# DESIGNING BREEDING PROGRAMS FOR IMPROVING MILK YIELD PERFORMANCE OF INDIGENOUS DAIRY CATTLE IN SUDAN

Dissertation for the acquisition of the academic degree of Doktor
der Agrarwissenschaften (Dr. agr.)

Submitted to the Faculty of Organic Agricultural Sciences
of the University of Kassel, Germany

By

Elhady Abaker Mohammed Omer

Main Supervisor: Prof. Dr. Dirk Hinrichs

Co-Supervisor: Prof. Dr. Eva Schlecht

Witzenhausen, Date of Disputation: 25th August 2022

The current work has been accepted by the Faculty of Organic Agricultural Sciences of the University of Kassel as a thesis for acquiring the academic degree of Doctor of Agricultural Sciences (Dr. agr.).

## Summary

The overall aim of the present study was to design appropriate breeding programs for the sustainable improvement of local dairy cattle breeds in Sudan. Butana cattle were used in the current study. Four studies were conducted, beginning with a comprehensive review of literature on indigenous dairy cattle breeding strategies in sub-Saharan Africa with a focus on the factors that contribute to their success or failure. It showed that crossbreeding of indigenous breeds with exotic breeds has been widely used for genetic improvement, but it has largely failed under low-input traditional production conditions due to the inability of crossbred animals to cope with harsh environments and poor management. Mostly, within-breed selection practices have been carried out in centralized breeding schemes controlled by state institutions, with a minimum participation of farmers. Based on the literature review, a community-based breeding program that allows farmers to engage in breeding efforts was suggested.

A second study was conducted to evaluate the performance of the Butana herd in a research station managed by the government in order to determine the progress made over five decades of selection. Data analyzed covered the years between 1961 and 2010. The results showed a significant increase in milk yield from 1209 kg/lactation between 1961 and 1970 to 1689 kg between 2001 and 2010. The age at first calving significantly decreased from 55.6 months to 45.9 months between 2001 and 2010. Some bulls with many daughters had negative genotypic values indicating under performance of selection criteria. With the currently reduced age at first calving as well as the large variation in lactation milk yield, intensive selection for rapid genetic progress in milk yield might be feasible. However, better selection criteria and management are needed.

In the third study, an investigation of the production conditions of Butana cattle, amongst other factors, was conducted, using a survey approach with 202 farmers across 17 villages.

The analysis showed that the majority (65.3%) of the farmers owned between 1 and 11 cattle heads per farm, and all of them relied on milk production for generating cash income or home consumption. Farmers prioritized milk yield as the most important trait for future improvement, followed by growth performance and lactation length. Challenges to cattle productivity in the study areas included the high cost of concentrate feed, a lack of financial support, insufficient genetic improvement services, and a high prevalence of diseases. Over 98% of farmers were willing to exchange information, and about 67% were willing to exchange breeding bulls and establish farmers' associations as relevant aspects for future breed improvement, which could be useful for the establishment of a community-based breeding program.

In the final study, the survey findings were used to simulate various breeding programs for future genetic improvement of Butana cattle under smallholder production conditions. In total, three breeding programs, including the use of farm bulls, the use of village bulls, and the rotational use of village bulls within village groups were modeled using a stochastic simulation program (AlphaSimR). In each of the breeding programs, three selection methods were considered. For the village bull breeding program, the results showed that with collaboration among farmers within the same village, the annual genetic gain (SD units) ranged from 0.01 to 0.21 (phenotypic selection) and 0.014 to 0.45 (selection based on EBV). In the farm bull breeding program, the annual genetic gain ranged from 0.01 to 0.19 (phenotypic selection) and from 0.014 to 0.39 (selection based on EBV). The rotational use of village bulls achieved the lowest annual genetic gain of all bull selection methods. However, it preserved more genetic diversity than the farm or the village bull breeding programs. Overall, the village bull breeding program with selection based on EBV of young bulls is the most promising breeding design for achieving the breeding goal.

## Zusammenfassung

Das übergeordnete Ziel dieser Dissertation war die Entwicklung geeigneter Zuchtprogramme zur nachhaltigen Verbesserung lokaler Milchviehrassen im Sudan. Dafür wurden im Rahmen der Arbeit vier Untersuchungen durchgeführt. Beginn war eine umfassende Literaturrecherche über Zuchtstrategien für lokale Milchviehrassen in Afrika südlich der Sahara mit besonderem Augenmerk auf Faktoren, die zu Erfolg oder Misserfolg der Zuchtstrategien beigetragen haben. Aus den ausgewerteten Artikeln geht hervor, dass die Kreuzung lokaler Rassen mit exotischen Rassen im großen Umfang zur Leistungssteigerung eingesetzt wurde, aber unter den traditionellen Produktionsbedingungen aufgrund von unpassenden Genotypen, rauen Umweltbedingungen und schlechtem Management weitgehend gescheitert ist. Die Selektion innerhalb der Rasse auf angepasste einheimische Genotypen ist eine Option für extreme Produktionsbedingungen. Die meisten Strategien zur Selektion innerhalb der Rasse wurden in staatlichen, von der Regierung kontrollierten Zuchtprogrammen mit minimaler Beteiligung der Kleinbauern durchgeführt. Basierend auf der Literaturanalyse erfolgte der Vorschlag eines gemeindebasierenden Zuchtprogramms, um Kleinbauern die Möglichkeit zu geben, an nachhaltigen Programmen zur genetischen Verbesserung teilzunehmen.

In einer zweiten Studie wurde die Leistung einer Butana-Herde in einer von der Regierung verwalteten Forschungsstation bewertet und die Zuchtfortschritte ermittelt, die in fünf Jahrzehnten der Selektion erzielt wurden. Die analysierten Daten umfassten die Jahre zwischen 1960 und 2010. Die Ergebnisse zeigten einen deutlichen Anstieg der Milchleistung von 1209 kg zwischen 1960 und 1970 auf 1689 kg pro Laktation zwischen 2001 und 2010. Das Erstkalbealter sank zwischen 2001 und 2010 von 55,6 Monaten auf 45,9 Monate. Einige Bullen mit vielen Töchtern hatten negative genomische Zuchtwerte, was auf eine unzureichende Erfüllung der Selektionskriterien hinweist. Angesichts des derzeit niedrigeren Erstkalbealters und der großen Unterschiede in der Laktationsmilchleistung könnte eine intensive Selektion einen genetischen Fortschritt bei der Milchleistung ermöglichen. Es sind jedoch bessere Selektionskriterien und ein besseres Management erforderlich. Eine dritte Studie wurde mit 202 Landwirten in 17 Dörfern durchgeführt, um die Produktionsbedingungen der Butana-Rinder, die Produktionsziele der Landwirte, die Produktionsbeschränkungen, die Zucht- und Haltungspraktiken sowie die Durchführbarkeit eines gemeindebasierten Zuchtprogramms für die Rasse mit Hilfe eines Umfrageansatzes zu untersuchen. Es wurde festgestellt, dass die Mehrheit (65,3%) der Landwirte zwischen 1 und 11 Rinder pro Betrieb besaß. Als Hauptgrund für die Haltung von Butana-Rindern wurde mehrheitlich die Milchproduktion zur Erzielung von Bargeldeinnahmen oder für den Eigenverbrauch angegeben, wobei die Milchleistung, gefolgt von der Wachstumsleistung, und der Laktationsdauer, als wichtigste zukünftige Selektionsmerkmale angegeben wurden. Zu den Herausforderungen für die Produktivität der Rinder in den Untersuchungsgebieten gehörten die hohen Kosten für Kraftfutter, fehlende finanzielle Unterstützung durch Kreditgeber, unzureichende Zuchtberatung und das Auftreten von Krankheiten. Über 98% der Landwirte waren bereit, Informationen auszutauschen, und etwa 67% waren bereit, Zuchtbullen auszutauschen und Bauernverbände zu gründen, was für die künftige Optimierung der Rasse von Bedeutung ist und für die Einrichtung eines gemeindebasierten Zuchtprogramms nützlich sein könnte.

In der abschließenden Studie wurden die Ergebnisse der Umfrage genutzt, um verschiedene Zuchtprogramme für die zukünftige genetische Verbesserung von Butana-Rindern unter kleinbäuerlichen Produktionsbedingungen zu simulieren. Insgesamt wurden drei Zuchtprogramme, darunter der Einsatz von Farmbullen, der Einsatz von Dorfbullen und der rotierende Einsatz von Dorfbullen innerhalb von Dorfgruppen, mit dem stochastischen Simulationsprogramm AlphaSimR modelliert. Die Ergebnisse zeigten, dass der jährliche genetische Gewinn (SD-Einheiten) im Dorfbullen-Zuchtprogramm, bei dem eine Zusammenarbeit zwischen den Landwirten innerhalb desselben Dorfes angenommen wurde, zwischen 0,01 und 0,21 (phänotypische Selektion) und 0,014 und 0,45 (Selektion auf der Grundlage des EBV) lag. Im Zuchtprogramm für Zuchtbullen reichte der jährliche genetische Gewinn von 0,01 bis 0,19 (phänotypische Selektion) und von 0,014 bis 0,39 (Selektion auf der Grundlage von EBV). Der rotierende Einsatz von Dorfbullen erzielte bei allen Selektionsmethoden den geringsten jährlichen genetischen Gewinn. Die Rotation von Bullen bewahrte jedoch mehr genetische Vielfalt als die Zuchtprogramme auf dem Einzelbetrieb oder im Dorf. Insgesamt ist das Dorfbullen-Zuchtprogramm mit der EBV-basierten Selektion von Jungbullen das vielversprechendste Zuchtdesign zur Erreichung des Zuchtziels Milchleistung.

## Table of Contents

**List of Tables**

## List of Figures

**List of Abbreviations**

| | |
|---|---|
| AU-IBAR | African Union-Inter-African Bureau for Animal Resources |
| AFC | Age at first calving |
| BLUP | Best linear unbiased prediction |
| CI | Calving interval |
| DP | Dry period |
| EBV | Estimated breeding value |
| F1 | First filial generation |
| F2 | Second filial generation |
| FAO | Food and Agricultural Organization |
| GDP | Agricultural gross domestic products |
| LL | Lactation length |
| LMY | Lactation milk yield |
| NE | Effective population sizes |
| QTL | Quantitative trait locus |
| SNP | Single nucleotide ploymorphsim |
| SPSS | Statistical package for social sciences |
| TBV | True breeding value |
| UNEP | United Nations Environment Program |
| USAID | United States Agency of International Development |

# 1.0 General introduction

## 1.1 Livestock in Sudan

Sudan is located in eastern sub-Saharan Africa and is one of the continent's largest countries with a total land area of 1,882,000 square kilometres (UNEP, 2020) and a population of 44.4 million people (FAO, 2020). The majority of Sudanese live in rural areas, and agricultural output from crop and animal farming represents their primary source of income and food security. The livestock sector accounts for 60 percent of Sudan’s agricultural gross domestic products (GDP), employing approximately 40 percent of people, and contributing valuable animal food to various rural dwellers (Wilson, 2018; FAO, 2020). Livestock are raised in almost all parts of the country and are mostly owned by smallholder farmers or communities of traditional pastoralists (Wilson, 2018). According to the Food and Agricultural Organization (FAO) report on the state of crop and food supply assessment mission (FAO, 2019), Sudan’s livestock population includes 31 million heads of cattle, 40 million sheep, 32 million goats, and 4 million camels.

## 1.2 Indigenous cattle breeds and their production systems

Indigenous cattle of Sudan are classified into different ecotypes according to geographic location or tribal ownership. Butana cattle are found in central Sudan, Kenana cattle between the White and Blue Niles, Baggara in Western Sudan, and the Aryashi and Gash breeds in Eastern Sudan (Rahman, 2007). However, data on the number of animals per breed for these indigenous cattle are currently unavailable. The indigenous breeds are considered a major component of poverty alleviation initiatives and mostly utilized for milk, meat, cash income and insurance (Yousif and El-Moula, 2006; Wilson, 2018). They are raised in a variety of production systems, including pastoral and semi-pastoral grazing systems, and small-scale mixed crop-livestock farming systems. The pastoral system is the commonest system of cattle production in Sudan, where pastoral communities own between 80 to 90% of the total number of livestock in the country, and are mostly concentrated in marginal and semi-arid areas (FAO, 2016). Under this system, natural rangelands are used for grazing, and cattle are moved around the country in response to change in weather conditions and the availability of livestock forage. Animals in this production system are primarily Western Baggara cattle, which are the main source of beef for domestic demand and export markets (Kambal et al., 2021). However, milk produced in excess of the calves' needs is transported to the nearest town or dwelling and sold as a source of income (Yousif and El-Moula, 2006).

Small-scale mixed crop-livestock farming is another type of cattle production system in Sudan. In this system, cattle owners in villages practice crop farming using traditional rain-fed or irrigated crop cultivation, which is a primary source of food for farmers and their families, while residues or crop-by-products are used to feed their cattle. Livestock owners who practice rain-fed agriculture in this system also send their animals with the nomads to feed on freely available rangelands. Indigenous cattle reared in this system are mostly dairy breeds such as Butana and Kenana (Musa et al., 2006). The system supplies milk to towns and urban areas and is characterized by low input and infrastructures.

With rapidly changing demand patterns for animal products, especially milk, new intensive and semi-intensive systems have recently developed around the urban areas (Ahmed et al., 2007). These include milk specialized large dairy enterprises, and individuals that own high producing milking cows, i.e., Holstein Friesian or their crosses (Holstein Friesian X Butana /Kenana) (The Frisian, 2016).

### 1.3 Study population

The Butana cattle breed was used in the present study, because it is regarded as one of the best native African breeds for milk production (Rege et al., 2011; Porter et al., 2016). Butana cattle are native to the semi-arid areas of the Butana region of central Sudan, between River Nile, the Atbara River, and the Blue Nile, at latitude 14°23' and 17°42'N, longitude 32°32' and 33°58'

E, and an altitude of 345 meters above sea level. They are widely preferred for their unique adaptability to the harsh environmental conditions of the tropics, e.g., high temperature, drought, and disease challenges. Butana cattle are kept by smallholder producers primarily for milk production, but they also serve other functions such as the provision of beef, draught power, insurance, and socio-cultural needs of rural communities (Mohammed et al., 2014).

## 1.4 Current efforts for genetic improvement of Butana cattle

Some attempts have been made by the government of Sudan to develop indigenous cattle breeds through the establishment of livestock research stations in areas of livestock concentration. Atbara Livestock Research Station was established at Atbara in 1945, and mandated to improve milk yield performance of Butana cattle through breeding (Saeed et al., 1987). However, this institution has deteriorated due to a number of management issues. Besides, smallholder farmers who form the majority of Butana cattle keepers were not actively engaged in the activities of the established research station, and they rarely had access to improved genetics, thereby, preventing them from effectively improving their cattle (Omer et al., 2020). Need for a solution to the problem of milk deficit has led to crossbreeding of indigenous breeds, either Butana or Kenana, with foreign high yielding breeds, e.g., Holstein Friesian (Ageeb and Hayes, 2000; Abdel Gader et al., 2007). It is acknowledged that the crossbreeding strategies are justifiable, and represent important opportunities for increasing productivity and improving human livelihoods in systems where resources allow for the exploitation of the potential of different breeds (Rege et al., 2011; Wilson, 2018). For example, the rearing of high-producing breeds has contributed to an increase in milk production on large-scale dairy farming systems around Khartoum and other major cities. (The Friesian, 2016). Milk production increased from 4.95 tons in 1989 to 6.46 tons in 2016 (Hassan et al., 2019). However, under traditional smallholder production conditions in remote areas, crossbred cattle face many problems such as inadequate feed resources with respect to quality and quantity, poor management, and the prevalence of parasites and diseases, and thus, little success has been achieved (Abdel Gader et al., 2007). Besides, the practice of crossbreeding for improving milk yield performance of Butana or other local breeds in Sudan is haphazard and there is no coherent breeding plan being implemented (Ahmed et al., 2007). Therefore, a within breed selection strategy has been recommended as a valuable option for genetic improvement of indigenous breeds, particularly in harsh environments in remote areas (Musa et al., 2008). This is because indigenous breeds, in general, have special adaptive characteristics such as diseases tolerance, heat tolerance, and the ability to better utilize limited and poor-quality feed (Mwacharo and Drucker, 2005). These characteristics enable them to survive and thrive under harsh tropical environments (Kosgey and Okeyo, 2007). However, to effectively utilize these unique characteristics of indigenous breeds, viable breeding programs that are compatible with existing low-input production systems must be developed and implemented.

A community-based or cooperative breeding program typically relates to low-input systems with farmers having a common interest to improve and share their genetic resources. It therefore offers new outlook for livestock sustainable breeding programs development in developing countries (Kahi et al., 2005; Haile et al., 2019). Community-based breeding programs take a holistic approach to production conditions, they involve local communities or smallholder farmers in the breeding program, consider their needs, and incorporate their indigenous knowledge (Gizaw et al., 2013; Haile et al., 2019). In addition, community-based breeding programs can assist farmers in gaining access to credit and markets, as well as provide a forum for locals to further develop their skills in creating self-help processes, analysing, and solving problems as a group (Kahi et al., 2005; Zumbach and Peters, 2002). Furthermore, community-based breeding programs can improve a local breed's resilience and genetic integrity without necessitating costly intervention (Karnuah and Dunga, 2018). The designing of a community-based breeding program follows a systematic process that includes several key elements such as a description of production systems, identification of farmers' production objectives, and a clear definition of a breeding goal that specifies traits to be improved (Kahi et al., 2005; FAO, 2007; Kosgey and Okeyo, 2007). This can be achieved by active communication action with farmers at the start of the breeding program planning phase (FAO, 2010; Wurzinger et al., 2011; Haile et al., 2019).

## 1.5 Aim of the study and thesis outline

The overall aim of this thesis was to design appropriate breeding programs for the sustainable improvement of the indigenous dairy cattle breeds in Sudan.

The thesis is divided into six chapters. Following a general introduction, Chapter 2 gives a brief literature review on breeding strategies for indigenous dairy cattle breeds in Eastern sub-Saharan Africa with a focus on the factors that contribute to their successes or failures.

In Chapter 3, the progress achieved in some production and reproduction traits through a within-breed selection program of Butana cattle kept at a research station was investigated.

Chapter 4 presented findings of a survey study. Here, the production systems under which Butana cattle are reared, farmers' production objectives and challenges were described. Additionally, farmers' willingness to participate in breeding associations and the possibilities of establishing a community-based breeding program for future breed development were discussed.

In Chapter 5, findings of the afore-mentioned survey study were used to design alternative breeding programs for improving milk production in Butana cattle via computer simulations. In this chapter, a single trait representing milk production was simulated as a breeding goal trait, and the effect of different breeding scenarios and selection methods on annual genetic gains, and genetic variances for the breeding goal were investigated. Finally, the findings of Chapters 2, 3, 4, and 5 were collectively discussed in Chapter 6.

# 2.0 Review: Breeding strategies for improving indigenous dairy cattle breeds in Eastern sub-Saharan Africa

## 2.1 Abstract

Indigenous cattle form one of Africa's most important livestock species serving multiple functions for farmers and contributing to the national economy of many countries. Several breeding efforts have been put in place to improve milk yield performance of indigenous breeds. This paper reviews breeding strategies as well as breeding organizations for improving milk yield performance of indigenous cattle genetic resources in sub-Saharan Africa, highlighting their successes and failures. Emphasis was placed on Sudan and other eastern sub-Saharan African countries. Our results showed that selection within indigenous breeds is crucial, but that large-scale breeding organizations in the region are missing. A lack of pedigree and performance records, inadequate infrastructure, and institutional frameworks are the key hurdles of implementing large-scale selection schemes for indigenous breeds in the region. Crossbreeding of indigenous and exotic breeds in various production environments has been widely used for improving milk yield performance of indigenous breeds. Thus, there exists a wide variety of crossbred dairy cattle in the region. However, most studies showed that crossbreds with 50% and 62.5% exotic blood inheritance are suitable for many production conditions in Eastern sub-Saharan Africa, whereas high-grade crossbreds could be justified under intensive production systems where better environment can be provided. Nevertheless, additional research is needed to identify the optimal crossbred genotypes, which suit each production environment in the region. Under production conditions with sever environmental restrictions, it may be preferable to perform selection within indigenous breeds. Furthermore, effective breeding organizations are critical for successfully implementing long-term breeding plans for indigenous breed genetic improvement.

Keywords: indigenous cattle, genetic improvement.

## 2.2 Introduction

Sub-Saharan Africa is home to a large population of cattle which consist of 145 indigenous breeds/strains (Rege, 1999). Population density of these indigenous breeds is highest in East Africa compared to other regions on the continent (Mwai et al., 2015; Ibeagha-Awemu et al., 2019). There are about 107.2 million heads of cattle in East Africa (USAID, 2019). Ethiopia has the largest cattle number (57 million heads), followed by Sudan, which has 31 million heads (FAO, 2019). Eastern Africa is also the leading milk-producing region in Africa, representing 68% of the continent's production (Bingi and Tondel, 2015). Indigenous cattle play a major role in milk supply. They are mainly kept by the rural poor (FAO, 2015; Ibeagha-Awemu et al., 2019). It is often said that through long periods of natural and human driven selection, the indigenous breeds have acquired unique features regarding adaptation to local environmental conditions (Philipson et al., 2006; Mwai et al., 2015). However, their performance in terms of milk production is low compared to exotic breeds (Philipsson et al., 2006; Renaudeau et al., 2012; Wilson, 2018). This low performance may reflect a lack of exploitation of their genetic potential as well as inadequate nutrition, health care and management (Gamaliel et al., 2019). Increasing demand for livestock products is a major driver of change in livestock production systems in the developing world (Rege et al., 2011). In sub-Saharan Africa, the demand for animal-derived products is increasing by more than 3% annually (FAO, 2016). However, output of cattle-derived items such as milk is woefully inadequate to satisfy the rising demand in a number of nations. As a result, many attempts for improving milk yield performance of the indigenous breeds have been carried out. Within-breed selection (pure breeding) and crossbreeding (using either local or exotic germplasm) are the two main tools used to achieve genetic change in livestock populations (FAO, 2010). Both breeding strategies have been implemented in Eastern sub-Saharan Africa, but the introduction of genetic material from western dairy breeds, either by live animals of both sexes or by importing semen for crossbreeding with indigenous cows is a widely used breeding strategy for improving the milk yield (Sysrstad et al., 1998). Seemingly, breeding strategies have been successful in some countries but spectacularly unsuccessful in many others (Wilson, 2018). Therefore, the objective of this paper to review breeding strategies for the development of indigenous cattle breeds for milk production in Eastern sub-Saharan Africa. Reasons for successes or failures of the breeding programs as well as opportunities and challenges that influence the sustainable breeding of indigenous cattle in the region were also discussed.

### 2.3 Predominant East African indigenous cattle breeds and their unique characteristics

Genetic diversity of indigenous breeds represents a unique source of adaptive traits that allow them to thrive in their own production environments (Mwai et al., 2015; Wilson, 2018). Cattle diversity serves as a repository for genetic variation, ensuring that future market demands are met through selection (Mapiye et al., 2019). The predominant indigenous cattle breeds used for milk production across the eastern countries of sub-Saharan Africa and their unique features from different articles are presented in Table 1. Each breed is then described in terms of main uses and its adaptive attributes, although information on the number of animals per breed are lacking. Boran cattle are indigenous to Ethiopia and widely spread across the country. They are well adapted to semi-arid tropical conditions and have the ability to survive long periods of feed and water shortage (Aynalem et al., 2011). Hardened hooves and lighter bones enable this type of cattle to endure long migrations (Mandefro et al., 2017). Boran is also known for its high degree of heat tolerance and resistance to ticks. In Kenya, Boran cattle that originally migrated from Ethiopia were improved for beef production. Thus, Boran is essentially a beef-type breed with a large and wide frame, but it is also an excellent breed for milk production, providing most of the staples in pastoral communities (Mandefro et al., 2017). The Fogera breed is another Ethiopian cattle widely distributed around the Lake Tana region. It is thought to be suitable for milk production and adapted to grazing in waterlogged areas (Tegegne et al., 2013). The Sahiwal breed originated in India and imported to Kenya in the late 1930s (Ilatsia et al., 2007). The breed has traditionally been used for milk and beef production in low-input production systems (Ilatsia et al., 2011). This breed shows unique adaptive traits, which makes it relatively competitive in low-input production systems of the tropics. Also, in Kenya, Nandi cattle are mostly found in the north rift area within the Nandi community. According to the African Union-Inter-African Bureau for Animal Resources (AU-IBAR) report on the Kenya livestock breed catalog (AU-IBAR, 2019), the Nandi breed is at risk of extinction due to replacement, upgrading, and crossbreeding. Butana and Kenana are Sudanese cattle breeds that are mainly kept by smallholder farmers for milk production under low input production systems (Rege, 1999; Musa et al., 2005). Butana cattle are found in the Butana plain, a desert area in central Sudan between the Blue Nile and Atbara River, whereas Kenana cattle can be found around the Blue and White Niles, and south-east to the Ethiopian border. Recent genome structure studies have shown that both Butana and Kenana breeds have unique genes that make them tolerant to heat stress under semi-arid environments (Bahbahani et al., 2018). Barka cattle are indigenous to Eritrea and are raised by the Barka people for milk production (Wilson, 2009). Ankole cattle are found in the south-western part of Uganda and mainly kept for milk supply (Grimaud et al., 2007). They are well adapted to the seasonal harsh conditions (variations in temperature, rainfall and feed quality) prevailing in Ugandan rangelands. Ankole cattle can also be found in Tanzania, Burundi and Rwanda. They are threatened due to cross-breeding with exotic dairy breeds (Bett et al., 2013). Among the indigenous cattle, Kenana and Butana breeds considered the highest milk producers (Rege, 1999; Philipsson et al., 2011).

**Table 1.** Nine populous indigenous cattle of Eastern sub-Saharan Africa

| Breeds | Group | Country | Key function of breed | References |
|---|---|---|---|---|
| Ethiopian Boran | Zebu | Ethiopia | Dual-purpose | (Mandefro et al., 2017) |
| Fogera | Zegna | Ethiopia | Milk, draught and meat | (Rege, 1999; Tegegne et al., 2013) |
| Kenyan Sahiwal | Zebu | Kenya | Dual-purpose | (Ilatsia et al., 2011) |
| Nandi | Zebu | Kenya | Milk production | (Wilson, 2009) |
| Butana | Zebu | Sudan | Milk production | (Rege, 1999; Musa et al., 2005) |
| Kenana | Zebu | Sudan | Milk production | (Rege, 1999; Musa et al., 2005) |
| Mpwapwa | A composite breed | Tanzania | Dual-purpose | (Rege, 1999) |
| Barka | Zebu | Eritrea | Milk production | (Rege, 1999; Wilson, 2009) |
| Ankole | Sanga | Uganda | Milk production | (Wurzinger et al., 2006 ; Grimaud et al., 2007) |

Sanga = crossbreds between the indigenous taurine and zebu (Rege, 1999)
Zenga = crossbreds between zebu and Sanga (Rege, 1999)

## 2.4 Genetic efforts for improving milk production of indigenous breeds in East Africa

### 2.4.1 Within-breed selection strategy

Within-breed selection is a genetic improvement strategy that is typically used in a single population (Kosgey et al., 2006). It is intended to increase the average level of genetic merit of the population. In many regions of Africa, particularly in extremely harsh production environments, using pure indigenous breeds is often the best production alternative and has a great advantage in many cases (FAO, 2013; Wilson, 2018). Arguments in favor of selection within indigenous breeds were summarized as follows: a) they are adapted to local environments which are characterized by high disease prevalence, high temperature, and limited and low quality feed (Mwacharo and Drucker, 2005; Kosgey and Okeyo, 2007); b) within-breed selection is considered to be an effective approach to optimize the conservation of indigenous breeds, specifically when the number of animals is too small (Biscarini et al., 2015); and c) local breeds are integral part of some crossbreeding programs such as rotational crossbreeding where exotic and indigenous breeds are used in rotation. There are numerous indigenous breeds in Eastern sub-Saharan Africa (Table 1) that could be improved via within breed selection strategies. However, these indigenous breeds are generally characterized by small herd-size (particularly in mixed crop/ livestock systems), with communally shared grazing and uncontrolled mating (Abdel-Salam et al., 2010). Furthermore, pedigree and milk performance recording that support selection decision are almost non-existent in smallholder production settings (Musa et al., 2006; Marshal et al., 2011; Opoola et al., 2019). Generally, reasons for failure of recording have been outlined by different authors (Peters and Zumbech, 2002; Opoola et al., 2019) and include: insufficient technical knowledge on recording and its utilization, lack of funding for animal recording, ignorance of recording by local communities, poor communication and lack of incentive for farmers to record data. These characteristics limit the implementation of effective genetic improvement programs. Therefore, nucleus breeding organizations with controlled mating and pedigree recording have been proposed to overcome the problems associated with field performance recoding and small herd sizes in low-input smallholder production systems (Kahi et al., 2004; Kariuki et al., 2014). Thus, genetic progress in the nucleus can be disseminated to the participating herds through the use of males originating from the nucleus. Mostly, nucleus breeding organizations are executed by government farms or research institutions. In the current study, selection within-indigenous breeds as well as key success and failure factors of nucleus breeding organizations are discussed under the following section.

#### 2.4.1.1 Nucleus based-breeding organizations

There are two types of nucleus schemes: closed and open. The closed nucleus scheme permits the flow of improved genetics only from the nucleus into the production population or participating herds. Open nucleus breeding permits high potential breeding animals to flow directionally between the nucleus and the production population, i.e., females that have proved superiority in participating herds are transferred for use in the nucleus. Because there are more potential candidates for selection in an open nucleus breeding system, there is more genetic gain. Furthermore, such a system integrates farmers' resources, and encourages more farmer engagement (Bondoc and Smith, 1993). Organization of open nucleus breeding schemes, and their genetic and economic efficiencies in developing countries have been described by Kahi et al. (2004). Both types have been implemented for dairy selection in east Africa. In Ethiopia, selection for Boran cattle has been carried out in the Dida Tuyera research station. Originally, the selection criterion was meant to produce Boran bulls to improve pastoralist herds for meat production, but dams for crossbreeding programs were also produced. However, the station did not have clear breeding objectives (Haile et al., 2011a). A challenge for breeders was how to identify which breeding objectives for the breeds need to be developed. Furthermore, there was a question on how to design appropriate strategies for sustainable genetic improvement without sacrificing a breed’s adaptation qualities. In Sudan, the government established Atbara and Umbenein Livestock Research Stations to study and improve the productivity of the native Butana and Kenana cattle breeds. Both institutions have deteriorated owing to a variety of administrative issues. This is because the Livestock Ministry is deemed understaffed and underfunded (Wilson, 2018). In Uganda, until the 1950s, attempts to improve dairy production in the country were based almost entirely on selective breeding within indigenous cattle with fears that exotic breeds were likely to be adversely affected by the prevailing climate (Nakimbugwe et al., 2002). This objective was later dropped because selective breeding within indigenous cattle proved to be too slow to match the rate of development of agriculture. Therefore, later attempts in the 1980s and early 1990s involved the introduction of more exotic breeds for both crossbreeding with the indigenous animals and for pure exotic breeding. Nevertheless, a success story of within-indigenous breed selection strategy has been reported for the Sahiwal cattle in Kenya in Nivasha station (Muasya et al., 2011; Mwangi et al., 2018). At the station, intense pedigree and performance recording as well as genetic evaluation are carried out. Selection and breeding procedures involved: a) breeding elite cows with proven bulls to produce young bulls for progeny testing within the nucleus closed herd; b) young bulls for progeny testing being selected on the basis of pedigree information and individual growth rate; and c) bull dams selected from the top 5-6% of the elite herd. Genetic gain achieved by selection in the nucleus is disseminated to the commercial population (primarily pastoralists). There are about 18 ranch herds that host approximately 7, 000 pure-bred Sahiwal cattle (Ilatsia et al., 2011). Recently, demand for Sahiwal from the range areas of Kenya has risen sharply. Semen or live animals have been exported to Tanzania, Zambia, Uganda, Burundi, Ruanda, Zaire, and Somalia. However, the lack of success of the few attempted central nucleus breeding programs led to criticisms that it is unsuitable for low-input production systems (Rewe et al., 2009). Nowadays, community-based breeding programs have been promoted as a strategy for livestock improvement in low input production systems (Haile et al., 2011b; Wurzinger et al., 2011). Mueller et al. (2015) described these breeding schemes as typically related to low-input systems with farmers within geographical boundaries having a common interest to work together for the improvement of their genetic resources. Community-based breeding schemes are planned, designed, and implemented by smallholder farmers individually or in cooperation with many others stakeholders (Muller et al., 2015; Karnuah et al., 2018). In most cases, the smallholder farmers are rural and have limited resources (Mueller et al., 2015). Thus, community-based breeding programs have attracted the interest of the global community and are being implemented in a number of developing countries, including Africa. For instance in Ethiopia , Malawi, Uganda, Tanzania, South Africa, and Mongolia, community-based breeding programs are used for small ruminant improvements (Gizaw et al., 2014; Haile et al., 2019). In Ethiopia, it is used for improvement of Fogera cattle, where breeding effort focused on within breed selection under the open nucleus breeding scheme with a community based breeding approach. The final goal of the breeding scheme was restocking the declining village Fogera cattle population and improving the livelihood of the farmers. All farmers were pleased with the services provided, such as better bulls, vaccination, forage improvement and grazing land management as part of the breed conservation and improvement effort. In Burkina Faso in West Africa, this breeding scheme is used for the improvement of Lobi cattle and their crosses, and also for Fulani Zebu in terms of milk production (Ouédraogo et al., 2019). Farmers agreed on the importance of belonging to an association and collaborating with other members. Generally, the arguments in favour a community-based breeding program have been summarized based on the studies of Gizaw et al. (2009), Mueller et al. (2015) and Haile et al.( 2019): a) community-based breeding schemes focus on indigenous genotypes, and farmers' needs, views, and their decisions are considered; b) keeping indigenous genotypes is economically beneficial and provides a sustainable option for their conservation; c) farmers are owners of the breeding program and benefit from it; d) community-based breeding programs have the potential to bridge the skills gap between breeders and farmers while ensuring farmers' property rights to improved genetic materials; e) the initiative is self-managed by the community, but is supported by the government and other organizations; and f) a community-based breeding program will help improve the productivity and profitability of indigenous breeds without undermining their resilience and genetic integrity, and without expensive interventions.

Through community-based initiatives, farmers are well positioned to perform the roles of a nucleus or centralized breeding scheme (Kahi et al., 2005). However, long-term sustainability of community-based breeding programs could be achieved via active involvement of farmers and other livestock partners such as breed associations and governmental research institutions (Rewe et al., 2009; Mueller et al., 2015). Key functions of livestock development partners include ensuring long-term follow-up of activities, provision of advisory services to community organizations, continuous revision of current and future strategies, and human capacity building. For example, the South African livestock breeders' associations, which supports performance recording and organized breeding for livestock species, is critical to the long-term viability and development of livestock breeding programs in South Africa (Rewe et al., 2009).

### 2.4.2 Crossbreeding strategies

It is often considered that indigenous breeds produce little and have limited genetic potential. Genetic improvement is thought to be feasible only via the introduction of exotic breeds with higher genetic value. Thus, crossbreeding indigenous cattle breeds with improved exotic dairy cattle breeds is widely practiced (Syrstad, 1996; Roschinsky et al., 2014). Holstein-Friesian is the main exotic dairy breed used for milk production in sub-Saharan Africa (Opoola et al., 2019). However, a smaller population of other exotic breeds such as Jersey, Guernsey, and Ayrshire are also found. Three types of crossbreeding breeding strategies are hereby discussed.

#### 2.4.2.1 Up grading

Grading up is a common crossbreeding strategy employed in most parts of the tropics (Ageeb and Hayes, 2000; Ahmed et al., 2007; Philipsson et al., 2011). Typically, an indigenous female and her offspring are mated to exotic sires. In this study, milk yield performance of different grades of crossbred cows from different countries in sub-Sahran East Africa were assessed. For instance, in Sudan, Fadlelmoula et al. (2007) investigated the performance of cross-bred cows with different proportion of Holstein Friesian blood, including 25%, 37.5%, 50%, and 62.5%, kept at the University of Khartoum research farm. The 50% crosses produced significantly higher milk yield than the others. This was confirmed by Yaha et al. ( 2011) who analyzed data from a dairy farm in Central Sudan and reported that lactation milk yield of 50% crossbred cows (Holstein X Kenana or Butana) was significantly higher than of cows with 62.5% or pure Holstein Friesian. The authors attributed the reason why pure Holstein Friesian and 50% crossbred cows produced the same amount of milk to the high ambient temperatures (36.4$^0$C) in the study area, which pure Holstein Friesian could not tolerate. Similarly, Ahmed et al. (2007) found no significant difference in lactation milk yield between crossbred cows with 62.5%, 75% or 87.5% of Holstein Friesian inheritance and cows with 50% Holstein Friesian blood. In Sudan, Ali et al. (1988) analyzed data from two different research farms and reported that lactation milk yield of crossbred (Friesian x Kenana or Butana) cows having 50%, 62.5%, and 75% Friesian blood were 1,953 kg, 2,548 kg and 1,876 kg, respectively.

The milk yield performance of Holstein Friesian (3,507 kg per lactation) reported by Yahya et al. (2011) in Central Sudan was comparable to that (3,476 kg per lactation) reported by Abdel-Gader et al. (2007) for the same breed in the south of Khartoum. However, in Kenya, Holstein Friesian cows realized 4,540 kg – 6, 000 kg milk per lactation, which is much higher than values reported from Sudan (Ojango et al., 2004). This difference could partly be attributed to the effect of climatic conditions, which are less severe in Kenya than in Sudan. Nonetheless, the performance of Holstein-Friesian cows in both countries is much lower than their expected performance in the temperate climate regions, e.g., 7,774 kg per lactation in the United Kingdom (Eastham et al., 2018) and 11,000 kg per lactation in United States of America (Brito et al., 2021). This clearly shows the negative impact of tropical conditions on Holstein Friesian performance. In the tropics, high temperatures combined with high relative humidity cause most of heat stress in Bos taurus cattle.

Haile et al. (2009), studied milk production traits of Boran cattle and their crosses in Ethiopia and reported that 50% Holstein Friesian crosses had a fourfold increase over the Ethiopian Boran breed in terms of lactation milk yield, 305-days milk yield, daily milk yield and life time milk yield. They were also milked for 97 more days than Ethiopian Boran. When crosses of 50%, 62.5%, 75% and 87.5% Holstein blood were compared, it was observed that lactation milk yield, 305-days milk yield, and daily milk yield were significantly higher for 75% and 87.5% crosses compared with 50%, 62.5% crosses. However, life time milk yield was higher in 50% crosses than in all other genetic groups. The authors attributed the higher life time milk yield of 50% crosses to their longer productive herd life time compared to the others (information on herd life time were not provided by the authors). Also, in Ethiopia, Muluye et al. (2017), assessed the performance of different types of crossbreds under smallholder production conditions and concluded that crossbred cows having 75% Holstein Frisian genetics are best suited to urban production systems, i.e., zero grazing systems. Medium exotic blood levels (50-62.5%) are best suited to peri-urban production systems, and lower exotic blood levels (25% to 50%) are best suited to rural production systems.

In Northeast Tanzania, a study on the lactation performance of crossbred cattle kept by smallholder farmers showed that milk performances of the first lactation records of cows with 62% and 75% Holstein blood were not significantly higher than the performance of crossbred cows with 50% Holstein blood (Msanga et al., 2000). However, in repeated lactations, cows with 62% of Holstein blood produced significantly more milk than the ones with 50% or 75%. The authors concluded that with optimal management, cows with 62% of Holstein inheritance are the most productive crossbreds in northeast Tanzania.

Crossbreds with high exotic inheritance, beyond 75%, can perform well in some tropical highland areas, such as parts of Kenya, and in some subtropical areas, such as Zimbabwe, where climatic conditions are less severe (Bebe et al., 2003; Wilson, 2009; Chawala et al., 2019). Crossbred cattle with a high level of exotic blood can also perform better under intense production systems, where better nutrition and management are possible (Halie et al., 2009). Kilifi Plantation’s crossbred dairy herd that is kept in the sub humid coastal lowland of Kenya is a good example of how a commercial farm benefits of supplementing crossbreeding with good management (Kahi, 2002). In this herd, lactation milk yield increased with increased level of exotic inheritance. However, it was observed that raising the proportion of exotic genes up to 80% was associated with additional feed costs.

Generally, due to the limited resources available to smallholder dairy producers, the production environments cannot easily be modified to satisfy the demands of crossbred animals with a high level of foreign blood. In such production environments, crossbred cows perform below their genetic potential and mortality rates are usually high (Philipsson et al., 2006). However, most smallholder farmers practice an upgrading strategy without following a defined crossbreeding plan. In Ethiopia, for example, the genotypes of crossbred cattle kept by smallholder farmers may be comprised of any percentage of exotic blood (Chebo and Alemayehu, 2012). In Sudan, many smallholder farmers are opting for continuous upgrading and acquiring a genetic potential that they are unable to harness due to the physical and biotic constraints of the local environment (Ahmed et al., 2007). Indeed, the optimum level of exotic inheritance has long been an important issue for discussions on crossbreeding for milk production in the tropics (Wilson, 2018). Improvement in almost all traits is achieved for up to 50% exotic blood inheritance (i.e. first-generation crosses), but further grading towards exotic breeds has given variable and often disappointing results. For maintaining 50% Holstein inheritance under village conditions, breeding organizations such as the one suggested by Philipsson et al. (2011) could be implemented (Figure 1 adapted). An advantage of such breeding organizations is that they allow for both conservation and improvement of indigenous breeds, because within-breed selection and systematic crossbreeding with exotic breeds are possible under the organization. With such arrangements, the exotic blood in village herds will not exceed the 50% recommended threshold in low input production systems. In addition, higher upgraded animals and synthetic breeds can also be produced under such breeding schemes if needed.

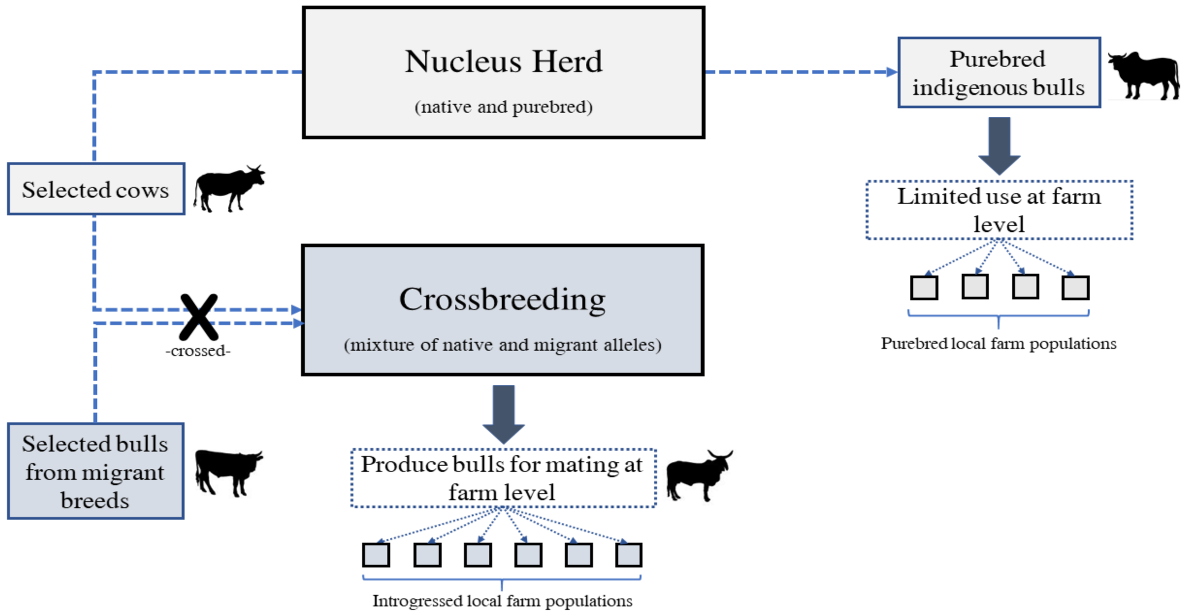

**Figure 1.** A schematic model of a proposed open-nucleus scheme, adapted after Philipson et al. (2011).

### 2.4.2.2 Synthetic breed creation

A synthetic breed can be developed in several ways. The aim of the creation of a synthetic breed is to benefit from the complementary qualities of two or more breeds; for example, the adaptation of indigenous breeds, and improved production of exotic ones (Leroy et al., 2015). Several attempts have been made to develop new synthetic populations in some parts of East Africa. For instance, the composite dual-purpose Mpwapwa breed in Tanzania was formed by crossing East African Zebu (Tanganyika Shorthorn and Boran), Indian Zebu (Red Sindhi and Sahiwal), and Ayrshire cattle (Chawala et al., 2017). However, changes in policy have prevented the Tanzanian effort to become fully effective, although the selection of Mpwapwa cattle still continues.

Inter se mating of first-generation crosses is also considered as one option for creating synthetic breed populations as described by Demeke et al. (2003) for the cross of Boran x Holstein Friesian cattle in Ethiopia. In this type, the breeding procedure involved crossbreeding of the local Boran cows with Holstein Friesian bulls to produce the first 50% generation crosses (F1). Subsequently, the F1 is inter se mated to produce the second filial generation (F2). The authors reported that both lactation milk yield and lactation length for F1 crossbred cows were higher compared to F2 cows produced through inter se mating. The lower performance of F2 is due to the breakdown of the heterotic superiority in subsequent generations (Kahi, 2002).

Some drawbacks of using synthetic breeding programs have been reported by Galukande et al. (2013) and Leroy et al. (2015) as follows: First, creation of a synthetic breed requires many generations to stabilize the genetic compositions of breeds that contributed to the program, during which the production environment could change. Second, the production of a synthetic breed can be expensive. Third, if all farmers adopt the new synthetic breed, such a program can constitute an important threat to the indigenous breeds. In addition, developing a synthetic breed is a long-term process that needs many resources, a large number of animals, detailed recording, and analytical facilities (Kahi et al., 2005). However, in some cases a program for synthetic breed creation is appropriate with respect to producing an animal that is able to cope with certain environments, and enable farmers to produce replacement heifers in their own herds without the need for replacing them from outsources (Leroy et al., 2015). Choice of the foundation breeds or strains to be used in the creation of synthetic breeds should be based on their performance under environmental conditions similar to those in which the synthetic breeds will be maintained (Kahi et al., 2005). In small scale dairy farming, the synthetic breeding strategy might for the time being present the most realistic approach to cattle crossbreeding in the tropics because of its organizational simplicity compared to rotational crossbreeding strategy (Syrstad, 1996; Wilson, 2018). Furthermore, the synthetic breeding strategy may be a solution to the challenges associated with continuously producing first-generation crossbred animals that are suitable for low input production conditions (Galukande et al., 2013).

### 2.4.2.3 Rotational crossbreeding scheme

In rotational crossbreeding, different pure breeds/lines are crossed and crossbred females' offspring are alternatively mated to males from the pure breeds in each generation. Therefore, it requires a continuous supply of pure breed from sire lines (Leyo et al., 2015). In theory, any number of different sire-lines or breeds can be used for rotational mating, however, it has some limitations; for instance, in a two-breeds rotational system, the genes contributed by the two breeds fluctuate between 1/3 and 2/3 between generations. Thus, it is difficult to harmonize adaptability and performance characteristics to appropriately match the management level or the prevailing natural environment (Galukande et al., 2013). In addition, the improvement system requires a supply of breeding males rotationally (Leyo et al., 2015). Furthermore, regular breeding under rotational schemes is expensive to maintain. Therefore, this improvement program is not practical for small-scale farmers whose herd sizes may not justify keeping more than one breeding bull (Galukande et al., 2013). However, when organizational and management issues can be overcome, such as in large, well-organized farms, rotational crossbreeding could be the preferred strategy of choice (Syrstad, 1996). A scheme that has been operated in Kilifi Plantations in Kenya, where Sahiwal x Ayrshire crosses have produced nearly 3,000 kg of milk per lactation is an example of one of the most widely reported successful rotational crossbreeding schemes in Eastern sub-Saharan (Kahi, 2002). However, this type of breeding scheme had shown only limited impact as a source of improved genetics to the Kenyan dairy cattle farming community.

## 2.5 Conclusion

This review discussed different breeding strategies and schemes that have been implemented for improving milk production of indigenous cattle breeds in Eastern sub-Saharan Africa. Within breed selection has received less attention as an improvement method, and many institutions that fulfil key functions of managing indigenous genetic resources are weak. Crossbreeding strategies have been widely adopted as an appealing alternative for enhancing milk yield performance of indigenous breeds. However, a wide range of crossbreds with varying levels of exotic blood may imply a lack of a consistent crossbreeding strategy in the region.

Under harsh production environments, using pure indigenous breeds is likely to be the best production strategy. The presence of a variety of production conditions for dairy cattle in the region may require additional research to find the optimum level of exotic inheritance for each production environment. Furthermore, the economic feasibility of rearing different crossbred genotypes as well as indigenous breeds under different production conditions is of overwhelming importance.

# 3.0 Evaluation of production and reproduction performance of Butana cattle managed at a research station in Central Sudan

## 3.1 Abstract

The Butana cattle of Central Sudan is nowadays gaining attention due to recent advocacy pertinent to the establishment of a breeding program for the breed. Over decades, within-breed selection attempts have been directed at improving the milk yield performance of the breed. The objective of this study was to evaluate milk production and reproduction performance achieved in Butana cattle over five decades starting from the 1960s. Additionally, the study evaluated sires used during the period. Production and reproduction traits studied were lactation milk yield, lactation length, calving interval, and age at first calving. A mixed model with year of calving and cow's parturition number as fixed effects and sires as random effect was implemented with the lmer4 package of R. The results revealed an influence of the calving year on lactation milk yield and age at first calving, while the number of parturitions influenced the lactation milk yield and lactation length. Lactation milk yield increased significantly during the calving year between 2000 and 2010; however, lactation length and calving interval were not significantly influenced by calving year. Age at first calving significantly declined from 55 months to 45.9 months between 2001 and 2010. The analysis also showed a significant effect of sire on all traits studied. Some bulls with many numbers of daughters had negative genotypic values indicating suboptimal selection decisions. Given the reduction in age at first calving and high variation in lactation milk yield, selection for rapid genetic progress in milk yield might be feasible. However, to enhance performance, better selection criteria and breeding management are needed in Butana cattle breeding.

Key words: Butana cattle, production performance, sire's evaluation

## 3.2 Introduction

Livestock production is an indispensable part of Sudanese agriculture and plays an important role in the livelihood of a greater part of the population. Indigenous cattle are used mainly as dairy animals in most Sudanese traditional production systems (Wilson, 2018). Like many other cattle in the tropics, they are well suited to their surroundings, yet their milk production performance is low when compared to commercial foreign breeds (Philipsson et al., 2006; Renaudeau et al., 2012). Among Sudanese indigenous cattle, the Butana breed is known for its relatively higher milk yield, hence, it has been traditionally used for milk production in the country. It has evolved under arid and semi-arid tropical environments and plays an important role in the livelihood of smallholder farmers who dwell in marginalized regions of Central Sudan. Efforts to improve the milk yield performance of Butana cattle, and to maintain their genetic purity, are evidenced by activities carried out at the Atbara Livestock Research Station (Saeed et al., 1987). After its inception, the Atbara Livestock Research Station encountered a number of issues related to funding, infrastructure, managerial and technical management. Nonetheless, the breeding project made some gains as a limited amount of data were collected over the years. Production and reproduction performance of the dairy animals are major factors and prerequisite for a sustainable dairy cattle production system (Zewdu et al., 2015). To devise an improvement of breeding efforts and management practices, it is essential to have information on different factors affecting production and reproduction traits and the magnitude of their influence. Basically, animal productivity is influenced by genetic (internal) and environmental (external) factors as well as the interaction of these two (Syrstad, 1998). Major environmental factors that may affect performance are year and season of calving, and management (Epaphras et al., 2004). Various animal-related factors such as age at calving, length of lactation, and parity may also affect milk production (Vijayakumar et al., 2107). The aim of this study was to investigate the effect of calving year (years of observation) on the production and reproduction trait performance of a Butana herd kept at Atbara Livestock Research Station. Furthermore, the random genotypic effects of some sires used for breeding on the station were assessed.

## 3. 3 Material and methods

### 3.3.1 Description of the research station

Records of milk production and reproductive traits were obtained from the Atbara Livestock Research Station, which is managed by Sudan Ministry of Animal Resources. The station is located on the eastern bank of River Nile, north to Atbara River, at latitude 17° 40 N, longitude 33° 58 E and altitude 345 meters above sea level. The climate of the region is tropical in nature. The average annual temperature in Atbara is around 37.2°C (https://www.weather-atlas.com/en/sudan/atbara-climate). June is the warmest month, with an average high-temperature of 42.6°C and average low temperature of 28.8°C, while January is the coldest month, with an average high temperature of 29.6°C and an average low temperature of 15.4°C. Humidity is relatively high in December (38%), but low (14%) in April, May and June. The average annual rainfall in the Atbara region is about 59 mm. The rainfall is limited to the months of July through October.

### 3.3.2 Animal management practices

All animals at the station were fitted with ear tags, each bearing a unique individual identification number. Animals were usually grazed on the Station pastures during the day, and housed in station barns at night, where they were provided with supplemented hay ad libitum. The hay was mostly composed of Abu-70 (*Sorghum bicolor*), *Sorghum arundinaceum*, and Sudan grass (*Sorghum drummondii*). These Sorghum types were grown on the station irrigated farm, but no information on their yield was available. Lactating cows were supplemented with concentrate, at each milking time. Each cow received 1 kilogram of concentrate for every 3 kilograms of milk produced. Mating was by natural bull service and the selection of breeding cows was based on cow's own milk yield performance, while bulls were selected based on their mother's milk yield. Date of calving, daily milk yield, dry period, dams and sire's identification numbers were recorded. Cows were milked twice a day by hand, in the morning and evening.

### 3. 3.3 Data collection

Data for the current study covered age at first calving (AFC), calving interval (CI), lactation milk yield (LMY), lactation length (LL), and dry period (DP) collected at the Research Station from 1961 to 2010. AFC, in months, was obtained by calculating the difference between the date of the first calving and the birth date of the cow. The difference in time between the birth of one calf and the birth of the following calf from the same cow was used to calculate the CI in days. Data on abnormal calving, e.g., abortion and stillbirth, were not provided and hence not considered in the calculation of calving interval. Cows on the station are usually culled after eight lactations, with an average age around 11 years.

### 3.3.4 Data analysis

Using descriptive statistics, records of LMY, LL, CI and DP were classified into groups based on calving year and lactation number. The data utilized for analysis are summarized in Table 2. Figure 2 also includes additional information on the sires, their daughters, and years of use. The implementation of a breeding program is expected to result in an improvement of milk production traits across calving years, which were defined as the years in which calving occurred. For the 50 year-period, calving years were categorized into five groups: (1) 1961-1970, (2) 1971-1980, (3) 1981-1990, (4) 1991-2000 and (5) 2001-2010. Cow's parity numbers during these periods (1961-2010) were also grouped into five categories: (1) first, (2) second, (3) third, (4) fourth and (5) fifth parity. These two variables (calving year and parity number) were treated as fixed effects, while the sire of a daughter was considered as a random effect. A linear mixed model with "lmer" function in the "lmer4" package of R version 4.2 (R Core Team

2020) was used to evaluate the fixed and random effects. LMY, LL, and CI were separately modeled following equation (1):

$y_{ijk} = cy_i + p_j + s_k + e_{ijk}$ (1)

where $y_{ijk}$ is the observed LMY, LL, or CI of a daughter of the k<sup>th</sup> sire, $cy_i$ is the fixed effect of calving year; $p_j$ is the effect of daughter's parity number, and $e_{ijk}$ is residual error. The modeling of AFC did not include parity number and therefore, follows equation (2):

$y_{ik} = cy_i + s_k + e_{ik}$ (2)

where $y_{ik}$ is AFC of daughter of the k<sup>th</sup> sire and $e_{ik}$ is the residual error. Subsequently, least-square means were computed and differences between the levels within each fixed effect were compared. Statistical differences in both models were considered significant at $P \leq 0.05$ and the results were presented as estimated marginal mean ± standard error of the mean. Random effects of sires for all traits were obtained from the mixed linear model using the "ranef" function of R. The random effects estimates were then sorted for each trait for the ranking of sires based on genetic effect. Phenotypic and genotypic correlation coefficients between traits were calculated. To investigate the effect of calving year and parity number on dry period, a two-way analysis of variance was applied.

Table 2. Total number of daughters, sires and observation for traits in the data set

| Years | No. daughters | No. sires | Duration of sire use (years) | Trait | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | LMY | LL | CI | AFC | DP |
| 1961-1970 | 53 | 6 | 1-3 | 105 | 105 | 65 | 53 | 72 |
| 1971-1980 | 35 | 5 | 1-6 | 126 | 126 | 95 | 35 | 80 |
| 1981-1990 | 90 | 3 | 1-6 | 293 | 293 | 205 | 90 | 176 |
| 1991-2000 | 138 | 3 | 3 | 288 | 288 | 214 | 138 | 196 |
| 2001-2010 | 64 | 1 | 6 | 206 | 206 | 101 | 64 | 92 |
| Parities | | | | | | | | |
| 1st | 209 | - | - | 209 | 209 | 166 | - | 142 |
| 2nd | 251 | - | - | 251 | 251 | 147 | - | 133 |
| 3rd | 184 | - | - | 184 | 184 | 158 | - | 133 |
| 4th | 151 | - | - | 151 | 151 | 128 | - | 128 |
| 5th | 223 | - | - | 233 | 233 | 81 | - | 80 |

LMY = lactation milk yield; LL = lactation length; CI = calving interval; AFC = age at first calving; DP = dry period

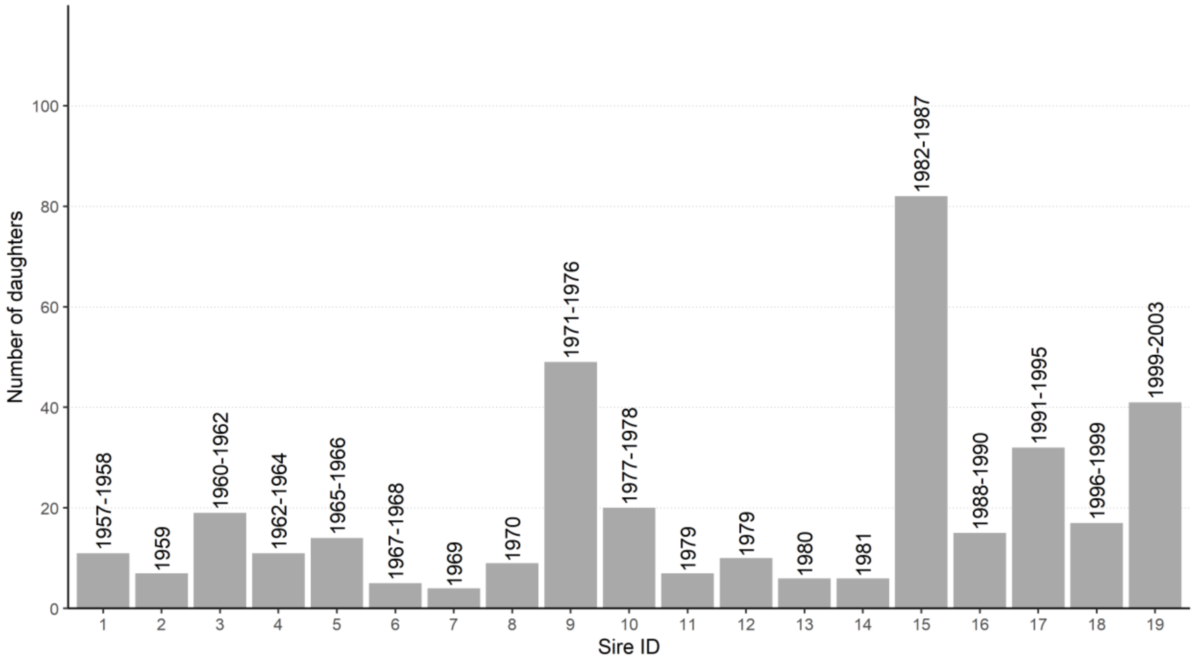

**Figure 2**. Number of daughters per sire and the duration of sire use. Numbers at the top of the bar indicate years of sire use

### 3.4 Results

Using descriptive statistics, a high variability was found in each of the traits studied as summarized in Table 3. For instance, from the 958 observations recorded across all calving years, LMY ranged from 111 kg to 4068 kg. Similarly, DP ranged from 30 to 199 days given 616 recorded observations.

**Table 3.** Descriptive statistics of production and reproduction trait performance of Butana cows.

| Trait | Records (n) | Mean | Median | Minimum | Maximum |
|---|---|---|---|---|---|
| AFC (months) | 380 | 46.79 | 46 | 26 | 79 |
| LMY (kg) | 1018 | 1367.2 | 1309 | 111 | 4068 |
| LL (days) | 1018 | 272.1 | 285 | 100 | 393 |
| CI (days) | 680 | 382.3 | 370 | 330 | 449 |
| DP (days) | 616 | 97.6 | 89 | 30 | 199 |

LMY = lactation milk yield; LL = lactation length; CI = calving interval; AFC = age at first calving; DP = dry period

The estimated least square means of the traits are presented for different calving years and parity numbers (Table 4). The effect of sire was significant on all studied traits ($P < 0.001$). The analysis of variance showed a significant effect ($P < 0.001$) of years on AFC. The longest AFC (55.6 ± 2.0 months) was observed for heifers that calved between 1961 and 1970, whereas the shortest AFC was observed in the calving years between 2001 and 2010. Differences in LMY between the calving years were large and highly significant ($P < 0.001$). The highest LMY (1,689.3 ± 111.89) was recorded for the most recent calving years (2001-2010) and the lowest was recorded between 1971 and 1980 (1,206.8 ± 87.53). LMY was significantly ($P < 0.001$) influenced by parity number as was LL. Compared to the third, fourth, and fifth parties, the first and second parties contributed less to LMY, while LL in the third parity was the longest. Both, LL and CI were not significantly ($P > 0.05$) influenced by the year of calving. Neither calving year nor parity number had a significant effect on length of dry period (not shown in table).

**Table 4.** Least square means of lactation milk yield, lactation length, and age at first calving of Butana cows at different years of calving and parity numbers.

| | LMY (kg) | | LL (days) | | AFC (months) | |
|---|---|---|---|---|---|---|
| Factor | LSM±SE | 95% CIs | LSM±SE | 95% CIs | LSM±SE | 95% CIs |
| Sire | *** | | *** | | *** | |
| Period | ** | | n.s. | | ** | |
| 1961-1970 | 1209±101$^{b}$ | 1002-1415 | 279±7 | 265-293 | 55.6±2$^{b}$ | 52-60 |
| 1971-1980 | 1206±88$^{b}$ | 1031-1381 | 279±6 | 265-292 | 51.7±2$^{ab}$ | 48-56 |
| 1981-1990 | 1398±68$^{ab}$ | 1258-1538 | 278±4 | 269-288 | 50.6±2$^{ab}$ | 42-52 |
| 1991-2000 | 1441±83$^{a}$ | 1272-1609 | 266±5 | 251-280 | 46.5±3$^{a}$ | 41-52 |
| 2001-2010 | 1689±112 | 1458-1921 | 261±6 | 246-276 | 45.9±2$^{a}$ | 42-50 |
| Parity | *** | | *** | | | |
| 1st | 1212±67$^{a}$ | 1077-1348 | 274±5$^{ab}$ | 263-284 | | |
| 2nd | 1232±64$^{a}$ | 1102-1363 | 267±5$^{b}$ | 258-277 | | |
| 3rd | 1403±66$^{b}$ | 1270-1538 | 284±5$^{a}$ | 275-294 | | |
| 4th | 1549±69$^{b}$ | 1410-1688 | 259±5$^{b}$ | 249-269 | | |
| 5th | 1545±74$^{b}$ | 1397-1693 | 279±6$^{ab}$ | 267-290 | | |

LMY = lactation milk yield; LL = lactation length; CIs = confidence interval; AFC = age at first calving; LSM = Least squares means; SE = Standard error.
LSM within the same factors followed by the same letter are not significantly different. **P < 0.01; *** P < 0.001; n.s. = not significantly different.

The distribution of random effect of sires for LMY, LL, CI and AFC are presented in Figure 3, while information on years and duration of sires used in the station is shown in Figure 2. The random effect of sires ranged from -341 kg to +253 kg (LMY), -2.8 to +1.6 days (LL), 12 to +15 days (CI), and -5.8 to +11 month (AFC). The effect of sire was significant on all studied traits (P<0.001). Relatively high and negative random effect values of LMY (Figure 3a) were estimated from the records of daughters of sire number 9 and sire number 15. Each of these sires was used for 6 years, from 1971-1976 (sire number 9) and from 1982-1987 (sire number 15), whereas the highest positive random effect for LMY was estimated from daughters of sire number 17, which was used from 1991-1995 (Figure 2). The years of sire use were defined as the years in which their daughters were born within the herd.

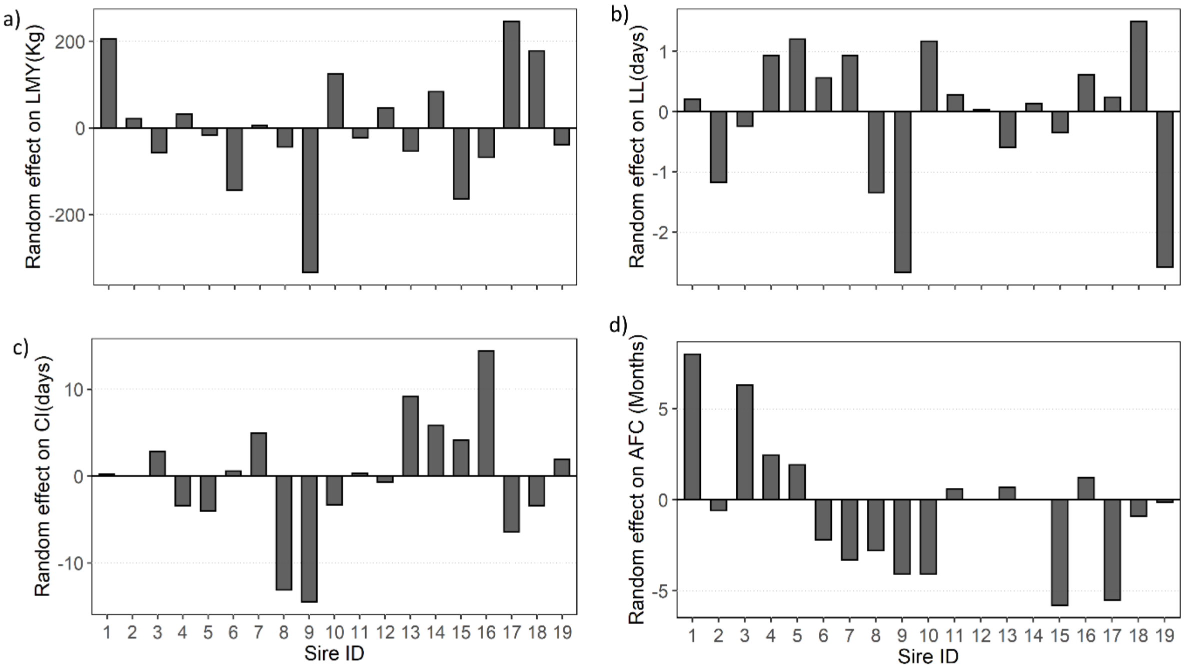

**Figure 3**. The distribution of random effect of sires for a) LMY, b) LL, c) CI, and d) AFC

Phenotypic correlation coefficients between LMY, LL, CI, AFC, and DP are provided in Table 5. Correlation coefficient estimates between the traits ranged from -0.384 to 0.249, suggesting a weak relationship between the traits in the herd. In terms of genotypic associations, there were no significant correlations between LMY and all other studied traits. The genotypic correlation values were -0.078 between LMY and AFC, -0.045 between LMY and CI, and 0.439 between LMY and LL (not shown in table).

**Table 5.** Phenotypic correlations between milk yield, lactation length, calving interval and dry period.

| Trait | LMY | AFC | LL | CI | DP |
|---|---|---|---|---|---|
| LMY | 1 | 0.043 n.s. | 0.17** | 0.065 n.s | -0.106 n.s |
| AFC | | 1 | 0.109 n.s. | 0.164** | 0.017 n.s |
| LL | | | 1 | 0.249** | -0.384** |
| CI | | | | 1 | 0.212** |

LMY = milk yield; AFC = age at first calving; LL = lactation length; CI = calving interval; DP = dry period ** P < 0.001; n.s. = not significant

### 3.5 Discussion

In the current study, production and reproduction potentials of Butana cattle at the Atbara Livestock Research Station were investigated. The results showed an increase of LMY over the calving years, while AFC declined. Sires had a significant effect on all studied traits. The overall milk yield performance (1,367.2 kg) of Butana cattle reported in the present study was lower than that reported for Kenana cattle in Sudan, 1,695kg (Yousif and Fadl El-Moula, 2006), but comparable to that of Sahiwal cattle in the Kenya Agricultural Research Institute (1,368 kg/282 days of lactation; Ilastsia et al., 2007). However, current LMY of Butana cattle is higher than the performance of the following breeds: Red Sindhi in India (1,060 kg/227 days; Kharti et al., 2004), White Fulani in Nigeria (1,018 kg/249 days; Mrode, 1988), and Ankole cattle at the Rwandan livestock research stations (535 kg/305 days; Manzi et al., 2020).

The increased LMY with increased parities in the present study is consistent with findings of Amasaib et al. ( 2011) that parities had a significant effect on lactation milk yield in crossbred dairy cattle in Sudan. Nyamushamba et al. (2014) also reported a progressive increase in milk yield as parity increased in Zimbabwean Red Dane cattle. Higher milk output in advanced parities supports the theory that increased body size and udder development throughout many pregnancies boosts milk supply (Ilastsia et al., 2007; Ramírez-Rivera et al., 2019).

Optimization of lactation length is an important management strategy for increasing the economic returns of dairy farms (Hossein-Zadeh, 2013). In most modern dairy farming, a lactation length of 305 days is commonly accepted as an optimal level (Mundan et al., 2020). This lactation length corresponds to a 12-month calving interval. Nonetheless, the current LL (272.2 days) for Butana cattle is lower than optimal, which could be attributed to managerial problems. Besides, Zebu cattle have a poor genetic potential to produce milk for a long time (Madalena, 1988). Furthermore, the short lactation length in tropical cattle may also be in part due to the inability of the cattle to let down milk in the absence of a calf (Ilatsia et al., 2007). The current lactation length (272.2 days) is, however, longer than those reported for Fuga (208 days), Butana (190 days), and Kenana (202 days) cattle under field conditions (Musa et al., 2006; Ibrahim et al., 2015). These differences may be due to differences in herd management as well as breed differences. By contrast, the estimate of LL in this study was relatively shorter than the lactation length (278.75 ± 6.52 days) recorded for 50% crossbred cows (Sudanese native breed X Holstein Frisian) in Sudan (Ahmed et al., 2007). This variation might be attributed to genetic differences between the two breeds.

Calving interval, the time between two consecutive parturitions, is an important aspect of the reproductive efficiency of dairy cows and associated with economics of milk production (Ayalew and Chanie, 2018; DeLay et al., 2020). It is also thought to be a useful indicator of a cow's fertility (Olori et al., 2002). The calving interval obtained in this study is much lower than the 20 month-period recorded for the same breed under smallholder production systems (Musa et al., 2006), indicating improved reproductive management efforts under research station conditions. Phenotypic correlation estimates between CI and LMY obtained in this study are consistent with those reported in Chilean dairy cattle (Montaldo et al., 2017). A positive phenotypic correlation between CI and LL found in the present study was also reported in Sahiwal cattle in India (Narwaria et al., 2015).

The AFC for the Sudanese cattle has been studied for different breeds under different production conditions (Yousif and Fadl El-Moula, 2006; Musa et al., 2005). In the present study, average AFC (46.8 months) of Butana cattle was lower than that estimated by Musa et al. (2006) for the same breed (52 months) or Kenana cattle (50.8 months) under smallholder production systems. Also, the current estimate was lower than that (57 months) reported in a herd of pure Kenana cows managed at a research station (Yousif and Fadl El-Moula et al., 2006). However, the steadily decreasing in AFC over the last two decades, i.e., 1991-2000 and 2001-2010, could be crucial for achieving a rapid genetic progress in the herds, because early AFC shortens the generation intervals (Brito et al., 2020) and allows for many rounds of selection per time. In addition, reducing AFC can improve the profitability of the enterprise by increasing milk production per year and per lifetime (Bazzoli et al., 2014). Furthermore, the AFC has a profound influence on the total cost of raising dairy replacements in which older calving heifers are more expensive to raise than younger ones. The positive association between AFC and CI in the presents study was also observed in Holstein cows (Froidmont et al., 2013).

Dairy cows are usually given a rest period after completing a specified period of milking. It was reported that such dry period is necessary to renew udder glandular tissues and to maximize milk yield in subsequent lactations (Annen et al., 2004; Kok et al., 2017). A 60-day dry period is recommended for a cow in order to improve milk supply in the following lactation and to increase the cow's lifetime productivity (Piepho et al., 2008; Hossein-Zadeh et al., 2013). The dry period estimated in the current study (97.7) is longer than recommended, which could be related to poor management strategies. However, this result is lower than that obtained by Yousif and Fadl El-Moula (2006) for Kenana cattle at a research station, which was 167±23 days. This variation may be attributed to the differences in dry-period management strategies implemented in these two herds.

Genetic improvement in dairy cattle is largely determined by the merit of bulls used as sires of each generation, therefore, dairy bull selection is an important step in any cattle breeding program (Andrabi and Moran, 2007; Kariuki et al., 2014). In many situations, the selected sires, including their pedigree information, appear the best platform for the effective ranking of potential breeding stock, particularly for animals maintained in nucleus herds with adequate record keeping (Phillipson et al., 2011). Although the random effects of sires were determined without the use of pedigree information in the current study, the results showed a large variability between sires for LMY, LL, CI, and AFC. Part of variances in those traits is most likely due to genotypic differences between sires, meaning that better genetic progress could be realized through proper selection practices. Between 1971 to 1976 and 1982 to 1987, the frequent use of sires with negative random effects may indicate a lack of proper genetic evaluation methods for selected sires on the station herd. Meanwhile, finding sires that excel at breeding value, is critical for achieving high genetic improvement. Methods such as the best linear unbiased prediction (BLUP), which maximize the likelihood of selecting the best animals to become parents, could thus be recommended. When employing BLUP, genetic and environmental effects are estimated simultaneously, ensuring unbiased estimates.

The moderately positive genotypic correlation between LMY and LL (0.44) observed in the present study is close to that observed in Murrah buffalo’s population (0.47) in Brazil (Malhado et al., 2012). However, high genetic correlation of 0.85 between the LL and LMY was reported for Sahiwal cattle in India (Narwaria et al., 2015). Negative genotypic correlation between LMY and AFC (-0.08) observed in this study was previously reported for Holstein cows in Iran (Hossein-zadeh et al., 2011). The very low and negative genotypic correlation (-0.045) between LMY and CI reported in the present study is very close to that (-0.06) reported for Mpwapwa cattle in Tanzania (Chawala et al., 2017). Also, this result is close to -0.01, which was reported for a population of dairy cows of Slovak Simmental cattle (Bujko et al., 2013). Non-significant genotypic association between LMY and the other traits investigated in the current study could be attributed to the limited number of observations recorded for these traits.

### 3.6 Conclusion

The present study assessed the production and reproduction performances of a Butana herd managed at a government research station. The findings revealed a steady increase in LMY accompanied by a substantial decline in AFC over time. There was a high variation in LMY, LL, and AFC. This opens up the possibility of further genetic improvement of those traits. It is likely that the small sample size in this study influenced the magnitude of genotypic relationship between trait estimates. Therefore, further investigations on large amounts of recorded data are required to better evaluate genotypic correlation between production and reproduction traits in Butana cattle.

## 4.0 Exploration of production conditions: a step towards the development of a community-based breeding program for Butana cattle

### 4.1 Abstract

In Sudan, many Butana cattle farmers practice indiscriminate crossbreeding to improve the milk yield performance of cows, as organized breeding programs are lacking. Objectives of this study were to identify the current production conditions of Butana cattle and to determine farmers' production objectives and trait preferences using a field survey. The overall aim was to explore the possibility of establishing a community-based breeding program for the genetic improvement of the breed. A semi structured questionnaire and field visits were used to collect data from 202 Butana cattle owners. Data were analyzed using Chi-squared test, multiple response analysis and binary logistic regression. Our results showed that Butana cattle farmers mainly raised their animals for milk production. On a five-point scale (5 = most important), milk yield (4.6 ± 0.05), growth performance (4.0 ± 0.07), and lactation length (3.9 ± 0.08) were highly preferred for future development of the breed. One-third of the farmers kept crossbred cattle with, on average, 4 crossbred animals per herd. About two-thirds of respondents were willing to adopt crossbreeding using exotic breeds to increase milk performance and about the same proportion were willing to exchange breeding bulls and establish farmers' associations. None of the respondents kept written performance records. However, educated farmers were more likely to adopt record keeping. Farmers' willingness to engage in associations could be useful for the establishment of a community-based breeding program. Based on the current farmers' production objectives, the future breeding program should emphasize increasing milk production of the Butana cattle by using improved Butana bulls in village herds.

Keywords: Butana cattle, breed development, breeding objectives.

## 4.2 Introduction

Indigenous livestock contribute to milk and meat supply, and represent an essential source of employment, income creation and export earnings of many communities in rural areas of African countries (FAO, 2015; Behnke and Osman, 2016). In Sudan, the number of indigenous cattle is estimated at 31 million heads (FAO, 2019). They are kept under different production systems, e.g., mobile, sedentary, pastoral, and agro-pastoral production. Among indigenous Sudanese cattle, the Butana breed is considered to be one of the most promising breeds suited for milk production in semi-arid regions (Musa et al., 2005; Badri et al., 2011). It plays an essential role in milk supply in addition to fulfilling other functions, such as the provision of draught power, insurance, and socio-cultural needs of rural communities. Under improved management conditions, Butana cattle are able to produce more than 1,500 kg of milk per lactation (Ahmed et al., 2007); however, they produce less milk under low input farm conditions (Musa et al., 2005). Generally, the traditional production systems under which Butana cattle as well as other indigenous breeds are managed do not match the increasing demands for milk in urban areas (Ahmed et al., 2007). Consequently, crossbreeding with exotic breeds is practiced indiscriminately by smallholder producers without any formal breeding policy or breeding programs to conserve the breed (Musa et al., 2008).

As early as 1945, the Sudan government began a within-breed selection improvement program for Butana cattle by establishing the Atbara Livestock Research Station (Saeed et al., 1987). However, the initiative encountered a series of problems associated with inadequate financial support, and the lack of infrastructure, managerial and technical skills. To our knowledge, Butana cattle owners were not actively involved in the government's instituted breed improvement program. The poor involvement of livestock producers in the design and implementation of breeding programs is one of several factors that affect the development of indigenous livestock breeds in developing countries (Philipsson, et al., 2011; Wurzinger et al., 2011). The aims of the current study, therefore, were to explore the production conditions of Butana cattle and to identify farmers’ production objectives and trait preferences as a step towards the development of a community-based breeding program for the breed. Moreover, breeding and husbandry management, production constraints, and future development aspects were evaluated.

## 4.3 Materials and methods

### 4.3.1 Study location

The study was conducted in the Butana region of central Sudan, between River Nile, Atbara River, and Blue Nile, between latitudes 14°23' and 17°34' N, longitudes 32°32' and 35°36' E, and at an altitude of 345 meters above sea level. The region is semi-arid and characterized by high temperatures, with an average annual temperature reaching over 38.5ºC. Annual rainfall amounts to about 300 mm while the dry season extends to around eight months, from November to June (Bahbahani et al., 2018).

### 4.3.2 Data collection

The data comprised a sample of 202 semi-structured questionnaires addressing owners of Butana cattle randomly selected from 17 villages in the study area. The villages were selected based on the clustering of Butana cattle owners under the guidance of the Atbara Livestock Research Station staff. Interviews were carried out from October 2018 to January 2019. The semi-structured questionnaire covered: (1) Socio-economic characteristics of households; (2) Herd sizes and composition; (3) Production objectives; (4) Feeding management; (5) Animal health management; (6) Breeding management; (7) Farm income and milk marketing; (8) Farmers’ evaluation of adaptation and production traits; (9) Production challenges; and (10) Future development aspects. Based on a five-point scale (from 1 = very poor to 5 = very good), respondents were asked to evaluate the performance of Butana cattle for milk production, lactation length, growth rate, disease tolerance, and grazing ability (being able to walk long distances in search of pastures and watering points). The respondents were also asked to rank their preferences for the traits' improvement in the future on a scale of five points (from 1 = not important to 5 = most important). On the same basis, respondents were asked to rank five major challenges of cattle production including costs of concentrate feeds, lack of financial support, lack of cattle improvement services, scarcity of rangeland, and competition from crossbred dairy cattle in terms of milk yield and selling price. The selection of these challenges was motivated by reports of previous studies e.g., Musa et al. (2006) and Ahmed et al. (2007). Additionally, three separate group discussions involving 4-11 herd owners were carried out to elicit information about production challenges that were not listed in the questionnaires. These group discussions, together with direct observations made during the survey strengthened the data collected.

### 4.3.3 Statistical analysis

The collected data were analyzed using the statistical package for social sciences (SPSS) version 20 (IBM SPSS 2011) and the results were graphically presented using R software version 3.6.3 (R Core Team, 2020). Descriptive statistic measures, which include means and their standard deviation, frequencies, and percentages, and furthermore, statistical tests including Chi-squared test for categorical variables and multiple response analysis were employed. As a form of post hoc analysis, the standardized residuals of the Chi-squared results were analyzed applying Bonferroni correction and by the use of the R package 'chisq posthoc. test' (Ebbert, 2019). To test the effect of farmers' education level on their willingness to participate in/perform practices associated with the future development of the breed (i.e., information exchange, adoption of crossbreeding, exchange of breeding bulls, participation in farmers' associations, and keeping records), a binary logistic regression model was applied. Related to the binary logistic regression test, the level of education of the farmers was rearranged into two groups: low education consisting of informal and primary education, and high education that consisted of secondary and graduate studies. These two groups were used as predictor variables, while the five different practices were used as response variables.

## 4.4 Results

### 4.4.1 Socio-economic characteristics

All household heads interviewed were men. The majority were above 49 years (43.5%) or between 30 and 39 years (32.7%) old, while 11.9% were between 40 and 49 or below 30 years old, respectively. Primary education was predominant among older (> 49 years) and middle age (30-39 years) farmers and the former had a high proportion of individuals who had only received informal education (Figure 4).

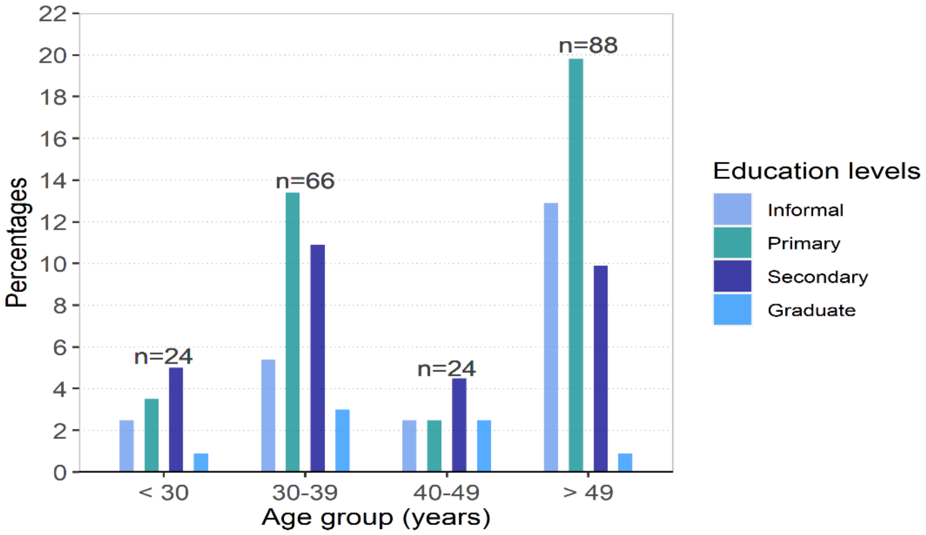

**Figure 4.** Educational level of farmers of different age groups.

Secondary education was predominant among young farmers (< 30 years old) and those between 40 and 49 years of age while across all age groups only a few farmers were graduates from higher education. The majority of respondents (59.9%) owned the farming land and almost all of them (89.6%) cultivated crops including sorghum, fruits, vegetables, groundnuts and dates for household consumption and for sale to generate cash income (Table 6). Farmers use only a small part of their farmland for livestock fodder cultivation, and landless farmers, rent land for crop cultivation and for grazing their cattle. Regarding the responsibilities of the family members and labor involvement in the management of cattle herds, 83.7% of the household heads (men) indicated that they were the main individuals responsible for farm decision-making, e.g., product marketing, selection of replacement animals, and the culling of cattle. About 40.1% and 47.6% of the respondents relied on their boys and hired laborers for cattle herding, respectively. Only 2% of women were involved in cattle management, mainly milk processing for home consumption or the collection of grasses from the fields.

**Table 6.** Households' socio-economic characteristics.

| Categorized variables | n | % |
|---|---|---|
| Type of land tenure | | |
| Own land | 121 | 59.9 |
| Landless | 81 | 40.1 |
| Activities beside cattle raising | | |
| Crop farming | 181 | 89.6 |
| Other | 21 | 10.4 |
| Family members' involvement in cattle farming [a] | | |
| Men | 169 | 83.7 |
| Women | 4 | 2.0 |
| Boys | 83 | 41.1 |
| Laborer's employment | | |
| Hired | 96 | 47.5 |

a = more than one answer allowed for. n = number of respondents.

### 4.4.2 Herd composition and production characteristics of Butana cattle

The majority of farmers (65.3%) owned between 1 and 11 cattle heads, and the proportions were 18.4% and 16.3% for farmers who owned 12 to 20 heads, and above 20 heads, respectively. There was a significant relationship between herds size and the employment of laborers on the farm ($\chi^2 = 10.74$, $p = 0.005$). There was no significant association between herd size and farmer's age ($\chi^2 = 10.38$, $p = 0.11$). On average, cattle herds were composed of 8.2 ± 0.70 cows and 1.2 ± 0.04 breeding bulls (Table 7). According to farmers' recall, the average daily milk yield per cow of the Butana breed was 6.6 ± 0.38 kg. Lactation length and calving interval were about 6.7 ± 0.10 months and 13.6 ± 0.20 months, respectively (Table7). The farmers keeping crossbred cattle (n = 61) had on average 3.8 ± 0.65 animals per herd. Farmers were not asked to provide information about the level of exotic blood of their crossbred cattle.

**Table 7.** Herd composition and production characteristics of Butana cattle.

| Items | n | Mean | SE |
|---|---|---|---|
| Herd Composition | | | |
| Cows | 202 | 8.2 | 0.70 |
| Heifer and calves | 202 | 4.1 | 0.29 |
| Bulls | 121 | 1.2 | 0.04 |
| Oxen | 24 | 1.9 | 0.20 |
| Overall | 202 | 12.3 | 0.77 |
| Production characteristics | | | |
| Milk yield (kg/day) | 202 | 6.6 | 0.38 |
| Lactation length (months) | 202 | 6.7 | 0.10 |
| Calving interval (months) | 202 | 13.6 | 0.20 |

n = number of herds. SE = standard error of the mean

### 4.4.3 Production objectives

All farmers stated that they kept Butana cattle mainly for milk production, either home consumption or to be sold for cash income. A considerable number of the farmers (42%) kept cattle for meat production, meaning that they sold live cattle for slaughter. Only 9% and 8% of the farmers used cattle for draught power (i.e., to prepare the field for crop production) and as an insurance against financial difficulties, respectively. We observed that keeping cattle for draught power was more important for farmers found in areas close to riverbanks, representing about 7% of the respondents.

### 4.4.4 Feeding management

The majority of the respondents (75.2%) fed their cattle irrigated fodders. Irrigated fodders comprised Clitoria (*Clitoria terenta*), Abu-70 (*Sorghum bicolor*) and alfalfa (*Medicago sativa*) fed green or dry. In addition, 65.8% of the farmers offered their cattle concentrate feeds, which were primarily composed of oilseed cakes of sesame (*Sesamum indicum*) or groundnuts (*Arachis hypogaea*), wheat (*Triticum* sp.) bran, sorghum grain, sugar cane (*Saccharum officinarum)* molasses and cotton (*Gossypium hirsutum)* seed cake (FAO, 2016). According to farmers, the concentrate feeds were usually mixed on the farm from all or some of these ingredients, but farmers also purchased concentrate feeds from the markets. The concentrate feeds were usually provided to lactating cows during milking period and to crossbred animals. The provision of concentrate feeds was significantly associated ($\chi^2 = 5.96$, $p = 0.02$) with the type of roughages offered to cattle (Table 8). Farmers who fed their cattle an irrigated green fodder tended to leave out concentrate feeds. The provision of concentrate feeds was not significantly associated with herd size ($\chi^2 = 5.52$, $p = 0.06$). Only 24.8% of the respondents fed their cattle crop residues as supplement, mainly in the dry season. There was no significant association between the types of roughages offered to cattle and farmer's age ($\chi^2 = 2.5$, $p = 0.48$). The crop residues comprised stubble of sugar cane and sorghum, or groundnut hulls. The majority (62.4%) of the farmers reported moving their cattle out of the permanent homes to communal grazing areas during the wet season that spans between July and October, in order to access green pastures freely. During the dry season (from November up to June), cattle are returned back to the permanent homes, where they graze on rangelands close to riverbanks. In this season, cattle are supplied with roughage fodder (irrigated or crop residues) and concentrates.

**Table 8.** Use of concentrate feeds across types of roughage and herd size.

| | Concentrate feed provided (%) | Chi-square (p value) |
|---|---|---|
| Type of roughage | | |
| Crop residues | 80 | $\chi2 = 5.96$ |
| Irrigated fodder | 61 | ($p = 0.02$) |
| Herd sizes (head) | | |
| 1-11 | 64 | $\chi2 =5.52$ |
| 12-20 | 57 | ($p = 0.06$) |
| >20 | 81 | |

### 4.4.5 Animal health management

According to farmers, private veterinarians provided veterinary services. The majority of respondents (79%) reported that they had limited access to appropriate animal health services, whereas only 21% were satisfied with the animal health services. The latter were specifically those farmers (n = 43) who lived in urban areas. During the survey, we observed that in case of disease occurrence, farmers brought a veterinarian to the farm to diagnose the disease, and to provide treatment for the animal. The most common diseases that farmers experienced on their farms included foot-and-mouth disease (31%), contagious bovine pleuropneumonia (14%), jaundice (14%), mastitis (11%), cowpox (10%), heart water (9%), bovine ephemeral fever (6%), and trypanosomiasis (5%). Farmers mentioned the local names of the diseases, which were then translated by a local veterinarian.

### 4.4.6 Breeding management

#### 4.4.6. 1 Mating method, source of breeding bulls and selection criteria

All farmers interviewed reported that natural mating was the only breeding method practiced since artificial insemination service using local bulls' semen was not developed. However, the Sudani Centre for Artificial Insemination and a Sudanese-Turkish Centre for semen production provide services for cattle insemination in Sudan, using semen from exotic bulls. The breeding bulls were allowed to run with the cows all year round. The majority of farmers (62.9%) selected the breeding bulls from their own herd, while 31.7% relied on bulls from their neighbors. Only 5.4% of the farmers relied on communal bulls, which were available at grazing sites. The source of breeding bulls was significantly associated with herd size ($\chi^2 = 25.47$, $p = 0.001$) (Figure 5). Farmers who had small herd sizes (1-11 heads of cattle) were less likely to keep their own breeding bulls (residual = -4.28, p = 0.0002), rather, they depended on their neighbors' bulls (residual = 4.82, p = 0.00001). Conversely, farmers who had larger herd sizes

(> 20 heads of cattle) tended to possess their own breeding bulls (residual = 3.25, p = 0.01) and were less likely to depend on neighbors' bulls (residual = -3.05, p = 0.02).

Regarding the selection criteria of breeding bulls, about 48.9% of farmers selected their bulls based on the observed phenotypes (e.g., coat color, chest width, body length, scrotal circumference, size of dewlap). The dark red coat color was preferred by the respondents, because dark red cattle were considered better milk producers, having heavier body weight. A similar proportion of farmers (48%) selected their bulls based on the observed milk yield of the bull's dam while only a few of them (3.3%) based their selection on observed phenotypes (e.g., muscularity, daughters' milk performance) of the bull's sire. The average age of a breeding bull at selection was 25.6 ± 1.56 months, and the length of time for using bulls for mating was 5.9 ± 0.23 years.

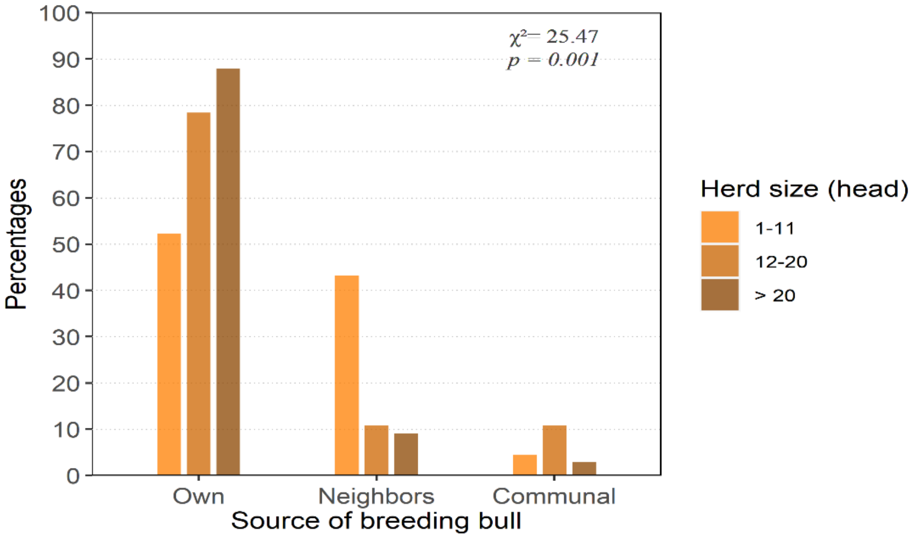

**Figure 5.** Source of breeding bulls across herd sizes.

### 4.4.7 Animal recording

Without exception, none of the respondents reported keeping written records of production, reproduction, or animal pedigree. The main reason was that farmers claimed they had abilities to memorize all relevant information (81.7%). About 13.3% of the respondents had difficulties to keep written records. Accordingly, all information related to cattle production and reproduction characteristics, pedigree, and bulls' selection criteria were based on farmers' memories.

### 4.4.8 Farm income and milk marketing

Nearly three-quarters (74.3%) of respondents indicated that they generated income from the sale of milk, followed by selling of live animals for slaughter (43.6%). Only 11.9% of farmers indicated that they derived their income from the sale of crops. About 48% of the farmers who sold milk indicated that they delivered the milk to final consumers using donkeys, followed by 27.3% who reported the use of cars or bicycles for milk delivery. The remaining 24.7% of the farmers sold their milk at the farm gate.

### 4.4.9 Evaluation of adaptation and production traits

Evaluating trait performances of the Butana cattle breed, the highest scores were given to grazing ability (4.3 ± 0.86) and disease tolerance (4.3 ± 0.78), indicating that Butana cattle were able to walk long distances in search of pastures and watering points, and were disease tolerant (Figure 6A). Moderate scores were found for growth performance (3.3 ± 1.19), milk yield (3.2 ± 1.04) and lactation length (2.8 ± 1.10). For future development of the traits in Butana cattle, farmers considered milk yield as very important (4.6 ± 0.79), followed by growth performance (4.0 ± 1.00) and lactation length (3.9 ± 1.12) (Figure 6B). The grazing ability was rated less important (2.4 ± 1.21) for future development.

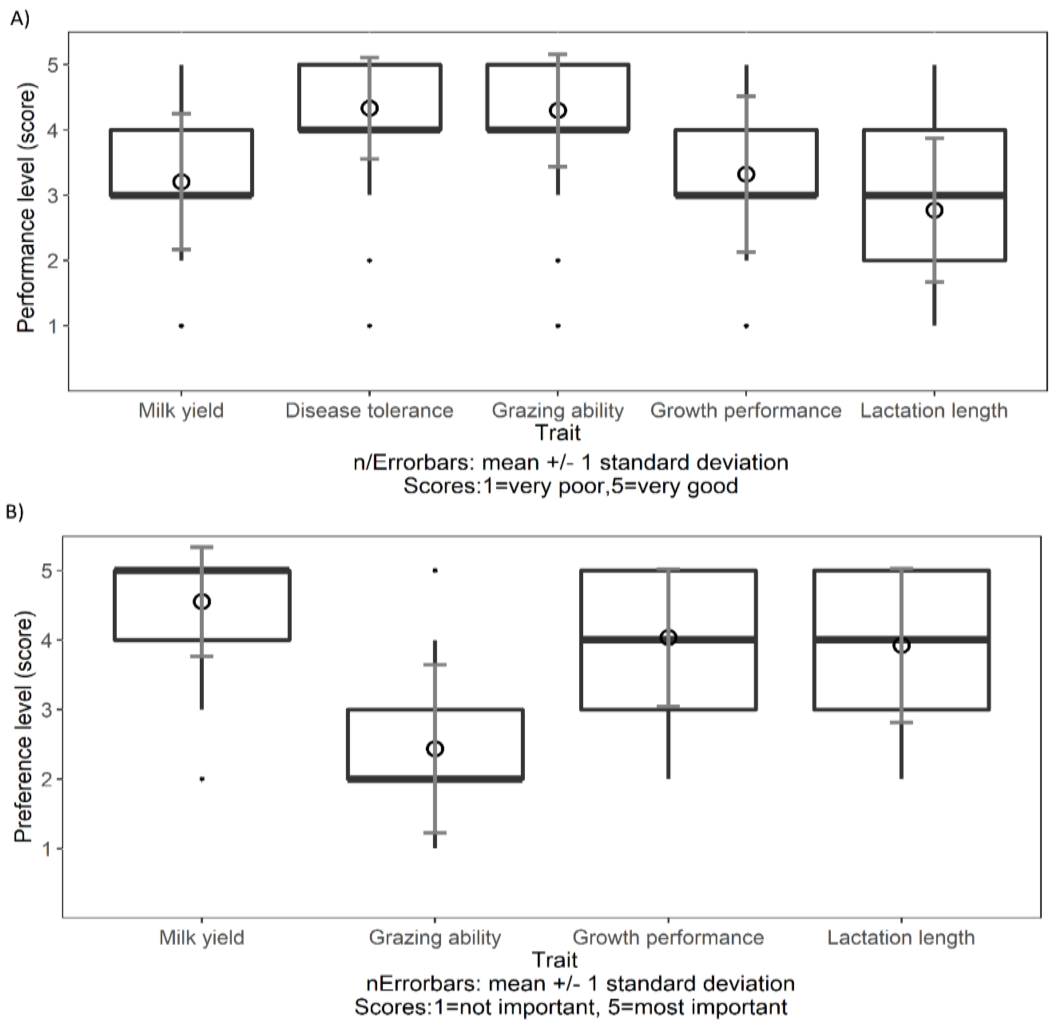

**Figure 6.** Evaluation of trait performance (A) and preference for trait development (B).

### 4.4.10 Challenges of cattle production

Based on mean score values, respondents considered high costs of concentrate feeds (3.7 ± 0.10), lack of financial supports (3.7 ± 0.10), competition from crossbred dairy cattle in terms of milk yield and selling price (3.7 ± 0.12), and lack of cattle improvement services (3.6 ± 0.08) as the major challenges associated with Butana cattle production (Table 9). Scarcity of rangeland was scored moderately important (3.4 ± 0.11). During the group discussions with the farmers, animal theft and high cost of water for watering cattle, specifically during the summer months, were reported as additional production challenges.

**Table 9.** Production challenges and their perceived importance.

| Item | Mean | SE |
|---|---|---|
| High cost of concentrate feed | 3.72 | 0.10 |
| Lack of financial support | 3.69 | 0.10 |
| Competition from crossbreds | 3.68 | 0.12 |
| Lack of cattle improvement services | 3.57 | 0.08 |
| Scarcity of rangeland | 3.36 | 0.11 |

Number of respondents n = 202. SE = standard error.
Scores (1 = not important, 2 = slightly important, 3 = moderately important, 4 = important, 5 = most important) indicate the importance given to the production challenges.

### 4.4.11 Farmers' willingness to participate in a future dairy cattle improvement program

Table 10 summarizes the respondents' willingness to participate in/adopt specific aspects associated with Butana cattle development in the future. The results revealed that almost all farmers (93%) were willing to exchange information, e.g., herd information. Only 26% of the farmers indicated to be willing to keep written records. In general, highly educated farmers were 4.4 times more likely to adopt crossbreeding compared to lower educated farmers ($p < 0.001$) (Table 11). Highly educated farmers were 1.9 times more likely to adopt record keeping than farmers with a low education background ($p < 0.05$). On the contrary, the willingness to exchange information, establish farmers' associations and exchange breeding bulls were not influenced by the farmers' educational level.

**Table 10.** Willingness to adopt future breed development aspects.

| Item | Frequency | Percentage |
|---|---|---|
| Information exchange | 187 | 92.3 |
| Exchange of breeding bulls | 135 | 66.8 |
| Adoption of crossbreeding | 137 | 67.8 |
| Farmers association | 129 | 64.0 |
| Record keeping | 52 | 25.7 |

Number of respondents n = 202

**Table 11.** Odds ratio estimates for impact of farmers' education level (low vs high education and low education as the reference) on their willingness to participate in/perform relevant aspects for breed development.

| Development aspects | Odds ratio | 95% CIs | p-value |
|---|---|---|---|
| Farmers' association | 1.41 | 0.77-2.60 | 0.26 |
| Exchange of breeding bulls | 0.58 | 0.33-1.06 | 0.08 |
| Information sharing | 0.81 | 0.33-1.92 | 0.46 |
| Adoption of crossbreeding | 4.43 | 2.14-9.20 | 0.001 |
| Record keeping | 1.92 | 0.28-0.99 | 0.047 |

CIs = confidence interval

### 4.5 Discussion

The development and successful implementation of a breeding program for local breeds require the definition of a comprehensive breeding objective, a holistic description of the production system, and the involvement of producers at every stage in the planning and implementation process (Kosgey et al., 2006; Duguma et al., 2010)

In this study, the prevailing production conditions for the indigenous Butana cattle, including farmers' socio-economic characteristics, herd sizes and management, production objectives, farmers' perception of trait performances, production challenges and farmers' willingness to participate in a future dairy cattle improvement program were described as a step towards the development of a community-based breeding program for the breed.

Our results showed that milk production is the main production objective for keeping Butana cattle. This is in line with the high proportion of respondents (74.3%) who considered the sale of milk as the main source of farm income. This result is consistent with the findings of Musa et al. (2006) who reported that owners of Butana cattle direct their production objectives toward increasing milk yield as a source of regular cash income and for home consumption. Accordingly, farmers prioritized milk yield over all other traits considered for future development of Butana cattle. High preference for production traits such as milk yield, body size, or growth performance was also reported by farmers of Ankole cattle in Burundi, Rwanda, Tanzania, and Uganda (Wurzinger et al., 2006), Sahiwal cattle in Kenya (Ilatsia et al., 2012) and by dairy cattle farmers in Tanzania (Chawala et al., 2019). Farmers' trait preferences play a crucial role in the development of breeding goals for sustainable livestock improvement breeding programs (Gemeda, 2010; Getachew et al., 2010; Afras, 2019). The importance of grazing ability for future development was medium, although the high costs of concentrate feeds and the scarcity of grazing land were major challenges. This indicates that under the prevailing production conditions of Butana cattle, grazing ability was considered optimal by the farmers, otherwise, they might be encouraged to move towards a more intensive system. In order to reduce the spending on concentrate feeds, these were usually only provided to cross-bred animals and lactating cows during milking.

Selection criteria of breeding bulls reported in the present study are in accordance with previous findings. For instance, the milk yield of a bull's dam (Musa et al., 2006) and general appearance of a breeding bull itself (Mohammed et al., 2014) were considered the most important criteria for bull selection by Butana cattle owners. Similarly, the selection of breeding bulls based on the bull's dam milk yield and body size or frame of the breeding bull itself was reported for Fulani cattle in Burkina Faso (Roessler, 2019). However, the selection of breeding bulls in the absence of performance records as currently practiced by Butana cattle owners remains a challenge for genetic improvement of the breed. Noticeably, the average daily milk yield reported in the current study (6.6 kg) is consistent with previously reported estimates (6.9 kg) for Butana cows managed in a research station (Badri et al., 2011). However, the current report was based on farmers' memories and may have been overestimated. In most dairy farming, a lactation length of 10 months is commonly accepted as gold standard (Ayalew and Chanie, 2018). However, a shorter lactation length of 6.7 months (201 days) was reported in our study, which is close to the mean lactation length estimates of 202.5 days and 208.6 days under field conditions reported for the indigenous Kenana and Fuga cattle, respectively (Musa et al., 2006; Ibrahim et al., 2015). Calving interval, the time between two consecutive parturitions, is an important aspect of the reproductive efficiency of dairy cows and associated with economics of milk production (Ayalew and Chanie, 2018; DeLay et al., 2020). The estimated calving interval for Butana cattle (13.7 months) in our study is much shorter than those reported for Butana (20.6 months), Kenana (17 months), and Fuga (15.9 months) cows under field conditions (Musa et al., 2006; Ibrahim et al., 2015). The differences may be due to differences in the herd management as well as breed differences, and for Butana farmers the low calving interval may be promising and a strength of the breed. Nevertheless, the relatively high number of farmers keeping crossbred cattle and the strong willingness of farmers to adopt crossbreeding with exotic breeds emphasized farmers' dissatisfaction with the current milk performance of the Butana breed. This finding supports previous claims about crossbreeding of local cattle with Holstein Friesian, which has been routinely adopted in Sudan in order to improve the milk performance of the indigenous breeds (Musa et al., 2008). According to the farmers in the present study, the main reason for keeping crossbred cattle was their higher milk production and market value. The complete absence of an organized or a formal breeding program for the Butana breed means that there are currently no alternative solutions to improve the breed's performance genetically. This could be a catalyst for the increased willingness to adopt crossbreeding, which improves performance faster, at least in the short term. Crossbreeding potentially leads to the loss of important adaptation and disease-resistance genes (Leroy et al., 2015; Sutarno and Setyawan, 2015). Additionally, crossbreeding with exotic breeds decreases purebred genetic diversity of indigenous breeds (Piyasatian and Kinghorn, 2003) and can be seen as a threat to native genetic diversity (Hoffmann and Scherf, 2006).

The synergy between crop farming and cattle raising (mixed crop-livestock farming) reported by 89.6% Butana cattle farmers in the current study is a common practice found in many parts of Africa. For example, Ankole cattle in Burundi, Tanzania, Rwanda and Uganda (Wurzinger et al., 2006) and Méré Baoulé and other cattle breeds in Côte d'Ivoire (Sokouri et al., 2014) are kept under mixed crop-livestock farming systems. The combination of cattle production with crop cultivation could be promising for overcoming the overall challenges of high costs associated with concentrate feeds and the general lack of financial support since farmers would be able to produce improved fodder or utilize crop by-products as low-cost feed resources.

Hired laborers were important for Butana cattle management, mainly for farmers who owned larger herd sizes and tended to move their cattle to grazing areas during the wet season, whereas family labor was more important for the farmers with small to medium herd sizes. Previous studies involving small dairy farmers in Burundi, Rwanda, Tanzania, Uganda, Ethiopia, and Burkina Faso have also reported that hired laborers and family members were important in raising indigenous cattle (Wurzinger et al, 2006; Zuria and Woredas, 2009; Soudré et al., 2020).

As most farmers owned small herd sizes and a simultaneously low number of breeding bulls, establishing farmers' associations could be an important step for optimizing a future breeding program for the Butana cattle. Rege et al. (2011) emphasized that the selection and use of village sires in situations where herd sizes are small will require the cooperation of community members to record, select and innovatively manage and use the selected sires. This could preserve genetic variability and keep the rate of inbreeding in the small herds at an optimal level, which are the main concerns in maintaining local breeds. That said, the exchange of breeding bulls that was generally accepted by the farmers in the present study may provide an opportunity for maintaining genetic diversity within the Butana cattle population.

Dairy production needs delivery of better animal health services and management. Even though the farmers in the current study indicated that Butana cattle are disease tolerant, the prevalence of diseases suggest that animal health services were poor and vaccinations programs were lacking. The most important diseases reported in the current study (foot-and-mouth disease, trypanosomiasis, and mastitis) have also been reported in previous studies (Musa et al., 2006; Mohammed et al., 2014; Ahmed et al., 2016). In this regard, Wilson (2018) and FAO (2019) reported that vaccination programs in Sudan prioritized diseases affecting livestock exports, mainly contagious bovine pleuropneumonia and rinderpest, as foreign markets (e.g., United Arab Emirates, Jordan, Saudi Arabia and Egypt) have more stringent health standards. Conversely, diseases that affect production such as mastitis and trypanosomiasis have received much less attention. Generally, crossbred animals are expected to be more prone to tropical diseases, however, in the current study, farmers did not distinguish between diseases along breed types.

Animal records are strongly required to establish genetic improvement programs and to support selection decisions in the long term. Our results revealed a complete absence of an official system for animal identification and performance recording. Instead, farmers purely relied on recall memory. The absence of performance recording has also been reported in previous studies for other indigenous cattle breeds (Opoola et al., 2019; Roessler, 2019). Major reasons associated with the lack of performance recording in most developing countries include the low awareness of potential benefits of recording among livestock owners, the research and development sector, and policy makers; problems of finding the right organization for animal recording; the challenge of attaining due participation; and insufficient technical know-how to implement and utilize records (Peters and Zumbach, 2002). In the present study, farmers' willingness to keep written records increased with higher educational level. Thus, educating farmers on the benefits of keeping written records could aid the adoption of record keeping. Such education can be offered to farmers collectively and with relative ease through novel farmers' associations since the majority of the respondents were willing to establish this type of association. The establishment of farmers' associations could enhance the strengthening of a so-called "Butana cattle farmer lobby" which represents and enforces farmers' interests, mainly for solving problems associated with better access to financial support, as well as veterinary and breeding services (Buch et al., 2009; FAO, 2013; Mueller et al., 2015; Ibeagha-Awemu et al., 2019; Lukuyu et al., 2019).

## 4.6 Conclusion

The present study highlighted the need for establishing community-based breeding programs for smallholder dairy cattle producers in Central Sudan. Our results showed that Butana cattle farmers mainly raised their animals for milk production. This was reinforced by farmers' reliance on the sale of milk as the predominant source of income and the prioritization of milk yield as the most important trait for improvement. The willingness of farmers to engage in associations will be useful for the establishment of a community-based breeding program.

# 5.0 Development of a breeding program for improving the milk yield performance of Butana cattle under smallholder production conditions using a stochastic simulation approach

## 5.1 Abstract

Butana is one of the local dairy cattle breeds of Sudan commonly kept by smallholder producers. It has been strongly promoted to advance the dairy production sector in the country. The main problem, however, is the lack of a systematic breeding program that involves smallholder producers. The aim of the current study was to identify the most promising design for a breeding program to improve the milk yield performance of Butana cattle under smallholder production conditions. In total, three breeding scenarios, including 1) the use of farm bulls, 2) the use of village bulls, and 3) the rotational use of village bulls within village groups, were simulated using a stochastic simulation approach. For each breeding scenario, three selection methods for bulls were considered, namely random mating, phenotypic selection, and selection based on estimated breeding value (EBV). The results showed that no genetic gain was realized with random mating in all breeding scenarios. In the farm bull breeding scenario, annual genetic gain (SD units) ranged from 0.01 to 0.19 (phenotypic selection), and from 0.01 to 0.39 (selection based on EBV). In the village bull breeding scenarios, the annual genetic gain ranged from 0.01 to 0.21 (phenotypic selection), and from 0.01 to 0.45 (selection based on EBV). The lowest genetic gain was realized for the rotational use of village bulls among villages within groups. Through the rotational use of village bulls, however, a higher genetic variance was maintained than in the farm and village bull breeding scenarios. We concluded that a village bull breeding program with selection based on EBV of young bulls is the most promising breeding design for achieving the breeding goal. Further studies are needed to assess the organizational feasibility of such a breeding program to ensure the participation of smallholder producers and its sustainability.

Keywords: Butana cattle, breeding program, village bull

## 5.2 Introduction

In Sudan, indigenous cattle are managed by smallholder producers and traditional pastoralists. They play an essential role in the Sudanese economy and are considered a major component of poverty alleviation initiatives (Wilson, 2018). Among Sudanese indigenous cattle, Butana is one of the most promising breeds suited for milk production due to its comparatively high production performance. The breed produces around 1,663 kg milk per lactation under research station management conditions (Musa et al., 2005). It is predominantly kept by semi-nomadic pastoralists under smallholder production conditions in the Butana region of central Sudan. The breed is well adapted to the harsh environment and poor nutritional conditions of this semi-arid region (Ahmed et al., 2017). Within-breed selection is practiced on a research station to genetically improve the milk yield performance of the breed. However, Butana cattle farmers are not actively involved in the planning and implementation of this public breed improvement program (Omer et al., 2020), and they often do not have access to the improved genetics. Therefore, many Butana cattle farmers are more focused on crossbreeding with Holstein Friesian cattle (Ahmed et al., 2007; Musa et al., 2005) as a method to quickly improve the milk yield and their income from milk sales (Abdel Gader et al., 2007; Omer et al., 2020). However, the extensive and unsystematic crossbreeding of Butana with Holstein Friesian has raised concerns over the fate and conservation of the Butana breed for present and future use (Musa et al., 2005). This points to the need for simple and effective breeding programs, which actively involve smallholder farmers and which optimize genetic gain for milk yield while maintaining the breed’s adaptation to smallholder production conditions. Cooperative village breeding programs have been widely suggested as an alternative option to central breeding schemes (Kahi et al., 2005; Wurzinger et al., 2008; Rewe et al., 2009). They constitute a means to overcome the constraints associated with managing a breed improvement program for smallholder herds, namely small herd sizes, low levels of organization and infrastructure, lack of performance recording and animal identification (Rege et al., 2011). In addition, cooperative breeding programs are considered appropriate for the conservation of indigenous livestock breeds and can contribute significantly to livestock genetic improvement in developing countries (Gizaw et al., 2009; Gizaw et al., 2014; Mueller et al., 2015). The design of livestock breeding programs implies proper breeding planning and evaluation of alternative breeding scenarios in order to identify the most appropriate breeding scheme. The objective of the present study was therefore, to compare alternative breeding and selection scenarios of cooperative village breeding programs for the genetic improvement of the milk yield performance of Butana cattle through a simulation study.

## 5.3 Materials and methods

The simulation of alternative breeding and selection scenarios was performed using AlphaSimR (Gaynor et al., 2019) within R software version 3.6.3 (https://www.r-project.org/). Use of AlphaSimR involved a two-step approach including a burn-in phase described as historic breeding and an evaluation phase called future breeding. The simulation was specifically designed to mimic the real Butana cattle population in central Sudan. No animals were used in this study, and ethical approval for the use of animals was thus deemed unnecessary.

### 5.3.1 Burn-in phase

The haplotype sequences of a founder population consisting of 5,000 animals were simulated via a Markovian Coalescent Simulator (Chen et al., 2009) using the runMacs2 function of AlphaSimR (Gaynor et al., 2019). The parameters used for creating the founder haplotypes included effective population sizes (Ne) over many generations, which describe the demographic history of cattle populations (MacLeod et al., 2013), i.e., Ne = 6,000 animals (1,000 generations ago), Ne = 24,000 animals (10,000 generations ago), and Ne = 48,000 animals (100,000 generations ago). Ne in the current generation was set to 1,035 animals, which reflects the high genetic diversity found in cattle populations in Africa (Powell et al., 2019). The founder genotypes were simulated with 10 chromosome pairs, each with $10^8$ base pairs length, mutation rate of $1\text{x}10^{-8}$ per base pair per generation, and 5,000 randomly chosen SNP marker loci. In addition, a 1,000 quantitative trait locus (QTL) per chromosome was considered to be the causal loci of a polygenetic trait influenced by many genes, each of them with minor effects. The chosen number of QTL per chromosome is consistent with many published studies (e.g, Obšteter et al., 2019; Selle et al., 2020; Obšteter et al., 2021). The simulated haplotypes were used to establish the founder population of 5,000 animals with 1:1 sex ratio. The sex of founder animals was randomly assigned.

A single polygenic trait was modeled with a pure additive genetic effect, and the initial mean genetic value and genetic variance for the trait were set to zero and one, respectively. Furthermore, QTL allele substitution effects were sampled from a standard normal distribution, and for each animal, the true breeding value (TBV) for the simulated trait was calculated by adding up its coded genetic value for its genotype across all QTLs. A narrow-sense heritability of 0.35 was assumed, and the phenotype ( $y_i$) for each animal was simulated by adding a random residual environmental effect (random error) to each animal's TBV. Thus, $y_i = g_i + e_i$, where $g_i$ denotes TBV of animal $i$ and $e_i$is the random error effect, which was drawn from a normal distribution with a mean of zero and a variance equals to the residual variance.

In the current simulation, we chose one polygenetic trait (lactation milk yield) in order to reflect the farmers' production trait preferences for future genetic improvement in Butana cattle as determined by a survey in a previous study (Omer et al., 2020).

### 5.3.2 Evaluation phase

In the evaluation phase, initial parents (first generation) of the breeding program consisted of 1,650 cows and 202 bulls randomly selected from the founder population. Three different breeding scenarios were simulated over 10 generations across which the number of cows remained constant. In each scenario, animals were randomly assigned to 202 farms in 17 villages according to their predefined herd size that varied from 2 to 23 cows (Table 12). These numbers represent the real number of villages, Butana cattle herds, and cows, in the Butana region of Sudan (Omer et al., 2020). The three different breeding scenarios are hereby described.

### 5.3.3 Farm bull breeding scenario

In the farm bull breeding scenario, it was assumed that each farm used its own breeding bull to improve the milk yield. The initial farm bulls (n = 202) were randomly selected from the founder population and one bull was randomly assigned to each farm. The decision to assign a breeding bull to each farm, including those with small herd sizes, was motivated by the observation that some Butana cattle farmers tend to keep breeding bulls within small-sized herds of up to two cows (Omer et al., 2020). For farmers with small herd sizes, however, this could be costly and can affect the economic viability of the scheme. In this breeding scenario, the selection of young bulls was carried out within each farm.

### 5.3.4 Village bull breeding scenario

The village bull breeding scenario assumed a cooperation between farms in the same village, meaning that all farms in one village used the same bull to mate their cows. For the 17 villages assumed, average number of farms per village ranged from 2 to 28, and the number of cows per village varied from 8 to 460 animals (Table 12). The required village breeding bulls (n = 17) were randomly selected from the list of farm bulls (n = 202) and 1 bull was assigned to each village.

**Table 12.** Number of farms and cows used for breeding program simulation.

| Village | Farms (n) | Cows (n) | Average number of cows per farm |
|---|---|---|---|
| 1 | 23 | 276 | 12 |
| 2 | 6 | 48 | 8 |
| 3 | 28 | 168 | 6 |
| 4 | 19 | 76 | 4 |
| 5 | 13 | 65 | 5 |
| 6 | 10 | 40 | 4 |
| 7 | 4 | 36 | 9 |
| 8 | 11 | 66 | 6 |
| 9 | 2 | 8 | 4 |
| 10 | 5 | 10 | 2 |
| 11 | 11 | 55 | 5 |
| 12 | 23 | 460 | 20 |
| 13 | 4 | 92 | 23 |
| 14 | 3 | 24 | 8 |
| 15 | 6 | 66 | 11 |
| 16 | 22 | 88 | 4 |
| 17 | 12 | 72 | 6 |
| Total | 202 | 1650 | 8 |

### 5.3.5 Rotational use of village bulls within village groups scenario

The rotational use of village bulls within village groups assumed a cooperation among villages within the same administrative unit. Based on the distribution of administrative units, the 17 villages were further combined into five groups. The number of cooperative villages within a group ranged from 1 to 6 (Table 13), with 12 to 80 farms and 72 to 730 cows each. Rotation of the village bulls among villages within the same group was assumed, meaning that after a breeding cycle of about a year, a village bull was transferred to another village in the same group. As groups 1 and 5 had only 1 village each, rotation was not possible in these groups, hence their exclusion from subsequent analyses.

**Table 13.** Number of cooperative groups, farms and cows per group used for breeding program simulation.

| Group | Number of cooperative villages (n) | Farms (n) per group | Cows (n) per group |
|---|---|---|---|
| 1 | 1 | 23 | 276 |
| 2 | 6 | 80 | 433 |
| 3 | 4 | 29 | 139 |
| 4 | 5 | 58 | 730 |
| 5 | 1 | 12 | 72 |

Both village bull breeding scenarios were used to create genetic relationships between the herds. For all breeding scenarios, three alternative selection methods for breeding bulls were considered. These include 1) random mating, in which bulls were randomly selected to mimic the situation where farmers utilize bulls based on availability rather than genetic merit, 2) phenotypic selection (phenotypic observations on the individual itself), and 3) selection based on estimated breeding value (EBV) for the breeding goal trait. Here, we assumed that farmers keep performance records of cow's milk yield, and that the bulls are evaluated and selected based on their relatives' performance. Thus, EBVs of bulls were computed from all available phenotype information from bull's relatives using a standard mixed model.

In the 2-village bull breeding scenarios, selection of young bulls was carried out within the respective village or group. No selection on the female path was assumed, meaning that all female calves were used for further breeding, replacing the respective number of old cows in each farm, regardless of their genetic merit.

For each breeding scenario and selection method, the mean genetic gain and variance were extracted into a csv file. The genetic gain in each generation was expressed in units of standard deviation (SD units) of the true breeding value, whereas the genetic variance is the variance of the breeding value (additive genetic variance). Furthermore, annual genetic gain was estimated by dividing the genetic gain per generation by the generation interval from the bull side. A generation interval of 5 yr was assumed for bulls used in the farm and village bull breeding scenarios, considering the age of bull at first mating and reproductive lifetime of bulls to be 2 and 3 yr, respectively. Generation interval differed for the rotational use of village bulls within group's scenario. Due to additional time required to complete the rotation within a group, the generation interval was assumed to be 6 yr for group 3, which consisted of 4 cooperative villages; 7 yr for group 4 with 5 cooperative villages, and 8 yr for group 2 with 6 cooperative villages.

### 5.3.6 Data analysis

The results were graphically visualized using R software version 3.6.3. For each breeding scenario, the genetic gains and genetic variances over the generation under the three selection methods were presented as line charts. Comparisons of genetic gains and genetic variances under the three breeding scenarios with different selection methods were presented as bar charts. Tuckey's test for pairwise comparisons under a 2-way ANOVA model was performed to detect significant differences ($P < 0.05$) in annual genetic gain and variance within and between the breeding scenarios and selection methods.

## 5.4 Results

### 5.4.1 Genetic trends of the breeding scenarios and selection methods

Genetic gain and variance in the simulated trait for random mating, phenotypic selection and selection based on EBV in the farm bull breeding scenario through the period of 10 generations are presented in Figures 7A and 7B, respectively. Notably, with random mating, almost no genetic gain was realized, whereas the genetic gain gradually increased with phenotypic selection and selection based on EBV over each generation. Compared to phenotypic selection, the genetic gain achieved by selection based on EBV was nearly doubled after the 10th generation (Figure 7A). As shown in Figure 7B, the genetic variance decreased as the number of generations increased, irrespective of the selection method. Across generations, the genetic variance was comparatively higher with selection based on EBV than with phenotypic selection or random mating.

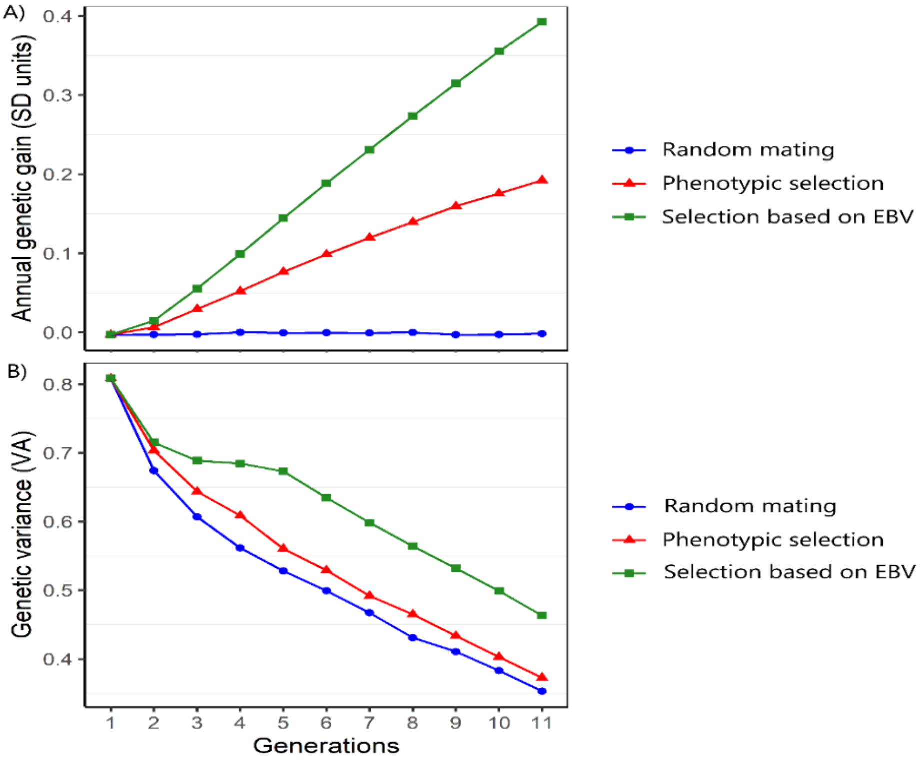

**Figure 7.** Annual genetic gain (A) and genetic variance (B) over 10 generations of selection under the farm bull breeding scenario.

Similar to the farm bull breeding scenario, nearly no genetic gain was realized when village bulls were randomly mated, while a positive genetic trend was observed when phenotypic and selection based on EBV selection of village bulls were applied (Figure 8A). Again, the genetic gain was generally higher for selection based on EBV than that for phenotypic selection of village bulls. Consequently, only 6 generations of selection are needed with selection based on EBV to achieve the same genetic gain (0.21 SD) as with phenotypic selection after 10 generations. Under the village bull breeding scenario, the genetic variance decreased throughout the generations irrespective of the selection method (Figure 8B).

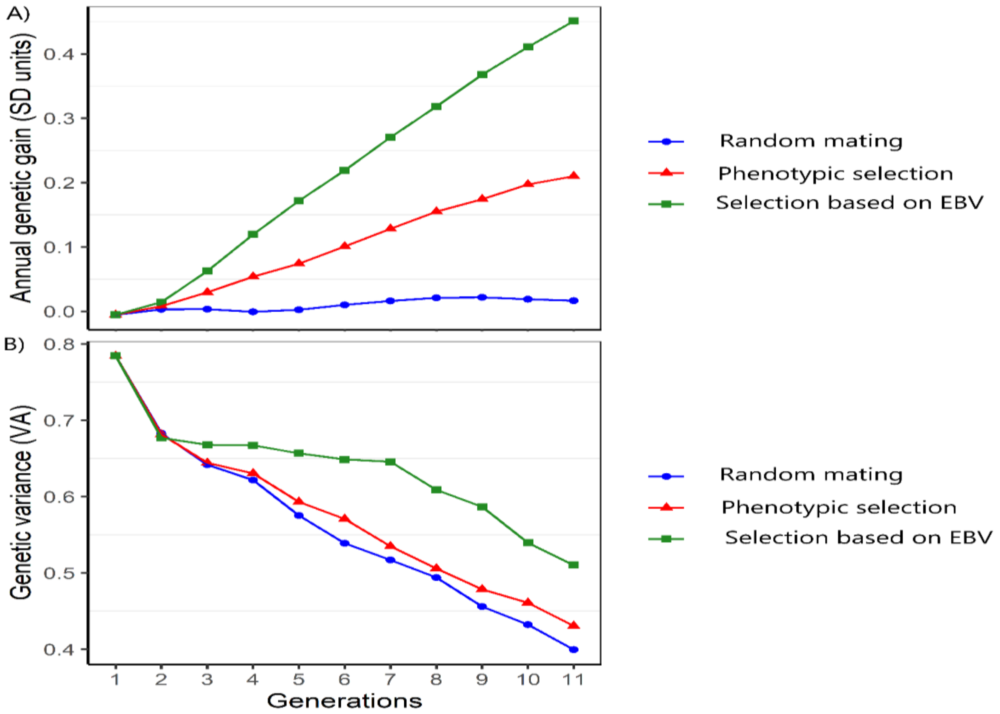

**Figure 8.** Annual genetic gain (A) and genetic variance (B) over 10 generations of selection under the village bull breeding scenario.

Figures 9A and 9B show the genetic gains and genetic variances for the rotational use of village bulls within village groups. For phenotypic and selection based on EBV, the genetic gain considerably fluctuated between generations 2 and 6, and subsequently increased after generation 7. Generally, the highest genetic gain was realized using selection based on EBV (Figure 9A). For all three selection methods, the genetic variance decreased between generations 2 and 6, while it fluctuated for phenotypic selection and selection based on EBV and increased for random mating after generation 7 (Figure 9B).

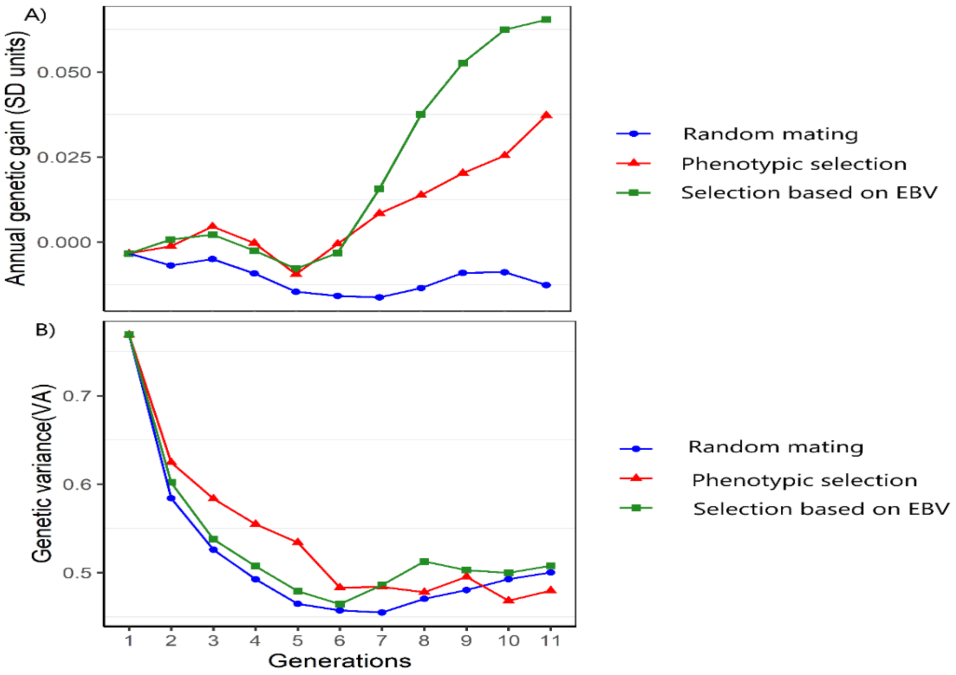

**Figure 9.** Annual genetic gain (A) and genetic variance (B) over 10 generations of selection under the rotational use of village bulls within village groups' scenario.

### 5.4.2 Genetic gain and genetic variance after 10 generations of selection

Comparisons of both genetic gain and variance for the simulated trait were made between the three breeding scenarios and selection methods after 10 generations as shown in Figures 10 and 11. With selection based on EBV, differences in genetic gain across breeding scenarios were statistically significant at $P < 0.001$ (Figure 10). The village bull breeding scenario resulted in the highest annual genetic gain (0.45 ± 0.22 SD) while the lowest was found for rotational use of village bulls within village groups (0.07 ± 0.07 SD). The rotational use of village bulls with phenotypic selection also yielded significantly ($P < 0.001$) lower genetic gains compared to the same selection method under the farm bull or village bull breeding scenario. Both, the farm bull breeding scenario and the rotational use of village, bulls had a negative genetic gain with random selection of bulls. Evaluating the genetic variance after 10 generations of breeding, the rotational use of village bulls within village groups retained significantly higher genetic variance with random mating and phenotypic selection compared to the farm bull and village bull breeding scenarios with the same selection methods ($p < 0.001$) (Figure 11). However, genetic variances for the village bull breeding scenario were significantly higher than those of the farm bull breeding scenario across all three methods of selection ($p < 0.05$).

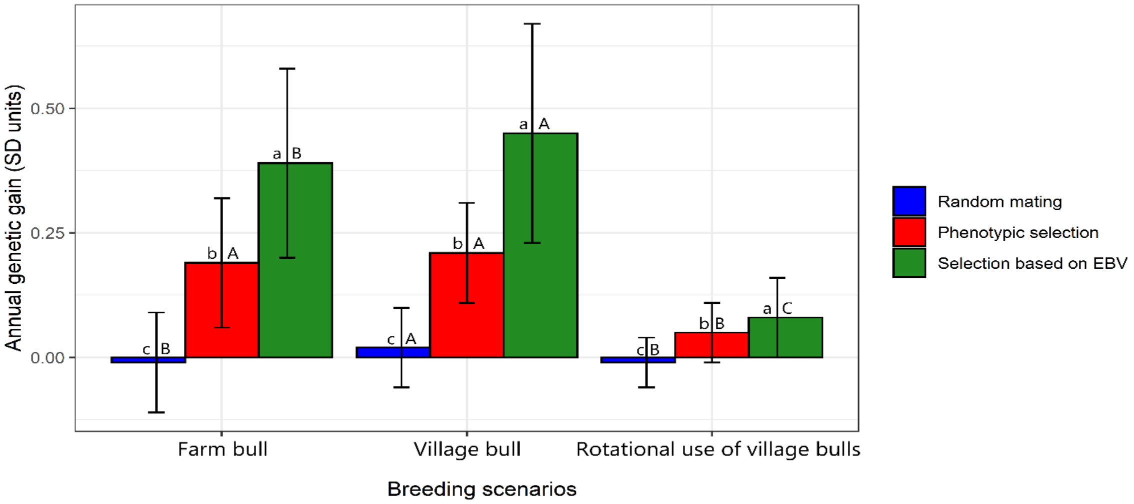

**Figure 10.** Annual genetic gain across all breeding scenarios after 10 generations of selection. Capital letters indicate differences between the breeding scenarios within each selection method ($p < 0.05$), and small letters indicate differences between the selection methods within the same breeding scenario. Error bars indicate SD.

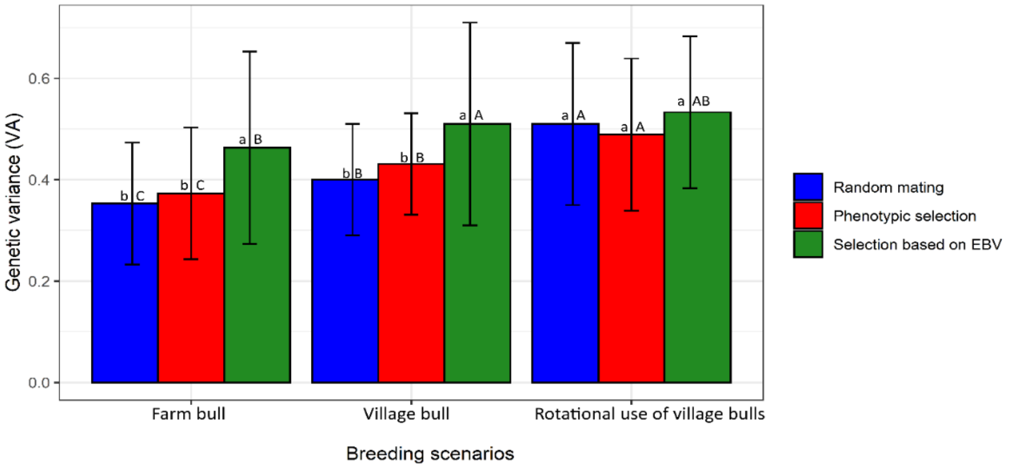

**Figure 11.** Genetic variance across all breeding scenarios after 10 generations of selection. Capital letters indicate differences between the breeding scenarios within each selection method ($p < 0.05$), and small letters indicate differences between the selection methods within the same breeding scenario. Error bars indicate SD.

## 5.5 Discussion

A breeding program based on within-breed selection has been advocated as a way of developing Butana cattle, which are predominantly found in marginal habitats and harsh environments. Previous studies investigated the possibility of developing a community-based breeding program for the genetic improvement of Butana cattle through a survey approach (Omer et al., 2020). Following that investigation, the present study simulated three alternative breeding scenarios, including a farm bull, a village bull, and the rotational use of village bulls within village groups using different methods of bull selection, namely random mating, phenotypic selection and selection based on EBV, in order to identify the most promising breeding program for the genetic improvement of this breed. Genetic gain in the simulated trait was used to compare the alternative breeding scenarios and selection methods. Our results showed a relatively high genetic gain for the simulated trait under all selection methods of the village bull breeding scenario. This could be attributed to a high selection intensity in this scenario as fewer number of bulls were needed. The use of a single breeding bull in a village implies a bull to cow ratio of 1:460 in some villages. This poses a challenge to the practical implementation of the village bull breeding scenario, given the requirements for replacing bulls that have problems, and logistics for artificial insemination practices. In each village, farmers collaborated and their herds were considered as one selection group from which a bull was chosen. According to Powell et al. (2019) and Selle et al. (2020), the genetic connectedness between herds improves the selection accuracy, thus resulting in higher genetic improvement. Similarly, village breeding programs have been suggested for genetic improvement of different breeding goal traits for indigenous livestock species in the tropics. For instance, a village breeding program has been implemented to improve pure Lobi cattle and their crosses (Lobi x Zebu) for meat production and trypanotolerance in the South-West of Burkina Faso (Ouédraogo et al., 2021). In India, a village breeding program has been implemented to conserve the Tharparkar cattle breed (FAO, 2013).

In this breeding program, Tharparkar bulls were selected, each bull was given to a family in the village who agreed to maintain it in exchange for earnings obtained through the use of the bull by other farmers for natural service mating of their cows. The breeding program has shown an increase of the number of pure Tharparkar cows. In addition, a village-based breeding program was suggested for improving beef production of indigenous cattle in the Mangwe district of Zimbabwe (Bidi et al., 2015). In small ruminants, a number of studies have shown that village breeding programs yield acceptable genetic improvement, for example, a cooperative village breeding program for Menz, Bonga, and Horro sheep, and for Western Lowland and Abergelle goats in smallholder farming systems in Ethiopia (Gizaw et al., 2009; Abegaz et al., 2014; Haile et al., 2020). Similarly, a village-based breeding program for a Ilama population in Bolivia has been suggested to improve fiber production (Wurzinger et al., 2008).

Our present simulation confirmed the benefits of cooperative breeding programs and demonstrated the potential of a village bull breeding program for future improvement of Butana herds under smallholder production conditions. Nevertheless, from a practical perspective, its implementation requires the involvement of farmers who are willing to genetically improve their cattle and to take an active part in the development and implementation of any measure from the design to the implementation phase (van Arendonk, 2011; Mueller et al., 2015; Haile et al., 2020). The willingness of Butana cattle farmers to engage in associations and exchange information (Omer et al., 2020) could aid the design and practical implementation of a village bull breeding program for Butana cattle. Furthermore, a village bull breeding program may only require a minimal change in already existing breeding methods among farmers, because some Butana cattle farmers already rely on bulls from their neighbors (Musa et al., 2006; Omer et al., 2020). The village bull breeding program simulated in the present study only assumed a single bull mating to all village herds. However, for better utilization of a bull within village herds, where possible, the development of village run artificial insemination (AI) schemes using frozen or fresh semen (van Arendonk, 2011; Rege et al., 2011) could be considered as a complement or alternative method to the natural bull mating. AI to exchange genetic material between village herds offers an opportunity to further increase the rate of genetic improvement (van Arendonk et al., 2011). Nonetheless, the benefits of AI services can be achieved if all prerequisites, including the sperm handling and storage facilities (e.g., electricity and liquid nitrogen) for the establishment of AI stations in villages are secured.

In contrast to the village bull breeding scenario, lower genetic gains achieved with the farm bull breeding scenario in the present study indicate that genetic progress by individual efforts of farmers is difficult, because of small herd sizes. Besides, the high loss in genetic variance under the farm bull breeding scenario is most likely due to inbreeding and the continuous selection of farm bulls within a farm herd (Gorjanc et al., 2015). However, the genetic variance is considered a key factor for genetic improvement, control of inbreeding, and effective utilization and exploitation of breed-specific characteristics (Makina et al., 2014; Cervantes et al., 2016; Ouédraogo et al., 2021). Generally, in a sustainable breeding program, sufficient rates of genetic gain in the short term, and the maintenance of genetic variance in the long term have to be considered (Bijma et al., 2001).

Several types of rotational mating systems exist, but in general, males that are used as sires are provided from another subpopulation than dams (Windig and Kaal, 2008). This type of rotational mating was evaluated in the present study. The results showed that across all selection methods, the rotational mating achieved lower genetic gain than the village bull breeding scenario. This could be attributed to the low number of selection cycles for bulls in the simulated rotational breeding scenario, since on average, bulls were rotated 4 to 6 yr before selection of young bulls was carried out to replace the old ones. This implies a longer generation interval for bulls in the rotational breeding scenario as compared to both the village and farm bull breeding scenarios. Conversely, shortening of generation intervals will result in more rounds of selection per unit time, hence increasing the achievable gains per unit time (Kariuki et al., 2014; Kasinathan et al., 2015). However, one positive aspect of the rotational use of village bulls within village groups is that a higher genetic variance could be maintained. Our results support previous findings that rotational mating can be generally used to increase the genetic diversity within a breed by balancing the genetic contributions of the breed's subpopulations (Windig and Kaal, 2008; Mucha and Komen, 2016). Therefore, in situations where breeding aims to maximize genetic variances rather than genetic gains, such a rotational breeding program might be a valuable option. However, willingness of farmers to adopt such a breeding program needs to be investigated as the rotational use of village bulls among villages within groups is not a customary practice in the Butana region, and increases the organizational complexity.

Genetic improvement in dairy cattle is largely determined by the merit of bulls used as sires of each generation, therefore, dairy bulls selection is an important step in any cattle breeding program (Andrabi and Moran, 2007; Kariuki et al., 2014). Breeders rely on various selection methods to improve breeding goal traits. In this study, random selection, phenotypic selection and selection of young bull based on their EBVs were simulated. We found that a substantial genetic gain could be achieved by selection based on EBV of young bulls in all breeding scenarios. In addition, a higher genetic variance was obtained by selection based on EBV in the simulated breeding scenarios. This may indicate that the impact of selection on reducing the additive genetic variance, i.e., change of allele frequencies, was small. A number of studies have shown selection based on EBV to achieve better genetic improvement. For instance, in their work on developing breeding schemes for pasture based dairy production systems in Kenya, Kahi et al. (2004) demonstrated that in a well-organized open-nucleus breeding program, young bull selection would be profitable and result in overall improvement of production in dairy cattle. Syrstad and Ruane (1998) compared 2 traditional schemes for dairy bull selection in the tropics, namely young bull selection (i.e., selection based on the performance of the bull's dam and selection based on bulls' daughters' performance; progeny testing). The authors found that young bull selection gave faster genetic gain per year due to a shorter generation interval. Philipsson et al. (2011) also emphasized that selection based on EBV of young bulls would be a better option than engaging in a poorly organized dairy cattle progeny testing program, because selection based on progeny testing prolongs the generation interval, contributing to slower genetic progress. Additionally, a young bull selection scheme is practically simple, and less expensive (Zumbach and Peters, 2002), which makes it suitable to animal breeding programs in the tropics. In Sudan, the selection of young bulls based on bulls' dam's milk yield performance is a customary practice by Butana cattle owners (Musa et al., 2006; Mohammed et al., 2014; Omer et al., 2020), and should thus be enhanced for the future genetic improvement of this breed. However, phenotypic selection yielded lower genetic gain compared to selection based on EBV. According to Oldenbroek and van der Waaij (2014), phenotypic selection is a straightforward way of ranking animals as breeding candidates, but it is not always the most accurate way if the phenotype for some reasons is not available for all animals, such as for milk production of males. However, it could be used for screening farmers' herds for selecting outstanding bulls or cows to initiate a base population for a breeding program (Philipsson et al., 2011). Organized recording schemes using all available information about relatives, i.e., maternal and paternal half-sisters of sires and dams, could form the basis for breeding value estimation, further enhancing the genetic progress of a future breeding program for Butana cattle in Sudan.

For a successful implementation of selection based on EBV for Butana cattle improvement, recording schemes should be established and performance recordings should be done in each farm within a cooperative group. In this regard, the main strength reported in the previous work

(Omer et al., 2020) was that Butana cattle farmers were willing to adopt performance record keeping. However, motivating farmers by offering incentives such as discounts on breeding males, veterinary health care, vaccinations, exhibitions, access to market auctions/sales and other production inputs could positively affect successful adoption of record keeping (Kahi et al., 2005; Mueller et al., 2015; Zoma-Traoré et al., 2021). Strong links and collaboration among farmers, relevant livestock development institutions (e.g., universities and research stations), and other development partners are widely suggested in developing countries to ensure information sharing (Wurzinger et al., 2011; Ibeagha-Awemu et al., 2019), and to help cooperative farmers receive essential inputs, e.g., measuring and recording facilities, genetic evaluation software and training to support genetic improvement activities (Kahi et al., 2005; Kosgey and Okeyo, 2007). Mueller et al. (2015) analyzed eight community-based breeding programs located in countries of Latin America, Africa, and Asia, and concluded that the involvement of relevant institutions in the planning and implementation of breeding stages is most important for the success of farmer cooperative breeding programs.

## 5.6 Conclusion

The present study simulated 3 alternative breeding scenarios for the genetic improvement of the milk yield of Butana cattle under smallholder producers' production conditions in Sudan using different selection methods. Our results showed the highest genetic gain for the village bull breeding scenario. Also, the genetic gain was highest with selection based on EBV for each breeding scenario. Conspicuously, the genetic variance was most strongly maintained for the rotational use of village bulls within village groups. Genetic gains under random selection across all breeding programs were much lower, and genetic variances were also often smaller than for phenotypic selection and selection based on EBV. Thus, this breeding program may have no relevance for the future breed development of Butana cattle. The findings of the present study will assist in designing a practical breed improvement program for Butana cattle kept under smallholder production conditions in Sudan. They may also serve as a blueprint for the development of breeding programs for other local breeds kept under similar conditions in the country.

## 6.0 General discussion

Livestock is an important source of economic security and a valuable asset for most households in Sudan's rural communities. Butana is an indigenous cattle breed that plays an essential role in milk supply and contributes a major source of income for smallholder farmers who dwell in central Sudan's marginalized areas. However, there is lack of a systematic breeding program for breed improvement in these areas. As the breed is mostly owned by smallholder farmers, a genetic improvement program that takes the interests and aims of the owners into consideration is essential. Designing appropriate breeding strategies for improvement in any livestock production can generally be achieved by thoroughly assessing animal production environments and identifying breeding objectives (Kosgey et al., 2006; Mekonnen, et al., 2012). In this study, the production conditions of Butana cattle under government station and field management were analyzed with the primary goal of developing a suitable breeding program to optimize milk yield performance of the breed.

In Chapter 3, the performance of Butana cattle under the management of Atbara Livestock Research Station has shown that the breed can efficiently respond to improved management practices, e.g., feeding. This was demonstrated by findings of cow’s longer lactation length (272 days) and shorter calving interval (12.7 months) on the station as opposed to the village management conditions (Chapter 4), under which lactation length and calving interval were 201 days and 13.6 months, respectively.

Nonetheless, the relatively high number of daughters sired by individual bulls with unfavorable genotypic effect on milk yield (Chapter 3) may reflect poor station herd selection practices. Similar observation was reported for the Sahiwal breed in Pakistan (Philipsson, 2000). The effectiveness of a breeding program can be measured by its ability to generate genetic progress through identification of superior individuals to be used as parents of the next generation (Kariuki et al., 2014). Thus, best linear unbiased prediction method that accounts for environmental effects, as well as making the best use of all available data could improve the possibilities for efficient Butana bull selection in the research station.

Mixed crop-livestock systems in which Butana cattle are kept under villages conditions (Chapter 4) are similar to the most commonly observed cattle production systems in many parts of Africa (Wurzinger et al., 2006; Sokouri et al., 2014). In this system, cattle owners in villages practice crop farming, utilizing conventional rain-fed or irrigated crop agriculture, which is a key source of food for farmers and their families. At the same time, wastes or crop-by-products are utilized to feed the cattle kept by farmers. Well-integrated crop-livestock production systems provide opportunities, such as the provision of draght power to cultivate the land, and the production of manure as fertilizer to support crop production (Thornton et al., 2018). As a result, the systems are associated with a minimum or no external inputs.

Small herd sizes observed in the current study (Chapter 4) are consistent with what is often found under mixed-crop livestock production systems in developing countries (Bebe et al., 2003; Abdel-Salam et al., 2010), whereby, samllholder dairy farmers contribute to about 75% of milk production (Herrero et al., 2010). However, the characteristics of small herd sizes generally limit the implementation of effective genetic improvement programs (Chapter 2).

A high cost of animal concentrate reported in the presents study was also observed by Lukuyu et al. (2011) for smallholder dairy farmers in Kenya's central and northern Rift Valley regions. In Sudan, animal feed industries play an important role in supplying concentrate feeds (Babiker, 2015); however, the high costs of concentrate feed, production and distribution makes it unaffordable for poor smallholder farmers in rural areas. More so, the availability of rangeland for livestock grazing has declined in recent decades due to the expansion of mechanized farming at the expense of natural rangelands (FAO, 2021). However, the combination of cattle production with crop cultivation, which is already happening in the study area, could be promising for overcoming the overall challenges of high costs associated with concentrate feeds and scarcity of rangelands. This is because farmers are thus able to produce improved fodder or utilize crop by-products as low-cost feed resources. In addition, farmers can incorporate available agro-industrial byproducts (e.g., oilseed cakes and molasses) into dairy concentrates produced on-farm. Commercial concentrates could be used as a last resort and only if their use is economically viable. Farmers could be encouraged to invest in feed conservation (i.e., hay and silage) to ensure adequacy of animal feed supply all year round. This necessitates the training and capacity building of farmers in terms of ration formulation and feed conservation. The training of farmers can be done by a relevant livestock development institution such as the Atbara Livestcok Research Station.

Despite Butana cattle farmers' reliance on the sale of milk as the predominant source of farm income, inadequate market facilities remain a challenge for milk marketing. Similar challenges of dairy marketing for smallholder farmers were reported from Ethiopia (Guadu and Bebaw, 2016). In most visited farms in the Butana region, surplus milk is sold at the farm gate at low prices to middlemen. Besides, farmers deliver their milk to consumers in villages or nearby markets using traditional transportation means including the use of donkeys and bicycles. A lack of efficient marketing systems substantially reduces farmers' incentives for production and results in raising their animals for subsistence rather than market-oriented production (Holloway and Ehu, 2002). Measures of overcoming the challenges associated with inadequate market facilities in the Butana region may include the establishment of dairy cooperative marketing. In India, for example, dairy cooperatives have been found to play an important role in providing a guaranteed market for milk at reasonable prices, hence alleviating rural poverty by increasing rural milk production and marketing (Anbu, 2020).

The major diseases reported by Butana cattle farmers are also endemic in many countries of Africa (Amanfu, 2009; Teodoro et al., 2020). Controlling such diseases remains a challenge in traditional production systems as smallholder farmers lack convenient access to veterinary services. In Sudan, government sponsorship for veterinary services in the country as a whole has declined in recent years, and livestock farmers in remote areas are typically excluded from public health service coverage (Wilson, 2018). Currently, veterinary services are usually provided by private sectors at high prices and mostly in urban areas, far from rural settings. Therefore, particular attention must be paid to disease control measures such as access to drugs, vaccines and veterinarians, and the adoption of sound management practices. Furthermore, training of farmers to be community-based animal health workers could be one option for providing animal health services in rural areas. Community-based animal health care has been developed to address the need for access to veterinary services in rural, and frequently pastoral communities (Leyland and Catley, 2002). Studies in Zimbabwe (Bidi et al., 2015), and Gambia (Macphillamy et al., 2020), have shown that rural community para-veterinarians can provide animal health services such as vaccination and animal treatments, overcoming the limited capacity of national veterinary services and meeting the livestock health needs of smallholder farmers in rural settings. Randolph et al. (2007) suggested that partnership between community animal health workers and professionals could be successful in affording the much-needed basic health and veterinary services to cattle in marginalized and remote communities.

The formation of farmers' associations could provide a premise for addressing the aforementioned production challenges. Through associations, farmers can form linkages that allow the allocation of essential production inputs such as access to financial assistance, market facilities, genetic improvement services, and improved animal health services (FAO, 2013; Mueller et al., 2015). However, the establishment of a functional association in a typical rural setting may require assistance from relevant livestock development organizations.

Keeping crossbred animals alongside indigenous breeds, as demonstrated in Chapter 4, is commonly observed in many other African countries (Wurzinger et al., 2006). This is because, indigenous breeds often produce relatively low amounts of milk and are considered to have limited genetic potential. Hence, rearing a few crossbred cows can boost farmers' income from the sale of milk. However, with the relatively high number of Butana cattle farmers keeping crossbred cattle and their sustained willingness to adopt crossbreeding, the Butana breed is threatened with a high risk of genetic dilution. In addition, there is concern that crossbred cattle may not always be suited in harsh environmental conditions (Chapter 2). Willingness of farmers to practice crossbreeding with exotic breeds is indicative of how a future breeding strategy for milk yield improvement must look like. Farmers' desires can simply not be ignored. Crossbreeding could be organized to satisfy farmers' needs; however, such a practice must follow appropriate breeding policies, which should ensure the carrying out of within-breed improvement programs as well. Sustainable use of the indigenous breeds may lower external inputs like feeding and health care and thus, improve the profits gained by smallholder producers in marginal areas. This will consequently contribute towards achieving sustainable food and nutrition security in Butana region. Arguments in favor of selection within indigenous breeds were summarized in Chapter 2. Raising awareness among cattle farmers and policy-makers about the uniqueness of the indigenous breeds, and importance of maintaining purity of the breeds could further promote utilization of indigenous animal genetic resources (Davis et al., 2016).

The lack of a pedigree and milk performance recoding systems as indicated by Butana cattle owners in the survey study (Chapter 4) is a common feature of smallholder dairy farming in Africa (Abdel-Salam et al., 2010). This is regarded as one of the most important constraints associated with genetic improvement programs for indigenous cattle (Chapter 2). However, such a challenge could be mitigated by the introduction of a simple animal identification, pedigree and performance recording systems for the Butana cattle farmers. In this regard, farmers could be trained on the keeping of written records, since educated farmers were more willing to adopt on-farm data recording (Chapter 4). The Atbara Livestock Research Station (Chapter

3) could play a role in training farmers through novel farmers’ associations since the majority of these farmers were willing to establish this type of associations.

In Chapter 5, a single trait reflecting milk yield was chosen as breeding goal, considering the cash from milk sale as primary source of farm revenue (Chapter 4). From an operationalization point of view, a single-trait selection scheme may be easier to execute than a multi-trait selection system, which appears to be impractical for community-based selection methods (Philipsson et al., 2006; Wurzinger et al., 2008). In addition, as the number of traits increases, genetic progress that can be made in improving any one trait slows down unless the traits are highly correlated genetically (Philipsson et al., 2011). However, simulation of a single trait as breeding goal in the current study is in sharp contrast with Oguma et al. (2004), who indicate that genetic improvement programs that focus on single traits such as milk or meat production in isolation of broader livestock system functions and constraints may result in genotypes that are not well adapted to the environment and are incapable of performing the multiple roles that livestock play in developing countries. Adaptation is also an important trait in the breeding goal for populations that are kept under harsh environments. In our study, the maintenance of adapation traits could be granted by selecting for improvement of milk production in the existing production environment. For the breeding of ruminants in the tropics, Franklin (1986) argued that if the environment in which animals are selected is the same environment in which animals will be used, then within-breed selection for maximizing production performance will allow natural selection to maintain adaptation. The decision on what trait to be improved when designing a breeding program is ideally based on the extent to which that trait reflects farmers' production objectives, considers their needs and economic interests (Duguma et al., 2010; Muller et al., 2015).

A village bull breeding program (Chapter 5) proved to be the best option among the potential breeding scenarios. Organization of such a breeding program is illustrated in Figure 12. Regardless of the selection methods, higher genetic gain under such a breeding program is attributed to higher selection intensity as fewer sires are needed. Similar results were observed in another simulation study (Mészáros et al., 2014). Using fewer bulls for breeding such as those considered in the current study is possible, however, problems with inbreeding may be encountered due to a fast narrowing of genetic base (Philipsson et al., 2011).

Currently, the endogenous breeding practices in the Butana region are mostly limited to individual herds. Practically, such breeding programs require farmers in each village to collaborate and consider their herds as one selection group from which a bull is chosen (Figure 12). This type of breeding program has been promoted as a viable approach implemented at the smallholder level where infrastructure is poor and low input production systems prevail (Rewe et al., 2009;  Haile et al., 2019; Wurzinger et al., 2021). Nonetheless, a successful implementation of a village breeding program requires some organizational regulation at the village level and strong participation of community members (Rewe et al., 2009; Mueller et al., 2015).

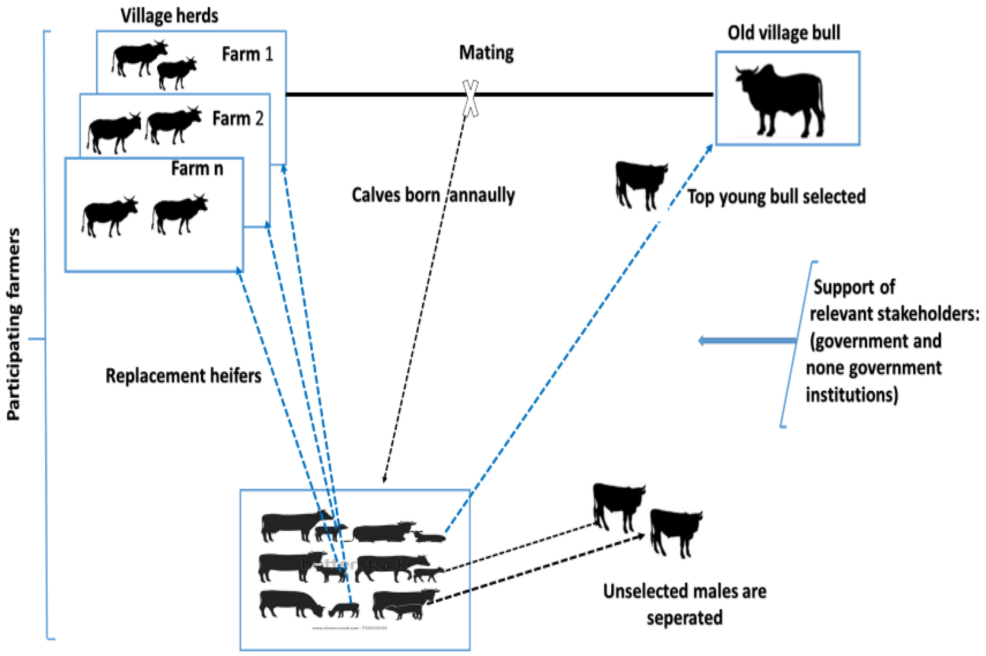

**Figure 12.** Organizational structure of a suggested village bull breeding program.

As shown in Table10, the establishment of a village bull breeding program in the Butana region may be feasible because farmers were willing to participate in/adopt specific aspects associated with Butana cattle improvement, and were also willing to engage in farmer associations. Furthermore, such breeding programs have traditionally been practiced by some farmers of Butana cattle, and the sharing of breeding bulls is widely accepted in most villages (Chapter 4). The existing traditional practice of village bull sharing could be enhanced by formally organizing farmers in cooperatives or associations. Breeding programs in the hands of farmers' cooperatives, often with the support of a relevant stakeholder such as the government and private organizations, have been successful for several livestock species around the world (Mueller et al., 2015; Leroy et al., 2017). Research organizations can provide scientific support for setting up breeding goals, conducting genetic evaluation, providing training to support genetic improvement activities (Ouédraogo et al., 2021), and for knowledge exchange between farmers and researchers (Wurzinger et al., 2011). In addition, stakeholder participation is important because cattle genetic resources are commonly managed as a common good involving private and public interests (Leroy et al., 2017).

Genetic evaluation and ranking of animals for selection is, among other aspects, the most important platform of a structured breeding program (Rewe et al., 2009). Selection based on estimated breeding values of young bulls was shown to generate higher genetic gain compared to phenotypic selection. This observation is consistent with results from other simulation studies (Verrier et al., 1993; Lewis et al., 2000; Sonesson et al., 2005). The higher genetic gain was the result of higher accuracy of selection based on estimated breeding values compared to phenotypic selection (Oldenbroek and van der Waaij, 2015).

Several studies about the advantages of young bull selection in the tropics can be found in literature. For instance, Syrstad et al. (1998) observed that in the tropics, such a selection method is much better than progeny testing in achieving faster genetic progress due to a lower generation interval. Zumbach and Peters (2002) reported that selecting young bulls based on dam's milk yield performance is practically simple, and less expensive, making it suitable for livestock breeding programs in the tropics. Furthermore, Gandini et al. (2013) indicated that a young bull scheme could be easily implemented in local breeds, including those with rather small herd sizes.

Interestingly, Butana cattle farmers already practice the selection of bulls based on bull dam’s milk yield performance (Chapter 4). Enhancing such selection practices by introducing a simple animal identification system and performance recording in village herds are important prerequisites for effective decision making regarding selection and breeding policies (Kahi et al., 2005; Kosgey and Okeyo, 2007).

Within a village, participating farmers, particularly those who keep the best females, are expected to present their available young male candidates for selection. Farmers' representatives and livestock development research station personnel could form a commission responsible for selecting young bulls based on relevant recorded data i.e., bull dam’s milk yield performance, and pedigree information. Rules and regulations such as exchanging village bulls after a predetermined period, must be made in order for the participating farmers to use the selected bulls effectively. The success of such arrangements will be determined by disease-control measures, the recognition and appreciation of superior bulls, and farmers' willingness to use them (Kosgey et al., 2006). The selected bulls could be used to mate the village herds for 3 years before being replaced by a young bull. For breeding purposes and to alleviate the challenges of utilizing a single bull in a large herd (Chapter 5), the number of young bulls selected should be determined by the number of cows in a village, and a bull to cow ratio of 1: 30 could be applied. Unselected bulls could be culled from individual herds by selling, castrating or keeping them separately to control mating (Figure 12). However, the level of controlled breeding and genetic gain achievable would be harmed if participants fail to comply with the set rules (Gizaw et al., 2014).

In the long term, as farmers would be more organized, single village herds in each administrative unit could be merged to form one selection group at the regional level. This would enable the selection of superior bulls from larger herds, resulting in higher selection intensity, hence, higher genetic gain in the entire population (Powell et al., 2003). However, further studies are needed to determine the optimum numbers of cows for village bull breeding programs that optimizes genetic gain with acceptable rate of inbreeding.

Artificial insemination (AI) stations in village settings can be established where resources allow for, and these services can be used as a complement or alternative method to the natural system of bull mating. Several studies have demonstrated that the utilization of reproductive technologies such as AI could achieve increased genetic gain due to increasing the selection intensity in males used as sires (Abdel-Salam et al., 2010; Sørensen et al., 2011). Furthermore, the use of AI would contribute to the control or eradication of diseases that can be transmitted in natural mating systems (Phillipson et al., 2011). More importantly, using AI gives farmers the opportunity to use a superior village bull’s semen without having to keep or transport the live bull within herds. However, adoption of AI services in rural villages utilizing frozen sperm may be possible only if the necessary infrastructure is put in place.

## 6.1 Conclusions

Findings of this study will aid in the development of a practical village bull breeding program to improve Butana cattle in Central Sudan. They could also serve as a model for developing breeding programs for other local breeds kept in similar production environments across the country. However, implementation of such a breeding program requires the full involvement of farmers in the planning process. The production constraints and the poor infrastructural setting that were identified in the Butana region must be considered when planning and implementing a long-term breeding program for Butana cattle improvement. Introduction of breeder's associations and activities with the support of government authorities are needed. The optimal herd number within a village that would result in increased genetic gains with the lowest risk of inbreeding was not quantified in this study. This is an area that needs to be researched further.

## References

Abdel Gader, A.Z., Ahmed, M.K.A., Musa, L.M.A., Peters, K.J., 2007. Milk yield and reproductive performance of Friesian cows under Sudan tropical conditions. Arch. Tierz. 50, 155–164. https://doi.org/10.5194/aab-50-155-2007.

Abdel-Salam, S.A., Sayed, A.I., Elsayed, M., Abou-Bakr, S., 2010. Genetic gain in open nucleus breeding scheme to improve milk production in Egyptian buffalo. Livest. Sci. 131, 162–167. https://doi.org/10.1016/j.livsci.2010.03.013.

Abegaz, S., Sölkner, J., Gizaw, S., Dessie, T., Haile, A., Mirkena, T., Getachew, T., Wurzinger, M., 2014. Optimizing alternative schemes of community-based breeding programs for two Ethiopian goat breeds. Acta. Agr. Kapso. 18, 47–55.

Afras, A.A., 2019. Review on breeding objectives and practices of dairy cattle production in Ethiopia. J. Cell Anim. Biol. 13, 1–7. https://doi.org/10.5897/jcab2018.0457.

Ahmed, M.K.A., Teirab, A.B., Musa, L.M.A., Peters, K.J., 2007. Milk production and reproduction traits of different grades of zebu x Friesian crossbreds under semi-arid. conditions. Arch. Tierz. 50, 240–249. https://doi.org/10.5194/aab-50-240-2007.

Ahmed, S.K., Rahman, A.H., Hassan, M.A., Salih, S.E.M., Paone, M., Cecchi, G., 2016. An atlas of tsetse and bovine trypanosomosis in Sudan. ParasitVectors. 9, 1–8. https://doi.org/10.1186/s13071-016-1485-6.

Ahmed, A.S., Rahmatalla, S., Bortfeldt, R., Arends, D., Reissmann, M., Brockmann, G.A., 2017. Milk protein polymorphisms and casein haplotypes in Butana cattle. J. Appl. Genet. 58, 261–271. https://doi.org/10.1007/s13353-016-0381-2.

Ageeb, A.G., Hayes, J.F., 2000. Genetic and environmental effects on the productivity of Holstein-Friesian cattle under the climatic conditions of Central Sudan. Trop. Anim. Health Prod.32, 33–49. https://doi.org/10.1023/A:1005241002743.

Ali ,T.E., Ahmed, F.A., Ombabi, Y.A., 1988. Productivity of crossbred zebu cattle with different levels of Friesian blood. Sudan J. Anim. Prod. 2, 69-78.

Amanfu, W., 2009. Contagious bovine pleuropneumonia (lungsickness ) in Africa. Onderstepoort J. Vet. Res. 13–17.

Amasaib, E.O., Fadel-Elseed, A.M., Mahala, A.G., Fadlelmoula, A.A., 2011. Seasonal and parity effects on some performance and reproductive characteristics of crossbred dairy cows raised under tropical conditions of the Sudan. Livest. Res. Rural Dev. 23,1-6

Amimo, J.O., Wakhungu, J.W., Inyangala, B.O., Mosi, R.O., 2007. The effects of non-genetic factors and estimation of genetic and phenotypic parameters and trends for milk yield in Ayrshire cattle in Kenya. Livest. Res. Rural Dev. 19, 1–7.

Anbu, S., 2020. Dairy cooperatives and dairy development in India. Pages 428-440 in: Non-farm Sector and Rural Development. Novel Corporation, Chennai, India.

Andrabi, S. M. H., Moran, C., 2007. The selection of dairy bulls for artificial insemination. Int. J. Agric. Biol. 9, 175–178. doi:10.1017/S0003356100029202.

Annen, E.L., Collier, R.J., Mcguire, M.A., Vicini, J.L., 2004. Effects of dry period length on milk yield and mammary epithelial Cells. J. Dairy Sci. 87, 66–76. https://doi.org/10.3168/jds.S0022-0302(04)70062-4.

AU-IBAR., 2019. Indignous cattle. Pages 1-11 in Kenya Livestock Breeds Catalogue. African Union-Inter-African Bureau for Animal Resources. Nairobi, Kenya

Ayalew, H., Chanie, D., 2018. Review on productive and reproductive performance of indigenous dairy cattle breeds under farmer’s management practices in Ethiopia. Online J. Anim. Feed Res. 8, 169–174.

Aynalem, H., Ayalew, W., Kebede, N., Dessie, T., Tegegn, A., 2011. Breeding strategy to improve Ethiopian Boran cattle for meat and milk production. IPMS (improving productivity and market success) of Ethiopain farmers project ,working paper no 26 pages, 1-46. ILRI (International Livetsock Research Institute), Nairobi, Kenya.

Babiker, I.A., 2015. Animal feed industry in Sudan, current status, problems and prospects. J. Dairy, Vet. Anim. Res. 2, 83–84. https://doi.org/10.15406/jdvar.2015.02.00036.

Badri, M., Atta, M., Ibrahim, T.M., Gubartalla, K.A., 2011. Genetic and non-genetic factors affecting production potential of Butana dairy cows at Atbara Research Station, Sudan. Reserach Opin. Anim. Vet. Sci. 1, 429–433.

Bahbahani, H., Salim, B., Almathen, F., Enezi, F. Al., Mwacharo, J.M., Hanotte, O., 2018. Signatures of positive selection in African Butana and Kenana dairy zebu cattle. PLoS One 13, 1–20. https://doi.org/10.1371/journal.pone.0190446.

Bajwa, I.R., Khan, M.S., Khan, M.A., Gondal, K.Z., 2004. Environmental factors affecting milk yield and lactation length in Sahiwal cattle. Pakistan Vet. J. 24, 23-27

Bazzoli, I., Marchi, M. De, Cecchinato, A., Berry, D.P., Bittante, G., 2014. Factors associated with age at slaughter and carcass weight , price , and value of dairy cull cows. J. Dairy Sci. 97, 1082–1091. https://doi.org/10.3168/jds.2013-6578.

Bebe, B.O., Udo, H.M.J., Rowlands, G.J., Thorpe, W., 2003. Smallholder dairy systems in the Kenya highlands: Cattle population dynamics under increasing intensification. Livest. Prod. Sci. 82, 211–221. https://doi.org/10.1016/S0301-6226(03)00013-7.

Behnke, R., Osman, H.M., 2016. The Contribution of Livestock to the Sudanese Economy. IGAD Livestock Policy Initiative 2, GAD LPI Working Paper No. 01 - 12 (odessa center).

Bett, R.C., Okeyo, M.A., Malmfors, B., Johansson, K., Agaba, M., Kugonza, D.R., Bhuiyan, A.K.F.H., Vercesi Filho, A.E., Mariante, A.S., Mujibi, F.D., Philipsson, J., 2013. Cattle breeds: Extinction or quasi-extant? Resources 2, 335–357. https://doi.org/10.3390/resources2030335.

Bidi , N . T ., Dube , A . B ., Khombe , C . T ., Assan, N., 2015. Community based small scale commercial cattle breeding program in Mangwe district of Zimbabwe. Agric. Adv. 4, 22–33. https://doi.org/10.14196/aa.v4i3.1845.

Bijma, P., Van Arendonk, J.A.M., Woolliams, J.A., 2001. Predicting rates of inbreeding for livestock improvement schemes. J. Anim. Sci. 79, 840–853. doi:10.2527/2001.794840x.

Bingi, S., Tondel, F., 2015. Recent developments in the dairy sector in Eastern Africa. Briefing note of the European Centre for Development Policy Management, 78, 19.

Biscarini, F., Nicolazzi, E., Alessandra, S., Boettcher, P., Gandini, G., 2015. Challenges and opportunities in genetic improvement of local livestock breeds. Front. Genet. 5, 1–16. https://doi.org/10.3389/fgene.2015.00033.

Bondoc, O.L., Smith, C., 1993. Deterministic genetic analysis of open nucleus breeding schemes for dairy cattle in developing countries. J. Anim. Breed. Genet. 110, 194–208.

Brito, L.C., Gabriela, M., Diniz, C., Carrara, E.R., Fonseca, F., Ventura, H.T., Angelo, F., Bruneli, T., Lopes, P.S., 2020. Genetic parameters for milk , growth , and reproductive traits in Guzerá cattle under tropical conditions. Trop. Anim. Health Prod. 52, 2251–2257.

Buch, L.H., Sørensen, A.C., Lassen, J., Berg, P., Christensen, L.G., Sørensen, M.K., 2009. Factors affecting the exchange of genetic material between Nordic and US Holstein populations. J. Dairy Sci. 92, 4023–4034. https://doi.org/10.3168/jds.2008-1541.

Bujko, J., Candrák, J., Strapák, P., Žitný, J., Hrn, C., 2013. The Associations between calving interval and milk production traits in population of dairy cows of Slovak Simmental cattle. Anim. Sci. Biotechnol. 42, 53–57.

Canaza-Cayo, A.W., Lopes, P.S., Cobuci, J.A., Martins, M.F., da Silva, M.V.G.B., 2018. Genetic parameters of milk production and reproduction traits of Girolando cattle in Brazil. Ital. J. Anim. Sci. 17, 22–30. https://doi.org/10.1080/1828051X.2017.1335180.

Cervantes, I., Gutiérrez, J.P., Meuwissen, T.H.E., 2016. Response to selection while maximizing genetic variance in small populations. Genet. Sel. Evol. 48, 1–9. https://doi.org/10.1186/s12711-016-0248-3.

Chawala, A.R., Banos, G., Peters, A., Chagunda, M.G.G., 2019. Farmer-preferred traits in smallholder dairy farming systems in Tanzania. Trop. Anim. Health Prod. 51, 1337–1344. https://doi.org/10.1007/s11250-018-01796-9.

Chawala, A.R., Banos, G., Komwihangilo, D.M., Peters, A., Chagunda, M.G.G., 2017. Phenotypic and genetic parameters for selected production and reproduction traits of Mpwapwa cattle in low-input production systems. South. Afr. J. Anim. Sci. 47, 307-319. https://doi.org/10.4314/sajas.v47i3.7.

Chebo, C., Alemayehu, K., 2012. Trends of cattle genetic improvement programs in Ethiopia: Challenges and opportunities. Livest. Res. Rural Dev. 24, 1–17.

Chen, G.K., Marjoram, P., Wall, J.D., 2009. Fast and flexible simulation of DNA sequence data. Genome Res. 19, 136–142. https://doi.org/10.1101/gr.083634.108.

Davis, K.E.,Terblanché, S.E., 2016 Challenges facing the agricultural extension landscape in South Africa, Quo Vadis? South. Afr. J. Agric. Ext. 44, 231–24.

DeLay, N.D., Thumbi, S.M., Vanderford, J., Otiang, E., Ochieng, L., Njenga, M.K., Palmer, G.H., Marsh, T.L., 2020. Linking calving intervals to milk production and household nutrition in Kenya. Food Sec. 12, 309-325. https://doi.org/10.1007/s12571-019-01006-w.

Demeke, S., Neser, F.W.C., Schoeman, S.J., Erasmus, G.J., Wyk, J.B., Van Gebrewolde, A., 2003. Crossbreeding Holstein-Friesian with Ethiopian Boran cattle in a tropical highland environment : preliminary estimates of additive and heterotic effects on milk production traits. S. Afr. J. Anim. Sci. 30, 32–33.

Duguma, G., Mirkena, T., Haile, A.L.I., 2010. Participatory approaches to investigate breeding objectives of livestock keepers. Livest. Res. Rural Dev. 22, 64.

Eastham, N.T., Coates, A., Cripps, P., Richardson, H., Smith, R., Oikonomou, G., 2018. Associations between age at first calving and subsequent lactation performance in UK Holstein and Holstein-Friesian dairy cows. PLoS One. 13, 1–13. https://doi.org/10.1371/journal.pone.0197764.

Ebbert, D., 2019. Chisq. posthoc. test: a post hoc analysis for Pearson's chi-squared test for count data. R Package Vers. 0.1 2.

Epaphras, A., Karimuribo, E.D., Msellem, S.N., 2004. Effect of season and parity on lactation of crossbred Ayrshire cows reared under coastal tropical climate in Tanzania. Livets. Res. Rural Dev. 166, 42-46.

Elhag, M., Walker, S., 2009. Impact of climate variability on vegetative cover in the Butana area of Sudan. Afr. J. Ecol. 47, 11–16. https://doi.org/10.1111/j.1365-2028.2008.01044.x.

Elemam, M.B., Abu Nekheila, A.M., 2012. Some productive traits of crossbred dairy cows in the farm of University of Khartoum, Sudan. Emirates J. Food Agric. 24, 155–158.

Fadlelmoula, A.A., Abu-Nikhaila, A.M.,Yousif, I.A., 2007. Lactation performance of crossbred dairy cows in the Sudan. Res. J. Agri. Biol.Sci. 5, 389-393.

FAO, 2021. Special Report – 2020/21 FAO Crop and Food Supply Assessment Mission (CFSAM) to the Republic of the Sudan. Rome. https://doi.org/10.4060/cb4159en.

FAO, 2020. Special Report - 2019 FAO Crop and Food Supply Assessment Mission to the Sudan. FAO Rome, Italy. https://doi.org/10.4060/ca7787en.

FAO, 2019. FAO Crop and Food Supply Assessment Mission to the Sudan – Special Report. Rome, Italy.

FAO, 2016. The State of Sudan's Biodiversity for Food and Agriculture : Country Reports 113.

FAO, 2015. The Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture, edited by B.D. Scherf & D. Pilling. FAO Commission on Genetic Resources for Food and Agriculture Assessments. Rome, Italy (available at http://www.fao.org/3/a-i4787e). Accessed 1 Apr 2020.

FAO, 2013. In vivo conservation of animal genetic resources. FAO Animal Production and Health Guidelines. No. 14. Rome, Italy.

FAO, 2010. Breeding strategies for sustainable management of animal genetic resources. Rome. Italy (available at www.fao.org/ docrep/012/i1103e/i1103e00.htm).

FAO, 2007. The state of the world's animal genetic resources for food and agriculture, edited by Rischkowsky, B. and Pilling, D. Rome. Italy. https://www.fao.org/3/a1260e/a1260e00.htm.

Franklin,I.R., 1986. Breeding ruminants for the tropics. Proceedings of the 3rd World Congress on Genetics Applied to Livestock Production, Vol. XI. Genetics of reproduction, lactation, growth, adaptation, disease, and parasite resistance. pp. 451–461.

Froidmont, E., Mayeres, P., Picron, P., Turlot, A., Planchon, V., Stilmant, D., 2013. Association between age at first calving, year and season of first calving and milk production in Holstein cows. Animal 7, 665–672. https://doi.org/10.1017/S1751731112001577.

Galukande, E., Mulindwa, H., Wurzinger, M., Roschinsky, R., Mwai, A.O., Sölkner, J., 2013. Cross-breeding cattle for milk production in the tropics: achievements, challenges and opportunities. Anim. Genet. Res. 52, 111–125. https://doi.org/10.1017/s2078633612000471.

Gandini, G., Stella, A., Del Corvo, M., Jansen, G.B., 2014. Selection with inbreeding control in simulated young bull schemes for local dairy cattle breeds. J. Dairy Sci. 97, 1790–1798. https://doi.org/10.3168/jds.2013-7184.

Gaynor, C., Gorjan, G., Wilson, D., Daniel, M., Hickey, J., 2019. Al-phaSimR: Breeding program simulations. Accessed Mar. 20, 2020.https://cran.microsoft.com/snapshot/2019-10-20/web/packages/AlphaSimR/index.html.

Gemeda, D., 2010. Participatory definition of breeding objectives and implementation of community based sheep breeding programs in Ethiopia Gemeda Duguma Jaleta Participatory definition of breeding objectives and implementation of community based sheep breeding program, in: PhD Thesis. University of Natural Resources and Life Sciences, Vienna, Austria.

Getachew, T., Haile, A., Tibbo, M., Sharma, A.K., Sölkner, J., Wurzinger, M., 2010. Herd management and breeding practices of sheepowners in a mixed crop-livestock and a pastoral system of Ethiopia. African J. Agric. Res. 5, 685–691. https://doi.org/10.5897/AJAR10.392.

Gichohi, P.M., 2019. The role of record keeping and maintenance in enhancing decision making among smallholder dairy farmers in Gitugi Ward in Murang'a County, Kenya. Inf. Dev. 36, 535–545. https://doi.org/10.1177/0266666919879728.

Gizaw, S., Getachew, T., Goshme, S., Valle-Zárate, A., Van Arendonk, J.A.M., Kemp, S., Mwai, .O., Dessie, T., 2014. Efficiency of selection for body weight in a cooperative village breeding program of Menz sheep under smallholder farming system. Animal 8, 1249–1254. https://doi.org/10.1017/S1751731113002024.

Gizaw, S., Komen, H., van Arendonk, J.A.M., 2009. Optimal village breeding schemes under smallholder sheep farming systems. Livest. Sci. 124, 82–88. https://doi.org/10.1016/j.livsci.2009.01.001.

Gorjanc, G., Bijma, P., Hickey, J.M., 2015. Reliability of pedigree-based and genomic evaluations in selected populations. Genet. Sel. Evol. 47, 1-15. https://doi.org/10.1186/s12711-015-0145-1.

Grimaud, P., Mpairwe, D., Chalimbaud, J., Messad, S. Faye, B., 2007. The place of Sanga cattle in dairy production in Uganda. Trop. Anim. Health. Prod. 39, 217-227.

Habtamu, A., Solomon, A., Yoseph, M., 2012. Influence of non-genetic factors on growth traits of Horro (Zebu) and their crosses with Holstein Friesian and Jersey cattle. Int. J. Livest. Prod. 3, 72–77. https://doi.org/10.5897/ijlp11.015.

Haile, A., Getachew, T., Mirkena, T., Duguma, G., Gizaw, S., Wurzinger, M., Soelkner, J., Mwai, O., Dessie, T., Abebe, A., Abate, Z., Jembere, T., Rekik, M., Lobo, R.N.B., Mwacharo, J.M., Terfa, Z.G., Kassie, G.T., Mueller, J.P., Rischkowsky, B., 2020. Community-based sheep breeding programs generated substantial genetic gains and socioeconomic benefits. Animal 14, 1362–1370. https://doi.org/10.1017/S1751731120000269.

Haile, A., Gizaw, S., Getachew, T., Mueller, J.P., Amer, P., Rekik, M., Rischkowsky, B., 2019.

Community-based breeding programmes are a viable solution for Ethiopian small ruminant genetic improvement but require public and private investments. J. Anim. Breed. Genet. 136, 319–328. https://doi.org/10.1111/jbg.12401.

Haile, A., Joshi, B.K., Ayalew, W., Tegegne, A., Singh, A., 2011a. Genetic evaluation of Ethiopian Boran cattle and their crosses with Holstein Friesian for growth performance in central Ethiopia. J. Anim. Breed. Genet. 128, 133–140. https://doi.org/10.1111/j.1439-0388.2010.00882.x.

Haile, A., Ayalew, W., Kebede, N., Dessie, T., Tegegne, A., 2011b. Breeding strategy to improve Ethiopian Boran cattle for meat and milk production. IPMS (Improving Productivity and Market Success) of Ethiopian Farmers Project Working Paper 26. Nairobi, Kenya, ILRI.

Haile, A., Joshi, B.K., Ayalew, W., Tegegne, A., Singh, A., 2009. Genetic evaluation of Ethiopian Boran cattle and their crosses with Holstein Friesian in central Ethiopia: Milk production traits. Animal 3, 486–493. https://doi.org/10.1017/S1751731108003868.

Hassan, S.A., Abdelaziz, H.H., Ibrahim, A.H., Mohamed Musa, K.S., 2019. Milk production forecasting in Khartoum state , Sudan. J. Agric. Res. 4, 6–13.

Henrique, C., Malhado, M., Claudia, A., Malhado, M., Amorim, A. De, Luiz, P., Carneiro, S., Souza, J.C. De, Pala, A., 2013. Genetic parameters for milk yield , lactation length and calving intervals of Murrah buffaloes from Brazil. Rev. Bras. Zootec. 42, 565–569.

Herrero, M., Thornton, P.K., Notenbaert, A.M., Wood, S., Msangi, S., Freeman, H.A., Bossio, D., Dixon, J., Peters, M., van de Steeg, J., Lynam, J., Parthasarathy, Rao. P., Macmillan, S., Gerard, B., McDermott, J., Seré, C., Rosegrant, M., 2010. Smart investments in sustainable food production: revisiting mixed crop-livestock systems. Science 327, 822–825.

Hoffmann, I., Scherf, B., 2006. Animal genetic resources -time to worry? In: Livestock report. Food and Agricultural Organization of the United Nations, Rome, Italy, 57–76. https://www.fao.org/3/a0255e/a0255e.pdf

Holloway, G., Ehui, S., 2002. Expanding Market Participation among Smallholder Livestock Producers: ACollection of Studies Employing Gibbs Sampling and Data from the Ethiopian Highlands, Socioeconomics and Policy Research Working Paper 48, International Livestock Research Institute,Nairobi.

Hossain, S.M.J., Afroz, M.F., Bhuiyan, A., Habib, M.A., 2018. Milk production performance of Red Chittagong cattle based on phenotypic and genetic parameters. Glob. Adv. Res. J. Agric. Sci. 7, 110–117.

Hossein-Zadeh, N.G., 2011. Estimation of genetic and phenotypic relationships between age at first calving and productive performance in Iranian Holsteins. Trop Anim Health Prod. 43, 967–973. https://doi.org/10.1007/s11250-011-9791-7.

Hossein-Zadeh, N.G., 2013. Factors affecting lactation length and effect of current lactation length on the subsequent production and reproduction in Iranian Holsteins. Arch. Anim. Breed. 56, 873–881. https://doi.org/10.7482/0003-9438-56-087.

Ibeagha-Awemu, E.M., Peters, S.O., Bemji, M.N., Adeleke, M.A., Duy, N., 2019. Leveraging available resources and stakeholder involvement for improved productivity of African livestock in the era of genomic breeding. Front. Genet. 10, 1-21 https://doi.org/10.3389/fgene.2019.00357.

IBM SPSS., 2011. IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.

Ibrahim, H.A., Abdel-Aziz, A. M., Salah-Eldein, S.A., Ahmed, S.A., Mohammed, S.H., 2015. Phenotypic and genetic characterization of Fuga cattle breed based on the analysis of microsatellites markers. Int. J. Pharm. Res. Anal. 5, 46–51.

Ilatsia, E.D., Muasya, T.K., Muhuyi, W.B., Kahi, A.K., 2007. Milk production and reproductive performance of Sahiwal cattle in semi-arid Kenya. Trop. Sci. 47, 120–127.

Ilatsia, E.D., Roessler, R., Kahi, A.K., Piepho, H.P., Zarate, A.V., 2011. Evaluation of basic and alternative breeding programs for Sahiwal cattle genetic resources in Kenya. Anim Prod. Sci. 51, 682–694.

Ilatsia, E.D., Roessler, R., Kahi, A.K., Piepho, H.P., Zárate, V., 2012. Production objectives and breeding goals of Sahiwal cattle keepers in Kenya and implications for a breeding programme. Trop. Anim. Health Prod. 44, 519–530. https://doi.org/10.1007/s11250-011-9928-8.

Kahi, A.K., 2002. Crossbreeding systems and appropriate levels of exotic blood: Examples from Kilifi Plantations. AGTR (Animal Genetic Training Resources) case study. pp. 1–10. ILRI (International Livestock Research Institue), Nairobi, Kenya. https://hdl.handle.net/10568/3578

Kahi, A.K., Nitter, G., Gall, C.F., 2004. Developing breeding schemes for pasture based dairy production systems in Kenya: II. Evaluation of alternative objectives and schemes using a two-tier open nucleus and young bull system. Livest. Prod. Sci. 88, 179–192. https://doi.org/10.1016/j.livprodsci.2003.07.015.

Kahi, A.K., Rewe, T.O., Kosgey, I.S., 2005. Sustainable community-based organizations for the genetic improvement of livestock in developing countries. Outlook Agric. 34, 261–270. https://doi.org/10.5367/000000005775454706.

Kambal, S., Abdelrahim, A.E., Hanotte, O., Nakao, R., Alkhaibari, A.M., Salim, B., 2021. Demographic expansion and high level of matrilineal diversity in two populations of East African Baggara cattle. J Anim. Breed Genet.139,161–169.https://doi.org/10.1111/jbg.12648.

Kariuki, C.M., Komen, H., Kahi, A.K., van Arendonk, J.A.M., 2014. Optimizing the design of small-sized nucleus breeding programs for dairy cattle with minimal performance recording. J. Dairy Sci. 97, 7963–7974. https://doi.org/10.3168/jds.2014-8545

Karnuah, A.B., Dunga, G., Rewe, T., 2018. Community based breeding program for improve goat production in Liberia. MOJ Curr. Res. Rev. 1, 216–221. https://doi.org/10.15406/mojcrr.2018.01.00036.

Kasinathan, P., Wei, H., Xiang, T., Molina, J.A., Metzger, J., Broek, D., Kasinathan, S., Faber, D.C., Allan, M.F., 2015. Acceleration of genetic gain in cattle by reduction of generation interval. Sci. Rep. 5, 5–8. https://doi.org/10.1038/srep08674.

Kharti, P., Bakhsh, B., Samro,U., 2004. Productive Performance of Red Sindhi Cattle. J. Anim. Vet. Adv. 3, 353–355.

Kok, A., Van Middelaar, C.E., Mostert, P.F., Van Knegsel, A.T.M., Kemp, B., De Boer, I.J.M., Hogeveen, H., 2017. Effects of dry period length on production, cash flows and greenhouse gas emissions of the dairy herd: A dynamic stochastic simulation model. PLoS One. 12, 1–21. https://doi.org/10.1371/journal.pone.0187101.

Krpálková, L., Cabrera, V.E., Vacek, M., Štípková, M., Stádník, L., Crump, P., 2014. Effect of prepubertal and postpubertal growth and age at first calving on production and reproduction traits during the first 3 lactations in Holstein dairy cattle. J. Dairy Sci. 97, 3017–3027. https://doi.org/10.3168/jds.2013-7419.

Kosgey, I.S., Baker, R.L., Udo, H.M.J., Van Arendonk, J.A.M., 2006. Successes and failures of small ruminant breeding programmes in the tropics: A review. Small Rumin. Res. 61, 13–28. https://doi.org/10.1016/j.smallrumres.2005.01.003.

Kosgey, I.S., Okeyo, A.M., 2007. Genetic improvement of small ruminants in low-input, smallholder production systems: Technical and infrastructural issues. Small Rumin. Res. 70, 76–88. https://doi.org/10.1016/j.smallrumres.2007.01.007.

Leroy, G., Baumung, R., Boettcher, P., Scherf, B., Hoffmann, I., 2015. Review: Sustainability of crossbreeding in developing countries; definitely not like crossing a meadow. Animal, 10, 262–273. https://doi.org/10.1017/S175173111500213X.

Lewis, R.M., Simm, G., 2000. Selection strategies in sire referencing schemes in sheep. Livest. Prod Sci. 67,129-141.

Leyland, T., Catley, A., 2003. Community-based animal health delivery systems: improving the quality of veterinary service delivery. Proceedings of the World Veterinary Congress, Tunisia, September 27-28, 2003, pp. 129-144.

Lukuyu, B., Franzel, S., Mudavadi, P.O., 2011. Livestock feed resources : Current production and management practices in central and northern rift valley provinces of Kenya. Livest. Res. Rural Dev. 5, 1-18.

Lukuyu, M.N., Gibson, J.P., Savage, D.B., Rao, E.J.O., Ndiwa, N., Duncan, A.J., 2019. Farmers' perceptions of dairy cattle breeds, breeding and feeding strategies: A case of smallholder dairy farmers in Western Kenya. East African Agric. For. J. 83, 351–367. https://doi.org/10.1080/00128325.2019.1659215.

Madalena, F.E., 1988. A note on the effect of variation of lactation length on the efficiency of tropical cattle selection for milk yield. Theor. Appl. Genet. 76, 830–834. https://doi.org/10.1007/BF00273667.

Macphillamy, I., Young, J., Siek, S., Bun, C., Suon, S., Peter, J.T., Russell, W., 2020. Improving village animal health worker participation in national disease surveillance systems : A case study from Cambodia. Transbound. Emerg. Dis. 60, 967–978. https://doi.org/10.1111/tbed.13432.

MacLeod, I.M., Larkin, D.M., Lewin, H.A., Hayes, B.J., Goddard, M.E., 2013. Inferring demography from runs of homozygosity in whole-genome sequence, with correction for sequence errors. Mol. Biol. Evol. 30, 2209–2223. https://doi.org/10.1093/molbev/mst125.

Makina, S.O., Muchadeyi, F.C., Marle-Köster, E. Van, Macneil, M.D., Juan, R., Cantet, C., 2014. Genetic diversity and population structure among six cattle breeds in South Africa using a whole genome SNP panel. Front. Genet. 5, 1–7. https://doi.org/10.3389/fgene.2014.00333.

Malhado, C.H.M., Malhado, A.C.M., Carneiro, P.L.S., Ramos, A.A., Ambrosini, D.P., Pala, A., 2012. Population structure and genetic variability in the Murrah dairy breed of water buffalo in Brazil accessed via pedigree analysis. Trop. Anim Health. Prod. 44,1891-1897.

Mandefro, A., Duguma, G., Mirkena, T., Dadi, H., 2017. Evaluation of alternative breeding plans for two indigenous cattle breeds of Ethiopia. Livest. Sci. 205, 122–128. https://doi.org/10.1016/j.livsci.2017.09.022.

Mapiye, C., Chikwanha, O.C., Chimonyo, M., Dzama, K., 2019. Strategies for sustainable use of indigenous cattle genetic resources in Southern Africa. Diversity 11, 1–14. https://doi.org/10.3390/d11110214.

Marshall, K., Quiros-Campos, C., Van der Werf, J.H.J., Kinghorn, B., 2011. Marker- based selection within smallholder production systems in developing countries. Livest Sci. 136, 45–54.

Manzi, M., Rydhmer, L., Ntawubizi, M.,D'Andre Hirwa, C., Karege, C., Strandberg, E., 2020. Milk production and lactation length in Ankole cattle and Ankole crossbreds in Rwanda. Trop. Anim. Health Prod. 52, 2937–2943. https://doi.org/10.1007/s11250-020-02311-9.

Mészáros, R.K.G., Kadlečík, O., Hazuchová, E., Šidlová, V., Pavlík, I., 2014. Influence of mating systems and selection intensity on the extent of inbreeding and genetic gain in the Slovak Pinzgau cattle. Czech J. Anim. Sci. 59, 219-226.

Marshall, K., Gibson, J.P., Mwai, O., Mwacharo, J.M., Haile, A., Getachew, T., Mrode, R., Kemp, S.J., 2019. Livestock genomics for developing countries - African examples in practice. Front. Genet. 10, 1–13. https://doi.org/10.3389/fgene.2019.00297.

McDermott, J.J., Staal, S.J., Freeman, H.A., Herrero, M., Van de Steeg, J.A., 2010. Sustaining intensification of smallholder livestock systems in the tropics. Livest. Sci. 130, 95–109. https://doi.org/10.1016/j.livsci.2010.02.014.

Msanga, Y.N., Bryant, M.J., Rutam, I.B., Minja, F.N., Zylstra, L., 2000. Effect of environmental factors and of the proportion of Holstein blood on the milk yield and lactation length of crossbred dairy cattle on smallholder farms in north-east Tanzania. Trop. Anim. Health Prod. 32, 23–31. https://doi.org/10.1023/A:1005288918672.

Montaldo, H.H., Trejo, C., Lizana, C., 2017. Genetic parameters for milk yield and reproduction traits in the Chilean Dairy Overo Colorado cattle breed. Cienc. e Investig. Agrar. 44, 24–34. https://doi.org/10.7764/rcia.v44i1.1562.

Mohammed, S.A., Rahamtalla, S., Ahmed, S.S., Ishag, I.A., Dousa, B.M., Ahmed, M.K.A., 2014. Smallholder dairy production systems of Kenana and Butana cattle in Sudan. Wayamba J. Anim. Sci. 6, 992–997.

Mucha, S., Komen, H., 2016. Rates of inbreeding and genetic adaptation for populations managed as herds in zoos with a rotational mating system or with optimized contribution of parents. J. Anim. Breed. Genet. 133, 323–332. https://doi.org/10.1111/jbg.12188.

Mrode, R.A., 1988. Lactation performance of the White Fulani cattle in Southern Nigeria. Trop. Anim. Health Prod. 20, 149–154. https://doi.org/10.1007/BF02240083.

Mueller, J.P., Rischkowsky, B., Haile, A., Philipsson, J., Mwai, O., Besbes, B., Valle Zárate, A., Tibbo, M., Mirkena,T., Duguma, G., Sölkner, J., Wurzinger, M., 2015. Community-based livestock breeding programmes: Essentials and examples. J. Anim. Breed. Genet. 132, 155–168. doi:10.1111/jbg.12136.

Muasya, T.K., Kariuki, J.N., Muia, J.M.K., 2011. Population structure of the Sahiwal breed in Kenya. Livest. Res. Rural Dev.23.http://www.lrrd.org/lrrd23/9/muas23186.htm.

Muhuyi, W.B., Lokwaleput, I., Ole Sinkeet, S.N., 1999. Conservation and utilisation of the Sahiwal cattle in Kenya. Anim. Genet. Resour. Inf. 26, 35–44. https://doi.org/10.1017/s1014233900001176.

Muluye, M., Alemayahu, K., Gizaw, S., 2017. Milk production performances of local and crossbred dairy cows in West Gojam Zone, Amhara Region, Ethiopia. J. App. Anim. Sci. 10, 35-46.

Mundan, D., Zonturlu, A.K., Öztürk, Y., Akkuş, T., Kaçar, C., 2020. Effect of calving season, calving year and lactation number on the milk yield traits in Holstein cows raising in Şanlıurfa. Turkish

J. Agric. Food Sci. Technol. 8, 313. https://doi.org/10.24925/turjaf.v8i2.313-317.3011.

Musa, L.M.-A., Bett, R.C., Ahmed, M.-K.A., Peters, K.J., 2008. Breeding options for dairy cattle improvement in the Sudan. Outlook Agric. 37, 289–295.

Musa, M.A., Peters, K.J., Ahmed, M.K.A., 2006. On farm characterization of Butana and Kenana cattle breed production systems in Sudan. Livest. Res. Rural Dev. 18, 12.

Musa, L.M.A., Ahmed, M.K.A., Peters, K.J., Zumbach, B., Gubartalla, K.E.A., 2005. The reproductive and milk performance merit of Butana cattle in Sudan. Arch. Anim. Breed. 48, 445–459. https://doi.org/10.5194/aab-48-445-2005.

Mwacharo, J.M., Drucker, A.G., 2005. Production objectives and management strategies of livestock keepers in South-East Kenya : Implications for a breeding programme. Trop. Anim. Health Prod. 37, 635–652. https://doi.org/10.1007/s11250-005-4253-8.

Mwai, O., Hanotte, O., Kwon, Y.J., Cho, S., 2015. - Invited review-African indigenous cattle: Unique genetic resources in a rapidly changing world. Asian-Australas J. Anim. Sci. 28, 911–921. https://doi.org/10.5713/ajas.15.0002R.

Mwangi, S., Muasya, T.K., Kahi, A.K., 2018. Within-population genetic structure and trend in genetic diversity for Sahiwal cattle breed in Kenya. Livest. Res. Rural. Dev. 30, 1-101.http://www.lrrd.org/lrrd30/7/mwang30129.html.

Nakimbugwe , N.H., Semambo, D.K.N., Ndumu, D. B., 2002. The animal breeding act as a strategy and instrument in streamlining animal breeding activities in Uganda. Proceedings of the 7th World Congress on Genetics Applied to Livestock Production, August 19-23, 2002, Montpellier, France. Session 25, p. 16.

Narwaria, U.S., Mehla, R.K., Verma, K.K., Lathwal, S.S., Yadav, R., Verma, A.K., 2015. Study of short lactation in Sahiwal cattle at organized farm. Vet. World 8, 690–694 https://doi.org/10.14202/vetworld.2015.690-694.

Nyamushamba, G.B., Chikwanda, D., Matondi, G.H.M., Marandure T., Mamutse J., Tavirimirwa, B., Banana, N.Y.D., Dhliwayo, M., 2014. The effect of non-genetic factors on milk yield and composition of Red Dane cattle in Zimbabwe. Livest. Res. Rural. Dev. 26,1-5 http://www.lrrd.cipav.org.co/lrrd26/5/nyam26093.htm

Obšteter, J., Jenko, J. Gorjanc, G., 2021. Genomic selection for any dairy breeding program via optimized investment in phenotyping and genotyping. Front. Genet. 12, 637017. https: //doi.org/10.3389/fgene.2021.637017.

Obšteter, J., Jenko, J., Hickey, J.M., Gorjanc G., 2019. Efficient use of genomic information for sustainable genetic improvement in small cattle populations. J. Dairy Sci. 102, 9971–9982. https: //doi.org/10.3168/jds.2019-16853.

Ojango, J.M.K., Pollott, G.E., 2004. The productivity of Holstein-Friesian dairy cattle in different farming systems of Kenya. Int. J. Agric . Rural Dev. 5, 145-155.

Oldenbroek, K., van der Waaij, L., 2015. Ranking the animals. Pages 160–170 in Textbook Animal Breeding and Genetics for BSc students. Wageningen University.

Olori, V.E., Meuwissen, T.H.E., Veerkamp, R.F., 2002. Calving interval and survival breeding values as measure of cow fertility in a pasture-based production system with seasonal calving. J. Dairy Sci. 85, 689-696.

Omer, A.M.E., Addo, A., Roessler, R., Schäler, J., Hinrichs, D., 2020. Exploration of production conditions : a step towards the development of a community-based breeding program for Butana cattle. Trop. Anim. Health Prod. 4, 9–10.

Opoola, O., Mrode, R., Banos, G., Ojango, J., Banga, C., Simm, G., Chagunda, M.G.G., 2019. Current situations of animal data recording, dairy improvement infrastructure, human capacity and strategic issues affecting dairy production in sub-Saharan Africa. Trop. Anim. Health Prod. 51, 1699–1705. https://doi.org/10.1007/s11250-019-01871-9.

Ouédraogo, D., Ouédraogo-Koné, S., Yougbaré, K.B., Zoma-Traoré, A.S.B., Mészáros, G., Khayatzadeh, N., Traoré, A., Sanou, M., Ally, O., Wurzinger, M., Burger, P.A., Sölkner, J., 2021. Population structure, inbreeding and admixture in local cattle populations managed by community- based breeding programs in Burkina Faso. Anim. Breed. Genet. 138, 379–388. https://doi.org/10.1111/jbg.12529.

Ouma, E., Abdulai, A., Drucker, A., Obare, G., 2004. Assessment of farmer preferences for cattle traits in smallholder cattle production systems of Kenya and Ethiopia. Proceedings of the International Agricultural Research for Development: Deutscher Tropentag, 2004. Berlin, Germany, pp.1-9.

Peters, I.K., Zumbech, B., 2002. Needs for research and development in Livestock Recording Systems (LRS) in transition and developing countries. In:Development of Sucessful Animal Recording Systems for Transition and Developing Countries. Proceedings of the FAO/ICAR seminar, Interlaken, Switzerland, 27 May, 2002, pp. 155-174.

Philipsson, J., 2000. Sustainability of dairy cattle breeding systems utilising artificial insemination in less developed countries-examples of problems and prospects. ICAR Technical Series.

Philipsson, J., Rege, J., Mwai, A., 2006. Sustainable breeding programmes for tropical farming systems. Anim. Genet. Train. Resour. 1, 25.

Philipsson, J., Rege, J., Zonabend, E., Okeyo, A.M., 2011. Sustainable breeding programmes for tropical low- and medium input farming systems In: Animal genetics training resource, version 3, 2011. Ojango, J.M., Malmfors, B. and Okeyo, A.M. (Eds). Animal Genetetic Training Resources, version 3, 2011. Ojango, J.M., Malmfors, B., Okeyo, A.M. (Eds). International Livestock Reseach Institute, Nairobi, Kenya and Swedish University of Agricultural Sciences, Uppsala, Sweden.

Powell, O., Mrode, R., Gaynor, R.C., Johnsson, M., Gorjanc, G., Hickey, J.M., 2019. Genomic data enables genetic evaluation using data recorded on low-middle income country smallholder dairy farms. bioRxiv. https://doi.org/10.1101/827956

Piepho, H.P., Möhring, J., Melchinger, A.E., Büchse, A., 2008. BLUP for phenotypic selection in plant breeding and variety testing. Euphytica161, 209–228. https://doi.org/10.1007/s10681-007-9449-8.

Piyasatian, N., Kinghorn, B.P., 2003. Balancing genetic diversity, genetic merit and population viability in conservation programmes. J. Anim. Breed. Genet. 120, 137–149. https://doi.org/10.1046/j.1439-0388.2003.00383.x.

Porter, V., Alderson, L., Hall, S.J.G., Sponenberg, D.P., 2016. Mason's World Encyclopedia of Livestock Breeds and Breeding. 2 Volume Pack. 6th ed. Cabi, Boston.

Rahman, I.M.K.A., 2007. Sudanese cattle resources and their productivity: A review. Agric.Rev. 28, 305–308.

Ramírez-Rivera, E.J., Rodríguez-Miranda, J., Huerta-Mora, I.R., Cárdenas-Cágal, A., Juárez-Barrientos, J.M., 2019. Tropical milk production systems and milk quality: a review. Trop. Anim. Health Prod. 51, 1295–1305. https://doi.org/10.1007/s11250-019-01922-1.

Randolph, T.F., Schelling, E., Grace, D., Nicholson, C.F., Leroy, J.L., Cole, D.C., Demment, M.W., Omore, A., Zinsstag, J., Ruel, M., 2007. Invited review: Role of livestock in human nutrition and health for poverty reduction in developing countries. J. Anim. Sci. 85, 2788-2800.

Rege, J., 1999. The state of African cattle genetic resources I. Classification framework and identification of threatened and extinct breeds. Anim. Genet. Res. Inf. 25, 1-25. doi:10.1017/S1014233900003448.

Rege, J.E.O., Marshall, K., Notenbaert, A., Ojango, J.M.K., Okeyo, A.M., 2011. Pro-poor animal improvement and breeding - What can science do? Livest. Sci. 136, 15–28. https://doi.org/10.1016/j.livsci.2010.09.003.

Renaudeau, D., Collin, A., Yahav, S., De Basilio, V., Gourdine, J.L., Collier, R.J., 2012. Adaptation to hot climate and strategies to alleviate heat stress in livestock production. Animal 6, 707–728. https://doi.org/10.1017/S1751731111002448.

Rewe, T.O., Herold, P., Kahi, A.K., Valle Zárate, A., 2009. Breeding indigenous cattle genetic resources for beef production in Sub-Saharan Africa. Outlook Agric. 38, 317–326. https://doi.org/10.5367/000000009790422205.

R Core Team., 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.Accessed 18 Mar 2020.

Roessler, R., 2019. Selection decisions and trait preferences for local and imported cattle and sheep breeds in peri-/urban livestock production systems in Ouagadougou, Burkina Faso. Animals. 9, 207.

Roschinsky, R., Kluszczynska, M., Sölkner, J., Puskur, R., Wurzinger, M., 2014. Smallholder experiences with dairy cattle crossbreeding in the tropics: From introduction to impact. Animal 9, 150–157. https://doi.org/10.1017/S1751731114002079.

Saeed, A.M., Ward, P.N., Light, D., Durkin, J.W., Wilson, R.T., 1987. Characterization of Kenana cattle at Umbenein, Sudan, ILCA Research Report (ILCA).

Selle, M.L., Steinsland, I., Powell, O., Hickey, J.M., Gorjanc, G., 2020. Spatial modelling improves genetic evaluation in smallholder breeding programs. Genet. Sel. Evol. 52, 69. https: //doi.org/10 .1186/s12711-020-00588-w.

Sokouri, D., Loukou, N., Yapi-Gnaoré, C., Soro, B., Simon-Pierre, N., 2014. Analysis of livestock production practices in the northern region of Côte d'Ivoire. Int. J. Curr. Res. 6, 9108–9115.

Sonesson, A.K., Gjerde, B., Meuwissen, T.H.E., 2005. Truncation selection for BLUP-EBV and phenotypic values in fish breeding schemes Truncation selection for BLUP-EBV and phenotypic values in fish breeding schemes. Aquaculture 243, 61–68. https://doi.org/10.1016/j.aquaculture.2004.09.024.

Sørensen, M.K., Voergaard, J., Pedersen, L.D., Berg, P. Sørensen, A.C., 2011. Genetic gain in dairy cattle populations is increased using sexed semen in commercial herds. J. Anim. Breed. Gen. 12, 267-275.

Staal, S.J., Pratt, A.N., Jabbar, M., 2008. Dairy development for the resource poor. Part 1: A comparison of dairy policies and development in South Asia and East Africa. Dairy development case studies. FAO/PPLPI Working Paper, No. 44-1. 55. Rome (Italy): FAO. https://hdl.handle.net/10568/1218.

Sutarno, S., Setyawan, A.D., 2015. Review: Genetic diversity of local and exotic cattle and their crossbreeding impact on the quality of Indonesian cattle. Biodiversitas 16, 327–354. https://doi.org/10.13057/biodiv/d160230.

Soudré, A., Khayatzadeh, N., Probst, L., Sölkner, J., Mészáros, G., 2020. From farmers to livestock keepers : a typology of cattle production systems in south-western Burkina Faso. Trop. Anim. Health Prod. 52, 2179-2189.

Syrstad, O., Ruane, J., 1998. Prospects and strategies for genetic improvement of the dairy potential of tropical cattle by selection. Trop. Anim. Health Prod. 30, 257–268. https: // doi .org/10 .1023/A:1005083430140.

Syrstad, O.,1996. Dairy cattle crossbreeding in the tropics: choice of crossbreeding strategy. Trop. Anim. Health Prod. 28, 223-229. doi: 10.1007/BF02240940. PMID: 8888529.

Tegegne, A., Gebremedhin, B., Hoekstra, D., 2013. Smallholder dairy production and marketing systems in Ethiopia: IPMS experiences and opportunities for market-oriented development. Working Paper No. 31. Nairobi, Kenya: International Livestock Research Institute (ILRI).

Teodoro, G. Di, Marruchella, G., Provvido, A. Di, Angelo, A.R.D., Orsini, G., Giuseppe, P. Di, Sacchini, F., Scacchia, M., 2020. Contagious Bovine Pleuropneumonia. A comprehensive overview. Vet. Pathol. 57, 476–489. https://doi.org/10.1177/0300985820921818.

The Friesian, 2016. Dairy quick scan Sudan. Report for: Rijksdienst voor Ondernemend Nederland. The Netherlands. https://netherlandsandyou.nl/binaries/netherlandsandyou/documenten/publications/economic-sector-studies-copy/Report+Quick+Scan+Dairy+Sudan+-+FINAL4.pdf.

Thornton, P.K., 2010. Livestock production: Recent trends, future prospects. Philos. Trans. R. Soc. B Biol. Sci. 365, 2853–2867. https://doi.org/10.1098/rstb.2010.0134.

Thornton, P.K., Herrero, M., 2015. Livestock farming systems in sub-Saharan Africa. Nat. Publ. Gr. 5. https://doi.org/10.1038/nclimate2754.

Thornton, P.K., Rosenstock, T., Förch, W., Lamanna, C., Bell, P., Henderson, B., Herrero, M., 2018. A qualitative evaluation of CSA options in mixed crop-livestock systems in developing countries. In: Lipper, L. (ed), Climate Smart Agriculture. Natural Resource Management and Policy, vol 52. Springer, Cham, 385-423. https://doi.org/10.1007/978-3-319-61194-5_17.

UNEP, 2020. Sudan First State of Environment and Outlook Report . United Nations Environment Program.UNEP, Khartoum.

USAID, 2019. East Africa trade and investment hub: Quarterly Progress Report United States Agency for International Development, Kenya. https://pdf.usaid.gov/pdf_docs/PA00TXJP.pdf.

van Arendonk, J.A.M., 2011. The role of reproductive technologies in breeding schemes for livestock populations in developing countries. Livest. Sci. 136, 29–37. https://doi.org/10.1016/j.livsci.2010.09.004.

Verrier, E., Colleau, J.J., Foulley, J.L., 1993. Long-term effects of selection based on the animal model BLUP in a finite population. Theor. Appl. Genet. 87, 446-454.

Vijayakumar, M., Park, J.H., Ki, K.S., Lim, D.H., Kim, S.B., Park, S.M., Jeong, H.Y., Park, B.Y., Kim, T.I., 2017. The effect of lactation number, stage, length, and milking frequency on milk yield in Korean Holstein dairy cows using automatic milking system. Asian-Australas. J. Anim. Sci. 30, 1093-1098.

Weerasinghe, S., Gibson, J., Gondro, C., Okeyo, M., Ojango, J., Rao, E.J.O., Dessie, T., Mujibi, D., Rege, J.E.O., 2018. Genetic diversity of the indigenous cattle of Kenya, Uganda, Ethiopia and Tanzania using high-density SNP data. Proceedings of the World Congress on Genetics Applied to Livestock Production, vol. Poster session 2, p. 777.

Weigel, K.A., Vanraden, P.M., Norman, H.D., Grosu, H., 2017. A 100-Year Review : Methods and impact of genetic selection in dairy cattle – From daughter – dam comparisons to deep learning algorithms. J. Dairy Sci 100, 10234–10250.

Wilson, R.T., 2009. Fit for purpose - the right animal in the right place. Trop. Anim. Health Prod. 41, 1081–1090. https://doi.org/10.1007/s11250-008-9274-7.

Wilson, R.T., 2018. Livestock in the Republic of the Sudan: Policies, production, problems and possibilities. Anim. Husbandry, Dairy Vet. Sci. 2, 1–12. https://doi.org/10.15761/ahdvs.1000142.

Wilson, R.T., 2018. Crossbreeding of cattle in Africa. J. Agric. Environ. Sci. 6, 16–31. https://doi.org/10.15640/jaes.v7n1a3.

Windig, J.J., Kaal, L., 2008. An effective rotational mating scheme for inbreeding reduction in captive populations illustrated by the rare sheep breed Kempisch Heideschaap. Animal 2, 1733–1741. https://doi.org/10.1017/S1751731108003029.

Wurzinger, M., Gutiérrez, G.A., Sölkner, J., Probst, L., 2021. Community-based livestock breeding: Coordinated action or relational process? Front. Vet. Sci. 8, 1–9. https://doi.org/10.3389/fvets.2021.613505.

Wurzinger, M., Sölkner, J., Iñiguez, L., 2011. Important aspects and limitations in considering community-based breeding programs for low-input smallholder livestock systems. Small Rumin. Res. 98, 170–175. https://doi.org/10.1016/j.smallrumres.2011.03.035.

Wurzinger, M., Willam, A., Delgado,J., Nürnberg, M., Zárate, A.V., Stemmer, A., Ugarte, G., Sölkner, J., 2008. Design of a village breeding programme for a llama population in the High Andes of Bolivia. J. Anim. Breed. Genet. 125, 311–319. https://doi.org/10.1111/j.1439-

0388.2007.00713.x.

Wurzinger, M., Ndumu, D., Baumung, R., Drucker, A., Okeyo, A.M., Semambo, D.K., Byamungu, N., Sölkner, J., 2006. Comparison of production systems and selection criteria of Ankole cattle by breeders in Burundi, Rwanda, Tanzania and Uganda. Trop. Anim. Health Prod. 38, 571–581. https://doi.org/10.1007/s11250-006-4426-0.

Yahya, A.K.H., EL-Tetraifl, M., Siddig, F.S., 2011. Performance of Kenana X Friesian cross-bred cattle in central Sudan. Online J. Anim. Feed Res. 1, 274–279.

Yousif, I.A., El- Moula, A.A.F., 2006. Characterisation of Kenana cattle breed and its production environment. Anim. Genet. Resour. Inf. 38, 47–56. https://doi.org/10.1017/s1014233900002042.

Zewdu, W., Thombre, B., Bainwad, D., 2015. Studies on some non-genetic factors affecting reproductive performance of Holstein Friesian Deoni crossbred cows. African J. Agric. Res. 10, 1508–1516. https://doi.org/10.5897/ajar2014.8952.

Zoma-Traoré, B., Probst, L., Ouédraogo-Koné, S., Soudré, A., Ouédraogo, D., Yougbaré, B. Traoré, A., Khayatzadeh, N., Mészáros, G., Burger,P.A., Mwai, O.A., Sölkner, J., Wurzinger, M., Martin-Collado, D., 2021. Livestock keepers´attitudes : Keystone of effective community-based breeding programs. Sustainability13, 1–14. doi:https://doi.org/10.3390/su13052499.

Zumbach, B., Peters, K.J., 2002. Sustainable breeding programmes for smallholder dairy production in the tropics. Proceedings of the 7th World Congress on Genetics Applied to Livestock Production, August 19-23, 2002 Montpellier, France. Session 25, p. 21.

Zuria, B.D., Woredas, M., 2009. Smallholder dairy production system and emergence of dairy cooperatives in Bahir Dar, northwestern Ethiopia. World 4, 185–192.

## Related publications

Below are publications related to the research project that forms the basis of this PhD thesis. Reference to the related chapters are provided in brackets.

1. **OMER, E. A.M.**, ADDO, S., ROESSLER, R., SCHÄLER, J., & HINRICHS, D. (2020). Exploration of production conditions: a step towards the development of a community-based breeding program for Butana cattle. Tropical Animal Health and Production, 53(1), 1-10 **(Chapter 4).**
2. **OMER, E. A.M.**, ADDO, S., SCHÄLER, J., & HINRICHS, D. (2020). Exploration of production conditions: a step towards the development of a community-based breeding program. 71st EAAP Conference, Virtual meeting, Dec 1 – 4, Book of Abstracts No. 26, 427, ISBN: 978-90-8686-349-5 **(Chapter 4).**
3. **OMER, E. A.M**., ROESSLER, R., & HINRICHS, D. (2021). Design of breeding programs for Butana cattle using a stochastic simulation approach. 72nd EAAP meeting, Book of Abstracts No. 27, 442, ISBN: 978-90-8686-366-2, Davos, Switzerland, 30th August – 3rd September **(Chapter 5).**
4. **OMER, E. A.M**., ADDO, S., & HINRICHS, D. (2021). A retrospective evaluation of production and reproduction performance of Butana cattle kept in research station. 72nd EAAP meeting, Book of Abstracts No. 27, 599, ISBN:978-90-8686-366-2, Davos, Switzerland, 30th August – 3rd September. **(Chapter 3).**
5. **OMER, E. A.M.,** HINRICHS, D., ADDO, S., & ROESSLER, R. (2022). Development of a breeding program for improving the milk yield performance of Butana cattle under smallholder production conditions using a stochastic simulation approach. Journal of the Dairy Science **(Chapter 5).**

**Acknowledgements**

First and foremost, I am grateful to my supervisor, Prof. Dr. Dirk Hinrichs, for his continuous support of my Ph.D. study, as well as his patience, inspiration, and immense knowledge. His advice was crucial during the research and writing of this thesis. Additionally, his financial support is highly appreciated. I would like to express my gratitude to my co-supervisor Prof. Dr. Eva Schlecht for providing me with a 6-months stipend from Georg-August-Universität, Göttingen. I am also extremely thankful to Prof. Dr. Eva Schlecht for her impactful comments and corrections to my thesis. I would like to acknowledge Dr. Regina Roessler for her valuable assistance with modelling of breeding program simulation. Thank you for introducing me to AlphaSimR software breeding programs simulation. I am also sincerely grateful to Regina for her support and encouragement during the challenging times. My heartfelt gratitude goes to Dr. Sowah Addo for his help and comments and for proofreading of this thesis. My sincere thanks also go to Dr. Lisa Jung for helping with the German translation of the summary of the dissertation. My appreciation goes to all my colleagues at the Department of Animal Breeding, University of Kassel, my family members and friends for their immense support in different ways. Everything has been falling into place so beautifully up to this point, and it is not a coincidence. I give thanks to Almighty Allah for this.