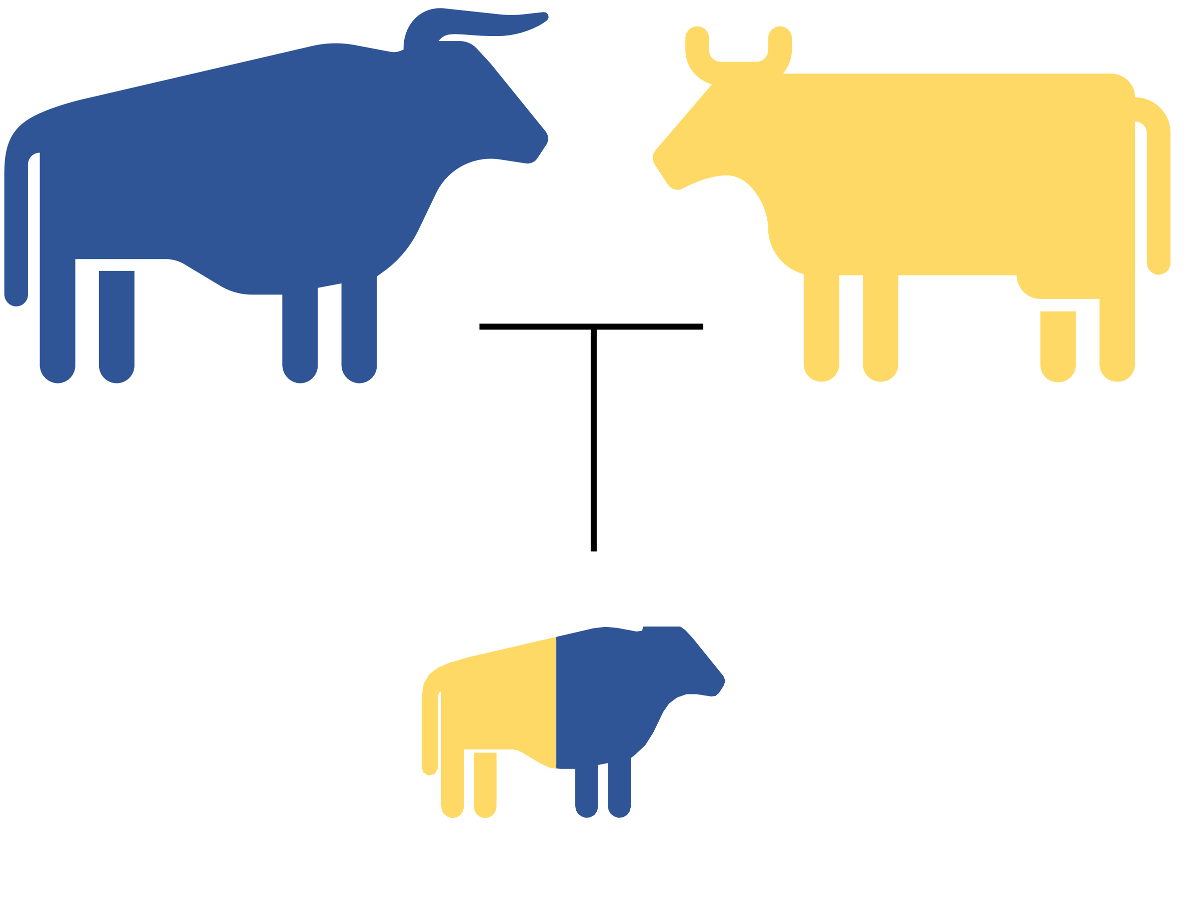
Effects of crossbreeding dairy cows with Angus sires on Swedish forage-based beef production systems with bulls



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European Engineer Degree Livestock Production

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PREFACE

Being part of the European Engineer Degree - dual certificate from Aeres University of Applied Sciences Dronten in the Netherlands and École Supérieure d'Agricultures Angers in France -, I had the opportunity to go in Sweden for a 3-month internship. I landed in Skara at the Swedish University of Agricultural Sciences.

SLU, ranked among the world's best agricultural universities, was created in 1977 and is mainly located in Uppsala, Alnarp, Umea and Skara with research stations, experimental and educational facilities. This institution is divided in 33 departments and units, involving research, education and environmental assessment. SLU creates knowledge (1800 articles and reviews in 2019) contributing to a sustainable development and Agenda 2030 from the United Nations which aims to reduce poverty, achieve food security, improve education and health, mitigate climate change and achieve a sustainable use of sea and land-based ecosystems. The interest in taking part in the EU horizon 2020 framework is important. By the way, SLU and the European Union use to collaborate, and this thesis is involved in a project launched by the EU. The project SusCatt was possible by funding from SusAn, an ERA-Net, co-funded under European Union's Horizon 2020 research and innovation programme (https://www.era-susan.eu/), Grant n°696231. Other financiers were The Swedish Research Council Formas, Västra Götalands Regionen Grants n°RUN-2018-00137-8, Interreg ÖKS Grant n°20200994, Agroväst and Nötkreatursstiftelsen Skaraborg. Project SusCatt link: https://www.nibio.no/en/projects/suscatt.

What is more important than feeding the world in a sustainable way? I grew up in a farm located in south of France where my parents have a beef cattle with Aubrac breed. Due to a difficult mountainous climate and following tradition, the farming system is extensive and adapted in its environment (e.g., grass and hay-based diet from native pastures). Animals are kept outdoors in a free grazing system and indoors during our real winters. When finishing animals, only grazing is allowed, without any complement. By the way, they are slaughtered in autumn to ensure a better quality after a long grazing period in spring and summer. I always enjoyed working in this type of system and I think that we should come back as far as possible to a more extensive and sustainable production. In that way, reporting this thesis seems very relevant for me since we need to find solutions to produce more but better for a growing population.

Update: The research questions and objectives (Chapter 1) have been modified from the research proposal and need to be reassessed.

This period and the resulting thesis come to end a great program in these three countries where I learnt so many things and met such nice people. This opportunity was for sure one of the best in my entire life and I feel really grateful and proud to have had it. I want to thank both Aeres and ESA for giving us this opportunity by creating this program. Thanks to our lecturers in Dronten and the quality of their education. I especially thank Jan van Beekhuizen, my thesis coach and our program coordinator together with Jantien Tempert, for their availability and help.

I thank Anders Karlsson, head of the Department of Animal Environment and Health, for having accepted me in the research team, even during these difficult times, but also for his great kindness, his regular presence and his positive mind. By the way, I want to thank all the SLU staff in Skara, as well as the great maintenance team, for the perfect work conditions they gave me and especially Frida, Gunilla and Dannylo. Moreover, thanks to the international team of SLU, especially Dannylo and his wife Larissa with who I spent some of my free time. They are great people.

I wish to attract the light on Elisabet Nadeau, my company coach, for all she brought me, her regular help, availability, joy of living. She gave me the opportunity to work on a big and relevant project. I might not have come in this beautiful country in she had not taken the time to discuss with me when I was late to find an internship due to the sanitary situation. For all of that, thank you so much!

In another hand, special thanks to the Dronten crew, from France and abroad, for all the moments we spent together on the campus, at TLab, at Soos, in the canals or wherever. It was wet with some kilometers of beer but also so great to meet them all and enjoy this amazing Erasmus period in the Netherlands.

Thanks to all my friends and family I was in contact with during my stay, it helped me to stay up to date and to enjoy my Swedish life as well. I am glad that Alex, Flo, Tim, Ulysse and Vianney could face the situation and join me in December to visit the Swedish Lapland and spend Christmas there. It was an amazing experience to end my period in Sweden. Special greetings to Emmaboy for her regular and entertaining conversations during my stay in Sweden.

I really enjoyed the Swedish trip with my parents in October and I was so glad they could visit me for a week. Finally, I thank them as well as my brother Tim once again for who they are and all they did for me. I am sure that I would never have been the same guy without them. I love them so!

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SUMMARY

Over the last decades, the increased demand in beef by the growing population led to an industrialization and intensification of the production systems. This resulted in many issues such as environmental impact, animal welfare, consumers acceptability, resource-use efficiency, growing reliance on edible food. By the way, the European Union launched the SusCatt project to strengthen the sustainability of European beef and milk production by evaluating yields, quality, health and welfare, economics, reliance on edible food, gas emissions, environmental impact and consumers acceptability of a transition to high forage and pasture diets. In Sweden, more than 60% of the beef production originates from dairy cattle since the country is more known as a dairy producer. In another hand, it has been reported that the dairy beef production was environmentally and economically more efficient than suckler cattle beef production. However, the number of dairy cows is decreasing in Sweden since higher individual milk yields are achieved. This results in a lack of calves for beef production. By the way, producing more beef in the current situation led to a growing demand for beef breed semen to produce crossbred animals, expected to be more performant and give greater carcass characteristics. This study examines the advantages from crossing dairy cows with early maturing beef breed sires to produce young bulls in a forage-based diet. The 2 x 2 factorial designed experiment included 69 bulls reared in same conditions in an experimental farm. The effects of two breeds (pure dairy and crossed dairy x Angus) and two feed intensities (high and low) were compared on performance and carcass characteristics, using measurements and recordings from the SLU Götala Beef and Lamb Research Centre and the slaughterhouse in Skövde. It has been reported that using an early maturing beef breed sire on dairy cows had a positive impact on animal performance and carcass characteristics. The 0.154 kg higher average daily gain ($P < 0.001$) resulted in a tendency to an improved feed efficiency. The final liveweight was by 64 kg ($P = 0.002$) and the carcass by 46 kg ($P = 0.001$) heavier when compared to purebred bulls. The carcass characteristics such as dressing percentage, conformation and fatness scores were also significantly improved. Consequently, these results showed the possibility to increase the efficiency and the sustainability of the Swedish dairy beef production by crossing dairy cows with early maturing beef breed sires.

RÉSUMÉ

Durant les dernières décennies, l’augmentation de la demande en viande bovine par la population croissante s’est accompagnée d’une industrialisation et d’une intensification des systèmes de production. Ceci a révélé beaucoup de problématiques telles que l’impact environnemental, le bien-être animal, l’acceptabilité des consommateurs, l’efficacité d’utilisation des ressources, la dépendance croissante aux aliments disponibles pour l’Homme. De ce fait, l’Union Européenne a lancé le projet SusCatt pour renforcer la durabilité de la production européenne de viande bovine et de lait en évaluant les rendements, la qualité, la santé et le bien-être, les facteurs économiques, la dépendance aux aliments comestibles, les émissions de gaz, l’impact environnemental et l’acceptabilité des consommateurs, d’une transition vers des systèmes basés sur les fourrages et le pâturage. En Suède, plus de 60% de la production de viande bovine vient du cheptel laitier, le pays étant plus réputé comme producteur de lait. Par ailleurs, il a été démontré que la production de viande depuis l’élevage laitier était plus efficace sur le plan environnemental et économique que celle provenant de l’élevage allaitant. Cependant, le nombre de vaches laitières diminue en Suède car la production de lait par vache est en augmentation. Ceci s’accompagne d’un manque de veaux disponibles pour la production de viande. Ainsi, produire plus de produits carnés dans cette situation a entraîné une demande croissante en doses de races à viande pour produire des animaux croisés, considérés plus performants et produisant de meilleures carcasses. Cette étude analyse les avantages de croiser des vaches laitières avec des taureaux de race à viande précoce pour produire des taurillons avec une alimentation à base de fourrages. L’expérimentation à 2 x 2 facteurs impliquait 69 taurillons élevés dans les mêmes conditions en ferme expérimentale. Les effets de deux types raciaux (pure laitier et croisé laitier x Angus) et de deux niveaux d’intensité alimentaire (élevé et faible) ont été comparés sur les performances et les caractéristiques des carcasses en utilisant les mesures et les enregistrements provenant du SLU Götala Beef and Lamb Research Centre et de l’abattoir de Skövde. Il a été démontré qu’utiliser un taureau de race à viande précoce sur des vaches laitières avait un impact positif sur les performances de l’animal et les caractéristiques de la carcasse. Le gain moyen quotidien augmenté de 0.154 kg ($P < 0.001$) s’est accompagné d’une tendance concernant une meilleure efficacité alimentaire. Le poids final s’est avéré plus élevé de 64 kg ($P = 0.002$) et le poids carcasse de 46 kg ($P = 0.001$), comparé aux taurillons de race pure. Les caractéristiques de la carcasse telles que le rendement, la conformation et l’état d’engraissement ont été aussi significativement améliorés. Par conséquent, ces résultats ont montré la possibilité d’augmenter l’efficacité et la durabilité de la production suédoise de viande provenant du cheptel laitier en croisant les vaches laitières avec des taureaux de race à viande précoce.

I. INTRODUCTION

1. Global and Swedish beef production context

In only six decades, the world population has increased from three billion to seven and half billion people. Moreover, estimations show that we should be around ten billion people on Earth in 2050 (United Nations, 2017). This evolution is leading to a huge increase in needs. By the way, over the past sixty years, the global meat production, including all types of livestock, has increased considerably. Since 1961, the world production has almost quintupled to represent around 340 million tonnes of meat per year in 2018 (Ritchie, 2017). The European meat production has more than doubled. In another hand, because beef consumption is relatively important in human nutrition, the world beef production has also more than doubled *(Figure 1)*. If Europe is now the third producer of beef (behind United States and Brazil), its production was the biggest in the 1990's before the widespread outbreak of Bovine Spongiform Encephalopathy, commonly known as mad cow disease, and its subsequent effect on consumer confidence.

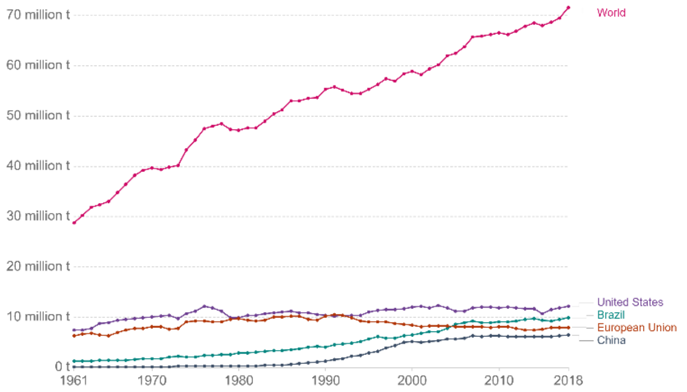

Figure 1 *Timeline comparing the beef production evolution in different regions since 1961. Beef and buffalo meat production from both commercial and farm slaughter, in terms of dressed carcass weight (Ritchie, 2017).*

The global beef production evolution during the last decades has led to an industrialization of farming systems and its well-known issues: environment, animal welfare, consumers acceptability, growing reliance on edible food. The public feels more and more confused when hearing simultaneously advantages (importance of beef and milk, preserved eco-systems on beautiful open landscapes unsuitable for crops) and disadvantages (contribution on climate change, low resource efficiency with grain feeding and imported soy) of cattle.

Nowadays, feeding the world in a sustainable way is one of the biggest challenges. In that way, the European Union (EU) has launched the SusCatt project ("Increasing productivity, resource efficiency and product quality to increase the economic competitiveness of forage and grazing based cattle production systems"). This aims to strengthen the sustainability of European beef and milk production by evaluating yields, quality, health and welfare, economics, reliance on edible food, gas emissions, environmental impact and consumers acceptability of a transition to high forage and pasture diets. This would stimulate a production that is climate-smart, resource efficient, producing good food, allowing a good living for farmers, keeping open landscapes as well as happy and healthy animals. Four work packages and seven agricultural research organisations from six European countries structure the project. It includes a part named Forage and pasture-based beef production and led by the Department of Animal Environment and Health, Swedish University of Agricultural Sciences (SLU), Skara, Sweden. This institution will formulate conclusions and recommendations on economic, environmental and social sustainability for the project as well as a guidance for the Swedish agricultural sector (farmers, advisors, organisations, policy).

SLU has already reported that an increased efficiency of the Swedish cattle production could decrease the negative environmental impact by implementing existing knowledge and technology (Hessle et al., 2017). This is in agreement with a study showing a decrease in land use and in environmental impact per unit produced when intensifying the production systems (Peters et al., 2010). As a study on environmental improvements is more valuable by including economics, Hessle et al. (2017) also demonstrated that an increase in efficiency could reduce costs to primary production. In different words, intensifying the production could be more sustainable but the authors also brought up issues, such as as animal welfare and consumers acceptability.

The Swedish beef production has increased somewhat in the last sixty years (Ritchie, 2017). The country is more known as a dairy producer where the main breeds are Swedish Red and Holstein (Jonsson, 2017). By the way, more than 60% of the Swedish beef production originates from the dairy cows and offspring (The Federation of Swedish Farmers, 2019). However, the number of dairy cows in Sweden is decreasing because of a higher individual milk yield which means less cows required to match the total milk volume (Hessle et al., 2017). This also represents a decrease in number of dairy calves available for beef production that is still not compensated by the increase in number of beef suckler cows (Eriksson et al., 2020). Moreover, studies showed that beef production from suckler cows has a greater negative impact on environment. Producing beef from these animals has to carry the whole burden of the dam and emissions are fully associated with meat from offspring. In dairy-based beef production, the milk carries a share of the environmental impact and emissions are associated with both milk and beef production (Flysjö et al., 2012; Hessle et al., 2017). Consequently, an intensification of the dairy beef production is an option to mitigate the greenhouse gas emissions per kilogram of meat produced. This could be associated to a decrease in beef imports which would impact positively both national economy and greenhouse gas emissions from transports (Hietala et al., 2014).

Calves are considered as a "cheap by-product" of dairy cows since they permit lower net costs than beef calves which need to cover all the costs related to the cows. This is even more important in the current situation where low beef prices combined with high feed costs make the profitability of beef production relatively low resulting in limited strategies to match the volume needed (Hietala et al., 2014). Hence, to avoid a decrease in Swedish beef production, producing higher carcass weight from dairy calves with higher meat proportion seems to be a more adapted path. As well as in other Nordic countries which face the same situation, the price for calf production is rising and slaughterhouses have favored heavier carcasses in the recent years (Huuskonen et al., 2013). However, fatness increases with heavier carcasses (Keane & Allen, 1998) and the beef production from purebred dairy calves remains difficult since they deposit fat earlier than crossbred or purebred beef calves. Indeed, the consumers demand is now more oriented to low-fat products and leaner beef meat. Low economic weight was placed on beef traits in the Nordic dairy cattle breeding goal in the past but more and more attention is paid to the genetic improvement of carcass traits (Hietala et al., 2014). This leads to a higher interest from dairy farmers for beef breed semen. Following tradition, the vast majority of Swedish dairy cows (89% in 2017) is still bred with same breed bulls (Växa Sverige, 2018). So, as well as in the other Nordic countries, most of the calves are of pure dairy breed. But, the proportion of beef bull semen in all inseminations on dairy cows has almost quadrupled in the past five years.

The Swedish bull production is a good example of the global evolution for intensive agriculture since 78% of the male calves from dairy cows are raised as intact bulls in intensive indoor systems (Hessle et al., 2019). The other part of the males is castrated and raised as steers. By removing testicles, the sexual hormone production is stopped resulting in an intermediate profile between male and female. However, castration represents a pain for animals and producing intact bulls avoids welfare issues due to this practice (Fisher et al., 1996). Castrating also represents a lower weight as well as a decreased meat quantity at the same slaughtering conditions. Studies have shown that steers had a lower feed efficiency than intact bulls (Hessle et al., 2017; Webster, 1980). Bulls have both higher metabolic rate and heat production, about 20% more than steers at same conditions (Webster et al., 1977), but when raised intensively with high energy diets, they convert food more efficiently because the heat production is counterbalanced by the lower energy content of their leaner carcass. Generally, studies show that feed intensity has an impact on the final liveweight at slaughter, average daily gain and carcass weight (Hessle et al., 2019). In that way, it shows difficulties to fulfil premium beef cut markets with higher fatness when the young bulls are finished in more extensive systems (Vestergaard et al., 2019). Steen & Kilpatrick (1995) concluded that rearing animals on high-forage diets and slaughtering at moderate levels of fatness decreased feed intake during the finishing period and reduced carcass fat content. Moreover, intact bull production may cause problems with aggression and safety at pasture, affecting carcass quality and pH due to fighting and excitement (Warriss, 1990). Consequently, combining their increased androgen activity and greater efficiency to convert nutrients to muscle compared to steers, it appears to be challenging to finish young bulls with an adequate fat cover (Steen & Kilpatrick, 1995). As mentioned before and reported by Bech Andersen et al. (1977), weight and age at slaughter also have a significant effect on the efficiency of young bull production. They reported a lower feed conversion with an increase in age and weight. On the other hand, a more intensive system with lower slaughter age would increase carcass output per hectare and contribute less to global warming potential with both lower lifetime feed consumption and entheric methane emissions (De Vries et al., 2015; Nogalski et al., 2014). However, animals slaughtered younger need a more intensive finishing diet to ensure acceptable carcasses and optimum performances (O'Riordan et al., 2012). As a rapid growth rate is related with a higher carcass weight (Hoving-Bolink et al., 1999), finishing younger bulls on a concentrate and high energy diet can also result in too high of a fat score and a loss in value as there is a greater resistance to beef with a high fat content by consumers.

2. Crossbreeding dairy cows and beef breed sires: a strategy already well reported

The current context is clear, it is needed to produce more and sustainably for a growing population. Regarding environmental issues, the greenhouse gas emissions must be mitigated, the landscape biodiversity preserved and the resources used efficiently to avoid negative impact and reliance on edible food. About economics, the primary production must be more competitive with higher returns and lower costs involving higher yields and performance, better quality and health. Concerning social issues, the consumers acceptability and confidence are essential, animal welfare and production must be transparent and respected. By the way, an efficient and local forage-based young bull beef production from dairy cattle seems to be a good strategy. However, since studies showed difficulties to finish purebred dairy young bulls with good performance and acceptable carcasses, especially on extensive systems, crossbreeding dairy cows with beef breed sires and its numerous advantages need to be considered.

A. Theoretical effects of crossbreeding

The aim of crossbreeding is to combine favourable attributes from breeds that are genetically different but with complementary qualities (Cartwright, 1970). Cundiff (1970) stated that combining crossbreeding with selection within breeds would maximize improvements since non-additive and additive genetic variation are both important. The most important parameters in choice of sire breeds to cross cows are determined on breeding values with average gene effects for the breeds and on heterosis effect with interaction of gene effects and differences in average gene frequency between breeds. In that way, involving heterosis effect, the performance of crossbred animals is generally superior to the mean of the parents (Keane, 2011). Consequently, crossing dairy cows and selected beef breed sires would result in progeny with superior beef traits to the dairy breed. To increase the dairy beef production, this type of sire breed when using inferior cows or heifers not used for herd replacement appeared to be the best strategy (Dal Zotto et al., 2009; Eriksson et al., 2020; Hietala et al., 2014; Huuskonen et al., 2013). Indeed, using a beef breed is expected to improve the value of the progeny with better performances and carcass characteristics compared to purebred dairy animals (Keane et al., 1989). In that way, crossbreeding can result in a greater economic revenue for the farmer since the conventional payment is higher with heavier carcasses, better EUROP conformation and optimized EUROP fatness. It is why Eriksson et al. (2020) noticed that maximizing the weight gain of an animal is not always equal to maximizing profitability. Consequently, the total benefit of this crossbreeding system depends mainly on the superiority of the beef sires used in different traits, such as growth capacity, feed conversion and carcass quality (Bech Andersen et al., 1977), while paying attention to the requirements.

Comparisons of liveweight gain and carcass characteristics are not sufficient to evaluate effects of beef breed crosses. As demonstrated by Eriksson et al. (2020), the choice of beef breed bulls needs to consider other expected effects, such as calving traits, especially when using this semen on heifers and old cows. Calving difficulty and stillbirth have a negative impact on recovery time, milk production and subsequent reproduction of the cow (Berry et al., 2007). These problems can be reduced considerably without affecting superiority of carcass traits by selecting bulls with high estimated breeding values for calving traits when used to dairy cows. Also, a reduced frequency of stillbirth can increase the number of slaughtered animals.

The most important issue for dairy farmers is to ensure a good herd replacement of a desired genetic merit. Hence, an adapted proportion of the cows needs to be bred to dairy bulls, leaving the surplus cows available for crossbreeding. Since half of the calves are male gender, the proportion of the cows bred to dairy bulls has to be at least twice the replacement rate. In that way, Hietala et al. (2014) reported that combining crossbreeding with the use of sex-sorted semen was even more efficient to increase the beef production from dairy cattle. They showed that the resulted decrease in replacement rate increased the production through the potential for crossbreeding with a higher proportion of dairy cows inseminated with beef bull semen. Increasing the use of breed semen from 10 to 30% while increasing the use of sex-sorted semen would result in 2% more bovine carcasses in kilograms (Eriksson et al., 2020). Also, even without paying attention to the crossbreeding rate, the reduced replacement rate results in an improved meat quality due to a fewer proportion of meat from culled cows. However, in calf production, even if there is an increasing interest from dairy farmers to use sexed semen (Dal Zotto et al., 2009), the price difference between female and male calves sold to specialized fattening farms is actually too low to cover the extra costs associated with this type of semen (Hietala et al., 2014).

Globally, increasing the proportion of beef breed semen in dairy cattle from 10 to 30%, whitout changing gender composition, would result in 0.9% more edible meat per carcass. The better carcass conformation from the crossbreds could increase the Swedish beef production by 3-4%. (Hansson, 1991).

B. Energetic efficiency of growth

The metabolizable energy (ME), known as the “physiological fuel for the body”, consumed by an animal is partitionned between gain in body tissues (protein and fat) and heat production. While maturing, an animal increases the ratio of fat to protein in the body gain. The feed conversion and the energy content of the body gains are constant during the first third of growth before declining (Webster, 1980). The leaner animal is assumed to be more efficient to convert feed because the energy of fat is about eight times that of lean meat. The energy of the diet, the breed type, sex and stage of maturiy determine the point at which the optimal efficiency is achieved (Webster, 1980). Consequently, the production system and its dietary energy intensity could affect the efficiency of crossbreeding. The breed effect of the beef bulls used shows greater improvements in intensive system as the genetic potential can be used in the former

(Hessle et al., 2019). With a low dietary energy intensity, the maintenance requirement involves a higher proportion of the energy expenditure. Typically, all Swedish calves, pure dairy breed and dairy x beef crossbred, for beef production are reared in similar finishing methods. By the way, the feed ration formulation and choice of slaughter period is generally optimized for dairy calves and suboptimal for crossbreds (Eriksson et al., 2020).

C. Main biological types of cattle and their differences

In Europe, cattle are mainly used for two types of production: beef and dairy. Over the years, huge work has been done on genetical improvements of selected traits (e.g. average daily gain for beef, milk yield for dairy) depending on needs in production and economic goals. Cattle breeds can now be easily differentiated, being specialized in one of the two purposes: dairy breeds and beef breeds. Moreover, Webster et al. (1982) reported that the two most popular traits in the selection for beef production was growth rate and ability to finish at an early chronological age. So, beef cattle can be differentiated on this second trait, also called maturity. We can separate late maturing breeds (Charolais, Limousine, Blonde d'Aquitaine) and early maturing breeds (Angus, Hereford, Aubrac) which have different characteristics.

Several studies show a negative genetic correlation between body weight and milk yield (Lee & Pollak, 2002). Selecting on carcass traits and muscle development as well as a greater energy requirement for maintenance has led to an increased protein accretion in beef breeds (Pfuhl et al., 2007). Whereas, selecting on milk production traits has increased the ability of dairy breeds to deposit fat as an energy source for milk production. Since the energy content of fat is much higher than the energy content of protein, the growth performances and the fat accumulation mechanisms are totally different between dairy and beef cattle with the same nutrient intake. Pfuhl et al. (2007) reported these differences with Charolais and Holstein young bulls. Per kilogram of body weight gain, beef bulls expensed 14% less energy and ingested 7.6% less dry matter than dairy bulls. They needed less energy per kilogram of protein gain in the hot carcass weight, resulting in a better feed conversion ratio. Beef breed bulls had a higher average daily gain and showed a greater carcass weight as well as a higher dressing percentage by 6.4% compared to dairy breed bulls. However, beef breed bulls had a lower marbling score with 1.44% less intramuscular fat. With a lower capability for protein accretion, the dairy bulls rerouted the ingested energy in internal fat depots. The results are in agreement with Murphy et al. (2018) who highlighted the difficulty to achieve the required carcass weight and conformation as well as fat score for dairy bulls slaughtered at 15 months.

Regarding beef breeds, late maturing breeds are known to be longer to finish since they start deposing fat at a higher weight than early maturing breeds (Keane & Drennan, 2008). Due to their ability to deposit a higher proportion of muscle instead of fat, late maturing breeds have higher maintenance requirements. At low dietary energy densities, this can result in less available energy for growth (Webster, 1980). Early maturing breeds with an intermediate profile between late maturing and dairy breeds, start deposit fat faster and show fatter and lighter carcasses, when compared to late maturing beef breeds under the same environmental conditions. Consequently, the difference in maturity affects the suitability of the breeds for production systems differing in intensity and slaughter age (Keane & Drennan, 2008). By comparing Holstein and early maturing beef breed (Hereford) steers on the net efficiency of energy utilization, it has been shown that Hereford steers was about 20% more efficient in converting feed energy consumed above maintenance for storage as fat and protein (Gareet, 1971).

Experiments showed that the best strategy to cross dairy cows was to use late maturing beef breed bulls. Jukna et al. (2009) did not report any significance on efficiency to cross dairy cows with early maturing beef breed sires. Eriksson et al. (2020) showed that the effect of using late maturing beef breed bulls was on average about twice that using early maturing breed. By the way, crossing dairy breeds with late maturing breeds is expected to give leaner carcasses with better conformation and dressing percentage, compared with purebred animals if slaughtered at the same weight. As mentioned previously, comparisons between beef breeds need to be undertaken within the productions systems. Then the results should permit measurements of interactions with other important factors, such as level of feeding and slaughter weight (Keane & Allen, 2002).

D. Comparisons between purebred and crossbred animals on performance

Since crossbreeding with beef breeds appeared to be theoretically a good strategy to increase dairy beef production, numerous studies have been done in the past to show its effects in practice. Some of them, with the most adapted criteria, have been summarized in *Table 1*.

a. *Final liveweight*

Studies showed that final liveweight differed between sire breeds (Hessle et al., 2019; Vestergaard et al., 2019). Depending on both studies, by comparing purebred dairy steers or bulls with dairy x late maturing beef breed, the latter weighed heavier by 42 and 41 kilograms, respectively. Keane & Drennan (2008) noticed a significant heavier weight from the purebred Holstein steers, compared to the Holstein x Angus crossbreds, and no difference when compared to the Holstein x Belgium Blue crossbreds. Jukna et al. (2009) did not show any difference between purebred dairy bulls and dairy x Angus crossbreds but showed a significantly higher final live weight by 9% when crossing with Charolais breed. In a huge dataset originating from an Italian wholesale cattle organization, it was reported that crossbreeding with beef bulls increased the calves body weight at auction by almost 4 kilograms compared to purebred dairy calves (Dal Zotto et al., 2009).

b. *Average daily gain*

It has also been reported that the growth rate, showed by the average daily gain (ADG), were influenced by the sire breed (Bech Andersen et al., 1977; Vestergaard, et al., 2019). These results have been found in young bull production systems. When compared to purebred dairy Holstein bulls, Limousine crossbreds showed a higher live weight gain by 91 g / day (9% higher). In another hand, within a comparison between dairy x early (Hereford) and late (Charolais) maturing beef crossbred, crossbreeding with late maturing breed gave a higher ADG by 94 g (Bech Andersen et al., 1977). Eriksson et al. (2020) showed a higher lifetime daily carcass gain for dairy x beef crossbreds compared with purebred Swedish Red and Swedish Holstein young bulls, especially when crossing with late maturing breeds with a 76 g / day difference. As a proportion, they stated a higher daily carcass gain by 5-7% and 8-15% when using early and late maturing beef breeds, respectively.

c. *Feed efficiency*

Despite a lack of information on the papers, several studies reported that the growing dairy x beef crossbred cattle had a higher feed efficiency than purebred dairy animals (Bech Andersen et al., 1977; Hessle et al., 2017). However, even with a difference in final live weight, Hessle et al. (2019) did not conclude a breed effect on the performance of living animals since the live weight gain and the feed efficiency did not differ.

Table 1 *Summary of studies on dairy x beef crossbreeding effect on animal performance. * P < 0.05.*

		N	Age at start of trial, months	Live weight at start of trial, kg	Age at slaughter, months	Live weight at slaughter, kg	Average daily gain, g/day
Bech Andersen et al., 1977	Crossbred dairy x Charolais bulls	31	1		15	463	1267*
	Crossbred dairy x Hereford bulls	39	1		15	434	1173*
Hessle et al., 2019	Purebred Swedish Red and Holstein Swedish steers	29	3 to 4	115	24.5	640*	840
	Crossbred dairy x Charolais steers	32	3 to 4	140	24.5	682*	860
Huuskonen et al., 2013	Purebred Holstein heifers	6348		40	15.5		
	Crossbred Holstein x Angus heifers	531		40	15.5		
	Crossbred Holstein x Charolais heifers	438		40	15.5		
Jukna et al., 2009	Purebred Lithuanian Black-and-White bulls	17	2 to 3		16	474	905
	Crossbred Lithuanian Black-and-White x Charolais bulls	17	2 to 3		16	516*	1019
	Crossbred Lithuanian Black-and-White x Angus bulls	17	2 to 3		16	463	921
Keane & Drennan, 2008	Purebred Holstein steers	18	1	64		572*	789
	Crossbred Holstein x Angus steers	18	1	60		541*	749
	Crossbred Holstein x Belgium Blue steers	18	1	58		568*	773
Vestergaard et al., 2019	Purebred Holstein bulls	15	4	141	17	534*	976*
	Crossbred Holstein x Limousine bulls	15	4	145	17	575*	1067*

E. Comparisons between purebred and crossbred animals on carcass characteristics

Table 2 summarizes results on carcass traits from the same studies as shown in *Table 1*. Most of the studies reported significant differences in carcass weights, dressing percentage, conformation score and fatness score. In general, crossbreeding dairy cows with beef breeds had a positive impact on most of these characteristics (Hessle et al., 2019; Huuskonen et al., 2013; Keane & Drennan, 2008; Vestergaard et al., 2019).

a. Carcass weight

Especially when using late maturing beef breeds, there is an increase in carcass weight. In a young bull production system, Vestergaard et al. (2019) found a 44 kg (or 16%) higher carcass weight when crossing Holstein cows with a Limousine sire. Another study found that using late maturing beef breed sires would permit to increase carcass weights of the progeny by 10% without an increase in slaughter age (Eriksson et al., 2020). This was mainly explained by a greater dressing percentage for the crossbred animals.

b. Dressing percentage

Each of the summarized studies stated a higher dressing percentage by 1.3 to 4.1 units when crossing with beef breeds. Huuskonen et al. (2013) showed that crossbreeding produced between 50 and 90% better conformed carcasses than purebred Holstein heifers. Moreover the dairy x late maturing breed crossbreds showed a higher dressing percentage than those originating from crossbreeding with early maturing breed (Bech Andersen et al., 1977; Keane & Drennan, 2008).

c. Conformation score

Consequently, every study reported a significantly better EUROP conformation when dairy cows were crossed with late maturing sires than purebred animals, crossbred from early maturing breeds being intermediate.

d. Fatness score

Results from EUROP fatness were different depending on the studies. Crossbred animals from dairy x early maturing breeds always showed a higher fat content than purebred and late maturing crossbreds (Huuskonen et al., 2013; Keane & Drennan, 2008). When comparing purebred dairy animals and crossbred with late maturing breeds, there were differences between the studies. It is known that purebred dairy animals deposit more fat and earlier than crossbred with beef sires but as mentioned previously, a heavier carcass corresponds to an increase in fat content. Since Vestergaard et al. (2019) did not show differences in fatness between purebred and crossbred animals, they stated that beef sires of other breeds (Hereford, Angus) should be considered to produce young bulls with acceptable carcass fatness. However, Huuskonen et al. (2013) noticed that using late maturing breeds would be a better strategy to match the growing consumer demand for beef with less fat, by producing leaner carcasses. Consequently, it is also necessary to take the actual market demands into account before planning production strategies. Finally, only one study found a sire breed x weight / age interaction in carcass composition (Bech Andersen et al., 1977). They mentioned that it was due to sire breed differences in maturity, earliness of fattening and rate of fat gain relative to the rate of weight increase in muscle and bone (growth coefficient for the three main carcass components). Consequently, they reported that crossing with late maturing breeds means a high muscle gain and a low fat gain in the weight interval 300-575 kg when early maturing crosses mean a low muscle gain and a high fat gain in the same interval.

Table 2 *Summary of studies on dairy x beef crossbreeding effect on carcass characteristics. * P < 0.05.*

		N	Carcass weight, kg	Dressing, %	Conformation score	Fatness score
Bech Andersen et al., 1977	Crossbred dairy x Charolais bulls	31	255	54.8*		
	Crossbred dairy x Hereford bulls	39	236	54*		
Hessle et al., 2019	Purebred Swedish red and Holstein Swedish steers	29	294*	45.8*	4/15*	7.2/15
	Crossbred dairy x Charolais steers	32	335*	49.1*	5.7/15*	7.4/15
Huuskonen et al., 2013	Purebred Holstein heifers	6348	208		3/15	2.7/5
	Crossbred Holstein x Angus heifers	531	221*		4.5/15*	3.3/5*
	Crossbred Holstein x Charolais heifers	438	246*		5.5/15*	3/5*
Jukna et al., 2009	Purebred Lithuanian Black-and-White bulls	17	246	51.3		2/5
	Crossbred Lithuanian Black-and-White x Charolais bulls	17	291*	56.4*		2.5/5
	Crossbred Lithuanian Black-and-White x Angus bulls	17	251	53.1		3/5
Keane & Drennan, 2008	Purebred Holstein steers	18	287*	50.1*	1.9/5*	3.09/5*
	Crossbred Holstein x Angus steers	18	278*	51.4*	2.15/5*	3.27/5*
	Crossbred Holstein x Belgium Blue steers	18	308*	54.2*	2.89/5*	2.59/5*
Vestergaard et al., 2019	Purebred Holstein bulls	15	272*	52*	3/15*	1/5*
	Crossbred Holstein x Limousine bulls	15	316*	55.1*	7/15*	1.2/5*

F. Comparisons between purebred and crossbred animals on economics

Since crossing dairy cows with beef breed sires has generally shown advantages on feed efficiency and carcass traits, it seems easier to reach an acceptable net return for the dairy beef production. Indeed, the higher feed efficiency decreases the feeding costs when greater muscle proportion give a more valuable carcass. Hessle et al. (2019) found that 97% of the crossbred steers reached carcass weights (275 to 424,9 kg), conformation score (at least O-) and fatness score (2 to 4-) qualifying them for premium prices on the current Swedish market. Only 59% of the purebred dairy steers reached the same criteria where the main problem was insufficient conformation. The higher conformation score was reflected in a greater proportion of valuable retail cuts. In another study, bull production when crossbreeding dairy cows with beef sires showed a decrease in net costs from 50 SEK / kg carcass for the current Swedish suckler cow-based beef production and 41 SEK / kg carcass for pure dairy beef production to 35-40 SEK / kg carcass for crossbred (Hessle, et al., 2017).

3. Lack of information and need in actualization noticed

Crossbreeding dairy cows with beef breed sires and its subsequent effects has been studied over the past. There are numerous advantages of crossbreeding a dairy breed dam with a beef breed sire on environmental impact and economics, resulting from an improved efficiency of the dairy beef production (increased and improved production, better resource-use efficiency and performance). Young bull production are intensive indoor systems to achieve acceptable carcasses at relatively low ages. In that type of production, crossbreeding seems even more interesting.

Regarding the consumer demand, it has been reported superior effects by using late maturing beef breeds since the progeny produces heavier and leaner carcass. However, in some cases, there was a lack of fat content to fulfil the actual requirements. By the way, using early maturing breeds appeared to be an alternative with more acceptable carcasses on fatness. Most of the studies ranked this crossbred progeny intermediately between purebred dairy animals and late maturing crossbreds. By deposing less muscle, having less maintenance requirements and achieving acceptable fatness faster, crossbred animals from early maturing breeds should be more suitable to improve the dairy beef production in extensive systems. Indeed, since the dietary energy intensity impacts efficiency of crossbreeding by affecting the proportion of energy expenditure from maintenance requirement, late maturing crossbred show a disadvantage. This is even more pronounced in Sweden where purebred and crossbred calves are finished under the same conditions with suboptimal feed ration formulations and choice of slaughter period for crossbred animals. However, a study reported higher carcass weight from purebred diary animals than crossbred from early maturing breed and other studies did not report significance about advantages to use early maturing sire breeds. It is why more results are needed to show advantages of using these breeds on dairy cows to increase and improve beef production. In that way, a significant interaction between genetic type and diet intensity would be interesting to report since most of the studies did not find any.

Limited information on feed efficiency has been noticed in the studies. To compare purebred dairy calves and crossbred calves, most of authors favoured carcass and production traits. This resulted in less information on lifetime performance which are relevant to an improved efficiency. By the way, complete results on dietary and nutrient intake as well as growth rates are needed to report relevant improvements when using early maturing beef breed sires on dairy cows.

Moreover, since intact bulls are reared in intensive indoors systems to reach an acceptable production, there is a lack of data from extensive systems. However, the Swedish bull production is based on high-quality forage diets and needs more relevant information and further studies to be improved. Showing the opportunity to finish dairy young bulls correctly on forage-based diets by using beef breed sires is required.

The literature review is consequent and involves numerous interesting papers. However, it is noticed that many are old since this type of crossbreeding has been studied for several decades. It is needed to actualize findings within the current production with improved animals and plant genetics and more accurate materials to be sure that they are still relevant and usable.

Finally, the literature review mainly contains specialized and specific articles, which is really important. However, in most of them, a conclusion about crossbreeding dairy cows with early maturing beef breed sire effects on global issues is missing. Consequently, a complete statement about every advantage of this type of crossbreeding on environmental, economic and social sustainability is needed. It remains necessary to show that producing young bulls from dairy cattle on forage-based diets, being climate-smart, resource efficient, producing good food, allowing a good living for farmers, keeping open landscapes as well as happy and healthy animals, is possible.

4. Research questions

Regarding the stated knowledge gap, the following research question characterizes this thesis:

How can crossbreeding dairy cows with early maturing beef breed sires impact Swedish forage-based beef production systems with bulls from dairy cattle?

To answer it, the following sub-questions are used:

- Is there an interaction between genetic type and feed intensity?
- What is the effect of crossbreeding on animal performance and therefore feed efficiency?
- What is the effect of crossbreeding on carcass characteristics and therefore beef production?
- How can crossbreeding seem like a good strategy for a sustainable young bull production from dairy cattle?

5. Objectives

This study aims to evaluate the impact of crossing an early maturing beef breed sire to dairy cows on performance and carcass characteristics of the offspring in a forage-based indoor system. This thesis is a quantitative testing research and is partitioned thanks to the sub-questions. Data and measurements were recorded from animals and environment parameters in a way to answer the questions. By the way, adapted indicators and variables were used. Each sub-question represents a complete paragraph or a part of it in which the relevant results are discussed:

- Interaction between breed and feed intensity
- Effect of crossbreeding on animal performance
- Effect of crossbreeding on carcass characteristics
- Evaluation of the dairy x beef crossbred young bull production sustainability.

It is hypothesised that crossbreeding increases average daily gain, feed efficiency, carcass weights, dressing percentage, conformation and fatness compared to beef production from pure dairy breeds. It is also expected to notice an interaction between genetic type and feed intensity by reporting even more interesting results when producing crossbred progeny on a low intensity diet. All those results should finally show the higher sustainability of crossbreeding dairy cows with early maturing beef breed sires, regarding most of issues.

In practice, this thesis aims to disseminate relevant results and advantages of using that type of crossbreeding. Advisors and farmers organisations could be largely involved in this goal to keep every dairy farmer up to date. It could be shown the better performances and production of the system which would improve their revenue by increasing returns and decreasing costs. Genetic companies would also be involved to produce high quality semen to dairy cows and heifers from early maturing beef sires selected on both carcass traits and calving ease. They also could work more on lower price for sex-sorted semen to make the profitability of this crossbreeding even greater. Moreover, governments and European institutions could attract the light and communicate on this sustainable production to professionals and consumers. They could also motivate more and more farmers in this way by involving funding and new Common Agricultural Policy orientations.

II. MATERIAL AND METHODS

To evaluate effects of crossbreeding dairy cows with Angus sires, purebred and crossbred progeny have been compared. To avoid external conditions, they must be reared together with the same environment from purchase to slaughter. By the way, their performance and productivity could be recorded, measured and analysed to find relevant results to answer the research question and reach the goals of the study. This chapter introduces the protocol and all the parameters included in the experiment.

1. Experimental design

The young bull experiment was located at the Götala Beef and Lamb Research Centre, Skara, in south-western Sweden (58°42′ N, 13°21′ E; elevation 150 m above sea level; *Figure 2*). The study is part of the EU project SusCatt – Increasing productivity, resource efficiency and product quality to increase the economic competitiveness of forage and grazing based cattle production systems.

The experiment is approved by the Ethics Committee on Animal Experiments in Göteborg (case number 187-2014).

Figure 2 *Nordic countries map showing the Götala Beef and Lamb Research Centre position (Google Maps, 2020).*

The bulls were reared indoors and housed in groups of six animals per pen with deep straw bedding and scraped floor by the feed bunks. The bulls were followed from weaning to slaughter in a 2 × 2 factorial arrangement of treatments: two breeds (dairy, D, and dairy × beef, C) and two feed intensities (high, H, and low, L). The high and low feed intensity correspond to slaughter at the ages of 15 and 18 months, respectively. The animals were introduced to the experiment as a pair of calves, one from each breed, D and C, and the two breeds were housed separate pens. Animals from the same pair were slaughtered at the same time when the average target age was reached.

2. Animals

The experiment included 69 bull calves, born on the same commercial dairy farm. After the colostrum period, they were separated in small groups of 5–8 calves and fed 5–7 L day^{-1} whole milk until 2–4 weeks of age. Then, they were housed in groups of 15–24 animals and fed milk replacer with a calf-feeder. The calves had access to tender hay and concentrate ad libitum and were dehorned at 6–8 weeks of age.

The experimental part started in March 2018 when the first bulls entered the station at an average age of 3.3 months and average weight of 119 kg. In total, 35 animals were of pure dairy breed (D; 15 Swedish Red and 20 Swedish Holstein), and 34 animals were from a dairy x beef cross (C; 15 Swedish Red × Angus and 19 Swedish Holstein x Angus). The purebred dairy calves originated from 18 different sires (ten Swedish Red and eight Swedish Holstein) and the crossbred calves originated from 4 Angus sires; two sires for the dams of Swedish Red and two sires for the dams of Holstein Swedish. During the trial, three bulls were lost due to death or disease. Data and measurements from these animals were excluded from the analyses.

3. Diets, feed sampling and registrations

During the experiment, all animals were fed a total mixed ration including grass-clover silage as forage, rolled barley, rolled peas and cold-pressed rapeseed cake. The protein and energy concentrations were adjusted with increasing live weight according to Swedish nutritional recommendations (Spörndly, 2003). The H and L diets had average forage proportions of 36% and 56% of dry matter, respectively *(Table 3)*. The grass-clover silage was supplemented with rolled barley until slaughter, with rolled peas until 275 kg to 425 kg body weight and with cold-pressed rapeseed cake until 175-225 kg bodyweight depending on the feed intensity *(Tables 4 and 5)*.

Silage was from the first, second, and third cut. It was composed of 90–95% grass (*Lolium perenne, Festuca pratensis, Phleum pratense, and Festulolium arundinacea*) and 5–10% clover (*Trifolium repens and Trifolium pratense*) and pre-wilted to 250 g kg^{-1} dry matter (DM). A preservative silage additive containing benzoate, nitrite, methenamine, and propionate was injected at 3 L tonne^{-1} silage (Konsil Ultra, Konsil Scandinavia, Tvååker, Sweden). The herbage was harvested at least four months before feeding and mainly ensiled in bunker silos but also as round bales. Round-baled silage was chopped to similar length as the silage in the bunker silos before feeding.

The bulls were fed once a day and individual feed intakes were registered automatically by the Biocontrol system (CRFI, Rakkestad, Norway). During the whole period, the feed rations were supplemented with vitaminized minerals to fulfil the requirements of the animals (VikingGenetics, 2020), and all animals had free access to water and salt.

Silage samples were collected daily and composited to one sample per month for analysis of chemical composition. Samples of barley, peas, and rapeseed cake were taken weekly and mixed to two samples per feed for analysis of the chemical composition.

The animals were weighed automatically on a scale placed in front of the water automat. A weight of the animal was registered automatically every time the animal drank water.

Table 3 *Proportion (% of dry matter) of grass-clover silage, rolled barley, rolled peas, cold-pressed rapeseed cake and chemical component in the total mixed ration fed to young purebred dairy and crossbred dairy x beef bulls at different feed intensities (DM = dry matter, NDF = neutral detergent fiber).*

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Component, % of DM	High intensity	Low intensity
Silage	35.8	55.8
Barley	59.5	42.5
Peas	3.9	1.2
Cold-pressed rapeseed cake	0.8	0.5
Crude protein	14.6	15.3
NDF	29.2	35.9
Starch	36.2	25.1
Crude fat	3.2	2.9
Metabolisable energy, MJ kg^{-1} DM	12.3	11.6

Table 4 *Proportion (% of dry matter) of grass-clover silage, rolled barley, rolled peas, and cold-pressed rapeseed cake in the total mixed ration fed to young purebred dairy and crossbred dairy x beef bulls at different liveweights during the experimental period. Low feed intensity (L).*

Liveweight, kg	Silage	Barley	Peas	Cold-pressed rapeseed cake
- 125	29	35	22	14
125 - 175	39	51	7	3
175 - 225	45	50	4	0
225 - 275	49	50	1	0
275 - 325	53	47	0	0
325 - 375	56	44	0	0
375 - 425	60	40	0	0
425 -	61	39	0	0

Table 5 *Proportion (% of dry matter) of grass-clover silage, rolled barley, rolled peas, and cold-pressed rapeseed cake in the total mixed ration fed to young purebred dairy and crossbred dairy x beef bulls at different liveweights during the experimental period. High feed intensity (H).*

Liveweight, kg	Silage	Barley	Peas	Cold-pressed rapeseed cake
- 125	32	35	22	11
125 - 175	32	48	14	6
175 - 225	33	57	8	1
225 - 275	36	58	6	0
275 - 325	37	59	5	0
325 - 375	36	60	4	0
375 - 425	36	62	1	0
425 -	37	63	0	0

Table 6 *Chemical composition of grass-clover silage fed to young purebred dairy and crossbred dairy x beef bulls (s.d. = standard deviation, DM = dry matter, ME = metabolizable energy, CP = crude protein, NDF = neutral detergent fiber, n = 21).*

Component, kg^{-1} DM	Silage	
	Mean	s.d.
DM, g kg^{-1}	288	70
ME, MJ	10.2	0.3
CP, g	175	27
NDF, g	501	55
Ash, g	93	14

Table 7 Chemical composition of rolled barley, rolled peas, and cold-pressed rapeseed cake fed to young purebred dairy and crossbred dairy x beef bulls (s.d. = standard deviation, DM = dry matter, ME = metabolizable energy, CP = crude protein, NDF = neutral detergent fiber, n = 2).

Component, kg^{-1} DM	Barley		Peas		Cold-pressed rapeseed cake	
	Mean	s.d.	Mean	s.d.	Mean	s.d.
DM, g kg^{-1}	957	0.2	957	0.2	961	0.3
ME, MJ	13.4		13.8		15.3	
CP, g	128	0.3	210	3.3	316	8.6
NDF, g	173	1.1	67	14.8	221	12.5
Starch, g	576	6.8	501	17.9	16	0.1
Crude fat, g	39	6.3	20	0.8	16	8.1
Ash, g	24	0.8	30	0	67	1

4. Chemical analysis

Concentrations of DM, crude protein (CP), neutral detergent fiber (NDF) and in vitro organic matter digestibility were analysed from silage and concentrate samples. The DM concentrations of silage and concentrate were determined at 60 °C and 105 °C, respectively, for 24 h, whereas ash was determined at 550 °C for 5 h. Crude protein was determined according to Dumas method (1831) and NDF according to Chai and Udén (1998). From the disappearance of rumen organic matter, metabolizable energy (ME) concentration of silage was calculated (Lindgren, 1979). The same component concentration of concentrate was calculated according to Axelsson (1941). Concentrations of starch and crude fat were determined in concentrates (Aman & Hesselman, 1984). In addition, silage samples were analyzed for pH and concentrations of NH_4-N (Tecator Kjeltec Auto sample system 1035 Analyzer, Tecator Inc., Höganäs, Sweden), organic acids, and ethanol (Andersson & Hedlund, 1983). *Tables 6 and 7* show the chemical composition of the grass-clover silage and concentrates.

5. Carcass measurements

The bulls were slaughtered in a commercial abattoir in Skövde, located 30 km from SLU Götala Beef and Lamb Research Centre. The carcasses were divided by the vertebral column and the cold carcass weight was estimated at 98% of the hot carcass weight. Conformation and fatness were scored according to the European Union Carcass Classification Scheme (Council of the European Union, 2020; Commision of the European Union, 2020).

For conformation, development of the carcass profile (round, back, and shoulder) was graded according to the EUROP classification system (E: excellent, U: very good, R: good, O: fair, P: poor). For the fat cover, the amount of subcutaneous fat and fat deposits in the thoracic cavity was measured, using a classification from 1 to 5 (1: low, 2: slight, 3: average, 4: high, 5: very high). Based on the Swedish system, both conformation and fatness scores were divided into three sub-classes (e.g., R−, R=, R+; 2−, 2=, 2+) to report a modified scale ranging from 1 to 15, with 15 being the best conformation and highest fatness.

After a two-day cooling at +2–4 °C, the carcass was separated into fore- and hindquarters (HQ) between the 10th and 11th ribs. Marbling was determined visually in *musculus (M.) longissimus dorsi* on left hindquarter, using a 5-point scale from 1 (no marbling) to 5 (abundant), based on the USDA standard (2020). The left hindquarter was weighed for each carcass, as well as seven high-value retail cuts: strip loin *(M. longissimus dorsi)*, fillet *(M. psoas major)*, topside *(M. semimembranosus)*, outside round *(M. biceps femoris)*, eye of round *(M. semitendinosus)*, top rump *(M. quadriceps femoris)*, and rump steak *(M. gluteus medius)*. Two commercially defined cuts (bone-free mincing and stewing meat, assumed to contain 10 and 23% fat), bones and trim fat were also weighed. The latter was defined as intermuscular and subcutaneous fat deposits separable in a standardized cutting procedure. Bones were weighed without extra cleaning and with closely bound connective tissue. The dressing proportion representing the ratio of cold carcass weight to liveweight, the proportions of retail cuts, the two commercial cuts from the hindquarter, bones and trim fat were calculated.

6. Statistical analysis

All data were computed in Microsoft Excel before the statistical analysis in SAS (SAS Institute Inc., 2018). The statistical analysis has been done with the Mixed procedure in SAS using the model:

$$y_{ijk} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + \gamma_k + \varepsilon_{ijk}$$

where μ is the population mean, α_i is the fixed effect of breed, β_j is the fixed effect of feed intensity, $\alpha\beta_{ij}$ is the interaction between breed and feed intensity, γ_k is the random effect of pen and ε_{ijk} is the error term. Only differences between purebred and crossbred young bulls were analysed, and not the possible breed effects between Swedish Red and Swedish Holstein.

Least square (LS) means were compared pairwise using the Tukey test, adjusted by the method of Kenward and Roger (1997), and stated as significant at $P < 0.05$ and as a tendency for significance at $0.05 < P < 0.10$.

7. Answering the research questions

A. Interaction between breed and intensity

This paragraph is from the same variables as the two next points. However, the significance of the results is analysed from interactions in the 2 x 2 factorial design. In that way, the following interactions are compared on performance and carcass characteristics: D x H, D x L, C x H, C x L.

B. Effect of crossbreeding on animal performance

To write this paragraph, the main indicators of the animal performance are reported: initial liveweight, feed intake, average daily gain and feed efficiency. Crossbred and purebred animals are compared with statistical analysis of comparable and repeatable variables. The daily weight, automatically measured each time the bull drank water, has been averaged to give the daily gain and discuss growth rate between the breeds. Then, the chemical composition of the feeds and the measured daily dietary intake as well as liveweight gain have been used to calculate the feed efficiency and show expected significant difference between animals.

C. Effect of crossbreeding on carcass characteristics

To write this chapter, the main indicators of the animal carcass characteristics are reported: final liveweight, carcass weight, dressing percentage, conformation score and fatness score. Crossbred and purebred animals are compared with statistical analysis of comparable and repeatable variables. Here, the measurements from slaughter were used. No variable needed further calculations. By the way, the raw data are statistically analysed to compare purebred and crossbred bulls.

D. Evaluation of the dairy x beef crossbred young bull production sustainability

This sub-question does not bring more result but is discussed using the literature review to show the hypothesised greater sustainability of crossbreeding dairy cows with early maturing beef breed sires, regarding most of issues.

III. RESULTS

The results are structured in different paragraphs regarding the established plan from methodology. *Table 8* includes every parameter used to compare breed effects on performance before slaughter. *Tables 9 and 10* contain carcass traits and cutting-up details which were used to compare animals and diets on carcass characteristics. Absolutely none significant difference was found from interactions between breed and intensity.

1. Intake and performance

Initial liveweight (LW) did not differ between dairy and dairy x beef bulls. Bulls of pure dairy breed and beef crossbreds had similar intakes of DM, OM, CP, NDF and ME. However, the ADG was significantly different between the breeds (P < 0.001). Crossbred bulls had a higher ADG by 0.154 kg per day compared to the pure dairy bulls. This resulted in a tendency to an improved feed conversion ratio. Crossbred bulls tended to use less dry matter and metabolizable energy to gain 1 kg of bodyweight (P = 0.084 and P = 0.089 respectively).

Table 8 *Initial liveweight, daily feed and nutrient intake, average daily gain and feed conversion of young purebred dairy (D) and crossbred dairy x beef (C) bulls at different feed intensity level (s.e.m. = standard error of the mean, LW = liveweight, DM = dry matter, OM = organic matter, CP = crude protein, NDF = neutral detergent fiber, ME = metabolizable energy, ADG = average daily gain).*

Item	**Breed**		**s.e.m.**	**Significance**
N	C	D		
	34	35		
Initial LW, kg	120	117	6.08	0.710
DM, kg	8.76	8.36	0.19	0.170
Silage DM, kg	4.03	3.84	0.08	0.121
OM, kg	8.28	7.90	0.18	0.172
CP, kg	1.31	1.25	0.03	0.175
NDF, kg	2.86	2.72	0.06	0.135
Silage NDF, kg	2.06	1.96	0.04	0.106
Starch, kg	2.67	2.55	0.07	0.279
ME, MJ	104.56	99.85	2.30	0.185
Crude fat, kg	0.27	0.26	0.01	0.205
DM intake, % LW	2.44	2.52	0.04	0.156
NDF intake, % LW	0.73	0.75	0.01	0.346
ADG, kg	1.483	1.329	0.02	< 0.001
DM kg / kg ADG	5.93	6.34	0.15	0.084
ME MJ / kg ADG	70.67	75.61	1.81	0.089

2. Carcass characteristics

Crossbred bulls showed a higher liveweight at slaughter of 64 kg compared to purebred bulls (P = 0.002). The higher LW and a higher dressing percentage (P = 0.003), the dairy x beef bulls had significantly heavier carcasses (P = 0.001). It was also observed an increase in conformation and fatness scores when bulls were crossbred (P < 0.001). In average, the conformation score was by 1.8 points and fatness score by 1.5 higher when comparing crossbred to purebred animals. When expressed in relation of HQ, only trim fat and bone percentages appeared significant. Trim fat varied from 12.3% for crossbred to 9.1% for purebred (P = 0.016) and the proportion of bones differed by more than 2 units (P < 0.001). Also crossbred bulls tended to have a higher proportion of high-value retail cuts compared to the purebred bulls (P = 0.066).

Table 9 *Carcass traits of young purebred dairy (D) and crossbred dairy x beef (C) bulls at different feed intensity levels (s.e.m. = standard error of the mean, LW = liveweight).*

Item	**Breed**		**s.e.m.**	**Significance**
N	C	D		
	34	35		
LW, kg	718	654	9.34	0.002
Carcass weight, kg	389	343	6.16	0.001
Dressing, %	54.2	52.5	0.29	0.003
Conformation [a]	7.3	5.5	0.20	< 0.001
Fatness [b]	9.6	8.1	0.17	< 0.001
Marbling [c]	2.3	1.5	0.11	< 0.001

[a] EUROP system: 5 = O, 6 = O+, 7 = R-. [b] EUROP system: 8 = 3, 9 = 3+. [c] Visually determined in M. longissimus dorsi between the 10th and 11th ribs (scale 1 = lean, 5 = well-marbled).

Table 10 *Carcass cutting-up details of young purebred dairy (D) and crossbred dairy x beef (C) bulls at different feed intensity levels (s.e.m. = standard error of the mean, HQ = hind quarter).*

Item	Breed		s.e.m.	Significance
	C	D		
N	34	35		
HQ, kg	94.9	83.4	1.39	< 0.001
Retail cuts [a], % HQ	43.3	42.7	0.87	0.066
Grade 2 meat assessment [b], % HQ	18.4	18.9	0.51	0.548
Grade 3 meat assessment [c], % HQ	11.7	10.9	1.10	0.631
Trim fat, % HQ	12.3	9.1	0.75	0.016
Bone, % HQ	16.9	19.2	0.22	< 0.001

[a] High-value cuts (strip loin, fillet, topside, outside round, eye of round, top rump and rump steak). [b] Commercial meat cuts estimated to contain 10% fat. [c] Commercial meat cuts estimated to contain 23% fat.

IV. DISCUSSION

The research method used permits to answer the research question and reach the established objectives of the study. The experiment design and its process were adapted to avoid external effects and to compare the breeds. The study is relevant thanks to the numerous and complete recordings and measurements about performance and carcass characteristics. Their SAS statistical analysis gave results in agreement with the research questions. The previous chapter showed how breeds and feed intensities significantly differed and which parameters have been affected. Moreover, explanations and comparisons need to be reported to understand why those results have been found and to notice the recommendations. This chapter follows the same structure as the previous one but including discussions related to the sub-questions and the conversion of findings to current dairy beef production issues in Sweden.

1. Interaction breed x intensity

One of the main objectives of this study was to report a significant advantage to produce crossbred dairy x early maturing beef breed bulls when feeding a low intensity forage-based diet. However, interactions between breeds and diet intensities did not show significant results. None of the parameters were different when producing crossbred instead of purebred bulls on a low intensity diet. It is in agreement with most of the reviewed studies (Hessle et al., 2019; Keane et al., 1989; Steen & Kilpatrick, 1995). However, Hessle et al. (2019) stated that the breed effect of beef bulls showed greater improvements in intensive system as the genetic potential can be used in the former. By the way, more studies on this interaction need to be conducted to find in which way crossbreeding dairy cows and beef breed sires could be optimized in forage-based systems.

2. Intake and performance

A. Feed intake

Calves entered the experiment as pair, one from each breed, at similar age and liveweights. Pure dairy breed and dairy x early maturing beef breed bulls were housed in the same barn under the same environmental conditions. In that way, feed and treatment effects were excluded between breeds and the different performance were the result of different nutrient utilization, presumably based on breed specific preferences of metabolic pathways. In the present study, purebred and crossbred bulls did not differ in intakes, when averaged over feed intensities. Thus, crossbreeding did not result in a higher intake capacity when compared to purebred. As mentioned before, a lack of information about difference in intake has been noticed from the literature review. However, Hessle et al. (2019) showed a higher dietary intake expressed by crossbred steers when compared to pure dairy breed.

B. Average daily gain

Even without differences in feed intake, crossbred bulls gained more weight. This confirms the genetic capacity of the beef breed to grow faster. By crossing these breeds with dairy cattle, the ADG is significantly improved due to a combination of favourable attributes from breeds that are genetically different but with complementary qualities (Cartwight, 1970) and due to heterosis effect which results in progeny with superior traits (Keane, 2011). Results from the present study are in agreement with previous experiments which reported that the growth rate was influenced by the sire breed (Bech Andersen et al., 1977; Vestergaard et al., 2019). This effect was even more important in this study with a 0.15 kg higher ADG compared to a study where dairy cows were crossed with late maturing beef breed sires (Limousine), showing a 91 g higher ADG for crossbred bulls. This fact makes the present experiment even more relevant and the type of crossbreeding more interesting. The present study also shows greater effects of crossbreeding compared to other studies where no significant effect was shown between dairy purebred and dairy x Angus crossbred bulls (Jukna et al., 2009) or steers (Keane & Drennan, 2008). Consequently, this performance is an opportunity to decrease the needed time to reach target final liveweights.

C. Feed conversion to liveweight gain

The significant difference in ADG showed a theoretically better nutrient utilization from crossbred bulls. However, only a tendency to significance was revealed regarding feed efficiency. Crossbred bulls tended to ingest less DM and ME to gain 1 kg of bodyweight, which can be related to other studies, where crossing dairy cows with beef sires has improved feed efficiency (Bech Andersen et al. 1977). However, Hessle et al. (2019) did not report differences on feed efficiency between purebred and crossbred steers, when crossing dairy cows with late maturing Charolais bulls. The difficulty to show significant better feed efficiency from dairy x beef crossbred could be explained by a greater energy requirement for maintenance for beef breeds while ADG is increasing (Pfuhl et al. 2007). Consequently, further studies need to focus on the genetic potential for feed efficiency to make that type of crossbreeding even more interesting.

3. Carcass traits

A. Final liveweight

Due to a higher ADG, crossbred bulls were significantly heavier at the end of the experiment compared to dairy bulls. Even though the initial liveweight was not different between breeds, crossbred final liveweight was 64 kg higher. This difference was expected as the crossbred bulls had higher ADG. Hessle et al. (2019) noticed a 42 kg and Vestergaard et al. (2019) a 41 kg difference between dairy purebred and dairy x late maturing beef crossbred steers or bulls. The possibility to reach the target final liveweight earlier would result in lower feed requirements and costs for a better revenue to the primary production. With lower requirements, the reliance on edible food would decrease and result in a better resource-use efficiency from the global beef production. Moreover, needing less time for the same final liveweight would help to reduce the lifetime emissions from crossbred bulls and improve the environmental impact.

B. Dressing percentage and carcass weight

Using a beef breed sire on dairy cows was expected to improve the dressing percentage since beef breeds have a higher protein accretion (Pfuhl et al., 2007). The resulting better muscular development was shown in the present study where crossbred had a significantly higher dressing percentage. Most of the previous studies have reported the same effect. The present study resulted in a lower difference between purebred and crossbred animals (1.7 unit) than those that used late maturing beef breed sires (Vestergaard et al., 2019). However, our study showed a greater difference in dressing percentage compared with results by Keane and Drennan (2008) who found a 1.3-unit difference between purebred Holstein and dairy x Angus crossbred steers. Consequently, crossbreeding had a positive effect on carcass weight. Similar results were shown with dairy x late maturing beef crossbred (Hessle et al., 2019; Huuskonen et al., 2013; Keane & Drennan, 2008). Vestergaard et al. (2019) found a 44 kg higher carcass weight from dairy x Limousine crossbred bulls compared to purebreds. The present study results were even more interesting since it showed a 46 kg difference when using an early maturing beef breed.

C. Conformation score

Crossbred bulls had a higher conformation score due to an increased protein accretion. By deposing a higher proportion of muscle instead of fat, the crossbred carcass was more conformed. Most of the studies reported this effect, especially when using late maturing beef breed sires. However, the present study showed a conformation score of 7.3, which is more than almost all the reviewed studies, including those using late maturing beef breed sires. Only Keane & Drennan (2008) reported a higher conformation score for crossbred which can be explained by the use of double muscled breed sires (Belgium Blue). The better conformation score from crossbred bulls resulted in a tendency to a higher proportion of high value retail cuts. With a higher dressing percentage, a better conformation and a tendency to higher proportion of high-value retail cuts, crossbred carcasses were improved in quantity as well as quality. By the way, these greater carcass traits are interesting to produce more sealable and valuable beef and by consequent improve economic returns to the production. Hence, less bulls would be required to reach the total volume of beef produced. This would match with the current Swedish situation where dairy cattle represents almost two thirds of the beef production but also where the number of dairy cows is decreasing. The resulted better efficiency and the decrease in cattle number would decrease the greenhouse gas emissions and the negative impact on environment. Moreover, it would result in a lower intensity of the beef production systems and, consequently, a greater consumer acceptability.

D. Fatness score

As mentioned before, selecting on milk production traits has increased the ability of dairy breeds to deposit fat as an energy source for milk production (Pfuhl et al., 2007). Naturally, purebred bulls had a high fatness score in the present study since they start deposing fat earlier. However, crossbred bulls showed a significantly higher fatness score by 1.5 units compared to crossbred bulls. This can be explained by the difference in carcass weight since fatness increases with heavier carcasses (Keane & Allen, 1998). It is in agreement with studies showing that dairy x early maturing beef crossbred had a higher fat content than purebred and late maturing crossbreds (Huuskonen et al., 2013; Keane & Drennan, 2008). The higher fat content of the crossbred carcass was associated with a higher marbling score and an increased trim fat proportion in the hind-quarter. Consequently, combining greater fatness and conformation from crossbred led to a significantly lower proportion of bones compared to purebred. With a higher fatness score and more marbling - which is the last deposed fat -, crossbreeding dairy cows and early maturing beef breed sires would result in more acceptable carcasses. If the fat amount matches consumers requirements, the primary production would also get a higher return.

However, all the advantages shown by that type of crossbreeding need to be firstly related to the dairy industry needs. Indeed, the dairy beef production should not skip dairy main production and milk traits by affecting the replacement rate. By the way, focusing on the use of sex-sorted semen seems to be a great strategy if the costs are not too high.

V. CONCLUSION

The European Union launched the SusCatt project ("Increasing productivity, resource efficiency and product quality to increase the economic competitiveness of forage and grazing based cattle production systems") to strengthen the sustainability of European beef and milk production by evaluating yields, quality, health and welfare, economics, reliance on edible food, gas emissions, environmental impact and consumers acceptability of a transition to high forage and pasture diets. The present thesis, sub-research of the project, evaluated the impact of crossing an early maturing beef breed sire to dairy cows on performance and carcass characteristics of the bulls in a forage-based indoor system.

The thesis aimed to show the advantages of this type of crossbreeding on both performance and carcass characteristics. One of the main objectives was also to investigate an interaction between feed intensity and breed. Finally, it was expected to report a greater sustainability of the young bull production when using dairy x beef crossbred, compared to purebred.

Regarding the established sub-questions, the present experiment showed that:

- no interaction was found between breed and feed intensity.
- crossbreeding resulted in a higher average daily gain without differences in feed intake. Consequently, the feed efficiency tended to be higher for crossbred bulls.
- carcass traits such as weight, dressing percentage, conformation and fatness were greater from crossbred progeny, resulting in improved quantity and quality.
- consequently, crossbreeding dairy cows with Angus sires would result in more sustainable Swedish forage-based young bull production systems from dairy cattle.

To conclude the main question, the present study showed that using Angus semen on dairy cows gives bull calves with a potential for higher weight gains, carcass weights and better carcass characteristics regardless of feed intensity and the proportion of forage in the diet. This leads to more efficient and sustainable Swedish forage-based beef production systems with bulls from dairy cattle.

The Swedish and European dairy industries (advisors, farmers organisations, agricultural companies) could use these results to spread an optimistic message for the future dairy beef production and, by the way, make that type of crossbreeding more important and practiced. In a longer term, governments and European institutions could attract the light and communicate on this sustainable production to professionals and consumers. They could also motivate more and more farmers in this way by involving funding and new Common Agricultural Policy orientations. However, all the advantages shown by that type of crossbreeding need to be firstly related to the dairy industry needs. Indeed, the dairy beef production should not skip dairy main production and milk traits by affecting the replacement rate.

By the way, for further studies on the topic, it would be interesting to focus on the use of sex-sorted semen which seems to be a great strategy to make crossbreeding even more relevant if the costs are suitable. Moreover, higher significancy would be important to show effects on feed efficiency and interaction between breeds and feed intensities. These results could be combined with the present study to report a complete crossbreeding positive impact on dairy beef production.

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