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TOWARDS MORE PROFITABLE AND SUSTAINABLE MILK AND BEEF PRODUCTION SYSTEM

DOCTORAL THESIS

PAULIINA KOKKO

ACADEMIC DISSERTATION

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Custos: **Professor Asko Mäki-Tanila**
                       Department of Agricultural Sciences
                       University of Helsinki, Finland

Supervisor: **Adjunct Professor Jarmo Juga**
                       Department of Agricultural Sciences
                       University of Helsinki, Finland

Reviewers: **Adjunct Professor Anna-Elisa Liinamo**
                       LUKE Natural Resources Institute Finland, Finland

                       Professor Lotta Rydhmer
                       Department of Animal Breeding and Genetics
                       Swedish University of Agricultural Sciences, Sweden

Opponent: **Assistant Professor Han Mulder**
                       Department of Animal Sciences
                       Wageningen University and Research, The Netherlands

ABSTRACT

Achieving and maintaining national self-sufficiency in milk and meat play important roles in ensuring future food security. Currently, Finland is self-sufficient in milk. However, beef production, which is strongly related to dairy production, has fallen below consumption mainly because of a decreased number of dairy cows and low profitability. Even though the efficiency and productivity in dairy herds have increased substantially during the last decades, the profitability of milk, and especially combined milk and beef production, has remained low. In addition, the environmental challenges facing the dairy cattle industry are increasing; the environmental impacts of dairy farming are of growing public concern and production is likely to be affected by new environmental legislation and constraints in the future. To meet the future challenge of safeguarding food security with more intensive use of resources, new breeding and production strategies for milk and beef production are needed.

The main goal of this thesis was to investigate sustainable breeding and production strategies for increasing the productivity and efficiency in dairy herds in order to improve profitability and contribute to mitigation of the environmental impact of milk and beef production. More specific objectives were to derive economic values of feed efficiency traits along with several production and functional traits in Finnish milk production and to evaluate economic benefits of including additional feed efficiency, growth, and carcass traits in the breeding goal for combined milk and beef production systems. Moreover, the possibilities of different production strategies for increasing beef production from dairy herds and mitigating overall greenhouse gas emissions from beef production were assessed.

The derivation of economic values of different traits for the Finnish Ayrshire breed using a bio-economic approach showed that milk yield with the highest relative economic value (29-40% of the sum of standardized economic values over all traits) strongly dominated the breeding goal under the Finnish production and economic conditions in 2011. However, the moderate relative economic values (given in parentheses) found for the traits not currently included in the breeding goal: daily gain of animals in the rearing and fattening periods (4-5% both), residual feed intake (RFI) trait group (6-7%) as well as mature live weight (LW) of cows (6-11%), indicate that the inclusion of these traits in the breeding goal for Finnish milk production systems could result in economic benefits.

The economic impact of including additional feed efficiency and beef production traits in the breeding goal for the combined milk and beef production systems was assessed using a deterministic approach with the derived economic values. According to the results, the inclusion of a better growth performance of fattening animals and growing replacement heifers in the breeding goal while simultaneously preventing higher LW of cows would be the most promising option to improve the profitability of the combined milk and beef production systems. When considering the studied feed efficiency-related traits, the inclusion of smaller LW of cows in the breeding goal seems to be more beneficial than the inclusion of RFI traits in

production systems where growth and carcass traits are subject to selection. This finding is also supported by the faster availability of LW of cows for selection and its lower recording costs. However, with the breeding goal that excludes growth and carcass traits, adding LW of cows alone to the breeding goal had a negative effect on the profit of the breeding program. Therefore, for production systems where growth and carcass traits are not subject to selection, selecting for RFI traits could be more profitable even with only small economic benefits. However, before any further conclusions can be made about the consequences of selection for RFI traits, more information on the genetic correlations between RFI traits and current breeding goal traits as well as on the most cost-effective selection methods for feed efficiency is needed.

Finnish beef production was modeled to study the potential of different production options to enhance beef production originating from dairy operations. The most efficient way to enhance beef production, and consequently, to mitigate greenhouse gas emissions from beef production would be to increase the use of crossbreeding with beef bulls in dairy herds carrying out inseminations with Y chromosome sorted beef semen. However, in order to increase the current rate of crossbreeding, procedures that would ensure a sufficient number of replacement heifers and clear economic benefits from the production of crossbred calves to dairy farmers are needed. When considering the studied strategies that enable the increased use of crossbreeding in dairy herds, reducing the herd replacement rate showed the most potential for enhancing beef production, even though it would require substantially higher use of crossbreeding.

The current global tendency towards specialized dairy and beef production systems will likely further reduce beef production from dairy herds, potentially leading to an increasing negative environmental impact of livestock production. The results of this thesis support that combined milk and beef production would likely be the most viable and sustainable way to achieve self-sufficiency in beef while maintaining sufficient milk production in Finland. Therefore, the current dairy production systems should be developed more towards systems that efficiently produce milk and beef rather than increased specialization.

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CONTENTS

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following articles, which are referred in the text by their Roman numerals:

I   Hietala, P., Wolfová, M., Wolf, J., Kantanen, J., and Juga, J. 2014. Economic values of production and functional traits, including residual feed intake, in Finnish milk production. Journal of Dairy Science, 97: 1092–1106.

II   Hietala, P. and Juga, J. 2016. Impact of including growth, carcass and feed efficiency traits in the breeding goal for combined milk and beef production systems. Animal,
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III   Hietala, P., Bouquet, P., and Juga, J. 2014. Effect of replacement rate, crossbreeding and sexed semen on the efficiency of beef production from dairy herds in Finland. Acta Agriculturae Scandinavica, Section A – Animal Science, 64: 199–209.

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Contribution of the author to articles I to III:

The author participated in planning of studies, data editing, statistical analyses, interpretation of results, and dissemination of research outcomes to the journals as the main author.

ABBREVIATIONS

ADG	Average daily gain
AI	Artificial insemination
CO_2-eq	Carbon dioxide equivalents
CW	Carcass weight
DGV	Direct genomic breeding value
EU	European Union
FAy	Finnish Ayrshire
GEBV	Genomic estimated breeding value
GHG	Greenhouse gas
LW	Live weight
NDE	Number of discounted expressions
NTM	Nordic total merit
RDC	Nordic Red dairy cattle
RFI	Residual feed intake
RFI_I	Indicator trait for residual feed intake in cows
RFI_T	Residual feed intake in young bulls in a test station

1 INTRODUCTION

Improving the efficiency and productivity of milk and beef production in an environmentally sustainable way are important goals for the livestock sector to ensure future food security. The global demand for livestock products continues to increase driven by economic growth, urbanization, and higher income per capita combined with underlying population growth, especially in developing countries (FAO, 2009). In addition, cattle production faces increasing challenges related to environmental and socio-ethical issues, such as animal welfare, environmental impact of livestock production, and loss of genetic diversity, simultaneously with the need for more efficient resource use in livestock production.

In the Nordic countries, a substantial increase in production efficiency in the livestock sector has been achieved during the last decades (Åby et al., 2014). However, while the efficiency and productivity in dairy herds have increased substantially, the profitability of milk, and especially combined milk and beef production, has remained low in Finland. Moreover, the European Union (EU) milk quota abolition in 2015 will likely lead to more market-oriented milk production, which can have a large impact on the profitability of milk production and, as a consequence, on the supply of domestic milk and beef. Currently, Finland is self-sufficient in milk, whereas, during the last few decades, beef production has fallen below the domestic consumption level (Statistic Finland, 2016) mainly as a result of low profitability and a declining number of dairy cows.

Genetic improvement of dairy cattle has been one of the main driving forces behind increased economic efficiency achieved on dairy farms during the last few decades. Traditionally, national breeding programs for dairy breeds have focused on improving milk production traits in many countries. More recently, however, the trend in dairy cattle breeding programs has been towards breeding objectives that give more emphasis to functional traits increasing efficiency by reducing input costs (Miglior et al., 2005). Considering the future challenges for meeting the growing demand for livestock products with more intensive resource use, genetic improvement is necessary in both existing and new traits in dairy cattle (Hayes et al., 2013). Important breeding goal traits in the dairy industry will likely be feed efficiency-related traits as well as other traits related to the reduced emissions and adaptation to climate change. In addition, the implementation of different genomic and advanced reproductive technologies will play an important role in developing more effective breeding programs to meet future needs (Hayes et al., 2013).

1.1 IMPROVING FEED EFFICIENCY IN DAIRY CATTLE

Feed costs are a major variable cost component in dairy production. Therefore, to enhance the profitability of dairy production, improving feed efficiency will likely be an important future breeding objective for the dairy industry. Moreover,

improved feed efficiency in dairy cattle has been associated with reduced greenhouse gas (GHG) emissions and nutrient losses in dairy farming through lower enteric methane and manure outputs as well as resource use in feed production (Bell et al., 2011; Connor, 2015). So far, feed efficiency in dairy cows has improved mainly indirectly through increased milk yield per cow. This improved production efficiency, known as the "dilution of maintenance effect" (Bauman et al., 1985), has decreased the maintenance costs of animals per unit of milk produced. However, the tradeoffs in selecting for increased milk production are the potential antagonistic effects on other production factors such as metabolic stress, production diseases, longevity, and fertility (Oltenacu and Broom, 2010). Therefore, selection strategies that do not have negative impacts on other production characteristics or animal welfare are needed to improve the efficiency of converting feed into milk. In addition, selection for milk yield has been connected to increased mature live weight (LW) of cows (Hansen, 2000). As heavier cows have higher maintenance costs, selection for increased milk yield in order to improve feed efficiency is not straightforward.

Many different definitions for feed efficiency have been used in dairy cattle, although all of them require individually and accurately measured dry matter and nutrient intake (Pryce et al., 2014b). To date, the use of feed efficiency as a breeding objective for dairy cattle has been limited mostly due to the lack of an accurate cost-efficient method to measure feed efficiency on a large scale in commercial dairy herds. However, genomic selection (Meuwissen et al., 2001) could be used to overcome this problem by predicting genetic merit of animals based on the reference population of individuals with both phenotypic and genotypic data available (Pryce et al., 2014b). In addition, feed efficiency indices that reduce the maintenance costs of animals, consequently selecting for improved gross feed efficiency (the ratio of milk output to feed input) based on indicator traits such as LW of cows, have been implemented in some countries (Pryce et al., 2014b and 2015). However, the use of a selection index that includes milk production while penalizing higher LW of cows is not likely to capture all of the genetic variation that exists for feed efficiency (Pryce et al., 2015).

1.1.2 RESIDUAL FEED INTAKE

In the recent literature, the most common measure of feed efficiency in dairy cattle has been residual feed intake (RFI). RFI is defined as a difference between the animal's actual feed intake (dry matter or energy intake) and its predicted feed intake, where the prediction is usually based on a regression model accounting for energy requirements for maintenance and production during a specific period (Koch et al., 1963; Connor, 2015). Therefore, an animal with a negative RFI value is more feed efficient than its cohort. Several studies have shown that genetic variation exists in RFI among dairy cattle (e.g. Korver et al., 1991; Van Arendonk et al., 1991; Williams et al., 2011), providing potential for the use of RFI as a selection criterion for feed efficiency. In general, heritability estimates for RFI in different

studies based on relatively low sample sizes have been between low and moderate, varying in growing dairy heifers from 0.22 to 0.40, (e.g. Korver et al., 1991; Lin et al., 2013), in growing beef cattle from 0.07 to 0.62 (e.g. Fan et al., 1995; Archer et al., 1997), and in lactating dairy cows from 0.01 to 0.40 (e.g. de Haas et al., 2011; Vallimont et al., 2011). Moreover, Liinamo et al. (2015) found that heritability estimates for residual energy intake differ substantially between different lactation stages in Nordic Red dairy cattle (RDC). Based on this finding, they suggested that residual energy intake is partially a different trait in different lactation periods. RFI has been found to be a moderately heritable trait also in other species such as growing pigs, broilers, and laying hens (e.g. Pakdel et al., 2005; Gilbert et al., 2007; Yuan et al., 2015).

The advantage of using RFI as a selection criterion is that it is proposed to account for variation in the animal's metabolic efficiency for being phenotypically independent of production level, body weight, and body weight change (Williams et al., 2011; Pryce et al., 2014b). However, Connor (2015) recently pointed out several challenges that need to be addressed before the inclusion of RFI in dairy cattle breeding programs can be implemented more widely. Firstly, measuring RFI in dairy cows is costly as well as complicated because of fluctuations in a cow's energy balance during the lactation cycle. Pryce et al. (2014a) showed that genomic estimated breeding values (GEBV) of RFI for growing heifers could be used for selecting cows for RFI with a moderate accuracy of genomic predictions. Therefore, selection for RFI in lactating cows by using RFI measured on growing animals could be possible as well as beneficial because there are no complications with lactation and measuring costs are lower (Pryce et al., 2014b). Secondly, accurate estimates for the genetic relationships between RFI and other traits that are of economic or ethical importance are needed. Because reported genetic correlations have indicated that an antagonistic genetic relationship between RFI and fertility traits exists (Vallimont et al., 2013; Gonzalez-Recio et al., 2014), sufficient emphasis should be placed on fertility traits in a selection index. Lastly, a better understanding of the underlying physiological causes of variation in RFI among animals and a determination of the variables that should be included in the regression model for predicting feed intake across different populations are needed.

1.1.3 EFFECTS OF SELECTION FOR IMPROVED FEED EFFICIENCY

Improving feed efficiency through selection for lower RFI could be a potential option for reducing the costs of milk and beef production, assuming that there are no associated declines in other production parameters such as feed intake capacity, fertility or lactation performance of cows (Connor, 2015). The studies carried out in growing dairy heifers and lactating cows have indicated that dry matter intake differs substantially when comparing animals with the lowest and highest RFI (Williams et al., 2011; Waghorn et al., 2012; Connor et al., 2013) without phenotypic differences in other production traits, such as energy corrected milk, somatic sell count, and LW of cows (Connor et al., 2013). This supports the concept that

selecting for lower RFI could maintain the same production level with a reduced amount of feed needed per unit of output without affecting other production components. However, in order to achieve substantial economic benefits from selecting for RFI in dairy cattle, investigation of methods that reduce the costs associated with identification of the most efficient animals in terms of RFI is needed.

From an environmental point of view, improving feed conversion efficiency is identified as one of the major factors affecting GHG emissions from dairy production at a herd level as well as per unit of output (Bell et al., 2011; Thoma et al., 2013). Mainly due to the relationship between RFI and dry matter intake, selecting for lower RFI has the potential to reduce GHG emissions from the three main sources of dairy farming: feed production, enteric methane, and manure outputs (Connor, 2015).

1.2 BEEF PRODUCTION IN FINLAND

In Finland, approximately 80% of beef is produced as a by-product of milk production (Niemi and Ahlstedt, 2013), and thus, beef production is strongly based on dairy breeds, the majority of which are purebred Finnish Ayrshire cattle (FAy) and Holstein. In the past ten years, the total number of dairy cows has declined by over 10% as a result of changes in the production structure of Finnish agriculture (Luke, 2016). This has led to a reduced number of dairy animals available for beef production. Even though beef production from suckler cow systems has increased, the level of self-sufficiency in beef has been only around 80% in recent years (Statistic Finland, 2016). Currently, 12 different beef breeds exist in Finland; the most commonly used are Charolais and Hereford (Pesonen and Huuskonen, 2015).

In the past decade, the decreasing supply of domestic beef has led to a carcass pricing system that favors heavier carcasses (Pesonen and Huuskonen, 2015) and has increased average carcass weights of slaughter animals (Luke, 2016). Based on data collected from Finnish slaughterhouses, the current average slaughter weight for the most frequently used dairy breeds is around 330 kg in bulls slaughtered at 20 months of age (Huuskonen, 2014). In dairy heifers, the average slaughter weight has been around 210 kg at 16 months of age (Huuskonen et al., 2013). Beef breed bulls and heifers are typically slaughtered about one month younger than dairy animals, at average slaughter weights of around 390 kg and 240 kg, respectively (Pesonen and Huuskonen, 2015).

In Finland, meat industry operations commonly deliver calves from dairy or suckler cow herds to cooperating calf-rearing units and finishing farms (Pesonen and Huuskonen, 2015). Most dairy calves are delivered to specialized calf stations at about two weeks of age and are transferred to finishing farms at about six months of age (Herva, 2015). However, some dairy farmers still fatten their own surplus calves or transfer them directly to finishing farms. Suckler cow herds commonly either fatten their own calves or deliver calves to finishing farms. The feeding of

animals in Finnish beef production has typically been based on grass silage and barley-based concentrates. However, the use of commercial concentrates to supplement grass silage-based rations is becoming increasingly common (Huuskonen, 2011).

The low profitability of beef production limits the possibilities to increase Finnish beef production. However, when considering the aim to achieve self-sufficiency in beef while maintaining the current milk production level, increasing beef production based on dairy operations instead of suckler cow systems could be more beneficial from an environmental as well as an economic point of view. This is because beef production based on dairy herds seems to be more profitable in Finnish economic and production conditions (Karhula and Kässi, 2010). In addition, beef produced as a by-product of milk generates fewer GHG emissions per unit of meat output than beef production from suckler cow systems (e.g. Nguyen et al., 2010; Gerber et al., 2013).

Over the last decade, the selection pressure on beef production traits has been weak or non-existent in the Nordic dairy cattle breeding programs. Currently, a growth index including carcass and growth traits has been presented for both Holstein and RDC. However, the growth index has been excluded from the Nordic Total Merit (NTM) index for RDC and included only with a very small weight for Holstein (NAV, 2016a). Because the majority of beef is produced from dairy breeds in Finland, giving more emphasis to beef traits in the breeding goal for dairy cattle is an important option to consider when increasing domestic beef production. Another option for increasing beef production from dairy animals is crossbreeding of dairy cows with beef bulls. Several studies have shown a better growth performance and carcass quality with either similar or lower feed intake in dairy-beef crosses compared with purebred dairy animals reared for beef production (McGee et al., 2005; Cummins et al., 2007; Huuskonen et al., 2014). Consequently, the profitability of beef production should improve when increasing the use of crossbreeding. In addition, the use of crossbreeding would enable a fast increase in beef production without affecting genetic gain in traits under selection in dairy cattle.

Currently, beef semen is used for only about 6% of the inseminations in dairy cows in Finland (Huuskonen et al., 2014). Considering the current replacement rate in dairy herds, the use of beef semen for dairy cows not needed to produce calves for replacement could be increased. In general, the majority of Finnish dairy farms sell surplus calves at a very young age to specialized fattening farms. Because the difference in the revenues from sold crossbred and dairy calves is relatively small and dairy farmers want to ensure a sufficient number of heifers available as herd replacements, increasing the use of crossbreeding is challenging under the current Finnish economic and production conditions. However, using female sexed semen to produce replacement heifers and reducing the replacement rate in dairy herds are possible alternatives to enhance the potential for increasing crossbreeding rate. Moreover, the efficiency of crossbreeding can be improved by using male sexed semen to produce better growing crossbred bull calves for beef production.

1.3 NORDIC BREEDING PROGRAM FOR DAIRY BREEDS

The current national breeding programs are the starting point for developing new breeding objectives and breeding strategies. In the Nordic countries, close cooperation between breeding organizations has resulted in a joint Nordic evaluation of breeding values for different traits within the framework of Nordic Cattle Genetic Evaluation (NAV, 2008). In 2005, Finland, Sweden, and Denmark published the first joint Nordic breeding values for fertility traits, type traits, milk ability, and temperament. A few years later, in 2008, a common Nordic breeding goal, the NTM index, was published. Furthermore, the formation of the breeding organization VikingGenetics across Denmark, Sweden, and Finland supported the development. Currently, the selection of bulls and cows is based on the breed-specific NTM index in the main dairy breeds (RDC, Holstein, and Jersey) in all three countries.

The common Nordic breeding goal is to improve the profitability of dairy farms, with a substantial emphasis on conformation and functional traits (NAV, 2008). The NTM index consists of over 40 traits that are combined into more than 10 main trait groups (NAV, 2013). The index weights of the sub-indices are defined mainly based on the economic values of traits separately for each breed within countries (Kargo et al., 2014). When considering the main trait groups in the NTM index, the largest relative economic value has been placed on production traits (37% in RDC and 29% in Holstein). The remaining emphasis is shared between different functional and conformation trait groups.

The breeding program of the main Nordic dairy breeds is based on about 600 000 Holstein, 300 000 RDC, and 70 000 Jersey cows in milk recording. Currently, VikingGenetics genotypes about 3000 bull calves in both Holstein and RDC breeds and 500 Jersey bull calves each year. Of these genotyped calves, about 100 bulls in both Holstein and RDC breeds and 40 Jersey bulls are selected for use in artificial insemination (AI) and further receive daughter proofs (VikingGenetics, 2016).

1.4 DESIGN AND OPTIMIZATION OF BREEDING PROGRAMS

The increasing demand for livestock products as well as the growing importance of environmental and animal welfare traits preferred by society will drive the development of breeding objectives for dairy cattle to better reflect future needs. In general, the definition of a breeding objective is the most important step when developing breeding programs. After traits of economic importance have been identified, the development of a breeding goal involves the derivation of economic values of these traits. This enables definition of the relative importance of each trait in a given production system.

Hazel (1943) defined the economic value of a trait as the change in profit resulting from a unit genetic change in that trait while genetic merits of all other traits included in the breeding goal are kept constant. Generally, derivation of

economic values for breeding objective traits has been based on profit functions and bio-economic models studying the impact of genetic changes on profit. More recently, preference-based approaches considering, for instance, consumers' or farmers' preferences and willingness to pay for goods or services, have been used to define economic weights, especially for traits that have no clear economic value (Nielsen and Amer, 2007). A profit function refers to a single equation model constructed to represent the relationship between animals' performance in traits of economic importance and farm profit (e.g. Bourdon, 1998). A profit function is considered also as an efficiency function due to the strict definition of profit as a difference between the output and input of a production system (e.g. Groen, 1989). In general, economic values are derived as the partial derivatives of a profit function with respect to each breeding goal trait expressed at the population mean (e.g. Harris, 1970; Brascamp et al., 1985). However, complex production systems are usually difficult to describe by applying only a single profit function. A bio-economic model is a multi-equation model where the relevant biological and economic aspects contributing to the revenues and costs of a production system are described as a system of equations (e.g. Groen et al., 1997; Bourdon, 1998). Bio-economic modeling offers an opportunity to account for a large number of elements as well as the interactions between them, and therefore, allows the implementation of mathematical programming techniques for optimizing production systems (Groen et al., 1997).

Because costs and returns occur at different times for different traits, the components of profit should be discounted when analyzing breeding programs. The discounted gene flow method (Elsen and Mocquot, 1974; Hill, 1974) is a commonly used procedure in discounting the economic values of traits as well as the returns and costs of a breeding program, as it accounts for differences in the frequency and time of the realization of performance or product in different traits. Discounted gene flow is expressed as the number of discounted gene expressions (NDE) determined separately for each selection path included in the breeding scheme. NDE reflects the time and frequency of a genetic superiority of selected parents for a trait, as it is realized in selected animals' descendants in subsequent generations.

Design of a breeding program is a complex process since many aspects that determine outcome (e.g. monetary genetic gain and profit) are interdependent (Henryon et al., 2014). Therefore, the key issue for optimizing breeding programs is to find the proper balance between input and output parameters (Täubert et al., 2010). In general, modeling of breeding programs is based on mathematical models that describe the structure of the population and predict the consequences of a breeding scheme in terms of, for instance, genetic gain, returns, costs, and profit of a breeding strategy for a studied animal production sector over an investment period. Deterministic and stochastic approaches are the most commonly applied methods in evaluating and optimizing breeding schemes. The advantage of stochastic models compared with deterministic models is that by using them it is easier to model two-stage selection and rates of inbreeding with overlapping generations (de Roos et al., 2011; Pryce and Daetwyler, 2012). Moreover, the effects of selection and inbreeding on genetic variation can more easily be taken into

account. Stochastic simulation models also provide estimates on variability related to the outcome of the breeding program. However, several different breeding scenarios as well as interactions between model parameters can more easily be evaluated by using deterministic models due to their generally lower computational requirements and shorter running time (Pryce and Daetwyler, 2012).

Lastly, continuous evaluation of the breeding program with respect to progress towards the breeding goal should be routinely carried out (e.g. Berry, 2015) so that modification of the breeding strategy or goal can be implemented if necessary. The improved efficiency of breeding strategies in dairy cattle breeding has increased the importance of this monitoring to ensure that undesired side-effects, such as a reduction in genetic variation or unfavorable genetic trends, are identified early (e.g. Sørensen et al., 2005; Berry, 2015). In case an unfavorable genetic trend is detected, a reversal of the trend can be achieved by implementing appropriate breeding strategies even for traits with low heritability (Berry, 2015).

2 OBJECTIVES OF THE STUDY

The main goal of this thesis was to investigate sustainable breeding and production strategies for increasing the productivity and efficiency in dairy herds in order to improve profitability and contribute to mitigation of the environmental impact of milk and beef production.

The main goal was divided into three more specific objectives (with article numbers in parentheses):

1) To determine the economic values of feed efficiency traits along with several production and functional traits in Finnish milk production (I).

2) To assess the economic benefits of including additional feed efficiency, growth, and carcass traits in the breeding goal for combined milk and beef production systems (II).

3) To investigate the possibilities of increasing beef production from dairy herds by different production strategies and to define the potential of this increased dairy beef production for mitigating overall GHG emissions from beef production (III).

The original articles included in this thesis were constructed so that economic values derived in Article I were used for investigating the inclusion of additional traits in the breeding goal in Article II. Article III was carried out as a separate study.

3 MATERIALS AND METHODS

3.1 DERIVATION OF ECONOMIC VALUES OF TRAITS

3.1.1 DEFINITION OF PRODUCTION SYSTEMS

FAy is generally used throughout this thesis when considering the Finnish Ayrshire dairy cattle population in national-level investigations. RDC referring to the Nordic Red dairy cattle population containing FAy and Swedish and Danish Red dairy cattle populations is used when evaluating results at the Nordic level. A deterministic bio-economic model was used to estimate the marginal economic values of feed efficiency traits along with several production and functional traits for FAy (I). The management of the production system, herd characteristics, and average production parameters reflected the situation on an average dairy farm with a loose-housing indoor system in Finland for the year 2011. All dairy farms raised their own replacement heifers, whereas two marketing strategies for surplus calves not needed for replacement were applied: either A) surplus calves were sold to specialized fattening farms at a young age or B) dairy farms fattened their own surplus calves. In marketing strategy B, an additional scenario was studied where crossbred calves were produced for beef production. In this scenario, 10% of the cows were inseminated with Limousin bulls since Limousin is the most frequently used sire breed in crossbreeding on Finnish dairy farms (Huuskonen et al., 2013 and 2014).

The main parts of the used bio-economic model (I) were the calculation of the steady-state herd structure, animal classes of progeny, growth patterns of animal groups, milk yield in different lactations, total profit of the production system based on revenues and costs of each animal class, and economic values of traits. The structure of the dairy herd in its steady state was generated using dynamic modeling (Markov chain) based on the procedure described by Wolfová et al. (2005). The herd dynamics were described in terms of different animal classes and probabilities of transitions between these classes. Different cow classes were characterized as a combination of two variables; the number of the reproductive cycle (15 reproductive cycles), and the stage of a cow within the given reproductive cycle (5 stages). The different cow stages were as follows: 1) cow died within the given reproductive cycle, 2) cow was culled between calving and start of mating due to health problems after dystocia, 3) cow was culled within the reproductive cycle due to low milk production or health problems excluding dystocia, 4) cow was culled after lactation due to no conception, and 5) pregnant cow entering the next reproductive cycle. For progeny, 9 to 17 different animal classes were assigned depending on the marketing strategy for surplus calves and the use of crossbreeding. The herd performance parameters used for calculating the herd structure were defined from field data of Finnish milk

recorded herds collected between 2006 and 2011 provided by the breeding organization Faba.

3.1.2 PROFIT FUNCTION

The economic efficiency of the studied marketing strategies (I) was evaluated based on total profit ($profit$) per cow and year at the steady state of a dairy herd structure (Wolfová et al., 2007a) as follows:

$$(1) \qquad profit = \boldsymbol{rev}' \times \boldsymbol{NDE}^{(rev)} - \boldsymbol{cost}' \times \boldsymbol{NDE}^{(cost)} ,$$

where $\boldsymbol{rev}$ and $\boldsymbol{cost}$ are row vectors of revenues and costs, respectively, and $\boldsymbol{NDE}^{rev}$ and $\boldsymbol{NDE}^{cost}$ are column vectors of NDE for revenues and costs, respectively, occurring in each animal class in a dairy herd. In the model, all revenues and costs occurring in a herd during a year and later during the lifetime of progeny born in that given year were discounted to the date of calving. An annual discount rate of 5% was used to account for the differences in the timing of revenues and costs occurring during the lifetime of an animal. The discount rate of 5% was chosen because it is commonly used in the economic evaluation of breeding programs (e.g. Groenendaal et al., 2004; Wolfová et al., 2007a and 2007b), and only one discount rate was allowed for returns and costs in the program for deriving economic values (Wolf et al., 2012).

The economic input parameters used for deriving the total profit were based on the Finnish economic conditions for the production and marketing of agricultural products in 2011. Revenues came mainly from milk sales, slaughtered cows and heifers, and the monetary value of slurry in both marketing strategies as well as from sold surplus calves or slaughtered fattened animals in marketing strategies A and B, respectively. Revenues from slaughtered animals were affected by live weight of an animal, dressing percentage, and average price per kg of carcass weight (CW). An average price per kg of CW was defined based on the distribution of carcasses for the class combination of fleshiness and fat covering according to the EUROP grading system. Revenues from milk were a function of fat and protein contents and amount of milk. The quality of milk was taken into account by correcting the price of milk based on the proportions of sold milk in three different somatic cell count classes. The effects of agricultural subsidies (paid per kg of milk and per fattened animal) on the profitability and economic values of traits were studied by either including or excluding agricultural subsidies in the revenues. Costs considered in the model were housing, feeding, healthcare, insemination, and fixed costs (labor, energy, reparations, and overhead costs) defined separately for each animal class. Feeding costs were calculated according to feed needed to meet daily energy and protein requirements for growth, milk production, maintenance, and pregnancy and were based on the average price of feed rations with given dry matter, net energy, and protein contents.

3.1.3 DERIVATION OF ECONOMIC VALUES

The marginal economic value (ev_l) per unit of the trait per cow and year for trait l was calculated as the partial derivative of the profit function (1) with respect to the mean value of that trait (Wolfová et al., 2007a) and was approximated as follows:

$$(2) \qquad ev_l = \frac{profit_h - profit_l}{TV_l^h - TV_l^l},$$

where TV_l^h and TV_l^l are the increased and decreased values of trait l, respectively, and $profit_h$ and $profit_l$ are the profits per cow and year calculated from the increased and decreased value of trait l, respectively. For most of the traits with continuous variation, the genetic level of the trait considered was increased and decreased by 0.5% of the trait mean (Wolfová et al., 2007a). However, because the mean values of the studied RFI traits were equal to zero, this procedure could not be applied. Therefore, for RFI traits, the change in the genetic level was set to ±0.05 kg of dry matter/day of the trait mean. The economic values for maternal and direct components of traits were calculated multiplying the marginal economic values by the NDE for direct and maternal trait components. In the calculation of the NDE, the discounted gene flow method (Elsen and Mocquot, 1974; Hill, 1974) with an investment period of 25 years and a discount rate of 5% was applied. To compare the economic importance of different traits within the breeding goal, the relative economic value of each trait was defined as the standardized economic value of a trait (marginal economic value multiplied by genetic standard deviation) expressed as a percentage of the sum of the absolute standardized economic values over all breeding goal traits.

3.2 INCLUSION OF ADDITIONAL TRAITS IN BREEDING GOAL

3.2.1 TRAITS

The economic values were derived for 21 different traits (I) that can be assigned into five different trait groups: production, functional, growth, carcass, and RFI traits. The traits (with their mean value and genetic standard deviation) for which the economic values were derived (I) are presented in Table 1. In addition, the breeding goal traits as well as the traits used as indicator traits (with their heritability, accuracy of direct genomic breeding value (DGV), and economic value) used in studying the inclusion of additional traits in the breeding goal (II) are summarized in Table 1.

Table 1 *Mean, genetic standard deviations (sd$_a$), heritability (h^2), economic value in € per genetic standard deviation (EV), and accuracy of direct genomic breeding value (r$_{DGV}$) for the studied traits (I, II).*

Traits (I) included in reference breeding goal (II)	mean	sd$_a$	h^2	EV[1]	r$_{DGV}$
Production traits					
305-day milk yield[2], kg	8862	562.4	0.32	202.46	0.54
Protein percentage, %	3.44	0.15	0.32	60.68	0.52
Fat percentage, %	4.27	0.34	0.55	37.06	0.62
Functional traits					
Somatic cell score[3], score	2.6	0.085	0.12	-7.16	0.51
Clinical mastitis incidence, cases/cow/year	0.11	0.04	0.05	-15.58	0.51
Calving difficulty, score	1.35	0.16	0.04	-2.34	0.48
Stillbirth[4], %	4.2	2.5	0.06	5.25	0.48
Calf mortality in the rearing period[5], %	3.0	2.0	0.02	-0.80	0.48
Productive lifetime of cows, year	2.8	0.24	0.06	22.06	0.43
Calving interval, day	413	8.98	0.04	-31.43	0.53
Interval from 1st AI to conception in heifers, day	20	6.6	0.03	-9.90	0.53
Growth traits[6]					
Birth weight, kg	39	4.2	0.22	2.10	0.48
Traits (I) introduced as additional breeding goal traits (II)					
Growth traits[6]					
Average daily gain of animals in rearing period, g/day	800	60	0.19	18.00	0.66
Average daily gain of animals in fattening period[7], g/day	800	47	0.35	18.80	0.66
Mature live weight of cows after 3th calving, kg	624	33.9	0.31	-57.63	0.66
Carcass traits[6]					
Dressing percentage, %	50	1.14	0.28	11.4	0.66
Fat covering[8], score	2.86	0.21	0.16	-2.73	0.66
Fleshiness[9], score	8.52	0.38	0.12	-3.04	0.66
Residual feed intake traits[10]					
Residual feed intake in fattening animals, kg/dry matter/day	0	0.27	0.25	-7.97	-
Residual feed intake in growing heifers, kg/dry matter/day	0	0.27	0.25	-6.89	-
Residual feed intake in lactating cows, kg/dry matter/day	0	0.38	0.19	-21.20	-
Indicator traits (II)					
Average daily gain in a test station	-	-	0.35	-	-
Residual feed intake in young bulls in a test station	-	-	0.25	-	0.51
Residual feed intake indicator trait in cows	-	-	0.20	-	0.68

[1]Undiscounted economic values of traits derived with agricultural subsidies used in Scenarios 1-4 (II).
[2]Milk with fat content of 4.3% and protein content of 3.4%.
[3]Somatic cell score defined as log$_2$ (somatic cell count/100 000) + 3.
[4]Stillbirth includes premature births, stillbirths, and calves dead within 24 h after calving.
[5]Duration of the rearing period is from the birth to 180 days of age of an animal.
[6]Means are given for heifers (except mature weight is given for cows), but the economic values include changes in revenues and costs in all animal classes.
[7]Duration of the fattening period is from 180 days of age to slaughter of an animal.
[8]For fat covering, five grades numbered from 1 to 5 were used, 1 representing low fat covering and 5 high fat covering.
[9] For fleshiness, 11 grades from E to P- were used and transformed into numbers such that 1 was given to E representing the best class and 11 to P- representing the worst class.
[10]Residual feed intake traits are defined as the difference between the animal's actual daily dry matter intake and its predicted daily dry matter intake.

3.2.2 MODEL PARAMETERS

The used economic values of different traits (II) accounted for the returns (including subsidies) and costs of the combined milk and beef production systems where surplus calves were fattened on dairy farms (Table 1). The population and biological parameters used in the deterministic simulation (II) were defined based on the following three sources: 1) field data collected between 2010 and 2014 from Finnish milk recorded herds that was received from the breeding organization Faba, 2) Finnish milk recording statistics from 2013 (ProAgria, 2013), and 3) AI bull statistics for RDC provided by VikingGenetics (A. Himanen, personal communication). The economic parameters of the AI program costs were taken from the study by Thomasen et al. (2014) and received from VikingGenetics (A. Himanen, personal communication). The costs of measuring RFI in a test station were estimated based on the labor costs for weighing of animals, data analyses, and collecting feed samples. In addition, RFI measuring costs included the costs of grass silage and concentrate sample analyses by a commercial laboratory.

Heritabilities of the evaluated traits (II) are presented in Table 1. The heritabilities together with phenotypic and genetic correlations between traits (II) were mainly taken from the literature, prioritizing parameters estimated for the red dairy breeds or secondly, using parameters estimated for the Holstein breed. Lastly, when no estimates were found for genetic correlations between individual traits, genetic correlations of sires' estimated breeding values between trait groups in the NTM index were applied for those traits similar to traits included in the NTM sub-indices. If no information was available or a genetic correlation found between traits was smaller than 0.10, a correlation equal to zero was assumed. Considering different RFI traits, genetic correlations between traits were assumed to range from 0.40 to 0.70. In addition, correlations between different breeding goal traits and RFI traits were set to zero. These assumptions were made mostly due to the lack of genetic and phenotypic correlations between RFI and other studied traits. In addition, if correlations were found they were not statistically significant or consistent

3.2.3 SCENARIOS

The reference breeding goal (II) consisted of 12 different traits (Table 1) reflecting the current breeding scheme of FAy with LW of cows, beef production, and RFI traits excluded. Because the combined milk and beef production system was assumed, beef production was given an economic value also in the reference situation. Therefore, in the economic evaluation of the reference and each scenario introducing additional traits, the correlated economic responses in beef traits as well as in all other new breeding goal traits were accounted for in the profit of the breeding program. Four scenarios were constructed to assess the economic benefits of selecting for additional traits. The additional traits that were included in the breeding goal in each scenario are summarized in Table 2.

Table 2 *Additional traits included in the breeding goal in different scenarios.*

	Scenario[1]						
	1		2		3		4
Additional breeding goal traits	a	b	a	b	a	b	
Growth traits							
ADG in fattening period	x	x					x
ADG in rearing period	x	x		x			x
Carcass traits							
Fat covering, Fleshiness, Dressing-%	x	x					x
LW of cows		x	x	x		x	x
RFI traits							
RFI in fattening animals, growing heifers, and lactating cows					x	x	x

[1]Additional breeding goal traits in different scenarios:
Scenario 1. a) Average daily gain (ADG) of animals in the rearing and fattening periods and carcass traits b) with mature live weight (LW) of cows,
Scenario 2. a) LW of cows b) with ADG of animals in the rearing period,
Scenario 3. a) Residual feed intake (RFI) traits b) with LW of cows,
Scenario 4. All additional traits (LW of cows, growth, carcass, and RFI traits).

The following five scenarios were used to study the sensitivity of the results to different economic conditions and genetic correlations between traits with the same breeding goal assumptions as in Scenario 4:

Sensitivity 1. Economic values of traits derived with a decline of 25% in the price of milk.

Sensitivity 2. Economic values of traits derived with an increase of 25% in the price of feed.

Sensitivity 3. Use of zero economic values for stillbirth and birth weight in the selection index.

Sensitivity 4. Use of an unfavorable genetic correlation of -0.3 between fertility and RFI traits.

Sensitivity 5. Use of a 20% reduced genetic correlations between additional growth traits and LW of cows.

3.2.4 STRUCTURE OF BREEDING SCHEME

The modeled breeding scheme (II) reflected the current Nordic breeding scheme of RDC. The breeding scheme was considered to be intermediate in terms of the use of both genotyped young bulls and progeny-tested bulls as bull sires. The breeding population consisted of 300 000 milk recorded cows. Each year, 4000 cows with

the highest estimated breeding values were selected as bull dam candidates for producing 2000 bull calves that were genotyped. From these bull calves, 200 bulls were selected for progeny testing based on their GEBV, which combines phenotypic information with genomic information. These young bulls sired 30% of cows in milk recording. In scenarios where RFI traits were included in the breeding goal, young bulls were tested for RFI. Each year, 30 superior young bulls were selected out of young bulls based on their GEBV. Superior young bulls were used for 40% and 20% of the inseminations in bull and cow dams, respectively. Finally, ten proven bulls were selected per year when their daughter proofs were available. Proven bulls sired 60% and 50% of bull and cow dams, respectively. The structure of the modeled breeding scheme is shown in Figure 1.
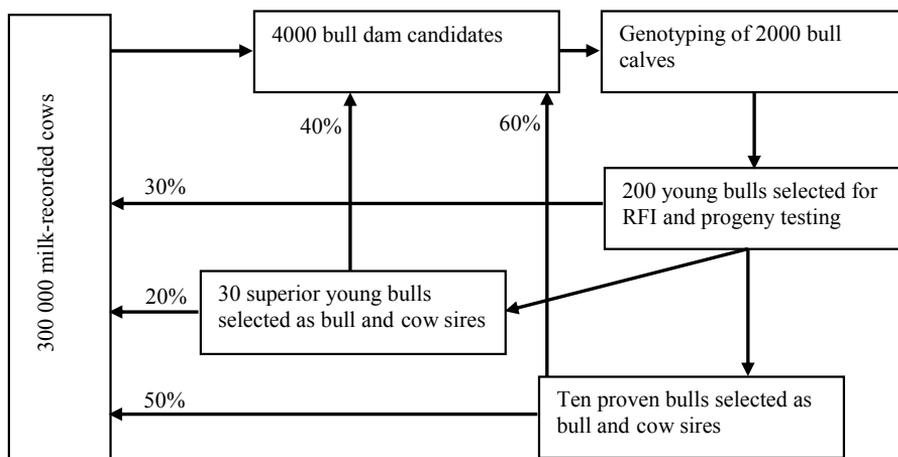
Figure 1 Structure of the modeled breeding scheme (II).

3.2.5 INFORMATION SOURCES IN SELECTION INDEX

The phenotypic information sources used in the selection index of each selection path (II) were records on half-sibs of sire and dam and on paternal half-sibs for the reference breeding goal traits as well as additional LW of cows, growth, and carcass traits if included in the breeding goal. In addition, proven bulls had 120 daughter records and genotyped bulls had DGV for these traits. For scenarios where RFI traits were included in the breeding goal, no phenotypic or genomic information was available for RFI breeding goal traits (RFI in fattening animals, growing heifers, and lactating cows). These traits were selected by using two indicator traits that were RFI in young bulls in a test station (RFI_T) and an indicator trait for RFI in cows (RFI_I). For RFI_T, phenotypic measures were available for young bulls. Because RFI_I was assumed to be possible to record for all cows in milk recording, the same phenotypic information sources for this trait were applied as for the

reference breeding goal traits. Genotyped bulls had DGV for both indicator traits for RFI (RFI_T and RFI_I).

When defining accuracies of DGVs (II), the average values based on two studies by Brøndum et al. (2011) and Gao et al. (2013) on the reliabilities of genomic predictions for the NTM index traits in the RDC population were applied for most of the traits. The accuracy of DGV for a corresponding trait group was used for all single traits within the group. For RFI_T and RFI_I, the accuracies of DGVs were calculated using the method described by Daetwyler et al. (2008) and (2010). In these calculations, the reference populations of 2000 bulls with own records for RFI_T and 2000 proven bulls with 50 daughter records for RFI_I were used. The accuracies of DGVs for the evaluated traits (II) are presented in Table 1.

3.3 MODELING OF BEEF PRODUCTION AND GHG EMISSIONS FROM DIFFERENT BEEF PRODUCTION SYSTEMS

3.3.1 BEEF PRODUCTION

A deterministic simulation model to describe Finnish beef production originating from dairy herds was constructed (III) based on the number of dairy cows at the national level in 2012 (283 600 cows). The rate of replacement set the number of cows that were available to produce calves for beef production as well as the number of slaughtered dairy cows. When defining the number of fattened animals, 0.88 calves per cow and year were assumed to be alive at the age of one year (Matilda Agricultural Statistic, 2013), and the mortality of calves in the rearing period was 3%. In the scenarios where the use of sexed semen was studied, cows inseminated with sexed semen produced 0.86 calves per year estimated on the basis of the results of the study by Heikkilä and Peippo (2012). With the use of X and Y chromosome-sorted sperm, 90% and 85% of the calves born were of the desired sex, respectively (Seidel, 2003). Without the use of sexed semen, the expected sex ratio was 50:50.

The parameters used to define beef production from different animal groups for the studied scenarios (III) are presented in Table 3. The potential of each scenario to increase domestic beef production was assessed by comparing the achieved change in the amount of beef (expressed in kg of carcass weight (CW)) with total domestic beef production (81.2 million kg of CW in 2012) that included beef originating from both dairy and suckler beef production systems. The effect of different production practices on the quality of carcasses was evaluated based on the changes in the average EUROP conformation class of carcasses, including cow, bull, and heifer carcasses. Under the EUROP system, five main classes (E, U, R, O, and P) for carcass conformation are used, with E representing the best class and P representing the worst class. In Finland, each main class is further divided into

three sub-classes (e.g. U+, U, U-), resulting in 15 different classes for carcass conformation. The classes were transformed into numbers from 15 to 1 so that 15 denoted the best conformation and 1 the worst conformation. The average CW and EUROP conformation classes for different animal groups were calculated based on data collected from the Finnish slaughterhouses between 2007 and 2010 and received from the breeding organization Faba.

Table 3 *Emission factors, estimated greenhouse gas (GHG) emissions, number of slaughtered animals in the reference scenario, average carcass weights (CW), and EUROP conformation classes of carcasses for different animal groups (III).*

Animal group	Emission factor, kg CO_2-eq[1]/kg CW	GHG emissions, million kg CO_2-eq/year	No. of animals, year	CW, kg	Conformation, score[2]
Dairy breed	17.7	1160.0 (77%)			
Slaughtered cows			99 260	268	2.9
Slaughtered bulls			114 504	322	4.6
Slaughtered heifers			15 244	212	3.5
Crossbred	17.7	81.0 (5%)			
Slaughtered bulls			6 027	363	7.1
Slaughtered heifers			6 027	236	5.6
Beef breed	24.9	275.5 (18%)			

[1] Carbon dioxide equivalents.
[2] For carcass conformation, conformation classes were transformed into numbers such that numbers from 1 to 15 replaced grades from P- to E+ (15 is the best class and 1 is the worst class).

3.3.2 GHG EMISSIONS

The GHG emission factors for different beef production systems (III) were defined based on the average values of whole-farm modeling studies for suckler beef (Casey and Holden, 2006; Williams et al., 2006; Beauchemin et al., 2010; Nguyen et al., 2010; Pelletier et al., 2010) and beef produced from dairy operations (Casey and Holden, 2006; Nguyen et al., 2010; Roer et al., 2013). The same emission factor was assumed for beef production from crossbred animals as for beef production from dairy animals due to the lack of information. The GHG emission factors and estimated GHG emissions used in the reference scenario for different beef production systems can be found in Table 3. In the evaluation of the GHG emission reduction potential, dairy and suckler beef production systems were assumed to be alternatives to each other because the goal was to increase the level of self-sufficiency in beef. Therefore, the GHG emission reduction potential of each scenario was defined as the difference between the GHG emissions from a changed amount of beef from dairy and crossbred animals and the GHG emissions from an equivalently changed amount of beef from beef breed animals.

3.3.3 SCENARIOS TO IMPROVE DAIRY BEEF PRODUCTION

In the reference scenario (III), the rate of replacement was 35%, 5% of calves born in dairy herds were beef crosses, and no sexed semen was used, which reflected the production practices in Finland in 2012. The scenarios to assess the potential of different production options for increasing beef production from dairy herds were as follows:

Scenario 1. The level of crossbred calves born in dairy herds was varied from 10% to 18% (the highest possible crossbreeding rate that can be achieved with the replacement rate applied in the reference scenario).

Scenario 2. The level of using Y-sorted sperm in crossbreeding was varied from 20% to 80%.

Scenario 3. The level of using X-sorted sperm in inseminations to produce replacement heifers was varied from 10% to 40%.

Scenario 4. The proportion of cows in first lactation (replacement rate) was varied from 20% to 30%.

In Scenarios 2 to 4, the crossbreeding rate of 18% was used, which, in theory, could be applied with the reference replacement rate. Because the studied scenarios were constructed to provide feasible alternatives for dairy farmers, this crossbreeding rate was considered to be possible to achieve in the Finnish production system when applying the studied production options to enhance potential for crossbreeding. The effects of the use of X-sorted sperm (Scenario 3) as well as a reduced replacement rate (Scenario 4) together with applying the maximal crossbreeding rate in each case on beef production and GHG emission reduction potential were also assessed.

3.4 SOFTWARE

The program EWDC (version 2.2.3) from the program package ECOWEIGHT (Wolf et al., 2012) was used in deriving the economic values of different traits (I). In this program, a deterministic bio-economic model including some stochastic elements is applied. The program package ECOWEIGHT was chosen because it provides a comprehensive and readily modifiable software platform for modeling dairy and combined dairy-beef production systems that correspond well with the Finnish production systems. Moreover, the program calculates economic values for several traits (e.g. feed efficiency traits) that are of economic interest as well as relevant when considering the objective of this study. In addition to providing economic values, the program is a useful tool for an economic evaluation of different

production systems, as the effects of production, management, and economic conditions on the economic efficiency of a given system can be investigated (Wolf et al., 2012).

The inclusion of additional traits in the breeding goal for combined milk and beef production systems (II) was modeled using the deterministic simulation program ZPLAN+ (Täubert et al., 2010). ZPLAN+ models breeding structures that take into account different biological, technical, and economic parameters. In the ZPLAN+ program, the discounted gene-flow method by Hill (1974), selection index procedures by Hazel (1943), and economic modeling are used for calculating monetary genetic gain, discounted returns, costs, and profit of a breeding program over a defined investment period. The choice to use ZPLAN+ was based on its good capacity to describe and economically assess complex breeding programs. Since ZPLAN+ integrates the possibilities to evaluate several traits, to include direct genomic information, and to model multi-stage selection (Täubert et al., 2010), the program was readily adaptable to and suitable for the analyses of this thesis. Lastly, a deterministic model to describe Finnish beef production (III) was constructed by using Microsoft Excel 2010 (Microsoft Corporation, Redmond, WA, USA).

4 RESULTS AND DISCUSSION

4.1 ECONOMIC VALUES OF TRAITS IN FINNISH MILK PRODUCTION

4.1.1 ECONOMIC EVALUATION OF PRODUCTION SYSTEMS

Under the Finnish production and economic conditions in 2011, the profitability of milk and beef production was generally low (I). When dairy farms applied either selling (A) or fattening of surplus calves (B) without accounting for subsidies, the profitability (the ratio of profit and costs) was -15.4% and -20.7%, respectively. The profitability was only slightly better (-20.5%) when 10% of the dairy cows were inseminated with beef semen in marketing strategy B. When including agricultural subsidies in the revenues, the profitability was 4.1% in strategy A where surplus calves were sold and 0.4% in strategy B where surplus calves were fattened on dairy farms.

As the results of this thesis show, the profitability of Finnish milk production and especially combined milk and beef production is strongly dependent on agricultural subsidies. When considering the derivation of economic values, it is debatable whether the agricultural subsidies should be included in the economic values of traits because the stability and continuity of the current subsidy program are uncertain. However, in this thesis, unprofitable beef production led to economic values that favored a decrease in the number of fattening animals when not including subsidies. Therefore, the economic values taking into account subsidies were applied to avoid the deterioration of functional traits in the investigation of including additional traits in the breeding goal (II).

In Finland, the latest change in subsidy regulations was in 2015 when the subsidies paid per liter of milk were removed from the subsidy region in southern Finland. This change directly decreases the economic value of milk production in this region. Another factor that affects the profitability of milk production, and consequently, the economic values of traits, is the EU milk quota abolition implemented in 2015. The milk quota abolition has already led to increased milk production in the EU (European Commission, 2016) and a more market-orientated dairy sector. This can have a substantial effect on the profitability of milk production, especially in countries similar to Finland, where the production costs in the dairy sector are among the highest in the EU (European Commission – EU FADN, 2014).

4.1.2 ECONOMIC VALUES OF TRAITS

The marginal economic values of the studied traits (I) for both analyzed marketing strategies of either selling or fattening surplus calves with and without subsidies included in the revenues are presented in Table 4. These marginal economic values express the change in profit per cow and year when increasing the mean value of the trait by one unit. Thus, the negative marginal economic value of the trait shows that an increase in the mean value of that trait would result in a decrease in total farm profit.

The marginal economic values for different milk production and feed efficiency traits were quite similar between the studied marketing strategies and the scenarios considering the inclusion of subsidies (I). However, substantial differences were found in the marginal economic values of traits related to the survival of calves, consequently affecting the number of surplus animals available for fattening or selling. In contrast to marketing strategy A, positive marginal economic values were obtained for calving difficulty score, stillbirth, birth weight, and calf mortality in the rearing period in marketing strategy B when excluding subsidies. This indicates that fattening of surplus calves is unprofitable under the given production and economic conditions. These traits obtained positive economic values due to the fact that any decrease in the mean value of the trait leads to an increased number of fattening animals, resulting in an economic loss. However, when subsidies were included, negative marginal economic values for calving difficulty score and calf mortality in the rearing period were obtained in marketing strategy B.

Considerable differences in the marginal economic values were also found for calving interval, carcass traits, and productive lifetime of cows between the marketing strategies as well as the subsidy scenarios (I). The changes in productive lifetime of cows affect several production factors such as the number of surplus calves, culled cows, and heifers needed for replacement as well as the amount of milk produced per cow and year. Therefore, its marginal economic value is strongly sensitive to the prices of inputs and outputs in beef and milk production as well as the marketing strategy used for surplus calves. The differences in the marginal economic values of carcass traits resulted mainly from the proportion of slaughtered animals between the studied production systems differing.

It should be pointed out that in this thesis the economic values of traits were derived based on a purely economic objective to maximize the profit of the given production system. Therefore, they are not necessarily directly usable or applicable to practical breeding programs. While some studies have argued that subsidies should not be included in the model for the derivation of economic values, the results of this study show that including subsidies results in a more realistic and applicable outcome. This is supported by the findings of Wolfová et al. (2006) who stated that for obtaining an appropriate weight for each trait in the breeding goal, especially considering the weights of functional traits that would avoid their deterioration, each segment of the production system should obtain a positive profit, e.g. by accounting for subsidies in a model.

The findings of this thesis correspond well with the results of other studies considering different cow-calf and dual-purpose production systems (Krupa et al., 2005; Krupová et al., 2016) where differences in the marginal economic values have been observed between marketing strategies applying either fattening or exporting of surplus calves. Based on the great differences in the economic values between the studied marketing strategies found in this thesis, it might be beneficial to construct two customized selection indices for within-farm selection. Farmers could use these selection indices to identify dairy sires suited to their production system depending on whether surplus animals are fattened or sold on dairy farms. However, since dairy breeds play an important role in beef production in the Nordic countries, the construction of a selection index for AI-bulls in the Nordic breeding program should be based on the goal to improve the profitability of both milk and beef production.

Table 4 *Marginal economic values of traits (in €/unit of the trait per cow and year) for two marketing strategies (I).*

Trait, €/unit	Marketing strategy[1]			
	A1	A2	B1	B2
305-day milk yield[2], €/kg	0.3	0.4	0.3	0.4
Protein percentage, €/%	404.5	404.5	404.5	404.5
Fat percentage, €/%	109.0	109.0	109.0	109.0
Somatic cell score[3], €/score	-84.3	-84.3	-84.3	-84.2
Clinical mastitis incidence, €/cases/cow/year	-389.4	-389.4	-389.4	-389.4
Calving difficulty score, €/score	-22.1	-25.8	4.6	-14.6
Stillbirth, €/%	-0.3	-0.3	5.6	2.1
Calf mortality in the rearing period, €/%	-1.3	-1.3	3.1	-0.4
Productive lifetime of cows, €/year	88.2	121.9	17.2	91.9
Birth weight, €/kg	-0.2	-0.2	0.5	0.5
Mature live weight, €/kg	-1.0	-1.0	-1.7	-1.7
Dressing percentage, €/%	2.8	2.8	10.0	10.0
Daily gain of calves in rearing period, €/g/day	0.3	0.3	0.3	0.3
Daily gain of animals in fattening period, €/g/day	-	-	0.4	0.4
Fat covering, €/score	-7.6	-7.6	-13.1	-13.0
Fleshiness, €/score	-0.2	-0.2	-8.2	-8.0
Calving interval, €/day	-4.8	-4.9	-1.6	-3.5
Interval from first AI to conception of heifers, €/day	-1.6	-1.6	-1.4	-1.5
RFI[4] in fattening animals, €/kg of DM/day	-	-	-29.5	-29.5
RFI in growing heifers, €/kg of DM/day	-25.5	-25.5	-25.5	-25.5
RFI in lactating cows, €/kg of DM/day	-55.8	-55.8	-55.8	-55.8

[1]Marketing strategies (A) surplus calves are sold and (B) surplus calves are fattened on dairy farms (1) without and (2) with consideration of agricultural subsidies in the revenues of the production system.
[2]Milk with average fat content of 4.3% and protein content of 3.4%.
[3]Somatic cell score is defined as $\log_2$ (somatic cell count/100 000) + 3.
[4]RFI = residual feed intake.

The relative economic values were calculated (I) to enable the comparison of the economic importance of different traits within the studied production systems. When comparing the relative economic importance of traits excluding subsidies,

305-day milk yield clearly dominated the breeding goal, as it contributed 34% in strategy A and 29% in strategy B to the sum of the absolute values of the standardized economic weights. The second most important trait was protein percentage in strategies A and B (13% and 11%, respectively). It was followed by calving interval (9%) and fat percentage (8%) in strategy A and by LW of cows (11%) and fat percentage (7%) in strategy B. In comparison of the scenarios including and excluding subsidies, the order of importance of the aforementioned traits was the same within the marketing strategies. However, with subsidies, a considerably higher relative economic value was found for milk yield because of increased revenues from milk sales in both marketing strategies (40% in strategy A and 36% in strategy B).

Figure 2 shows the sums of the relative economic values for different trait groups (I) for both marketing strategies with and without subsidies. The relative economic importance of milk production traits increased while the economic importance of functional as well as growth traits decreased within both marketing strategies when including subsidies. This was as expected due to increased revenues from milk. However, no substantial differences in other trait groups considering the inclusion of subsidies were found between scenarios.
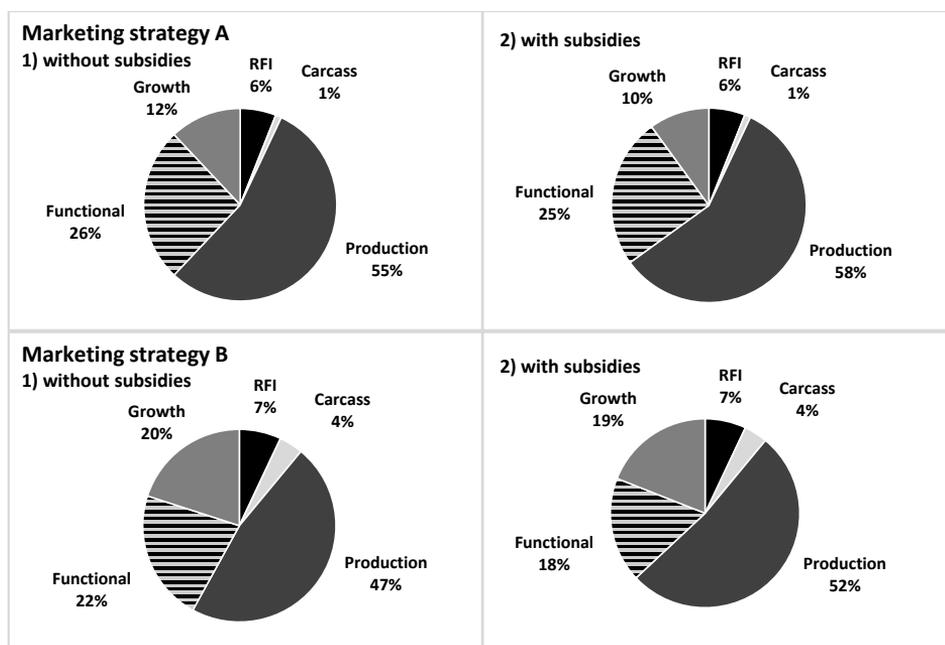

Figure 2 Sums of the relative values for different trait groups for two marketing strategies (A) surplus calves are sold and (B) surplus calves are fattened on dairy farms without (1) and with (2) taking into account agricultural subsidies in the revenues of production (I).

When considering the relative economic importance of traits (I) introduced as additional breeding goal traits (II), the growth trait group obtained a relatively high economic importance (19-20%) in marketing strategy B with fattening of surplus calves. A moderate economic importance (10-12%) was observed for the growth trait group in marketing strategy A with selling of surplus calves. Among growth traits (I), the highest relative economic value was found for LW of cows (6-7% in strategy A and 10-11% in strategy B), with a negative marginal economic value that favored smaller cows. This negative marginal economic value was caused by the fact that the marginal revenues from the higher slaughter weight of cows did not cover the marginal costs resulting from the higher maintenance requirements of heavier cows. The finding is in line with the results of the study by Liinamo and van Arendonk (1999) who observed a negative economic value for cow carcass weight under the Finnish economic situation in 1997. In addition, also several other studies where the economic value of LW of cows has been mostly dependent on the feed and beef prices have reported a negative marginal economic value for LW of cows (e.g. van der Werf et al., 1998; Wolfová et al., 2007a; Komlósi et al., 2010). Considering the remaining growth traits, relative economic values between 4% and 5% were found for both ADG of animals in the rearing and fattening periods. This indicates that selection for improved growth rate in fattening animals and growing replacement heifers could result in moderate economic benefits in beef and dairy production. The carcass trait group reached only 1-4% of the total economic importance of all studied traits in different marketing strategies. This low economic importance was caused by the low producer price of beef, small differences in the prices between different fleshiness and fat covering classes, and, in marketing strategy A, a small proportion of slaughtered animals.

The relative economic values of 6% in strategy A and 7% in strategy B obtained for the RFI trait group (I) indicate that improved feed efficiency would have a moderate positive economic impact on farm profit. The same situation was reported by Krupová et al. (2016) for the Slovak Pinzgau breed in dairy and cow-calf production systems where a relative economic importance of 8% for the RFI trait complex was observed. In addition, a very similar marginal economic value for RFI in lactating cows (-55.2 €/kg of DM/day per cow and year) was estimated for Pinzgau cattle, as found in this thesis (I) (-55.8 €/kg of DM/day per cow and year). However, the marginal economic values for RFI in fattening animals and growing heifers found by Krupová et al. (2016) differ from those derived in this study mainly because of the differences in the number of animals in these animal classes per cow and year.

4.2 ECONOMIC EVALUATION OF INCLUDING ADDITIONAL TRAITS IN BREEDING GOAL

4.2.1 EXPECTED ECONOMIC GENETIC GAIN

The 305-day milk yield with the highest economic value generally dominated the breeding goal, thus determining the rate and direction of genetic response in other traits in the different scenarios studying the inclusion of additional traits in the breeding goal (II). As a result, 305-day milk yield had the largest annual genetic gain in all studied scenarios. In addition, undesired consequences of selection were observed in several traits having an antagonistic relationship with milk yield. The economic values used were influenced by the unprofitable beef production. Therefore, even though agricultural subsidies were accounted for in the economic values, a few traits related to the survival of calves had an economic value that would result in a decline in the number of fattening animals. From an ethical perspective, this led to unwanted genetic changes in stillbirth and birth weight in most of the studied scenarios.

The monetary genetic gains in the groups of traits and LW of cows for different scenarios (II) are presented in Table 5. In all studied scenarios, the obtained economic response to selection was highest in production traits, while a deterioration in functional traits was observed. Among the additional breeding goal traits, a relatively high response to selection was observed in growth traits when included with carcass traits in the breeding goal (Scenario 1a, II). In addition, a substantial favorable response leading to decreased LW of cows was found when including LW only in the breeding goal (Scenario 2a, II). However, in those scenarios (Scenarios 1a and 3a, II) where selection was based on the breeding goal, excluding LW of cows, a comparatively large unwanted genetic change increasing LW of cows was noted. The use of a selection index that included growth and carcass traits, while penalizing higher LW of cows (Scenario 1b, II), reduced the achieved response to selection in growth traits. However, this selection index resulted in a considerably smaller unfavorable increase in LW of cows than the selection index excluding this trait (Scenario 1a, II). Due to a strong antagonistic relationship between growth traits and LW of cows, the reduced genetic response in growth traits (Scenario 1b, II) was as expected. In addition, LW of cows had the third highest economic value among breeding goal traits. However, the results of this study suggest that improving growth and carcass traits would be possible while only negligibly increasing LW of cows when selecting all of these traits simultaneously. In general, economic genetic responses to selection in RFI and particularly in carcass traits were relatively small mainly due to their relatively low economic values.

Table 5 *Discounted monetary genetic gain (∆G) in the groups of traits for different scenarios (II).*

Scenario[1,2]	∆G (€/cow and investment period of 15 year)					
	Production	Functional	LW of cows	Growth	Carcass	RFI[3]
Reference	372.5	-30.2	-7.9	21.3	-0.4	0.0
Scenario 1a	357.7	-30.3	-29.3	56.9	3.3	0.0
Scenario 1b	371.6	-30.1	-1.1	25.5	2.3	0.0
Scenario 2a	349.7	-28.6	35.5	-10.3	-1.6	0.0
Scenario 2b	364.2	-30.7	17.7	5.0	-1.2	0.0
Scenario 3a	366.5	-29.7	-7.8	21.1	-0.5	10.9
Scenario 3b	344.4	-28.1	35.0	-10.1	-1.6	10.5
Scenario 4	366.5	-29.7	-1.1	25.2	2.3	10.1
Sensitivity 1	278.1	-32.7	2.5	26.1	3.2	12.9
Sensitivity 2	340.6	-28.0	3.5	26.9	2.3	16.4
Sensitivity 3	365.8	-29.0	-0.4	24.0	2.3	10.1
Sensitivity 4	365.1	-30.8	-0.7	21.8	2.4	24.9
Sensitivity 5	360.6	-30.8	4.0	31.7	2.1	10.0

[1]Additional breeding goal traits in different scenarios:
Scenario 1. a) Average daily gain of animals in the rearing and fattening periods and carcass traits b) with mature live weight (LW) of cows,
Scenario 2. a) LW of cows b) with average daily gain of calves in the rearing period,
Scenario 3. a) Residual feed intake (RFI) traits b) with LW of cows,
Scenario 4. LW of cows, growth, carcass, and RFI traits.
[2]Different sensitivity scenarios:
Sensitivity 1. Economic values of traits derived with a decline of 25% in the price of milk,
Sensitivity 2. Economic values of traits derived with an increase of 25% in the price of feed,
Sensitivity 3. Zero economic values for stillbirth and birth weight in the selection index,
Sensitivity 4. Unfavorable genetic correlation of -0.3 between fertility and RFI traits,
Sensitivity 5. 20% reduced genetic correlation between the additional growth traits and LW of cows.
[3]Monetary genetic gains in residual feed intake (RFI) traits were zero in the scenarios where it was excluded from the breeding goal (Scenario 1 and 2) because no genetic correlations between RFI and other breeding goal traits were included in the reference assumptions.

4.2.2 ECONOMIC EVALUATION OF ALTERNATIVE BREEDING GOALS

The discounted costs of the breeding program operations (II) were 10.1 € per cow for the investment period of 15 years. These costs consisted of the variable costs of the breeding program connected with the selection process of sires. The inclusion of the RFI trait group had no substantial effects on the costs of the breeding program per cow because the additional testing costs of 13.5 € per tested bull were spread over all 300 000 cows in the population.

The discounted profit of the breeding program and the undiscounted annual monetary genetic gain for different scenarios (II) are summarized in Table 6. The discounted profit of the breeding program was 5.1% higher in Scenario 4 (II), which introduced all additional breeding goal traits, than in the reference scenario. Among the other scenarios, the highest increase in the discounted profit (3.7%) was found with the breeding goal including growth and carcass traits together with LW of cows

(Scenario 1b, II). A substantially smaller increase in the profit (0.8%) was observed when selection was based on the breeding goal including growth and carcass traits but excluding LW of cows (Scenario 1a, II). In the scenarios considering the inclusion of feed efficiency-related traits only, the profit of the breeding program decreased by -3.1% when adding LW of cows to the breeding goal (Scenario 2a, II). However, a small increase of 1.4% in the profit was found when RFI traits were added to the breeding goal (Scenario 3a, II).

Table 6 *Discounted profit of the breeding program over a 15-year period and undiscounted annual monetary genetic gain (ΔG) for different scenarios (II).*

Scenario[1]	Profit, €/cow/15-year period	Change[3], %	ΔG, €/cow/year	Change[3], %
Reference	345.3	-	64.2	-
Scenario 1a	348.2	+0.8	63.1	-1.8
Scenario 1b	358.1	+3.7	66.5	+3.6
Scenario 2a	334.7	-3.1	64.0	-0.5
Scenario 2b	344.9	-0.1	65.1	+1.3
Scenario 3a	350.1	+1.4	64.9	+1.1
Scenario 3b	339.7	-1.6	64.6	+0.6
Scenario 4	362.8	+5.1	67.2	+4.6
Sensitivity 1	279.8	-22.9	52.1	-22.4
Sensitivity 2	351.2	-3.2	65.1	-3.2
Sensitivity 3	362.4	-0.1	67.2	-0.0
Sensitivity 4	372.2	+2.6	68.8	+2.4
Sensitivity 5	367.3	+1.2	67.7	+0.7

[1]Additional breeding goal traits in different scenarios:
Scenario 1. a) Average daily gain of animals in the rearing and fattening periods and carcass traits b) with mature live weight (LW) of cows,
Scenario 2. a) LW of cows b) with average daily gain of calves in the rearing period,
Scenario 3. a) Residual feed intake (RFI) traits b) with LW of cows,
Scenario 4. LW of cows, growth, carcass, and RFI traits.
[2]Different sensitivity scenarios:
Sensitivity 1. Economic values of traits derived with a decline of 25% in the price of milk,
Sensitivity 2. Economic values of traits derived with an increase of 25% in the price of feed,
Sensitivity 3. Zero economic values for stillbirth and birth weight in the selection index,
Sensitivity 4. Unfavorable genetic correlation of -0.3 between fertility and RFI traits,
Sensitivity 5. 20% reduced genetic correlation between the additional growth traits and LW of cows.
[3]Scenarios 1 to 4 compared with the reference scenario; Sensitivity scenarios 1 to 5 compared with Scenario 4.

In general, genetic gains in carcass traits and ADG of animals in the rearing and fattening periods are realized earlier in animals' life cycle, obtaining a higher weight than genetic gain in LW of cows. As a result, the inclusion of growth and carcass traits was beneficial particularly according to the discounted profits (II). However, in terms of undiscounted annual economic genetic gains with similarly weighted genetic gains of traits, the inclusion of growth traits without LW of cows in the breeding goal was not beneficial (Scenario 1a, II). Therefore, to obtain economic benefits from selection on growth and carcass traits the simultaneous inclusion of

LW of cows in the breeding goal seems to be even more important than was found based on the discounted profits.

The results of this thesis (II) suggest that the inclusion of growth of fattening animals and replacement heifers in the breeding goal while preventing higher LW of cows could improve the profitability of the combined dairy and beef production systems under the Finnish economic conditions. However, the economic benefits obtained from the inclusion of carcass traits in the breeding goal were small, mainly due to their low economic value. In the Nordic countries, commercial slaughterhouse data are routinely received for genetic evaluation, and the growth index has been presented for both Holstein and RDC. Therefore, selection for growth and carcass traits would be readily available with only negligible additional breeding program costs.

Economic values for beef production traits as well as the effects of including these traits in the breeding goal for combined milk and beef production from the Finnish dairy cattle population have been investigated earlier in the simulation study by Liinamo and van Arendonk (1999). Under the Finnish economic conditions in 1997, they also found an economic benefit of including beef production traits in the breeding goal since it could extend farm income sources without reducing genetic response in milk production traits. However, because the economic and production conditions in Finland have changed after the study by Liinamo and van Arendonk (1999) was carried out the results are not entirely relevant in the current conditions. In addition, they considered only a relatively small proportion of the traits (i.e. milk production traits) that are included in the current breeding goal for FAy.

Meat quality traits were not considered in this thesis. However, improving meat quality might become a more important breeding objective also in dairy cattle breeds used for both milk and beef production because of increasing consumer demand for high-quality meat. In addition, improving the quality of beef from dairy animals would ensure that Finnish beef production remains competitive with high-quality imported beef products with relatively low prices. Some early studies reviewed by Marshall (1999) and later studies (e.g. Moore et al., 2005) in beef cattle have suggested an unfavorable genetic relationship between growth rate and some meat quality traits such as intramuscular fat content. However, Marshall (1999) also concluded that a genetic antagonism between growth rate and meat quality should not be a major cause for concern in most populations. This statement is supported by at least a few studies in beef cattle with relatively large sample sizes and more traits included, suggesting that selection for improved growth rate could even have a low or moderate positive effect on several meat quality traits (Reverter et al., 2003; Wolcott et al., 2009). Based on the findings in beef cattle, there is a possibility that selecting for improved growth rate could have a negative effect on some meat quality traits in dairy cattle. However, information on genetic relationships in dairy breeds is needed before any conclusion can be drawn. Meat quality traits are not currently directly taken into account in the pricing system for cattle carcasses in Finland, and no routinely collected field data on these traits exist.

Due to this lack of direct economic incentives to improve meat quality traits, their inclusion in the breeding goal for FAy seems unlikely in the near future.

The inclusion of smaller LW of cows in the breeding goal had a bigger positive impact on the profit of the breeding program than the inclusion of the RFI trait group to improve feed efficiency in production systems where growth and carcass traits are subject to selection. The body index containing several linear conformation traits (e.g. stature, body depth, and chest width), which have relatively strong genetic correlations with LW of cows (e.g. Veerkamp and Brotherstone, 1997; Vallimont et al., 2011; Banos and Coffey, 2012), is published for RDC, but excluded from the current NTM index. Banos and Coffey (2012) showed that linear conformation traits could be used for predicting LW of cows rather accurately at the phenotypic and genetic merit levels. Since large-scale recording of actual LW of cows is not necessarily needed, selection for LW of cows would be possible to implement immediately. In addition, the costs for measuring LW of cows are likely to be lower than for RFI. However, it should be pointed out that selecting for milk yield concurrently with preventing an increase in LW of cows is associated with a risk of simultaneously selecting for a lower body condition score and a greater negative energy balance of cows (e.g. Veerkamp, 1998). Therefore, the inclusion of LW of cows in the breeding goal should be carried out with caution, for example, by selecting for LW that is adjusted for body condition score (Veerkamp, 1998) or by using a restricted selection index (Kempthorne and Nordskog, 1959) to avoid unwanted genetic changes.

The results of this thesis showed that the inclusion of LW of cows alone in the breeding goal would be unprofitable, whereas the inclusion of the RFI traits group would increase marginally the profit of the breeding program. The latter is in line with the findings of Gonzalez-Recio et al. (2014) who also observed only a small increase in the profit of the breeding program (2.4%) when adding RFI in growing heifers and lactating cows to the Australian dairy cow breeding goal. Based on our results, selecting for RFI traits could be a more beneficial option compared with selecting for LW of cows, although with only a small effect on the profitability to improve feed efficiency in production systems that exclude growth and carcass traits from the breeding goal. By definition, RFI is at least phenotypically independent of growth and other traits that are used to predict it (Pryce et al., 2014b). However, information on genetic relationships between RFI and other economically important traits in dairy cattle is still limited. Therefore, more information on these relationships is needed so that the consequences of selection for RFI can be evaluated more carefully before considering the inclusion of RFI traits in the breeding goal.

The costs of measuring RFI during a performance test of young bulls did not substantially affect the total costs of the breeding program (II). However, the initial investments needed for constructing suitable testing facilities in performance test stations were not taken into account. In addition, an indicator trait for feed efficiency in cows that is possible to measure in commercial herds at a low cost is still widely under investigation. Thus, also these recording costs were excluded from the costs of the breeding program. However, according to the results (II) the

economic response achieved by selecting for RFI traits allows that additional discounted costs related to measuring a new indicator trait in cows could be 5 €/cow for investment period before the profit of the breeding program becomes negative.

In this thesis, RFI traits were incorporated into the breeding goal (II) by using correlated indicator traits and genomic selection that have been proposed to be the most promising cost-effective selection methods for RFI (Egger-Danner et al., 2015). McParland et al. (2014) suggested that RFI in lactating cows could be predicted based on the mid-infrared spectroscopy analysis of milk samples. Other suggested indicators for RFI include rumen activity (Fogh et al., 2013) and measures based on feed, feces, and urine samples (Egger-Danner et al., 2015). The review by Pryce et al. (2014b) summarized the few published studies that have estimated the accuracy of genomic selection for RFI to be around 0.4 in dairy and beef cattle. In addition, Pryce et al. (2014a) showed that GEBVs estimated in growing heifers could be used for selecting cows for RFI with a moderate accuracy of genomic prediction (0.27). While showing that selection for RFI based on measurements in growing heifers should lead to improved RFI in lactating cows, Pryce et al. (2014a) also highlighted the advantages of measuring RFI in growing heifers because there are no complications with lactation. However, more information on the most suitable indicator traits as well as on the accuracy of genomic selection for RFI in the RDC population is needed before the most cost-efficient method for measuring feed efficiency and its total costs in the Nordic dairy cattle breeding program can be determined.

4.2.3 SENSITIVITY TO CHANGES IN ECONOMIC CONDITIONS

The sensitivity of the profitability of including additional traits in the breeding goal to changes in the economic conditions was investigated to assess whether the results (II) are applicable under different conditions. The use of economic values that were derived by applying a decreased producer price of milk (Sensitivity 1, II) substantially reduced the monetary genetic gain in milk production traits, and consequently, the discounted profit of the breeding program (-22.9%) (Tables 5 and 6). However, the observed differences in monetary genetic gains in other trait groups were small since, despite having a lower economic value, milk production traits remained most influential compared with other traits. In 2014, Russia imposed an embargo on imports of certain agricultural products from the EU, USA, Canada, Australia, and Norway (EPRS, 2016). This embargo has had substantial negative effects particularly on the profitability of the Finnish dairy production sector, as Russia has been one of the major export destinations for Finnish dairy products. Another factor affecting the profitability of milk production, and thus, producer prices of milk, is the EU milk quota abolition implemented in 2015. The liberalization of the European milk market has already led to increased milk production in the EU (European Commission, 2016) and a more market-orientated dairy sector. These changes in economic conditions will likely lead to reduced revenues from milk sales on dairy farms, which would shift the selection pressure

and response only marginally from milk production traits mostly towards RFI traits and LW of cows with the given breeding goal.

With the economic values derived applying increased feed prices (Sensitivity 2, II), the response to selection in production traits was reduced (Table 5). In contrast, the response to selection increased in traits associated with feed efficiency (LW of cows and RFI traits), as expected. In general, increasing requirements to mitigate the environmental impact of livestock production will likely lead to the implementation of different regulations for livestock production and consumption of animal-based food products, such as environmental taxes on animal products or subsidies favoring more environmentally sustainable livestock production (Gerber et al., 2010). Considering the effects of these possible regulations on the breeding goals for dairy cattle, the economic values of traits connected to the potential to mitigate GHG emissions should increase in the future if environmental costs are included in the milk and beef pricing systems. Therefore, even though the results of this thesis generally showed only moderate or marginal economic values and expected responses for feed efficiency related traits, improving the efficiency to convert feed into milk and beef will likely become a more important future breeding goal.

Because the economic values (II) were derived under the economic conditions where beef production was unprofitable, stillbirth and birth weight had economic values that favored a decrease in the number of fattening surplus animals and an increase in birth weight of calves. However, from an ethical point of view a deterioration in traits connected with animal welfare should be avoided in a breeding program. Therefore, we investigated the subjective modification of the breeding goal to prevent undesired genetic changes in terms of the biological goal. In this investigation, the economic values of stillbirth and birth weight were set to zero in the selection index (Sensitivity 3, II). The use of this selection index resulted in an annual genetic change close to zero in stillbirth and a small genetic change in birth weight (towards the biological breeding goal of lower birth weight) with a slightly reduced overall profit of the breeding program (-0.1%) (Table 6). This situation was as expected since the subjectively modified breeding goal does not usually lead to maximal profit. In this thesis, the economic values were derived by only taking into account the direct economic values of traits. However, to obtain sustainable and socially acceptable milk and beef production, the breeding goal should be modified so that the deterioration of functional traits is avoided by taking into account also the non-economic values of traits. The subjective modification of the breeding goal is a common practice in the Nordic dairy cattle breeding programs where a substantial emphasis is given to health and fertility traits (Oltenacu and Broom 2010; NAV, 2013).

4.2.4 SENSITIVITY TO CHANGES IN GENETIC CORRELATIONS

Due to lack of information, the correlations between RFI traits and other studied breeding goal traits were set to zero in the reference assumptions (II). However, at

least some of the studied breeding goal traits are likely correlated with RFI. Recently, Connor (2015) summarized the results of earlier studies that have estimated genetic and phenotypic correlations between RFI and other traits in growing and lactating dairy cattle. In these summarized studies, there were mainly no correlations available between RFI and the traits evaluated in this thesis. In addition, if correlations were found they were not statistically significant or consistent. However, a few published studies (Vallimont et al., 2013; Gonzalez-Recio et al., 2014) have indicated an antagonistic – albeit not significant – relationship between RFI and fertility.

Given that fertility is a trait of worldwide concern and also an important breeding goal in the Nordic countries, the sensitivity of selection response to the possible antagonistic genetic correlation between RFI and fertility traits (-0.3) was evaluated (Sensitivity 4, II). In this sensitivity analysis, a minor decline in the monetary genetic gain in fertility traits (-1 €/cow and investment period) was found. In contrast, the monetary genetic gain in RFI traits increased, resulting in a 2.6% higher discounted profit of the breeding program than in the reference situation (Tables 5 and 6). This was because the undesired genetic change in fertility traits was observed even when assuming no correlation between RFI and fertility. Consequently, when the antagonistic genetic correlation between traits was applied the declined genetic merit for fertility increased genetic response in RFI traits. In the study by Gonzalez-Recio et al. (2014) where an antagonistic correlation of -0.13 between RFI and fertility was found in Holstein cows, the inclusion of RFI in the Australian selection index led to improved feed efficiency with only a slightly lower selection response in fertility. Therefore, the results of the study by Gonzalez-Recio et al. (2014) and this thesis suggest that even if there is an antagonistic relationship between RFI and fertility, simultaneous selection for these traits by using a multi-trait selection index could improve feed efficiency with only a negligible impact on fertility, assuming that the correlation between the traits is relatively weak. However, enough emphasis should be placed on fertility traits in a selection index to avoid unwanted genetic changes.

Because the dairy cattle industry has traditionally focused on improving the profitability of milk production, little attention has been paid to the genetic components of different growth traits associated with beef production in dairy cattle. In this thesis, the genetic correlations between LW of cows and growth traits were based on the study by Groen and Vos (1995) because their trait definitions were relatively close to the definitions of the studied traits (I, II). Groen and Vos (1995) estimated a very strong (>0.9) genetic correlation between average daily gain in calves and live weight of heifers after first calving. However, the growth trait definitions in their study were somewhat different than in this thesis. Therefore, slightly lower genetic correlations between growth traits and LW of cows were applied in this thesis than estimated by Groen and Vos (1995). In addition, a few studies have found only moderate genetic correlations (0.5-0.6) between carcass or LW of cows and carcass weight of growing animals in the Nordic dairy breeds (Liinamo et al., 2001; Closter et al., 2015), indicating that genetic background of growth traits in growing and mature animals can to some extent be different

(Closter et al., 2015). In general, one likely explanation for the differences in the results of these above-mentioned studies is that genetic correlations between growth traits are strongly dependent on the trait definitions.

Given the importance of genetic correlations when studying the simultaneous inclusion of growth traits and LW of cows in the breeding goal, we assessed the sensitivity of the results to the correlations between growth traits (ADG of animals in the rearing and fattening periods) and LW of cows (Sensitivity 5, II). In this sensitivity analysis, an increase of 1.2% in the discounted profit of the breeding program was observed with 20% lower genetic correlations between given traits (Table 6). This resulted from increased genetic responses in LW of cows and growth traits with only slightly decreased responses in production and functional traits (Table 5). In addition, a minor desired economic genetic gain in LW of cows was obtained in contrast to the reference situation. On the basis of these results, the genetic correlations between growth traits and LW of cows do not substantially affect the total profit of the breeding program. However, with simultaneous selection, genetic improvement in growth traits without genetically increasing LW of cows could be achieved if the genetic relationships between the traits are weaker than in the reference assumptions.

Several simulation studies evaluating alternative breeding schemes have assessed an expected genetic response only in some of the most important traits or combined trait groups such as functional and production traits (e.g. Thomasen et al., 2014; Hansen Axelsson et al., 2015). However, very few have evaluated several single traits. One drawback of studies concentrating only on the most important traits or combined trait groups is that important information on unwanted correlated changes in single traits can be lost. Even though studies evaluating trait groups show the genetic change in each trait group, the comparability of the results with different total merit indices that usually include numerous traits can be expected to be weak. Including several traits in a simulation study reflects practical breeding programs better and provides results that are easier to utilize. However, the genetic correlations between single traits studied in practical breeding programs are often at least partly unknown and estimated with a high level of uncertainty or not estimated in the affected population.

In this thesis, the studied breeding goals consisted of 12 to 21 different traits, leading to a very complex correlation matrix among traits, wherein a substantial proportion of correlations was unknown or estimated in a different dairy cattle population. However, when considering an option to study only trait groups, an assumption that genetic and phenotypic correlations are the same between each trait belonging to one group and each trait belonging to another group should be made. This assumption can be considered to be even stronger than setting unknown correlations equal to zero between some single traits. Despite the fact that some relationships between the studied traits were unknown, proper heritability estimates as well as economic values used for the studied traits provide results that show the relative importance of all traits in the breeding goal. These results clearly indicate that the economic benefits achieved from selecting for RFI traits would be only marginal. By contrast, the inclusion of growth traits together with LW of cows

in the breeding goal would be the most cost-efficient way to improve the profitability and environmental efficiency of the combined milk and beef production systems.

Due to several unknown genetic relationships between traits, it should be mentioned that there is a risk that selection for a new trait could result in an undesired correlated change in some other trait of economic or ethical importance. Therefore, before any recommendations to include new traits in the breeding goal can be made, the genetic correlations between all studied additional traits and current breeding goal traits must be obtained to determine the overall consequences of selection. Lack of some information is not necessarily an obstacle for the inclusion of new traits in the breeding goal, providing that the changes in animal characteristics are monitored regularly, ensuring the early identification of possible unfavorable trends. Attention should especially be paid to potential antagonism between RFI and fertility.

4.3 STRATEGIES TO IMPROVE BEEF PRODUCTION FROM DAIRY HERDS

4.3.1 CROSSBREEDING

The effect of different crossbreeding rates on beef production from dairy herds was studied under Scenario 1 (III). With the reference replacement rate of 35% and no use of sexed semen, the annual beef production increased by 0.4 million kg CW (0.5%) for each 5-percentage-unit increase in the crossbreeding rate. Increasing the proportion of crossbred calves from the current (5%) to the theoretical maximum (18%) resulted in 1.0 million kg CW (1.2%) increase in annual beef production and 0.3 units improvement in the average carcass conformation score. In addition, this increased crossbreeding rate would enable the annual reduction of -7.1 million kg of carbon dioxide equivalents (CO_2-eq) (-0.5%) in GHG emissions from beef production when dairy and suckler beef production systems were considered to be alternatives to each other.

Increasing the use of crossbreeding with beef bulls in dairy herds would enable a fast increase in beef production without affecting the genetic gain in traits under selection in dairy cattle. In addition, several studies have found a better growth performance and carcass quality with either similar or lower feed intake in dairy-beef crossbred animals compared with purebred dairy animals reared for beef production (e.g. McGee et al., 2005; Cummins et al., 2007; Huuskonen et al., 2014). Therefore, increasing the use of crossbreeding should improve the profitability of beef production originating from dairy herds. This is supported by the results of this thesis (I), where the more valuable carcasses and faster growth of dairy-beef crosses led to a 1.5% higher net profit of the production system when 10% of dairy cows were inseminated with Limousin bulls relative to no crossbreeding. Similar results

have been reported by Wolfová et al. (2007b), who found an improved economic efficiency of a dairy production system resulting from the use of Charolais bulls in dairy herds to produce slaughtered crossbred animals. Currently, in Finland many dairy farms sell surplus calves to specialized fattening farms. Even though the price paid for a crossbred calf is higher than that for a purebred dairy calf, the price difference is relatively small. Moreover, because dairy farmers want to ensure a sufficient number of heifers available as herd replacements, increasing the use of crossbreeding is challenging under the current Finnish economic and production conditions.

4.3.2 USE OF SEXED SEMEN

The changes in annual beef production, annual GHG emission reductions, and average EUROP conformation classes for Scenarios 2 to 4 (III) are summarized in Table 7. The use of Y-sorted semen with an increased crossbreeding rate (Scenario 2, III) was the most efficient option for enhancing beef production, and consequently, for mitigating GHG emissions. However, the profit calculation (III) showed that the use of Y-sorted semen in crossbreeding is unprofitable under the Finnish price assumptions in 2013. This was due to the fact that the price difference between a crossbred male and female calf was too small to cover the extra costs arising from the higher price and lower conception rate with sorted sperm.

The use of X-sexed semen to produce replacement heifers with an increased crossbreeding rate of 18% (Scenario 3, III) reduced annual beef production in all studied cases. The effect of applying the highest possible crossbreeding rate at each studied level of the use of X-sexed semen was also assessed. In this evaluation, annual beef production slightly increased (0.4 million kg CW, 0.5%) and GHG emissions decreased (-2.8 million kg CO_2-eq, -0.2%) only at the lowest level of the use of X-sorted semen (10% of inseminations carried out with X-sorted semen enabling a crossbreeding rate of 25%). This was due to the fact that a relatively low slaughter weight of crossbred heifers resulted in a lower average slaughter weight of crossbred animals than of purebred dairy bulls. Therefore, an increased proportion of slaughtered crossbred animals did not cover the reduced amount of beef from slaughtered dairy bulls when more than 10% of the inseminations were done with X-sorted semen. In addition, the use of sexed semen with a lower conception rate reduced the total number of slaughtered animals.

The results of this thesis indicate that the use of X-sexed semen is an inefficient alternative to increase beef production with the given slaughter weights. However, the genetic progress in the dairy population that could be achieved by using the studied production practices was not taken into consideration in this thesis (III). It should be pointed out that the use of X-sorted semen to produce replacement heifers would increase the selection intensity on cow dams, and consequently, the genetic gain in the population, since an annual genetic response in a population depends on the selection intensity in each selection path (Rendel and Robertson, 1950). This is supported by the simulation study by Sørensen et al. (2011) who

estimated that the annual genetic gain of the entire population would increase by 2-3% when using sexed semen in the best cow dams or in all heifers. Sørensen et al. (2011) also studied the effect of the use of sexed semen on a genetic lag defined as an average difference between the genetic level of active sires and commercial cow dams over a simulation period from year 10 to year 30. They found that the use of sexed semen would reduce the genetic lag by 6-14%, and on the basis of this could result in a relatively fast improvement in dairy farm profitability.

Table 7 *Changes in annual beef production, annual greenhouse gas (GHG) emission reductions and average carcass conformation scores for different scenarios with 18% of calves born from crossbreeding (III).*

Scenario[1]	Beef production, million kg CW (%[2])	GHG emissions[3], million kg CO_2-eq (%[4])	Carcass conformation[5], score
Scenario 2			
20%	1.29 (1.59)	-9.30 (-0.61)	4.33
40%	1.60 (1.97)	-11.52 (-0.76)	4.35
60%	1.91 (2.35)	-13.75 (-0.91)	4.38
80%	2.22 (2.73)	-15.98 (-1.05)	4.41
Scenario 3			
10%	-0.20 (-0.25)	1.46 (0.10)	4.27
20%	-1.39 (-1.71)	10.00 (0.66)	4.23
30%	-2.57 (-3.17)	18.53 (1.22)	4.19
40%	-3.76 (-4.63)	27.06 (1.78)	4.15
Scenario 4			
30%	0.19 (0.23)	-1.34 (-0.09)	4.34
25%	-0.61 (-0.75)	4.40 (0.29)	4.39
20%	-1.41 (-1.75)	10.13 (0.67)	4.43

[1]Scenario 1. Different levels of the use of Y-sorted sperm in crossbreeding varying from 20% to 80%,
Scenario 2. Different levels of the use of X-sorted sperm to produce replacement heifers varying from 10% to 40%,
Scenario 3. Different percentages of first lactation cows varying from 20% to 30%.
[2] Compared with total domestic beef production in 2012.
[3]A negative value for a GHG emission reduction describes the potential to mitigate GHG emissions from beef production given that dairy and suckler beef production systems are alternatives to each other.
[4]Compared with the estimated total GHG emissions from beef production in 2012.
[5]The average EUROP conformation class in the reference scenario is 4.0. For carcass conformation, 15 is the best class and 1 is the worst class.

The use of sexed semen to produce replacement heifers could potentially improve the profitability of dairy farms if the economic value of an increased genetic level of a herd would cover the extra costs of sorted semen caused by its higher price and lower conception rate. In the Danish economic and production conditions for the year 2009, Ettema et al. (2011) found only a slightly increased gross margin per cow-year (0.7%) with repeated inseminations using sexed semen in 50% of the best heifers selected on the breeding value for milk yield. In the simulation study by

Kärkkäinen (2014), the economic benefits of using X-sorted semen and increasing crossbreeding rate in Finnish dairy herds were evaluated. When all replacement heifers were produced with X-sorted semen and considering a single round of selection, the genetic merit of the herds increased by 0.8 NTM index points per generation. However, even though the economic values of the increased genetic merit and crossbreeding rate were accounted for, the average net profit of the dairy farms decreased by 14 € per cow and generation. Therefore, based on the results of this thesis and the study by Kärkkäinen (2014), the profitability of using X-sorted semen and its potential to enhance dairy beef production are weak under the present price and production assumptions in Finland.

4.3.3 REDUCED REPLACEMENT RATE

In Scenario 4 (III), a minor increase in annual beef production and a decrease in GHG emissions were achieved when applying a reduced replacement rate of 30% together with an increased crossbreeding rate of 18% (Table 7). However, with all lower replacement rates annual beef production declined. When the studied replacement rates varied from 30% to 20% using a maximal crossbreeding rate in each case, annual beef production increased from 1.1 to 1.3 million kg CW (1.4 to 1.6%) and GHG emissions from beef production decreased from -7.9 to -9.6 million kg CO_2-eq (-0.5% to -0.6%) compared with GHG emissions from a similar amount of beef from suckler cow systems. An improved average carcass quality was observed for all lower replacement rates. Due to the smaller proportion of meat from culled cows, this improved carcass quality was achieved even when not accounting for the effect of crossbreeding on the average carcass conformation. The revenues from the sale of meat can thus be expected to increase when reducing the replacement rate even with the current crossbreeding rate. In general, the results of this thesis indicate that reducing a replacement rate of dairy herds is a potential option to enhance crossbreeding, and thus, to increase domestic beef production. However, an increase in beef production was achieved only when the crossbreeding rate was close to its theoretical maximum.

A lower replacement rate in dairy herds could potentially improve the efficiency of milk production through several mechanisms: the number of unproductive heifers needed to be raised annually decreases, the proportion of first lactation cows declines, which favors more productive animals in later lactations, resulting in increased milk output per cow, and selection intensity in a female selection path increases, leading to faster genetic gain in the population. In addition, a reduced number of replacement heifers would mitigate GHG emissions from the unproductive part of a dairy herd from an environmental point of view (Wall, 2010). However, when considering combined milk and beef production systems, a reduction in the replacement rate only shifts the contribution of the livestock sector's GHG emissions from dairy production towards beef production. This is due to fewer emissions from replacement heifers being allocated to milk production, while more emissions from surplus heifers are allocated to beef production. In

consequence, the total emissions from combined dairy and beef production are not likely to diminish considerably. As the conclusions depend on the chosen perspective (milk, beef, or combined production system), the environmental effects of milk and beef production should be evaluated simultaneously when assessing options for mitigation of GHG emissions, especially in countries where beef is mainly produced as a by-product of milk.

4.3.4 COMBINED PRODUCTION STRATEGIES

The changes in annual beef production and GHG emission reductions for the combination of the most promising scenarios (Scenarios 1, 2, and 4, III) with the maximal rate of calves born from crossbreeding are presented in Figure 3. Among these combinations, the highest achieved increase in annual beef production was 5.1 million kg CW (6.2%) when a replacement rate of 20%, a crossbreeding rate of 53%, and use of Y-sorted semen of 80% in crossbreeding were applied. Even when combining the most potential production strategies, the achieved improvements in Finnish beef production found in this thesis were relatively small, as the above-mentioned highest increase represents only 24% of the amount of beef imported to Finland in 2012. However, it should be taken into consideration that any increase in domestic beef production could reduce beef imports. Reducing beef imports could lead to a global emission saving given that Finnish beef production based on dairy animals can be expected to generate fewer GHG emissions than imported beef that is mostly produced in specialized cow-calf production systems.
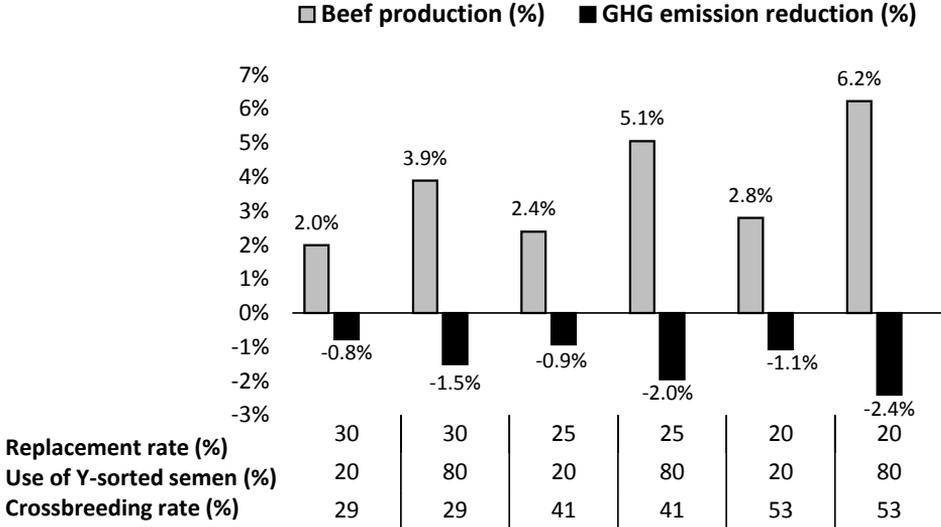

Figure 3 Changes in annual beef production (in % of reference beef production) and greenhouse gas (GHG) emission reductions (in % of the reference GHG emissions) for the combination of Scenario 2 (use of Y-sorted semen in crossbreeding) and Scenario 4 (reduced replacement rates) together with a maximal rate of calves born from crossbreeding in each case.

4.4 CURRENT BREEDING GOAL AND FUTURE DEVELOPMENTS

The economic evaluation of the Nordic breeding goal for RDC has shown that genetic improvement in growth and carcass traits has a positive effect on farm profit in the Nordic dairy cattle production systems (Kargo et al., 2014). When considering the relative economic importance of different sub-indices in the NTM index for RDC, a comparatively high economic weight (0.11 relative to the weight for the yield index) has been found for the growth index including different growth and carcass traits (Pedersen et al., 2008). Substantially higher relative economic weights were observed only for the yield, fertility, and udder health indices. However, growth and carcass traits have been excluded from the current NTM index for RDC because of the subjective modification (NAV, 2016a). The correlation between the growth and current NTM indices for RDC and Holstein is favorable (NAV, 2015), which should lead to improved growth and carcass quality when selection is based on the NTM index. This, however, has not been shown in the genetic trend of the growth index, which has been negative in Finnish Holstein and almost unchanged in FAy during the last few decades (NAV, 2016b). The weak selection pressure on beef traits in dairy breeds is a considerable limitation if the aim is to increase beef production based on dairy herds to meet the national demand for beef in Finland.

One of the main goals of this thesis was to find the most potential traits for inclusion in the breeding goal for the combined production systems to improve the sustainability and productivity of both milk and beef production. At this point, it should be noted that the results are not fully comparable with the current breeding goal for FAy because the model and trait definitions differ from those used in the NTM index. Moreover, the structure of the Nordic breeding scheme has changed recently more towards a pure genomic system, as the proportion of bull sires that are genotyped young bulls without daughter records has increased. However, the results here provide a good starting point for developing the current breeding goal for FAy or other dairy breeds used to produce both milk and beef. The development of the breeding goal to better reflect the current and future needs in Finnish and Nordic production conditions could ensure that FAy as well as other breeds in the RDC population will remain a competitive alternative to the Holstein breed on both Nordic and international markets.

In the overall evaluation of the economic, ethical, and environmental advantages that could be achieved when implementing the production and breeding practices investigated in this thesis, the following viewpoints should be noted. Firstly, from an economic point of view, fattening of surplus dairy calves on specialized fattening farms is unprofitable under Finnish production conditions (Karhula and Kässi, 2010; III). Therefore, improving the beef production potential of fattening dairy calves is one of the key factors that could improve the profitability, and consequently, ensure the continuity of Finnish beef production. In the profit calculations carried out in this thesis (III), about three times better net profit was found for beef production based on dairy calves than for beef production from

suckler cow systems mainly because of the high maintenance costs of a suckler cow herd. Therefore, increasing beef production originating from dairy herds is likely to be the most profitable option if the aim is to achieve self-sufficiency in beef.

Secondly, from an ethical viewpoint, practices in the livestock sector that are increasingly perceived by consumers as unethical are likely to change the relative demand for different livestock products. These changes in demand can have a large impact on the profitability and continuity of milk and beef production in the future. Currently, in many EU countries (excluding Finland), a common practice in specialized dairy production systems is to cull surplus calves soon after birth or use them for veal production despite the fact that a public concern regarding the welfare of calves in veal production has arisen (Harper and Henson, 2001). Improving beef production potential of fattening dairy animals through selection for beef traits would increase the market value of surplus purebred dairy calves. This could ensure that the effective use of dairy calves in Finnish beef production continues also in the future.

Lastly, from an environmental point of view, beef production based on dairy herds has been shown to generate fewer GHG emissions per unit of meat than beef production from suckler cow systems (e.g. Nguyen et al., 2010; Gerber et al., 2013). This is mainly because emissions from dairy herds are allocated to both milk and beef, whereas emissions from suckler cow herds are allocated to only meat (Gerber et al., 2013). In addition, even though increasing productivity of dairy cows has been proposed to mitigate GHG emissions per unit of milk through the "dilution of maintenance effect" (Capper et al., 2009; Wall, 2010), the current specialization of the dairy sector will not likely reduce the overall GHG emissions from milk and beef production when considering constant production levels (Flysjö et al., 2012; Zehetmeier et al., 2012). This is due to generally a higher milk yield per cow leading to a lower number of dairy cows, reducing the beef supply from dairy animals. To maintain the prevailing production levels, the reduced amount of beef is likely to be compensated for by increasing beef production from specialized beef production systems with a more negative environmental impact. Zehetmeier et al. (2012) showed that increasing milk yield per cow would lead to higher total GHG emissions if milk yield was already relatively high given the constant milk and beef production outputs. Therefore, in Finnish cattle production with high-producing dairy cows and beef production that falls below the consumption level, the further specialization of milk production could potentially lead to increasing total GHG emissions if the ratio of meat and milk demand is to remain at the present level.

Future trends in the consumption of milk and meat will affect the overall environmental effects of the specialization in cattle production systems. In general, both milk consumption and meat consumption have increased, especially in developing countries, and this growth is expected to continue (FAO, 2009). However, in Finland, as well as in many other industrial countries, beef consumption has somewhat stabilized, while pork and especially poultry meat have increased in importance (Luke, 2016). In addition, the Finnish trend in milk consumption is decreasing, although the importance of some other dairy products has grown (Luke, 2016). Growing consumer awareness in industrial countries about

human health, ethical, and environmental issues will influence the demand for different livestock products (Thornton, 2010). This is likely to affect particularly beef consumption because it has been associated with several human health problems and negative environmental impacts in numerous studies (e.g. Pan et al., 2011; Tilman and Clark, 2014; Springmann et al., 2016). When considering possible changes in consumption patterns, the further specialization of milk production might be advantageous in terms of GHG emission reductions if the consumption level of beef declines substantially relative to the consumption level of milk. However, also in this case, the specialization would mitigate GHG emissions only up to the point where reduced beef supply from dairy animals is not compensated by increasing specialized beef production.

The several benefits of improving dairy beef production highlight the importance of developing the current dairy sector towards systems that more efficiently and profitably produce both milk and beef. These benefits together with the results of this thesis showing that selection for growth and carcass traits could improve the profitability of the combined milk and beef production systems lead to the conclusion that inclusion of beef traits in the Nordic breeding goal for RDC should be considered. In addition, the simultaneous prevention of an increase in LW of cows seems advisable. As genetic evaluations for growth, carcass, and linear conformation traits are already routinely calculated for RDC, selection for beef traits and LW of cows could readily be implemented without additional breeding program costs.

A potential option for achieving an increase in beef production without affecting genetic gain in breeding goal traits would be to increase the use of crossbreeding in dairy herds. Although the rate of crossbreeding could be substantially increased with the current replacement rate, only a relatively small proportion of cows can be inseminated with beef semen to ensure a sufficient number of heifers available as herd replacements. Therefore, even with an increased rate of crossbreeding, a substantial proportion of slaughtered animals would still be purebred dairy animals, highlighting the importance of selecting simultaneously for improved growth and carcass characteristics in dairy breeds. Reducing the herd replacement rate would be an option for enhancing the potential for crossbreeding while simultaneously increasing the dairy farm income as a result of, for instance, lower replacement costs. Thus far, the price difference between crossbred and purebred dairy calves has not been sufficient to motivate farmers to increase the use of crossbreeding in their herds. Therefore, incentives that give clear benefits to dairy farmers from producing crossbred calves for beef production are needed in order to improve Finnish beef production based on dairy herds.

5 CONCLUSIONS

This thesis studied different breeding and production strategies for improving the profitability and environmental efficiency in dairy herds considering both dairy and beef production. The results show that the profitability of Finnish dairy farms is strongly dependent on agricultural subsidies. Especially the profitability of beef production is weak, which limits the possibilities for increasing beef production from dairy herds to meet the domestic demand. Increasing beef production originating from combined dairy and beef production systems rather than suckler cow systems is supported by its economic and environmental advantages; producing beef as a by-product of milk is more profitable based on the profit calculations of this thesis and has also been found to generate fewer GHG emissions per unit of meat. Therefore, to ensure continuity and sustainability of Finnish beef production in the future, practices that improve the profitability and productivity of beef production from dairy operations are needed.

The economic values of feed efficiency traits along with several production and functional traits in Finnish milk production indicate that the current breeding goal of FAy should be re-evaluated. Moderate relative economic values were found for several traits not included in the current breeding goal: daily gain of fattening animals and growing replacement heifers, RFI trait group, and LW of cows. However, the relative economic importance was only marginal for carcass traits. Inclusion in the breeding goal of a better growth performance of fattening animals and growing replacement heifers, while preventing higher LW of cows was the most promising option to improve the profitability of the combined milk and beef production systems. Since beef production is currently below consumption in Finland, the inclusion of these traits in the breeding goal for dairy breeds should be considered. Because data from commercial slaughterhouses is routinely collected for the genetic evaluations of growth and carcass traits, selection for beef traits could readily be implemented without additional operational costs.

Among the studied feed efficiency-related traits, selecting for lower LW of cows could be a more beneficial option than selecting for RFI traits to improve feed efficiency with a breeding goal that includes growth and carcass traits. This finding is supported by the fact that costs for measuring LW of cows are likely to be lower than for measuring RFI traits. In addition, selection for smaller LW of cows could be implemented immediately by, for instance, using highly correlated linear conformation traits that are already routinely evaluated in the current breeding program. However, the inclusion of LW of cows in the breeding goal should be carried out with caution since selecting for milk yield while simultaneously preventing an increase in LW of cows is associated with antagonistic side-effects on energy balance and body condition score of cows.

Adding LW of cows alone to the breeding goal had a negative effect on the profit of the breeding program with the breeding goal that excludes growth and carcass traits. Therefore, the inclusion of RFI in the breeding goal could be more profitable despite giving only marginal economic benefits for production systems where

growth and carcass traits are not subject to selection. However, more information on the genetic correlations between RFI traits and other breeding goal traits as well as on the most cost-effective selection methods for feed efficiency is needed before firm conclusions can be made on the consequences of selection for RFI traits.

The increased use of crossbreeding of dairy cows with beef bulls by using Y-sorted beef semen would be the most efficient way to improve beef production from dairy herds, and consequently, to mitigate GHG emissions from beef production. Under the current producer prices and production conditions, increasing the rate of crossbreeding would be challenging without practices that would ensure a sufficient number of replacement heifers or clear economic benefits from producing crossbred calves to dairy farmers. To increase the rate of crossbreeding, a decrease in the replacement rate of dairy herds showed more promise for enhancing beef production than the use of X-sorted semen. However, reducing replacement rate would enhance beef production only if the use of crossbreeding increases substantially. In order to evaluate the overall benefits of reducing the herd replacement rate, its several other positive impacts, such as reduced replacement costs, on the dairy farm income should also be considered.

Increasing national self-sufficiency plays an important role in ensuring future food security. The current global tendency towards specialized dairy and beef production systems will likely reduce beef production from dairy herds, potentially leading to an increasing harmful environmental impact of livestock production. The results here suggest that combined milk and beef production would provide the most viable and sustainable way to achieve self-sufficiency in beef while maintaining sufficient milk production in Finland. Therefore, the current dairy production systems should be developed towards systems that efficiently produce both milk and beef rather than moving towards increased specialization.

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