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Possibilities to breed for internal parasite resistance in Swedish beef breeds

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Titel: Möjligheter att avla för parasitresistens i svenska nötköttsraser
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Abstract

The aim of this review is to investigate the possibilities to breed for parasite resistance in the Swedish purebred beef population, with starting point in the organic production. The present population structure, breeding objectives and genetic evaluation will be discussed as well as four common internal parasites found among cattle in Sweden, registration of resistance by using faecal worm egg counts (FEC), the genetic background of FEC, and last the possibilities of using quantitative trait loci (QTL) and marker-assisted selection (MAS).

Due to strict regulations in organic production concerning the use of anthelminthics it is necessary to find alternative methods to control parasites, and breeding for increased parasite resistance may be one way to go. There are breeding programmes in operation today among some sheep breeds in Australia and New Zealand where FEC is used as a selection criterion. Studies on Aberdeen Angus indicate that breeding programmes for resistance could probably be implemented successfully among cattle from temperate regions as heritability estimates for FEC range from low to moderate. But there are still a number of issues that needs to be addressed. One major issue is the lack of available information. The Swedish dairy association runs the Swedish beef recording scheme, Kött Avel Produktion (KAP), where information is collected about the Swedish beef populations. At present FEC is not registered in KAP.

Sammanfattning

Syftet med denna litteraturstudie är att undersöka möjligheterna att avla för parasitresistens i den svenska nötköttspopulationen, med utgångspunkt från den ekologiska produktionen. I studien tas dagens populationsstruktur upp, samt avelsmål, dagens avelsvärdering, fyra vanligt förekommande invärtes parasiter hos nötboskap i Sverige, hur resistens registreras med hjälp av faecal worm egg counts (FEC), den genetiska bakgrunden till FEC och sist möjligheter att använda quantitative trait loci (QTL) och marker-assisted selection (MAS) i avelsarbetet.

På grund av de strikta reglerna i den ekologiska produktionen rörande användning av avmaskningsmedel, måste man finna andra alternativ för att kontrollera parasiter. Att avla för en ökad parasitresistens skulle kunna vara en väg att gå. I dagsläget finns det avelsprogram för vissa fårraser i Australien och Nya Zeeland som inkluderar resistens och där selektionen baseras på FEC. Skattningar av arvbarheten för FEC hos köttdjur är låga till medelhöga och studier på Aberdeen Angus visar att det skulle kunna vara möjligt att införa parasitresistens i avelsprogram för nötboskap från tempererade regioner. Innan detta är möjligt är det dock flera problem och frågeställningar som måste undersökas. I den svenska köttboskapskontrollen, Kött Avel Produktion (KAP) som drivs av Svensk Mjölk, sker ingen registrering av parasitresistens eller FEC och det är därför i dagens läge inte möjligt att avelsvärdera för denna egenskap.

Introduction

During the 1970's an increased concern for the environment began to spread which led to a demand for more sustainable production systems. This demand resulted in the development of organic farming (Lund, 2003). The present definition of organic farming according to the council of the European Union is a production system in which a high level of self-support is strived for. Organic farmers have to comply with the rules and regulations agreed upon by the council. This means for example that animals on organic farms shall have permanent possibilities of being outdoors, when allowed by weather conditions, and diseases shall be treated immediately to prevent any suffering. At the same time there are strict regulations concerning the use of antibiotics and other allopathic veterinary drugs to prevent disease outbreaks (Europeiska Unionens Råd, 2007). These regulations have great impacts especially concerning the treatment of internal parasites. As the animals spend more time outdoors they may be exposed to higher parasite pressures compared to animals in conventional farms. Since regular anthelminthic drug treatment schemes are forbidden, the parasite problem is further reinforced (Lund, 2003; Europeiska Unionens Råd, 2007).

In Sweden farmers can also choose to belong to KRAV which has its own regulations on top of those set by council of the European Union. KRAV is run as a private financial organisation and is a Swedish trademark for organic products. The regulations set by KRAV for organic production are similar to what has been decided by the council of the European Union in (EEG) number 2092/91 (which, from the first of January 2009, will be replaced by EG 2007:834). In certain cases KRAV has even stricter requirements than the EEG regulations (Europeiska Unionens Råd, 2007; Livsmedelsverket, 2008). In organic farming it is therefore necessary to implement other preventive environmental measures to control parasites. Parasite resistance has been found to be heritable. This means that by including parasite resistance in the breeding objectives and having a deliberate selection, resistance to internal parasites could be increased (Näsholm, 2003).

The purpose of this literature review is to investigate the possibilities to breed for parasite resistance in the Swedish purebred beef population, and emphasis will be placed on organic production. The present beef population structure, breeding objectives and genetic evaluation will be discussed as well as four common internal parasites found among cattle in Sweden, how resistance can be registered by using faecal worm egg counts (FEC), the genetic background of FEC, and last the possibilities of using quantitative trait loci (QTLs) and marker-assisted selection (MAS). Parallels with sheep will be drawn as this industry in some parts of the world has already successfully included parasite resistance in their genetic evaluation.

Structures in the Swedish beef population

Sweden has a long tradition of breeding dairy cattle that also produce meat. The selection for higher milk yield has resulted in a decreased number of animals necessary to maintain the level of milk production. In turn this has created a need for other beef production systems and breeds to satisfy the demand for beef from consumers and the industry. As early as in the 1940's a large scale import of beef breeds began. The first breed to be imported was Aberdeen Angus in 1946, followed by Hereford in 1952 (Johansson, 1996). Today there are seven main beef breeds in Sweden, these are Charolais, Hereford, Simmental, Highland Cattle, Limousin, Aberdeen Angus and Blonde d'Aquitaine (Näsholm, 2003).

In December 2007 the total number of beef cows was close to 183 000. This corresponds to approximately 30% of the total number of cows in Sweden (Statens Jordbruksverk, 2008). Out of these 183 000 cows, around 15 500 were part of organic herds approved by KRAV (KRAV, 2008). During 2007 an average of 1175 herds (approximately 27 000 cows) took part in Kött Avel Produktion (KAP). Out of these around 14 300 cows were purebred animals, which is more or less the whole purebred beef cow population (Svensk Mjölk, 2008). There are no records showing how many of the KAP-herds that are also part of KRAV (KRAV, 2008; Svensk Mjölk, 2008).

Current breeding objectives and genetic evaluation

For Charolais, Hereford, Simmental, Limousin, Aberdeen Angus and Blonde d'Aquitaine the breeding objectives are quite similar and include traits such as fertility, easy calvings, high growth rate, low feed utilisation, high meat quality and other carcass properties, good mothering abilities (milk yield) and good temper (Svenska Angusföreningen, 2008; Svenska Herefordföreningen, 2008; Svenska Blonde d'Aquitaine föreningen, 2008; Svenska Charolaisföreningen, 2008; Svenska Limousinföreningen, 2008; Svenska Simmentalföreningen, 2008). There is some variation between breeding organisations in the perceived importance of the traits. A survey carried out in 2003 showed that there were differences in breeding goals between the breeds and those differences indicated a need of breed specific selection indices (Fjelkner, 2003). Today breeding values are estimated for the same traits in all beef breeds, birth weight (direct and maternal), daily gain birth to 200days (direct and maternal), daily gain 200days to 365days, carcass properties (carcass fatness, fleshiness and net gain birth to slaughter) and calving ability (direct and maternal) (Roth, 2008 personal communication). The genetic evaluation of calving ability and carcass traits was introduced 2005 (Taurus, 2005; Taurus, 2008).

The genetic evaluation is performed twice a year for all traits using multiple trait animal models. The traits can be divided into three groups which are analysed separately. Birth weight, daily gain from birth to 200d, and daily gain from 200d to 365d form one group and are analysed simultaneously. Carcass fleshiness, carcass fatness and net gain from birth to slaughter form another group and calving ability form the last group. Then the net gain is analysed together with live weight gain and calving ability is analysed with birth weight (Svensk Mjölk, 2000). As the breeding value for net gain is estimated in a multitrait evaluation together with live weight gain there is an automatic correction for animals slaughtered and those kept for breeding. By evaluating calving ability together with birth weight the genetic correlation between these two traits is taken into consideration, which especially increases the reliability of the breeding value for calving ability (Taurus, 2005; Taurus, 2008).

Common internal parasites

The main category of cattle susceptible to parasite infection is the first grazing season (FGS) calves. Adult animals have usually developed immunity to parasites and clinical symptoms of infection are rare in this category of cattle. There are indications that growth reductions due to parasite infections in young stock may have effects later in the life of the animals resulting in lifelong reduced performance (Ploeger *et al.*, 1996). In a study of control strategies for FGS cattle in Sweden the results showed that calves treated regularly with Ivermectin could weigh up to 65 kg more compared to untreated calves (Dimander *et al.*, 2003). Assuming production losses averaging 20 kg per calf and a cost of 20 SEK per kg profit losses may add up to 400 SEK per calf at the end of the grazing season (Höglund *et al.*, 2008). There are few studies that investigate and compare organic and conventional production in terms of the prevalence parasite infections and to what extent it is a problem in organic herds. Hansson *et al.* (2002) compared the carcass quality in organic and conventional production based on remarks from meat inspections performed at abattoirs in Sweden during 1997. The post-mortem inspections showed that 27% of the conventionally reared cattle and 28% of the organic cattle had at least one or more pathological finding. The main reason for remarks of the organically reared cattle was due to parasitic affections.

Stromberg & Corwin (1993) found that the most common internal parasites among cattle in the American Midwest were *Ostertagia ostertagi* and *Cooperia oncophora*. Later reports show that these two gastrointestinal nematodes and also the lungworm, *Dictyocaulus viviparus*, have negative effects on livestock health worldwide (Corwin, 1997). The results from a grazing trial performed in south-central Sweden in a herd of beef cattle showed that the predominant genera of parasites were *Ostertagia* spp. and *Cooperia* spp. (Larsson *et al*., 2007). In a Swedish nationwide study, *D. viviparus* was found in 39.5% of the herds under observation and seems to be a relatively common parasite. There are contradictory results concerning its prevalence in organic herds (Höglund *et al*., 2001; Höglund *et al*., 2004). In another Swedish study, carried out by Svensson *et al*. (1994), it was discovered that the coccidium *Eimeria alabamensis* may also be an important pathogen.

Isenstein (1963) and Frankena (1987) describes the detailed life cycle of *C. oncophora*. On pasture animals are infected by ingestion of third-stage larvae which exsheath in the abomasum and then travel to the small intestine. Around 15 days after ingestion the first adult pregnant females can be found and eggs may occur in the faeces after another five days. Coop *et al.* (1979) found that the majority of *C. oncophora* inhabit the duodenum and anterior jejunum. Changes of the intestinal wall that could be observed in infected calves were only minor and included compressions and distortions of villi that had been in contact with the worms. No clinical signs were observed, apart from a small reduction in liveweight gain, and the voluntary dry matter intake was not affected. Similar growth depressions and also diarrhoea have been observed in other studies (Borgsteede & Hendriks, 1979; Albers, 1981).

O. ostertagi has a similar life cycle to *C. oncophora*. The life cycle is direct with no intermediate hosts and the larvae are free-living and infectious in the third stage. However *O. ostertagi* inhabit the abomasum rather than the small intestine. Ingested larvae make their way into the gastric glands and around 18 days following infection adult worms begin to emerge (Frankena, 1987). The symptoms following infection are similar to *C. oncophora* infections, such as diarrhoea and weight loss, but seem to be more severe (Michel *et al.*, 1978; Armour & Ogbourne, 1982). *D. viviparus* has a life cycle that is very similar to both *O. ostertagi* and *C. oncophora*. But the final habitat of *D. viviparus* is the lungs. So ingested larvae break through the intestinal walls and migrate to the lungs where they enter the alveoli and mature to adult worms (Mason, 1994). Infected animals may have increased respiratory rates, decreased oxygen partial pressure and they may also show a reduced weight gain (Boon *et al.*, 1984; Schnieder & Daugschies, 1993).

The major part of the life cycle of the coccidium *E. alabamensis* occurs inside the nucleus of epithelial cells in the intestines, usually in the posterior part of the small intestine (Davis *et al.*, 1957). Oocysts are infectious after sporulation which occurs outside the host. Ingested infectious oocysts break and form sporocysts which then enter the epithelial cells. Multiplication of the coccidium damages the host cell and oocysts are shed with the faeces (Larsson, 2006). In a study on calves by Hooshmand-Rad *et al*. (1994), the infected animals developed diarrhoea within six to eight days and had a decreased dry matter intake. The animals inoculated with the highest doses of *E. alabamensis* (400 million sporulated oocysts) also showed signs of abdominal pain and were reluctant to stand. All infected calves had a depressed growth rate.

Genetics of parasite resistance

Resistance is defined by Woolaston & Baker (1996) as “the ability of a host to initiate and maintain responses to suppress the establishment of parasites and/or eliminate the parasite load”. This can be accomplished by modification of the morphology or physiology of the parasites, the killing of mature worms or the elimination of infectious larvae (Axford *et al.*, 2000). Extensive research and a number of reviews show that there is strong evidence for a genetically determined variation among animals in their ability to resist parasite infections (Gray & Gill, 1993; Eady *et al.*, 1996; Stear & Wakelin, 1998).

Parasite resistance belongs to the group of health traits which like production and reproductive traits etc are quantitative in their nature. Quantitative traits are distinguished from qualitative traits by being influenced by many genes, each with a small effect, and the environment. For quantitative traits it is possible to estimate a heritability, which describes how much of the phenotypic variation in a trait that is determined by the genes.

Heritability of faecal egg count

From the definition of resistance it can be assumed that fewer parasites reside inside resistant animals compared to susceptible animals. Therefore FEC, which indicate an individual’s parasite burden (number of nematode eggs per gram faeces), also indicate if an animal is resistant. Leighton *et al.* (1989) estimated the heritability of FEC in Angus calves to approximately 0.29 with a standard error (SE) of 0.18. In a New Zealand study on Angus cattle the heritability of $\log_e$ (FEC + 100) was estimated to 0.32 (SE = 0.16). The natural logarithm of FEC was used as the trait did not show a normal but rather a skewed distribution (Morris *et al.*, 2003). A larger Australian study utilised information from calf crops between the years 1983 to 1991 from two herds within the Australian Belmont Red breed. The animals were referred to as AX and AXBX, where AX cattle had a genetic composition of 25% Hereford, 25% Shorthorn and 50% Africander and the AXBX breed were composed of 25% Africander, 25% Brahman, 25% Hereford and 25% Shorthorn. In this study the estimation of the heritability of FEC and also tick counts was in the range of 0.35-0.44 (Burrow, 2001).

Genetic correlations between faecal egg count and production traits

In the New Zealand study by Morris *et al.* (2003), the genetic correlation between calf weaning weight and $\log_e$ (FEC + 100) was estimated to 0.41 (SE = 0.21). The genetic correlation between yearling weight and $\log_e$ (FEC + 100) was estimated to 0.34 (SE = 0.20). According to the authors these positive but unfavourable genetic correlations could possibly be explained by another trait called resilience. Woolaston & Baker (1996) define resilience as “the ability of the host to maintain a relatively undepressed production level under parasite challenge”. Burrow (2001) found that the relationship between FEC and growth and between FEC and fertility in cattle was close to zero. In this study the genetic correlation between tick and worm counts was also estimated and was found to be approximately 0.30. According to the authors this may indicate that parasite resistance is more or less independent from production traits but that relationships may exist among different resistance traits.

Biological mechanisms for resistance to parasites

Li *et al.* (2007) studied the mechanism behind resistance in a population of Angus cattle when challenged experimentally with *O. ostertagi* and *C. oncophora*. In the study the expression of 17 cytokines, cytokine receptors and chemokines were investigated. The results showed that seven days after infection elevated levels of cytokines such as tumor necrosis factor (TNF)-α, interleukin (IL)-1β and macrophage inflammatory protein (MIP)-1α could be found in the fundic and pyloric regions of the abomasum in heifers displaying resistance. In the same tissues it was also found that resistant heifers had higher expression levels of IL-10, polymeric immunoglobulin receptor gene (PIGR) and WSX-1 (a class 1 cytokine receptor) compared to susceptible heifers. In the small intestine, resistant animals showed elevated levels of MIP-1α, IL-6 and IL-10. These results show that resistant animals may have the ability to maintain inflammatory responses in the area where infection occur. The different profiles of cytokine expression in the abomasum and in the small intestine also indicate that parasites could induce inflammatory responses specific for the species of parasite. This is supported by the results from a study by Gasbarre *et al.* (2001), where no correlation was found between the number of *O. ostertagi* and *C. oncophora* in individual calves. It was suggested that the reason for this result was that the two species triggered different immune responses. However, results from a study by Schmidt *et al.* (1998) on nematode genera diversity in cattle suggest that the host only has a limited effect on the diversity, indicating that host resistance is similar for different species of parasites. In Australia there are indications that sheep selected for resistance against Barber's Pole also may have an increased resistance against other worms (CSIRO, 2006)

Quantitative traits may also be influenced by a major gene or a QTL. There are a number of candidate genes expected to influence parasite resistance and which may prove to be possible locations of QTLs. Many of these are involved in controlling the immune system such as genes coding for immunoglobulins, major histocompatibilty complex (MHC) antigens, T-cell receptors etc (Axford *et al.*, 2000).

Selection for parasite resistance

Eady *et al.* (1996) found sufficient genetic variation within several Merino sheep bloodlines allowing selection of resistant sires within lines or flocks to improve parasite resistance in the breed. In both Australia and New Zealand there are consulting services (Nemesis and WormFec respectively) in operation to aid sheep producers to implement breeding programmes that include parasite resistance. Both these systems are based on FEC as a selection criterion (CSIRO, 2006; McEwan, 2006). Faecal worm egg count is a trait that is relatively easy to measure and it also seems to be an effective selection criterion for improved parasite resistance (Woolaston *et al.,* 1996). There are also other advantages of using FEC as it directly measures the pasture contamination by each animal and it is relatively inexpensive to measure. However, the costs involved can increase rapidly if many animals are used and if there are several observations per animal (Woolaston & Baker, 1996). For sheep there exist detailed instructions on how to collect FEC samples. Sampling is performed during one day and on all sheep in a herd. The samples are collected by grab sampling, where approximately six pellets are removed with the finger from the anus of the sheep. Experienced personnel can sample around 100 animals per hour. The samples are then sent to laboratories for counting (CSIRO, 2006).

According to Sonstegard & Gasbarre (2001), measuring FEC in a commercial production setting becomes too complicated and may as mentioned result in high costs. Another strategy could instead be to indentify and select animals based on DNA marker haplotypes coupled to reduced FEC values. This type of marker-assisted selection (MAS) would greatly benefit if parasite resistance was found to be controlled by a major gene or QTL. When mapping QTLs microsatellite DNA markers are used and their possible association with the trait of interest is systematically tested. A high density of markers in reference linkage maps allows flexibility when selecting markers for genome scans. Bovine linkage maps available today contain more than 1800 markers scattered across around 3000 cm of genome. Most of these markers are microsatellites, there is however ongoing research to find markers which are based on single nucleotide polymorphisms (SNPs) (Sonstegard & Gasbarre, 2001).

Gasbarre *et al.* (2002) are currently completing an analysis of parasite resistance and possible economical trait loci (ETLs) in a herd of Angus cattle. The preliminary results indicate that there may be QTL for FEC and associated immune response on chromosome 3, 5 and 6. In a study on sheep that were selected for resistance against the parasite *Trichostrongylus colubriformis* the animals were challenged twice with parasites. For the second challenge possible genomic locations for QTLs affecting the resistance were found on chromosomes 1, 3, 6 and 12. According to the authors the results for chromosome 1 and 3 have to be treated with caution due to a wide marker spacing in some sheep families (Beh *et al.*, 2002). There are other studies in progress to detect new QTL or other possible production and fitness QTL in various crossbreed cattle (Sonstegard & Van Tassell, 2004).

If there are differences in parasitic pressures and types of parasites present in organic compared to conventional herds, possible genotype x environment interactions may also have to be taken into consideration in the selection process. Different breeding strategies or selection criterions for resistance might then be necessary in the two production systems. Studies in sheep by McEwan *et al.* (1997) indicate that even though some genotype x environment interactions may exist these are relatively small.

Discussion and Conclusions

Parasites may have vast negative effects on cattle production in terms of both productivity and animal welfare (Corwin, 1997). Swedish studies show that calves treated regularly with anthelminthics may have as much as a 65 kg advantage on untreated calves (Dimander *et al.*, 2003). They are especially of concern in organic production where the animals spend more time outdoors and where the regulations forbid regular anthelminthic drug treatment schemes (Europeiska Unionens Råd, 2007). Today organic production mainly relies on environmental measures to control parasites (Lund, 2003). However, another possible strategy could be to select individuals that seem to have a superior resistance determined genetically.

There are seven main beef breeds in Sweden today. Each breed is relatively small and in total there are approximately 14 300 purebred beef cows registered in KAP, which is more or less the whole purebred beef cow population. In total there are around 27 000 cows in KAP. No records show how many organic herds that are registered in KAP (KRAV, 2008; Svensk Mjölk, 2008). This could pose a problem as this relatively narrow database may not allow enough accuracy in the estimated breeding values for parasite resistance (Roth, 2008 personal communication). However, it is interesting to note that calving ability which also has a low heritability was included in the genetic evaluation in 2005. So it is possible that even though the Swedish beef population is relatively small there may still be enough animals registered in KAP to allow accurate estimations of parasite resistance. Of greater importance is the lack of available information as there is no registration of the trait at present. Information from registered organic herds may also increase the chance of finding the genetically superior animals. In conventional herds, where the animals are treated regularly with anthelminthics, the animals are not in an environment which allows them to express their genotype associated with parasite resistance to the same extent as animals in organic herds. It is important to note though, that information whether from conventional or organic herds is still valuable for the genetic evaluation of parasite resistance.

Another issue is whether a separate breeding value is needed for each specific parasite species. Four common internal parasites in Sweden are *O. ostertagi*, *C. oncophora*, *D. viviparus* and *E. alabamensis*. Although there are some similarities in the life cycles of these parasites (Isenstein, 1963; Coop *et al.*, 1979; Mason, 1994; Larsson, 2006) the differences may still be significant enough to trigger immune responses specific to the species. Results from two separate studies support the assumption that a number of different immune responses may be of importance in parasite resistance (Gasbarre *et al.*, 2001; Li *et al.*, 2007). Schmidt *et al.* (1998) suggest the opposite, that host resistance may be similar for different species of parasites. The two more recent studies indicate that separate breeding values may be needed for each specific parasite species. This leads to another question, which parasites should be included in the breeding programme? One and the same species of parasites may not necessarily have great economical impacts and cause great animal welfare concerns at the same time. Conventional and organic herds may also have problems with different species of parasites.

The impact on the host depends both on the number of parasites and the species. For example during infections with *C. oncophora* only minor alterations were observed on the intestinal wall of infected calves and the animals only suffered from a slight reduction in growth and diarrhoea (Borgsteede & Hendriks, 1979; Albers, 1981). Infections with *O. ostertagi* seem to give the same symptoms but they are more severe than *C. oncophora* infections (Michel *et al.*, 1978; Armour & Ogbourne, 1982). In ruminants out on pasture a sufficient level of immunity against most internal parasites is usually established after a few months. However, even after months, up to two years, of exposure to *O. ostertagi* cattle may remain susceptible to infection (Axford *et al.*, 2000). This may result in production losses if the animals have to be sent to slaughter before they have had the time to compensate for earlier growth reductions. Alternatively extended rearing may result in increased costs. Compared with for example *O. ostertagi* infections, it would seem that *E. alabamensis* may be of more importance from an animal welfare perspective due to the suffering an individual animal may experience. All infected animals develop diarrhoea and animals inoculated with high doses of *E. alabamensis* may also show signs of abdominal pain (Hooshmand-Rad *et al*., 1994).

There are breeding programmes for parasite resistance in operation today among sheep herds in Australia and New Zealand. It seems that Australian sheep selected for resistance against Barber's Pole also show lower burdens of a range of other worms. The selection is based on FEC in both countries (CSIRO, 2006; McEwan, 2006). Faecal egg counts measures an animal's parasite burden and is therefore an indirect measure of an animal's ability to resist parasite infections. Estimates of the heritability of FEC, in cattle, seem to range from low to moderate (Leighton *et al.*, 1989; Burrow, 2001; Morris *et al.*, 2003). However, many of the studies are based on small numbers of animals and the results should therefore be viewed with some caution. More studies using larger data sets are necessary to get a more reliable estimate of the heritability.

Another selection criterion that has been investigated is circulating eosinophils. Eosinphils are a type of white blood cells that among other things are responsible for combating parasites. Results from studies on sheep showed that this offered no advantages over FEC (Woolaston *et al.*, 1996). An alternative to selection based on breeding values estimated from phenotypic values, could be to use MAS. This type of selection is based on estimation of the additive effects of DNA markers and is especially effective for traits with low heritability (Quarrie, 1996). Using MAS would be even more effective if parasite resistance was controlled by a QTL. There are a number of candidate genes thought to influence parasite resistance and most of these are involved in controlling the immune system (Axford *et al.*, 2000). A number of studies on sheep and calves have found possible QTLs on chromosomes 1, 3, 5, 6 and 12 (Beh *et al.*, 2002; Gasbarre *et al.*, 2002) and more studies are being carried out around the world (Sonstegard & Van Tassell, 2004). One problem with MAS is that to perform genome scans and find possible QTLs, thousands of marker genotypes first have to be produced to allow detection of marker effects that are significant (Sonstegard & Gasbarre, 2001).

When discussing quantitative traits it also important to remember that there may exist genetic correlations. Morris *et al.* (2003) found positive but unfavourable genetic correlations between weaning weight and $\log_e$ (FEC + 100) and yearling weight and $\log_e$ (FEC + 100) which might be explained by an animal's resilience to parasites. It was concluded that it would be possible to apply direct selection to reduce FEC but that the use of index selection, to combine an increased live weight and reduced FEC, would be preferable. In study by Burrow (2001) the relationship between FEC and growth and between FEC and fertility in cattle was found to be close to zero. The authors concluded that parasite resistance may be more or less independent from the production traits but that relationships may exist among different resistance traits. There are few studies in this area and most have been done using relatively small data sets and may therefore have a low accuracy. There are also few studies of correlations between FEC and other traits related to production and fertility in cattle. Most of the research has been concentrated to sheep.

In conclusion, due to strict regulations there is a greater need in organic herds to control parasites using alternatives to anthelminthics and breeding may be a good tool to accomplish this. Though the heritability of parasite resistance may be low to moderate, the genetic variation appears to be large enough to allow improvement through selection using FEC as a selection criterion or perhaps MAS in the future. Foreign studies on Angus indicate that breeding programmes could probably be implemented successfully in this beef breed. More studies are necessary to say whether parasite resistance can be found among the Swedish beef breeds as well.

It is difficult to say whether separate breeding values are needed for different parasite species and if organic herds need to breed for resistance against other species of parasites than conventional herds. However, first and foremost it is important to start collecting information about parasite resistance. If FEC is to be used as a selection criterion it is necessary to develop a practical and viable method for sampling and counting adjusted to Swedish conditions.

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