crossbreeding will harm the overall economics of milk production. Used properly, heterosis is a bonus on top of the gain from traditional dairy cattle breeding programs.

One of the most important things in regard to efficient breeding schemes is size of the test capacity for young bulls. With large numbers of crossbred cows in the population, the test capacity might be reduced if crossbred offspring cannot be used to calculate PTA of A.I. bulls. Methods, such as those presented by Paul VanRaden at this symposium and by Lidauer et al. (2006), which include crossbred cows in the calculate of PTA, must be in place if systematic crossbreeding becomes routine.

Systematic crossbreeding could also reduce genetic gain in the pure breeds if the number of purebred cows is reduced, which would lower the selection intensity for bull dams. As long as the proportion of crossbred cows is less than 50%, this should not be a problem. Calculations from New Zealand have shown that the reduction in genetic gain will be 10% for Jerseys and Holsteins in a systematic 3-breed crossbreeding program compared to the present gain, if 90% of the New Zealand dairy producers turn to crossbreeding (Lopez-Villalobos et al., 2000). For Ayrshire, the third breed in New Zealand, an extra genetic gain of 10% results because of more progeny-tested bulls than in the present situation. If new technologies such as genomic selection become important contributors to dairy cattle breeding schemes, the importance of progeny testing and bull dam selection within the whole population will decrease. In that case, the negative side-effects of crossbreeding would be eliminated.

### **The Næsgård experiment**

Because of knowledge from other species and other experiments with dairy cattle, a large crossbreeding experiment (The Næsgård Experiment) was conducted in Denmark from 1972 to 1985. To my knowledge, this crossbreeding experiment was the largest carried out under research conditions, and three pure breeds were maintained, as well as crosses between the breeds. The breeds were Holstein, original Danish Red, and Ayrshire, and the experiment included more than 3,000 lactations of cows. Unfortunately, the results are published only in Danish (Christensen and Pedersen, 1988). The main conclusions from the experiment were:

"F1 heterosis for total economic merit (expressed per live born female calf from birth to first calving or culling) was 9.9% when estimated by the dominance model. The obtained heterosis by 3-breed rotational crossing estimated by the recombination model was 19.4%. The total merit for cows was expressed per heifer in a 3 year period from first calving. F1- heterosis was 21.2% (dominance model), and the obtained heterosis by 3 breed rotational crossing was 30.4% (recombination model). The estimates for total merit were only slightly dependent on the prices used. A major part of the heterosis for total merit was due to good stay ability and high survival rate of crossbreds. The high survival rate among crossbred cows could not be explained by favorable heterosis for yield, reproduction and resistance to diseases but was rather due to general superiority in constitution (robustness). It was concluded that crossbreeding of dairy cattle breeds can be expected to produce a considerable amount of economic heterosis and that crossbreeding is particularly beneficial in herds with sub optimum environmental conditions"

Based on the results from this experiment, one might have expected large numbers of dairy farmers to start systematic crossbreeding. That was not the case, and some have argued the results from this experiment came 15 years too early, because dairy producers today think more in terms of economics compared to 15 years ago. Approximately 10 to 15 herds that started crossbreeding at that time have continued using systematic crossbreeding. Among those are Ann and Anders Grosen.

### A case study - long term experience with systematic crossbreeding

Ann and Anders Grosen took over their dairy farm in 1991. At that time, the former owner had started crossbreeding with Danish Red sires in the Jersey herd. They have continued crossbreeding and have done so for many years with a 3-breed rotational system using Jersey, Danish Red, and Holstein. In the meanwhile, they have become organic dairy producers with their 110 cows. Their income per cow is well above average for organic dairy producers, and the reasons are good production of cows combined with excellent health of their cattle. The production level is 1,418 lb fat plus protein per cow per year, with average SCC of 296,000 and veterinarian costs per cow per year of \$44, which is approximately one half of normal veterinary costs. Furthermore, they have had only five stillborn calves during the past 12 months.

One nuisance is variation of cow size with Jersey included in the 3-breed rotational system, which causes some problems in the milking parlor and for stall sizes. Ann and Anders have addressed this by using Jersey bulls with high PTA for body size and Holstein bulls with low PTA for body size.

### Danish situation in 2007

The Danish dairy industry consists of 510,000 dairy cows enrolled in milk recording out of a total of approximately 550,000 dairy cows (92% of cows are enrolled in milk recording). Average herd size has increased steadily in recent years. Average herd size in March 2007 was 110.6 cows, and the average annual production of cows enrolled in milk recording was 829 lb fat and 664 lb protein. The breed distribution is 73% Holsteins, 12% Jerseys, 8% Danish Red, and the remaining 7% are crosses among dairy breeds; however, most of the crossbreds are the result of grade-up programs or unsystematic crossbreeding.

During the late 1990s and early years of this decade, crossbreeding was discussed very little; however, increased concern about inbreeding has resulted in more discussion of crossbreeding. In 2004, crossbreeding was a theme at the Danish Cattle Congress, and many dairy farmers became interested. Dansire, the Danish A.I. company, decided to actively provide advice on crossbreeding programs. Two of Dansire's breeding advisors were appointed as crossbreeding specialists, and a crossbreeding support group was established. Furthermore, informational material was produced, which stated heterosis effects are specific to breed, meaning that crosses of two breeds might not contribute the same heterosis as crossings of two other breeds. The general rule is crossing breeds that are more genetically distant results in higher heterosis. Nevertheless, Dansire provided general estimates of heterosis for important traits. The estimates, in Table 3, are based on the scientific literature available in 2004, and effects of epistasis were ignored.

**Table 3.** General estimates for heterosis effects for important traits within dairy cattle production.

| Trait                   | Obtained heterosis |                                   |                                   |
|-------------------------|--------------------|-----------------------------------|-----------------------------------|
|                         | F1-animals         | 2-breed crisscross at equilibrium | 3-breed rotational at equilibrium |
| Production traits       | Ca. 3%             | Ca. 2%                            | ca. 2,5%                          |
| Fertility               | Ca. 10%            | ca. 7%                            | ca. 9%                            |
| Calving ease (maternal) | Ca. 15%            | ca. 10%                           | ca. 13%                           |
| Stillbirth (maternal)   | 2-3%               | 1-2%                              | 2-3%                              |
| Longevity               | 10 –15%            | 7-10%                             | 9-13%                             |
| Income per cow per year | Min. 10%           | Min. 7%                           | Min. 9%                           |

More dairy producers have started systematic crossbreeding in Denmark because of the impact of the two breeding advisors at Dansire, who advise 72 herds that use systematic crossbreeding on at least some of their cows. Beyond that, a few herds are using breeding advisors other than from Dansire to implement crossbreeding systems. The average herd size of herds using crossbreeding is approximately 150 cows.

A common argument is more heterosis is realized for herds with low management level. However, new research from New Zealand reports largest effects of heterosis in herds with average production (Bryant et al., 2007).

## Breeds

The actual breeds selected for crossbreeding are critically important for the success of systematic crossbreeding. In Denmark, most dairy producers initiating systematic crossbreeding have Holstein herds of cows; however, a few Danish Red and Jersey herds have also started crossbreeding. A 3-breed rotational system for crossbreeding is recommended. For Holstein herds, the first breed of sire to use in a 3-breed rotational system, obviously, is one of the Nordic Red breeds. The Nordic Red breeds are Swedish Red (SRB), Norwegian Red (NRF), Finish Ayrshire (FAY), and Danish Red (RDM). The approximate population sizes of the breeds are 160,000; 270,000; 210,000; and 45,000, respectively (Sonesson, 2005). The breeds are related to some extent, because of substantial semen exchange. Somewhat different breeding strategies have been implemented for each of the four breeds, which has resulted in slightly different genetic levels for the various traits. These differences will be reduced in the future, because of increased cooperation among the breeds. Danish informational material reviews the strengths of the different populations of most interest for Danish dairy farmers, and a summary is in Table 4.

**Table 4.** Possible breeds for crossbreeding, and the more stars – the better.

| Breed                   | Milk production | Milk content | Meat production | Size  | Feet and legs | Udder | Milking speed | Still birth | Fertility | Health |
|-------------------------|-----------------|--------------|-----------------|-------|---------------|-------|---------------|-------------|-----------|--------|
| <b>Holstein</b>         | *****           | **           | **              | ***** | **            | ***** | **            | **          | **        | **     |
| <b>Jersey</b>           | **              | *****        | *               | *     | *****         | ***** | **            | **          | **        | **     |
| <b>Nordic Red:</b>      |                 |              |                 |       |               |       |               |             |           |        |
| <b>Danish Red</b>       | **              | **           | **              | **    | **            | **    | **            | **          | **        | **     |
| <b>Swedish Red</b>      | *****           | **           | **              | **    | **            | **    | **            | *****       | *****     | *****  |
| <b>Norwegian Red</b>    | **              | **           | *****           | **    | **            | **    | **            | *****       | *****     | *****  |
| <b>Finnish Ayrshire</b> | *****           | **           | **              | **    | **            | **    | **            | *****       | *****     | *****  |
| <b>Montbéliarde</b>     | **              | **           | *****           | ***** | -             | -     | -             | -           | -         | -      |

The stars in Table 4 say nothing about economic profit using one or another breed, but there is little reason to expect large differences for total profit from these breeds (e.g., Lidfeldt, 2006).

In Denmark, Swedish Red sires are used most often for crossbreeding on Holstein females. Danish Red sires with little or no Holstein genes are, of course, also used on Holsteins. In the future, the percentage of Holstein genes in the Danish Red breed will be reduced. As a third breed, Jersey is an obvious choice for Danish dairy producers, because Denmark progeny tests more than 60 Jersey young sires each year. However, dairy producers need to be aware of the variation of cow size and milk composition that results

when Jersey is used in a 3-breed rotation; therefore, the Montbéliarde breed is preferred by some Danish dairy producers over the Jersey breed.

### **General dairy farmer opinions**

As a consequence of the growing interest in crossbreeding in Denmark, a survey was conducted to assess dairy producer attitudes toward crossbreeding (Laursen, 2005). The survey was sent to 475 dairy producers, representing nearly 10% of Danish dairy producers. Sixty percent of the dairy producers responded to the survey, which is a very high response rate compared to the survey on crossbreeding by Weigel and Barless (2003) in the U.S. Forty percent of respondents revealed a positive attitude toward crossbreeding, while 34% did not like crossbreeding. Also, 24% thought crossbreeding was a potentially rewarding breeding strategy, but 40% would not consider using it.

### **The future**

In both the U.S. and Europe, dairy herds are increasing in size, and dairy producers spend less time with each cow. Therefore, robust cows will probably become more important in the future. Because of the increased focus on functional traits in dairy cattle breeding, systematic crossbreeding of dairy cattle is expected to increase substantially in the future. The introduction of sexed semen could accelerate this trend, because sexed semen facilitates breeding schemes with F1 crossbred cows in production.

### **Conclusions**

Crossbreeding can provide dairy producers increased economic output and improve the welfare of animals at the herd level; therefore, crossbreeding can be an important part of sustainable breeding. However, it must be stressed that crossbreeding is not “the total solution” for herds with low management levels or with fertility problems. On the other hand, crossbreeding can be an important contributor to “the solution”, along with other management tools. Furthermore, crossbreeding is not a substitute for sustainable breeding schemes in the pure breeds, which require broad breeding goals based on quality data recording for the functional traits and proper control of increases in inbreeding. The combination of sustainable breeding within the pure breeds and systematic crossbreeding at the herd level could provide optimal results for commercial milk production. The gain is expressed as more profit for dairy producers and as improved animal welfare for dairy cows.

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