OPTIMISING DAIRY CATTLE BREEDING SYSTEMS BY INCORPORATING REPRODUCTIVE TECHNOLOGIES, PROTEIN YIELD AND RESISTANCE TO MASTITIS

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not, wholly or in part, been presented in this or any other University for an award of a degree.

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Recommendation

This thesis has received our approval for final submission as the official University supervisors.

Signed________________________________

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Date__26th June 2020

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ABSTRACT

The objective of this study was to contribute to dairy cattle improvement in Kenya through optimization of breeding systems that incorporate reproductive technologies and milk quality traits in the dairy cattle breeding programme. Specifically, the study: 1) compared response to selection realized in a closed two-tier nucleus breeding system utilizing different reproductive technologies, 2) estimated the economic values for milk protein yield and mastitis resistance, and 3) compared response to selection realized in a closed two-tier nucleus breeding system utilizing the current and alternative breeding goal accounting for protein yield and mastitis resistance in dairy cattle in Kenya. The current breeding goal which does not account for milk quality traits such as for protein yield and mastitis resistance was considered as base scenario. Deterministic computer simulation programme ZPLAN was used to model and evaluate response to selection. The economic values for milk protein yield and mastitis resistance were estimated using bio-economic model and selection index methodology, respectively. Four strategies considered were Multiple ovulation and embryo transfer using conventional semen (MOET-CS) and X-sorted semen (MOET-XS) and Artificial Insemination using conventional semen (AI-CS) and X-sorted semen (AI-XS). The findings demonstrate that, reproductive technologies that increased reproductive rates of both males and females (MOET-CS) realized higher annual genetic gain and profit of KES 301.42 and 1,769.91 per cow per year, respectively compared to corresponding values of KES 143.97 and 992.84 for (AI-CS). The cost per cow per year for MOET-CS and MOET-XS, however, was 3.4 and 2.5 fold higher than those realized in AI-CS and AI-XS, respectively. Although the type of semen did not have an effect on annual genetic gain and return per cow when used with AI or MOET, they affected the costs and profitability per cow per year. The AI-XS and MOET-XS realized additional costs of KES 31.54 compared with AI-CS and MOET-CS strategies. The corresponding profitability per cow per year was therefore reduced by a similar amount. The economic values for PY and MR were KES 778.99 and -2,364.00, respectively. The alternative breeding goal outperformed the base scenario by KES 358.48 and 613.65 in annual genetic gain and profit per cow per year, respectively. This study has demonstrated that, adoption of reproductive technologies that increase reproductive rate of both males and females such as MOET- CS and incorporating milk quality traits in the breeding goal of dairy cattle optimize response to selection.

Key words: Artificial insemination, Breeding goal, , Multiple ovulation and embyo transfer

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LIST OF ABBREVIATIONS

AGDP	Agricultural Gross Domestic Product
AI	Artificial Insemination
AI-CS	Artificial Insemination with conventional semen
AI-XS	Artificial Insemination with X-sorted semen
CAIS	Central Artificial Insemination Station
CS	Conventional Semen
MOET-CS	Conventional Semen and Multiple Ovulation and Embryo Transfer
EVs	Economic Values
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
KAGRC	Kenya Animal Genetic Resource Centre
KCC	Kenya Cooperative Creameries
KNBS	Kenya National Bureau of Statistics
KNDMP	Kenya National Dairy Master Plan
iLINOVA	Innovations for Livestock industry
MOET	Multiple Ovulation and Embryo Transfer
PY	Protein Yield
SCC	Somatic Cell Count
SIP	Selection Index Programme
XS	X-chrosome sorted semen
MOET-XS	X-sorted Semen and Multiple Ovulation and Embryo Transfer

CHAPTER ONE
GENERAL INTRODUCTION

1.1 Background Information

The dairy sub-sector is regarded as a success case within the agriculture sector in Kenya since it supports the poor, creates employment and is commercially oriented (KDB, 2016). The sub sector is reorienting towards quality and milk processors are adopting the component based milk payment system. It accounts for 4.5 % of Kenya's Gross Domestic Product (GDP) and approximately 14% and 44% of the Agricultural and Livestock GDP, respectively (Rademaker *et al*., 2016; KDB, 2016). The dairy industry provides income and employment to over 1.5 million households along the dairy value chain (Ndambi *et al*., 2019). According to the 2009 population census, Kenya's animal resource base comprises of 17.5 million cattle (KNBS, 2010; MoALF, 2019). Milk production from dairy cattle has been on an upward trend and has been estimated at 5.5 billion litres per year with per capita milk consumption of 145 litres (KNDMP 2010; Wahinya *et al*., 2015). It is projected that, by 2030 the per capita milk consumption will be 220 litres whereas demand for milk is expected to reach 12.76 billion litres per year (KNDMP, 2010, KDB, 2016). Following the enactment of the Constitution of Kenya in 2010, agriculture was devolved. Most of the dairy activities are now undertaken by county governments. Subsequently most of the counties have made dairy one of their flagship projects (KDB, 2015). This underscores the importance attached to the dairy industry by stakeholders at both national and county levels. As demand for dairy products increases it is important for breeders to optimize the use of available and emerging technologies.

Reproductive technologies can be applied to propagate superior genetics and improve herd quality within a shorter period of time in comparison to traditional breeding techniques (Hernandez & Gifford, 2013). The first reproductive technology that has had a major impact on breeding schemes is artificial insemination (AI) (van Arendonk, 2011). Research has shown that the rate of genetic progress in dairy cattle can increase by up to 50% through AI (Rodriguez-Martinez, 2012). In Kenya, superior germplasm has been conventionally disseminated using AI, and to a limited extend multiple ovulation and embryo transfer (MOET) (Murage & Ilatsia, 2011).

In developing countries, Kenya included, low milk quality attributed to cow's poor health is a major constraint to profit maximization in dairy cattle production (Glantz *et al.*, 2009). Somatic cell count (SCC), protein and butter fat contents are the major parameters used to quantify milk quality (Ruegg & Pantoja, 2013; Botaro *et al.,* 2017). Mastitis incidences have been associated with the intense selection for milk production which characterizes most dairy production systems in developing countries (Abebe *et al*., 2016). Mastitis is one of the most costly disease in dairy cattle production systems, costing the dairy industry millions of dollars annually (Berry *et al.*, 2011). In the tropics, however, the losses have been valued at $38.00 per cow per lactation (Mungube *et al*., 2005). The disease incidence in Kenya is extremely high with over 60.7% dairy cows in smallholder production systems producing milk with SCC greater than 200,000 cells/ml (Kashongwe *et al*., 2017). Low milk quality is also associated with dairy products of inferior quality, which translates to economic losses (Glantz *et al*., 2009). Milk quality traits especially protein yield (PY) and SCC are crucial to the dairy industry, since they have a significant impact on milk processing efficiency and product quality (Visentin *et al*., 2017). They also determine the technological properties and the process ability of various milk based products, including cheese, butter, ghee, ice cream and yoghurt (Glantz *et al.*, 2009). In component based pricing systems premium prices are awarded for milk that exceeds certain thresholds, and penalties are imposed on milk that falls below minimum quality thresholds (Foreman & Leeuw, 2013). In Kenya, milk has mainly been marketed in terms of volume. This trend, however, has been changing with most processors imposing penalties in terms of low prices or rejection of deliveries that do not meet the prescribed standards for fat content and pass a given threshold of SCC (Ndambi *et al*., 2018).

Due to the aetiology of this complex disease (mastitis), conventional ways of prevention have yielded limited progress (Berry *et al*., 2011). Antibiotics treatment needs to be used judiciously in the livestock sector to help reduce the emergence of antibiotic resistant pathogens (Mallard *et al*., 2015). Beside use of antibiotics and management practices, one of the most promising approaches to control mastitis in dairy cattle populations is breeding for mastitis resistance (Heringstad *et al*., 2003;Thompson-Crispi *et al*., 2014; Mallard *et al*., 2015). Improvement of animal health through genetic selection is advantageous, because genetic gain is cumulative and permanent, as genes introduced can persist for many generations (Berry *et al*., 2011). Although mastitis resistance (MR) is a difficult trait to measure, selection can be based on the indicator trait such as SCC. Mastitis resistance (MR) has a fairly low heritability (0.09). However, for traits with low heritability, family information is used. Secondly when evaluated with other correlated traits the accuracy of expected breeding values increases. Protein yield (PY) has a fairly high heritability (0.34) impying that direct selection for this trait is possible. Identifying and selectively breeding livestock with the inherent ability to make superior immune responses can reduce disease occurrence, improve milk quality and increase farm profitability (Thompson-Crispi *et al.*, 2014). Fortunately, genetic intervention could be feasible as regions of the genome associated with milk fat, protein content, milk yield and mastitis resistance have been identified (Viguier *et al.*, 2009). Therefore the quality of milk can be improved by genetically modifying the milk component traits and MR through selection (Pretto *et al.*, 2012)

Inclusion of protein yield (PY) and MR in the dairy cattle breeding goal require derivation of their economic values. Economic value can be defined as the change in profitability of an enterprise per unit output due to a unit change in performance of a trait of interest while holding other traits constant (Enns & Nicoll, 2008). Including PY and SCC in the breeding goal would result in dairy cattle genotypes that not only produce high quality milk, but also resistant to mastitis. The superior genetic materials of the resultant genotypes could be disseminated in the dairy cattle population through structured breeding systems. The benefit of this include improved milk quality, animal health and welfare, access to export market and economic status of the dairy industry players.

1.2 Statement of the Problem

In Kenya, dairy cattle production is a major economic activity contributing to food and nutrition security, incomes and employment to a sizeable majority of the population. The dairy sector is reorienting towards quality and milk processors are adopting the component based milk payment system. Farmers are losing out because of high SCC due to mastitis incidences and low milk protein yield. To mitigate against milk rejection, there is need to breed for reduced SCC and high PY. Inclusion of PY and SCC in the breeding goal requires estimation of their economic values which are currently lacking in Kenya. Dairy farmers are also adopting the use of reproductive technologies such as AI and MOET with either sexed or conventional semen. The genetic and economic gains of incorporating these reproductive technologies and milk quality traits in the dairy cattle breeding goal, however, have not been quantified in Kenya.

1.3 Objectives

The overall objective of this study was to contribute to dairy cattle improvement in Kenya through optimization of breeding systems that incorporate reproductive technologies and milk quality traits in the breeding goal. The specific objectives were:

i. To compare response to selection realized in a closed two-tier nucleus breeding system utilizing different reproductive technologies under the current dairy cattle breeding goal in Kenya
ii. To estimate economic values for milk protein yield and mastitis resistance in dairy cattle in Kenya.
iii. To compare response to selection realized in a closed two-tier nucleus breeding system utilizing the current and alternative breeding goal accounting for protein yield and mastitis resistance in dairy cattle in Kenya

1.4 Research Questions

1. What are the responses to selection realized by a closed two-tier nucleus breeding system utilizing different reproductive technologies based on the current dairy cattle breeding goal in Kenya?
2. What are the economic values for milk protein yield and mastitis resistance in dairy cattle in Kenya?
3. What are the responses to selection realized in a closed two-tier nucleus breeding system utilizing the current and alternativebreeding goals accounting for protein yield and mastitis resistance in the dairy cattle in Kenya?

1.5 Justification

The goal of a dairy farmer is to remain competitive in the local market, access international markets and increase profitability. This can only be realized by keeping dairy cattle breeds with high genetic potential for quality milk production. Determining the response to selection for various reproductive technologies would enable farmers make informed decision on the most appropriate technologies to adopt under the Kenyan production conditions. Estimation of economic values for PY and MR would enable their inclusion in the breeding goal. Breeding goal with PY and MR would increase the farmers' profitability for two reasons. First, it would enable selection of candidates that not only produce quality milk, but also resistant to mastitis. This would reduce the quantity of milk rejected by processors due to quality issues. Milk of high quality would also enable farmers to access international markets leading to expansion of their market share especially within the East Africa Community. Secondly, MR would enable cows to remain productive in the herd for long time, as there would be minimal culling from the milking herd.

CHAPTER TWO
LITERATURE REVIEW

2.1 Dairy cattle production systems in Kenya

Dairy cattle production in Kenya can be categorized either based on management or commercial categories. The management categorization is based on intensity of management level employed by the farmers. Three production systems in this category include zero, semi-zero and free grazing system (Onono *et al.*, 2013; KDB, 2016, Ndambi *et al*., 2019). Zero grazing is predominant in high agricultural potential areas. These areas are characterized by reliable rainfall throughout the year, high human population growth rate, frequent land divisions and urbanization. This implies that, although pasture for grazing can grow well in these areas, the grazing land is scarce. The animals are, therefore, kept in barns or zero grazing units. This production system, therefore demands high level of inputs and is labour intensive. The cows are fed on high quality rations and breeds with high genetic potential for high milk production such as Holstein-Friesian and Ayrshire are preferred. Milk production per animal under this system has been demonstrated to be high with herd average production per day of at least 20 litres (Muia *et al*., 2011; Wambugu *et al*., 2011). The semi-zero grazing system partially practices zero and free-grazing. The animals are grazed on pastures, but supplemented in the barns or zero grazing units with formulated rations especially during milking and also with pastures from cut and carry. This production system is mainly common among smallholder dairy farmers in peri-urban areas. Both pure breeds and their crossbreds with local breeds are kept in this production system. The milk production per cow, however, is lower compared to zero grazing (Muia *et al.*, 2011; Wambugu *et al.*, 2011). The free-grazing system is more pasture based. It is the most common production system practiced by most dairy farmers in Kenya especially the smallholder farmers. They mainly raise crossbreds and dual purpose breeds such as Sahiwal and Boran (Ojango *et al*., 2010). Although they produce 80% of marketed milk per year, their production per unit animal is lower (Muia *et al.*, 2011; Wambugu *et al.*, 2011; Wahinya *et al.*, 2015).

The commercial classification of the dairy cattle production systems is dependent on the number of animals kept and level of milk production. They include large and smallholder dairy production systems. The large scale dairy production was mainly practiced by colonialists before independent Kenya. Currently, large-scale dairy production account for 30% of dairy cattle population and produce 20% of the dairy cattle marketed milk (Njarui *et al*., 2011). After independence in 1963, the Government developed policies that strongly supported the sub-division and selling of large-scale farms in the highlands at subsidized rates to smallholder farmers (Bebe *et al*., 2002). Currently, smallholder farms own 70% of the dairy herd and account for about 80% of the total produced and marketed milk in Kenya (Njarui *et al.*, 2011; Wambugu *et al.*, 2011).

2.2 Milk marketing in Kenya

Since the liberalization of the dairy sub sector in Kenya in 1992 (Karanja, 2003), milk marketing has been mainly through formal and informal channels. The informal sector is the major channel through which most producers especially the smallholder farmers who produce over 80% of total milk sell their milk. This has been explained by preference for raw milk by most consumers and low prices for unprocessed compared to processed milk (Njarui *et al*., 2011). The formal sector is mainly driven by processors (Ndambi *et al*., 2019). Currently, there are several milk processors in Kenya, but the main ones include government run New Kenya Corporative Creameries (KCC) and private companies such as Brookside, Daima and Githunguri Dairies. These firms process over 80% of the milk that go through the formal sector (Wambugu *et al.*, 2011). These companies not only process whole milk, but also different products such as yoghurt, cheese, butter, ice-cream and ghee. Their main clientele includes the middle and upper class households, corporate companies and export market within East and Central Africa.

Milk pricing in Kenya is mainly by volume and differ between the two marketing channels. In the informal sector the mean farm gate price is KES 40 compared to KES 26-35 per litre for the formal sector, (Wahinya *et al*., 2015; KDB, 2016). Although the milk marketed through the formal sector is priced based on volume, the processors specify the quality of milk purchased (Ndambi *et al*., 2019). For instance the processors accepts only milk with butter fat content of at least 3.5% and SCC of not more than 200,000/ml and reject any milk delivered without meeting these set standards (Barkema *et al.*, 2015). This has been attributed to the fact that processors process other products other than whole milk which require given level of milk quality.

In Kenya , the dairy sector is shifting towards payment of milk based on quality (Foreman and Leeuw, 2013). This is driven by the fact that there is a market incentive by processors and end buyers of dairy products to provide incentive payment to farmers to stimulate the production of higher quality raw milk (Foreman & Leeuw, 2013). Since 2014, Some processors like Happy Cow started conducting a pilot project on tracking, tracing and implementing quality-based payment system (Ndambi *et al*., 2018). Premium prices are awarded and penalties imposed for milk that exceeds or falls below certain thresholds repectively (Ndambi *et al*., 2019). Protein yield (PY) and SCC have an impact on milk product processing efficiency and quality (Visentin *et al*., 2017). Studies have shown that mastitis lowers milk yield, product quality and safety, and animal welfare (Bobbo *et al*., 2016, 2017; Heikkilä *et al*., 2018; Gonçalves *et al*., 2018).

2.3 Dairy cattle breeding in Kenya

The history of dairy cattle breeding in Kenya dates back to 1920 with the formation of Kenya Stud Book that keep the upgrading register. In 1946 the Central Artificial Insemination Station (CAIS) was established with the objectives of semen production and facilitation of dairy recording services in Kenya (MoALF, 2009). The CAIS has since been rebranded to Kenya Animal Genetic Resources Centre (KAGRC). The KAGRC was created on 5th September 2011 as a State Corporation through Legal Notice No. 110. Its mandate is to produce, preserve and conserve animal genetic material (semen, embryo, tissues and live animals) and rear breeding bulls for provision of high quality disease free semen for local use and export. The KAGRC runs the Bull Station at Kabete for the production of semen. To achieve its objectives, the KAGRC collaborates with other breeding organizations such as the Kenya Stud Book, Dairy Recording Services of Kenya and Livestock Recording Centre in implementation of National Dairy Cattle Breeding Programme. The Centre has linkages with breeding organizations, individuals and institutional farms which provide the herds for its contract mating programme through artificial insermination.

Since the liberalization of AI services in Kenya in 1992 superior germplasm have conventionally been disseminated through bull service, AI, and to a very limited extent, Multiple Ovulation and Embryo Transfer (MOET) (Karanja *et al*., 2003; Murage & Ilatsia, 2011). Dairy cattle breeding programmes rely on both local and imported genetic materials (semen and embryos) for genetic improvement (Ojango *et al*., 2012; Kariuki *et al.*, 2017). Importation of semen is accelerated by need for higher milk yield and inadequate semen production and testing from local proven bulls (Ojango *et al*., 2005). The Kenya government has tried to improve dairy productivity by improving farmer accessibility to breeding services through subsidized AI services (Owango *et al*., 1998). One way of enhancing farmer accessibility to breeding services such as AI is through dairy hubs (Omondi *et al.*, 2017).

Dairy hubs are collective farmer owned/ managed milk bulking /or chilling businesses from which farmers may also gain access to other services they need for their dairy enterprises (Mutinda *et al*., 2015). They are potentially strong platforms for improving smallholder farmers’ access to markets and inputs. Nge’eno *et al*. (2018) reported that there is a positive and significant relationship between participation in dairy hubs and milk yields and farm net returns. Prompt follow ups on AI repeats and flexible payment systems for services offered has made dairy hubs more attractive to farmers (Omondi *et al*., 2017).

The breeding programme in Kenya depicts a closed nucleus breeding system where the coordinated nucleus herds are the main source of breeding stock for the medium and smallholder dairy farmers. Dissemination of superior genetic materials is mainly through AI both in the nucleus and commercial sector. Nucleus breeding programmes have been recommended for genetic improvement in dairy cattle in developing countries (Kahi *et al.*, 2004), since they are easier and cheaper to implement because recording is carried out in the nucleus. The nucleus is usually composed of high performing herds and adequate useable data as the aim is to increase genetic variability for accurate identification of superior genotypes (Groen *et al*., 1997). However, Muasya *et al*. (2013) noted that the breeding programme in Kenya, can be strengthened by recruiting more herds into the nuleus and enhance pedigree recording to realize long term variabity and genetic improvement. Nucleus breeding schemes in dairy cattle in developing countries are advantageous due to lower operational costs, ability to record more traits and achieve accurate identification of superior genotypes because the environment is controlled (Muasya *et al*., 2013).

Until 2015, Kenya did not have comprehensive livestock breeding policy to promote development, conservation and sustainable use of its domestic and emerging livestock genetic resources (MoALF, 2019). The guidelines in livestock breeding were scattered in various government policy and strategy documents such as the National Livestock Policy, Agricultural Sector Development Strategy and the Dairy Master Plan. There exists a national dairy cattle breeding programme. This is a major livestock improvement initiative that is meant to improve the dairy breeds for enhanced productivity. It involves the progeny testing programmes, the contract mating scheme, the recording services for milk and the AI delivery services that together are used to improve the dairy herds in Kenya. The improvement of the dairy cattle herds have been focused volume and not quality.

2.4 Dairy Cattle Breeding Goal

Development of breeding goal is the first step in genetic improvement as it defines the direction of selection and genetic merits of performance traits (Wolc *et al.*, 2011; Åby *et al.*, 2012). In recent decades, dairy cattle breeding goals have become more complex, as the relative emphasis on the milk production traits has decreased compared to the functional traits such as disease resistance (Miglior *et al*., 2017; McClearn *et al*., 2020). Functional traits are those that increase efficiency by lowering cost of production and they include ease of calving, fertility traits, feed efficiency and disease resistance (Groen *et al*., 1997). Functional traits have become important for efficient breeding schemes in the dairy industries, due to increased costs of production relative to milk prices and consumer demands for safe, quality food and attention to animal welfare (Kosgey *et al.*, 2011). Development of breeding goal involves, (a) identification of the breeding, production and marketing systems; (b) identification of sources of income and expenditure; (c) determination of biological traits influencing revenues and costs; and (d) derivation of economic values for each trait in the breeding goal.

Identification of breeding, production and marketing systems

Understanding the breeding system to be adopted helps in identification of the genotype/breed to be raised to realize the desired product (Ponzoni & Newman, 1989). Different dairy cattle breeds are raised in Kenya mainly for milk production. The most preferred dairy cattle breed is the Holstein Friesian followed by the Ayrshire. Other dairy breeds such as the Jersey and Guernsey, and the dual-purpose breeds like the Sahiwal, Brown Swiss, Red Poll, Zebu and Boran (for the pastoralists) are also reared (Wambugu *et al*., 2011). Milk is sold via the formal and informal channels to the milk processors, neighbours and middlemen based on volume. Heifers are sold to medium and smallholder farmers on a willing buyer willing seller basis.

Sources of income and expenses

The sources of income and costs are needed for computation of profitability of the production system. Inputs are related to the overheads, while incomes can be measured in terms of returns that are generated from the sale of the farm’s products (Åby *et al.*, 2012). In dairy cattle production the major sources of income include sale of whole milk and milk products such as cheese, butter, ice cream and yoghurt, heifers and culled cows and bull calves. The main sources of costs in the Kenyan dairy cattle production systems include: feeding, veterinary services, labour, marketing costs and insurance (Kahi & Nitter, 2004). Costs are categorized as either variable or fixed. Variable costs vary depending on the level of production while fixed costs are independent of the level of production (Bett *et al*., 2012).

Traits influencing revenues and costs

The biological traits that influence revenues and costs in dairy cattle production systems in Kenya have been identified (Kahi & Nitter, 2004). The traits in the breeding goal include: milk yield, milk fat, age at first calving, calving interval, average daily gain, pre-weaning daily gain, live weight, pre-weaning survival rate, post-weaning survival rate and cow productive time. This breeding goal, however, ignored most of the milk quality traits. This could be because milk is mainly marketed in terms of volume and no restriction on milk quality. Milk components include fat, protein, ash among others and their proportion in milk varies with breed, season, diet and parity (Glantz *et al*., 2009). The current milk marketing system in Kenya, however, is shifting towards quality and therefore there is need to adjust the current breeding goal to be in tandem with the new market needs.

Derivation of economic values

Economic value is the change in profitability of a production system due to a unit change in genetic gain of a given trait independent of the other traits in the breeding goal (Groen, 1990). Different methods have been used to derive economic values. They include analysis of field data and bio-economic models (Kahi & Nitter, 2004; Sölkner *et al*., 2007). Deriving economic values based on field data is not common because it uses historical prices while breeding is future oriented. Most studies therefore have derived economic values using bio-economic models. In this model, economic values can be estimated using either simple or risk rated models (Kulak *et al.*, 2003; Okeno *et al.*, 2012; Mbuthia *et al*., 2015). Simple profit models have been demonstrated to overestimate economic values because it assumes perfect knowledge of all relevant parameters and constant economic circumstances (Kulak *et al.,* 2003; Okeno *et al.,* 2012). On the other hand, risk-rated models account for imperfect knowledge concerning risk attitude of producers and variance of input and output prices (Kulak *et al.*,2003; Okeno *et al.,* 2012; Mbuthia *et al.,* 2015). Table 1 shows the economic values for traits in the dairy cattle breeding goal in Kenya.

Table 1: Economic values in Kenya Shillings for traits in the breeding goal under the two milk payment systems

Trait	Payment system	
	Milk volume	Milk volume and fat
Milk yield	18.93	16.05
Fat yield	-2.76	79.44
Age at first calving	-2.72	-2.72
Calving interval	2.65	2.65
Average daily gain	1.04	1.04
Pre-weaning daily gain	3.40	3.40
Live weight	7.95	7.95
Pre-weaning survival rate	9.96	9.96
Post-weaning survival rate	45.15	45.15
Cow productive life time	0.07	0.07

1US$=KES 100.00

Source: Kahi & Nitter, (2004)

In Kenya, the economic values of traits in the breeding goal have been derived using simple bio-economic model (Kahi & Nitter, 2004). These economic values reflect the production and economic environment under which the dairy cattle are raised in Kenya and account for farmers, marketers and consumer needs. The economic values for milk protein yield and mastitis resistance, however, were not included and therefore needs to be estimated.

2.5 Genetic and phenotypic parameters for traits in the dairy cattle breeding goal

The importance of genetic and phenotypic parameters as input variable in evaluation of breeding programmes cannot be over emphasized. Reliable estimates of genetic and phenotypic correlations among traits are needed in order to obtain accurate expected breeding value from multi-trait evaluations (Seyedsharifi *et al*., 2018). Estimates of the genetic parameters are also required in order to predict how the genetic improvement of one trait will cause simultaneous changes in other traits (Kruuk, 2004). Ideally this should be done before a breeding goal is implemented. A good understanding of the often unfavourable genetic correlations between milk production traits and functional traits is especially needed so that harmful correlated responses to selection do not come as a surprise. Genetic and phenotypic parameters also facilitate computation of accuracies of the index. Their reliability is environment and population specific and requires reliable data for estimation (Mulder *et al*., 2013; de Lima Silva *et al*., 2019). Unfortunately, performance recording in Kenya as in other developing countries is one of the main challenges facing the breeding programmes (Kosgey *et al*., 2011), therefore, literature estimates have been adopted to evaluate most breeding programmes in the tropics (Kahi *et al*., 2004; Ilatsia *et al*., 2011). The importance of having local, population specific genetic parameter estimates in the design of breeding goals in the tropics has been reported (Aknano *et al*., 2013). The current study therefore adopted the genetic and phenotypic parameters used by Kahi *et al.*(2004) as presented in Table 2. The genetic and phenotypic correlation with milk component traits were obtained from other studies conducted in the tropics (Al-Seaf *et al.*, 2007; Banga *et al.*, 2009; Glantz *et al*., 2009; Pfeiffer *et al*., 2015), as they were not accounted for in Kahi *et al.*(2004). Protein Yield (PY) and MR were introduced as additional traits in the breeding goal since they influence revenue in milk component pricing systems. Protein yield has a heritability of 0.34 implying that this trait can be included in the breeding goal by direct selection. Resistance to mastitis has a relatively low heritability and indirect selection can be used to include this trait in the breeding goal (Weigel & Shook, 2018). In this study SCC was used as the indicator trait for resistance to mastitis.

Table 2: Heritability (along diagonal bold), phenotypic standard deviations, economic values, genetic correlations (above diagonal) and phenotypic correlations (below diagonal) for traits in the breeding goal and selection criteria

Traits[a]	MY	FY	PY	SCC	AFC	CI	DG	PDG	LW	PreSR	PostSR	PLT
σ_p[b]	1208.46	36.57	39.5	1.85	448.76	75.34	19.00	743.00	54.14	30.00	30.00	864.90
EVs[c]	16.05	79.44	-	-	-2.72	2.65	1.04	3.40	7.95	9.96	45.15	0.07
MY	0.30	0.75	0.70	-0.03	0.20	0.17	0.10	0.11	0.23	0.00	0.00	0.00
FY	0.73	0.32	0.61	-0.19	-0.10	0.08	0.10	0.11	0.12	0.00	0.00	0.00
PY	0.95	0.78	0.34	-0.02	-0.14	0.10	0.00	0.00	0.13	-0.20	-0.20	0.16
SCC	-0.20	0.02	-0.13	0.09	0.00	0.17	0.00	0.00	0.00	0.00	-0.13	0.06
AFC	-0.21	0.05	0.22	0.00	0.38	-0.21	-0.20	-0.20	0.15	0.00	0.00	-0.13
CI	0.17	0.08	0.00	0.00	-0.21	0.06	0.00	0.00	-0.40	0.00	0.00	0.10
DG	0.10	0.10	0.00	0.00	-0.25	0.10	0.29	-0.25	0.20	0.06	0.03	0.10
PDG	0.11	0.11	0.00	0.00	-0.25	0.10	0.49	0.32	0.25	0.03	0.06	0.10
LW	0.23	0.12	0.06	0.00	0.15	-0.43	0.40	0.47	0.30	0.01	0.00	0.27
PreSR	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.03	0.01	0.09	0.00	0.00
PostSR	0.00	0.00	0.11	-.14	0.00	0.00	0.03	0.06	0.00	0.01	0.09	0.00
PLT	0.00	0.00	0.00	0.00	-0.13	0.10	0.10	0.10	0.27	0.00	0.00	0.11

[a]MY, milk yield (kg); FY, fat yield (kg); PY, protein yield (kg); SCC (cells/ml); AFC, age at first calving (days); CI, calving interval (days); DG, pre-weaning daily gain (g/day); PDG, post-weaning daily gain to 18 months (g/day); LW, live weight (kg); PreSR, pre-weaning survival rate (%); PostSR, post-weaning survival rate (%); PLT, cow productive life time (days).

σp[b], phenotypic standard deviation

EVs[c], economic values

(Source: Kahi *et al*., 2004; Kahi and Nitter 2004).

2.6 Dairy cattle breeding programmes and dissemination of superior genetic materials

A variety of breeding structures for the development and delivery of appropriate genetic materials have been reported (Kosgey *et al.,* 2011; Rege *et al.,* 2011). They include sire rotation or loan schemes, community based and nucleus-based programmes. The sire rotation or loan schemes and community based programmes require active participation of the communities involved to be successful (Rege *et al.,* 2011). Nucleus-based programmes on the other hand, reduce the requirement for community cooperation and intensive recording in smallholder herds. This is because they concentrate pedigree and performance recording within few herds or population called nucleus and therefore reduces the production costs associated with recording (Kosgey *et al.,* 2006*)*. Nucleus-based programmes are pyramid like structures where genetic improvement is done within the nucleus and the superior genes generated within the nucleus is disseminated to the entire population either through natural mating or different reproductive technologies such as AI and MOET (Rege *et al*., 2011; van Arendonk, 2011). Where natural mating is involved, a three tier nucleus breeding programme is required. The middle tier is called "multiplier", and its main role is to multiply candidates from the nucleus to meet the numbers needed for breeding in the lower tier (commercial tier). Where reproductive technologies are applied, a two-tier nucleus system is adopted. This implies that, the multiplier level is ignored and therefore superior genetic materials from the nucleus are transferred directly to the commercial population (van Arendonk, 2011). In dairy cattle breeding a two-tier nucleus breeding programme is practiced. The two or three-tier nucleus breeding systems can either be closed or open (Kosgey *et al.,* 2006).

Closed nucleus breeding system

This breeding system involves unidirectional flow of genes from the elite populations (nucleus) to the commercial herds or populations (Ilatsia *et al.,* 2011; Rege *et al*., 2011). This implies that the nucleus does not allow introduction of genetic materials from outside. The genetically superior candidates are therefore retained in the nucleus as replacement stock while the remaining candidates are sold to the multiplier or commercial tiers for breeding (Santos *et al*., 2017). Closed nucleus breeding system has been demonstrated to be superior in profitability, but inferior to open nucleus breeding scheme in genetic gain (Ilatsia *et al*., 2011; Rewe *et al*., 2011). Their superiority in profitability could be explained by non-recording in the commercial herds which reduces the cost of production. The low genetic gain, on the other hand could be attributed to higher rate of inbreeding due to rapid loss in genetic variance in closed population (Carrillo & Siewerdt, 2010).

Open nucleus breeding system

This breeding system has similar structure as closed nucleus breeding system, but allow flow of genetic materials from the lower tiers to the nucleus. The superior candidates in the lower tiers are introduced in the nucleus for breeding (Wakchaure & Ganguly, 2015). Mainly the superior females are introduced into the nucleus. The introduction of females from the lower tiers to the nucleus has been attributed to Mendelian sampling which can lead to high performing animals in the lower tiers irrespective of the fact that they are daughters of nucleus born candidates. Open nucleus breeding systems with reproductive technologies such as AI and MOET have been recommended for developing countries due to their high response to selection (Wakchaure & Ganguly, 2015). This system has been demonstrated to have lower rate of inbreeding and provide approximately 10% more genetic gain than closed systems (Roden, 1995).

2.7 Breeding for disease resistance

Disease resistance has an array of definition owing to the thin line between resistance and tolerance (Bishop, 2012). Mastitis resistance could be defined as the ability to avoid any infection or the quick recovery from an infection (Thompson-Crispi *et al*., 2014). Generally, mastitis resistance is a multifactorial quantitative trait (Morris, 2007; Tiezzil *et al.*, 2015) and susceptibility is controlled by both genetic and non-genetic factors. Disease resistance is one of the desirable traits in animal production. The current situation is that antibiotics are administered more judiciously because of consumer fears of residual drugs in animal products and microbial resistance to commonly used antibiotics. Consequently, genetic and genomic as well as epigenetic methods to improve livestock health that capitalize on the animal's own inherent ability to make appropriate immune responses are being exploited (Mallard *et al*., 2015). Numerous studies over two decades of research have shown that breeding for enhanced disease resistance based on breeding values of immune responses improves livestock health while not negatively impacting production traits (Thompson-Crispi *et al*., 2014). Breeding for mastitis resistance seems to be the most promising application that can be used to complement the strategic use of antibiotics and improved herd management. From a genetic perspective, understanding the natural, innate, and acquired immune systems is crucial in developing selection programmes for disease resistance (Berry *et al*., 2011).

2.8 Reproductive technologies in dairy cattle production

The use of reproductive technologies is increasing in developing countries, following the huge flow of information and globalization (Rodriguez-Martinez, 2012). Sexed semen has been a dream of dairy cattle producers and it is now the game changer in the dairy industry (Fleming *et al.*, 2018). Currently, production of progeny of the desired gender using sex sorted semen has become an established realizable technique in dairy herds (Mikkola *et al.*, 2015). Beside use of sex sorted semen in insemination of single ovulating cows and heifers, it is also used in super ovulated animals in production of both in vivo and invitro embryos (Mikkola *et al*., 2015). Semen sexing is credited for improving production efficiency through producing replacement heifers from genetically superior animals (Seidel, 2012). Despite the advantage of predetermination of sex on profitability, use of sexed semen has little value on increasing rate of genetic improvement (Nicholas, 1996; Fleming *et al*., 2018).

Embryo transfer is a technique used to increase the number of offspring from females of high genetic merit. However, since its inception over five decades ago, its adoption and success rate has been low (Pedersen *et al*., 2012). This is due to heat stress and inefficiencies in heat detection in dairy herds (Fleming *et al*., 2018). Fixed time embryo transfer (FTET) is an alternative technique that has been proposed to make embryo transfer independent from oestrus detection (Rodrigues *et al*., 2010). Generally, MOET produces substantial genetic improvement. However, substantial increase in inbreeding has been noted (van Arendonk, 2011), therefore it is important to account for Bulmer effect, which is defined as reduction in additive variance due to selection.

Artificial insemination (AI) remains the most important and widely used reproductive technology in developing countries owing to the fact that it is simple and economical (Rodriguez-Martinez, 2012). Implying that it plays a pivotal role in dissemination of genetically superior material. The application of reproductive techniques has had a major impact on the structure of breeding Programmes, the rate of genetic gain and the dissemination of genetic superiority in livestock production (van Arendonk, 2011). Modern reproductive technologies have been integrated with modern genomic selection tools to improve economically important traits including fertility (Veerkamp & Beerda, 2007; Berendt *et al*., 2009)

As demand for dairy products increases. It is important that dairy breeders optimize the use of available technologies and also consider emerging technologies that are currently under investigation in various fields (Fleming *et al*., 2018). In Kenya, the choice of a reproductive technology is determined by various factors: the socioeconomical status of the farmer, the size of the farm, scale of production, education level and age of the farmer (Murage & Ilatsia, 2011). Prior to the implementation of any reproductive technology, their effect on genetic gain, financial implications, and societal acceptance of these technologies should be considered (Fleming *et al*., 2018). Reproductive technologies aimed at improving reproductive efficiency have been a high priority and will play a crucial role in meeting the rising challenges of food supply (van Arendonk, 2011). This study therefore focused on AI since it is the commonly used reproductive technology in Kenya and MOET as an alternative strategy.

CHAPTER THREE

INCREASING REPRODUCTIVE RATES OF BOTH SEXES IN DAIRY CATTLE BREEDING OPTIMIZES RESPONSE TO SELECTION

Abstract

It was reasoned that technologies that increase the reproductive rate of males and females in dairy cattle would realize higher responses to selection. The authors tested this hypothesis using deterministic simulation of breeding schemes that resembled those of dairy cattle in Kenya. The response to selection was estimated for four breeding schemes and strategies. Two breeding schemes were simulated, based on artificial insemination (AI) and multiple ovulation and embryo transfer (MOET) reproductive technologies. The strategies were defined according to the use of conventional semen (CS) and X-chromosome-sorted semen (XS). The four strategies therefore were AI with CS (AI-CS) and XS (AI-XS), MOET with CS (MOET-CS) and XS (MOET-XS). The four strategies were simulated based on the current dairy cattle breeding goal in Kenya. A two-tier closed nucleus breeding programme was considered, with 5% of the cows in the nucleus and 95% in the commercial. Dissemination of superior genetic materials in the nucleus was based on all four breeding strategies, while in the commercial only the AI-CS strategy was considered. The strategies that increased the reproductive rates of both males and females (MOET-CS and MOET-XS) realized 2.1, 1.4, and 1.3 times more annual genetic gain, return, and profitability per cow, per year, respectively, than strategies that increased the reproductive rates only of males (AI-CS and AI-XS). The use of CS or XS, however, did not affect response to selection in the two schemes. The findings demonstrate that reproductive technologies such as MOET maximize response to selection in dairy cattle breeding.

3.1 Introduction

Dairy cattle production plays an important economic role at household and national level in the tropics (Smith *et al*., 2013). It is the most vibrant sector in the livestock industry in Kenya (Bebe *et al.*, 2017), and supports over 1.8 million smallholder farmers, who own one to three cows, and account for 70% and 80% of the milk produced and marketed, respectively (KDB, 2015). In the recent past there has been a rise in demand for dairy products in Kenya (Bingi & Tondel, 2015). This has been attributed to an increase in human population, urbanization, increased income per household, and greater demand for milk products in East African countries (Bingi & Tondel, 2015). This demand could be met only through good management of dairy animals and breeding. Improvement through breeding requires an efficient and sustainable breeding programme that accounts for the needs of stakeholders in the dairy cattle value chain. In Kenya, the breeding programme for dairy cattle is well structured as large-scale farms represent the nucleus, and smallholder farms form the lower tier. Although the efficiency of this programme has been assessed,, the most effective way to disseminate genetic materials that are generated in the nucleus to smallholder farmers has not been investigated.

Reproductive technologies such as artificial insemination (AI) and multiple ovulation and embryo transfer (MOET) are currently being used with conventional (CS) and sexed semen (XS). AI-CS is the most widely used reproductive technology in Kenya (Omondi *et al.*, 2017). In the recent past, however, most farmers have used MOET and XS (Moore & Thatcher, 2006; Kosgey *et al*., 2011), possibly because they are interested in maximizing female reproduction and increasing the number of female calves born to overcome the challenge of heifer unavailability. Reproductive technologies could shorten generational intervals, increase selection intensities, and reduce the cost of production, which is attributed to having to transport live breeding candidates from one location to another. Since these technologies increase the reproductive rate of candidates, they would enhance accuracy of selection owing to large numbers of related candidates being recorded. Enhancing the reproductive rate of males and females through AI and MOET, respectively, therefore could optimize response to selection compared to increasing the reproductive rate of only one sex.

Studies have demonstrated that the utilization of reproductive technologies could achieve increased genetic and economic response to selection (Sørensen *et al*., 2011). Such evaluations, however, are scarce in the tropics. To the authors' knowledge, no studies have compared genetic and economic responses to reproductive technologies in Kenya. These technologies were therefore used, based on the assumption that they would yield similar results. The authors used the Kenyan dairy cattle breeding programme as their model to compare the genetic and economic response to selection for reproductive technologies based on AI and MOET with CS and XS. The evaluation was based on the dairy cattle breeding goal in Kenya, in which milk sales are based on volume (Kahi *et al.*, 2004). They hypothesized that a combination of the reproductive technologies that increase the reproductive rate of males and females would bring about a higher response to selection than those targeting only one sex.

3.2 Materials and methods

A deterministic simulation was used to model and estimate the response to selection that is attained by dairy cattle breeding schemes that utilize AI and MOET with CS and XS in a closed two-tier nucleus breeding system. AI-CS was the base scenario with which other strategies were compared. It is the most commonly used reproductive technology among dairy cattle farmers in Kenya. The genetic and economic returns per cow per year for each strategy formed the basis of comparison. In Kenya, two main dairy cattle production systems are recognized, namely commercial and smallholder systems (Onono *et al.*, 2013). Commercial production systems own 20% of the dairy cattle population and produce 30% of the marketed milk. They are characterized by owning at least 50 milking dairy cows, and producing their own replacement stock with intensive management regimes (KDB, 2015). The smallholders, on the other hand, own 80% of the dairy cattle population and produce 70% of the marketed milk (KDB, 2015). However, they have small pieces of land and cannot produce enough feed and raise heifers. They depend on culled cows and heifers from the commercial farms. This depicts a two-tier closed nucleus system breeding programme as the flow of genetic materials is unidirectional from commercial farms, which act as the nucleus, to smallholder farms, which represent the commercial tier. The breeding programme was developed in such a way that AI and MOET with conventional and sexed semen were used in the nucleus, while only AI-CS was considered in the commercial population. Genetic and economic responses to selection for the breeding strategies were used to compare the schemes.

Development of a breeding goal is the first step in genetic improvement as it defines the direction of selection and genetic merits of performance traits (Åby *et al.*, 2012). It involves i) identifying the breeding, production and marketing systems; ii) identifying sources of income and expenditure; iii) determining the biological traits that influence revenues and costs; and iv) deriving economic values for each trait in the breeding goal. The breeding goal for dairy cattle production in Kenya has been defined (Kahi & Nitter, 2004). It is market oriented and strives to produce dairy cattle with high milk production under Kenyan conditions. The traits include milk yield (MY), fat yield (FY), age at first calving (AFC), calving interval (CI), pre-weaning daily gain (DG), post-weaning daily gain to 18 months (PDG), live weight (LW), pre-weaning survival rate (PreSR), post-weaning survival rate (PostSR) and productive lifetime (PLT).The economic values of these traits were estimated objectively based on change in profitability of the production system due to a unit change in one trait and holding other traits constant. They were estimated under fixed herd and pasture production systems. In each system the economic values were estimated when the price of milk was based on volume or fat content. In this study, the economic values that were estimated under a fixed herd production system were adopted after adjustments to reflect current market inflation rates. In Kenya factors such as land size, labour, management skills and availability of feed determine herd size. The adjustments of the economic values were necessary because the market is dynamic, and input and output prices change over time depending on inflation rates. These economic values were therefore adjusted by multiplying them by their cumulative discounted expressions. Cumulative discounted expressions reflect time and frequency of future expression of a trait in a superior genotype from selected parents (Berry *et al*., 2006). The traits in the breeding goal, their economic values and genetic parameters are presented in Table 3. The genetic parameters were obtained from studies conducted in Kenya. Where such values were missing, other studies in the tropics were consulted (Kahi & Nitter, 2004; Kahi *et al*., 2004; Ilatsia *et al*., 2011).

Table 3: Heritabilities (along diagonal bold), phenotypic standard deviations, economic values, genetic correlations (above diagonal) and phenotypic correlations (below diagonal) for traits in the breeding goal and selection criteria

Traits[a]	MY	FY	AFC	CI	DG	PDG	LW	PreSR	PostSR	PLT
σ_p[b]	1208.46	36.57	448.76	75.34	19.00	743.00	54.14	30.00	30.00	864.90
EVs[c]	16.05	79.44	-2.72	2.65	1.04	3.4	7.95	9.96	45.15	0.07
MY	**0.30**	0.91	0.20	0.17	0.10	0.11	0.23	0.00	0.00	0.00
FY	0.73	**0.32**	-0.10	0.08	0.10	0.11	0.12	0.00	0.00	0.00
AFC	-0.21	0.05	**0.38**	-0.21	-0.20	-0.20	0.15	0.00	0.00	-0.13
CI	0.17	0.08	-0.21	**0.06**	0.00	0.00	-0.40	0.00	0.00	0.10
DG	0.10	0.10	-0.25	0.10	**0.29**	-0.25	0.20	0.06	0.03	0.10
PDG	0.11	0.11	-0.25	0.10	0.49	**0.32**	0.25	0.03	0.06	0.10
LW	0.23	0.12	0.15	-0.43	0.40	0.47	**0.30**	0.01	0.00	0.27
PreSR	0.00	0.00	0.00	0.00	0.06	0.03	0.01	**0.09**	0.00	0.00
PostSR	0.00	0.00	0.00	0.00	0.03	0.06	0.00	0.01	**0.09**	0.00
PLT	0.00	0.00	-0.13	0.10	0.10	0.10	0.27	0.00	0.00	**0.11**

[a]MY: milk yield (kg), FY: fat yield (kg), AFC: age at first calving (days), CI: calving interval (days), DG: pre-weaning daily gain (g/day), PDG: post-weaning daily gain to 18 months (g/day), LW: live weight (kg), PreSR: pre-weaning survival rate (%), PostSR: post-weaning survival rate (%), PLT: cow productive lifetime (days)

[b]σ_p: phenotypic standard deviation

[c]EV: economic values

(**Source:** Kahi *et al.*, 2004; Kahi & Nitter 2004; Ilatsia *et al*., 2011)

A two-tier closed nucleus breeding system was considered. This system assumed a single direction of flow of genetic material in which the genetic gain that was generated in the nucleus was disseminated to the commercial population. This implies that the nucleus does not allow genetic materials to be introduced from outside. The genetically superior candidates were therefore retained in the nucleus as replacement stock, while the remaining candidates were sold to the commercial tier for breeding. Four strategies were considered, based on the reproductive technology adopted in the breeding programme:

Artificial Insemination with conventional semen (AI-CS): This strategy assumes that AI was the only reproductive technology used to disseminate genetic materials in the nucleus. In this strategy only CS was considered. This strategy represent the most commonly used reproductive technology in dairy breeding in Kenya currently.

Artificial Insemination with X-sorted semen (AI-XS): This strategy is similar to AI-CS, but only XS was used to inseminate cows in the nucleus. The use of this strategy is currently increasing in Kenya, especially in large-scale dairy farms.

Multiple ovulation and embryo transfer with conventional semen (MOET-CS): This strategy increases the reproductive rate of both males and females. It involves stimulating a donor cow to release many ova from its ovaries, which are then fertilized with conventional semen. Thereafter, the embryos develop and can be flushed from the uterus of the donor cow and transplanted to heat-synchronized recipient cows that carry the pregnancy to term. Although this strategy is not common in Kenya, it is being practised on some large-scale farms.

Multiple ovulation and embryo transfer with X-sorted semen (MOET-XS): This strategy is similar to MOET-CS, but the oocytes are fertilized with XS.

A simulated population of 50,000 cows was distributed between the two tiers. The top tier (nucleus) consisted of 5% of the highest ranking cows in the population, while the remaining 95% constituted the lower tier (commercial population). The biological and economic parameters used in the current study were obtained from previous studies on dairy cattle in Kenya (Kahi & Nitter, 2004; Kahi *et al*., 2004; Ilatsia *et al*., 2011). Truncation selection based on estimated breeding values was used to select top ranking males and females for breeding in the nucleus. The second top ranking males and females were used for breeding in the lower tier. The young bull scheme was used to disseminate genetic materials in the population. The use of the young bull scheme was recommended because of the short generation interval (Kahi *et al*., 2004). Candidates that were not selected for breeding in the nucleus and commercial populations were culled and sold for meat production. AI-CS, AI-XS, MOET-CS and MOET-XS were used in the nucleus, and only AI-CS was adopted in the commercial population.

The mating ratio was one bull to 100 cows in both the nucleus and commercial systems. The number of calves per cow per year in AI strategies was assumed to be 0.95 and

0.60 in the nucleus and commercial, respectively. In the MOET strategies, each cow in the nucleus was assumed to produce 10 calves per year. The sex ratio for strategies using CS was 0.5, while the male to female ration for those using XS was 0.05:0.95. Two and three inseminations per conception were assumed for use of CS and XS, respectively. Various selection pathways were considered in disseminating genetic gain. The main pathways were sires to breed sires (SS) and dams (SD), and dams to breed sires (DS) and dams (DD). Each selection group had different sources of information for traits in the breeding goal. The information sources for SS and SD were records of individual, sire, dam, dams of the sire and dam, while those for DS and DD were records of the individual, dam, sire, all female paternal half sibs of the dam and sire, dams of the sire and dam. The input populations, biological and technical parameters that were used to model the breeding schemes are presented in Table 4.

Table 4 Population, biological and technical parameters for nucleus and commercial herds of cattle used in the study

Population parameters	**Nucleus**	**Commercial**
Number of cows	2500.00	47500.00
Proportion of cows in the nucleus and commercial (%)	5.00	95.00
Productive life time (years)		
Bulls to breed bulls in the nucleus	5.00	
Dams in the nucleus to breed bulls in the nucleus	5.00	
Bulls in the nucleus to breed dams in the nucleus	5.00	
Dams in the nucleus to breed dams in the nucleus	7.00	
Bulls in the nucleus to breed bulls in the commercial	5.00	
Dams in the commercial to breed bulls in the commercial		7.00
Bulls in the commercial to breed dams in the commercial		3.00
Age at first calving (years)		
Bulls to breed bulls in the nucleus	2.00	
Dams in the nucleus to breed bulls in the nucleus	3.00	
Bulls in the nucleus to breed dams in the nucleus	2.00	
Dams in the nucleus to breed dams in the nucleus	3.00	
Bulls in the nucleus to breed bulls in the commercial	2.00	
Dams in the commercial to breed bulls in the commercial		4.00
Bulls in the commercial to breed dams in the commercial		3.50
Additional parameters		
Pre-weaning survival rate (%)	0.99	0.90
Post-weaning survival rate (%)	0.99	0.92
Calving interval (years)	1.30	1.30
Proportion of sires suitable for breeding (%)	0.89	0.80
Proportion of cows suitable for breeding (%)	0.90	0.81
Number of calves per cow per year in Artificial Insemination strategy	0.95	0.60
Number of calves per cow per year for Multiple Ovulation and Embryo Transfer strategy	10.00	0.00
Number of cows per bull	500.00	500.00
Replacement rate of cows per year (%)	0.25	0.25
Number of inseminations per conception using conventional semen	2.00	2.00
Number of inseminations per conception using sexed semen	3.00	0.00
Probability of getting a heifer when using sexed semen	0.90	0.00
Probability of getting a heifer when using conventional semen	0.50	0.50

The breeding system was initiated by sampling unrelated base populations of bulls and cows. There were 2,500 cows in the nucleus and 47,500 in the commercial. Five hundred bulls were used in both the nucleus and commercial. Semen was collected from the bulls.

Half was used as CS and the other half was sorted for X-chromosome, prior to use. For each animal ***i*** in the base population, a vector of true breeding values (tbv_i) was calculated for all simulated traits using the following equation:

$$tbv_i = L'*r_1 \tag{1}$$

where: **L'** is the Cholesky decomposition of the (co)variance matrix **G**, and $\mathbf{r_l}$, is a vector of random numbers from standardized normal distribution.

In later generations $\boldsymbol{tbv_i}$ was simulated as;

$$tbv_i = 0.5*(tbv_{i(sire)} - tbv_{i(dam)}) \tag{2}$$

The phenotypes of the traits for the i^{th} based animal were calculated as;

$$obs_i = tbv_i + c'*r \tag{3}$$

where: **C**' is the Cholesky decomposition of the environmental (co)variance matrix **R**, and **r** is a vector of random numbers from a standardized normal distribution.

All the breeding values were predicted using best linear unbiased prediction (BLUP) by fitting a multivariate animal model to the phenotypes. The model was computed as:

$$\mathbf{y} = \mathbf{Xb} + \mathbf{Za} + \mathbf{e} \tag{4}$$

where: *Y* is the vector of phenotypes, a vector of fixed effects, *a* is a vector of random animal effects, **e**, a vector of residual errors, and *X* and *Z* the incidence matrices.

The breeding values were computed using (co)variance matrix presented below:

$$\begin{pmatrix} \mathbf{a} \\ \mathbf{e} \end{pmatrix} \sim \mathrm{N}\left(0; \begin{bmatrix} \mathrm{G} \otimes \mathrm{A} & 0 \\ 0 & \mathrm{R} \otimes \mathrm{I} \end{bmatrix}\right) \tag{5}$$

where: the matrix **A** is the numerator relationship matrix among all animals, the matrix **G** is the additive genetic (co)variance matrix of traits in the breeding goal, and the matrix **R** is the (co)variance matrix for residual effects.

The economic returns were determined based on profitably per cow in each breeding system. The profitability per cow was estimated as:

$$\pi = \sum_{t=0}^{T} \left(\frac{R_t - c_t}{(1 + r)^t} \right) \tag{6}$$

where: *T* is the evaluation period (25 years), R_t the annual benefits of genetic improvement calculated as realized genetic gain per cow per year, c_t the costs of genetic improvement which includes fixed and variable costs and *r* the discounting rate. The discounting rate of 5% was recommended when evaluating animal breeding programmes (Bird & Mitchel, 1980) and was adopted in the current study. Variable costs are presented in Table 5. These included costs that were directly related to performance and pedigree recording. Fixed costs were those incurred in one round of selection and were the overhead costs of running the nucleus of 2,500 cows. The average time at which fixed costs occurred was assumed to be the mean generation interval. Variable and fixed costs affect only the profit, and not the genetic response. The interest rates for returns (8%) and costs (6%) were based on the current marketing conditions in Kenya (CBK, 2017).

Table 5: Variable costs in the nucleus in Kenya shillings **(**Kenya Shillings 100 = 1 USD)

Parameters	Costs (KES)
Identification, pedigree recording and data processing	105.00
Milk recording	30.00
Fat analysis and recording	100.00
Age at first calving recording	30.00
Calving Interval recording	30.00
Daily gain recording	30.00
Post weaning daily gain recording	30.00
Bull assessment	200.00
Cows assessment	200.00
Semen collection, storage and artificial insemination services per straw	1000.00
Semen collection, sexing, storage and artificial insemination services per straw	5000.00
Cows synchronisation, embryo collection and transfer	50,000.00
Labour	0.14

The responses to selection in all the simulated breeding strategies were evaluated in terms of annual genetic gain, return on investment, and profitability after an investment period of 25 years. Genetic gain was calculated per cow per year. The rate of genetic gain for each cow was predicted as linear regression of true breeding values for each trait in the breeding goal weighted by its corresponding economic values and expressed per year. Profitability was computed as the difference between the returns and the total costs.

A deterministic computer programme for simulating livestock breeding programmes, namely ZPLAN z10 (Willam *et al.*, 2008), was used to model and evaluate the breeding systems. Using the gene flow methods and selection index procedures, ZPLAN simulates various breeding plans in any livestock species. It computes genetic gain for the aggregate breeding value, the annual response for each selection and correlated trait and the profit per female animal in the population by subtracting breeding costs from returns. The programme uses the genetic, biological and economic parameters provided in the input files to calculate the costs and returns. The calculations assume that the input parameters and selection strategies remain unchanged over the investment period with one round of selection. Reduction in genetic variance and change in rate of inbreeding, however, is not considered. The programme applies order statistics to obtain adjusted selection intensities for population with finite sizes. ZPLAN has been used widely to model and evaluate cattle breeding programmes such as those for dairy cattle (Kahi *et al.*, 2004), dual-purpose cattle (Ilatsia *et al*., 2011) and beef cattle *(*Rewe *et al*., 2010).

3.3 Results

The findings of the current study confirmed the hypothesis that breeding schemes that utilize technologies that increase the reproductive rates of males and females realize a higher response to selection compared with those that increase the reproductive rates of only one sex. The responses to selection based on annual genetic gain, returns, costs and profit of these strategies after the investment period of 25 years are presented in Table 6.

Table 6: Annual genetic gain, returns, costs and prifits (KES) per cow for four breeding strategies after 25 years

Parameters	Strategies			
	AI-CS	AI-XS	MOET-CS	MOET-XS
Genetic gain	143.97	143.97	301.42	301.42
Returns per cow	1046.51	1046.51	1951.06	1951.06
Cost per cow	53.67	85.21	181.15	212.71
Profit per cow	992.84.	961.30	1769.91	1738.35

AI-CS: artificial insemination with conventional semen, AI-XS: artificial insemination with X-chromosome-sorted semen, MOET-CS: multiple ovulation and embryo transfer with conventional semen and MOET-XS: multiple ovulation and embryo transfer X-chromosome-sorted semen

Genetic gain and profitability were affected by the reproductive technology, whereas the use of CS and XS affected only the costs and profitability of the breeding programme.

The strategies that increase the reproductive rates of males and females (MOET-CS and MOET-XS) realized 2.1, 1.8, and 1.8 times more annual genetic gain, return, and profitability per cow, respectively, compared with those that increased only the reproductive rates of males (AI-CS and AI-XS). The cost per cow per year for MOET-CS and MOET-XS, however, was 3.4-fold and 2.5-fold higher than those realized in AI-CS and AI-XS, respectively. Although the use of CS and XS did not have an effect on annual genetic gain and return per cow when used with AI or MOET, they affected the costs and profitability per cow per year. AI-XS and MOET-XS realized additional costs of KES 31.54 compared with AI-CS and MOET-CS strategies. The corresponding profitability per cow per year was therefore reduced by a similar amount.

The response to selection for individual traits in the breeding goal followed the same trend that was observed in returns to selection. Traits in the breeding goal for the schemes using strategies that increased reproductive rates of both males and females (MOET based) realized higher genetic gains than those that were AI based (Table 6). The use of CS and XS, however, did not have an effect on response to selection for the individual traits and therefore only the findings from AI-CS and MOET-CS are presented in Table 7.

Table 7: Annual genetic gain in individual traits in the four scenarios using various reproductive technologies

	Breeding strategies	
Trait	AI-CS	MOET-CS
Milk yield	6.97	20.04
Fat yield	0.35	0.77
Age at first calving	-1.12	-2.54
Calving Interval	0.02	0.11
Average daily gain	0.01	-0.01
Pre-weaning daily gain	1.69	4.57
Live weight	0.06	0.23
Cow productive life time	0.16	1.20

AI-CS: artificial insemination with conventional semen, MOET-CS: multiple ovulation and embryo transfer with conventional semen

Productive traits such as Milk yield, Fat yield, Daily gain, Pre-weaning daily gain, and Live weight realized additional 13.07, 0.42, 0.02, 2.88, and 0.170 kg, respectively, in the MOET-CS compared with AI-CS schemes. On the other hand, the reproductive and longevity traits realized an increase in response to selection. Age at first calving was reduced by 1.42 days and Calving Interval increased by 0.09 days. Cow productive lifetime increased by 1.04 days

The intensity and accuracy of selection for the estimated breeding values in the AI-CS and MOET-CS are presented in Table 8. As expected, this was affected by the reproductive technology and sex of the selection candidates. The reproductive technology that increased the reproductive rate of both sexes (MOET-CS) realized an additional 0.21 and 0.61 in selection intensity of males and females, respectively, compared with AI-CS. The corresponding increase for accuracy of selection was 10% and 11%. The males generally realized high intensity and accuracy of selection compared with females. In the two breeding strategies, males out-performed females in intensity and accuracy of selection by 0.68 and 14%, respectively.

Table 8: Intensity and accuracy of selection for males and females in the breeding schemes

Breeding strategies[a]	Selection Intensity		Accuracy of selection	
	Males	Females	Males	Females
AI-CS	2.34	1.46	0.66	0.53
MOET-CS	2.55	2.07	0.77	0.63

[a]AI-CS: artificial insemination with conventional semen, MOET-CS: multiple ovulation and embryo transfer with conventional semen.

3.4 Discussion

The findings of this study support the hypothesis that increasing the reproductive rate of both males and females would optimize response to selection in dairy cattle. These findings are supported by Kosgey *et al.* (2005) and Pedersen *et al.* (2012), who demonstrated that the adoption of MOET breeding schemes realized a higher response to selection compared with AI schemes using either CS or XS in dairy cattle. This implies that irrespective of the semen used to inseminate the cows (conventional or sexed), increasing the number of offspring per cow has a major impact on total genetic gain and monetary returns. The superiority of MOET over AI breeding schemes was attributed to intensity and accuracy of selection. The contribution of selection intensity has two possible explanations. First, intensity of selection has a direct impact on repose to selection. Therefore any breeding strategy that increases the number of candidates for selection realizes a higher response to selection. This was evident in the current study as the number of candidates from which to select increased from one to ten calves per cow per year in the MOET breeding schemes. Since the number of selection candidates was constant throughout the simulation period, there were more proven candidates from which to select. This is reflected in the current study as MOET schemes had 21% and 61% increased intensity to selection in males and females, respectively, compared with AI schemes. Second, the intensity of selecting males was high than those of females in both MOET and AI schemes. This is because few males are needed for breeding compared with females. The high intensity of selecting males was reported in other studies (Kosgey *et al.*, 2005; Pedersen *et al*., 2012; Granleese *et al*., 2015). MOET technology enables each cow to produce more offspring per year, thus increasing the number of selection candidates. This results in high selection intensity and therefore higher response to selection compared with AI, which increases the reproductive rate only of males. Increased accuracy of selection in the MOET-CS scheme compared with AI-CS could be attributed to the higher number of offspring per cow. Each cow produced ten calves per year. These offspring were closely related to the selection candidates and therefore provided the information to compute their breeding values, thus increasing response to selection. Increasing the number of phenotypes increases accuracy of selection and therefore response to selection in breeding programmes (Dekkers, 2004). The non-differences in genetic gain and returns per cow that were observed in the breeding goal when conventional or sexed semen were used in AI and MOET schemes were confirmed by the response for individual traits . These findings partially agree with those reported by Sørensen *et al.*, (2011). In that study, the use of sexed semen with MOET was found to marginally increase the response to selection, although it was not significantly different from zero. The current findings could be attributed to the higher contribution of males to genetic gain females. This is in line with previous studies that compared the contributions of males and females to response to selection (Henryon *et al.*, 2012; Okeno *et al*., 2014). In these studies, response to selection was found to be optimized when males were genotyped and phenotyped. The current study therefore demonstrates that the superiority of MOET over AI in response to selection could be attributed to increased intensity and accuracy of selection.

Although no differences were observed in response to genetic gain and returns per cow when CS and XS were used in AI and MOET breeding schemes, the costs were higher in schemes that used XS. This contributed to the low profitability realized in AI-XS and MOET-XS in the current study. The high costs in schemes that use XS could be explained by the high price of XS in Kenya, because of the marketing narrative by semen companies that XS produces superior breeding stock compared with CS. This narrative has been disapproved in the current study. The combination of MOET-XS was less attractive as it realized low profitability. This implies that the utilization of MOET-CS would be more attractive in the genetic and economic responses under Kenyan production conditions.

The implementation of MOET-CS, however, may remain a challenge for two reasons. First, the scheme requires a well-established infrastructure and trained personnel for implementation, which are still inadequate (Kosgey *et al*., 2006; Van Arendonk, 2011). Second, the high costs of synchronizing the cows, semen importation and technician services pose challenges. This was evident in the current study as MOET schemes were 3.40 times more expensive than AI schemes. This implies that most of the smallholder farmers, who own 80% of dairy cattle in Kenya (KDB, 2015), would not be able to participate in this scheme. MOET-CS may be feasible only with government intervention in subsidies. Since the Kenyan dairy sector is completely liberalized (KDB, 2015), subsidies should not be expected by dairy farmers in the near future. Therefore AI schemes may continue to play significant role in the genetic improvement of dairy cattle.

3.5 Conclusion

The findings of this study confirmed that breeding schemes such as MOET that increase the reproductive rates of both males and females maximize response to selection. It also demonstrated that although genetic gain and returns per cow per year were not influenced by the use of conventional or sexed semen, sexed semen influenced the costs and therefore the profitability of the breeding programme. Adoption of a breeding strategy that uses CS with MOET would be more beneficial to dairy cattle farmers in Kenya if the necessary infrastructure is put in place for smooth operation of the breeding programme.

CHAPTER FOUR

INCLUDING PROTEIN YIELD AND MASTITIS RESISTANCE IN DAIRY CATTLE BREEDING GOAL OPTIMIZES RESPONSE TO SELECTION

Abstract

Selection response from a two-tier nucleus breeding scheme using the current Kenyan breeding goal was compared with an alternative that also accounts for protein yield (PY) and mastitis resistance (MR). The economic value for PY was estimated using a bio-economic model. For mastitis resistance, like other disease resistance traits, the economic value cannot be estimated with profit equations because they have multi-fold effects on input and output, which affects profitability. Therefore, selection index methodology was used. Somatic cell count (SCC) was used as an indicator trait for MR. The ZPAN computer programme was used to model the breeding schemes and evaluate response to selection. The alternative breeding goal, which included PY and MR, realized additional KES358.48, 613.55, and 613.65 in annual genetic gain, returns and profit per cow per year, respectively, compared with the current breeding goal. Economic values for PY and MR were KES778.99 and -2364, respectively. Relative economic values for milk yield (MY, kg), fat yield (FY, kg), protein yield (PY, kg), MR, calving interval (CI, days), preweaning daily gain (DG, g/day), postweaning daily gain (PDG, g/day), live weight (LW, kg), preweaning survival (SR1, %), postweaning survival (SR2, %), and length of productive life (PLT, days) were 23 689.80, 4 146.77, 34 665.50, -992.88, 33.66, 62.40, 159.80, 391.94, 987.04, 4 474.37, and 7.56, respectively. This implies that including milk quality traits such as PY in the breeding goal would optimize response to selection in dairy cattle production.

4.1 Introduction

The production of high-quality milk is necessary to sustain a profitable dairy industry (Ruegg and Pantoja, 2013). The market demands better quality and, in particular, more healthful products that are produced by healthy animals. Milk quality, as reflected by its technological properties, affects milk processing and ultimately product quality (Barbano *et al*., 2006; Parna *et al*., 2012; Zhao *et al*., 2014). The milk pricing system is the most important factor that affects the relative weightings of milk volume, fat, and protein percentages, clinical mastitis and somatic cell count (SCC) in the breeding goal (Wolfova *et al*., 2007). Milk payment in Kenya is currently based on volume. However, this is likely to shift towards quality owing to commercialization of the dairy sector. Somatic cell count, protein and butter fat contents are the major characteristics that are used to quantify milk quality (Ruegg and Pantoja, 2013). Premium prices are awarded for milk that exceeds certain thresholds, and penalties are imposed on milk that falls below minimum quality thresholds. Thus, SCC and PY directly affect revenue from sale of milk (Nightingale *et al*., 2008). In quality-based markets, increased PY typically results in positive marginal returns, and the value of protein is usually greater than that of other milk components (Banga *et al*., 2011). The SCC is routinely used to identify sub-clinical mastitis with a somatic cell count of less than 200 000 cells/ml indicating a healthy mammary quarter (Ruegg and Pantoja, 2013). A greater SCC is an indirect indicator for mastitis in dairy cattle.

Mastitis is the costliest disease in dairy cattle production, resulting in heavy economic losses annually (Berry *et al*., 2011). In the tropics, these losses have been valued at US$ 38.00 per cow per lactation (Mungube *et al*., 2005). The incidence of mastitis in Kenya is extremely high and over 60.7% of dairy cows in smallholder production systems produce milk with SCC that is greater than 200 000 cells/ml (Kashongwe *et al*., 2017). This implies most smallholder farms incur losses that are attributed to reduced MY and quality, discarded milk during the withdrawal period after the use of therapeutic drugs, veterinary costs, increased culling, and occasional mortality (Omore *et al*., 1999; Mungube *et al*., 2005). Previous attempts to overcome this challenge through conventional strategies such as improved udder hygiene and treatments have not been successful (Omore *et al*., 1999). Therefore, alternative strategies are needed. Breeding for resistance to mastitis has been proposed as an alternative for various reasons. First, animals that are resistant to mastitis may not be afflicted with the disease and therefore would not incur the economic losses. Second, breeding for resistant animals ensures animal welfare concerns and prevents traces of drugs residues in milk. Lastly, animals that are genetically resistant to disease pass their genes to their offspring, and therefore the improvement is progressive and cumulative after each generation. Breeding for resistance requires the inclusion of the disease indicator trait in the breeding goal (Pfeiffer *et al*., 2015).

The current dairy cattle breeding goal in Kenya (Kahi and Nitter, 2004) does not account for either protein yield or mastitis resistance. Inclusion of milk quality traits in the dairy cattle breeding goal is an inexpensive and sustainable strategy to improve milk quality. Therefore, there is a need to include PY and MR in the breeding goal for dairy cattle in Kenya. Their inclusion requires estimation of the associated economic values. These economic values are currently lacking under Kenyan production conditions. Thus, the first objective of this study was to derive economic values for PY and MR using SCC as an indicator trait. Having realized the first objective, predicted response to selection for the current breeding goal was compared with that which may result from implementation of a breeding goal which includes PY and MR.

4.2 Materials and Methods

The computer programme ZPLAN (William *et al*., 2008) was used to compare response to selection that was realized in a closed two-tier nucleus breeding system using the current breeding goal with an alternative breeding goal that included PY and MR for dairy production in Kenya. The current breeding goal, in which marketing of milk is based on volume, was used as the base scenario. The alternative breeding goal foresaw the marketing of milk based on its quality. Hence, PY and MR were introduced in the breeding goal. The breeding goals were compared based on economic and genetic gains per cow per year.

Two breeding goals were considered in the current study. The first considered the current dairy cattle breeding goal in Kenya. The traits in this breeding goal included MY, FY, age at first calving (AFC, days), CI, DG, PDG, LW, SR1, SR2, and PLT. The current breeding goal (H) is:

$$H = MY * v_1 + FY * v_2 + DG * v_3 + PDG * v_4 + LW * v_5 + CI * v_6 + AFC * v_7 + SR1 * v_8 + SR2 * v_9 + PLT * v_{10} \quad (7)$$

and the alternative breeding goal (H') which includes PY and MR in addition to all the traits in the current breeding goal is:

$$H' = H + PY * v_{11} + MR * v_{12} \quad (8)$$

The first requisite for inclusion of a trait in the breeding goal is estimation of its economic value (Hazel, 1943). The economic values for traits in the current breeding goal in Kenya have been estimated (Kahi & Nitter, 2004). However, the economic values for MR and PY have not been estimated. The economic value for MR, like other disease resistance traits, cannot be estimated with profit equations because it has multi-fold effects on input and output, all of which affect profitability (Sivarajasingam, 1995). Nielsen *et al*. (2005) described a method for estimating economic value for MR based on selection index methodology (Hazel, 1943; Wagenaar *et al*., 1995). In this method, for a given set of assumptions, the breeding goal is matched to the expected responses in production traits, and responses in these traits are maximized relative to overall gains. The economic value for mastitis resistance was estimated relative to MY. Somatic cell count was used as the indicator trait of mastitis resistance due to its large positive genetic correlation (0.7) with mastitis (Carlen *et al*., 2004). Therefore, the assumption was that animals were selected for increased MY and reduced SCC. The computer programme SIP (Wagenaar *et al*., 1995) was used to compute the economic value for SCC. The phenotypic standard deviations, heritability estimates, phenotypic and genetic correlations for MY and SCC were obtained from Pfeiffer *et al*. (2015) and are presented in Table 9. Genetic responses to selection for traits in the breeding goal were computed as:

$$SR_T = \frac{\sigma_{IT}}{\sigma_I} * i \quad (9)$$

where: SR_T = the trait-specific selection response in monetary units; σ_{IT} = covariance between index and trait in the breeding goal *T*; σ_I = standard deviation of the index; and i = selection intensity.

Table 9: Economic value in Kenyan shillings (US$1 = KES100), phenotypic standard deviations, heritability estimates, and the phenotypic and genetic correlations of milk yield with somatic cell count.

Traits	Economic values	Phenotypic standard deviation	Heritability	Phenotypic correlation	Genetic correlations
Milk yiels (kg)	43	120.80	0.30	-0.02	-0.03
Somatic cell count	-	0.05	0.09		

This study used a data simulation approach to derive an economic value for PY in dairy cattle. Simulation models have been used to predict economic values for traits in the breeding goals for meat sheep (Kosgey *et al*., 2003), dairy cattle (Kahi and Nitter, 2004), beef cattle (Rewe *et al*., 2006) and pigs (Mbuthia *et al*., 2015) that are produced in the tropics. The model expressed profit through grouping terms by class of cattle and calculated revenue and costs per cow per year. In general, the model predicted profitability as follows:

$$P = R - C \quad (10)$$

where: P, R and C = profit, revenue and costs per cow per year in Kenyan shillings, respectively. Total revenue was calculated as:

$$R = R_{male\ calves} + R_{culled\ heifers} + R_{culled\ cows} + R_{milk} \quad (11)$$

where: $R_{male\ calves}$ = revenue from sale of male calves; $R_{culled\ heifers}$ = revenue from sale of culled heifers; $R_{culled\ cows}$ = revenue from sale of culled cows; and R_{milk}= revenue from sale of milk. Total cost was computed as:

$$C = CM_{male\ calves} + CF_h + CH_h + CR_h + CL_h + CM_h + CF_c + CH_c + CR_c + CL_c + CM_{milk} + CM_c + FIXC \quad (12)$$

where *CM* = marketing cost; *CH* = health care cost; *CR* = husbandry cost; *CL* = labour cost; *CM* = marketing cost; and the subscripts *h* and *c* denote heifers and cows respectively.

The economic values were computed as:

$$EV = {}^{\Delta P}/_{\Delta T} \quad (13)$$

where: ΔP = change in profit resulting from after a unit increase in the trait of interest and (ΔT)= marginal change in the trait of interest after a unit increase.

Estimates of the phenotypes that were used to compute economic values for traits in the breeding goal are presented in Table 10. They were grouped into biological and nutritional variables that were obtained from various studies in Kenya and the tropics (Kahi & Nitter, 2004; Kahi *et al.*, 2004; Ilatsia *et al.*, 2011).

A population of 50000 cows that were distributed in the two tiers was simulated. The top tier (nucleus) consisted of 2500 cows with the greatest genetic merit, while the remaining 95%, which constituted the lower tier, were deemed the commercial population. The biological and economic parameters that were used in the current study were obtained from previous studies on dairy cattle in Kenya (Kahi & Nitter, 2004; Kahi *et al*., 2004; Ilatsia *et al*., 2011). The selection pathways included sires to breed sires (SS) and dams (SD) and dams to breed sires (DS) and dams (DD). Each selection group had different sources of information for traits in the breeding goal. The information sources for SS and SD were records on individual, sire, dam, and dams of the sire and dam, while those for DS and DD were records on the individual, dam, sire, all female paternal half sibs of the dam and sire, dams of the sire and dam.

Genetic and phenotypic parameters for the selection criteria and traits in the aggregate genotype are required to compute composition and accuracy of selection indices and to obtain accurate expected breeding values (Ilatsia *et al*., 2011; Visentin *et al*., 2017).

Table 10: Estimates of phenotypes used to compute economic values for Kenyan breeding goal for dairy cattle

Trait	Units	Symbols	Estimate
Biological variables			
Milk yield per cow per year	Kg	MY	3124.00
Fat yield per cow per year	Kg	FY	125.00
Protein yield per cow per year	Kg	PY	100.00
Age at first calving	Days	AFC	1016.00
Calving interval	Days	CI	402.00
Pre-weaning daily gain	g/day	DG	488.00
Post-weaning daily gain	g/day	PDG	506.00
Mature live weight	Kg	LW	435.00
Pre-weaning survival rate	%	PSR	0.93
Post-weaning survival rate	%	PWR	0.93
Productive lifetime	Days	PLT	1893.00
Nutritional variables			
Dry matter content in silage	%	Sil	15.00
Dry matter content in concentrates	%	conc	89.00
Dry matter content in pasture	%	DMp	20.00
Energy content in concentrates	MJ of NE_Lper kg		7.19
Energy content in pasture	MJ of NE_L per kg		5.65

It is important that traits in the breeding objective should be heritable and have variation, and that their phenotypic and genetic correlations with the traits in the selection criteria should be known (Rewe *et al.*, 2006). Estimates of heritability and genetic and phenotypic correlations for traits in the breeding objective from various studies are presented in Table 11. Genetic parameters are a characteristic of the population in which they were estimated, and may change overtime due to selection and management decisions (Missanjo *et al*., 2013). Production traits (MY, FY, LW) are highly heritable than functional traits (AFC, CI, DG, SR1, SR2, and PLT) and more correlated.

Table 11: Heritability (along diagonal bold), phenotypic standard deviations, economic values, genetic correlations (above diagonal) and phenotypic correlations (below diagonal) for traits in the breeding goal and selection criteria

Traits[a]	MY	FY	PY	SCC	AFC	CI	DG	PDG	LW	PreSR	PostSR	PLT
σ_p[b]	1208.46	36.57	39.5	1.85	448.76	75.34	19.00	743.00	54.14	30.00	30.00	864.90
EVs[c]	16.05	79.44	-	-	-2.72	2.65	1.04	3.40	7.95	9.96	45.15	0.07
MY	0.30	0.75	0.70	-0.03	0.20	0.17	0.10	0.11	0.23	0.00	0.00	0.00
FY	0.73	0.32	0.61	-0.19	-0.10	0.08	0.10	0.11	0.12	0.00	0.00	0.00
PY	0.95	0.78	0.34	-0.02	-0.14	0.10	0.00	0.00	0.13	-0.20	-0.20	0.16
SCC	-0.20	0.02	-0.13	0.09	0.00	0.17	0.00	0.00	0.00	0.00	-0.13	0.06
AFC	-0.21	0.05	0.22	0.00	0.38	-0.21	-0.20	-0.20	0.15	0.00	0.00	-0.13
CI	0.17	0.08	0.00	0.00	-0.21	0.06	0.00	0.00	-0.40	0.00	0.00	0.10
DG	0.10	0.10	0.00	0.00	-0.25	0.10	0.29	-0.25	0.20	0.06	0.03	0.10
PDG	0.11	0.11	0.00	0.00	-0.25	0.10	0.49	0.32	0.25	0.03	0.06	0.10
LW	0.23	0.12	0.06	0.00	0.15	-0.43	0.40	0.47	0.30	0.01	0.00	0.27
PreSR	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.03	0.01	0.09	0.00	0.00
PostSR	0.00	0.00	0.11	-.14	0.00	0.00	0.03	0.06	0.00	0.01	0.09	0.00
PLT	0.00	0.00	0.00	0.00	-0.13	0.10	0.10	0.10	0.27	0.00	0.00	0.11

MY: milk yield (kg); FY:fat yield (kg); PY: protein yield; SCC: somatic cell count; AFC: age at first calving (days); CI: calving interval (days); DG: pre-weaning daily gain (g/day); PDG: post-weaning daily gain to 18 months (g/day); LW: live weight (kg); SR1: pre-weaning survival rate (%); SR2: post-weaning survival rate (%); PLT: cow productive lifetime (days); σp: phenotypic standard deviation

(Sources: Kahi *et al*., 2004; Kahi & Nitter 2004; Ilatsia *et al*., 2011)

Production and functional traits are more correlated to their related production and functional traits. For example, MY and FY are both highly genetically and phenotypically correlated between themselves. The low heritability values for reproductive and survival traits suggest that they are more influenced by the environment.

The two breeding goals were simulated and evaluated by a deterministic approach using the computer programme ZPLAN version z10 (William *et al*., 2008). The ZPLAN programme uses biological, statistical and economic parameters to calculate the annual genetic gain for the breeding objective, genetic gain for single traits, and returns on investment adjusted for costs using gene flow and selection index methodology. Profits were calculated for five generations, which is equivalent to a 25-year investment period. The effect of only one round of selection was considered. The effect of inbreeding was not considered in the prediction of genetic gain, and parameters and selection strategies remained unchanged over the investment period. The current breeding goal, in which marketing of milk is based on volume, was used as the base scenario. The alternative breeding goal was that in which marketing of milk is based on quality. Hence two additional milk quality traits, namely PY and MR, were introduced in the breeding goal. The breeding goals were compared based on the economic and genetic gain per cow per year.

All the breeding values were predicted using best linear unbiased prediction by fitting a multivariate animal model to the phenotypes. The model was computed as:

$$y = Xb + Za + e \qquad (14)$$

where: y = the vector of phenotypes; b = vector of fixed effects; a = vector of random animal effects; e = vector of residual errors, and X and Z are incidence matrices relating the observations to the fixed effects and animals, respectively. The distribution of phenotypes was assumed to be:

$$\begin{bmatrix} a \\ e \end{bmatrix} \sim N\left(0; \begin{bmatrix} G \otimes A & 0 \\ 0 & R \otimes I \end{bmatrix}\right) \qquad (15)$$

where: G denotes the additive genetic (co)variance matrix for traits in the breeding goal; A denotes the numerator relationship matrix among all animals; R denotes the (co)variance matrix for traits in the breeding goal; and I is an identity matrix of rank equal to the number of animals.

The economic returns were determined based on profitably per cow in each breeding system. The profitability per cow was estimated as:

$$\pi = \sum_{t=0}^{25} \left(\frac{R_t - C_t}{(1+r)^t} \right) \quad (16)$$

where the planning horizon is 25 years, R_t = the annual return from genetic improvement calculated as realized genetic gain per cow per year; C_t = the annual cost of genetic improvement including the fixed and variable costs; and r = the discount rate.

A discount rate of 5% has been recommended when evaluating animal breeding programmes (Berry *et al.*, 2006), and was adopted in the current study. Variable costs are presented in Table 12. These included costs that were directly related to performance and pedigree recording. Fixed costs were those that were incurred in one round of selection, and were the overhead costs of running the nucleus of 2500 cows. The average time at which fixed costs occurred was assumed to be the mean generation interval. Variable and fixed costs affect only the profit, and not the genetic response. The interest rates for returns (8%) and costs (6%) were based on current marketing conditions in Kenya.

Table 12: Assumed costs for farm goods and services used in computation of economic values

Variable	Unit	symbol	Value (KES)
Price of milk per kg	Kg	pm	45.00
Price of fat per kg	Kg	pf	645.00
Price of protein	Kg	pp	800.00
Price of a calf	Kg	pc	3000.00
Price of live weight	Kg	plw	250.00
Cost of concentrates	Kg	Pconc	22.85
Price of silage	Kg	psil	14.00
Cost of pasture	Kg	ppas	16.67
Heifer health costs/head/day	head	cHhealth	0.97
Cow health costs per head per year	head	CHcow	3276.79
Cost of heifer reproduction per head per year	head	Cowrepch	591.30
Labour costs per head per year	head	Clabour	9.27
Cow labour costs per head per year	head	CLcows	3383.55
Marketing costs per kg of milk	KES	mmilk	2.25
Marketing costs per head for male calves	KES	mLW	821.25
Calving rate	%	cr	0.95
Heifer calf birth weight	Kg	bw	30.90
Survival rate to 24 hours of birth	%	Sr24	0.98
Period from birth to weaning	days	wa	126.00
Period from weaning to 18 months	days	dwm	414.00
Period from 18 months to first calving	days	dafc	476.00
Weaning weight	Kg	ww	92.00

4.3 Results and Discussion

The objective of this study was to compare the response to selection that was realized in a closed two-tier nucleus breeding system that utilized the current breeding goal with an alternative that also accounted for milk quality traits in the dairy cattle. The findings demonstrate that including milk quality traits in the current breeding goal was not only economically viable, but also increased annual genetic gain. The magnitude of the change of response to selection when the alternative breeding goal was adopted, however, depended on the economic value of milk quality traits that were included in the breeding goal and the accuracy of selection.

Responses to selection in terms of annual genetic gain, returns, costs and profit per cow per year in the current and alternative breeding goals are presented in Table 13. The alternative breeding goal, which included PY and MR, realized an additional KES358.48, 613.55 and 613.65 in annual genetic gain, returns and profit per cow per year, respectively, compared with the current breeding goal. Including these two traits in the breeding goal did not affect the cost of production.

Table 13: Annual genetic gain, returns, costs and profit per cow for the current and alternative breeding goals in Kenyan shillings

Parameters	Breeding goals		Variance in response
	CBG	ABG	
Annual genetic gain	301.42	659.90	358.48
Returns per cow	1491.39	2104.94	613.55
Costs per cow	181.26	181.15	-0.11
Profit per cow	1310.14	1923.79	613.65

CBG: current breeding goal; ABG: alternative breeding goal

(1US$ = KES100.00)

The annual genetic gains for individual traits in the two breeding goals are presented in Table 14. Generally, the response to selection for most of the individual traits in the breeding goal followed the same trend as those of economic returns. The genetic gains for most traits in the alternative breeding goal were higher than those in the current breeding goal. Productive traits such as MY, FY and PY increased by 3.3, 0.01 and 0.1 units, respectively, when an alternative breeding goal was adopted. On the other hand, PDG increased by 0.09 units while DG and LW decreased by 1.78 and 0.02, units, respectively.

The CI and PLT decreased by 0.03 and 0.10 days, respectively, while AFC increased by 0.83 days. The level of SCC remained constant at -0.0002 cells per unit.

Table 14: Annual genetic gains for individual traits resulting from selection based on the current and alternative Kenyan breeding goals for dairy cattle

Traits	Units	Breeding goals		Differences in resonse to selection
		CBG	ABG	
Milk yield	Kg	20.0400	23.5400	3.50
Fat yield	Kg	0.7700	0.7800	0.01
Protein yield	Kg	0.3700	0.4700	0.10
Mastitis resistance	cells/ml	-0.0002	-0.0002	-
Age at first calving	Days	-2.54.000	-1.7100	-4.25
Calving Interval	Days	0.1100	0.0800	-0.03
Pre-weaning daily gain	Kg	4.5700	2.7900	-1.78
Post-weaning daily gain	Kg	-0.0100	0.1000	0.09
Live weight	Kg	0.2300	0.2100	-0.02
Productive lifetime	Days	1.2000	1.1000	-0.10

CBG: current breeding goal; ABG: alternative breeding goal

The economic values of PY and MR were +779.0 and -2364.0, respectively. The economic values for the other traits in the proposed breeding goal remained unchanged. These findings provide vital information that is a prerequisite for the inclusion of PY and MR in the current dairy cattle breeding goal in Kenya. Standardized relative economic values are important in comparing the proportionate contribution of each trait in the breeding goals. The relative economic values were standardized relative to protein yield and presented in Table 15.

Table 15: Economic values, genotypic standard deviation and relative economic values for traits in the alternative Kenyan breeding goal for dairy cattle.

Trait	Economic value (KES)	Genetic Standars deviation	Relative economic value	Proportional contribution, %
Milk yield (kg)	16.05	1476.00	23,689.80	34.03
Fat yield (kg)	79.44	52.20	4,146.77	5.96
Protein yield (kg)	779.00	44.50	34,665.50	49.80
Mastitis resistance (cells/ml)	-2364.00	0.42	-992.88	1.43
Age at first calving (days)	-2.72			
Calving interval (days)	2.65	12.70	33.66	0.05
Pre-weaning daily gain (%)	1.04	60.00	62.40	0.09
Post weaning daily gain (g/day)	3.40	47.00	159.80	0.23
Live weight (kg)	7.95	49.30	391.94	0.56
Pre-weaning survival rate (%)	9.96	99.10	987.04	1.42
Post-weaning survival rate (%)	45.15	99.10	4474.37	6.43
Productive lifetime (days)	0.07	108.00	7.56	0.01

Standardized economic values reflect the relative importance of the traits. Protein yield is the most important trait. Milk yield and FY are 32% and 89% less valuable than protein, respectively. The contribution of other traits relative to protein yield was basically low at 1–3% for MR, LW and SR2. The other traits such as CI, DG, PDG, and PLT had a contribution of less than zero in comparison with protein yield.

The findings for the current study confirm the authors' premise that accounting for milk quality traits in the breeding goal of dairy cattle in Kenya would improve response to selection. The realization of additional 118.9, 21.04 and 46.84% in annual genetic gain, returns to selection and profitability, respectively (Table 13), in the alternative breeding goal was a clear demonstration that including PY and MR in the current breeding goal was beneficial. Similar trends were observed in the individual traits (Table 14).For instance, increased response to selection was realized in MY, FY and PY, when PY and MR were accounted for in the alternative breeding goal.

The increase in response to selection in the alternative breeding goal could be attributed to three reasons. First, previous studies demonstrated a strong positive genetic and phenotypic correlation between MY, FY, and PY in dairy cattle (Miglior *et al*., 2009). This implies that an increase in response to selection in MY and FY would contribute to increased response to selection in PY. Second, greater accuracy of selection that was attributed to the additional information from PY and MR in the breeding goal contributed to the increased response to selection. Since PY and MR were correlated with other traits in the breeding goal, the information they added had a positive effect on response to selection (Van Grevenhof *et al*., 2012). Third, PY and MR had relatively large economic values. The inclusion of traits with large economic values in the breeding goal has a significant effect on response to selection based on the direction of economic value. This was evident in the current study. Protein yield had positive large economic value and therefore realized 54.3% more response to selection compared with its correlated response in the current breeding goal. On the other hand, the response to selection for MR in the alternative breeding goal was similar to that observed in the current breeding goal because of the negative economic value for indicator trait SCC.

The constant response to selection that was obtained when MR was included in the alternative breeding goal confirms that selection for disease resistant traits is not easy. This could be because of low heritability of the indicator trait and difficulty in measuring MR (Carlen *et al*., 2004). This implies that MR could be better managed through improved management to reduce the accumulation of pathogens that cause mastitis in dairy cattle rather than through breeding. In the current study, the inclusion of MR in the breeding goal increased the response to selection by only KES0.44, 2.53, and 2.04 for monetary gains, returns to selection, and profitability per cow per year, respectively. The corresponding increases that were attributed to inclusion of PY in the breeding goal were 358.48, 613.55, and 1338.26. This implies that it would be economical to include PY in the breeding goal and observe for dairy cattle management practices to reduce or minimize occurrence of mastitis incidences in the herd.

4.4 Conclusions

Inclusion of PY in the breeding goal increased genetic and economic response to selection. On the other hand, inclusion of MR produced minimal change in the economic response to selection. Inclusion of PY in the breeding goal and improvement in environmental management would result in dairy cattle that not only produce high quality milk, but are also resistant to mastitis. The superior genetic materials of the resultant genotypes could be disseminated in the dairy cattle population through structured breeding systems. The benefit of this is fourfold, namely improved milk quality, animal health and welfare, access to export market and economic status of the dairy industry players.

CHAPTER FIVE
GENERAL DISCUSSION

5.1 Introduction

Dairy production has been identified as a major economic activity contributing to food and nutrition security, incomes, employment and insurance at household levels (Behnke & Muthami, 2011). Increase in demand for animal products is the main driver for genetic improvement of dairy cattle populations in developing countries (FAO, 2012). Recent advances in reproductive technologies is a powerful tool to improve productivity and quality of animal products, which in the long run would address food insecurity (Hernandez & Gifford, 2013). Production of quality livestock products such as milk is driven by improvement of people's living standards and the stringent requirements by the export market. This has been achieved to a certain extent by sound herd management and improved hygiene standards in handling milk. Selecting for milk quality traits (protein yield and mastitis resistance) is another option for improving milk quality. The overall objective of this thesis was to contribute to genetic improvement of dairy cattle in Kenya through optimization of breeding systems that incorporate reproductive technologies and milk quality traits in the dairy cattle breeding programme. This was realized by; first, comparing response to selection realized when different reproductive technologies were used to disseminate superior genetic materials in the breeding programme. Secondly, estimation of economic values for protein yield and somatic cell count which was used as an indicator trait for mastitis resistance. Lastly, comparing response to selection realized by the current and alternative breeding goal, which accounted for PY and MR. This Chapter therefore discusses the major findings in relation to breeding structure, strategies, organizational structure and feasibility of their implementation in the current dairy cattle breeding programme in Kenya.

5.2 Dairy cattle breeding structure and goal

The current dairy cattle breeding goal in Kenya emphasizes increased milk yield but the market is shifting towards milk quality (Foreman & Leeuw, 2013). Therefore there is need to expand the breeding goal to include milk quality traits. To implement the proposed alternative breeding goal that accounts for milk quality traits, a two tier nucleus breeding system has been recommended for developing countries (Bondoc & Smith, 1993). This is due to small population sizes, lack of systematic animal performance recording and high illiteracy levels among producers in developing countries (Kosgey & Okeyo, 2007; Kosgey *et al.*, 2011). In Kenya, 80% of the dairy cattle are owned by the smallholder farms (Wambugu *et* *al*., 2011). These farmers are characterized by low productivity, poor record keeping and lack of specialization in terms of breeds kept. On, the other hand, the large-scale farms own 20% of the dairy cattle population in Kenya. Their productivity is high, they are more specialized on breeds kept, keep records for informed decision making and carry out genetic evaluations and selection. Such farms are found in National Research Institutions (NRI) such as University farms, Kenya Agricultural and Livestock Research Organization (KALRO), Agricultural Development Corporation (ADC) and private farms. These large-scale farms therefore fit the description of a nucleus. They would therefore fit to form the nucleus while the smallholder farms form the commercial sector of the two-tier breeding programme. The mandate of the large-scale farms therefore would be to include milk quality traits such as PY in the current dairy cattle breeding goal, select superior candidates for traits in the breeding goal and disseminate the improved genetic materials to the smallholder farms. Such arrangements have been demonstrated to enhance faster response to selection in countries where smallholder farms form the bulk of dairy cattle production. Dissemination of superior genetic materials from the large-scale farms identified as nucleus to smallholder dairy farms (commercial) would require efficient breeding strategies.

5.3 Breeding strategy

The success of a breeding programme depends on how the improved genetic material can be disseminated into the entire population. Lack of properly co-ordinated dissemination strategies has been identified as one of the contributing factors to the unsuccessful setup and running of sustainable dairy cattle breeding programmes in the tropics (Kosgey *et al*., 2006). In Kenya, dairy cattle farmers rely on imported semen from developed breeding programmes in the temperate regions to improve their herd performance (Ojango *et al*., 2012). This has resulted to high yielding genotypes especially in the large-scale farms. Although, some of the smallholder farmers have also realized improved milk production, majority of them have not benefited from the improvement realized in large-scale farms. This could be attributed to genotype by environment (GxE) interaction and partial or low adoption of reproductive technologies such as AI and MOET as has been the case in large-scale farms. Although, AI is fairly used, the current findings in Chapter 3 show that, utilization of MOET would realize higher response to selection than AI. The low adoption of MOET could be explained by the high costs involved *Vis a Vis* the number of dairy cattle the smallholder farmers keep. Most smallholder farmers keep 2 to 10 dairy cows (Wambugu *et al.*, 2011), which might not be economical to practice MOET. To overcome this problem and embrace MOET for optimization of response to selection, the smallholder farmers could pool their resources together. This would enable them benefit from economies of scale and also overcome the effect of GxE. This could be done in such a way that, several farmers in the village put their dairy cattle together under one management. Each farmer would receive revenue based on the ratio of productivity of his/her cows. Some revenue will remain within the management unit for daily operations. Such resources can be used to implement MOET. Since farmers receive revenue based on the productivity of their dairy cows, this would encourage them to go for high quality breeds for optimum production hence making it reasonable to practice MOET. Such a model will boost smallholder farmers' income in two ways. First, farmers will receive more income from their cows because they are under good management and therefore would be expected to produce more milk. Second, the farmers will have time to engage in other income generation activities other than dairy production since their animals are managed by someone else. Pooling of resources together would also enhance quality milk production (Chagwiza *et al*., 2016).

The milk market in Kenya has been demonstrated to be slowly but, steadily shifting from quantity to quality based (KNDMP, 2010). This could be attributed to the fact that, local milk processors do not only process pasteurized milk but, also other milk products such as cheese, butter and ice cream which require different levels of milk solids (KNDMP, 2010). The opening of East African Community market, which require given standards also drive processors from quantity to quality. Previous studies have demonstrated that, the milk in the market currently, do not meet the minimum required standards for non-soluble solids (Bebe *et al*., 2015). This implies that a breeding goal that focuses not only on milk volume but, also quality is paramount. The alternative quality based breeding scheme that accounts for the milk quality traits in the breeding goal in the current study therefore becomes important to overcome milk quality challenges. Implementation of such a breeding goal require well-structured breeding programme with efficient strategies to disseminate superior genetic materials in the population. The adoption of the alternative breeding goal defined in the current study and MOET as a means of disseminating genetic materials in the population has been demonstrated to be profitable in this thesis. This therefore implies that these two strategies should be adopted in the current dairy cattle breeding programme for optimization of genetic and economic response to selection. Adoption and sustainable implementation of these strategies would, however, require efficient organizational structure in the current dairy cattle breeding programme.

5.4 Sustainable measures

Sustainability of a breeding programme is determined by its long term ability to generate and disseminate genetic superiority profitably (Kariuki *et al.*, 2017). The large number of smallholder dairy farmers and the high demand for milk and milk products form a major market for semen and embryos. Currently, farmers are reluctant to keep or remit data to Government run institutions due to lack of feedback. Majority of farmers, especially smallholder dairy cattle producers prefer purchasing breeding services from different dairy hubs or cooperatives (Mutinda *et al.*, 2015; Omondi *et al*., 2017). This is because the dairy hubs or cooperatives offer incentives to farmers such as flexible payment services and cost sharing in case of repeated inseminations which public institutions do not do (Omondi *et al.*, 2017). Ideally, involvement of the private sector in the breeding programme is the best way to go. The public institutions should be more involved in the setup of the breeding programmes, policy formulation and monitoring. The private investors on the other hand, should be more involved in the business component of the breeding programme to ensure sustainability. This would ensure that, services are delivered on time and consumers (farmers) pay for the services rendered. Involvement of the private sector would also encourage easy adoption of reproductive technologies described in this thesis and new technologies such as genomic selection. The combination of genomic selection and reproductive technologies such as MOET have been demonstrated to increase response to selection (Pfeiffer *et al.*, 2015). Breeding programmes spearheaded by the private sector has worked efficiently in the developed countries as most of the breeding programmes are run as business entities hence their sustainability (Sousa *et al*., 2011; van Arendonk, 2011).

Increased productivity in dairy cattle cannot be realized through genetic improvement only. A holistic approach, that account for genetic and environmental improvement should therefore be considered. Improvement of production environment such as feeding and nutrition, housing, health care and animal welfare would allow the animals to express their genetic potential. This would enable improved productivity per cow, and production of quality milk to meet the local and international market standards.

5.5 General Conclusions

This study optimised dairy cattle breeding systems by incorporating reproductive technologies, protein yield and resistance to mastitis. From the findings, it can be concluded that;

1. Reproductive techonogies that increase reproductive rates of males and females such as MOET optimizes response to selection compared to those that increase reproductive rate of one sex only like AI.
2. Protein yield and Mastitis resistance relised positive and nagtive economic values, respectively. This makes them favourable for includion in the breeding goal.
3. Alternative breeding goal that accounts for milk quality traits such as protein yield and mastitis resistance realised higher response to selection than the current dairy cattle breeding goal that focuses on volume.

5.6 General Recommendations

1. Further studies on response to selection when using other reproductive technologies and stochastic simulation is recommended.
2. Use of MOET in both nucleus and commercial herds is recommended.
3. There is the need to apply genomic selection to further optimise the dairy cattle breeding systems.

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APPENDICES

Appendix I: ZPLAN Outputs for Objective 1

BASIC RUN: RESULTS FOR THE SELECTION GROUPS

I	1	2	3	4	5	6	7	8	9	10
I	BNOB>BN	DN>BN	BNYB>DN	BNOB>DN	DN>DN	BNYB>B	DC>BC	BNYB>D	BC>DC	DC>DC
#NAME?	------------	--------	----------	------------	--------	----------	--------	----------	---------	----------
SEL.ANIM. I	1	25	1	1	357.143	1	13.3	6785.71	13.3	9.5
PROV.ANIM.I	1	357.143	936.169	1	946.687	1	936.169	13504.7	936.169	13338
PROP.SEL. I	0.083	0.07	0.001	0.083	0.377	1	0.014	0.502	0.014	0.001
SEL.INT(i)I	1.84	1.908	3.345	1.84	1.006	0	2.527	0.794	2.527	3.441
GEN.INT I	4.079	6.402	4.079	4.527	6.202	4.642	10.479	4.642	4.668	10.479
GENE-OFF I	95	100	95	5	100	100	100	70	30	100
SD(AT) I	219.618	169.726	219.618	3.354	51.068	62.075	32.623	405.828	173.736	367.461
RAI I	0.557	0.662	0.431	0.557	0.662	0.431	0.065	0.431	0.065	0.065
LT-GENE I	8.08	8.5	8.08	3.59	71.76	0	0	0	0	0
monGG(AT) I	1222.477	1198.977	1723.122	1222.477	632.258	0	0	0	0	0
GG MY-1 I	69.446	48.326	107.477	69.446	25.484	0	0	25.865	0	0
GG FY-2 I	2.579	3.044	3.808	2.579	1.605	0	0	0.905	0	0
GG PY-3 I	1.336	1.193	1.993	1.336	0.629	0	0	0.475	0	0
GG SCC-4 I	-0.001	-0.001	-0.001	-0.001	0	0	0	0	0	0
GG AFC-5 I	-1.574	-13.494	-2.491	-1.574	-7.116	0	0	-0.361	0	0
GG CI-6 I	0.209	0.15	0.554	0.209	0.079	0	0	0.131	0	0
GG DG-7 I	-0.099	0.139	0.026	-0.099	0.073	0	0.023	0.003	0.023	0.032
GG PDG-8 I	21.989	11.788	20.668	21.989	6.216	0	1.912	4.87	1.912	2.603
GG LW-9 I	0.671	0.407	0.915	0.671	0.215	0	0	0.224	0	0
GG PSR-10 I	0.002	0	-0.002	0.002	0	0	0	-0.001	0	0
GG PWR-1 I	0.016	0.03	0.008	0.016	0.016	0	0.682	0.002	0.682	0.929
GG LT-12 I	1.789	0.741	3.702	1.789	0.391	0	0	0.876	0	0
GG ummy-1 I	0	0	0	0	0	0	0	0	0	0
SDE MY-1 I	0.18	0.138	0.18	0.003	0.042	0.051	0.027	0.333	0.142	0.3
SDE AFC-5 I	0.043	0.024	0.043	0.001	0.016	0.014	0.005	0.143	0.061	0.097
RETURN TOTI	225.242	214.214	316.661	3.426	31.997	0	5.363	138.793	28.559	82.256
RET MY-1 I	-78.989	-42.298	-122.247	-1.206	-6.711	0	0	-54.438	0	0
RET FY-2 I	282.888	256.878	417.682	4.32	40.758	0	0	183.674	0	0
RET AFC-5 I	-2.174	-10.473	-3.441	-0.051	-3.694	0	0	-1.648	0	0
RET CI-6 I	0.517	0.208	1.367	0.012	0.073	0	0	1.067	0	0
RET DG-7 I	0.114	-0.123	-0.03	0.002	-0.019	0	-0.004	-0.006	-0.021	-0.06
RET PDG-8 I	20.499	8.456	19.268	0.313	1.342	0	0.264	8.401	1.404	4.045
RET LW-9 I	-0.738	-0.345	-1.007	-0.011	-0.055	0	0	-0.456	0	0
RET PSR-10I	0.044	0.002	-0.062	0.001	0	0	0	-0.036	0	0
RET PWR-1I	0.788	1.177	0.387	0.012	0.187	0	5.103	0.157	27.176	78.272
RET LT-12 I	2.292	0.73	4.744	0.035	0.116	0	0	2.077	0	0

Monetary g e n e t i c g a i n per year 143.974

Mean generation interval 5.816

R e t u r n

return total / unit 1046.512

Return/trait/unit:

My-1=-305.889 fy-2 =1186.200 afc-5= -21.480 ci-6= 3.244

Dg-7 = -0.148 pdg-8= 63.992 lw-9= -2.611 psr-1= -0.050

Pwr-= 113.259 lt-12= 9.995

C o s t s

Costs total / unit 53.666

Fix = 31.595 per dam = 16.495

Variable = 5.575

P r o f i t

Profit / unit 992.846

Appendix II: ZPLAN Outputs for objectives 2 and 3

BASIC RUN: RESULTS FOR THE SELECTION GROUPS

		1	2	3	4	5	6	7	8	9	10
	I	BNOB>B N	DN>BN	BNYB>DN	BNOB>	DN DN>	BNYB>B	DC>BC	BNYB>DC	BC>I	DC>DC
----------	I	-----------	---------	----------	----------	----------	----------	--------	----------	----------	----------
SEL.ANIM.	I	1	25	1	1	357.143	1	13.3	6785.71	13.3	9.5
PROV.ANIM.	I	1	357.143	11013.75	1	11137.5	1.000 1	1013.75	13504.7	11013.8	13338
PROP.SEL.	I	0.083	0.07	0	0.083	0.032	1	0.001	0.502	0.001	0.001
SEL.INT(i)	I	1.84	1.908	3.972	1.84	2.238	0	3.301	0.794	3.301	3.441
GEN.INT	I	4.079	6.402	4.079	4.527	6.202	4.642	10.479	4.642	4.668	10.479
GENE-OFF	I	95	100	95	5	100	100	100	70	30	100
SD(AT)	I	373.367	287.74	373.367	5.702	86.576	105.628	55.321	690.561	294.614	623.125
RAI	I	0.56	0.873	0.942	0.56	0.873	0.504	0.038	0.504	0.038	0.038
LT-GENE	I	8.08	8.5	8.08	3.59	71.76	0	0	0	0	0
monGG(AT)	I	2101.547	3178.472	8009.072	2101.55	3729.23	0	0	0	0	0
GG MY-1	I	72.775	111.963	305.482	72.775	131.363	0	0	29.164	0	0
GG FY-2	I	2.246	3.839	8.62	2.246	4.504	0	0	0.902	0	0
GG PY-3	I	1.231	2.307	5.297	1.231	2.707	0	0	0.554	0	0
GG SCC-4	I	-0.002	-0.001	-0.002	-0.002	-0.001	0	0	0	0	0
GG AFC-5	I	0.265	-11.361	7.165	0.265	-13.329	0	0	0.456	0	0
GG CI-6	I	-0.173	0.369	1.704	-0.173	0.433	0	0	0.14	0	0
GG DG-7	I	0.257	0.603	0.206	0.257	0.708	0	0.03	0.035	0.03	0.032
GG PDG-8	I	34.142	10.551	30.85	34.142	12.38	0	2.497	3.775	2.497	2.603
GG LW-9	I	2.623	0.759	2.402	2.623	0.89	0	0	0.201	0	0
GG PSR-10	I	0.033	0.016	-0.024	0.033	0.019	0	0	0	0	0
GG PWR-1	I	0.04	0.023	-0.013	0.04	0.027	0	0.891	0.001	0.891	0.929
GG LT-12	I	7.926	4.771	13.089	7.926	5.598	0	0	0.933	0	0
GG ummy-1	I	0	0	0	0	0	0	0	0	0	0
SDE MY-1	I	0.18	0.138	0.18	0.003	0.042	0.051	0.027	0.333	0.142	0.3
SDE AFC-5	I	0.043	0.024	0.043	0.001	0.016	0.014	0.005	0.143	0.061	0.097
RETURN TOT	I	378.411	479.161	1396.895	5.779	165.568	0	7.006	277.275	37.31	82.256
RET MY-1	I	-82.776	-97.997	-347.462	-1.264	-34.595	0	0	-61.383	0	0
RET FY-2	I	246.298	323.981	945.426	3.761	114.371	0	0	183.12	0	0
RET PY-3	I	172.539	248.909	742.571	2.635	87.869	0	0	143.782	0	0
RET SCC-4	I	0.73	0.262	0.939	0.011	0.093	0	0	0.14	0	0
RET AFC-5	I	0.366	-8.817	9.896	0.009	-6.918	0	0	2.084	0	0
RET CI-6	I	-0.427	0.512	4.204	-0.01	0.402	0	0	1.141	0	0
RET DG-7	I	-0.294	-0.532	-0.236	-0.004	-0.188	0	-0.005	-0.073	-0.027	-0.06
RET PDG-8	I	31.829	7.569	28.76	0.486	2.672	0	0.344	6.512	1.835	4.045
RET LW-9	I	-2.885	-0.642	-2.641	-0.044	-0.227	0	0	-0.408	0	0
RET PSR-10	I	0.875	0.331	-0.652	0.013	0.117	0	0	0.008	0	0
RET PWR-1	I	1.998	0.88	-0.682	0.031	0.311	0	6.667	0.139	35.503	78.272
RET LT-12	I	10.156	4.705	16.772	0.155	1.661	0	0	2.213	0	0

G e n e t i c g a i n per year for the single traits

My-1= 23.5447 fy-2 = 0.7765 py-3 = 0.4659 scc-4= -0.0002

Afc-5= -1.7056 ci-6= 0.0791 dg-7 = 0.1042 pdg-8= 2.7946

Lw-9= 0.2069 psr-1= 0.0029 pwr-= 0.0042 lt-12= 1.1011

Dummy-= 0.0000

Monetary g e n e t i c g a i n per year 659.904

Mean generation interval 5.816

R e t u r n

Return total / unit 2104.940

Return/trait/unit:

My-1=-625.477 fy-2 =1816.959 py-3 =1398.304 scc-4= 2.174

Afc-5= -3.380 ci-6= 5.823 dg-7 = -1.420 pdg-8= 84.052

Lw-9= -6.846 psr-1= 0.692 pwr-= 123.117 lt-12= 35.662

C o s t s

Costs total / unit 181.153

Fix = 31.595 per dam = 16.495 variable = 133.062

P r o f i t

Profit / unit 1923.787

Appendix III: Publications

Objective 1

Journal homepage: http://www.sasas.co.za/journals

South African Journal of Animal Science 2019, 49 (No. 4)

Increasing reproductive rates of both sexes in dairy cattle breeding optimizes response to selection

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(Received 18 April 2018; Accepted 12 June 2018; First published online 24 July 2019)

Abstract

It was reasoned that technologies that increase the reproductive rate of males and females in dairy cattle would realize higher responses to selection. The authors tested this hypothesis using deterministic simulation of breeding schemes that resembled those of dairy cattle in Kenya. The response to selection was estimated for four breeding schemes and strategies. Two breeding schemes were simulated, based on artificial insemination (AI) and multiple ovulation and embryo transfer (MOET) reproductive technologies. The strategies were defined according to the use of conventional semen (CS) and X-chromosome-sorted semen (XS). The four strategies therefore were AI with CS (AI-CS) and XS (AI-XS), and MOET with CS (MOET-CS) and XS (MOET-XS). The four strategies were simulated based on the current dairy cattle breeding goal in Kenya. A two-tier closed nucleus breeding programme was considered, with 5% of the cows in the nucleus and 95% in the commercial. Dissemination of superior genetic materials in the nucleus was based on all four breeding strategies, while in the commercial only the AI-CS strategy was considered. The strategies that increased the reproductive rates of both males and females (MOET-CS and MOET-XS) realized 2.1, 1.4, and 1.3 times more annual genetic gain, return and profitability per cow, per year, respectively, than strategies that increased the reproductive rates only of males (AI-CS and AI-XS). The use of CS or XS, however, did not affect response to selection in the two schemes. The findings demonstrate that reproductive technologies such as MOET maximize response to selection in dairy cattle breeding.

Keywords: artificial insemination, conventional semen, deterministic simulation, multiple ovulation and embryo transfer, X-chromosome-sorted semen
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Introduction

Dairy cattle production plays an important economic role at household and national level in the tropics (Smith *et al*., 2013). It is the most vibrant sector in the livestock industry in Kenya (Bebe *et al*., 2017), and supports over 1.8 million smallholder farmers, who own one to three cows, and account for 70% and 80% of the milk produced and marketed, respectively (KDB, 2015). In the recent past there has been a rise in demand for dairy products in Kenya (Bingi & Tondel, 2015). This has been attributed to an increase in human population, urbanization, increased income per household and greater demand for milk products in East African countries (Bingi & Tondel, 2015). This demand could be met only through good management of dairy animals and breeding. Improvement through breeding requires an efficient and sustainable breeding programme that accounts for the needs of stakeholders in the dairy cattle value chain. In Kenya, the breeding programme for dairy cattle is well structured as large-scale farms represent the nucleus, and smallholder farms form the lower tier. Although the efficiency of this programme has been assessed based on the current breeding goal, the most effective way to disseminate genetic materials that are generated in the nucleus to smallholder farmers has not been investigated.

Reproductive technologies such as artificial insemination (AI) and multiple ovulation and embryo transfer (MOET) are currently being used with conventional (CS) and sexed semen (XS). AI-CS is the most widely used reproductive technology in Kenya (Omondi *et al*., 2017). In the recent past, however, most farmers have used MOET and XS (Moore & Thatcher, 2006; Kosgey *et al*., 2011), possibly because they are

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Appendix IV: Objectives 2 and 3

South African Journal of Animal Science 2019, 49 (No. 6)

Including protein yield and mastitis resistance in dairy cattle breeding goal optimizes response to selection

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Abstract

Selection response from a two-tier nucleus breeding scheme using the current Kenyan breeding goal was compared with an alternative that also accounts for protein yield (PY) and mastitis resistance (MR). The economic value for PY was estimated using a bio-economic model. For mastitis resistance, like other disease resistance traits, the economic value cannot be estimated with profit equations because they have multi-fold effects on input and output, which affects profitability. Therefore, selection index methodology was used. Somatic cell count (SCC) was used as an indicator trait for MR. The ZPAN computer program was used to model the breeding schemes and evaluate response to selection. The alternative breeding goal, which included PY and MR, realized additional KES358.48, 613.55, and 613.65 in annual genetic gain, returns and profit per cow per year, respectively, compared with the current breeding goal. Economic values for PY and MR were KES778.99 and -2364, respectively. Relative economic values for milk yield (MY, kg), fat yield (FY, kg), protein yield (PY, kg), MR, calving interval (CI, days), preweaning daily gain (DG, g/day), postweaning daily gain (PDG, g/day), live weight (LW, kg), preweaning survival (SR1, %), postweaning survival (SR2, %), and length of productive life (PLT, days) were 23 689.80, 4 146.77, 34 665.50, -992.88, 33.66, 62.40, 159.80, 391.94, 987.04, 4 474.37, and 7.56, respectively. This implies that including milk quality traits such as PY in the breeding goal would optimize response to selection in dairy cattle production.

Key words: breeding objective, economic values, genetic evaluation, milk quality, traits, udder health
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Introduction

The production of high-quality milk is necessary to sustain a profitable dairy industry (Ruegg and Pantoja, 2013). The market demands better quality and, in particular, more healthful products that are produced by healthy animals. Milk quality, as reflected by its technological properties, affects milk processing and ultimately product quality (Barbano *et al*., 2006; Parna *et al*., 2012; Zhao *et al*., 2014). The milk pricing system is the most important factor that affects the relative weightings of milk volume, fat, and protein percentages, clinical mastitis and somatic cell count (SCC) in the breeding goal (Wolfova *et al*., 2007). Milk payment in Kenya is currently based on volume. However, this is likely to shift towards quality owing to commercialization of the dairy sector. Somatic cell count, protein and butter fat contents are the major characteristics that are used to quantify milk quality (Ruegg and Pantoja, 2013). Premium prices are awarded for milk that exceeds certain thresholds, and penalties are imposed on milk that falls below minimum quality thresholds. Thus, SCC and PY directly affect revenue from sale of milk (Nightingale *et al*., 2008). In quality-based markets, increased PY typically results in positive marginal returns, and the value of protein is usually greater than that of other milk components (Banga *et al*., 2011). The SCC is routinely used to identify sub-clinical mastitis with a somatic cell count of less than 200 000 cells/ml indicating a healthy mammary quarter (Ruegg and Pantoja, 2013). A greater SCC is an indirect indicator for mastitis in dairy cattle.

Mastitis is the costliest disease in dairy cattle production, resulting in heavy economic losses annually (Berry *et al*., 2011). In the tropics, these losses have been valued at US$ 38.00 per cow per lactation (Mungube *et al*., 2005). The incidence of mastitis in Kenya is extremely high and over 60.7% of dairy cows in smallholder production systems produce milk with SCC that is greater than 200 000 cells/ml (Kashongwe *et*

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Appendix V: Research Permit

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