

**EVALUATING THE EFFECT OF SELECTED FODDER INTERVENTIONS ON
DAIRY COW MILK PERFORMANCE IN SMALLHOLDER FARMS IN KENYA**

CALEB WANYIRI OKTOTO

**A Thesis Submitted to the Graduate School in Partial Fulfilment of the
Requirements for the Master of Science Degree in Animal Nutrition of Egerton
University**

EGERTON UNIVERSITY

OCTOBER, 2024

DECLARATION AND RECOMMENDATION

Declaration

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


Signature:  _____ Date: 18th September 2024

Caleb Wanyiri Oktoto

KM113/13029/21

Recommendation

This thesis has been submitted with our approval as University supervisors

Signature:  Date: 20th September 2024

Prof James O. Ondiek, PhD

Department of Animal Sciences

Egerton University

Signature:  Date: 24th September 2024

Dr. Asaah O. Ndambi, PhD

Animal Science Group

Wageningen University and Research

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DEDICATION

This work is dedicated to all smallholder dairy farmers, particularly those in dairy cooperatives in Bomet, Nyandarua, and Nyeri, as well as across Kenya. It is also dedicated to researchers and dairy production policymakers who contribute to advancing the dairy industry.

ACKNOWLEDGMENTS

I am deeply grateful to the Almighty God for His unwavering protection, abundant provision, and steadfast guidance throughout my studies. My heartfelt thanks go to Egerton University, the Graduate School, and the Department of Animal Science for their continuous support, which played a pivotal role in the successful completion of my academic journey. I extend my sincere appreciation to the Milk Africa Project for their invaluable support, both in terms of financial assistance and supervision, which played a pivotal role in the successful execution of my research. I am also deeply grateful to the RUFORUM-TAGDev Program at Egerton University for their generous funding of my Master's studies and research. Their financial support has been instrumental in realising my academic aspirations, enabling me to pursue Master of Science studies at Egerton University.

I am particularly indebted to my esteemed supervisors, Prof James O. Ondiek from the Animal Science Department at Egerton University, Kenya, and Dr. Asaah O. Ndambi from Wageningen University and Research/University of Nairobi. Their invaluable support and guidance during the proposal development, research and thesis writing stages were instrumental to the quality and depth of my research. Special thanks are extended to the dedicated laboratory technologists in Egerton University Departments of Animal Sciences and Food Science for their indispensable assistance in conducting rigorous chemical analyses and enhancing the credibility of my research findings. Lastly, I want to express my deepest gratitude to my beloved wife and family. Their unwavering support, constant encouragement, and invaluable assistance have been the pillars that sustained me throughout this challenging academic journey. To everyone mentioned and those not explicitly named but who contributed in various ways, I offer my sincerest thanks. May God bless each one of you abundantly.

ABSTRACT

In Kenya, dairy cows produce an average of 8 litres of milk per day, translating to approximately 2,440 litres annually. This is significantly lower than the 21 litres per day, or 7,653 litres annually, recorded in the European Union. The disparity is largely attributed to nutritional challenges affecting over 70% of smallholder dairy farms in Kenya. This study evaluates the effect of selected fodder on dairy cow milk performance in smallholder farms across three counties: Bomet, Nyandarua, and Nyeri. The first objective of the study focuses on evaluating the nutritional value and chemical composition of five selected fodders, within the three counties. The study analysed fodders' proximate composition, metabolisable energy, van Soest composition, and *in vitro* digestibility, revealing significant variations in their nutritional profiles across the counties. The second objective examines the effects of dietary supplements on milk yield across the three counties. Twelve Friesian dairy cows, all in similar lactation stages, were randomly selected for the study. They were fed a basal diet of Boma Rhodes (*Chloris gayana*) grass hay and supplemented with a feed mixture containing lucerne (*Medicago sativa*), green leaf desmodium (*Desmodium uncinatum*), sweet potato vines (*Ipomoea batatas*), and chicory (*Cichorium intybus* L.), chopped and mixed in a ratio of 1:2:3:1. Supplementation was provided at four levels: T1 (0%), T2 (10%), T3 (20%), and T4 (30%) of the cows' estimated daily dry matter intake, based on 4% of their live body weight. The study spanned nine weeks, with one week dedicated to backgrounding, two weeks for adaptation, and six weeks for data collection. Data analysis was conducted using ANOVA in a randomized complete block design (RCBD) to control for county-level variation. Significant means were determined using New Duncan's multiple range test at a 5% confidence level. The results showed that in Bomet, the highest milk yield (4.1 litres) was achieved at 20% supplementation, while in Nyandarua, the highest yield (10.0 litres) was recorded at 30% supplementation. In Nyeri, 8.0 litres was achieved at 20% supplementation at $P < 0.05$. The third objective focused on the economic feasibility of dietary treatments by calculating the Income Over Feed Costs (IOFC) for each county. In Bomet, the highest IOFC (KSh 55) was observed at 20% supplementation, while Nyandarua recorded the highest IOFC (KSh 169) at 30%, and Nyeri achieved the highest IOFC (KSh 140) at 20% at $P < 0.05$. In conclusion, this study emphasizes the importance of region-specific dietary interventions to optimise milk yield and profitability in smallholder dairy farms. Future research should explore the long-term impacts of these interventions and investigate alternative, cost-effective fodder sources to improve sustainability in smallholder dairy farming systems.

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LIST OF ABBREVIATIONS AND ACRONYMS

ACET	-African Centre for Economic Transformation
AOAC	-Association of Official Analytical Chemists
CAN	-Calcium Ammonium Nitrate
CGN	-County Government of Nyeri
CP	- Crude Protein
DAP	-Di-ammonium Phosphate
DM	-Dry Matter
EADDP	-East Africa Dairy Development Project
EAZ	-East African Zebu
EU	-European Union
FAO	-Food Agriculture Organization of the United Nations
GDP	-Gross Domestic Product
GOK	-Government of Kenya
IOFC	-Income Over Feed Cost
KDB	-Kenya Dairy Board
KES	-Kenya Shilling
KIHBS	-Kenya Integrated Household Budget Survey
KNBS	-Kenya National Bureau of Statistic
MoLD	-Ministry of Livestock Development
MPS	-Market Price Support
ROF	-Return on Feed
SDF	-Smallholder Dairy Farming
UN	-United Nations
USAID-KAVES	-United States Agency for International Development -Kenya

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Countries, both developing and developed benefit greatly from the global dairy industry (Herrero *et al.*, 2013). The production systems and efficiencies of the two economies differ significantly. There is a large-scale dairy production system in developed countries characterised by high adoption of new technology and large capital investment. On the other hand, small-holder farmers in developing countries with limited management, specialist skills, and access to limited resources are largely constrained in their dairy production (Muriithi *et al.*, 2014). Some studies estimate that the dairy cattle sector in developed nations produces an average of 5.45 tonnes of milk per cow per year, compared to developing nations whose average milk yield is 0.73 tonnes of milk per cow per year, (OECD/FAO, 2018). Australia, China, India, and New Zealand, on the other hand, report average production volumes of 5,750, 3,700, 956, and 3,868 litres/cow/year, respectively. Total milk production in EU member countries is regulated by quotas assigned to each country; as a result, production is pre-determined (FAO, 2019). Animal husbandry is an important part of many countries' economies . Livestock production accounted for 40% of total agricultural output in 2014 in developed countries, and only 20% in developing countries according to FAO (2018).

Africa's milk production is among the best globally, and Kenya is among the top milk yielders in Eastern Africa (Muriithi *et al.*, 2014). While Uganda, Tanzania, and Kenya all produce milk per cow per year that is far lower than South Africa; the country's production system is the most efficient in Africa, producing 2.5 times as much milk per cow per year, much more than the three countries combined (ACET, 2015; FAO, 2019; Susan *et al.*, 2019). Many countries have a low-cost production system like Kenya's, which is centred on rain-fed pasture production. More than 1.5 million small-scale dairy producers in Kenya rely on dairy products for their livelihoods, which account for 4.5 per cent of Kenya's GDP and 12 per cent of agricultural GDP. As a result, it creates 500,000 indirect jobs and 750,000 direct jobs and contributes to other service sectors such as livestock feed and processing, animal health – care, and breeding. On average, 80 to 100 kg of dairy products are consumed annually per person in Kenya, according to the Kenya Dairy Board (2016). In contrast, in most Central and East African countries, the per capita dairy consumption is less than 30 kg (Kasirye & Ssewanyana, 2015). Kenya generates roughly 5.2 billion litres of fresh milk each year, primarily from dairy cattle, thanks to the country's well-developed dairy subsector. For an estimated 1.6 million

small-scale farmer households, dairy production has proven to be an important source of income and food, producing 80 per cent of the country's total milk output, according to reports (KDB, 2016).

In smallholder dairy farming systems, particularly in developing regions like Kenya, enhancing lactation performance is essential for increasing milk yields and overall farm profitability. Lactation performance, which includes both the quantity and quality of milk produced, is influenced by various factors such as nutrition, management practices, and genetic potential (Habimana *et al.*, 2023). Smallholder farmers often face challenges related to feed quality and availability, which directly affect lactation outcomes and, consequently, farm income. The quality of fodder plays a crucial role in determining lactation outcomes. Nutritional adequacy directly impacts milk production, with deficiencies leading to suboptimal performance and reduced economic returns for farmers (Crovetto *et al.*, 2022). Traditional fodder often fails to meet the full nutritional requirements of dairy cattle, leading to lower milk yields and higher production costs. Therefore, exploring alternative feed interventions that offer more balanced and nutritious diets is essential (McAllister *et al.*, 2020). Non-conventional fodder options have the potential to address these nutritional gaps by providing essential nutrients that are often lacking in conventional feeds.

Recent studies highlight that improved fodder varieties, including lucerne, green leaf desmodium, chicory, and sweet potato vines, have shown potential in addressing these nutritional deficiencies. These non-conventional feeds may enhance the nutritional profile and feed efficiency, offering promising alternatives to conventional fodder (Katoch *et al.*, 2018). Incorporating these improved fodders into smallholder dairy systems could lead to better lactation performance, increased milk yield, and improved profitability (Tegemeo Institute, 2023). Additionally, the adoption of such feed interventions could reduce reliance on expensive commercial feeds and mitigate the financial burden on smallholder farmers. Furthermore, the integration of these alternative fodders could contribute to more sustainable dairy farming practices by improving resource use efficiency and reducing environmental impacts associated with traditional feed production. Sustainable feeding strategies are crucial for ensuring long-term viability in dairy farming, especially in regions where resources are limited and environmental pressures are increasing (FAO, 2024). By adopting high-quality, locally available fodders, smallholder farmers may not only enhance milk production but also support broader goals of environmental sustainability and economic resilience in the dairy sector.

1.2 Statement of the Problem

Smallholder dairy cows which are mostly utilised for milk production in the majority of parts of Kenya, are of low milk productivity, which results in lower profitability. The milk production of dairy cattle has long been a problem for dairy farmers. In Kenya, the average milk production per dairy cow is around 7-8 litres per day, which translates to about 1,825-2,555 litres per year per cow (Kenya Dairy Board, 2023). This is significantly lower than in high-yield countries. For instance, in the European Union (EU), the average milk yield per cow is approximately 7,653 litres annually, which translates to about 21 litres per day (European Commission, 2023). In New Zealand, the average dairy cow produces about 4,350 litres annually or roughly 12 litres per day. In Finland, the average yield is even higher, at around 9,043 litres annually, equivalent to approximately 25 litres per day (Statista, 2023).

Nutritional constraints in dairy cattle farming have been cited as the primary cause of low milk productivity. Inadequate feeds, high feed costs, a lack of supplements, and low-quality feedstuffs have all contributed to this. Feeds are a major obstacle to dairy cattle production for more than 70 per cent of small-scale dairy farm-holders (Nyokabi, 2023; OECD/FAO, 2018). The solution to the aforementioned issue may lie in the development of high-quality non-conventional feedstuffs that can be economically affordable and readily available, such as a feed mixture of home-grown lucerne, green leaf desmodium, chicory and sweet potato vine (Mburu *et al.*, 2024)

Research from Egerton University's Tegemeo Institute Analysis (2023) indicates that feed constraints, particularly low-quality fodder and the high cost of commercial feeds, are among the primary challenges in reducing milk productivity in Kenya. The study underscores that even with the government's efforts to subsidize feed costs, the rising prices and poor quality of available feed remain significant barriers to achieving higher milk yields. Another report published under the Business Daily Report on Kenya's Dairy Sector (2023) outlines the challenges facing the Kenyan dairy industry, with feed quality and cost being central issues. It notes that feed and fodder quality vary widely, and poor mixing practices by farmers often result in inadequate nutrition for dairy cows, leading to lower milk production. The report also highlights how intensive production systems suffer the most from high feed costs, which significantly reduce profitability despite higher productivity.

1.3 Objectives

1.3.1 General Objective

To contribute to the sustainable development goals through improved national food security and poverty reduction by increasing dairy cows' milk production and profitability through selected fodder-related interventions.

1.3.2 Specific Objectives

- i. To determine the chemical composition of selected fodders; lucerne, green leaf desmodium, sweet potato vines and chicory supplemented to Boma Rhodes grass hay, as feed intervention to be adopted in smallholder dairy farms in Bomet, Nyandarua and Nyeri counties.
- ii. To evaluate the effect of supplementing Friesian dairy cows fed on Boma Rhodes grass hay with a feed mixture of lucerne, green leaf desmodium, chicory and sweet potato vines on milk yield in smallholder dairy farms in Bomet, Nyandarua and Nyeri Counties.
- iii. To assess the Income Over Feed Cost (IOFC) of the utilization of a feed mixture comprised of lucerne, green leaf desmodium, sweet potato vines, and chicory as supplemented on Boma Rhodes in smallholder Friesian dairy farms in Bomet, Nyandarua, and Nyeri Counties.

1.4 Research Hypotheses

- i. The chemical composition of selected fodders; lucerne, green leaf desmodium, sweet potato vines and chicory supplemented to Boma Rhodes grass hay, as feed intervention to be adopted in smallholder dairy farms in Bomet, Nyandarua and Nyeri County has no significant difference.
- ii. The effect of supplementing Friesian dairy cows fed on Boma Rhodes grass hay with a feed mixture of lucerne, green leaf desmodium, chicory and sweet potato vines on milk yield in smallholder dairy farms in Bomet, Nyandarua and Nyeri County has no significant difference.
- iii. The Income Over Feed Cost (IOFC) of the utilization of a feed mixture comprised of lucerne, green leaf desmodium, sweet potato vines, and chicory as supplemented on Boma Rhodes in smallholder Friesian dairy farms in Bomet, Nyandarua, and Nyeri County has no significant difference.

1.5 Justification of the Study

This study is designed to provide a comprehensive understanding of the impact of feeding Friesian dairy cows with a carefully formulated mixture of lucerne, green leaf desmodium, sweet potato vines, and chicory, supplemented with Boma Rhodes grass hay, on milk production. Addressing critical nutritional challenges in the dairy sector, such as inadequate feed, high feed costs, lack of supplements, and poor-quality feedstuffs, this investigation is highly relevant. As highlighted by Mburu *et al.* (2024) and OECD/FAO (2018), these challenges often prevent farmers from fully exploiting the potential of their dairy cows.

Traditionally, the impact of inadequate nutrition is most evident during the dry season. However, with the increasing unpredictability of climate due to climate change, these dry periods have become longer and more erratic, leading to higher feeding costs. This unpredictability poses a substantial financial burden on smallholder dairy farms, impeding their growth and profitability. The study also acknowledges the interplay between feed shortages, inadequate knowledge of feed conservation, population growth, and climate change, all of which reduce the land available for dairy production. To mitigate these challenges, farmers are encouraged to provide home-grown feeds to their dairy cows to reduce costs. This study contributes to this effort by offering a detailed analysis of the type, quality, and proportion of nutrients in selected fodder species grown on smallholder dairy farms, as well as their impact on dairy performance. Given that feed costs constitute a significant portion (50-60%) of total production costs in dairy enterprises, understanding the cost-benefit dynamics of utilizing these fodders is crucial for economic sustainability (FAO, 2014).

There is a significant gap in existing research regarding the biomass and nutritional value of these fodders for dairy cows, as well as their specific effects on milk yield. This study aims to fill this gap, providing valuable insights that can inform strategic interventions to alleviate nutritional constraints in the dairy sector, particularly for smallholder farms. By enhancing our understanding of these factors, the study aligns with the goals of the Malabo Declaration, contributing to global efforts to eradicate world hunger by 2025 (FAO, 2018). Ultimately, increased milk production resulting from the proposed fodder interventions has the potential to uplift smallholder dairy farms, advancing broader agricultural sustainability objectives.

This study aligns with several key local and international goals, particularly in the realms of agriculture, food security, economic development, and environmental sustainability. Locally, the study supports Kenya's Vision 2030 by contributing to agricultural productivity

and sustainability and optimizing dietary supplementation to improve milk production efficiency, which is critical for dairy industry development. It also aligns with the Bottom-Up Economic Transformation Agenda, supporting rural and smallholder farmers' livelihoods by increasing productivity and economic opportunities through improved feeding strategies. At the county level, particularly in Bomet, Nyandarua, and Nyeri, this research contributes to economic growth by enhancing milk yield, which bolsters local economies. Internationally, the study supports several United Nations Sustainable Development Goals (SDGs), including SDG 2: Zero Hunger by contributing to food security, SDG 12: Responsible Consumption and Production by encouraging efficient resource use, SDG 8: Decent Work and Economic Growth by improving income opportunities for farmers, and SDG 13: Climate Action by promoting sustainable farming practices that reduce environmental impact. The study is further aligned with global food security initiatives, ensuring sustainable milk production to meet growing nutritional demands.

1.6 Scope and Limitation of Study

This study focuses on evaluating the effects of selected fodder interventions on the milk performance of lactating Friesian cows in smallholder dairy farms across selected counties in Kenya, specifically Bomet, Nyandarua, and Nyeri. The research assesses the nutritional value of experimental diets, their impact on milk yield, and their influence on income over feed cost (IOFC). Data collection involved a controlled feeding trial, monitoring of milk production, and economic analysis to measure the efficiency and economic viability of the interventions. The study aims to provide insights into region-specific feeding strategies and their potential to improve milk yield and farm profitability, considering the unique agroecological conditions of each county.

The study's findings may be influenced by several limitations. First, the results may not be fully generalizable to all smallholder dairy farms in Kenya, as the selected counties have distinct agroecological conditions that may not represent other regions. Additionally, factors such as farm management practices, cow health, and local feed availability may introduce variability in the outcomes. The study also assumes consistent adherence to the feeding protocols, which may not be uniformly maintained across all farms. Lastly, external factors like fluctuating market prices for milk and feed may impact the economic analysis, potentially affecting the accuracy of the income over feed cost assessment.

CHAPTER TWO

LITERATURE REVIEW

2.1 General Overview of Milk Production Globally

Milk production across the globe is influenced by various regulatory, economic, and environmental factors. In the European Union (EU), total milk production is regulated by quotas assigned to each member country, which predetermines production levels (FAO, 2019). This quota system helps stabilize the dairy market but also limits production. For example, in 2015, productivity losses in the EU were estimated to range between 70 and 550 kilograms of milk per day for a 100-cow herd. The economic impact of these losses is significant, with milk price fluctuations causing annual losses of approximately \$670 million in 2014, a figure projected to rise to \$2.2 billion by the end of the century (Mauger *et al.*, 2015). In the same year, cow milk production in the United States accounted for 14.2% of global production, with India, China, Germany, and Brazil also contributing significantly (FAO, 2019). Geographic variation, among other factors, has played a role in the declining trends in milk production in certain regions (Mauger *et al.*, 2015).

Both developing and developed countries benefit substantially from the global dairy industry (Herrero *et al.*, 2013). However, there are notable differences between the production systems and efficiencies in these economies. In developed countries, dairy production is characterized by large-scale operations with high capital investment and advanced technology adoption. In contrast, dairy farming in developing countries is often dominated by smallholder farmers who face constraints due to limited resources, poor management practices, and insufficient specialist skills (Muriithi *et al.*, 2014).

In terms of output, developed countries typically produce an average of 150-200 tonnes of milk per year in the dairy cattle sector, whereas developing nations average only 35-45 tonnes per year (OECD/FAO, 2018). Despite these disparities, Africa is recognized for its promising dairy sector, with Kenya being a leading milk producer in Eastern Africa (Muriithi *et al.*, 2014). However, Kenya, Uganda, and Tanzania lag behind South Africa in terms of milk production per cow. South Africa's dairy system is notably more efficient, producing 2.5 times more milk per cow annually than the combined output of these three East African countries (ACET, 2015; FAO, 2019; Susan *et al.*, 2019). While developed countries benefit from advanced technology and greater resources, developing nations, especially in Africa, show significant potential for growth in milk production. Bridging the gap between these production

systems will require targeted interventions, particularly in enhancing smallholder dairy farming efficiencies in countries like Kenya.

2.2 A General Overview of Milk Production in Sub-Saharan Africa

Milk and dairy products have long been essential components of the African diet, and their importance continues to grow as populations expand in both rural and urban areas (Fratkin, 2013). Livestock-derived food products contribute approximately 35% to the agricultural Gross Domestic Product (GDP) in North Sub-Saharan Africa (NSSA), playing a critical role in ensuring food security and sustaining the livelihoods of millions of people (Enahoro *et al.*, 2019). The majority of milk production in Sub-Saharan Africa (SSA) occurs in NSSA, which accounted for around 86% of all milk produced in the region during 2019–2020. Milk production in SSA has seen significant growth, increasing by 3.3% annually over the past 40 years, reaching approximately 30 million tonnes (Mt). Cattle contribute 65% of the total milk production, while small ruminants and camels contribute 25% and 10%, respectively (FAOSTAT, 2021). Notably, this increase in milk production is largely driven by growth in livestock populations rather than improvements in livestock productivity.

The demand for dairy products in SSA is expected to triple by 2050 due to rising consumption levels (Herrero *et al.*, 2014). Approximately 90% of the milk supply in SSA comes from extensive pastoral and traditional mixed crop-livestock systems. However, these systems are increasingly strained by climate-related stressors, including reduced feed production, limited water access, heat stress, and heightened disease risks, all of which undermine the sustainable production of milk (Nardone *et al.*, 2010). Kenya is a major contributor to dairy production in Sub-Saharan Africa, with approximately 4.3 million dairy cattle producing an estimated 3.43 billion litres of milk annually, accounting for 18% of the region's milk output. This represents 3% of global milk production.

In Kenya, dairy is a key component of rural livelihoods, with 54% of households owning less than one acre keeping cattle. Additionally, in regions where dairy farming is prevalent, more than 75% of households are involved in agriculture, and 73% practice integrated crop-dairy farming (RoK, 2015). Despite the success of smallholder milk production in Kenya, the industry faces numerous challenges, including disease outbreaks, limited access to financial services, inadequate processing facilities, the prevalence of informal milk markets, and low feed quality and availability (Mutavi *et al.*, 2016). Kenya's dairy industry primarily rears Friesian, Guernsey, Ayrshire, and Jersey cows, along with their crossbreeds. These exotic breeds are often crossed with the native East African Zebu (EAZ), which possesses significant

genetic potential for milk production. However, with improved management and feeding practices, there is considerable potential to enhance milk yields further (Kibiego *et al.*, 2015).

2.3 Smallholder Dairy Farming in Kenya

Kenya produces approximately 5.2 billion litres of fresh milk annually, largely due to its well-developed dairy subsector. Milk production serves as a crucial source of income and food security for an estimated 1.5 million small-scale farming households, benefitting approximately 80% of Kenya's population (KDB, 2016). More than 80% of Kenya's dairy cows are owned by smallholder farmers, who contribute around 56% of the country's milk production (Odero, 2017). These smallholder farmers operate under various farming systems, with some practising intensive dairy farming and others adopting integrated crop-dairy systems. Small-scale farmers produce about 70% of Kenya's milk, primarily through extensive and semi-intensive systems (Mawa *et al.*, 2014). In high-density areas of Kenya, particularly the highlands, smallholder dairy farmers commonly use zero-grazing systems, which involve stall-feeding crop residues and cultivated fodder crops, supplemented with concentrates (Njarui *et al.*, 2016).

Many smallholder farmers have less than an acre of land, where they integrate dairy and crop production. Typically, these farms have herds of one to five purebred or crossbred cows. Around 71% of these farmers own between one and three dairy cows, and they often grow cash crops such as coffee, tea, or pyrethrum alongside grain-based crops (Mugambi *et al.*, 2015). These integrated farming systems contribute significantly to rural livelihoods, providing both food and income, but they face challenges such as limited land size, disease management, and inconsistent access to high-quality feed. Smallholder dairy farming, while essential to Kenya's agricultural sector, continues to grapple with productivity constraints that could be alleviated through improved feed management, better access to resources, and more robust market linkages.

2.4 Contribution of the Dairy Sector to Kenya's Economic Development

The dairy sector plays a significant role in the economies of many countries, contributing to both agricultural output and national development. Globally, livestock production accounted for 40% of total agricultural output in developed countries in 2014, compared to only 20% in developing nations (FAO, 2018). In Kenya, the dairy industry is a vital part of the economy, significantly impacting both national economic growth and public health (Wambugu *et al.*, 2011). Dairy production contributes approximately 4.5% of Kenya's

GDP and 12% of its agricultural GDP, supporting the livelihoods of around 1.5 million smallholder dairy farmers (KDB, 2016).

Beyond its economic contributions, dairy production is essential for enhancing food security, nutrition, and household livelihoods in both rural and urban areas of Kenya. The country has around 4.3 million dairy cows, and per capita dairy consumption ranges from 80 to 100 kilograms annually, far higher than in most East and Central African countries, where consumption is less than 30 kilograms (Kasirye & Ssewanyana, 2015). The Kenya Integrated Household Budget Survey (KIHBS) also highlights the significance of dairy cows in milk production, with unpackaged fresh milk being one of the most consumed food items in the country. The dairy sector accounts for 4% of Kenya's overall GDP and 14% of the agricultural GDP (KNBS, 2019).

The sector's contribution to Kenya's economic development is further highlighted by the fact that more than 1.7 million people rely on the dairy industry for their livelihoods. The industry has grown by approximately 5% per year in recent years, indicating its capacity to continue driving economic progress (MoALF, 2019). With proper structuring, the dairy sector has the potential to support Kenya's development goals by generating employment, particularly for young people. For every 1,000 litres of milk sold, the industry is estimated to create 76 jobs, demonstrating its significant capacity to contribute to job creation (FAO, 2011). Moreover, as Kenya's dairy sector is expected to grow by 35% by 2030, the potential for further employment opportunities—both on and off the farm—is substantial (KDB, 2019). Despite its promise, the dairy industry in Kenya still faces challenges, with 80% of milk produced and marketed through informal channels, while only 20% is sold via formal trade channels (Muriuki, 2011). Addressing these structural issues could unlock the sector's full potential, creating a more robust supply chain and enhancing the economic benefits for smallholder farmers and the nation as a whole.

2.5 Cost-Benefits of the Feeding Models in Smallholder Dairy Farms

Feed costs account for up to 60% of dairy production expenses, thus boosting feed conversion efficiency can have a big impact on dairy profitability. To ensure a plentiful supply of food and fibre while maintaining producer profitability, animal agriculture has long strived to improve production efficiency (Connor, 2015). Income over feed cost (IOFC) is a phrase used to measure and define feed efficiency in dairy herds, and it looks at efficiency from a profit standpoint, also known as return on feed (ROF). It's estimated as the difference between

the overall revenue from milk sales during a given period and the feed costs involved with producing it (Hemme *et al.*, 2014).

The cost of milk production, particularly the assessment of cash and economic costs, is an important indication for long-term dairy farming as well as a means of assessing overall economic competitiveness, both in the factor and product markets, both locally and globally. Dairy organizations and farmers must therefore aim to minimize expenses at the farm level to remain competitive (Koonawootrittriron *et al.*, 2012). The cost-benefit analysis considers the value of net benefits after subtracting costs from benefits. While benefits come in a variety of forms and can be combined using a variety of weights (or ranges of weights), costs are considered forfeited benefits.

2.6 Determination of Milk Production Costs

Dairy farming is profitable, with an average gross margin of KES 32 per litre, ranging from KES 38 in Kisumu to a low of just KES 21 in Uasin-Gishu, based on the USAID-KAVES baseline data. Compared to the margins of KES 2 per litre for zero-grazing systems and KES 4 per litre for non-zero-grazing systems in Kiambu, these are significantly higher. KES 8.46 in Meru to KES 14.73 in Uasin Gishu are the lowest and the highest cost of production, respectively (Wambugu *et al.*, 2011).

Average production costs in Kenya vary significantly, with extensive dairy systems ranging from KES 10.3 to 21.0 per litre, and semi-extensive systems showing lower costs between KES 8.1 and 14.9 per litre (Ojango *et al.*, 2011). According to Baltenweck *et al.* (2012), the disparities in production intensity and geographic location were the primary causes of these discrepancies. Forage markets and production in Kenya are heavily influenced by volume and seasonality. As of now, the nutritional content of forages is of secondary importance. Price hikes on market forages (mostly hay and napier grass) are common during the dry season, with a bale of poor-quality hay fetching as much as KES 300-350. Dry matter weighs roughly KES 31-36 per kilogram (at 80 per cent DM content). Hay quality may be greatly enhanced by properly managing, fertilizing, and harvesting the crop at the proper stage of growth, and this is especially true if better grass seed varieties are made available on the market (Leeuward *et al.*, 2019).

Farmer profitability depends on reducing milk losses. Individual rural households can easily fulfil their annual consumption expenditures with an average dairy enterprise in this sample. The dairy industry faces threats to its financial health from a variety of potential sources, including those that could reduce or increase costs (Hanrahan *et al.*, 2018). Milk

pricing, purchased feed prices, hired labour, and crop/forage production are among these concerns. Dairy farming in Kenya is plagued by a slew of risks that lead to high production costs and low output.

It is critical for a farmer to track his production costs in order to determine whether or not he is making a profit. However, determining the expenses and revenues of milk production is not as straightforward as determining the milk price (Hanrahan *et al.*, 2018). Milk production costs and profitability can be influenced by factors that affect farm-gate milk pricing in rural Kenya (Kumar *et al.*, 2017). Farmers' decisions on how to produce and market their goods contribute to high production costs and low productivity. Therefore, the public and policymakers have continued to be interested in the competitiveness of Kenyan dairy farming. Knowledge of the costs and advantages for smallholder dairy farmers is, therefore, a key prerequisite for the creation of policies targeted at increasing productivity levels.

2.7 Global Overview of Feeding Systems and Feed Resources

Feeding systems for livestock vary significantly across the globe, influenced by regional climates, agricultural practices, and economic factors. In developed countries, intensive feeding systems dominate, characterized by high inputs of commercial feeds and advanced technology. These systems often rely on high-energy concentrates, silage, and high-quality forages to maximize productivity, especially in dairy and beef cattle production (FAO, 2020). Conversely, in many developing nations, smallholder and traditional systems are prevalent, where livestock are primarily fed on natural pastures, crop residues, and locally available feed resources. In sub-Saharan Africa, for instance, extensive pastoralism and mixed crop-livestock systems are common, with farmers utilizing crop residues and native grasses as major feed sources (Thornton *et al.*, 2019). The efficiency and sustainability of these systems are often limited by feed quality, seasonality, and accessibility, posing challenges to improving livestock productivity in these regions.

Recent trends in global feed resources show a growing focus on sustainable and alternative feed options due to environmental and economic pressures. The use of agro-industrial by-products, such as oilseed cakes and molasses, has gained prominence in various parts of the world as a means to reduce feed costs while enhancing feed efficiency (Makkar, 2018). Moreover, the integration of climate-smart feeding practices, such as rotational grazing and improved fodder conservation techniques, is being increasingly adopted to mitigate the effects of climate change on feed availability (Herrero *et al.*, 2020). In many regions, research into unconventional feed resources, including insects and algae, is emerging as a potential

solution to supplement traditional feedstuffs, contributing to more resilient and sustainable livestock feeding systems (Huis *et al.*, 2013). These developments underscore the global shift toward optimizing feed resources to meet the demands of a growing livestock sector while minimizing environmental impacts.

2.8 East African Overview of Feeding Systems and Feed Resources

In East Africa, livestock feeding systems are predominantly shaped by the region's diverse agroecological zones, ranging from arid and semi-arid areas to highland regions with favourable rainfall. Extensive pastoralism is common in the arid and semi-arid zones of countries like Ethiopia, Kenya, and Somalia, where livestock primarily graze on natural pastures (Paul *et al.*, 2021). In these areas, the availability of feed resources is highly seasonal, with periods of abundance during the rainy seasons and feed shortages during dry spells. In contrast, mixed crop-livestock systems dominate in the highland regions of Uganda, Tanzania, and parts of Kenya, where livestock are fed on crop residues and cultivated fodder crops (Njarui *et al.*, 2016). However, across East Africa, feed quality and accessibility remain major challenges due to factors such as land degradation, erratic rainfall patterns, and limited access to high-quality forages and commercial feeds (Rao *et al.*, 2015).

In recent years, efforts have been made to improve the resilience of livestock feeding systems in East Africa through the introduction of improved forage varieties and feed conservation techniques, such as silage and haymaking (Mwangi *et al.*, 2020). Agro-industrial by-products, including oilseed cakes and molasses, are increasingly being incorporated into feeding regimes to improve nutritional intake and reduce feed costs. However, the adoption of such practices varies widely across the region, with smallholder farmers in remote areas often lacking the resources and knowledge to implement these innovations effectively (Thornton *et al.*, 2019). This variability in adoption highlights the need for region-specific interventions that address the unique feed challenges faced by pastoralists and smallholder farmers across East Africa.

2.9 Kenya Overview of Feeding Systems and Feed Resources

In Kenya, the dairy sector is a crucial component of the agricultural economy, with smallholder farmers contributing over 70% of the country's milk production (Muriuki, 2011). Feeding systems in Kenya are diverse and depend on geographical location, farm size, and available resources. In the highland regions, zero-grazing systems—where cows are confined and fed with cultivated fodder such as Napier grass, crop residues, and concentrates—are prevalent (Njarui *et al.*, 2016). In contrast, extensive grazing systems are common in arid and

semi-arid regions, where livestock rely on natural pastures, which are often inadequate during dry seasons. Feed shortages, especially during droughts, pose significant challenges, leading to reduced livestock productivity (Odero *et al.*, 2017).

In recent years, Kenya has made strides in improving feed availability through the introduction of improved fodder varieties such as *Brachiaria* and Boma Rhodes, as well as feed conservation practices like silage and haymaking (Mwangi *et al.*, 2020). However, access to high-quality commercial feeds remains limited, particularly for smallholder farmers. The high cost of feeds and lack of proper storage facilities further exacerbate feed insecurity. As Kenya continues to expand its dairy sector, there is an increasing need for sustainable feeding solutions that are affordable and adaptable to the country's diverse farming systems. Developing region-specific feed interventions and promoting the adoption of improved fodder varieties are key strategies for enhancing livestock productivity in Kenya.

2.10 Lucerne or Alfalfa (*Medicago sativa* L.)

Lucerne (*Medicago sativa*), commonly known as alfalfa, has long been a cornerstone in animal feed due to its high nutritional value, particularly for ruminants is one of the most widely cultivated forage crops due to its high nutritional value and adaptability to various climates. It is particularly prized for its rich protein content, making it an excellent source of nutrition for ruminants (Annicchiarico *et al.*, 2015). As shown in Plate 1, the distinctive morphological characteristics of lucerne, including its leaves and stems, highlight its potential as a robust forage crop. However, changing climate dynamics necessitate a reassessment of lucerne's role in modern farming systems (Bouton, 2012). Furthermore, its ability to fix nitrogen contributes to improved soil fertility, which benefits subsequent crop rotations (Frame, 2019). A key aspect of maximizing lucerne's effectiveness lies in the management of leaf defoliation, which has a direct impact on its quality, yield, and longevity in pastures (Chen *et al.*, 2012). Strategic harvesting practices, such as optimizing the frequency of defoliation, are essential to maintain forage biomass and extend the lifespan of lucerne pastures (Teixeira *et al.*, 2015). As such, effective management of lucerne is critical to ensuring its continued role in sustainable animal production.



Plate 1: Flowered lucerne leaves (*Medicago sativa* L.)

Source: <https://www.namibian.com.na/>

2.10.1 Lucerne's Versatility in Human Nutrition and Medicine.

Lucerne acknowledged for its acquired taste, has secured a place in diverse human recipes, such as puree sauté, tortilla, tea, croquettes, soufflé, pudding, and both raw and cooked salads (Mielmann, 2013). Despite its distinctive flavour, it is recommended to persevere due to its nutritional value. In traditional medicine across regions like Iraq, Turkey, America, and even in traditional Chinese medicine, lucerne has been recognized for its nutritional benefits. It has been used to stimulate appetite, alleviate boils and abscesses, promote healthy blood circulation, and enhance resistance to diseases (Bora & Sharma, 2011; Gawel *et al.*, 2017). Lucerne's leaves contain essential nutrients, including β -carotene, calcium, iron, phosphorus, potassium salts, and vitamins B, C, D, E, and K. Notably, its chlorophyll content contributes to its anticarcinogenic and detoxifying properties, particularly in the gastrointestinal tract (Iqbal *et al.*, 2021).

Beyond its traditional applications, lucerne's aerial parts contain plant protein, sugars, mineral salts, and vitamins (Gawel *et al.*, 2017). In a comparative study, ruminants fed lucerne pasture showed higher concentrations of vitamin E, essential omega-3 fatty acids, and carcass weight compared to those on a feedlot diet or grazing yearly pastures with concentrate supplements (Ponnampalam *et al.*, 2017). This underscores lucerne's potential to enhance the nutritional profile of animal products in agricultural settings. Thus, lucerne stands as a versatile resource, benefiting both human nutrition and animal husbandry. The timing of when forage is

available is affected by a plant variety's degree of dormancy, which causes the plant to grow later in the spring and finish earlier in the autumn (Lattimore, 2013).

2.11 Sweet Potato Vines (*Ipomoea batatas* L.) Background Information

After wheat, rice, corn, potato, barley and cassava, sweet potatoes (*Ipomoea batatas* L.) are the most significant crop (Gundadhur, 2012). It is an important staple that is widely grown throughout many parts of Nigeria and is a member of the Morning Glory family, Convolvulaceae. Due to their enormous starchy, sweet-tasting storage roots that can be used as human food, animal feed, and seed vines for commercial root production, sweet potatoes are well-established in savanna and rainforest regions as shown in plate 2 (Nwankwo & Bassey, 2021).



Plate 2: Sweet potato vines (*Ipomoea batatas* L.)

Source: <https://kilimonews.co.ke/>

Sweet potato leaves, constituting 27% real protein, 8% starch, 4% sugar, and 10% ash on a dry weight basis, are rich in pro-vitamin A, vitamins B and C, calcium, potassium, and sodium, with variations in vegetative morphology and leaf shapes (Nwankwo & Bassey, 2021). The diminishing agricultural land for forage production has led to the exploration of dual-purpose crops like sweet potatoes, which thrive in semi-arid environments. Research by the International Potato Centre (CIP) in 2008 highlighted the preference for dual-purpose sweet potato varieties among farmers, offering both human consumption and livestock feed. These cultivars, harvestable throughout the growing season, hold promise for enhancing the nutritional and food security of resource-limited households in rural areas (Nyathi *et al.*, 2019). Despite concerns about genetic selection for high storage root yield in sweet potatoes, additional efforts are underway to release varieties like Kenspot 1-5, addressing the gap in

research on biomass production and nutritional value for farm animals (Kenana *et al.*, 2021; Urgessa *et al.*, 2014).

2.12 Green Leaf Desmodium (*Desmodium intortum*)

The robust tropical forage legume, green leaf desmodium, exhibits perennial growth with branched, decumbent stems measuring 1.5 to 7.5 m long and 7 mm in diameter. Featuring trifoliate leaves with ovate reddish-brown to purple leaflets (2-7 cm long by 1.5-5.5 cm wide), it has climbing pubescent stems rooting at the nodes. Terminal compact racemes bear flowers in deep lilac to deep pink hues. Pods, 5 cm long, contain 8–12 kidney-shaped seeds (1.5 mm wide, 3 mm long) that cling to clothing. Notably, green leaf desmodium, in contrast to silver leaf desmodium, is characterised by its rounder leaflets as shown in Plate 3 (Mutai, 2017)



Plate 3: Green leaf desmodium (*Desmodium uncinatum*)

Source: www.fedipedia.com

Green leaf desmodium, originating from Central and North-Western America, is a versatile fodder legume with applications in cutting for hay, silage, fresh feeding, or as a long-term fodder option (Heuzé, 2017). Thriving in subtropical regions between 30°N and 30°S, it exhibits adaptability to various elevations and regions with heavier rainfall (Ecocrop, 2014). Resilient to diverse soil types, except those excessively saline or extremely acidic, it proves valuable in agriculture (Heuzé, 2017). Boasting a notable 24% protein content (Heinritz *et al.*, 2012), green leaf desmodium serves as a valuable plant protein source with no reported cases of toxicity. Beyond its agricultural applications, certain desmodium species are employed in

herbal medicine for treating conditions like rheumatism and wounds (Heuzé, 2017; Rahman *et al.*, 2013).

2.13 Chicory (*Cichorium intybus* L.) Background Information

Cichorium intybus L., commonly known as chicory or kasni in Hindi, is a significant medicinal herb belonging to the Asteraceae family. The aerial parts, flowers, seeds, and roots of this plant are extensively utilized for their medicinal properties as shown in Plate 4 (Shad *et al.*, 2013). Rich in essential compounds such as lactones, volatile oil, fatty acids, coumarins, alkaloids, unsaturated sterols, cardiac glycosides, sesquiterpene, anthocyanins, and phenols, each part of the plant contributes to its overall medicinal value (Abbas *et al.*, 2015).



Plate 4: Chicory commander (*Cichorium intybus* L.)

Source: www.agricom.co.nz

Cichorium intybus, commonly known as chicory, is a valuable medicinal herb with uses in various parts, including aerial parts, flowers, seeds, and roots. Rich in compounds such as lactones, volatile oil, fatty acids, coumarins, alkaloids, sterols, glycosides, sesquiterpene, anthocyanins, and phenols, the plant exhibits medicinal properties across its entirety (Helaly & Abdullah, 2017). Chicory roots, containing inulin with a minimal impact on blood sugar, are beneficial for diabetics. Traditionally, it has been employed to address conditions like gallbladder stones, jaundice, diarrhoea, and high fever. Additionally, *C. intybus* demonstrates a range of pharmacological activities, including antibacterial, anthelmintic, antimalarial, liver-

protective, antidiabetic, gastroprotective, antioxidant, anti-inflammatory, analgesic, tumor-inhibitory, and antiallergic properties, as reported by Al-Snafi (2016) and Street *et al.* (2013).

2.14 Boma Rhodes (*Chloris gayana* L.)

Rhodes grass is a versatile tropical grass that can be annual or perennial, growing 1-2 meters tall. Its diverse features include culms that can be decumbent or erect, tufted or creeping, and roots that extend up to 4.5 meters below the surface. The glabrous linear leaves are 12–50 cm long and 10–20 mm wide, with a tapering tip. The seed head resembles an open hand with two to ten racemes, maturing from light greenish-brown to darker brown. The spikelets, numbering more than 32, are strongly imbricated and feature two awns. The fruit is a caryopsis with longitudinal grooves as shown in Plate 5 (Heuzé, 2016).



Plate 5: Boma Rhodes grass (*Chloris gayana* L.)

Source: www.fedipedia.com

Rhodes grass, a versatile fodder, is used for grazing, hay, and deferred feed. Cultivars cater to different environments, and their deep roots make them valuable for soil enhancement (Heuzé, 2016). Thriving in temperatures of 25–30°C, Rhodes grass tolerates climates with lows of 16.5°C and highs of 26°C, with ideal annual rainfall from 600 to 750 mm. Drought-tolerant, it endures up to 6 months of dry spells, with a yield range of 10 to 16 T DM/ha (Ecocrop, 2014). Adaptable to various soils, it prefers well-structured ones with pH levels of 5.5–7.5 (Heuzé, 2016). Both vegetative and seed propagation are possible, with seeds sown in autumn and rapid germination on well-prepared seedbeds (FAO, 2014; Heuzé, 2017).

CHAPTER THREE

CHEMICAL COMPOSITION OF SELECTED FODDERS; FEED INTERVENTION IN SMALLHOLDER DAIRY FARMS IN SELECTED COUNTIES IN KENYA

Abstract

In Kenya, many smallholder farmers rely on conventional fodder types that often lack the necessary nutrients to meet the dietary needs of dairy cows. This results in suboptimal milk yields, exacerbating the economic struggles of these farmers. Evaluating the chemical composition of selected fodders; Boma Rhodes, lucerne, green leaf desmodium, chicory, and sweet potato vines is essential to identify feed options that can enhance milk production. Fodder samples were collected using a systematic random sampling technique from the three selected counties. By analysing proximate composition, metabolisable energy, van Soest composition and *in vitro* digestibility, the study aims to provide insights into region-specific fodder strategies that can improve dairy cow nutrition and overall farm productivity. This study evaluated the chemical composition of five selected fodder which were collected from Bomet, Nyandarua, and Nyeri counties, and taken for chemical analysis in the Animal Nutrition laboratory at Egerton University. All these analyses were done on a dry matter basis. All variables were subjected to ANOVA in a RCBD, to control for the variation among blocks. The New Duncan's multiple range test was used to declare significant means at the 5% confidence level. Results showed that in Bomet, Boma Rhodes had the highest dry matter (DM) content at 96.55%, while sweet potato vines had the highest crude protein content at 16.21% ($P < 0.05$). In Nyandarua, Boma Rhodes also had the highest DM (96.55%), but chicory had a crude protein content of 16.35%, not significantly different from sweet potato vines at 16.19% ($P < 0.05$). In Nyeri, Boma Rhodes recorded the highest DM at 97.4%, and chicory had the highest crude protein at 17.25% ($P < 0.05$). The results revealed significant variations in the nutritional profiles of these diets across the three selected counties. Bomet exhibits specific trends in crude protein and dry matter, while Nyandarua showcases variability in ether extract and total ash content. Nyeri emphasizes differences in crude protein and ash content. These findings provide valuable insights into the regional variations in the chemical composition of fodder, highlighting the importance of tailoring dietary strategies for livestock based on the local environment. Future research and experimentation should consider conducting additional research to explore the impact of supplementation on other aspects of dairy cow management, such as reproduction.

3.1 Introduction

In Kenya, the livestock sector plays a critical role in the economy contributing to income, jobs and food security. 12% of the GDP is generated by the livestock sector with the dairy sector which has been growing at a rate of 4% contributing to 4-8% of the GDP (Bebe *et al.*, 2017). Smallholder dairy farmers in Kenya produce about 80% of the country's milk, providing a living for about 1.8 million people along the value chain. The dairy sector's growth is hampered by the high cost of milk production, which is largely related to the low quality of feeds and fodders, and the lack of year-round availability of quality forages (Mawa *et al.*, 2014). In Kenya, the majority of forages that contribute to livestock feeds are tropical grasses augmented by legumes and crop residues.

The chemical composition of fodder are crucial factor in improving dairy cattle productivity, particularly in smallholder farming systems. In Kenya, where smallholder dairy farming is a significant component of the agricultural sector, optimizing feed resources is essential for enhancing milk yield and overall animal health. Nutritional value directly influences dairy cattle productivity. Dairy cows require a balanced intake of nutrients, including proteins, fibres, and energy, to maintain optimal milk production and health (Bradford & Mullins, 2012). Lucerne (*Medicago sativa*) and green leaf desmodium (*Desmodium intortum*) are known for their high protein content and digestibility, which are beneficial for dairy cattle (Belete *et al.*, 2024). Sweet potato vines (*Ipomoea batatas*) and chicory (*Cichorium intybus*) also offer significant nutritional benefits, including energy and fibre, which can enhance overall feed quality (Jancic *et al.*, 2017).

Chemical composition analysis, including proximate analysis, Van Soest fibre analysis, and metabolizable energy estimation, provides a detailed understanding of fodder quality. The proximate analysis assesses moisture, crude protein, crude fibre, ether extract, and ash content, which are fundamental for evaluating the basic nutritional profile of fodder (Van Soest, 1994). Van Soest's method further evaluates the fibre fractions, such as neutral detergent fibre (NDF) and acid detergent fibre (ADF), which are critical for understanding digestibility and feed intake (Van Soest, 1994). Metabolizable energy (ME) quantifies the usable energy available to the animal after accounting for losses in faeces, urine, and gases, and is crucial for assessing the overall energy value of the feed (NRC, 2001).

Supplementing Boma Rhodes grass hay with higher-quality fodders like lucerne, green leaf desmodium, sweet potato vines, and chicory may address nutritional deficiencies and improve milk production. Boma Rhodes grass, while commonly used, is often criticized for its

low nutritional value (Crovetto *et al.*, 2022). Incorporating these supplementary feeds could provide a more balanced diet, potentially improving milk yield and livestock health (Havemann *et al.*, 2019). In regions like Bomet, Nyandarua, and Nyeri County, where smallholder dairy farms predominate, optimizing feed resources is vital for sustainable agricultural practices and enhancing farm productivity (Orodho, 2021). Therefore, this research endeavours to undertake a comprehensive exploration into the nutritional composition of these selected fodders. The primary objective is to gain a nuanced understanding of how these specific fodders contribute to both the quantity of milk production.

3.2 Material and Methods

3.2.1 Description of the Study Areas

The first set of laboratory samples were collected in Tagiamin village, in Kongasis ward, Chepalungu sub-county in Bomet County-0.7942421° 47' 8.0196" S, 35.3478951° 20' 20.8968" E, 223 Km from Nairobi according to Latlong (2023). In 2019, its population was 875,689, and its total area was 1,630.0 square kilometres. Bomet Town is the county seat of Bomet County. As the country's centre, the capital is easily accessible from across all corners and districts of the area. The Narok-Kisii road, where the town is situated, is bustling (BCG, 2020).

Bomet experiences brief, warm, and cloudy summers and long, cool, mostly clear winters. The average yearly temperature ranges from 11.67°C to 26.11°C, with only a few exceptions when it drops below 10°C or rises above 28.89°C. There is an average daily temperature of 25.56°C during the warm season, lasting from January 13th to March 21st. February is the hottest month in Bomet, with an average high temperature of 26.11°C and a low temperature of 12.22°C. Summer begins on April 29th and ends on August 29th, with an average daily high temperature of 22.78°C or lower. Bomet's coldest month is July, with an average low temperature of 11.67°C and a high temperature of 22.22°C (weatherspark, 2016)

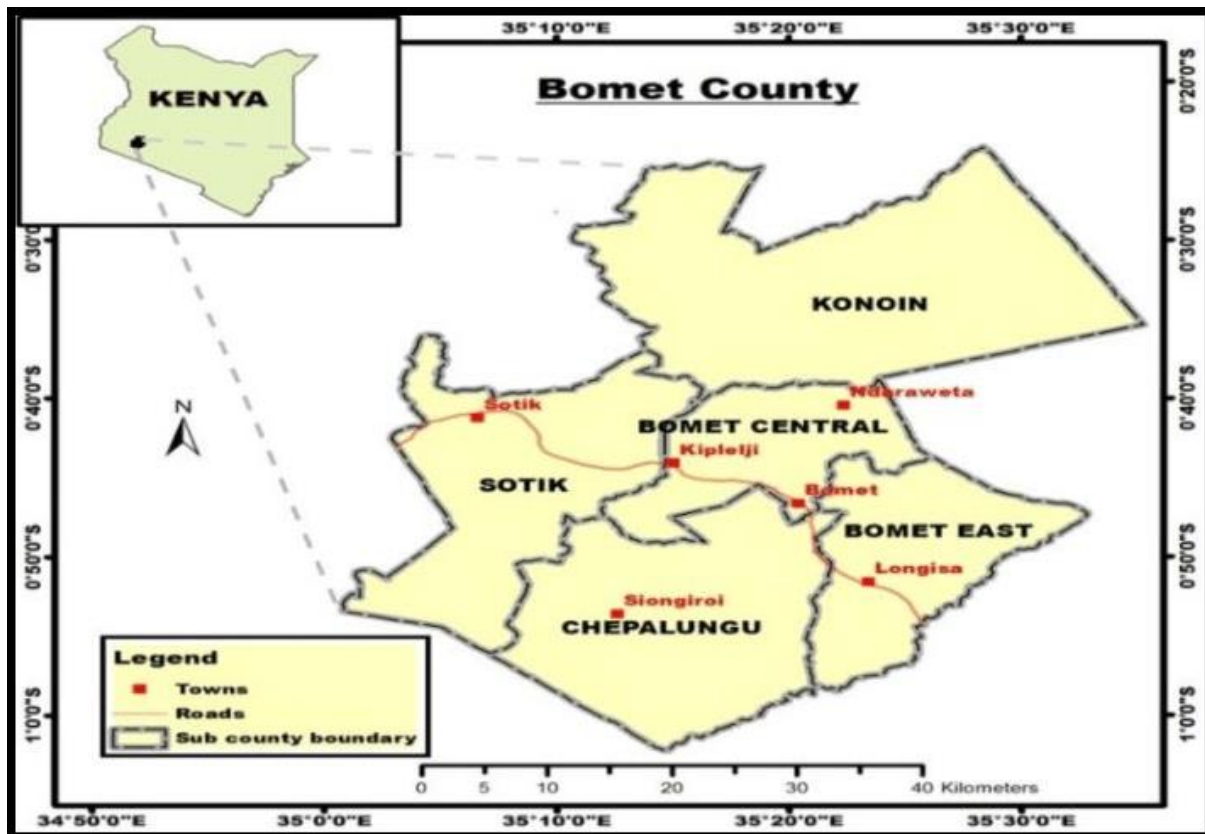


Figure 1: Map of Bomet County showing the study area (Objective one)

Source: Kenya Independent Electoral and Boundaries Commission (2012).

The second set of laboratory samples was collected in Ndaragwa Central constituency, Ngamini Ward, Kahothia Village in Nyandarua County located between geographical coordinates -0.480098611S, and 36.54974917E. Nyandarua County is a County in the former Central Province of Kenya. Its capital and largest town is Ol Kalou. Formerly the capital was Nyahururu, which is now part of Laikipia County. Nyandarua County has a population of 596,268 and an area of 3,304 km². The county is located in the northwestern part of the old Central Province and contains the Aberdare Ranges (KNBS, 2022).

It has a total area of 3,107.7 km² (1,199.9 sq mi). It has a population of 638,289 as per the 2019 general census. The main economic activity in Nyandarua is farming (crop cultivation and dairy farming) as well as potato farming. The climate here is classified as Cfb by the Köppen-Geiger system. The temperature here averages 15.8 °C. The rainfall here is around 2276 mm | 89.6 inches per year. The county is located in the northwestern part of the old Central Province and contains the Aberdare Ranges, the distance between Nyandarua and Nakuru is 48 km while the road distance is 295.4 km. The predominant soils are nitosols, andosols, leptosols, luvisols, phaezems and planosols (KNBS, 2020)

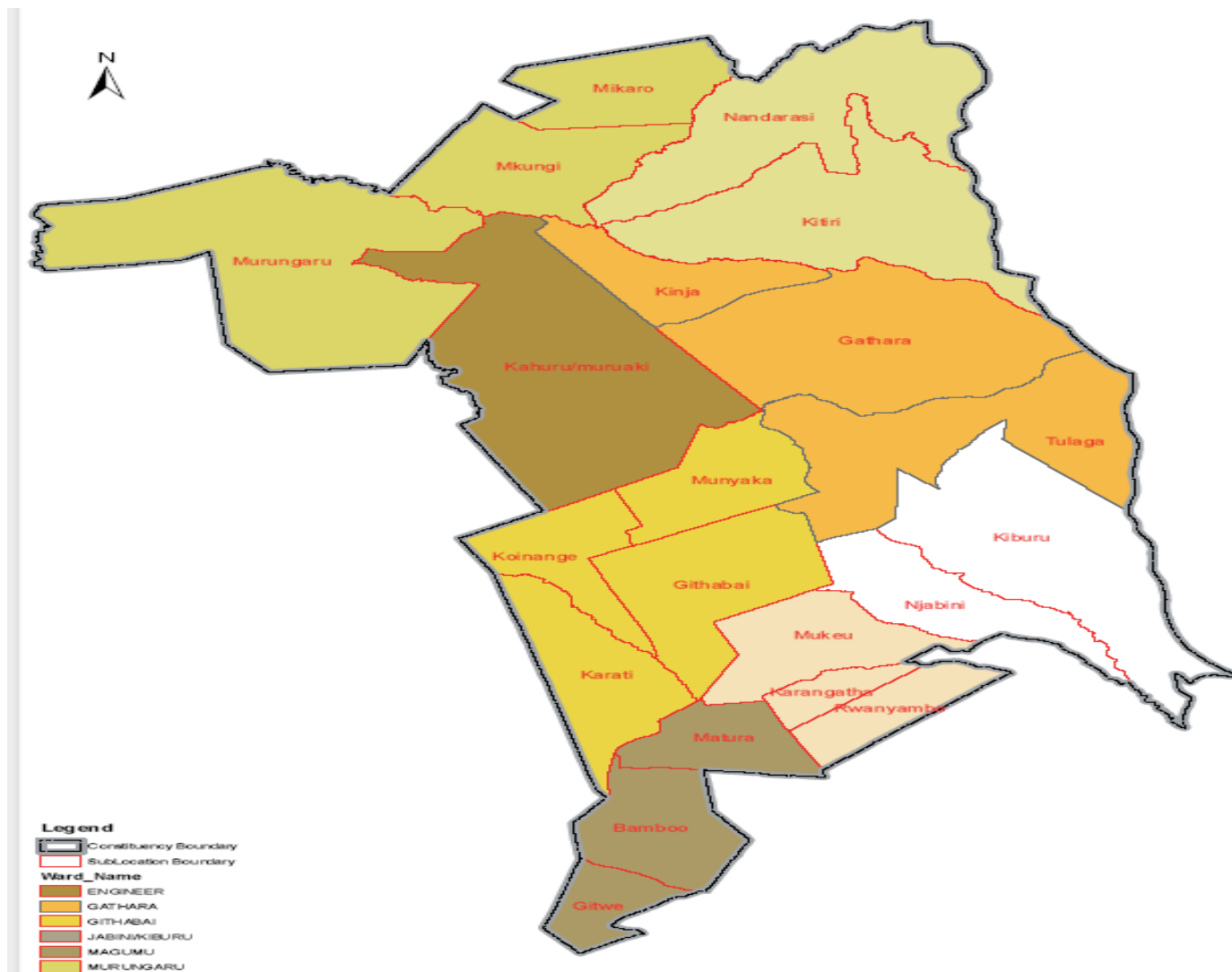


Figure 2: Map of Kinangop sub-county in Nyandarua County showing the administrative boundaries and wards (Objective one)

Source: The guide.org

The third set of laboratory samples were collected in Nyeri County. Mathira West Sub-Counties was chosen for the study based on the number of dairy farmers in it. A population of 759,164 residents in 207.8/km² as estimated by the Kenya National Bureau of Statistics (KNBS) in 2019 (KNBS, 2020). There are common borders with five counties, including Meru to the north and Laikipia to the northern side, Nyandarua to the western side, Murang'a to the southern side, and Kirinyaga to the eastern side, which makes it a leading agricultural innovation hub, located between latitudes 0°25'12" S and 36°56'51" E, the county has an elevation range of 3,076 meters to 5,199 meters above sea level, making it about 150 kilometres north of Nairobi in the distance. The county has both cold and hot months, with an average temperature of 12.80°C in June and July and 20.8°C in the hot months (January-March and September-

October). Between 500 and 1600 millimetres of rainfall each year, with the heaviest rains occurring between April and May (MALF, 2016).

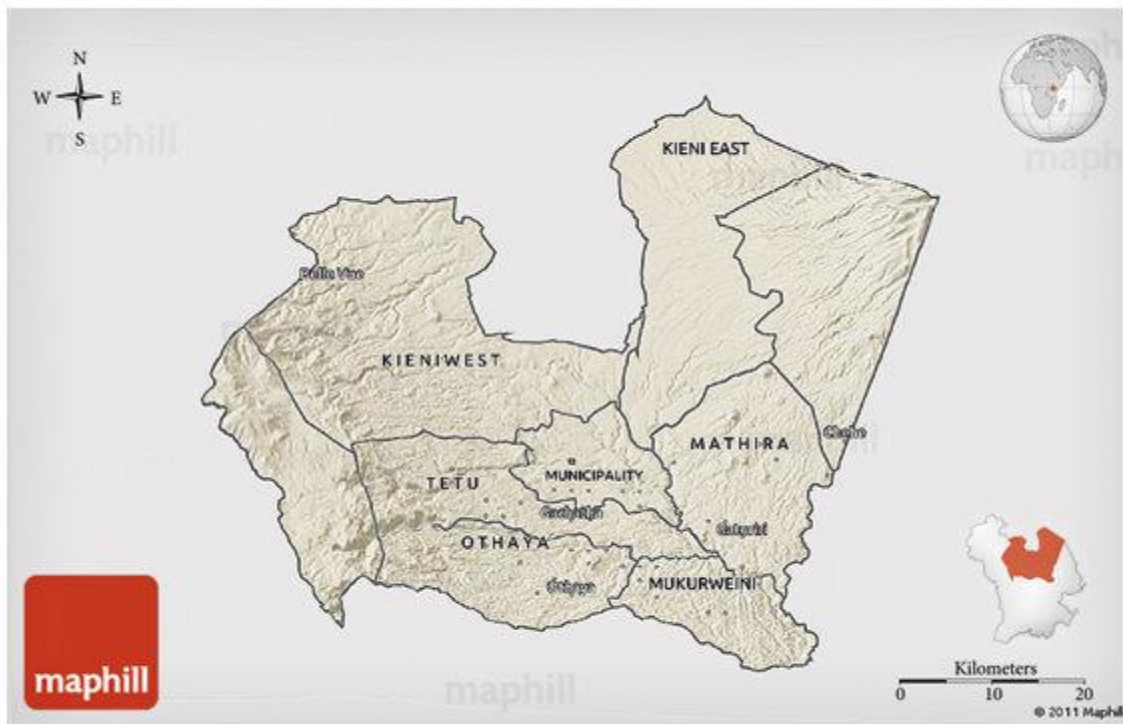


Figure 3: Map of Nyeri County showing the different sub-counties (Objective one)

Map courtesy of Maphill

3.2.3 Sampling

In this study, systematic random sampling was employed to collect fodder samples for laboratory analysis across the three counties (Bomet, Nyandarua, and Nyeri). The process involved selecting sampling points at regular intervals from pre-determined locations within fodder-growing areas. Initially, a random starting point was selected within each field, ensuring that the choice was unbiased. From this starting point, fodder samples were collected at fixed intervals (every 10 meters) across the field. This approach ensured that the samples were evenly distributed and representative of the entire fodder-growing area, reducing the risk of bias in the selection process. By applying systematic random sampling, the study ensured the collection of consistent and representative samples for accurate analysis of the nutritional composition of the fodder across the three regions.

3.2.4 Proximate Analysis

The samples were analysed at the Animal Nutrition Laboratory at Egerton University's Department of Animal Science in Kenya. Samples of the selected fodder were evaluated for

their proximate chemical composition, as follows; dry matter using the weight method and drying the samples in a forced air oven at 105°C (DM; AOAC Official method 934.01), ether extracts by continuous extraction performed on a dry sample in a Soxhlet extractor without previous acid hydrolysis (EE; AOAC Official method 934.01), crude protein was calculated based on nitrogen content determined using kjeltec 2300 Foss Tecator apparatus (Haganäs, Sweden) and multiplying the nitrogen content by 6.25; (CP; Kjeldahl method, AOAC Official method 984.1), crude fibre, according to Henneberg-Stohmann method, by subsequent hydrolysis of the fodder samples with acid and base solution using a Fibertec Tecator (Haganäs, Sweden) apparatus (CF; AOAC Official method 978.10), and crude ash was determined by sample combustion in a muffle furnace at 550°C (Ash; AOAC Official Method 942.05), using the AOAC standard procedures (AOAC, 2012).

The fibre component was examined using the Van Soest *et al.* (1994) method using a Fibertec Tecator (Haganäs, Sweden) apparatus for neutral detergent fibre (NDF; method 2002.04 of AOAC), acid detergent fibre (ADF; method 973.18 of AOAC), and acid detergent lignin (ADL; method 973.18 of AOAC) (AOAC, 2005). Also, the metabolizable energy levels of the feed were determined using the bomb calorimeter, and fodder digestibility was done using the *in vitro* gas production technique. Before feeding, this was done to know how much to feed the animal in terms of its daily nutrient requirement and to have an impression of their contribution to the milk yield per experimental animal.

3.2.5 In Vitro Gas Production

This approach aimed to determine the digestibility of the fodders. The fodder samples from Bomet were milled through a 1mm mesh and 200mg DM incubated in 100ml glass syringes containing rumen fluid and buffer solution which was set in a thermally controlled water bath at 39.5°C for a period initial or 0, 3, 6, 12, 24, 36, 48 and 96 hours when the amount of gas as a result of incubation was recorded. A blank tube was set and incubated without the feed sample following procedures by Menke and Steingass (1988). The calculated value of gas produced was fitted into a model to determine the degradability of the feeds. Similar to how the gas produced over the incubation period is directly related to digestibility, it can also be used to estimate the energy value of feedstuffs.

3.2.6 Calibration and Measurement of in Vitro Gas Production

If the gas produced exceeds 60ml, the accurate reading was recorded as 1Vl (first calibrated volume). The clip was unlocked and the piston was driven back to the 30ml mark while maintaining a vertical position, allowing the generated gas to escape. The second

calibrated volume (2Vl) was the sum of the 1Vl and the most recent reading taken before the second calibration. 2Vl was used like the 1Vl only to calibrate the net gas production for the next incubation hours.

3.2.7 Calculation and Interpretation of the Result

The following is the general formula for computing the adjusted gas output at the time T:

$$(\text{ml}/200\text{mg DM}) = (XV1 - 30VT_{\text{final}}] - VO - GPO) \cdot X200(CF) / \text{Weight in grams DM.}$$

where:

X = The number of times the syringe's gas is expelled, resetting the volume to 30ml.

VO = The initial volume of gas measured before the start of incubation.

V1 = Before the start of incubation, the initial volume of the gas is recorded.

VT final = The final volume of gas recorded at the end of the incubation time.

GPO = The mean blank value.

CF = The correction factor for the standard/standards.

DM = Dry matter.

The net gas volume data was then fitted in the equation of Ørskov and McDonald (1979):

$$G = a + b(1 - e^{-ct})$$

Where:

G = the volume of gas produced (ml) at time t,

a = the gas production from the immediately soluble fraction (ml),

b = the gas production from the insoluble but degradable fraction (ml),

a + b = the potential gas production (ml),

c = the rate constant of gas production (fraction/h).

3.2.8 Statistical Analysis

For each chemical composition parameter (e.g., Dry Matter, Crude Protein, Ether Extract, etc.), an analysis of variance (ANOVA) in a randomised complete block design (RCBD) was performed, to control for the variation among blocks (Counties), where ANOVA indicated significant differences, a posthoc test was applied to determine which specific fodder types differ from each other. The New Duncan's multiple range test was used to declare significant means at the 5% confidence level (Steel & Torrie, 1980). SAS version 9.4 Statistical Package's General Linear Model Procedures (proc glm) was used.

$$H_0: \mu_1 = \mu_2 = \mu_3$$

$$H_a: \mu_i \neq \mu_j \text{ for at least one pair } i, j$$

Model:

$$Y_{ij} = \mu + \theta_j + \tau_i + \tau_{Bij} + \varepsilon_{ji}$$

Where:

Y_{ij} is the random variable representing the response for treatment i observed in block j ,

μ is the overall mean

θ_j is the (additive) effect of the j^{th} block $\{j = 1, 2, 3\}$

τ_i is the (additive) effect of the i^{th} treatment $\{i = 1, 2, 3, 4\}$

τ_{Bij} is the Interaction between i^{th} treatment and j^{th} block

ε_{ji} is the random error for the i^{th} treatment in the j^{th} block.

Fixed effects: Treatment

Random effects: Block, Block *treatment

3.3 Results

Table 1 shows the compounded chemical composition (% DM basis) of selected fodder species in Bomet County, from proximate analysis to van Soest analysis to metabolizable energy. There was no significant difference in dry matter % between lucerne, green leaf desmodium and Boma Rhodes, at $P > 0.05$. Dry matter of sweet potato vines, green leaf desmodium, green leaf desmodium and chicory also had no significant difference at $P > 0.05$. However, there was a significant difference between Lucerne dry matter % and that of sweet potato vine and chicory at $P < 0.05$. There was a significant difference in crude protein % across all the five experimental fodders; lucerne, green leaf desmodium sweet potato vines, chicory and Boma Rhodes at $P < 0.05$.

There was no significant difference in ether extract % between sweet potato vine, green leaf desmodium, chicory and Boma Rhodes at $P > 0.05$. However, ether extract % of Lucerne differed significantly from all four fodder at $P < 0.05$. There was a significant difference in ash content across all the five fodders; lucerne, green leaf desmodium sweet potato vines, chicory and Boma Rhodes at $P < 0.05$. There was a significant difference in crude fibre % across all the five fodders; lucerne, green leaf desmodium sweet potato vines, chicory and Boma Rhodes at $P < 0.05$.

There was no significant difference in neutral detergent fibre content level between sweet potato vine and chicory at $P > 0.05$. While, neutral detergent fibre content levels of lucerne, green leaf desmodium, and Boma Rhodes differed significantly at $P < 0.05$. Green leaf desmodium differed significantly in neutral detergent fibre content level from that of sweet

potato vine and chicory at $P < 0.05$. Boma Rhodes also differed significantly in neutral detergent fibre content level from that of sweet potato vine and chicory at $P < 0.05$. The neutral detergent fibre content level of Lucerne had a significant difference from that of sweet potato vine and chicory at $P < 0.05$. There was no significant difference between acid detergent fibre % of sweet potato vines, green leaf desmodium and chicory at $P > 0.05$. while acid detergent fibre % of Lucerne and Boma Rhodes differed significantly at $P < 0.05$. Lucerne also differed significantly in terms of acid detergent fibre % with sweet potato vines, green leaf desmodium and chicory at $P < 0.05$. Boma Rhodes had a significant difference in acid detergent fibre % from that of sweet potato vines, green leaf desmodium and chicory at $P < 0.05$.

There was a significant difference in acid detergent lignin% across all five fodders; lucerne, green leaf desmodium sweet potato vines, chicory and Boma Rhodes at $P < 0.05$. There was no significant difference between the metabolizable energy (J/kg) of lucerne and that of Boma Rhodes at $P < 0.05$. However, there was a significant difference between the metabolizable energy (J/kg) of sweet potato vine, green leaf desmodium and that of chicory at $P > 0.05$. However, sweet potato vine differed significantly in terms of metabolizable energy(K/kg) from that of lucerne and Boma Rhodes at $P < 0.05$. Green leaf desmodium differed significantly in terms of metabolizable energy(K/kg) from that of lucerne and Boma Rhodes at $P < 0.05$ as well as chicory which differed significantly in terms of metabolizable energy(K/kg) from that of lucerne and Boma Rhodes at $P < 0.05$.

Table 1: Compounded chemical composition (% DM basis) of selected fodder species in Bomet County

Sample	DM	CP	EE	Ash	CF	NDF	ADF	ADL	ME (J/Kg)
Lucerne	97.13 ^a	14.20 ^a	1.73 ^a	13.35 ^a	19.22 ^a	32.89 ^a	27.41 ^a	5.02 ^a	12.72 ^a
Sweet Potato Vines	95.85 ^b	16.21 ^b	2.76 ^b	14.82 ^b	16.27 ^b	28.33 ^b	38.13 ^b	14.57 ^b	12.05 ^b
Green leafdesmodium	96.41 ^{ab}	15.63 ^c	2.87 ^b	9.67 ^c	27.03 ^c	44.79 ^d	40.39 ^b	6.00 ^c	13.27 ^c
Boma Rhodes	96.55 ^{ab}	4.30 ^d	2.72 ^b	12.35 ^d	36.61 ^d	68.61 ^c	47.73 ^c	18.96 ^d	12.73 ^a
Chicory	95.9 ^b	17.55 ^e	2.53 ^b	19.47 ^e	14.54 ^e	29.08 ^b	40.85 ^b	2.09 ^e	11.64 ^d
P-value	0.0337	<.0001	0.0431	<.0001	<.0001	<.0001	0.0005	<.0001	<.0001
SEM	0.261	0.131	0.2401	0.111	0.155	0.481	1.985	0.265	0.046

DM= dry matter; CP=crude protein; EE= Ether extract; CF=crude fibre; NDF=neutral detergent fibre; ADF=acid detergent fibre; ADL=acid detergent lignin; ME= Metabolisable energy;

a, b, c, d, e: means with the same superscripts in the same column are not significantly different at (P<0.05)

Table 2 shows the Compounded chemical composition (% DM basis) of selected fodder species in Nyandarua County, from proximate analysis to van Soest analysis to metabolizable energy. There was no significant difference in dry matter % across all the five fodders; lucerne, green leaf desmodium sweet potato vines, chicory and Boma Rhodes at $P>0.05$. There was no significant difference in crude protein % of sweet potato vines and that of chicory at $P>0.05$. However, There was a significant difference in crude protein % of lucerne, green leaf desmodium and Boma Rhodes at $P<0.05$. Lucerne also differed significantly in crude protein % from that of sweet potato vines and that of chicory at $P<0.05$. Also, green leaf desmodium differed significantly in crude protein % from that of sweet potato vines and that of chicory at $P<0.05$ which is the same case with Boma Rhodes at $P<0.05$.

There was a significant difference in ether extract % of Lucerne and that of sweet potato vines, green leaf desmodium, chicory and Boma Rhodes at $P<0.05$. However, there was no significant difference in ether extract % between sweet potato vines, green leaf desmodium, chicory and Boma Rhode at $P>0.05$. All five fodder; lucerne, sweet potato vines, green leaf desmodium, chicory and Boma Rhodes differed significantly at $P<0.05$. All five fodders; lucerne, sweet potato vines, green leaf desmodium, chicory and Boma Rhodes differed significantly at $P<0.05$ in terms of ash content. All five fodder; lucerne, sweet potato vines, green leaf desmodium, chicory and Boma Rhodes differed significantly at $P<0.05$ in terms of neutral detergent fibre content.

There was a significant difference in the acid detergent fibre of sweet potato vines, green leaf desmodium and Boma Rhodes at $P<0.05$. However, Chicory and sweet potato vines show no significant difference in acid detergent fibre content level at $P>0.05$. Chicory and sweet potato vines had a significant difference in terms of acid detergent fibre content level of sweet potato vine, green leaf desmodium and Boma Rhodes at $P<0.05$. All five fodders; lucerne, sweet potato vines, green leaf desmodium, chicory and Boma Rhodes differed significantly at $P<0.05$ in terms of acid detergent fibre lignin. There was no significant difference in metabolizable energy (J/kg) of lucerne and Boma Rhode at $P>0.05$. Green leaf desmodium, sweet potato vines, and chicory exhibited a significant difference in terms of metabolizable energy (J/kg) at $P<0.05$. However, each of these three fodders; Green leaf desmodium, sweet potato vines, and chicory differed significantly in terms of metabolizable energy (J/kg) from that of lucerne and that of Boma Rhode.

Table 2: Compounded chemical composition (% DM basis) of selected fodder species in Nyandarua County

Sample	DM	CP	EE	Ash	CF	NDF	ADF	ADL	ME (J/K g)
Lucerne	97.13 ^a	12.55 ^a	1.67 ^a	12.86 ^a	19.03 ^a	32.07 ^a	23.53 ^a	5.02 ^a	12.7 2 ^b
Sweet Potato Vines	95.85 ^a	16.19 ^b	2.67 ^b	14.29 ^b	16.10 ^b	28.02 ^b	40.47 ^b	14.57 ^b	12.0 5 ^c
Green leafdesmodium	96.41 ^a	13.99 ^c	2.97 ^b	9.62 ^c	26.21 ^c	44.87 ^c	38.01 ^c	6.00 ^c	13.2 4 ^a
Boma Rhodes	96.55 ^a	4.63 ^d	3.14 ^b	12.13 ^d	34.57 ^d	68.01 ^d	49.97 ^d	18.96 ^d	12.7 3 ^b
Chicory	95.90 ^a	16.35 ^b	2.81 ^b	18.63 ^e	14.39 ^e	29.07 ^e	38.77 ^b	2.09 ^e	11.6 3 ^d
P-value	0.6192	<.0001	0.0005	<.0001	<.0001	<.0001	0.0005	<.0001	<.00 01
SEM	0.5295	0.1661	0.1585	0.2281	0.1482	0.2934	0.4395	0.1602	0.04 61

DM= dry matter; CP=crude protein; EE= Ether extract; CF=crude fibre; NDF=neutral detergent fibre; ADF=acid detergent fibre; ADL=acid detergent lignin; ME= Metabolisable energy;

^{a, b, c, d, e}: means with the same superscripts in the same column are not significantly different at (P<0.05)

Table 3 shows the Compounded chemical composition (% DM basis) of selected fodder species in Nyeri County, from proximate analysis to van Soest analysis to metabolizable energy. There was no significant difference in dry matter % of lucerne and that of Boma Rhodes at $P < 0.05$. Also, lucerne, sweet potato vine, green leaf desmodium and chicory showed no significant difference in terms of dry matter % at $P > 0.05$. The latter three fodders; sweet potato vine, green leaf desmodium and chicory, each exhibited a significant difference in terms of dry matter % from that of lucerne and that of Boma Rhodes at $P < 0.05$. All five fodders; lucerne, sweet potato vines, green leaf desmodium, chicory and Boma Rhodes differed significantly at $P < 0.05$ in terms of crude protein %.

Sweet potato vines, green leaf desmodium and chicory had no significant difference in terms of ether extract % at $P > 0.05$. Lucerne and Boma Rhode differed significantly in ether extract content level at $P < 0.05$. Each of the former three diets; Sweet potato vines, green leaf desmodium and chicory, differed significantly in terms of ether extract from that one of lucerne and that of Boma Rhode at $P < 0.05$. There was no significant difference in ash content between Boma Rhodes and lucerne at $P > 0.05$. Sweet potato vines, green leaf desmodium and chicory, each had a significant difference in ash content at $P < 0.05$. Each of the latter three fodders; Sweet potato vines, green leaf desmodium and chicory differed significantly in terms of ash content from the former two fodders; Boma Rhodes and lucerne at $P < 0.05$.

All the five fodders; lucerne, sweet potato vines, green leaf desmodium, chicory and Boma Rhodes differed significantly at $P < 0.05$ in terms of crude fibre %. There was no significant difference in neutral detergent fibre % between sweet potato vines and that of chicory. However, Lucerne, sweet potato vines, green leaf desmodium and Boma Rhodes, each showed a significant difference in terms of neutral detergent fibre % at $P < 0.05$. Lucerne, green leaf desmodium and Boma Rhodes, each differed significantly in terms of neutral detergent fibre %, from that of sweet potato vines and that of chicory $P < 0.05$. There was no significant difference in acid detergent fibre % between sweet potato vines, green leaf desmodium and chicory. Also, green leaf desmodium, chicory and Boma Rhodes had no significant difference in terms of acid detergent fibre % at $P > 0.05$. Lucerne also differed significantly from each of the other four fodders; sweet potato vines, green leaf desmodium, chicory and Boma Rhodes.

All five fodders; lucerne, sweet potato vines, green leaf desmodium, chicory and Boma Rhodes differed significantly at $P < 0.05$ in terms of acid detergent lignin %. There is no significant difference in metabolisable energy (J/kg) between sweet potato vines and Boma Rhodes at $P > 0.05$. Lucerne, green leaf desmodium and chicory, differed significantly at $P < 0.05$

in terms of metabolisable energy (J/kg). The later three fodders; Lucerne, green leaf desmodium and chicory, each had a significant difference in terms of metabolisable energy (J/kg), that one sweet potato vines and that of Boma Rhodes at $P < 0.05$. In this study, Table 4 presents results from *in vitro* fodder analysis, shedding light on gas production dynamics. These findings elucidate key factors influencing gas production, providing valuable insights for optimizing fodder composition. This research contributes to the enhancement of livestock nutrition and sustainable agricultural practices.

Table 3: Compounded chemical composition (% DM basis) of selected fodder species in Nyeri County

Sample	DM	CP	EE	Ash	CF	NDF	ADF	ADL	ME (J/Kg)
Lucerne	96.57 ^{ab}	14.04 ^a	1.8 ^a	11.70 ^a	19.27 ^a	32.50 ^a	25.50 ^a	4.7 ^a	12.60 ^a
Sweet PotatoVines	95.72 ^a	16.09 ^b	2.75 ^b	13.79 ^b	15.99 ^b	28.32 ^b	39.47 ^b	14.57 ^b	12.20 ^b
Green leafdesmodium	96.24 ^a	15.51 ^c	2.96 ^{cb}	9.62 ^c	25.31 ^c	44.54 ^c	41.52 ^{bc}	6.07 ^c	13.44 ^c
Boma Rhodes	97.40 ^b	4.06 ^d	2.11 ^d	11.37 ^a	36.67 ^d	68.32 ^d	44.69 ^c	18.70 ^d	12.20 ^b
Chicory	95.94 ^a	17.25 ^e	2.50 ^b	19.24 ^d	13.81 ^e	28.04 ^b	41.98 ^{bc}	2.36 ^e	11.27 ^d
P-value	0.0122	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
SEM	0.2767	0.0199	0.0951	0.2090	0.1135	0.4648	1.510	0.1640	0.0973

DM= dry matter; CP=crude protein; EE= Ether extract; CF=crude fibre; NDF=neutral detergent fibre; ADF=acid detergent fibre; ADL=acid detergent lignin; SEM = standard error of mean.

a, b, c, d, e: means with the same superscripts in the same column are not significantly different at (P<0.05)

Table 4: *In vitro* gas production (ml/200mg DM) of the selected fodders fodder species

Sample	24	48	a (ml)	b (ml)	c (ml/h)	a+b (ml)	RSD
Chicory	7.284 ^d	3.649 ^f	0.953 ^h	3.088 ⁱ	1.759 ^J	4.041 ^l	2.902 ^m
Lucerne	11.841 ^d	4.637 ^f	1.031 ^h	3.047 ⁱ	8.577 ^k	4.078 ^l	3.721 ^m
SPV	10.957 ^d	4.692 ^f	1.042 ^h	2.824 ⁱ	7.278 ^k	3.867 ^l	3.864 ^m
GLD	11.928 ^d	4.661 ^f	1.035 ^h	2.936 ⁱ	7.253 ^k	3.971 ^l	3.967 ^m
Boma Rhodes	3.621 ^d	7.748 ^e	0.092 ^g	3.828 ⁱ	0.062 ^J	3.920 ^l	2.289 ^m
SEM	0.240	0.811	0.037	0.407	1.729	0.423	0.876
P-value	0.240	0.043	<.0001	0.478	0.020	0.996	0.617

a, b, c are constants (Ørskov and McDonald, 1979), RSD=Relative Standard Deviation. c = the rate constant of gas production (ml/h); a = gas production (ml) from readily soluble fraction; b = gas production (ml) from insoluble but degradable fraction; (a+b) = potential gas production
^{defghijklm} Means in the same column with different superscripts are significantly different at (P<0.05); SEM = standard error of mean

The *in vitro* fermentation characteristics of the fodder species varied narrowly among the five selected fodder species. The total gas production (ml/200 mg DM) at 24hr shown in Table 4 shows variations in the digestibility potential with green leaf desmodium (11.928) being the highest and Boma Rhodes (3.621) being the lowest, although their gas production levels are not significantly different at P<0.05. However, this characteristic trend changes at 48 hours, where the highest level of gas production is observed in Boma Rhodes (7.748) while the lowest level of gas production is observed in chicory (3.649) at P<0.05. At 48 hours Boma Rhodes grass differed significantly at P>0.05, with all the other four selected fodder species in terms of gas production while the other four fodder shows no significant differences at P>0.05 in terms of gas production.

In terms of gas production potential (a+b), lucerne registered the highest level (4.078) with sweet potato vines registering the lowest gas production potential level (3.867) however, there was no significant difference at P>0.05 in terms of gas production potential (a+b) among the selected fodder species. The gas production (ml) from a readily soluble fraction(a) among the selected fodder species differed variably. The highest gas production (ml) from a readily soluble fraction (a) was observed in sweet potato vines (1.042) while the lowest gas production (ml) from a readily soluble fraction (a) was observed in Boma Rhodes (0.092) at P<0.05. Boma

Rhodes differed significantly at $P < 0.05$ from that of chicory, lucerne, sweet potato vines, and green leaf desmodium in terms of gas production (ml) from a readily soluble fraction (a).

The highest gas production (ml) from an insoluble but degradable fraction (b) was observed in Boma Rhodes (3.828) while sweet potato vines (2.824) registered the lowest gas production (ml) from an insoluble but degradable fraction (b) at $P < 0.05$. However, there was no significant difference in terms of gas production (ml) from an insoluble but degradable fraction (b) of the five selected fodders at $P < 0.05$. The rate constant of gas production (ml/h) (c) among the five selected fodder species differed variably. Lucerne (8.577) had the highest rate constant of gas production (ml/h), while Boma Rhodes (0.062) had the lowest rate constant of gas production (ml/h) at $P < 0.05$. There was no significant difference in terms of the rate constant of gas production (ml/h) between lucerne, green leaf desmodium and sweet potato vines, with the same characteristic observed between chicory and Boma Rhodes at $P > 0.05$. The latter two and the former three fodder species differed significantly at $P < 0.05$ in terms of the rate constant of gas production (ml/h) as shown in Table 4.

The degradation curve in Figure 4 clearly shows that chicory had the highest degradation at the 48th hour while Boma Rhodes had the lowest among the five selected fodders. Figure 4 shows that there was an exponential increase in degradation in all five fodders until they reached the 48th hour when they began to flatten signifying almost complete degradation of fodders. The coefficient of variation of all the data sets of the selected fodder showed no significant differences at $P > 0.05$ as shown in Table 4 by the relative standard deviation of the selected fodder species.

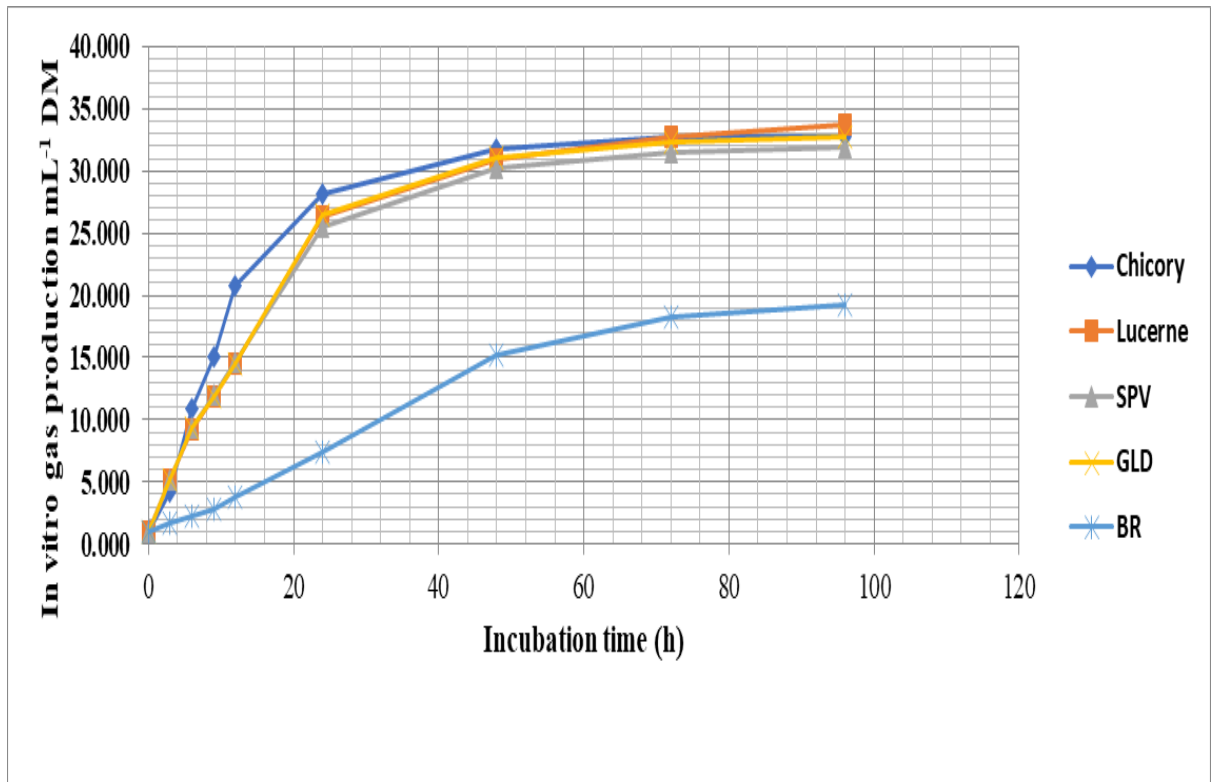


Figure 4: *In vitro* dry matter degradability for five selected feed resources

Metabolizable energy (MJ/kg DM) determined by *in vitro* digestibility, differed among the selected fodder species. The ME MJ/kg DM for chicory, lucerne, sweet potato vines, and green leaf desmodium had no significant difference at $P > 0.05$. Metabolizable energy (MJ/kg DM) for chicory and Boma Rhodes had no significant difference at $P > 0.05$. However, Boma Rhodes differed significantly at $P < 0.05$ from lucerne, sweet potato vines and green leaf desmodium in terms of metabolizable energy (MJ/kg DM) as shown in Table 5. The short-chain fatty acids (SCFA mmol/200mg DM) for all five fodder species were similar $P > 0.05$. Organic matter digestibility (OMD%) among the selected fodder species differed variably. The OMD% (DM) for chicory differed significantly at $P < 0.05$ from that of Boma Rhodes. However, there was no significant difference at $P > 0.05$ in terms of OMD% (DM) for chicory, lucerne, sweet potato vines and green leaf desmodium. There was also no significant difference at $P > 0.05$ in terms of OMD% (DM) for lucerne, sweet potato vines, green leaf desmodium and Boma Rhode as shown in Table 5.

Table 5: Evaluated metabolizable energy (ME MJ/kg DM), organic matter digestibility (OMD%), and short-chain fatty acids (SCFA mmol/200mg DM) of selected fodder species by *in vitro* digestibility

Sample	ME (MJ/KG DM)	SCFA (mmol/200mg DM)	OMD% (DM)
Chic	2.700 ^{ab}	0.157 ^c	22.849 ^e
Luc	3.431 ^a	0.259 ^c	23.581 ^{de}
SPV	3.496 ^a	0.239 ^c	23.740 ^{de}
GLD	4.018 ^a	0.261 ^c	23.680 ^{de}
BR	1.579 ^b	0.076 ^c	25.921 ^d
SEM	0.465	0.063	0.751
P-value	0.032	0.241	0.1224

ME= Metabolizable energy; SCFA = Short-chain fatty acids; OMD = Organic matter digestibility ^{Abcde} Means in the same column with different superscripts are significantly different at (P<0.05); SEM = standard error of mean

3.4 Discussion

The meticulous analysis of forage composition across the distinct counties of Bomet, Nyandarua, and Nyeri offers a nuanced understanding of the inherent similarities and intriguing discrepancies. These variations are reflective of multifaceted interactions involving environmental conditions, agricultural practices, and regional peculiarities influencing forage growth and nutritional content. The evaluation reveals a notable commonality in dry matter content across all three selected counties. The absence of significant differences suggests potential similarities in environmental conditions, harvesting practices, or forage management strategies that collectively contribute to consistent moisture levels. A shared aspect emerges in the realm of crude fibre content, showcasing significant differences in all counties. This could indicate a commonality in the impact of plant maturity or similar processing methods affecting the fibre composition of forage as clearly elaborated in the finding of Moore *et al.* (2020), on how various factors affect fodder nutrient composition.

While Bomet exhibits pronounced differences in crude protein content across fodders, Nyandarua and Nyeri showcase uniformity in certain fodders. This disparity hints at potential variations in soil fertility, fertilization practices, or the inherent genetic makeup of forage plants

specific to each county. Notably, Bomet displays significant differences in ether extract content for Lucerne, whereas Nyandarua and Nyeri do not. This discrepancy could be rooted in variations in lipid synthesis influenced by sunlight exposure, soil conditions, or the genetic composition of forage plants. This finding is in line with the findings of Elgersma and Søgaard (2018) on plant factors that bring diversity in plant nutrient composition.

Nyandarua and Nyeri present significant differences in total ash content, contrasting with Bomet. These disparities may be linked to variations in soil mineral composition, fertilization practices, or regional geographical influences shaping the nutritional makeup of forage. Bomet exhibits distinctive differences in NDF, ADF, and ADL across fodders, while Nyandarua and Nyeri display variations in specific fodders. These discrepancies may be attributed to counties' differences in forage plant genetics, growth conditions, or processing methods employed, these findings concur with the work of Jangra and Madan (2018)

Bomet and Nyeri manifest significant differences in metabolizable energy, whereas Nyandarua does not. This variation could be associated with differences in carbohydrate composition, plant metabolism, or regional climatic conditions influencing forage quality. In delving deeper into the observed discrepancies, several factors warrant consideration. Geographical and climatic variances stand out as influential determinants, as the three selected-counties encompass diverse climates, soil types, and altitudes. These factors collectively impact plant growth, nutrient absorption, and forage composition. Agronomic practices also contribute to the observed variations. Differences in fertilization practices, crop management, or harvesting techniques may introduce discrepancies in forage composition. The genetic makeup of forage plants can play a pivotal role, with regional variations influencing nutrient content and composition, as it is with the findings of López-Angulo *et al.* (2020).

Differences in gas production among the feed ingredients could be a result of the amount of substrate fermented *in vitro*. The *in vitro* gas production and fermentation parameters indicate the presence of potential degradable nutrients in the feed ingredients. This variation in gas production is due to differences in levels of fermentable carbohydrate nutrient availability or organic matter (OM) availability which was fermented to form volatile fatty acids and, therefore, a varying amount of gas volumes was produced. It could also be due to fodder species difference, the amount of substrate fermented *in vitro* between grasses and legumes have a different degradation rate, as well as the presence of the neutral detergent fibre and lignin content or anti-

nutritive factors which affect nutrient utilization by the microbes thus delaying the onset of degradation of nutrients in the rumen (Pratama *et al.*, 2020), suggested that gas production from protein fermentation is relatively small as compared to carbohydrate fermentation while the contribution of fat to gas production is negligible. The differences in gas production between the indigenous browse species could be a result of the quantity of substrate fermented (Kemboi *et al.*, 2017). On the other hand, it is a reflection of microbial growth and the accessibility of feed to microbial enzymes (Fetissov, 2017).

The level of short-chain fatty acids (SCFA) (Acetate, Propionate, and Butyrate) is an indicator of the energy value of fodders. Despite being waste products, fermentative gases (primarily CO₂ and CH₄) represent degraded feed components. Conceptually, the use of *in vitro* gas tests is then only justified by a close linkage between the waste products and useful fermentation products, i.e., short-chain fatty acids (SCFA) and/or microbial biomass (Pérez-Márquez *et al.*, 2023). Likely, additional nitrogen amino acid and peptide supply in the protein feed sources increase overall substrate incorporation into microbial cells, with less substrate being converted to SCFA (Acetate, propionate, and butyrate) and gases. In this case, the depressing effect of protein on gas production would be caused by a change in the partitioning of the fermented substrate between microbial cells and SCFA and gases and not by a distortion of the stoichiometrical relationship between SCFA and gas production as such (Klop *et al.*, 2017). This explains why the high mmol/kg⁻¹ DM of SCFA produced by the five selected fodder was not significantly different at P>0.05.

Furthermore, processing methods, such as drying or chopping, may introduce variations in nutritional content. Soil fertility emerges as a critical factor, with differences in nutrient levels potentially contributing to variations in mineral content across the three selected counties. The observed variations in forage composition across the counties of Bomet, Nyandarua, and Nyeri are intricately linked to the subsequent impact on the milk yield of Friesian dairy cows, as discussed earlier. The nutritional content of forage directly influences the dietary intake and, consequently, the performance of dairy cows.

3.5 Conclusion

This study provides a comprehensive analysis of the chemical composition and nutritional value of selected fodder species—lucerne, green leaf desmodium, sweet potato vines, chicory, and Boma Rhodes—across three counties in Kenya: Bomet, Nyandarua, and Nyeri. The proximate and van Soest analysis, along with the metabolizable energy evaluation, revealed significant differences in various nutritional parameters among the fodder species, with critical implications for livestock feeding strategies. Across the three regions, lucerne consistently exhibited higher crude protein content compared to the other fodders, making it a superior option for enhancing livestock protein intake. However, the variation in crude protein and fibre content, particularly in green leaf desmodium, sweet potato vines, and chicory, emphasizes the need for region-specific feed interventions. The study found no significant differences in dry matter and ether extract content between certain fodder types, but lucerne differed significantly from the others in ether extract content, highlighting its potential to offer higher energy yields for ruminant animals.

Neutral detergent fibre (NDF) and acid detergent fibre (ADF) values indicated that lucerne, green leaf desmodium, and Boma Rhodes had significantly different fibre profiles compared to sweet potato vines and chicory. This difference suggests that these three fodders may provide more digestible fibre, which is essential for improving rumen function and enhancing feed efficiency. The significant variation in acid detergent lignin across all five fodders further supports the conclusion that different fodder species may contribute variably to animal performance, depending on their fibre quality. In terms of metabolizable energy, lucerne, green leaf desmodium, and chicory consistently outperformed sweet potato vines and Boma Rhodes. This indicates that these fodders are better suited for energy-demanding stages of animal production, such as lactation or growth.

Furthermore, the *in vitro* gas production analysis provided valuable insights into the fermentation dynamics of the fodders, offering a deeper understanding of their digestibility and potential to optimize livestock nutrition. In conclusion, this study demonstrates the importance of selecting appropriate fodder species based on their nutritional profiles, especially in terms of crude protein, fibre content, and metabolizable energy. The findings underscore the potential of lucerne and green leaf desmodium as key components of sustainable feeding strategies in smallholder dairy systems in Kenya.

CHAPTER FOUR
EFFECT OF SUPPLEMENTING FRIESIAN COW DIETS WITH SELECTED
FODDER-MIXTURE ON MILK YIELD IN SMALLHOLDER DAIRY FARMS IN
THREE SELECTED COUNTIES IN KENYA

Abstract

Over three decades, the mean daily milk production per cow in these counties has remained stagnant at a mere 6 kg/day, despite the pivotal role it plays in improving the well-being of impoverished farmers and addressing poverty and hunger. With most smallholder farmers yielding a mere 3.67 litres of milk per cow daily, it's evident that their productivity falls well below par. In an effort to address this issue, a study conducted delves into the second objective, which revolves around assessing the effects of diverse dietary supplements on milk yield across three geographically distinct counties: Bomet, Nyandarua, and Nyeri. The study involved the utilization of a supplementary feed mixture with a dry matter content of 400 g/kg DM, incorporating lucerne, green leaf desmodium, sweet potato vines, and chicory, with a dry matter content of 900 g/kg DM, mixed in specific proportions. The supplement feed mixture with a dry matter content of 400 g/kg DM, composed: of lucerne, green leaf desmodium, sweet potato vines and chicory was chopped and mixed in a ratio of 1:2:3:1. Supplementation was done at the following inclusion levels; T₁ (0%), T₂ (10%), T₃ (20%) and T₄ (30%) of the estimated daily dry matter intake of 4% of the live body weight of the dairy cow. This study ran for nine weeks in each county; one week of backgrounding all the animals, then two weeks of adaptation and then six weeks of data collection. Data analysis was conducted by subjecting the variables to ANOVA within a randomised complete block design (RCBD) to account for variations across counties. Significant differences between means were determined using the New Duncan's multiple range test at a 5% confidence level. The results revealed that in Bomet, the highest milk yield of 4.1 litres was achieved with a 20% supplementation rate. In Nyandarua, the maximum yield of 10.0 litres was recorded at a 30% supplementation rate. In Nyeri, a yield of 8.0 litres was observed with a 20% supplementation rate, with significance established at $P < 0.05$. These outcomes underscore the regional nuances in the influence of dietary supplementation on milk production, offering valuable insights for dairy farmers to tailor feeding strategies based on geographical considerations. Further research could explore the nutrient utilization efficiency and metabolic pathways involved in milk synthesis.

4.1 Introduction

Many countries have a low-cost production system like Kenya's, which is centred on rain-fed pasture production. More than 1.5 million small-scale dairy producers in Kenya rely on dairy products for their livelihoods, which account for 4.5 per cent of Kenya's GDP and 12 per cent of agricultural GDP. As a result, it creates 500,000 indirect jobs and 750,000 direct jobs and contributes to other service sectors such as livestock feed and processing, animal health – care, and breeding (KDB, 2016). On average, 80 to 100 kg of dairy products are consumed annually per person in Kenya, according to the Kenya Dairy Board (KDB). In contrast, in most Central and East African countries, the per capita dairy consumption is less than 30 kg (Kasirye & Ssewanyana, 2015).

Kenya generates roughly 5.2 billion litres of fresh milk each year, primarily from dairy cattle, thanks to the country's well-developed dairy subsector. For an estimated 1.6 million small-scale farmer households, dairy production has proven to be an important source of income and food, producing 80 per cent of the country's total milk output, according to reports (KDB, 2016). Livestock husbandry is an important part of many countries' economies (FAO, 2018). Livestock production accounted for 40% of the total agricultural output in 2014 in developed countries, according to FAO (2018), and only 20% in developing nations. About 20% of the world's population, who primarily live in rural and peri-urban areas, depend on small-holder dairy farming (SDF) for their livelihood (McDermott *et al.*, 2010). Kenya has the second-largest dairy sector in Sub-Saharan Africa in terms of milk production and consumption. In the dairy industry, there are around 2,209,980 alien cattle and 13,005,664 native cattle (GOK, 2019). Dairy cows produce about 88%, while camel and dairy goat production accounts for the rest of the milk supply (GoK, 2013). Kenyans consume an average of 90 kilograms of milk per person each year. To put it another way, Kenya is regarded as among the most milk-producing countries on the continent of Africa (FAO, 2011).

Despite the fact that small-holder production of milk is a profitable business in Kenya, it is hampered by a lack of adequate feeds, both quantitatively and qualitatively (Mutavi *et al.*, 2016). In market price support (MPS) in the tropics, one of the most significant difficulties that producers face is livestock nutrition, which is directly associated with environmental factors like temperature and rainfall (Edson *et al.*, 2018), these are two main issues plaguing tropical MPS. The dry period, which can last up to six months, reduces pastures' quantity and quality. Their low crude protein

content (80g/ kg) and high digestibility coefficient neutral fibre detergent content are quite apparent during this time (Mekuriaw & Asmare, 2018). High-potential agroecological zones can yield up to 4575 kilograms of milk per cow per year (Mugambi *et al.*, 2015). In response to variations in animal breeds and production systems, agroecological zones had an impact on production owing to the accessibility of high-quality feeds (Muia *et al.*, 2011). In order to support the production of milk proportions, reserved proteins in the body of an animal must be mobilised due to nutritional stress in cattle. And because of that, milk yield decreases, and the productive capacity of livestock, including even improved breeds, is not optimally exploited (Mwendia *et al.*, 2018). On the other hand, small-scale dairy farmers only yield 3.67 litres of milk per day, which indicates that they are not very productive (Wambugu *et al.*, 2011). Poor feeding techniques and a lack of technical support for dairy and crop farming are to be blamed for this low productivity (Mawa *et al.*, 2014).

Supplements of commercial protein concentrate are commonly used to counteract the seasonal nutritional deficit. This practice drives up production costs for small producers and reduces their profit margins (Edson *et al.*, 2018; Mendieta-Araica *et al.*, 2011); Low productivity and high production costs are other important difficulties for the dairy sector, according to Tegemeo Institute (2016). Due to the rapidly urbanising Kenyan population, growing milk demand, and rising incomes, there is an urgent need to boost the country's dairy productivity (Wambugu *et al.*, 2011). It was found by Mutua (2015) that the average daily milk production per cow was only 5.46 litres rather than the 12 litres expected. The dairy industry's inefficiency is evident in this situation. Small-scale dairy farmers in the country may be experiencing inefficiencies as a result of high feed-input costs and low productivity.

The level of milk production in the country has been the subject of a number of studies (Mugambi, 2014). Despite the fact that milk production has remained low while costs have risen, very few researchers have attempted to determine the economic feasibility of dairy production among small-scale farmers. As a result, there has been no evaluation of the dairy farmers' economic efficiency as a result of the nutritional training provided by the Canadian organisation known as Farmer Helping Farmers in 2013. Researchers in Kenya set out to determine the economic efficiency of milk production among small-scale dairy farmers; identified nutritional constraints as a major source of inefficiency and thus provided measures to reduce the inefficiency. The

Malabo Declaration's goal of eradicating world hunger by 2025 was made easier with increased milk production (FAO, 2018).

Friesian dairy cows are renowned for their high milk production potential, but their performance can be significantly affected by the quality of their diet. In smallholder, dairy farms in Kenya, where conventional feed often consists primarily of Boma Rhodes grass hay, supplementation with nutrient-dense fodders is critical to enhance milk yield and overall productivity (Balehegn *et al.*, 2020). Boma Rhodes grass, while a common choice, may not provide sufficient nutritional value on its own, leading to suboptimal milk yields. Supplementing this with a diverse feed mixture, including lucerne, green leaf desmodium, chicory, and sweet potato vines, could potentially address these nutritional gaps and improve lactation performance (Mburu *et al.*, 2024).

Recent research underscores the importance of optimizing feed compositions to maximize dairy cow productivity in smallholder systems. High-quality supplements like lucerne and green leaf desmodium are known for their superior protein and mineral content, which can significantly enhance milk production when combined with Boma Rhodes grass (Crovetto *et al.*, 2022). Additionally, chicory and sweet potato vines provide valuable vitamins and additional nutrients that contribute to overall dairy cow health and milk yield (Hilbert & Rambaud, 2023). Evaluating the impact of such a feed mixture on Friesian cows in specific Kenyan counties; Bomet, Nyandarua, and Nyeri, could provide valuable insights into improving dairy farm productivity and offer practical recommendations for enhancing feed strategies in similar smallholder settings.

4.2 Material and Methods

4.2.1 Description of the Study Areas

The first experimental study was carried out in Tagiamin village, in Kongasis ward, Chepalungu sub-county in Bomet County-0.7942421° 47' 8.0196" S, 35.3478951° 20' 20.8968" E, 223 Km from Nairobi In according to Latlong (2023). In 2019, its population was 875,689, and its total area was 1,630.0 square kilometres. Bomet Town is the county seat of Bomet County. As the country's centre, the capital is easily accessible from across all corners and districts of the area. The Narok-Kisii road, where the town is situated, is very busy (BCG, 2020). Bomet experiences brief, warm, and cloudy summers and long, cool, mostly clear winters. The average yearly temperature ranges from 11.67°C to 26.11°C, with only a few exceptions when it drops below

10°C or rises above 28.89°C. There is an average daily temperature of 25.56°C during the warm season, lasting from January 13th to March 21st. February is the hottest month in Bomet, with an average high temperature of 26.11°C and a low temperature of 12.22°C. Summer begins on April 29th and ends on August 29th, with an average daily high temperature of 22.78°C or lower. Bomet's coldest month is July, with an average low temperature of 11.67°C and a high temperature of 22.22°C (Weatherspark, 2016)

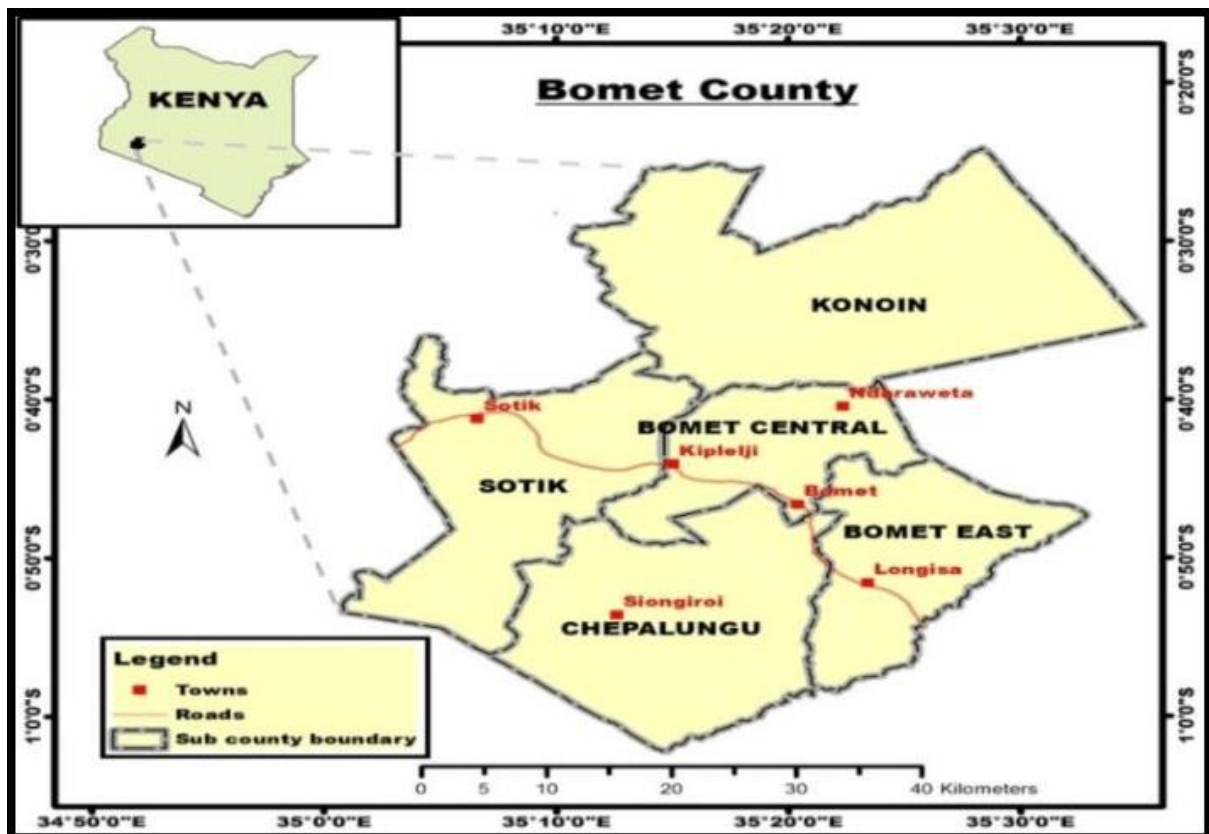


Figure 5: Map of Bomet County showing the study area (Objective two)

Source: Kenya Independent Electoral and Boundaries Commission (2012).

The second experimental study was conducted in Ndaragwa Central constituency, Ngamini Ward, Kahothia Village in Nyandarua County located between geographical coordinates - 0.480098611S, and 36.54974917E. Nyandarua County is a County in the former Central Province of Kenya. Its capital and largest town is Ol Kalou. Formerly the capital was Nyahururu, which is now part of Laikipia County. Nyandarua County has a population of 596,268 and an area of 3,304 km². The county is located in the northwestern part of the old Central Province and contains the Aberdare Ranges (KNBS, 2022). It has a total area of 3,107.7 km² (1,199.9 sq mi). It has a

population of 638,289 as per the 2019 general census. The main economic activity in Nyandarua is farming (crop cultivation and dairy farming) and potato farming. The climate here is classified as Cfb by the Köppen-Geiger system. The temperature here averages 15.8 °C. The rainfall here is around 2276 mm | 89.6 inches per year. The county is located in the northwestern part of the old Central Province and contains the Aberdare Ranges, the distance between Nyandarua and Nakuru is 48 km. While the road distance is 295.4 km. The predominant soils are nitosols, andosols, leptosols, luvisols, phaezems and planosols (KNBS, 2020)

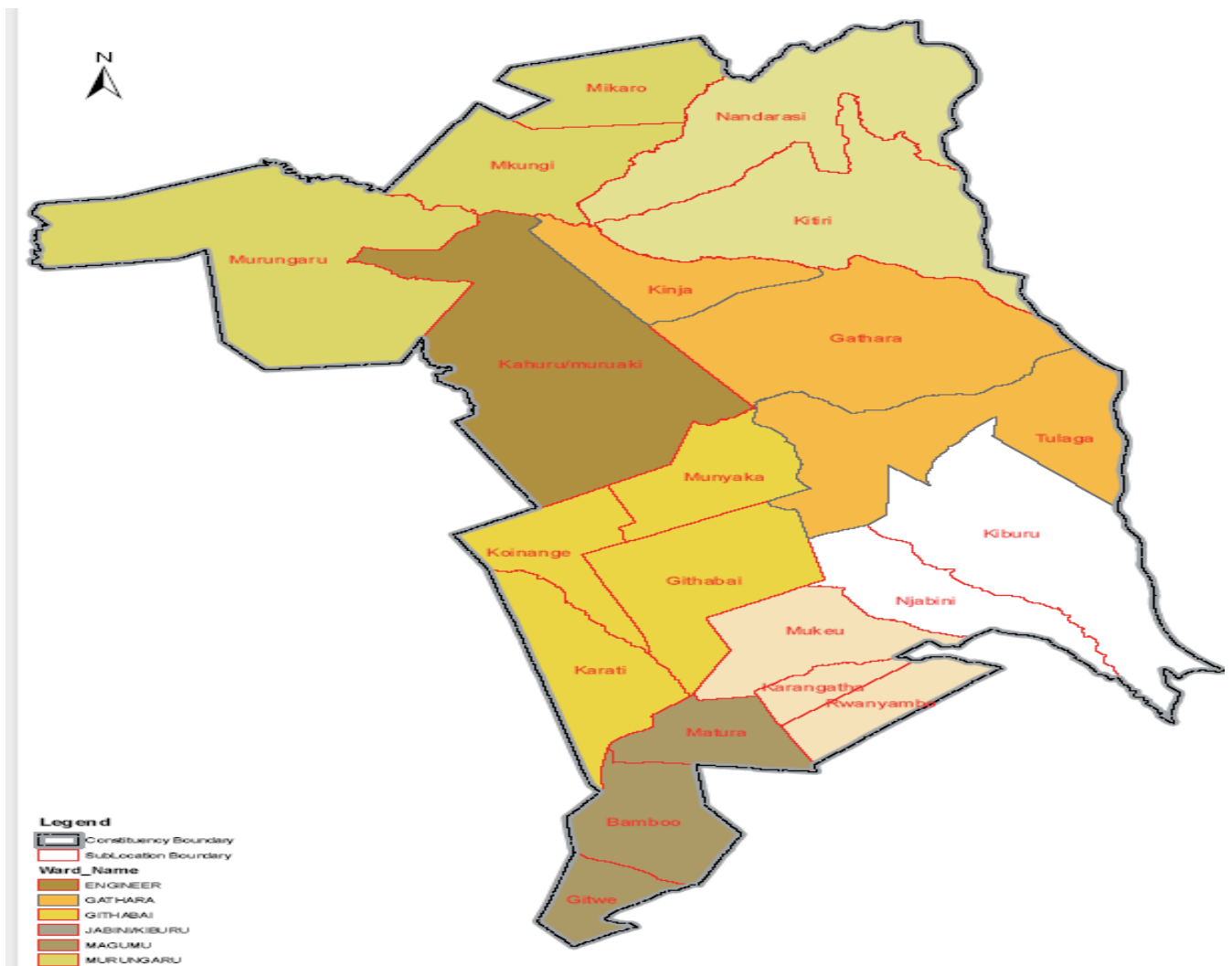


Figure 6: Map of Kinangop sub-county in Nyandarua county showing the administrative boundaries and wards (Objective two).

Source: The guide.org

The third experimental study was carried out in Nyeri County. Mathira West Sub-Countries was chosen for the study based on the number of dairy farmers in it. A population of 759,164 residents in 207.8/km² as estimated by the Kenya National Bureau of Statistics (KNBS) in 2019 (KNBS, 2020). There are common borders with five counties, including Meru to the north and Laikipia to the northern side, Nyandarua to the western side, Murang'a to the southern side, and Kirinyaga to the eastern side, which makes it a leading agricultural innovation hub, located between latitudes 0°25'12" S and 36°56'51" E, the county has an elevation range of 3,076 meters to 5,199 meters above sea level, making it about 150 kilometres north of Nairobi in the distance. The county has both cold and hot months, with an average temperature of 12.80°C in June and July and 20.8°C in the hot months (January-March and September- October). Between 500 and 1600 millimetres of rainfall each year, with the heaviest rains occurring between April and May (MALF, 2016).

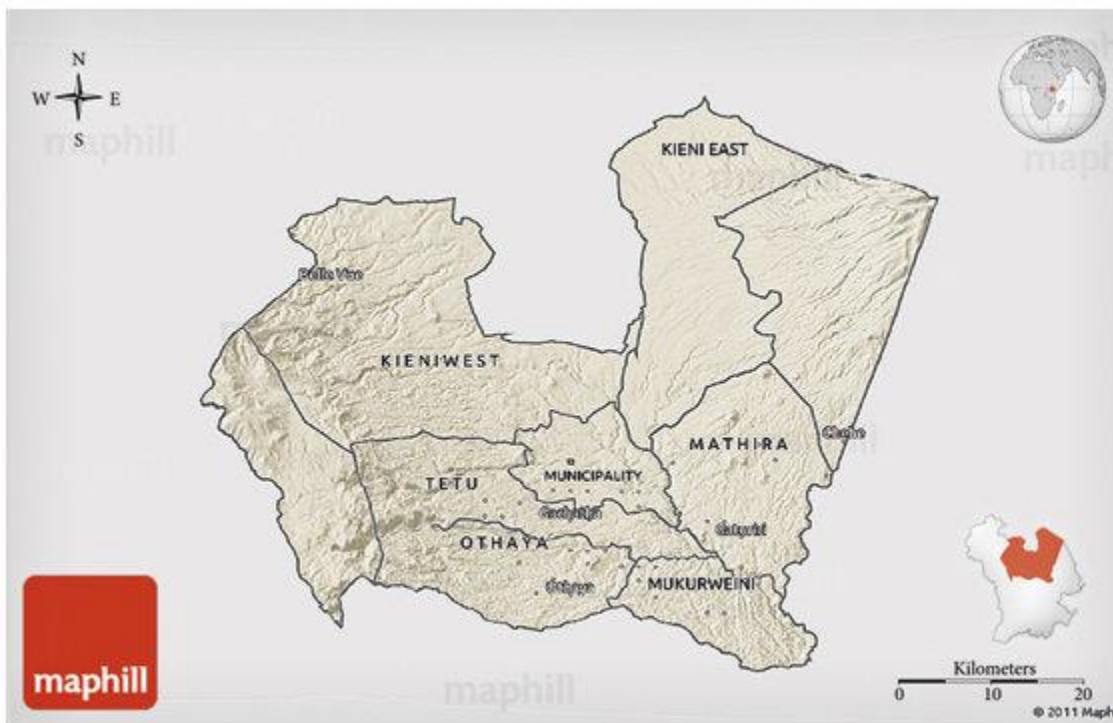


Figure 7: Map of Nyeri County showing the different sub-counties (Objective two)

Map courtesy of Maphill

4.2.2 Sampling

Twelve Friesian lactating cows of the same mid-lactation stage weighing 400 kg \pm 100 live body weight, were selected randomly using the simple random technique from dairy farms around the areas of study in Bomet, Nyandarua and Nyeri County. The sampled animals were isolated in zero grazing stalls. Each replicate contained three Friesian cows which were at their mid-lactation stage. Four dietary treatments were offered to the cows, with each dietary treatment being assigned to a group of three cows per replicate. This setup ensured that each diet was replicated across each county.

4.2.3 Fodder Production and Selection

The selected fodders were established in a 1.2 acre of land belonging to the respective counties' Dairy Cooperative. Where the land was subdivided into units of 70 by 100 feet plot size, and each unit was used to establish a pure stand of fodder. Cattle manure was evenly broadcasted in each land unit and thoroughly mixed with soil. All the fodders were established using standard procedures of specific fodder establishment where DAP Fertilizer was used at the time of establishment and later after 30 days, the fodders were top-dressed using CAN fertilizer. The fodders include Boma Rhode, lucerne, green leaf desmodium, sweet potato vine and chicory. Weeding was done manually after every two weeks. Watering was done using sprinklers and watering cans on days when the rain failed. Before establishing a soil, the analysis was done to determine various soil parameters like pH, salinity and organic matter, that can affect the establishment and growth of the fodders and appropriate measures were taken where needed.

4.2.4 Feed Preparation

Boma Rhodes was harvested four weeks after flowering following 2 to 3 days of dry weather so that drying was possible. Drying was done under shade so that the dried fodder retains its green colour, which is an indicator of quality. It was stored to be used later as hay, while lucerne was harvested when it was 10 per cent flowering, dehydrated under shade and then chopped (Barnhart, 2010) green leaf desmodium was harvested just before flowering around 110 days after establishment (Yegrem *et al.*, 2019). Sweet potato vine was harvested around 120 days after establishment just before the onset of the yellowing of leaves, it was dehydrated and chopped for mixing (Truong *et al.*, 2018). Chicory commander was harvested when the maximum leaf has been attained just before the stem elongates dehydrated and set ready for ration formulation (Deng *et al.*, 2022).

Identified fodders in Bomet that were used as a supplement feed mix on top of the basal diet of Boma Rhodes; lucerne, green leaf desmodium, sweet potato vines and chicory which was cut, dehydrated and chopped into small pieces and mixed thoroughly and stored in a storage container. A feed supplement mixture of lucerne, green leaf desmodium, sweet potato vines and chicory, was mixed in the ratio of 1:2:3:1 respectively, because of the availability and abundance. The experimental diet used in the feeding trial was formulated to meet the nutrient requirements for lactating cows (NRC, 2001).



Plate 6: Experimental fodder being harvested and carried for diet preparation

4.2.5 Experimental Design

The feeding trial to evaluate the suitability of an admixture of lucerne, green leaf desmodium, sweet potato vines and chicory supplementation on milk production and quality in smallholder dairy farms was done across the three selected counties. Twelve Friesian dairy Cows weighing $400 \text{ kg} \pm 100$ live body weight which were of the same mid-lactation stage, subsisting on a basal diet of Boma Rhodes grass hay with a dry matter content of 900 g/kg were selected and isolated in zero grazing stalls. The supplementation feed mixture with a dry matter content of 400 g/kg comprised: lucerne, green leaf desmodium, sweet potato vines and chicory which was chopped and mixed in a ratio of 1:2:3:1 respectively and was supplemented at the following inclusion levels T_1 (0%), T_2 (10%), T_3 (20%) and T_4 (30%) of the estimated daily dry matter intake of 4 per cent of the live body weight of the dairy cows, where three (3) dairy cows being allocated per each dietary treatment. Each dietary treatment was made up of an iso-nitrogenous and isocaloric level.

All the experimental diets were randomized and distributed independently first in each block. This was done in Excel by generating random numbers using the RAND function, [DATA, SORT by column w/ =rand ()]. Boma Rhodes grass hay was used as the negative control as well as the basal diet. The feeding trial ran for a period of 9 weeks in each county, with the 1st week

being used for backgrounding all dairy cows on the basal hay diet only, followed by a two-week adaptation period where the dairy cows were under a basal diet of Boma Rhodes and the supplementation with the feed mixture at various inclusion levels and finally 6 weeks of data collection.

Dietary treatments are 4 Supplementation levels of inclusion i.e., T₁ (0%), T₂ (10%), T₃ (20%) and T₄ (30%)

T₁= Control only (No supplementation)

T₂= Control + 10% experimental diet

T₃ = Control + 20% experimental diet

T₄= Control + 30% experimental diet

Dairy Cows = 4 dietary treatments each fed to each respective replicate which comprises 3 Friesian dairy cows (total no of dairy cows = 12 Dairy cows)

Table 6: Quantity of the experimental diet required for the various inclusion levels.

Experimental diets	Quantity			
	T ₁	T ₂	T ₃	T ₄
Boma Rhodes (Basal diet)	100%	90%	80%	70%
Feed Mixture(supplement)	0%	10%	20%	30%

4.2.6 Management of Experimental Animals

The animals were isolated in specific zero-grazing stalls where they were earmarked with an ear tag for identification. They were dewormed using 30ml Endocure® 10 % v/v Albendazole was administered to control internal parasites and sprayed with 10ml of TikDip 522.5 EC emulsifiable concentrate diluted into 10 litres containing chlorpyrifos 475g/L + cypermethrin 47.5g/L acaricide to control ticks, fleas and mites after every one week. Occasionally this acaricide was alternated with Amitraz 12.5% TickBuster.® An organophosphate acaricide to prevent the external parasites from developing resistance. Vaccination was also done to control East Coast Fever using 20ml Buparvex Injection.® containing Buparvaquone by the intra-muscular route. Other common prevalent diseases affecting dairy cows in the Rift Valley region were also vaccinated against by veterinary officers in the case of an outbreak. 250g of Norbrook milking salve containing 0.55% w/w Dichlorophen BP with lanolin (as an emollient) was used after

milking. All animals were tested for mastitis using the California Mastitis Test (CMT) and then administered antibiotics where appropriate.

The animal weight was determined using a weigh band by utilizing the table of girth circumference (cm) to estimate the weight (kg). Adequate feeds of a mixture of lucerne, green leaf desmodium, sweet potato vines and chicory supplemented to Boma Rhodes were supplied according to the animal nutrient requirement, and the daily dry matter intake of 4 per cent of their live body weight. Feeding was made for seven (7) days to background the dairy cows. After that, it shall be fed for fourteen (14) days for the adoption of the animal and later a thirty-one days feeding was done during which data was collected and recorded. They were fed twice a day, 0800hrs in the morning and 1400hrs in the afternoon and then allowed to have access to water and Maclik Super minerals *ad libitum*.

4.2.7 Data Collection

After 14 days of adapting, the milk yield of each experimental animal was collected and recorded in an Excel sheet separately on a daily basis. This was done on a daily basis at 06:00 hr and 15:00 hr.



Plate 7: Milking the experimental cow during data collection

4.2.8 Statistical Analysis

All variables were subjected to analysis of variance (ANOVA) in a randomised complete block design (RCBD) so as to control for the variation among blocks (Counties) and provide a more accurate estimate of the treatment effects (different dietary inclusion levels). SAS version 9.4 Statistical Package's General Linear Model Procedures (proc GLM) was used. A post-hoc test

to identify specific differences between treatment means was done, where the Significant means were separated using least significance difference (LSD) at 5% significance.

$$H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4$$

$$H_a: \mu_i \neq \mu_j \text{ for at least one pair } i, j$$

Model:

$$Y_{ij} = \mu + \theta_j + \tau_i + \tau_{Bij} + \varepsilon_{ji}$$

Where:

Y_{ij} is the random variable representing the response for treatment i observed in block j ,

μ is a constant (which may be thought of as the overall mean)

θ_j is the (additive) effect of the j^{th} block $\{j= 1, 2,3\}$

τ_i is the (additive) effect of the i^{th} treatment $\{i = 1, 2,3,4\}$

τ_{Bij} is the Interaction between i^{th} treatment and j^{th} block

ε_{ji} is the random error for the i^{th} treatment in the j^{th} block.

Fixed effects: Treatment

Random effects: Block, Block *treatment

4.2.9 Mixed-Effects Model for Cross-Regional Analysis

To accurately assess the impact of dietary supplementation on milk production across the three selected counties (Bomet, Nyandarua, and Nyeri), a mixed-effects model was employed. This statistical approach was chosen to account for the hierarchical structure of the data, where dairy cows and the nutritional composition of the dietary supplements within each county may exhibit variability due to location-specific factors. The mixed-effects model incorporated both fixed and random effects. The fixed effects represented the dietary treatments, specifically the inclusion levels of a supplementary feed mixture (T1: 0%, T2: 10%, T3: 20%, T4: 30%). These fixed effects allowed for the assessment of the average impact of each dietary treatment on milk production.

To account for the variability between counties, random effects were included in the model. These random effects captured the location-specific deviations in milk production, providing a more accurate and generalizable understanding of the dietary treatments' effects. By incorporating these elements, the mixed-effects model provided a robust framework for analysing the suitability of the supplementary feed mixture on milk production, while considering the inherent variability across different geographical locations.

The model can be expressed as follows:

$$Y_{ijk} = \beta_0 + \beta_1 i + U_j + \epsilon_{ijk}$$

Where:

Y_{ijk} is the milk production for the i -th cow in the j -th county due to the k -th diet.

β_0 is the overall intercept (baseline milk yield for T1).

$\beta_1 k$ represents the fixed effect of the k -th dietary treatments.

U_j is the random effect for the j -th county, accounting for variability between counties.

ϵ_{ijk} is the residual error term.

Table 7: Table showing the random distribution of treatment in the blocks by use of random numbers

BLOCK(Countries)		TREATMENT			
BLOCK 1	¹ T2	² T1	³ T4	⁴ T3	
BLOCK 2	⁵ T4	⁶ T2	⁷ T3	⁸ T1	
BLOCK 3	⁹ T3	¹⁰ T4	¹¹ T1	¹² T2	

Legend: The numbers in the upper left-hand corner are stall numbers. Letters T1, T2, T3, and T4 are the treatment

An ANOVA Table 8 was constructed so as to show how the sum of squares is distributed according to the source of variation, and hence the mean sum of squares,

Table 8: Table of Analysis of Variance

Source of Variation	of	Sum of square	Mean square	sum of	Degree of Freedom
Block	r-1				2
Treatment	t-1				3
Error	(r-1) (t-1)				6
Total	(rt)-1				11

Significant Mean Separation was done if we rejected the null hypothesis ($H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4$).

4.3 Results

In this investigation of milk yield dynamics in Table 9 resulting from selected fodder supplementation, it unveils significant findings that shed light on the impact of enhanced feed on dairy production. These results highlight the positive correlation between specific fodder

supplements and increased milk yield, offering valuable insights for dairy farmers seeking to optimize nutritional strategies. This research contributes to the advancement of sustainable dairy practices by providing evidence-based guidance for maximizing milk production through effective fodder supplementation.

Table 9: Dairy performance in different experimental animals under different Intervention levels in Bomet, Nyandarua and Nyeri

Treatment Intervention)	Milk Yield (Litres)		
	Bomet	Nyandarua	Nyeri
1	1.7±0.07 ^a	2.6±0.20 ^a	2.2±0.17 ^a
2	2.7±0.26 ^{ab}	8.0±0.58 ^b	4.5±0.29 ^b
3	4.1±0.09 ^b	7.5±0.29 ^b	8.0±0.29 ^c
4	4.1±0.68 ^b	10.0±0.29 ^c	8.5±0.29 ^c
P-value	0.0033	<.0001	<.0001

a, b and c: means with the same superscripts in the column are not significantly different (P>0.05).

In Bomet, there was no significant difference between the milk yield of experimental animals fed on diet 1 and experimental animals fed on diet 2 at P>0.05. There was also no significant difference in milk yield between the experimental animals fed diet 2, and 3 and the experimental animals fed diet 4 at P>0.05. However, there was a significant difference in milk yield between the experimental animals fed on diets 1 and those fed on diets 3 and 4 at P<0.05. In Nyandarua, there was no significant difference in milk yield for the dairy cow fed on diets 2 and 3, at P>0.05. However, milk yield from the experimental animals fed on diet 4 had a significant difference from that of the cattle fed on diets 1, 2 and 3 at P<0.05. Milk yield from the experimental animals fed on diet 1 had a significant difference from that of the milk yield of experimental dairy cows fed on diets 2, 3 and 4 at P<0.05. In Nyeri, there was no significant difference in milk yield from the experimental dairy cow fed on diets 3 and 4 at P>0.05. There was a significant difference in milk yield from the experimental animals fed on diets 1 and 2 at P<0.05, also milk yield from the experimental animal fed on diets 3 and 4 differed significantly from milk yield from the experimental animal fed on diet 1 as well as those which were fed on diet 2 at P<0.05.

4.4 Discussion

In the comparison between Diet 1 (the control diet with no supplementation) and Diet 2 (basal diet + 10% experimental diet) in Bomet County, there was no significant difference in milk yield at $P > 0.05$. This implies that a 10% supplementation level did not lead to a substantial increase in milk production. For Friesian dairy cows in the specified lactation stage and parity, this suggests that a 10% supplementation might not be sufficient to significantly impact milk yield. Similarly, when comparing Diet 2 (basal diet + 10% experimental diet), Diet 3 (basal diet + 20% experimental diet) and Diet 4 (basal diet + 30% experimental diet), there was no significant difference in milk yield at $P > 0.05$. This finding indicates that elevating the supplementation level from 10% to 20% or 30% did not proportionally increase milk production. The study suggests that a moderate supplementation level, around 20%, could be a practical and effective approach to enhancing milk yield in this county. The absence of a significant difference between milk yield due to Diet 3 and Diet 4 suggests the possibility of a plateau in the cow's ability to utilize the supplemented nutrients. These findings agree with the results of Barros *et al.* (2017) on the possible plateau in the cow's ability to utilize supplemented nutrients.

The most significant finding in Bomet County is the substantial and statistically significant difference in milk yield between milk yield due to Diet 1 and milk yield due to Diet 2, Diet 3 and Diet 4. This implies that a considerable increase in milk production can be achieved by supplementing the basal diet with higher levels of the experimental diet (10%, 20% and 30% supplementation). This finding agrees with research done by Kitilit *et al.* (2013) in Bomet County, which found that a better supplementation of dairy cows had positive effects on milk yield which improves when cattle are supplied with sufficient highly digestible energy, crude proteins.

In Nyandarua County, the evaluation of different dietary treatments on milk yield revealed noteworthy distinctions among the experimental animals. The comparison between milk yield due to Diet 1 (control diet) and milk yield due to Diets 2 (basal diet + 10% experimental diet) and Diet 3 (basal diet + 20% experimental diet) demonstrated a significant difference, suggesting that a 10% and 20% supplementation level resulted in a statistically significant change in milk yield. However, Diet 4, with the highest supplementation level at 30%, exhibited a substantial increase in milk yield, demonstrating a significant difference from Diet 1 (basal diet only), Diet 2 (basal diet + 10% experimental diet), and Diet 3 (basal diet + 20% experimental diet). This outcome

underscores the positive impact of higher supplementation levels on milk production in this specific county this is in line with the findings of Hanrahan *et al.* (2018) on the impact of dietary supplementation in different inclusion levels on milk production.

Furthermore, the comparison between Diet 1 and the supplemented diets (Diets 2, 3, and 4) revealed that the absence of supplementation led to a significantly lower milk yield. Additionally, there was no significant difference in milk yield between Diets 2 (basal diet + 10% experimental diet) and 3 (basal diet + 20% experimental diet), indicating that increasing the supplementation level from 10% to 20% did not result in a statistically significant change in milk production. These findings highlight the importance of carefully selecting the appropriate level of dietary supplementation to optimize milk yield in Nyandarua County. Overall, the study emphasizes the nuanced relationship between dietary supplementation and milk production, providing valuable insights for dairy farmers in Nyandarua County. The results suggest that a strategic approach to supplementation, particularly at higher levels, can significantly enhance milk yield, contributing to more informed decision-making in dairy farming practices in this county which is in line with the findings of Pirondini *et al.* (2015) on the significance of higher supplementation on milk yield on dairy farms.

In Nyeri County, the comparison between Diet 1 (control) and Diet 2 (basal diet +10% experimental diet) showed a significant difference in milk yield, suggesting that a relatively low level of dietary supplementation (10%) led to a significant increase in milk production at $P < 0.05$. The comparison between Diet 3 (basal diet + 20% experimental diet) and Diet 4 (basal diet + 30% experimental diet) also resulted in no significant difference in milk yield at $P > 0.05$. This implies that increasing the supplementation level from 20% to 30% did not lead to a proportional increase in milk production for Friesian dairy cows in Nyeri County. The study suggests that, in this county, higher supplementation levels, such as 20% and 30%, can be more effective in boosting milk yield. The absence of a significant difference between Diet 3 and Diet 4 (20% and 30% supplementation) suggests that the cow's ability to utilize the supplemented nutrients may have reached a plateau at these levels and any additional supplementation may not be economical and effective. Thus, this study suggests that a moderate supplementation level, around 20%, could be a practical and effective approach to enhancing milk yield in this county, this finding goes hand in hand with the research findings of Duguma and Janssens (2016) on the need to find the optimum level of supplementation for maximum milk yield.

The most significant finding in Nyeri County is the substantial and statistically significant difference in milk yield between Diet 1 and Diet 2 (10% and 20% supplementation respectively) and the supplemented diets Diet 3 and Diet 4 (20% and 30% supplementation). This indicates that a significant increase in milk production can be achieved by supplementing the basal diet with higher levels of the experimental diet (20% and 30% supplementation).

4.4.1 Cross-County Comparative Analysis of Dietary Treatments on Milk Yield

In comparing dietary treatments across Bomet, Nyandarua, and Nyeri Counties, variations in milk yield response were observed. Analysis of different supplementation levels (10%, 20%, and 30%) revealed diverse patterns, shedding light on the nuanced relationship between supplementation and milk production. In Bomet County, a 10% supplementation level did not significantly impact milk yield, suggesting that this level may not be sufficient for a substantial increase. However, a notable increase in milk production was observed when supplementation levels were elevated to 20% and 30%. This finding aligns with the notion that higher supplementation levels could be more effective in enhancing milk yield. Similarly, Nyandarua County exhibited significant differences in milk yield between 10% and 20% supplementation levels, with the highest supplementation level at 30% resulting in a substantial increase. This underscores the positive impact of higher supplementation levels on milk production in this county. In Nyeri County, a significant increase in milk yield was observed with a relatively low 10% supplementation level. However, increasing the supplementation level to 30% did not lead to a proportional increase in milk production. The study suggests that, in this county, a moderate supplementation level of around 20% may be a practical and effective approach to enhancing milk yield.

Nyandarua and Nyeri Counties both showed no significant differences in milk yield between diets 1 and 2 (10% and 20% supplementation), as well as Bomet and Nyeri which showed no significant difference in Diet 3 and 4 (20% and 30% supplementation respectively) suggesting a unique response in the pattern. These findings agree with Mwendia *et al.*(2017) research in Nyandarua which highlights the importance of high-quality on-farm fodder to realize a peak in milk yield. Nyandarua County demonstrated a significant difference only between diet 4 and diet 1. However, all three counties showed a significant difference in milk yield due to diet 1, and milk yield due to diet 4. This indicates a distinct result pattern in this county thus emphasizing a notable county variation in response to supplementation. This distinct result pattern may necessitate further

investigation into local factors influencing the observed discrepancies as it is in the findings of Bateki *et al.* (2020).

Cross-county insights reveal commonalities in the lack of significant differences between certain supplementation levels across counties. Factors such as soil types, climate, altitude, forage quality, and cow adaptability may contribute to county disparities in milk yield responses. The observed distinct patterns in response to supplementation highlight the need for county-specific approaches, taking into account local conditions and characteristics. This cross-county analysis emphasizes the importance of understanding the regional nuances in the relationship between dietary supplementation and milk production. Tailoring supplementation strategies based on regional variations can contribute to more effective and informed practices for dairy farmers across diverse geographical areas. This study agrees with the findings of Liu *et al.* (2020).

Bomet County is known for varied agroecological zones, potentially leading to differing responses to supplementation in milk production. Local factors such as soil composition and climate could influence the availability and effectiveness of the supplemented forage. Nyandarua County, characterized by diverse climatic conditions, may exhibit varied responses to supplementation. Local feed availability and cow adaptability to the supplemented forage could contribute to the observed differences. These findings agree with the results of Ajak *et al.* (2020) research in Nyeri where they realised that there was a positive association between milk production and quantity of supplemental diet in Friesian dairy cows. Despite all breeds being Friesian dairy cows, variations in the individual Friesian dairy cows' characteristics across counties may have also contributed to different milk-yield responses to the experimental diet. Differences in dairy farm management practices, including feeding protocols and healthcare, may influence the overall milk–yield response to supplementation.

4.5 Conclusion

In conclusion, the detailed examination of the experimental results from Bomet, Nyandarua, and Nyeri Counties yields nuanced insights into the relationship between dietary supplementation and milk production in Friesian dairy cows. Across the counties, the study reveals that a 10% supplementation level did not consistently lead to a significant increase in milk production, suggesting that this proportion might not be sufficient to impact yield significantly. Furthermore, elevating the supplementation level to 20% and 30% did not consistently result in

proportional increases in milk yield, indicating a potential plateau in the cows' ability to utilize the supplemented nutrients. Notably, the absence of significant differences between the Diet 3 which had 20% dietary supplementation levels and Diet 4 which had 30% dietary supplementation levels in Bomet and Nyandarua Counties suggests a point of diminishing returns, emphasizing the importance of moderation in supplementation. In contrast, Nyandarua County exhibited proportional increases in milk yield with higher supplementation levels, suggesting a county-specific response.

Economic considerations are paramount, as highlighted in the analysis. While the goal is to maximize milk yield, farm profitability must be carefully weighed against the costs associated with higher levels of supplementation. A tailored cost-benefit analysis is recommended for farmers to make informed decisions based on their unique circumstances. The study underscores the need to acknowledge individual variations in cow responses to dietary changes, encompassing genetic factors, health status, and other individual characteristics. Moreover, the county specificity observed in the study emphasizes the importance of considering local conditions, including soil, climate, and farming practices, when formulating effective supplementation strategies. In summary, a moderate level of supplementation, around 20%, emerges as a practical and effective approach for enhancing milk yield in Friesian dairy cows. However, the study underscores the complexity of these relationships, urging continuous monitoring and further research to refine recommendations and address the diverse contexts of individual cow responses in varying environments.

CHAPTER FIVE
INCOME OVER FEED COST ANALYSIS OF UTILIZING SELECTED FODDER
MIXTURE IN SMALLHOLDER FRIESIAN DAIRY FARMS IN THREE SELECTED
COUNTIES IN KENYA

Abstract

Feed costs can account for up to 60% of dairy production expenses, so enhancing feed conversion efficiency to milk is crucial for improving dairy profitability and ensuring sustainable production. This research delves into the intricate dynamics of the economic feasibility of the various dietary treatments by calculating the Income Over Feed Costs (IOFC) in smallholder dairy farms in; Bomet, Nyandarua, and Nyeri, focusing on the optimization of milk production through strategic dietary supplementation. The study, conducted across diverse counties scrutinizes the economic implications of varying levels of experimental feed incorporation. Twelve Friesian dairy cows of the same mid-lactation stage and with consistent parity were subjected to four dietary treatments, each representing different percentages of experimental diet supplementation (0%, 10%, 20%, and 30%). The experiment spanned eight weeks, incorporating a backgrounding period, adaptation phase, and extensive data collection. Results unveiled intriguing county disparities, with Bomet, the highest Income Over Feed Cost (IOFC) of KSh 55 was observed with 20% supplementation, whereas Nyandarua achieved the highest IOFC of KSh 169 with 30% supplementation, and Nyeri recorded the highest IOFC of KSh 140 with 20% supplementation at $P < 0.05$. The study underscores the significance of tailoring dietary strategies to regional contexts, emphasizing the economic benefits of strategic feed supplementation. Future research and experimentation should consider conducting additional research to explore the impact of supplementation on other aspects of dairy cow management, such as reproduction.

5.1 Introduction

Feed costs contribute to up to 60% of dairy production costs, Therefore, improving the efficiency of feed conversion to milk can have a significant impact on the profitability of dairy production. This has always been a goal of animal production to ensure sufficient food, and to maintain producer profitability. The current volatility of milk and feed prices may increase this to 70 per cent (Connor, 2015). The cost of milk production especially the estimation of cash and economic costs is the key indicator for sustainable dairy farming as well as the means of measuring overall economic competitiveness (Ndambi *et al.*, 2017, 2018). Therefore, to remain competitive, dairy organizations and farmers must strive to reduce costs at the farm level (Koonawootrittriron *et al.*, 2012; Leeuwarden, 2019).

Income Over Feed Cost (IOFC) is a critical financial metric in dairy farming, reflecting the profitability of feeding strategies. It represents the difference between the revenue generated from milk production and the cost of feed inputs. Optimizing IOFC is essential for enhancing the financial sustainability of dairy farms, particularly in smallholder systems where resource constraints and economic pressures are prominent. It is used to assess and define feed efficiency of dairy herds and examines efficiency directly from a profitability standpoint also called return over feed (ROF) (Sakwa, 2020). It is calculated as the difference between the total revenue obtained from the sale of milk during a selected time interval and the feed costs associated with its production (Hemme *et al.*, 2014). The IOFC information can be used to assess the viability of future cash flow plans during an upcoming month or year. This information allows the producer to make management adjustments when expected cash flow looks tight and also provides information to evaluate forward-pricing opportunities to determine when pricing milk and feed would be beneficial to farm cash flow.

Income over feed cost, feed cost per day, and feed cost per hundredweight are all measures of efficiency that dairy farmers can use. This allows farmers to determine how much income they put at risk by making a feeding change. Or, how much income they stand to gain from making a feeding change. In turn, it allows the farmers to make better business decisions. Monitoring financial performance and production efficiency frequently is necessary for the economic sustainability of the dairy business at all times, and it is critical during times of low milk prices, high feed prices, or both. This is one of the numerous financial performance indicators that managers can apply to support profitable decision-making (Ferreira, 2015).

Feed mixtures, including those composed of high-quality fodders like lucerne (*Medicago sativa*), green leaf desmodium (*Desmodium intortum*), sweet potato vines (*Ipomoea batatas*), and chicory (*Cichorium intybus*), can potentially improve milk yield and feed efficiency. These forages are known for their high nutritional value compared to traditional feeds like Boma Rhodes grass hay, which is often criticized for its lower nutritional content (Crovetto *et al.*, 2022). Lucerne is rich in protein and highly digestible, making it a valuable component in dairy rations (Thomson *et al.*, 2017). Green leaf desmodium provides both protein and valuable minerals (Havemann *et al.*, 2019). Sweet potato vines are high in energy and fibre, while chicory offers high digestibility and additional minerals (Jancic *et al.*, 2017). Supplementing Boma Rhodes grass with these high-quality forages could lead to improved milk production, potentially increasing income from milk sales.

Assessing IOFC involves analysing both the costs and benefits associated with different feeding strategies. By evaluating the economic impact of supplementing Boma Rhodes grass with a mixture of lucerne, green leaf desmodium, sweet potato vines, and chicory, it is possible to determine whether the additional cost of these supplements is outweighed by the increase in milk production and revenue. This analysis helps in making informed decisions about feed management practices, optimizing profitability, and enhancing farm sustainability (Orodho, 2021). In regions like Bomet, Nyandarua, and Nyeri County, smallholder dairy farmers face unique challenges including limited access to high-quality feed and financial constraints. Improving feed quality and optimising feed costs are crucial for enhancing the profitability of these smallholder farms. By examining the IOFC associated with using a diverse feed mixture, this research aims to provide actionable insights that could support more sustainable and profitable dairy farming practices in these areas.

5.2 Material and Methods

5.2.1 Description of the Study Areas

The first experimental study was carried out in Tagiamin village, in Kongasis ward, Chepalungu sub-county in Bomet County-0.7942421° 47' 8.0196" S, 35.3478951° 20' 20.8968" E, 223 Km from Nairobi In according to Latlong (2023). In 2019, its population was 875,689, and its total area was 1,630.0 square kilometres. Bomet Town is the county seat of Bomet County. As the

country's centre, the capital is easily accessible from across all corners and districts of the area. The Narok-Kisii road, where the town is situated, is bustling (BCG, 2020).

Bomet experiences brief, warm, cloudy summers and long, cool, mostly clear winters. The average yearly temperature ranges from 11.67°C to 26.11°C, with only a few exceptions when it drops below 10°C or rises above 28.89°C. There is an average daily temperature of 25.56°C during the warm season, lasting from January 13th to March 21st. February is the hottest month in Bomet, with an average high temperature of 26.11°C and a low temperature of 12.22°C. Summer begins on April 29th and ends on August 29th, with an average daily high temperature of 22.78°C or lower. Bomet's coldest month is July, with an average low temperature of 11.67°C and a high temperature of 22.22°C (weatherspark, 2016)

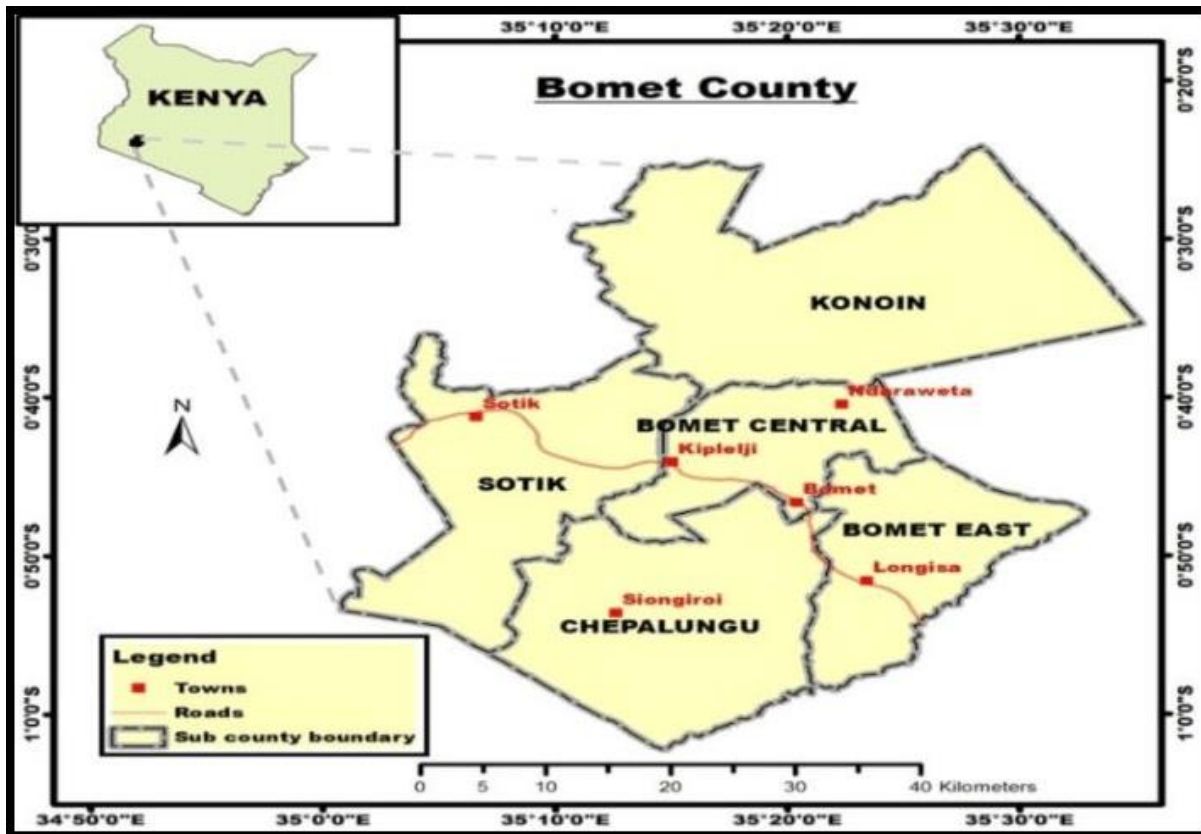


Figure 8: Map of Bomet County showing the study area (Objective three)

Source: Kenya Independent Electoral and Boundaries Commission (2012).

The second experimental study was conducted in Ndaragwa Central constituency, Ngamini Ward, Kahothia Village in Nyandarua County located between geographical coordinates - 0.480098611S, and 36.54974917E. Nyandarua County is a County in the former Central Province

of Kenya. Its capital and largest town is Ol Kalou. Formerly the capital was Nyahururu, which is now part of Laikipia County. Nyandarua County has a population of 596,268 and an area of 3,304 km². The county is located in the northwestern part of the old Central Province and contains the Aberdare Ranges (KNBS, 2022).

It has a total area of 3,107.7 km² (1,199.9 sq mi). It has a population of 638,289 as per the 2019 general census. The main economic activity in Nyandarua is farming (crop cultivation and dairy farming) and potato farming. The climate here is classified as Cfb by the Köppen-Geiger system. The temperature here averages 15.8 °C. The rainfall here is around 2276 mm | 89.6 inches per year. The county is located in the northwestern part of the old Central Province and contains the Aberdare Ranges, the distance between Nyandarua and Nakuru is 48 km. While the road distance is 295.4 km. The predominant soils are nitosols, andosols, leptosols, luvisols, phaezems and planosols (KNBS, 2020)

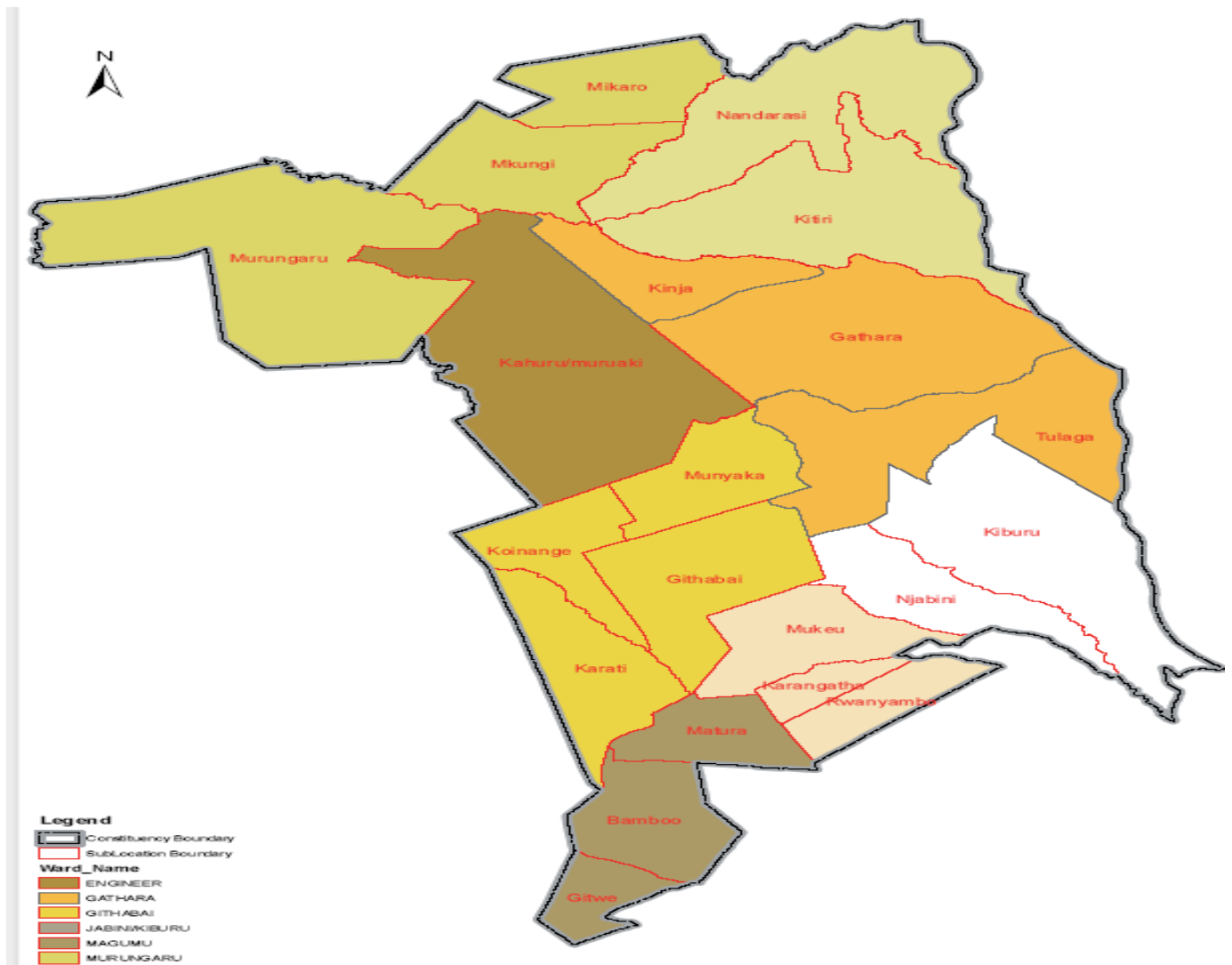


Figure 9: Map of Kinangop sub-county in Nyandarua county showing the administrative boundaries and wards (Objective three)

Source: The guide.org

The third experimental study was carried out in Nyeri County. Mathira West Sub-Counties was chosen for the study based on the number of dairy farmers in it. A population of 759,164 residents in 207.8/km² as estimated by the Kenya National Bureau of Statistics (KNBS) in 2019 (KNBS, 2020). There are common borders with five counties, including Meru to the north and Laikipia to the northern side, Nyandarua to the western side, Murang'a to the southern side, and Kirinyaga to the eastern side, which makes it a leading agricultural innovation hub, located between latitudes 0°25'12" S and 36°56'51" E, the county has an elevation range of 3,076 meters to 5,199 meters above sea level, making it about 150 kilometres north of Nairobi in the distance.

The county has both cold and hot months, with an average temperature of 12.80°C in June and July and 20.8°C in the hot months (January-March and September- October). Between 500 and 1600 millimetres of rainfall each year, with the heaviest rains occurring between April and May (MALF, 2016).

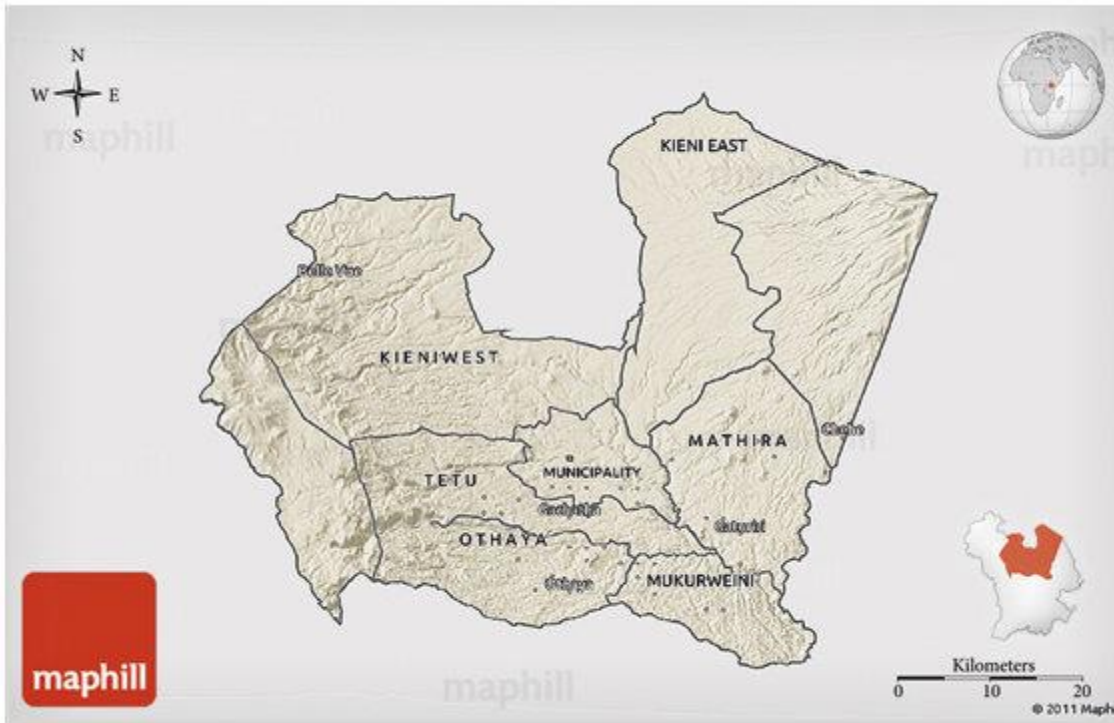


Figure 10: Map of Nyeri County showing the different sub-counties (Objective Three)
Map courtesy of Maphill

5.2.2 Data Collection

Feed cost associated with milk production, and income from milk sales, was included in the data. All of the following information was collected: The number of dairy cows per replicate, feed cost, and milk yield were collected and recorded. The data collected included the quantities and prices of input (feeds) and output (milk production). The study calculates Feed costs (KES/L, Cow/d) and income from milk sales (KES/L, Cow/d) to get the margin (income over feed costs).

The formula used to calculate income over feed cost (IOFC) was;

$$\text{IOFC (KES/L/d)} = (P_{\text{milk}} * \text{DAMP}) - (\text{DFC (KES/L/d)}) \quad (\text{Bailey et al., 2009}).$$

where;

IOFC = income over feed cost

KES/L/d = Kenya shillings per litre per day

$P_{milk} * DAMP$ = price of milk multiplied by daily average milk production

DFC = daily feed cost

A farm's gross margin is defined as the difference between the value of its gross output and the variable costs of the farm, which change depending on the quantity of production. (Kibiego *et al.*, 2015) provided the formula:

Profit and loss were calculated as:

Profit/loss = Total Benefits (Revenue) – Total costs

Empirically this model is specified as outlined below:

$$\prod i = \sum_{i=1}^{i=n} P_y Y - \sum_{i=1}^{i=n} P_x X$$

where;

$\prod i$ = Profit and loss

P_y = Price of dairy products sold

Y = Quantity of dairy products sold

$$\sum_{i=1}^{i=n} P_y Y = \text{Total benefits from the sales of dairy products and other outputs}$$

P_x = Cost of inputs/variables

X = Quantity of inputs/variables

$$\sum_{i=1}^{i=n} P_x X = \text{Total costs incurred by the farmer}$$

The gross margin derived by the dairy farm was a measure of its performance. Revenue in this study was considered as the value of the milk produced on the farm. In the case of milk revenue, $R = p \cdot q$ Where R = Revenue, p = Price of milk per litre, and q = Milk output (litres)

5.2.3 Data Analysis

All variables were subjected to analysis of variance (ANOVA) in a randomised complete block design (RCBD) to control for the variation among blocks (counties) and provide a more accurate estimate of the treatment effects (different diets). SAS version 9.4 Statistical Package's General Linear Model Procedures (proc glm) was used. A post-hoc test to identify specific

differences between treatment means was done, where the Significant means were separated using least significance difference (LSD) at 5% significance.

$$H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4$$

$$H_a: \mu_i \neq \mu_j \text{ for at least one pair } i, j$$

Model:

$$Y_{ij} = \mu + \theta_j + \tau_i + \tau_{Bij} + \epsilon_{ji}$$

Where:

Y_{ij} is the random variable representing the response for treatment i observed in block j ,

μ is a constant (which may be thought of as the overall mean)

θ_j is the (additive) effect of the j th block $\{j= 1, 2,3\}$

τ_i is the (additive) effect of the i th treatment $\{i = 1, 2,3,4\}$

τ_{Bij} is the Interaction between i th treatment and j th block

ϵ_{ji} is the random error for the i th treatment in the j th block.

Fixed effects: Treatment

Random effects: Block, Block *treatment

5.3 Results

$$IOFC = \frac{\text{Milk Yield (litres)} \times \text{Milk Price per litre} - \text{Cost of Feed per cow}}{\text{Number of Cows}}$$

Estimating feed costs involved: Understanding the nutritional needs of the cow, then based on the nutritional requirements, the daily feed requirements for each cow were calculated. A thorough search of the local prices of each selected fodder feed mixture price was considered before estimating the daily feed consumption for each type of feed.

$$\text{Daily Feed Cost} = \text{Daily Feed Consumption} \times \text{Feed Price}$$

Estimated that one litre of milk is retailing at KSh 60, and the cost of each fodder diet is as follows:

$$\text{Daily Dry Matter Intake per cow} = 4\% \times \text{Live Body Weight}$$

$$\text{Daily Dry Matter Intake per cow} = 0.04 \times 400\text{kg}$$

$$\text{Daily Dry Matter Intake per cow} = 16\text{kg}$$

Cost of Boma Rhode and Experimental Diet:

$$\text{Daily Feed Cost per cow} = \text{Daily amount Feed Consumption per cow (kg)} \times \text{Feed Price per kg}$$

When the farm price of 1kg Boma Rhodes was KSh 4.69, Therefore,

Daily Feed Cost per cow $\text{KSh } 4.69 \times 16 = \text{KSh } 75$.

The cost per kg of the experimental diet was found to be KSh 9.4 based on this calculation.

Cost per kg of Experimental Diet = Total weight of Diet /The overall cost of Diet

The cost of the experimental diet at KSh 9.4 per kg was determined by considering various costs associated with fodder production. This comprehensive calculation includes expenses related to the procurement of different fodder components, their proportions in the overall diet, and additional costs associated with feed production. The goal was to incorporate all relevant expenses to arrive at an accurate and representative cost per kilogram of the experimental diet. This approach ensures a thorough understanding of the financial implications of formulating and implementing the experimental diets in the study.

Table 10: Fodder quantities used at different levels of inclusions

Dietary Treatment	Level of Supplementation			
	T1(0%)	T2 (10%)	T3 (20%)	T4 (30%)
Basal diet (Boma Rhodes) per animal/Day	16Kg (100%)	14.4Kg (90%)	12.8Kg (80%)	11.2Kg (70%)
Basal diet (Boma Rhodes) for 3 animals/Day	48Kg	43.2 Kg	38.4 Kg	33.6 Kg
Fodder supplement per Animal per day	0.00	1.6kg	3.2Kg	4.8 Kg
Supplement for 3 cows per day DM	0.00	4.8Kg	9.6 Kg	14.4 Kg

To calculate the total cost of feed:

Diet 1 (100% Boma Rhodes):

Cost per kg: KSh 4.69

Daily feed intake per cow: 16 kg

Number of cows: 1

Number of days: per day

Total feed cost for Diet 1 consumed per day/cow = $(\text{KSh } 4.69/\text{kg}) \times (16 \text{ kg/cow}) \times = \text{KSh}$

Diet 2 (90% Boma Rhodes + 10% Experimental Diet):

Cost per kg for Boma Rhodes: KSh 4.69

Cost per kg for the experimental diet: KSh 9.4

Daily feed intake per cow: 16 kg

Number of cows: 1

Number of days: per day

Total feed cost for Diet 2 per cow per day = (90% of 16kg × KSh 4.69) + (10% of 16kg × KSh 9.4) = KSh 83

Diet 3 (80% Boma Rhodes + 20% Experimental Diet):

Cost per kg for Boma Rhodes: KSh 4.69

Cost per kg for the experimental diet: KSh 18.8

Daily feed intake per cow: 16 kg

Number of cows: 1

Number of days: per day

Total feed cost for Diet 3 = ((80% of 16kg × KSh 4.69) + (20% of 16 kg × KSh 9.4)) × = KSh 90

Diet 4 (70% Boma Rhodes + 30% Experimental Diet):

Cost per kg for Boma Rhodes: KSh 4.69

Cost per kg for the experimental diet: KSh 28.2

Daily feed intake per cow: 16 kg

Number of cows: 1

Number of days: per day

Total feed cost for Diet 4 = ((70% × KSh 4.69) + (30% × KSh 9.4)) (42 days) = KSh 98

Therefore, the costs are:

Diet 1: KSh 75

Diet 2: KSh 83

Diet 3: KSh 90

Diet 4: KSh 98

In this study, Table 10 presents results regarding the Income Over Feed Cost (IOFC) in dairy cow management, providing critical insights into the economic dimensions of dairy farming. These findings illuminate the factors influencing IOFC, offering valuable perspectives for optimizing feed efficiency and maximizing profitability in dairy operations. This research serves as a cornerstone for enhancing the economic sustainability and performance of dairy production practices.

Table 11: Income Over Feed Cost (IOFC) for each dietary treatment in each county: Bomet, Nyandarua, and Nyeri.

DIET	BOMET (KSh)	NYANDARUA (KSh)	NYERI (KSh)
1	8.7±1.2 ^a	27±4.0 ^a	16±3.21 ^a
2	25.7±5.49 ^a	132±11.55 ^b	60.7±4.91 ^b
3	55±2.08 ^b	121±5.77 ^b	140±6.08 ^c
4	59±8.54 ^b	169±5.77 ^c	159.7±6.06 ^c
P-value	0.0004	<.0001	<.0001

In Bomet, there was no significant difference in IOFC for diets 1 and 2 at $P>0.05$. Diets 3 and 4 also show no significant difference in IOFC at $P>0.05$. However, diet 1 and 2, each showed a significant difference in IOFC from the IOFC of both diet 3 and 4 at $P<0.05$. In Nyandarua, there was no significant difference in IOFC of diet 2 and diet 3 at $P>0.05$. However, IOFC of diet 1 and IOFC of diet 4, differed significantly at $P<0.05$. There was also a significant difference at $P<0.05$ in the IOFC of 2 and 3 and the IOFC of both diets 1 and 4 at $P<0.05$. In Nyeri, the IOFC of diet 1 and the IOFC of diet 2, differed significantly at $P<0.05$. The IOFC of diet 3 and the IOFC of diet 4 had no significant difference at $P>0.05$. The IOFC of diet 3 and the IOFC of diet 4 differed significantly from the IOFC of both diet 1 and diet 2 at $P<0.05$.

5.4 Discussion

The analysis of Income Over Feed Cost (IOFC) across the three counties reveals interesting patterns and differences. In Bomet, the IOFC for diets 1 and 2 did not exhibit a significant difference, indicating that the additional 10% experimental diet did not significantly impact the income over feed cost. Similarly, diets 3 and 4 did not differ significantly, suggesting that increasing the experimental diet from 20% to 30% did not proportionally affect IOFC. However,

there was a noteworthy distinction between the IOFC of diets 1 and 2 compared to diets 3 and 4, signifying that a moderate level of supplementation (10% and 20%) might be more economically viable. This finding agrees with the findings of Buza *et al.* (2015) on the impact of dietary supplementation on IOFC in dairy cows. Moving to Nyandarua, the comparison reveals that the IOFC of diet 2 and diet 3 showed no significant difference, emphasizing that a 10% experimental diet may be economically comparable to a 20% supplementation level. However, there were significant differences in the IOFC between diet 1 and diet 4, suggesting that extremes in supplementation levels can impact economic returns. The comparison between diets 2 and 3 with diets 1 and 4 also underscored economic distinctions, reinforcing the importance of appropriate supplementation levels for optimal IOFC.

In Nyeri, the study demonstrated that a 10% experimental diet (diet 2) significantly differed from the control diet (diet 1), emphasizing the potential economic benefit of a modest level of supplementation. Diets 3 and 4 did not show a significant difference in IOFC, indicating that beyond a 20% supplementation level, there might be diminishing economic returns. The significant distinctions between diets 1 and 2 compared to diets 3 and 4 further emphasize the economic considerations of supplementation strategies. This finding agrees with the findings of Bach (2023), on the relation of feed cost to milk price and overall farm return. The cross-county comparison suggests that the economic impact of supplementation levels on IOFC varies across counties, emphasizing the importance of region-specific strategies for optimizing income over feed costs in smallholder dairy farms. Factors such as local feed availability, market prices, and county variations in milk production may contribute to these observed differences. This is congruent with the finding of Cabrera and Kalantari, (2016) on factors influencing county variation of IOFC in smallholder dairy farms. Future research could delve into these factors to provide more nuanced insights into effective dairy farm management strategies.

5.5 Conclusion

In conclusion, the comprehensive analysis of Income Over Feed Cost (IOFC) across the diverse counties: Bomet, Nyandarua, and Nyeri sheds light on the nuanced relationship between dietary supplementation and economic returns in smallholder dairy farming. The findings suggest that optimal supplementation levels for maximizing IOFC vary by county, emphasizing the need for county-specific strategies. In Bomet, moderate supplementation levels (10% and 20%) exhibit

economic comparability, while in Nyandarua, the study highlights distinctions between a 10% and a 30% experimental diet. Nyeri, on the other hand, underscores the economic benefits of a 10% supplementation. The cross-county differences underscore the influence of local factors on optimal dietary strategies. This research contributes valuable insights for dairy farmers and policymakers, stressing the significance of tailoring supplementation practices to specific regional contexts for enhanced economic sustainability in smallholder dairy farming.

CHAPTER SIX

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1 General Discussion

This study was designed to address the nutritional challenges affecting milk production in smallholder dairy farms in Kenya, particularly in Bomet, Nyandarua, and Nyeri counties. The nutritional inadequacy of conventional feedstuffs has been a significant constraint, impacting milk yield and farm profitability. By evaluating the nutritional value of selected fodders and their impact on milk production and economic viability, the study provides insights into improving smallholder dairy farming through better feeding strategies.

The chemical composition and nutritional value of the selected fodders—lucerne, green leaf desmodium, chicory, and sweet potato vines—varied across the counties, indicating the potential for region-specific dietary strategies. Supplementing Boma Rhodes grass hay with these fodders led to measurable improvements in milk yield, particularly at moderate supplementation levels. The findings demonstrate that optimizing feed mixtures can help increase milk production while maintaining or improving economic efficiency. Additionally, the economic analysis, via the Income Over Feed Costs (IOFC) metric, showed that different supplementation levels yielded varying economic outcomes across the counties. The economic feasibility of the feed mixtures further supports the need for tailored interventions that consider both milk yield and cost efficiency.

6.2 Conclusions

- i. The selected fodders—lucerne, green leaf desmodium, sweet potato vines, and chicory—supplemented to Boma Rhodes grass hay have varying chemical compositions and nutritional values across the three counties, indicating the need for region-specific feed strategies.
- ii. Supplementing Friesian dairy cows with a mixture of lucerne, green leaf desmodium, sweet potato vines, and chicory significantly increases milk yield, with optimal results at moderate supplementation levels, especially in Bomet and Nyeri counties.
- iii. The Income Over Feed Cost (IOFC) analysis indicates that supplementation at 20% and 30% levels yields the highest economic returns, with Bomet showing optimal results at 20%, while Nyandarua and Nyeri reached peak efficiency at 30% supplementation.

6.3 General Recommendations

- i. Smallholder dairy farmers in Bomet should adopt a 20% supplementation level using a feed mixture of lucerne, green leaf desmodium, sweet potato vines, and chicory to optimize milk yield and economic returns.
- ii. In Nyandarua and Nyeri counties, a higher supplementation level of 30% is recommended to achieve the best balance between increased milk production and economic efficiency.
- iii. Region-specific dietary interventions should be implemented, as the varying nutritional profiles of fodders across the counties suggest the need for localized feeding strategies.
- iv. Policy interventions should focus on supporting farmers with access to high-quality fodder, and subsidies should be explored for the most effective feed mixtures identified in this study.

6.4 Areas for Further Research

Future research should explore the long-term impacts of these dietary interventions on cow health, milk quality, and farm sustainability. Additionally, research should investigate the feasibility of integrating other non-conventional, locally available fodder types that may offer cost-effective and sustainable alternatives. Expanding the scope to include different agroecological zones and climates in Kenya would help further refine feeding strategies, and studies on the environmental impacts of these feeding interventions, including their role in sustainable resource use, would also be valuable.

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APPENDICES

Appendix A: Published Paper on Objective One



Journal of Veterinary Science and Animal Husbandry

Volume 12 | Issue 2

ISSN: 2348-9790

Research Article

Open Access

Nutritional Value and Chemical Composition of Selected Fodders; Feed Intervention in Smallholder Dairy Farms in Kenya

Caleb Wanyiri Oktoto¹, James Ombiro Ondiek

Egerton University, Department of Animal Science, Nakuru, Kenya

¹Corresponding Author: Caleb Wanyiri Oktoto, Egerton University, Department of Animal Science, Nakuru, Kenya, Tel.: 0713228915, E-mail: calebwanyiri@gmail.com

Citation: Caleb Wanyiri Oktoto, James Ombiro Ondiek (2024) Nutritional Value and Chemical Composition of Selected Fodders; Feed Intervention in Smallholder Dairy Farms in Kenya, J Vet Sci Ani Husb 12(2): 201

Received Date: April 27, 2024 **Accepted Date:** May 27, 2024 **Published Date:** May 31, 2024

Abstract

This study evaluated the nutritional value and chemical composition of five selected fodder; Boma Rhodes, lucerne, greenleaf *Desmodium*, chicory, and sweet potato vines which were collected from three geographically distinct regions: Bomet, Nyandarua, and Nyeri, and taken for chemical analysis in the Animal Nutrition laboratory in Animal Science department at Egerton University. These fodder species were analysed for their proximate composition, metabolisable energy, and van Soest composition. All these analyses were done on a dry matter basis. All these results were analysed at P<0.05. The results revealed significant variations in the nutritional profiles of these diets across the three regions. Bomet exhibits specific trends in crude protein and dry matter, while Nyandarua showcases variability in ether extract and total ash content. Nyeri emphasises differences in crude protein and ash content. These findings provide valuable insights into the regional variations in the chemical composition of fodder, highlighting the importance of tailoring dietary strategies for livestock based on the local environment. The study contributes to the existing literature by offering a comprehensive analysis of the nutritional value of common livestock diets in diverse regions, aiding farmers and researchers in optimizing animal nutrition and enhancing overall agricultural practices.

Keywords: Boma Rhodes; lucerne; greenleaf *Desmodium*; chicory; sweet potato vines



Effect of Selected Fodder Intervention on Milk Yield in Friesian Dairy Cows in Selected Counties in Kenya

Caleb Wanyiri Oktoto^{1,*}, James Ombiro Ondiek¹ and Assah Oghaiki Ndambi²

¹Egerton University, Department of Animal Science, Nakuru, Kenya

²Animal Science Group, Wageningen University and Research, The Netherlands

*Corresponding Author: Caleb Wanyiri Oktoto, Egerton University, Department of Animal Science, Nakuru, Kenya, Tel.: 0713228915, E-mail: calebwanyiri8@gmail.com

Citation: Caleb Wanyiri Oktoto, James Ombiro Ondiek, Assah Oghaiki Ndambi (2024) Effect of Selected Fodder Intervention on Milk Yield in Friesian Dairy Cows in Selected Counties in Kenya, J Vet Sci Ani Husb 12(1): 105

Received Date: April 27, 2024 Accepted Date: May 27, 2024 Published Date: May 31, 2024

Abstract

Over three decades, the mean daily milk production per cow in these regions has remained stagnant at a mere 6 kg/day with most smallholder farmers yielding a mere 3.67 litres of milk per cow daily, it's evident that their productivity falls well below par. In an effort to address this issue, a study conducted delves into the second objective, which revolves around assessing the effects of diverse dietary supplements on milk yield across the distinct geographical areas of Nyandarua, Bomet, and Nyeri. The study involved the utilization of a supplementary feed mixture which was 400 g/kg DM of dry matter content, comprising; lucerne, green-leaf desmodium, sweet potato vines, and chicory, which was chopped and mixed in a ratio of 1:2:3:1. Supplementation was done at the following inclusion levels; T₁ (0%), T₂ (10%), T₃ (20%) and T₄ (30%) of the estimated daily dry matter intake of 4% of the live body weight of the dairy cow. A basal diet of boma Rhodes which was 400 g/kg DM of dry matter content was used. This study ran for nine weeks in each region; one week of backgrounding all the animals, followed by fourteen days of adaptation and a month and a half of data collection. The research scrutinizes the outcomes of milk production resultant from diets featuring supplementation levels ranging from 10% to 30% in Friesian dairy cows. The findings reveal that, in Bomet, There isn't a significant variation in milk production between diets exhibiting 10% and 30% supplementation, suggesting a potential plateau in response to heightened supplementation levels. Conversely, in Nyandarua, diets supplemented with 20% and 30% show no significant variance in milk yield, spotlighting the efficacy of a moderate supplementation level. In Nyeri, noteworthy disparities in milk yield emerge between diets with 10% and 30% supplementation levels.

Keywords: Dietary supplement; Friesian; fodder intervention; zero grazing

Appendix C: Published Paper on Objective Three

IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)

e-ISSN: 2319-2380, p-ISSN: 2319-2372. Volume 17, Issue 4 Ser. 1 (April. 2024), PP 28-39

www.iosrjournals.org

Income Over Feed Cost Analysis Of Utilizing Selected Fodder Mixture In Smallholder Friesian Dairy Farms In Kenya.

Caleb Wanyiri Oktoto ^{*1}, James Ombiro Ondiek ¹, Oghaiki Asaah Ndambi ²

¹ *Department Of Animal Sciences, Egerton University Kenya*

² *Animal Science Group, Wageningen University And Research , The Netherlands*

Abstract

This research delves into the intricate dynamics of the economic feasibility of the various dietary treatments by calculating the Income Over Feed Costs (IOFC) in smallholder dairy farms in; Bomet, Nyandarua, and Nyeri, focusing on the optimization of milk production through strategic dietary supplementation. The study, conducted across diverse regions scrutinizes the economic implications of varying levels of experimental feed incorporation. Twelve Friesian dairy cows, spanning different lactation stages but with consistent parity, were subjected to four dietary treatments, each representing different percentages of experimental diet supplementation (0%, 10%, 20%, and 30%). The experiment spanned eight weeks, incorporating a backgrounding period, adaptation phase, and extensive data collection. Results unveiled intriguing regional disparities, with Bomet County showcasing optimal economic returns at a 20% supplementation level, Nyandarua favouring a 30% supplementation level, and Nyeri maximising economic efficiency at 30%. The highest overall Income Over Feed Cost (IOFC) was associated with the 30% supplementation level. The study underscores the significance of tailoring dietary strategies to regional contexts, emphasizing the economic benefits of strategic feed supplementation. This research contributes valuable insights for optimizing milk production, enhancing farm profitability, and promoting resilience in the face of dynamic agricultural landscapes.

Key Word: *Economic returns, supplementation level, fodder Bomet, Nyandarua, Nyeri*

Date of Submission: 04-04-2024

Date of Acceptance: 14-04-2024

Appendix D: Key Data Analysis Output for Objective Two
The SAS System

Obs	Diets	rep	Nyeri	Bomet	Nyand
1	1	1	2.0	1.6	3.0
2	1	2	2.5	1.8	2.4
3	1	3	2.0	1.6	2.4
4	2	1	4.0	3.1	9.0
5	2	2	4.5	2.7	7.0
6	2	3	5.0	2.2	8.0
7	3	1	8.5	4.3	7.0
8	3	2	8.0	4.0	8.0
9	3	3	7.5	4.1	7.5
10	4	1	9.0	5.3	10.5
11	4	2	8.5	4.0	9.5
12	4	3	8.0	3.0	10.0

TheSAS System

TheGLMProcedure

ClassLevelInformation		
Class	Levels	Values
Diets	4	1 2 3 4

Number of Observations Read	12
Number of Observations Used	12

The SAS System

The GLM Procedure

Tukey's Studentized Range (HSD) Test for bomet

Note: This test controls the Type I experiment-wise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	8
Error Mean Square	0.3925
Critical Value of Studentized Range	4.52877
Minimum Significant Difference	1.6381

Means with the same significantly.				
Tukey Grouping		Mean	N	Diets
	A	4.1333	3	3
	A			
	A	4.1000	3	4
	A			
B	A	2.6667	3	2
B				
B		1.6667	3	1

The SAS System

The GLM Procedure

Tukey's Studentized Range (HSD) Test for α

Note: This test controls the Type I experiment-wise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	8
Error Mean Square	0.405
Critical Value of Studentized Range	4.52877
Minimum Significant Difference	1.664

Means with the same significantly.			
Tukey Grouping	Mean	N	Diets
A	10.0000	3	4
B	8.0000	3	2
B			
B	7.5000	3	3
C	2.6000	3	1

TheSAS System

TheMEANSProcedure

Diets	N Obs	Variable	StdError
1	3	Nyeri	0.17
		bomet	0.07
		nyand	0.20
2	3	Nyeri	0.29
		bomet	0.26
		nyand	0.58
3	3	Nyeri	0.29
		bomet	0.09
		nyand	0.29
4	3	Nyeri	0.29
		bomet	0.67
		nyand	0.29

Appendix C: Key Data Analysis Output for Objective Three

TheSAS System

Obs	Diets	rep	nyeri	bomet	nyand
1	1	1	15	8	35
2	1	2	22	11	23
3	1	3	11	7	23
4	2	1	52	35	152
5	2	2	61	26	112
6	2	3	69	16	132
7	3	1	141	58	111

8	3	2	129	56	131
9	3	3	150	51	121
10	4	1	149	52	179
11	4	2	170	76	159
12	4	3	160	49	169

The SAS System

The GLM Procedure

ClassLevelInformation		
Class	Levels	Values
Diets	4	1 2 3 4

Number of Observations Read	12
Number of Observations Used	12

TheSAS System

The GLM Procedure Dependent Variable: Nyeri

Source	DF	Sum of Squares	MeanSquare	FValue	Pr > F
Model	3	40869.58333	13623.19444	167.84	<.0001
Error	8	649.33333	81.16667		
Corrected Total	11	41518.91667			

R-Square	Coeff Var	RootMSE	nyeriMean
0.984361	9.575824	9.009255	94.08333

Source	DF	Type I SS	MeanSquare	FValue	Pr > F
Diets	3	40869.5833	13623.19444	167.84	<.0001
		3			

Source	DF	Type III SS	MeanSquare	FValue	Pr > F
Diets	3	40869.5833	13623.19444	167.84	<.0001
		3			

TheSAS System

The GLM Procedure Dependent Variable: bomet

Source	DF	Sum of Squares	MeanSquare	FValue	Pr > F
Model	3	5217.583333	1739.194444	21.30	0.0004
Error	8	653.333333	81.666667		
Corrected Total	11	5870.916667			

R-Square	Coeff Var	RootMSE	Bomet Mean
0.888717	24.36933	9.036961	37.08333

Source	DF	Type I SS	MeanSquare	FValue	Pr > F
Diets	3	5217.58333	1739.194444	21.30	0.0004
		3			

Source	DF	Type III SS	MeanSquare	FValue	Pr > F
Diets	3	5217.58333	1739.194444	21.30	0.0004
		3			

TheSAS System

The GLM Procedure Dependent Variable: nyand

Source	DF	Sum of Squares	MeanSquare	FValue	Pr > F
Model	3	32864.25000	10954.75000	67.62	<.0001
Error	8	1296.00000	162.00000		
Corrected Total	11	34160.25000			

R-Square	Coeff Var	RootMSE	nyandMean
0.962061	11.33891	12.72792	112.2500

Source	DF	Type I SS	MeanSquare	FValue	Pr > F
Diets	3	32864.25000	10954.75000	67.62	<.0001
		0			

Source	DF	Type III SS	MeanSquare	FValue	Pr > F
Diets	3	32864.25000	10954.75000	67.62	<.0001
		0			

The SAS System

The GLM Procedure

Tukey's Studentized Range (HSD) Test for μ_i

Note: This test controls the Type I experiment-wise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	8
Error Mean Square	81.1666 7
Critical Value of Studentized Range	4.52877
Minimum Significant Difference	23.556

Means with the same significantly.			
Tukey Grouping	Mean	N	Diets
A	159.66 7	3	4
A			
A	140.00 0	3	3
B	60.667	3	2
C	16.000	3	1

The SAS System

The GLM Procedure

Tukey's Studentized Range (HSD) Test for b o m e t

Note: This test controls the Type I experiment-wise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	8
Error Mean Square	81.66667
Critical Value of Studentized Range	4.52877
Minimum Significant Difference	23.629

Means with the same significantly.			
Tukey Grouping	Mean	N	Diets
A	59.000	3	4
A			
A	55.000	3	3
B	25.667	3	2
B			
B	8.667	3	1

The SAS System

The GLM Procedure

Tukey's Studentized Range (HSD) Test for α

Note: This test controls the Type I experiment-wise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	8
Error Mean Square	162
Critical Value of Studentized Range	4.52877
Minimum Significant Difference	33.279

Means with the same significantly.			
Tukey Grouping	Mean	N	Diets
A	169.00	3	4
B	132.00	3	2
B			
B	121.00	3	3
C	27.00	3	1

TheSAS System***TheMEANSProcedure***

Diets	N Obs	Variable	StdError
1	3	Nyeri	3.21
		Bomet	1.20
		Nyand	4.00
2	3	Nyeri	4.91
		Bomet	5.49
		Nyand	11.55
3	3	Nyeri	6.08
		Bomet	2.08
		Nyand	5.77
4	3	Nyeri	6.06
		Bomet	8.54
		Nyand	5.77

Appendix E: NACOSTI Research Licence




REPUBLIC OF KENYA
NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Ref No: 490365 **Date of Issue: 25/April/2023**

RESEARCH LICENSE



This is to Certify that Mr.: CALEB WANYIRI OKTOTO of Egerton University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Bomet on the topic: EVALUATING THE EFFECT OF SELECTED - FODDERS INTERVENTIONS ON DAIRY COW'S MILK PERFORMANCE AND PROFITABILITY IN SMALLHOLDER DAIRY FARMS for the period ending : 25/April/2024.

License No: NACOSTI/P/23/25261

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THE SCIENCE, TECHNOLOGY AND INNOVATION ACT, 2013 (Rev. 2014)

Legal Notice No. 108: The Science, Technology and Innovation (Research Licensing) Regulations, 2014

The National Commission for Science, Technology and Innovation, hereafter referred to as the Commission, was established under the Science, Technology and Innovation Act 2013 (Revised 2014) herein after referred to as the Act. The objective of the Commission shall be to regulate and assure quality in the science, technology and innovation sector and advise the Government in matters related thereto.

CONDITIONS OF THE RESEARCH LICENSE

1. The License is granted subject to provisions of the Constitution of Kenya, the Science, Technology and Innovation Act, and other relevant laws, policies and regulations. Accordingly, the licensee shall adhere to such procedures, standards, code of ethics and guidelines as may be prescribed by regulations made under the Act, or prescribed by provisions of International treaties of which Kenya is a signatory to
2. The research and its related activities as well as outcomes shall be beneficial to the country and shall not in any way;
 - i. Endanger national security
 - ii. Adversely affect the lives of Kenyans
 - iii. Be in contravention of Kenya's international obligations including Biological Weapons Convention (BWC), Comprehensive Nuclear-Test-Ban Treaty Organization (CTBT/O), Chemical, Biological, Radiological and Nuclear (CBRN).
 - iv. Result in exploitation of intellectual property rights of communities in Kenya
 - v. Adversely affect the environment
 - vi. Adversely affect the rights of communities
 - vii. Endanger public safety and national cohesion
 - viii. Plagiarize someone else's work
3. The License is valid for the proposed research, location and specified period.
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14. The Commission shall have powers to acquire from any person the right in, or to, any scientific innovation, invention or patent of strategic importance to the country.
15. Relevant Institutional Scientific and Ethical Review Committee shall monitor and evaluate the research periodically, and make a report of its findings to the Commission for necessary action.

National Commission for Science, Technology and
Innovation(NACOSTI),
Off Waiyaki Way, Upper Kabete,
P. O. Box 30623 - 00100 Nairobi, KENYA
Telephone: 020 4007000, 0713788787, 0735404245
E-mail: dg@nacosti.go.ke
Website: www.nacosti.go.ke

Appendix F: Ethical Approval

EGERTON

TEL: (051) 2217808

FAX: 051-2217942

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**EGERTON UNIVERSITY INSTITUTIONAL SCIENTIFIC AND ETHICS
REVIEW COMMITTEE**

EU/RE/DIR/009*Approval No. EUISERC/APP/229/2023**30th March, 2023*

Caleb Wanyiri Oktoto
Department of Animal Sciences,
Egerton university
P. O. Box 536– 20115,
Egerton – Kenya.
Telephone: 0713228915
E-mail: calebwanyiri6@gmail.com

Dear Caleb,

RE: ETHICAL APPROVAL: EVALUATING THE IMPACT OF SELECTED - FODDER INTERVENTIONS ON DAIRY COW PERFORMANCE AND PROFITABILITY IN SMALLHOLDER DAIRY FARM

This is to inform you that *Egerton University Institutional Scientific and Ethics Review Committee* has reviewed and approved your above research proposal. Your application approval number is *EUISERC/APP/229/2023*. The approval period is *30th March, 2023 – 1st April, 2024*

This approval is subject to compliance with the following requirements;

- i. Only approved documents including (informed consents, study instruments, MTA) will be used.
- ii. You are required to adhere Institutional Experimental Animals use and Care policy.
- iii. All changes including (amendments, deviations, and violations) are submitted for review and approval by *Egerton University Institutional Scientific and Ethics Review Committee*.
- iv. Death and life-threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to *Egerton University Institutional Scientific and Ethics Review Committee* within 72 hours of notification
- v. Any changes, anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to *Egerton University Institutional Scientific and Ethics Review Committee* within 72 hours.

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N

- vi. Clearance for Material Transfer of biological specimens must be obtained from relevant institutions.
- vii. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
- viii. Submission of an executive summary report within 90 days upon completion of the study to *Egerton University Institutional Scientific and Ethics Review Committee*.

Prior to commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology and Innovation (NACOSTI) <https://oris.nacosti.go.ke> and also obtain other clearances needed.

Yours sincerely,



Prof. Raphael M. Ngure

CHAIRMAN, EGERTON UNIVERSITY INSTITUTIONAL SCIENTIFIC AND ETHICS REVIEW CTTEE

RMN/BK/