PERFORMANCE OF LACTATING DAIRY GOATS FED ON SWEET SORGHUM (*Sorghum bicolor* (L.) Moench) SILAGE SUPPLEMENTED WITH FORAGE CHICORY (*Cichorium intybus* (L.)

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DECLARATION AND RECOMMENDATION

Declaration

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

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Recommendation

This thesis has been submitted with our approval as the official University Supervisors.

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DEDICATION

This thesis is dedicated to my beloved daughter Gianna Givens, my father Zablon Ndubi, my mother Beatrice, my sisters; Mercy and Deborah, and my brothers; Edwin, Nehemiah, and Frankline.

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ABSTRACT

This study investigated the performance of lactating dairy goats fed on sweet sorghum (*Sorghum bicolor* (L.) Moench) silage supplemented with forage chicory (*Cichorium intybus* (L.). The specific objectives were to determine the nutritional value based on proximate analysis and *in vitro* digestibility, the effect of supplementing sweet sorghum silage diet with forage chicory on the performance of dairy goats, and to assess income over feed cost of dairy goats fed on sweet sorghum silage supplemented with forage chicory. Results from proximate analysis showed that T4 (30%) recorded the highest amount of ash (121.4 g/kg DM), CP (138.7 g/kg DM), CF (323.8 g/kg DM), EE (30.6 g/kg DM), ADL (51.8 g/kg DM), and CT (0.9 g/kg DM) while T1 recorded the least. *In vitro* gas production was considerably higher ($p<0.05$) in T4 indicating highest digestibility than T1. To determine the performance, twelve (12) Toggenburg dairy goats with the same body weight (38.7 ± 9.7 kg), same parity, and mid-stage lactation aged between 18-24 months were randomly assigned to four dietary treatments and replicated three times in a completely randomized design. The dairy goats were fed on sweet sorghum silage *ad libitum* and supplemented with forage chicory at 0, 10, 20, and 30%. The feeding trial lasted for ten weeks, two weeks for the adaptation period, and eight weeks for the measurement of dry matter intake, average daily gain, milk yield, and milk composition. Data were analysed by the general linear model of the analysis of variance (ANOVA) using the statistical analysis system SAS version 9.4. The significant differences in means were separated using Tukey's Honestly Significant Difference test at ($P<0.05$). Results showed that dry matter intake, average daily gain, and milk yield were significantly different at ($p<0.05$) with T4 (30%) performing better than T1 (0%). While in milk composition, there was no significant difference in T1, T2 and T3, T4 of fats and protein at ($p>0.05$). However, there was a significant difference in T3 from T1 and T2. There was no significant difference ($p>0.05$) in lactose and total solids of T2, T3 and T4. To determine income over feed cost, data from feed cost associated with milk production, and income from milk sales was included in the data from the feeding experiment conducted for eight weeks. Data were analysed by the general linear model of the analysis of variance (ANOVA) using the statistical analysis system SAS version 9.4. The significant differences in means were separated using Tukey's Honestly Significant Difference test at ($P<0.05$). Results showed that there was no significant difference ($p>0.05$) in IOFC of T1 and T2, and T3 and T4 but there was significant difference ($p<0.05$) in T3 from T1 and T2. This study concluded that a 30% supplementation level of forage chicory had the highest nutritional value and digestibility that led to the improvement of the performance of dairy goats.

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LIST OF ABBREVIATIONS AND ACRONYMS

ADF	Acid Detergent Fibre
ADL	Acid Detergent Lignin
ANOVA	Analysis of Variance
CP	Crude Protein
CT	Condensed Tannins
DM	Dry Matter
EE	Ether Extract
FAO	Food and Agriculture Organization of the United Nations
GE	Gross Energy
GMA	Gross Margin Analysis
GOK	Government of Kenya
HPIK	Heifer Project International-Kenya
ICRISAT	The International Crops Research Institute for the Semi-Arid Tropics
ME	Metabolizable Energy
NDF	Neutral Detergent Fibre
NGOs	Non-Governmental Organizations
OMD	Organic Matter Digestibility
SCFA	Short Chain Fatty Acids
SDG	Sustainable Development Goals
WSC	Water-Soluble Carbohydrates

CHAPTER ONE
INTRODUCTION

1.1 Background information

The increase in human population pressure, land scarcity, and diminishing production resources have stimulated the rearing of dairy goats over cattle. Many smallholder farmers in Kenya rely on goats as a significant source of income (Ngila *et al*., 2016). Dairy goat production is becoming an important economic activity for farmers since they are more adaptable to the environment than cattle, require less acreage, reproduce quickly, and can feed on a range of vegetation. Goats produce milk that ranges from 0.5 to 5 litres per day, with an average butter fat content of approximately 4.5% (Jerop, 2012). High-yielding breeds developed in temperate climates, such as the Toggenburg, Saanen, and Alpine, can produce up to 15 litres per day. Kenya has the greatest per capita milk consumption in sub-Saharan Africa, with an estimated 121 litres compared to 25 litres in sub-Saharan Africa. This remains below the World Health Organization's global recommendation of 220 litres per capita (Ngunjiri, 2020).

Goat milk has gained popularity and increased demand throughout the world due to the health and nutritional benefits that the milk and its products give humans (Kiura *et al*., 2020). With cardiovascular disease being the primary cause of death in the world and the cancer burden increasing due to aging and changing lifestyles, goat milk would be of great benefit because it contains anticarcinogens and other substances that can help prevent coronary heart disease. Goat milk consists of small fat globule suspensions that make it easier to assimilate, making it particularly helpful in the diets of children and adults who are sensitive to or allergic to cow's milk (Getaneh *et al*., 2016). Goat milk is beneficial to HIV/AIDS patients due to its high protein molecules that are better absorbed than other proteins and strengthen antibodies. It is also a suitable option for mothers who prefer not to breastfeed. Despite the widely recognized benefits of goat milk, worldwide production does not meet the demand.

Feed is an essential input in all livestock production systems, accounting for 60–70% of the total production costs. Ruminant livestock productivity in Kenya is considered low due to inadequate and poor-quality feeds (Ngila *et al*., 2016). In addition, many regions experience a feed resource deficit for around 4-6 months of the year, particularly during the dry season when pasture growth is limited. During this time, the majority of the forage feed resources available, such as standing hay, dry grass, and crop residues such as cereal stover and straw, are of very low quality. However, the feeds are characterized by a high degree of lignification, high cell-wall content, low organic matter digestibility (<55%), low crude protein (less than

8%), negligible available protein (3 to 4%), low soluble sugar contents, deficiency in calcium and phosphorus minerals and vitamins, and low metabolizable energy (5 to 8 MJ/kg DM) (Kashongwe *et al.*, 2017). These nutritional attributes tend to depress DM digestibility, restricting animal dry matter intake to levels that are insufficient to meet production and even maintenance requirements in some circumstances.

Another barrier to livestock productivity is scarcity of suitable fodder crops that are capable of producing adequate green forage throughout the year (Misra, 2019). The situation worsens throughout the dry season and drought period, when precipitation is low enough to support significant growth and production of plant biomass. Climate change, a result of greenhouse gas emissions, has recently exacerbated the problem associated with poor feed quality and shortages. As a result, there are challenges in feed production from conventional pasture and fodder species. Sweet sorghum silage fits in well with the need to grow climate-smart forage in this era of climate change to boost ruminant production, and dairy goats are best suited as their requirements are low, and its supplementation with chicory will improve the performance of dairy goats.

Sweet sorghum is one of the crops that can withstand climate change conditions in the future, including increased drought, soil salinity, and high temperatures (ICRISAT, 2014). It is a multipurpose crop where its grains can be used for food, bioconversion to ethanol, and fodder for animal feed (Athar, 2012). This sorghum is an excellent option for silage production compared to forage sorghum. This is because sweet sorghum has a greater water-soluble carbohydrates (WSC) content, which may allow the production of high-quality silages without the need to add expensive molasses. Furthermore, sweet sorghum stalks contain more fermentable sugars making it a perfect crop for ensiling (Jalajakshi *et al.*, 2018; Makori, 2014).

Notwithstanding its enormous potential as a feed resource, available literature shows that sweet sorghum silage does not provide sufficient nutrients, especially protein for optimum growth and production due to its low crude protein content (8%) (Cardoso *et al.*, 2014). Therefore, there is a need to supplement sweet sorghum silage with protein sources like forage chicory (*Cichorium intybus* (L.) which is locally available and reasonably cheap to increase livestock productivity. Using chicory alone in dairy goats' diets provides high protein and digestibility but lacks other essential nutrients, particularly energy and fiber, necessary for balanced rumen function and overall health. As a sole diet, forage chicory may lead to nutrient imbalances, potentially lowering milk yield and affecting goat health. Therefore, combining forage chicory with other forages or energy sources creates a more balanced and complete diet.

Forage chicory is a drought-tolerant perennial herbaceous plant in the Asteraceae family. It is fed as a supplement due to its higher CP (16-27%), digestibility (70-80%), and energy (13.7 MJME/kg DM) (Nwafor *et al*., 2017). Forage chicory is comparable to Lucerne as it contains similar proportions of lipids, protein, minerals, and other nutrients. In addition, forage chicory contains 98% inulin, which has a beneficial effect on the probiotic intestinal flora. This study aims to determine the performance of lactating dairy goats fed on sweet sorghum (*Sorghum bicolor* (L.) Moench) silage supplemented with forage chicory (*Cichorium intybus* (L.).

1.2 Statement of the problem

Milk production levels of less than 1.9 L/goat/day in dairy goats have been reported even though higher production is possible with better nutrition. Goats produce milk that ranges from 0.5 to 5 litres per day with high-yielding breeds producing up to 15 litres per day. Therefore, to raise milk production to more than 1.9 L/goat/day, sweet sorghum with drought-hardy characteristics through silage making will ensure a consistent supply of feed throughout the year. In addition, sweet sorghum has less competition with humans as food thus enhancing the climate resilience of dairy goat farmers. Although sweet sorghum silage provides higher bulk, it is generally low in nutrients especially protein (8%) for optimum growth and production. Therefore, there is a need to supplement it with protein sources such as forage chicory (16-27% CP) that are locally available and reasonably cheap. However, the utilization of sweet sorghum silage, especially as a basal forage for dairy goats, and the nutritional benefit of using it with forage chicory supplement is unknown. As a result, there is insufficient information to give recommendations to farmers on the best strategies for feeding sweet sorghum silage supplemented with forage chicory to dairy goats.

1.3 Objectives of the study

1.3.1 General objective

To contribute to food and nutrition security through increased dairy goat milk production by supplementing sweet sorghum (*Sorghum bicolor* (L.) Moench**)** silage with forage chicory (*Cichorium intybus* (L.).

1.3.2 Specific objectives

i. To determine the nutritional value based on proximate analysis and *in vitro* gas production of sweet sorghum silage supplemented with forage chicory
ii. To determine the effect of supplementing basal sweet sorghum silage with forage chicory on milk quantity and quality, feed intake, and weight changes of lactating dairy goats

iii. To assess the income over feed cost of dairy goats fed on sweet sorghum silage and forage chicory

1.4 Hypotheses

i. There is no significant difference in the nutritional value based on proximate analysis and *in vitro* gas production of sweet sorghum silage supplemented with forage chicory

ii. There is no significant difference in the effect of supplementing sweet sorghum silage with forage chicory on milk quantity and quality, feed intake, and weight changes of lactating dairy goats

iii. There is no significant difference in the income over feed cost of dairy goats fed on sweet sorghum silage and forage chicory

1.5 Justification of the study

Goat milk has gained popularity and increased demand around the world due to its health and nutritional benefits (Kiura *et al*., 2020). However, dairy goat productivity is constrained by nutritional deficiencies leading to low output. This could be resolved by feeding dairy goats with sweet sorghum silage as a basal. Sweet sorghum plant is characterized by high photosynthetic capacity, high biomass yield potential, sugar yield, and low grain yields (ICRISAT, 2014). However, a diet consisting solely of sweet sorghum silage may not provide adequate nutrition due to low protein content (8%). An additional supply of proteins like forage chicory is recommended. This forage chicory was selected from other types of chicory since it is mainly used for livestock feeding as compared to other varieties that are either used for coffee substitute/inulin extraction, industrial crop, and fresh salads (Street *et al.,* 2013). Forage chicory stands out among other protein sources due to its unique benefits. While it has a comparably high protein content, it also provides additional functional compounds such as inulin, which improves rumen health and digestion. Unlike conventional sources that are expensive. Forage legumes also supplementation may be limited by anti-nutritional factors like tannins that cause bloat. This study will provide insight into the nutritional, quality, and proportions of diets, as well as their impact on dairy goat performance. It will also provide an understanding of the income over feed costs of the dairy goats fed on sweet sorghum silage supplemented with forage chicory. Consequently, this will contribute to the BETA and Vision 2030 agenda and the National Food and Nutrition Security Policy, thereby achieving sustainable development goals (SDGs) 1, 2, and 12 of ending poverty, zero hunger, and climate action. Therefore, this research will contribute to improving the dairy goat industry and through extension agents, by providing information on the optimal supplementation levels for feeding dairy goats, to enhance animal productivity.

CHAPTER TWO
LITERATURE REVIEW

2.1 Global growth and impact of goat farming

The global goat population has been rising since the 1960s because of the changing human incomes and food preferences, as well as climate change limiting cattle-raising areas. In 2013, the global goat herd comprising over one billion head, increased by more than 34% from 2000 (Miller & Lu, 2019), whereas the sheep population increased only by 10% and the cattle population remained relatively constant at around one billion. In 2017, Asia had the highest proportion of the global population (52%), followed by Africa (39%), Europe (5%), the Americas (4%), and Oceania (<1%) (Figure 1). Although meat sales generate the majority of global goat production revenue, goat milk production and consumption have increased at the same time. The worldwide production of goat milk in 2017 was predicted to reach 19 million tons (Ceccobelli *et al*., 2020; Kiura *et al*., 2020).

The production of goats is quickly increasing in the agricultural sector in many countries. Goats are becoming important suppliers of meat and milk for rural populations around the world, especially in arid and semi-arid regions (Oliveira *et al*., 2011). Goats have relatively low input production, substantial worth, and the ability to thrive in adverse conditions with limited rainfall or agricultural potential could account for this. Furthermore, the small size of goats enables the raising of massive herds in limited areas. Lobo (2010) states that developing countries account for 95% of goats worldwide, offering numerous opportunities for food security and poverty alleviation (Getaneh *et al*., 2016).

The demand for dairy goat products is increasing in both traditional and new markets. Goats are found in almost every country and are no longer limited to low-income producers or dry areas. Low-income countries across Africa, Asia, Latin America, and other regions raise locally adapted goats for milk and meat, with the majority selling them informally. Goat milk holds significant value and appreciation in pastoralist areas, particularly in drier and drought-prone zones, often serving as the sole protein in children's diets. Nonetheless, many African countries, such as Sudan, Mali, Somalia, Kenya, and Algeria, produce a large amount of goat milk (Miller & Lu, 2019).

There are almost 500 different goat breeds in the world, but only a half dozen is typically raised for milk. They live in a variety of climates, including high-altitude mountains and deserts. The dairy goat is primarily made up of exotic breeds, including Toggenburg, Anglo-Nubian, German and British Alpines, Saanen, and Boer, as well as crosses with indigenous goats. The indigenous breeds include mainly the Galla and small East African goats.

Toggenburg is the best breed that produces a large amount of milk; it is not uncommon to acquire two gallons (7.57 litres) per day.

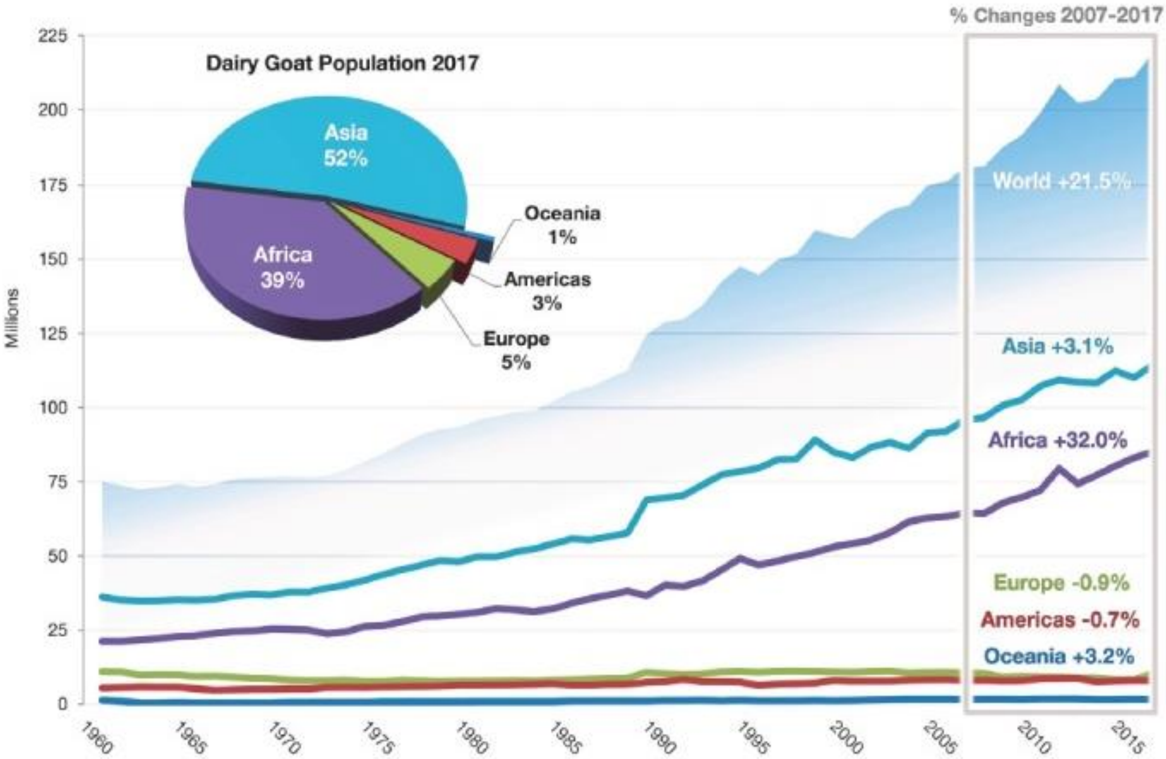

Figure 2.1: Global Dairy Goat Population (Heads) from 1961 to 2017 (FAO, 2019)

2.2 Dairy goat industry in Kenya

In the 1950s, British settler farmers introduced dairy goats to Kenya. Subsequent introductions were made through partnerships between the Government of Kenya (GoK) and donor agencies, or non-governmental organizations (NGOs), to upgrade local goats for meat and milk production (Kiura *et al*., 2020). The agencies included the German Agricultural Team (GTZ/GIZ) from 1992 to 1999, Farm Africa NGO from 1996 to 1998, and Heifer Project International-Kenya (HPIK) in 2005. Kenya has approximately 28 million goats, of which 502,044 are dairy goats, with 200,000 in the Mt. Kenya area. Dairy goats were introduced in the Mt. Kenya region to help alleviate poverty and malnutrition. Dairy goats were introduced in the Mt. Kenya region to help alleviate poverty and malnutrition. According to Jerop (2012), cattle produce about 83% of Kenya's annual milk production of 5.31 million litres, with goats and camels producing the remaining portion (MoLD, 2008–2012).

The goats are distributed in all the agroecological zones, with pastoralists in the lowlands owning the majority of them. People primarily keep them for milk, meat, skin, income, risk mitigation, property security, monetary savings, and other socioeconomic and cultural functions (Kipronoh *et al*., 2016). Goats are a significant source of revenue for many smallholder farmers in Kenya. Smallholder farmers prefer goats over cattle due to their rapid conversion into cash. They also provide more offtake than cattle due to their shorter generation interval and higher prolificacy (Ngila *et al*., 2016). African pastoralists, such as the Maasai in Kenya and Tanzania, rely heavily on milk from cattle and goats to supplement their nutrition. Increased drought and unpredictable weather have hindered their ability to raise cattle; therefore, goats are currently taking up a larger share of their herds.

2.3 Factors affecting milk production in goats

Factors influencing milk production in dairy goats include genetics, nutrition, lactation management, environmental conditions, and health (Goetsch *et al*., 2011). Genetic factors, such as breed and crossbreeding (e.g., Saanen and Alpine crosses), impact milk yield and quality, with some breeds naturally producing higher volumes of milk. Proper nutrition, particularly a diet high in energy and protein, is essential for sustaining milk production, and supplements like forage chicory have been shown to boost yield (Kahi & Wasike, 2019). Environmental factors such as climate and housing also affect production, as extreme temperatures can reduce intake and milk output. Lactation stage and udder health, including the control of somatic cell counts, are additional critical components for maintaining consistent milk quality and quantity.

2.4 Milk production and milk quality

Goats are important milk producers in various tropical regions and significantly contribute to human nutrition in many developing countries. Goat milk is becoming an increasingly important dairy product globally, with total production rising from 12 million tons in 1993 to over 19 million in 2017. Asia produces and consumes the majority of goat milk globally (Lu & Miller, 2019). Goat milk is commonly consumed fresh, particularly in regions where goats are raised for family consumption, such as Asia, Africa, and South America. People often compare goat milk to cow milk. Cow milk production is significantly cheaper, and the volumes are much higher, resulting in a lower market price. Commercial goat milk production is more expensive due to reduced productivity, seasonal changes, and the requirement for larger herd sizes (Zenebe *et al*., 2014).

Goat milk and its products are, therefore, an essential niche in the overall dairy industry sector. As a result, goat milk and its products play an important role in the overall dairy business. Apart from production differences, goat milk differs from cow or human milk in that it is more digestible, has a stronger buffering capacity, and has specific uses in medicine and human nutrition. Goat milk quality is described as its ability to withstand numerous technological treatments to produce a product that meets consumer demands in terms of health, nutritional value, safety, and pleasure (sensory characteristics). In defense of the main milk quality control criteria, Raynal-Ljutovac said that they should be backed up by other factors like bacteriology, somatic cell count, immunoglobulins, inhibitors, freezing point, and lipolysis, in addition to qualitative factors like color and smell. However, such criteria may evolve as consumers' knowledge and expectations change (García *et al*., 2014).

2.5 Health benefits and nutritional value of goat milk

Goat milk has gained popularity and increased demand across the world due to the health and nutritional benefits that the milk and its products provide to people (Kiura *et al*., 2020). With cardiovascular disease being the main cause of death in the world and the cancer burden increasing due to ageing and changing lifestyles, goat milk would be of great benefit because it contains anticarcinogens and other agents that can help prevent coronary heart disease. Small fat globule suspensions in goat milk simplify its assimilation, making it particularly advantageous for children and adults sensitive to or allergic to cow's milk (Getaneh *et al*., 2016). HIV/AIDS patients benefit from goat milk due to its high protein content, which enhances absorption and fortifies antibodies more effectively than other proteins. It is also a suitable option for mothers who choose not to breastfeed. Despite the well-known benefits of goat milk, worldwide production fails to meet the demand.

Goat milk contains protein, fats, carbohydrates, vitamins, and minerals. Goat milk's superior digestibility, proper fatty acid composition, and bioactive compounds appear to render it useful for treating or preventing specific health conditions (Zenebe *et al*., 2014). Milk proteins serve primarily as a source of amino acids and nitrogen for young mammals and are an essential component of adult dietary proteins. Intact milk proteins serve specific activities, such as micelle creation. Furthermore, milk proteins have physiological significance; they aid in the absorption of various key nutrients, including trace elements and vitamins, and contain a group of proteins that have a protective function. Researchers recommended that people with malnutrition, anaemia, and osteoporosis take goat milk daily or take iron supplements for a longer period because it has been proven to promote haemoglobin regeneration (Ngunjiri, 2020).

2.6 Sweet sorghum

2.6.1 Taxonomy of sorghum

Sorghum (*Sorghum bicolor* (L.) Moench) belongs to the genus sorghum family of *Gramineae* (Motlhaodi *et al*., 2016; Zhan *et al*., 2012). In 1974, Moench established the genus Sorghum and brought all the sorghum together under the name *Sorghum bicolor*. *Sorghum bicolor* is further broken down into three subspecies: *Sorghum bicolor bicolor*, *Sorghum bicolor drummondii*, and *Sorghum bicolor verticilliflorum*. *Sorghum bicolor bicolor* is represented by agronomic types such as grain sorghum, sweet sorghum, Sudan grass, and broomcorn (Berenji *et al*., 2011; Dahlberg *et al.,* 2011). Grain sorghum is primarily used as a food and a raw ingredient in alcoholic beverages. Broomcorn and sweet sorghum are used as raw materials to make broom and sugar syrup, respectively, while grass sorghum is farmed for green feed and forage use. The subspecies bicolor has been partitioned into five races, namely *bicolor, guinea, caudatum, kafir, and dura* (Chepkoech, 2021).

2.6.2 Biological classification and agronomic uses of sorghum

Sorghum biology is classified as diploid with 20 chromosomes (Motlhaodi *et al*., 2016). Commercial cultivars of sorghum are categorized according to the purpose and these are for grain, forage, fibre, broom, sweet, and biomass sorghum depending on their agronomic importance (ICRISAT, 2014). Though classified, there are almost no biological or taxonomic distinctions between these cultivated forms since all belong to the same species, Sorghum bicolor. Based on its final use, cultivated sorghum is classified into three types: grain sorghum for grain production, sweet sorghum for sugar and grain production, and biomass sorghum for biomass production.

2.6.3 General information on sorghum

Sorghum ranks fifth among the most widely cultivated cereals globally, following maize, rice, wheat, and barley. Mexico, the USA, Nigeria, Sudan, and India are the major producers, contributing 12.2%, 16%, 9.8%, 9.1%, and 7.8% of total world production, respectively (Salaraz-Lopez *et al.*, 2018). Since sorghum can be grown in tropical, subtropical, temperate, and semi-arid areas as well as on poor soils worldwide, it is a crop with a high universal value. Because of its drought-resistant qualities, it is referred to as "the sugarcane of the desert" or "the camel among crops" (Olugbemi, 2017). Sweet sorghum can fall into dormancy during extremely dry spells, and growth will resume when enough moisture levels return.

2.6.4 Characteristics of sweet sorghum

Sweet sorghum is cultivated due to its high sugar content in the stem. It is tall and stores carbohydrates in the stalk as simple sugars (fructose, glucose, and sucrose) with concentrations ranging from 10 to 25% (Makori, 2014). Sweet sorghum is a C4 plant with low grain yields, a high potential biomass production, a high photosynthetic capacity, and a sugar yield. Sweet sorghum's short production cycle and ability to vegetatively create new stalks allow for up to four harvests throughout each life cycle. One of the few crops that is hardly enough to withstand the effects of future climate change, especially the rising levels of drought, salinity in the soil, and extreme heat (ICRISAT, 2014). The crop's great water and nutrient efficiency allows it to thrive in conditions where soil moisture is scarce. However, because sweet sorghum has a large amount of water-soluble carbohydrates (WSC), it has a significant carbohydrate content (Pecka-Kiełb *et al*., 2021). With a greater WSC content that could enable the production of silages of superior quality, this variety of sorghum is a good substitute for forage sorghum in the production of silage.

2.6.5 Significance of sweet sorghum

Sweet sorghum is a crop that can be used for a variety of purposes, such as food, feed, fodder, and fuel. Worldwide, grains are used for human food; traditionally, they use sorghum in unfermented and fermented bread, porridges, snacks, tortillas, malted (traditional) beers, alcoholic and non-alcoholic beverages, and for bee feeding in many African and Asian countries. The United States and Europe can incorporate gluten-free sorghum into new meals (Athar, 2012). Its stalk is chewed, and the juice is used to make industrial products such as sugars and syrup, which is used as a sweetener in beverages, as well as ethanol, starch, monosodium glutamate, acids, and vitamins. The fiber from sweet sorghum stalks can be fermented to produce methane and hydrogen. Sweet sorghum leaves are used as fodder, while bagasse, following juice extraction, is used to make pulp and paper, animal feed, roof thatching or fence in some rural areas of Africa, and organic fertilizer (Makori, 2014).

2.6.6 Nutritional value of sorghum

Sorghum contains carbohydrates (60–70%), protein (8–12%), oil (2.8–3.6%), fiber (approximately 8%), ash (1-2%), vitamins, and phytochemicals such as phytosterols, policosanols, carotenoids, and phenolic compounds such as flavonoids, tannins, and anthocyanins, among others, which contribute to its biological potential (Cardoso *et al*., 2014; Chávez *et al*., 2017). Sorghum has a high crude protein level, moderate structural carbohydrate, and lignin content, making it a desirable animal feed component. According to Xie and Xu (2019), sweet sorghum leaves have the highest protein content, with up to 22%. However, developed countries have not used sorghum as fodder because the most common variety is grain sorghum, which has poor forage qualities.

2.6.7 Advantages of ensiling sweet sorghum

Ensiling is one way of preserving forage with a lower risk of losing feed nutrient value due to unfavourable conditions (Olusola *et al*., 2022). Ensiling sweet sorghum significantly reduced the anti-nutritional factors, such that it would encourage intake by small ruminants. It would also enhance palatability, well degraded in rumen and consequently be well utilized for growth by small ruminants (Kumar, 2011).

2.7 Chicory (*Cichorium intybus* (L.)

2.7.1 Taxonomy of chicory

The plant's name is derived from both Greek and Latin. *Cichorium* signifies "field," while *intybu*s derives from the Greek verb "to cut" referring to the leaves, and from the Latin word "*tubu*s" signifying the hollow stem. Chicory (*Cichorium intybus* (L.) belongs to the family *Asteraceae*, a very big family with over 23,000 species classified into 1,535 genera and three subfamilies: *Barnadesioideae*, *Cichorioideae*, and *Asteroideae* (Barcaccia *et al*., 2016). *Cichorium intybus* L, generally known as chicory, is a perennial, deep-rooting, erect rather woody herb, roughly 1m in height, with a fleshy taproot of up to 75cm in length and huge basal leaves (Pena-Espinoza *et al*., 2020; Street *et al*., 2013). The peripheral blooms are pale blue, while the central tube flowers are darker. The blooms bloom exclusively on sunny days. Honeybees easily pollinate them due to their high nectar and pollen content (Janda *et al*., 2021).

2.7.2 Historical use and distribution of chicory

Egypt has long and distinguished used chicory as a medicinal plant, cultivating it for its ability to treat liver, bile, and kidney diseases (Moraru *et al*., 2012). The ancient Greeks and Romans also grew it as a vegetable crop, and today, in many countries, wild chicory is considered a weed. Chicory is primarily grown in continental Europe, south-western Asia, a small portion of North America, South Africa, and Australia. It can be found in various ecological areas, but it is most commonly found in uncultivated grasslands, haymaking fields, uncultivated areas, and hill and mountain regions. Forage chicory has been introduced as a viable forage crop for livestock in East Africa, including Kenya, to improve nutrition and resilience in animal feed systems. The International Livestock Research Institute (ILRI) and its partners highlighted it in a 2020 factsheet in order to promote chicory as part of the efforts to enhance forage options in the region.

2.7.3 Chemical composition of chicory

All parts of this plant possess great medicinal importance because they contain many important compounds for medicine, including alkaloids, inulin, sesquiterpene lactones, coumarins, vitamins, chlorophyll pigments, unsaturated sterols, flavonoids, saponins, and tannins. Typically, fresh chicory contains 68% inulin, 14% sucrose, 5% cellulose, 6% protein, 4% ash, and 3% other compounds, while dried chicory contains approximately 98% inulin and 2% other compounds. Abbas *et al*. (2015) reported that grazing chicory reduces several internal parasites in livestock, potentially reducing the use of anthelmintics. Chicory leaves contain inulin, vitamins A, B1, B2, and C, minerals (Ca, K, Mg, Na, Fe, Cu, Mn, and Zn), and phenolic compounds, among others. Flowers contain a variety of sugars, coumarin derivatives (e.g., umbelliferone, esculin, tuticorin (esculetin 7-O-glucoside, scopoletin), silicic acid, taraxosterol, valeric acid, flavonoids (hyperoside), etheric oils, and anthocyanins, the latter of which contribute to the perianth's blue color. Chicory roots contain sap, sesquiterpene lactones, such as germacranolides (lactucin, lactucopicrin, and 8-deoxylactucin), and guajanolides (cycriozides B and C, sonchuzide C), which give a bitter taste (Janda *et al*., 2021).

2.7.4 Types of chicory

Chicory is a typical European horticulture crop. Despite not being autochthonous, continental Europe domesticated chicory as a vegetable crop, leading to the evolution of several cultivated varieties (Barcaccia *et al*., 2016). According to Street *et al*. (2013), Chicory is grown for a variety of purposes. Depending on its purpose and usage, it can be categorized into four types: (1) "industrial" or "root" chicory, predominantly cultivated in north-western Europe, India, South Africa, and Chile, produces the taproot as a coffee substitute or for inulin extraction; (2) "Brussels" or "witloof" chicory is commonly cultivated around Europe as an industrial crop for etiolated buds obtained by forcing (i.e., the specific whitening process adopted to obtain the commercial product usually named "Chicon"). (3) "Leaf" chicory, also known as "Radicchio," which is generally known as a major component of fresh salads and is typically cooked and prepared differently according to traditions and alimentary habits, (4) "Forage" chicory, which was originally developed from wild chicory, has been domesticated since the mid-1970s to improve herbage availability in perennial pastures for livestock (Pena-Espinoza *et al*., 2018). This indicates the growing global interest in forage chicory. Currently, forage chicory is regarded as a species having the potential to minimize ruminant methane emissions. Furthermore, it has been evaluated in Turkey as a potential bio monitor of heavy metals in areas with varying levels of pollution.

2.7.5 Varieties of chicory

Despite its natural distribution throughout Europe, forage chicory is a relatively recent crop in many regions. Much of the breeding for improved forage properties has taken place in New Zealand, with the first variety, Puna, released in 1985. Since then, France, the United States, Australia, and China have created more forage chicory types, including Lacerta, Forage Feast, Oasis, and Puna II (Mangwe *et al.*, 2020). Newer cultivars derived from Grasslands Puna include Grasslands Choice and Grasslands Puna II. This is due to increased cool-season activity, morphological consistency, and a focus on low amounts of sesquiterpene lactones, a chemical that generates a contaminated or bitter aftertaste in milk. Research has proven that feeding chicory (cv. Choice) to dairy cows increases water intake and lowers urinary nitrogen concentrations, leading to increased milk output and an improved milk fatty acid profile.

2.7.6 Economic and nutritional importance of chicory

The following characteristics make chicory economically and nutritionally important: Chicory can be sown in either spring or autumn, and weed management is required to ensure establishment. It has a long life (5-7 years), similar to orchard grass or alfalfa, and is best suited to well-drained or moderately drained soils with medium to high fertility and a pH of 5.5 or above. It has a relatively deep taproot that allows it to withstand drought. Its high nutritive value (higher than that of other well-known fodder species such as alfalfa, cock's foot, and clover) led to its introduction in various fodder crop structures, particularly in moist-deficit areas, where it is grown in both monoculture and various temporary grassland mixtures (Neciu *et al.*, 2017). Chicory recovers quickly after grazing or mowing, which shortens the production cycle (28–30 days) and allows for more production cycles or grazing (4-6 per year) than other perennial plants. Chicory is highly expendable in all ruminant species (cattle, sheep, and goats) due to its nutritional value; chicory pure culture production varies according to natural and technological conditions (30–60 T/ha green mass, 7–15 T / ha dry matter), with a daily production rate of 150–400 kg/day/ha of green mass during the growing season.

2.7.7 Nutritional value of chicory

Chicory provides nutritional value comparable to Lucerne since it contains similar amounts of protein, fats, minerals, and other nutrients (Girelli *et al.*, 2021). According to

Nwafor *et al*. (2017), forage chicory has comparable animal performance to legumes and outperforms grass-based pastures. In general, forage chicory varieties grow at temperatures above 10°C, are high in minerals (Zn, B, and Mn), have variable protein levels [100–250 g crude protein/kg dry matter (DM), depending on N input and defoliation frequency], have low neutral detergent fiber levels, and have high voluntary feed intakes in ruminants. Ruminants feeding pure forage chicory have shown similar or greater weight gains than animals grazing ryegrass when given comparable levels of DM intake.

Forage chicory is low in fiber, has less dry matter (DM), and has fewer structural carbohydrates than other forage species because it may stay green for a longer period of time (Pena-Espinoza *et al*., 2018). Farmers highly appreciate chicory due to these characteristics. A proportion of 70% leaves and 30% stems should be desirable in forage chicory because of the higher digestibility of leaves compared to stems. To ensure higher-quality forage and nutritive value, chicory should be harvested at the vegetative stage. The forage has a high nutritional content, with 14–27% CP, 70–80% digestibility in the leaves, and ME of 13.7 MJ/kg DM.

2.8 Anti-nutritive factors (ANFs)

ANFs are chemical components found in feeds that might hinder feed consumption, decrease animal productivity, or impact animal health (Jeyakumar *et al*., 2022; Ramteke *et al*., 2019). In other words, they are feed additives that reduce an animal's development and productivity (Yacout, 2016). Reduced nutritional utilization and intake of plants or plant products used as human foods or animal feeds are brought about by these substances, which are also called plant secondary metabolites. The term can also refer to biological substances found in foods consumed by humans or animals that have the effect of decreasing nutritional utilization and worsening metabolic and gastrointestinal function.

Anti-nutrients are secondary metabolite substances evolved by plants for their protection. At doses below the fatal threshold, these components may not necessarily pose a threat. Concentration, chemical structure, exposure duration, and interactions with other dietary components determine the balance between the positive and harmful effects of anti-nutrients (Kemboi *et al*., 2023). For example, cyanogens, lectins, and proteinase inhibitors are examples of heat-labile plant toxins; condensed tannins, antigenic proteins, saponins, gossypol, and phytoestrogens are examples of heat-stable plant toxins. This research will focus on tannins in sweet sorghum and chicory, as well as saponins in chicory.

2.8.1 Tannins

Plant polyphenols like tannin have astringent and bitter properties; they can bind or precipitate proteins and other chemical molecules like alkaloids and amino acids. The majority of plants contain tannins, which are antinutritional. Tannins, composed of several phenolic hydroxyl groups, can bind to proteins and form both reversible and irreversible complexes. Tannins are classified into three categories: (1) hydrolyzable tannins found in garlic acid; (2) condensed tannins found in most legumes; and (3) pseudo-tannins found in brown-green algae (Akande *et al*., 2010). Ruminants are more resistant to microbial attack and are hazardous to many different types of microorganisms; thus, it is logical that concentrations of condensed tannins exceeding 4% would be hazardous to them. While hydrolysable tannins can induce a variety of harmful symptoms when broken down in the rumen, condensed tannins significantly reduce digestibility. In both animals and humans, tannins are heat-stable and reduce protein digestibility. This is likely due to tannins' ability to either make protein partially unavailable or hinder digestive enzymes, leading to an increase in fecal nitrogen.

Tannins appear in food products and have the ability to inhibit the activities of several enzymes, including trypsin, chymotrypsin, amylase, and lipase. Additionally, they can lower the protein quality of foods and interfering with iron absorption. It is widely known that tannins reduce experimental animals' feed intake, growth rate, feed efficiency, and protein digestibility. A high level of tannin in the diet has the potential to inhibit the activity of microbial enzymes involved in digestion of cellulose and other dietary components (Gemede & Ratta, 2014). It is possible that the tannin-protein complexes, which are insoluble complexes of tannins with proteins, cause the anti-nutritional effects of the food containing tannins. Apparently, these make it difficult for the body to absorb nutrients like vitamin B12 and iron. However, tannins may also have some beneficial effects on animal health as these can be used as an antioxidant, free-radical, anti-bacterial, anti-diarrhoea, scavenging, and anti-proliferative activity in liver cells.

2.8.2 Saponins

Saponins are secondary chemicals found mostly in plants; they are non-volatile, surface-active, and widely distributed in nature. These molecules, composed of non-polar aglycones connected to one or more monosaccharide moieties, exhibit a variety of structures. They act like soap in water because their molecules contain both polar and non-polar components (Tadele, 2015). Saponins' structural complexity gives them a wide range of physical, chemical, and biological characteristics, such as the ability to impart flavors (sweet or bitter), to foam or emulsify, to have medicinal or pharmacological effects, to break down blood cells, and to kill microbes and insects (Gemede & Ratta, 2014). Saponins inhibit the intestinal absorption of glucose and cholesterol via physicochemical interactions inside the lumen. Consequently, researchers have observed hypocholesterolemic effects. Some studies have shown that saponins in chicken feed can hinder growth, feed efficiency, and the absorption of vitamins A and E. Among the many plant chemicals that have positive benefits are saponins. Saponins's many biological impacts include antibacterial and antiprotozoal properties.

2.8.3 Methods of reducing the level of anti-nutritive factors

There have been multiple attempts to make tannins and saponins inactive (Kemboi *et al*., 2023). These include mechanical or physical processes such as wilting, processing, and ensiling; chemical approaches such as treatment with alkalis, organic solvents, and precipitants; and inoculation involving bacteria that are resistant to tannin. This study will employ physical methods like ensiling sweet sorghum to inactivate tannins, and wilting chicory to inactivate saponins and tannins.

2.8.4 Beneficial effects of ant-nutritive factors

Animal feeding with tannin can help with a number of issues, such as better protein utilization, fewer parasites, less proteolysis during ensilage, preventing bloat, raising the quality of animal products, lowering pollution, and rumen defecation. In sheep fed temperate forages, condensed tannins (CT) have decreased the impact of gastrointestinal parasites and increased reproductive efficiency, wool production, and live weight growth (Tadele, 2015). However, there are environmental benefits to using them as well, such as less nitrogen pollution from rumen fermentation and animals grazing in nitrogen-rich pasturesSaponins have been found to have a wide range of activities, including antioxidant, anticancer, antitumor, cholesterol-lowering, immune-potentiating, and an increased resistance to coronary heart disease.

2.8.5 Income over feed cost

When evaluating the feed efficiency of dairy herds, one way to look at it is in terms of income over feed cost (IOFC), which is also known as return over feed (ROF). This measurement method takes a profitability perspective. It is determined by subtracting the feed costs from the total revenue earned from milk sales over a given time period (Connor, 2015). We can determine the effectiveness of ration and feed management strategies and the reasonableness of feed expenditures given milk production by tracking IOFC over a specific period. The income over feed cost determines the marginal milk yield and break-even point. It also aids in determining the most efficient usage of both on-farm and purchased ingredients. Furthermore, it can be utilized for herd management and feeding decisions (Tanwiriah *et al*., 2019). Income over feed cost is a gross margin notion that can be used to determine whether a feeding management strategy is profitable in the short term. On the other hand, gross margin isn't a good indicator of a farm's profitability since it doesn't account for fixed costs (administration, insurance, rates, taxes, depreciation of buildings and machinery, and so on) or capital (i.e., machinery, land, buildings, and irrigation equipment) (Lawrence *et al*., 2015).

2.8.6 Supplementation in ruminant animals

Ruminant animals mostly consume cereal crop residues and low-quality roughages as a source of feed (Amole *et al*., 2022). These feeds are associated with low digestibility, energy, and protein, so they cannot sustain effective animal production or even maintenance when fed alone, particularly during the dry season. Supplementing dairy goats' diets with the right kinds of nitrogen, energy, and protein can boost their production because it encourages the growth of beneficial bacteria in their rumens and increases the amount of feed that the animals voluntarily consume (Kumar *et al*., 2015). Soybean meal, cotton seed cake, sunflower seed cake, and groundnut cake are some examples of protein sources included in supplements. Molasses, wheat bran, rice bran, and maize bran are energy sources, and minerals and non-protein nitrogen (NPN) are popular (Gachuiri & Lukuyu, 2021).

It is expensive to supplement with conventional sources of protein and energy. According to Wilkinson and Lee (2018), this might potentially lead to ruminant production being in direct competition with that of humans and monogastric farm animals. Forage legume supplementation may include supplementation with herbaceous, shrubby, or tree legumes. In addition to an abundance of minerals, vitamins, and fermentable and bypass proteins, forage legumes also contain high levels of tannins. The use of fodder from both herbaceous and shrubby or tree legumes as a supplement to crop residues and poor-quality pastures creates an opportunity to minimize body weight losses during the dry season and to enhance productivity (Menbere *et al*., 2015).

2.9 Research gaps

Sweet sorghum silage does not provide sufficient nutrients especially protein for optimum growth and production due to its low crude protein (8%). Therefore, more research is needed on the nutrition composition of the combination of sweet sorghum silage and forage chicory. Although literature is available for forage sorghum silage, there is limited information on the use of sweet sorghum silage. Therefore, more research on the use of sweet sorghum silage is needed, especially its use as a basal forage for dairy goats. There is a paucity of information on sweet sorghum silage being supplemented by forage chicory, especially in dairy goat nutrition and feeding.

CHAPTER THREE

NUTRITIONAL EVALUATION AND *IN-VITRO* ORGANIC MATTER DIGESTIBILITY OF SWEET SORGHUM (*SORGHUM BICOLOR* (L.) MOENCH) SILAGE AND CHICORY (*CICHORIUM INTYBUS* (L.)

Abstract

Chemical composition and *in vitro* organic matter digestibility were evaluated in twelve diets consisting of sweet sorghum silage supplemented with 0, 10, 20, and 30% levels of forage chicory. The *in vitro* gas production properties, polyphenols, saponins, and chemical composition were determined. The SAS software (version 9.4) was used to analyse data using the general linear model of ANOVA and significant differences in means were separated using Tukey's Honestly Significant Difference Test at ($p<0.05$). The results shows that addition of forage chicory to the diets led to a significant rise ($p<0.05$) as per the chemical composition results. T4 (30%) recorded the highest amount of ash (121.4 g/kg DM), CP (138.7 g/kg DM), CF (323.8 g/kg DM), EE (30.6 g/kg DM), ADL (51.8 g/kg DM), CT (0.9 g/kg DM), TEPH (51.3 g/kg DM), SAP (5.7 g/kg DM), and TET (22.2 g/kg DM) while T1 recorded the lowest. The decrease ($p<0.05$) in dry matter digestibility can be explained by the addition of forage chicory levels to the diets, which dramatically reduced both the NDF and ADF. Therefore, the NDF and ADF levels of forage chicory were lower than those of sweet sorghum silage. The CT in the diets varied from 0.3 to 0.9 g/kg DM. This is less than what has been reported to be harmful to an animal's intake (50 g/kg DM). It was evident that T4 was more digestible than T1 based on the *in vitro* gas production (ml/200 mg DM) at 24 and 48-hour incubation periods, which was considerably higher ($p<0.05$) in T4 and lower in T1. Forage chicory could be used as a protein supplement for ruminants, especially dairy goats, as shown by its comparatively high CP of 224.1 g/kg DM. Sweet sorghum silage supplemented with forage chicory could be interesting alternative animal feed sources and valuable in the ruminant feeding.

3.1 Introduction

The livestock industry is crucial for ensuring food and nutrition security, creating employment opportunities, and generating revenue by selling livestock and livestock products, particularly for rural populations in Kenya. Herrero *et al.* (2021) reported that livestock are kept by 60-80% of rural households as a means to increase their food supply and income. In addition to employing around half of the agricultural workforce, the livestock industry contributes 12% to the country's GDP and 40% to the agricultural sector. About 58 percent of

Kenya's 46 million small ruminants are goats, so the animal is an integral part of the country's agricultural sector (Mbae *et al*., 2020).

Goats are significant for providing food and nutritional security by offering milk and meat, generating cash from selling surplus stock, and serving as a safeguard against unforeseen hazards and immeasurable cultural values (Waineina *et al*., 2021). Goat milk's nutritional and therapeutic advantages have caused a rise in its popularity among individuals of varying financial brackets, contrary to the historical perception of goats as the "poor man's cow." Providing sufficient and high-quality forages to the dairy goats on the farm is a cost-effective method to boost milk output and growth rates and to obtain replacement stock. This decreases manufacturing expenses and expenditures associated with replacing items (Ngunjiri, 2020). High-quality forage is characterized by its high protein and digestible nutrient content and low fibre and lignin content (Bakhashwain, 2010). Efforts should be increased by utilizing uncomplicated and cost-efficient methods to enhance the animals' productivity and reproductive performance.

The utilization of maize plant in making silage has been done widely as compared to sweet sorghum. However, the use of maize forage is considered less economical as compared to sweet sorghum. This is because maize is only harvested once in one production cycle as compared to sweet sorghum that can be harvested 3-4 times in one production cycle. Sweet sorghum is more drought tolerant compared to maize (Ratnaningtyas *et al*., 2023). In addition, the cost of production of sweet sorghum is 50% cheaper than the cost of maize production. Sweet sorghum contains more sugar content that supports improved fermentation and provides more energy in support of milk synthesis or body weight gain.

Sweet sorghum, therefore, stands out among other crops due to its potential to produce a large amount of forage with characteristics that favour the silo fermentation process and without the need for large amounts of inoculants or additives (De Oliveira *et al*., 2021). Like maize, sorghum has excellent production potential and desirable characteristics to produce high-quality silage: appropriate dry matter content (237 g/kg), high crude protein (84.8 g/kg DM), high content of water-soluble carbohydrates (141.4 g/kg DM), low buffer capacity (16.0 g/kg DM), and low pH (5.87) at the harvest time (Avasi *et al*., 2006). Furthermore, sorghum, with lower water deficit sensibility than maize, has become an exciting option for arid and semiarid regions worldwide, hence regarded as a climate-smart forage crop (Getachew *et al*., 2016). Sweet sorghum alone could not fully meet the production requirements of the dairy goats because of its low digestibility, energy, and protein, hence the need for a protein supplement such as forage chicory.

Forage chicory is a potential alternative to supplementing dairy goats with rumen degradable N and by-pass protein to increase basal food intake and thus nutritional absorption, and improving production performance. Other forages used to feed ruminants are either grasses, like Napier grass (*Pennisetum purpureum*), Rhodes grass (*Chloris gayana*), and Brachiaria (*Brachiaria decumbens*), or legumes, like Lucerne (*Medicago sativa*) and Greenleaf Desmodium (*Desmodium intortum*). Forage chicory, on the other hand, is a herb that is showing increased potential for large yields due to their elevated crude protein content (16–27%) and good digestibility (70–80%) (Nwafor *et al*., 2017). As a result of its high nutritional value, forage chicory is highly expendable in all ruminant animals, including cattle, sheep, and goats. Therefore, assessing the nutritive value of sweet sorghum (*Sorghum bicolor* (L.) Moench) silage and forage chicory (*Cichorium intybus* (L.) is essential feed for lactating dairy goats.

3.2 Materials and methods

3.2.1 Study site

This research was conducted at Tatton Agriculture Park (TAP) in Egerton University, Njoro. The University is located in Njoro Sub-County of Nakuru County. Positioned at an elevation of 1,800 meters above sea level, the location is approximately 0°22'11.0 "S, 35°55'58.0" E (Longitude: 35.932779; Latitude: -0.369734). The average temperature is 17-22 °C, although it may drop to 11 °C from July to August when the temperature drops to that magnitude. In short and long seasons, the average yearly rainfall is 1,200±100 mm. According to Egerton Station (2019), the prolonged rain begins in March and continues until July, whereas the short rain begins in October and ends in December.

3.2.2 Fodder production

Sweet sorghum was established on one acre of land in Tatton Agriculture Park. Before planting sweet sorghum, the land was prepared to a fine tilth, and 100 kg of diammonium phosphate (DAP) was used. After one month of establishment, 100 kg of calcium ammonium nitrate (CAN) was top-dressed to supply nitrogen and calcium. To make silage, sweet sorghum was harvested at the hard dough stage. In addition, forage chicory was established in the nursery and thereafter transplanted to Tatton Agriculture Park, which was 0.25 acres of land, and planted at a spacing of 15 cm between the lines at a depth of 1cm. 25 kg of diammonium phosphate fertilizer (DAP) was used during planting. After one month of establishment, forage chicory was top-dressed by 25 kg of calcium ammonium nitrate (CAN) to provide nitrogen and calcium. Forage chicory was harvested after attaining a maximum leaf size before stem elongation.

3.2.3 Feed preparation

Sweet sorghum was finely cut using mounted forage harvester and thereafter placed into AgroZ silage bags with dimensions of 1 meter by 2.5 meters. To ensure airtightness, the upper portion of the silage bags were tightly fastened. The silage bags were stored in one of the stores in Tatton Agriculture Park. The forage chicory leaves were harvested two days earlier, spread in the shade to dry, and measured before being fed daily to the dairy goats.

3.2.4 Feed sample preparation

Sweet sorghum silage and forage chicory leaves were sampled, dried and milled to pass through a 1mm screen for chemical analysis and a 4 mm sieve for feeding purposes (AOAC, 2005). The feeds were then formulated into four diets and kept at the lab for further analysis.

3.2.5 Chemical analysis

The samples were dried at 105°C in a forced-air oven to determine the dry matter (DM) (AOAC method 934.01). The procedure for determining the amount of crude protein involved multiplying the nitrogen content by 6.25 (CP; Kjeldahl, method 984.13 of AOAC) and estimating the nitrogen concentration using a Kjeltec 2300 Foss Tecator device (Häganäs, Sweden). The ether extracts were obtained by continuous extraction in a Soxhlet extractor without prior acid hydrolysis (EE; method 920.39 of AOAC). Crude fibre was determined by applying the AOAC standard methods (AOAC, 2005), hydrolyzing the samples with an acid and base solution using the Fibertec Tecator equipment (Häganäs, Sweden) in accordance with the HennebergStohmann technique (CF; method 978.10 of AOAC). Using the AOAC standard methods (AOAC, 2005), crude ash was determined by burning samples at 550°C in a muffle furnace (method 942.05 of AOAC). The fibre component was investigated using the Van Soest *et al*. (1994) method for acid detergent fibre (ADF; method 973.18 of AOAC), neutral detergent fibre (NDF; method 2002.04 of AOAC), and acid detergent lignin (ADL; method 973.18 of AOAC) using Fibertec Tecator (Häganäs, Sweden) apparatus (AOAC, 2005).

A 70% aqueous acetone was used to extract the total phenolics, and acetone was used to calculate the total extractable tannins in accordance with Folin-Ciocalteu techniques as expounded by Makkar (2003). The condensed tannin content was determined using the procedure outlined by Porter *et al*. (1986). The condensed tannin concentration was ascertained by measuring the total phenolic content and then precipitating the tannins with

Polyvinylpolypyrrolidone (PVPP). The condensed tannins were then calculated as a percentage of the tannic acid equivalent on a dry matter basis by subtracting the findings from the phenols.

3.2.6 Rumen fluid sampling and *in-vitro* digestibility

This was done after the eight weeks of the feeding experiment. A vacuum pump was used to obtain 500 ml of rumen fluid from three donor dairy goats before their morning feeding. The liquid was quickly moved into a thermos flask and filtered through two layers of cheesecloth. To keep the environment anaerobic, the flask was continuously flushed with carbon dioxide (CO2). A 1:2 (v/v) ratio of buffers to rumen fluid was used to mimic saliva's effect. Following a gentle swirl and the release of any air bubbles, 30 ml of the buffer-rumen fluid mixture was measured and added to the syringes containing the samples. 200 mg of the treatment diet in a 1 mm fine sample was put into two graduated 100 ml glass syringes. Petroleum jelly was used to lubricate the syringes to facilitate the piston's movement and stop gas leakage. A plastic clip was then used to seal the silicon rubber tube. The gas production method (Menke & Steingass, 1988) was used to determine the fermentative activity of the mixed fluid and feed. Finally, the syringes were incubated for 0–96 hours at 39^{o}C in a thermostatically controlled water bath. The samples and the blank (rumen fluid + buffer) were run in duplicates. Finally, the amount of gas produced at 0, 3, 6, 9, 12, 18, 36, 48, 72, and 96 hours was determined by examining the syringe's calibration. Consequently, the net gas production was calculated as the total volume increased minus the mean blank value from the recorded gas production of all samples. Using NEWAY Excel software version 6, the computed gas production numbers were fitted in the equation of Ørskov and McDonald (1979) to find the feed's potential degradability.

$Y = a + b\,(1-e^{-ct})$

Where:

Y = the volume of gas generated with time (t)

a = the soluble fraction's initial gas production

b = gas produced by the insoluble but slowly fermenting fraction at time t during incubation

c = gas production rate constant (fraction /hour)

t = the time of fermentation.

Then (a+b) represents the possible amount of gas production.

A graphical representation was plotted to illustrate the progress of the incubation process. Estimations of metabolizable energy (ME), organic matter digestibility (OMD), and short-chain fatty acids (SCFA) were carried out as well using the produced gas. The SCFA was determined by utilizing the formulas proposed by McDonald *et al*. (1995) and (Menke & Steingass, 1988): SCFA (m mol/200 mg DM) = (0.0222*GP24) - 0.00425, with GP24 being the net gas production during 24-hour (ML/200 mg DM). GP48 is the 48-hour net gas production, and CP is the crude protein. The formula for OMD (%) is 18.53 + (0.9239*GP48) + (0.0540*CP) (Menke & Steingass, 1988). According to Menke and Steingass (1979), the formula for ME (MJ/kg DM) is 2.20 + (0.1357 * GP24) + (0.0057* CP) + (0.0002859* EE2), where GP24 is the 24h net gas production, CP is the crude protein, and EE is the ether extract.

3.3 Statistical analysis

After conducting each nutrient analysis in triplicate, the data were subjected to an analysis of variance (ANOVA) using the general linear model (GLM) procedure of statistical analysis system (SAS, 2013) version 9.4, which followed a completely randomized design (CRD). Significant differences in means were separated using Tukey's HSD Test at ($p< 0.05$). The statistical model:

$Y_{ij} = \mu + \tau_i + \varepsilon_{ij}$

Where:

Y_{ij} = observation on the i^{th} treatment in the j^{th} block

μ = overall population mean,

τi = effect due to the i^{th} treatment, i= {1, 2, 3, 4}

ε_{ij} = random error associated with Y_{ij}

3.4 Results

3.4.1 Nutritional composition of sweet sorghum silage and forage chicory

Table 3.1: Chemical composition of sweet sorghum silage and forage chicory (g/kg DM)

Parameter	Sweet sorghum silage	Forage chicory
Dry matter	972.6±0.14	968.7±0.13
Ash	115.8±0.05	173.1±0.04
Crude protein	81.1±0.18	224.1±0.15
Crude Fiber	295.8±0.15	113.8±0.15
Ether extracts	18.3±0.04	25.6±0.10
Neutral detergent fibre	647.0±0.49	337.7±1.26
Acid detergent fibre	419.5±1.32	353.5±0.90
Acid detergent lignin	50.6±0.71	107.8±0.35
Condensed tannins	0.3±0.00	1.0±0.00
Total extractable phenolics	22.6±0.38	20.1±0.35
Saponins	0.5±0.03	3.3±0.06
Total extractable tannins	2.7±0.10	4.0±0.23

The nutritional composition presented in Table 3.1 shows that sweet sorghum silage had higher DM content (972.6 g/kg) than forage chicory (968.7 g/kg). Sweet sorghum silage had the lowest ash content (115.8 g/kg DM), while forage chicory had the highest (173.1 g/kg DM). The CP in sweet sorghum silage (81.1 g/kg DM) was lower while it was higher in forage chicory (224.1 g/kg DM). Sweet sorghum silage had the lowest EE (18.31 g/kg DM), while forage chicory had the highest EE (25.61 g/kg DM). Sweet sorghum silage recorded the highest CF (295.8 g/kg DM), NDF (647.0 g/kg DM), ADF (419.5 g/kg DM), and TEPH (22.6 g/kg DM), while forage chicory recorded the highest ADL (107.8 g/kg DM), CT (1.0 g/kg DM), SAP (3.3 g/kg DM), and TET (4.0 g/kg DM).

3.4.2 Nutritional composition of the treatment diets

Table 3.2: Chemical composition of the treatment diets with different levels of sweet sorghum silage and forage chicory (g/kg DM)

Parameter	**Treatment diets**				
Sample	T1	T2	T3	T4	p-value
DM	972.6±0.14^{a}	924.7±0.06^{b}	921.9±0.09^{b}	920.9±0.07^{b}	<.0001
Ash	115.8±0.05^{b}	116.1±0.10^{b}	117.9±0.07^{ab}	121.4±0.13^{a}	0.0076
CP	81.1±0.18^{d}	105.9±0.20^{c}	119.1±0.14^{b}	138.7±0.13^{a}	<.0001
CF	295.8±0.15^{c}	298.7±0.06^{d}	309.0±0.07^{b}	323.8±0.10^{a}	<.0001
EE	18.3±0.04^{c}	24.1±0.08^{b}	26.4±0.05^{ab}	30.6±0.17^{a}	0.0010
NDF	647.0±0.49^{a}	560.7±0.22^{b}	517.0±0.22^{c}	433.7±0.39^{d}	<.0001
ADF	419.5±1.32^{a}	287.3±0.33^{b}	218.5±0.64^{c}	199.3±0.46^{c}	<.0001
ADL	50.6±0.71^{a}	50.9±0.13^{b}	51.3±0.13^{ab}	51.8±0.12^{a}	0.0207
CT	0.3±0.00^{b}	0.3±0.00^{b}	0.9±0.00^{a}	0.9±0.00^{a}	<.0001
TEPH	22.6±0.38^{c}	22.8±0.15^{c}	34.4±0.06^{b}	51.3±0.12^{a}	0.0002
SAP	0.5±0.03^{c}	2.4±0.05^{bc}	4.1±0.01^{ab}	5.7±0.05^{a}	0.0006
TET	1.56±0.10^{a}	15.2±0.21^{a}	21.3±0.21^{a}	22.2±0.08^{a}	0.0423

$^{a, b, c, d}$ Means in a row with different superscript significantly differ at ($p<0.05$). T1=100% sweet sorghum silage; T2=90% sweet sorghum silage+10% forage chicory; T3=80% sweet sorghum silage+20% forage chicory; T4=70% sweet sorghum silage+30% forage chicory. DM=Dry matter, CP=Crude protein, CF=Crude Fiber, EE=Ether extracts, NDF=Neutral detergent fibre, ADF=Acid detergent fibre, ADL=Acid detergent lignin, CT=Condensed tannins, TEPH=Total extractable phenolics, SAP= Saponins, TET= Total extractable tannins.

The result in Table 3.2 shows that T1 had the highest DM (972.6 g/kg) while T4 had the lowest DM (920.9 g/kg). T4 had the highest ash (121.4 g/kg DM), CP (138.7 g/kg DM), CF (323.8 g/kg DM), EE (30.6 g/kg DM), ADL (51.8 g/kg DM), CT (0.9 g/kg DM), TEPH (51.3 g/kg DM), SAP (5.7 g/kg DM), and TET (22.2 g/kg DM). T1 had the lowest ash (115.8 g/kg DM), CP (81.1 g/kg DM), CF (295.8 g/kg DM), EE (18.3 g/kg DM), ADL (50.6 g/kg DM), CT (0.3 g/kg DM), TEPH (22.6 g/kg DM), SAP (0.5g/kg DM), and TET (1.56 g/kg DM) respectively. Both the NDF and ADF decreased significantly ($p<0.05$) with addition of forage chicory levels to the diets hence T4 recording the lowest NDF (433.7 g/kg DM), and ADF (199.3 g/kg DM) while T1 recording the highest NDF (647.0 g/kg DM), and ADF (419.5 g/kg DM).

3.4.3 *In vitro* gas production and fermentation characteristics

Table 3.3: *In vitro* gas production and fermentation characteristics

	GP24	**GP48**	**A**	**B**	**C**	**A+B**	**RSD**	**SCFA**	**OMD**	**ME**
T1	4.63^{a}	8.22^{b}	0.80^{bc}	2.41^{b}	3.88^{b}	1.67^{a}	2.72^{a}	6.29^{b}	3.56^{b}	26.55^{c}
T2	8.67^{a}	9.69^{ab}	3.17^{ab}	2.51^{b}	5.58^{b}	2.70^{b}	3.19^{a}	8.67^{ab}	4.16^{ab}	28.07^{ab}
T3	10.76^{a}	9.75^{ab}	3.31^{a}	3.08^{ab}	5.82^{b}	5.63^{a}	3.50^{a}	10.76^{a}	4.53^{ab}	28.23^{b}
T4	10.81^{a}	11.36^{a}	0.54^{c}	5.47^{a}	6.02^{a}	19.81^{a}	4.1^{a}	10.81^{a}	4.76^{a}	29.55^{a}
SEM	0.96	0.39	0.45	0.44	2.49	0.26	0.21	0.68	0.37	0.15
P-value	0.0395	0.0085	0.0086	0.0111	<0.0001	0.0057	0.0094	0.0255	0.0007	0.0069

[a, b, c] Means in a row with different superscript significantly differ at ($p<0.05$). SEM=Standard error of the mean; A=Initial gas production; B=Actual gas produced during degradation; C=The rate of gas production per hour; A+B=The total gas produced during fermentation; RSD=Relative standard deviation; SCFA=Short chain fatty acids; OMD=Organic matter digestibility; ME=Metabolizable energy; T1=100% sweet sorghum silage; T2=90% sweet sorghum silage+10% forage chicory; T3=80% sweet sorghum silage+20% forage chicory; T4=70% sweet sorghum silage+30% forage chicory.

In vitro gas production provides an effective method for assessing feed quality. Table 3.3 presents *in vitro* gas produced at 24- and 48-hours and the fermentation characteristics of each treatment diet. The gas is frequently produced when microbes in the feed ferment and decompose organic materials (Blümmel & Fernandez-Rivera, 2002). Estimating the amount and pace of feed digestion involves measuring the gas produced during incubation. Both the 24- and 48-hours' total gas production (ml/200 mg DM) shows changes in the digestibility potential. Digestibility at 24- and 48-hours was highest in T4 (10.81, 11.36) and lowest in T1 (4.63, 8.22). From all the four experiments, T4 had the highest results for initial gas production (0.54), actual gas production (5.47), rate of gas production (19.81), total gas production (A+B) (6.02), residual standard deviation (4.1), short-chain fatty acids (SCFA) (0.24), organic matter digestibility (OMD) (29.55), and metabolizable energy (ME) (4.76). In contrast, T1 had the lowest results.

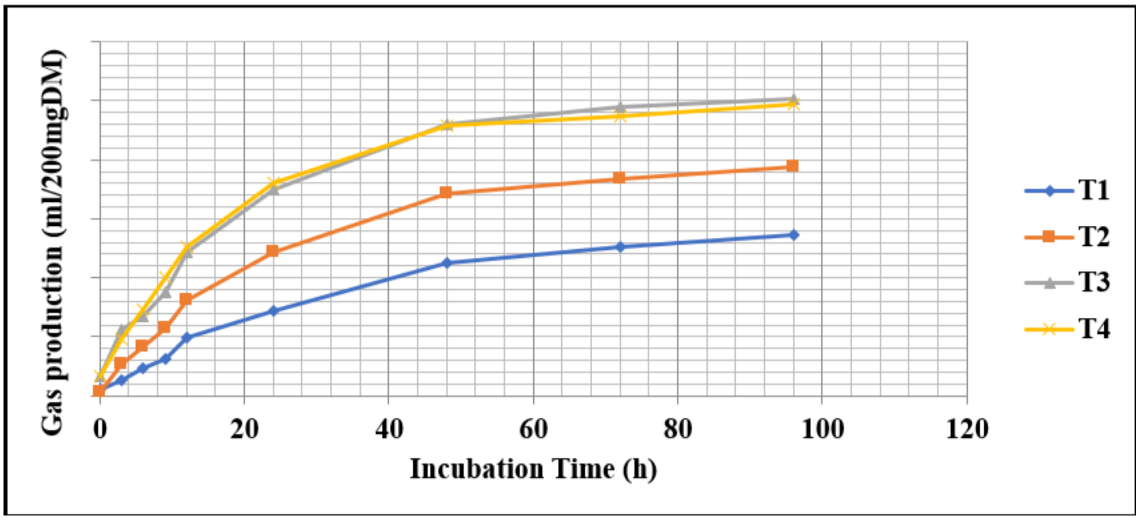

Figure 3.1: Patterns of *in-vitro* cumulative gas production of T1, T2, T3, and T4 diets

3.5 Discussion

Forage chicory is one of the alternative forage protein sources. The nutritional quality can be compared to Lucerne as it contains similar proportions of lipids, protein, minerals, and other nutrients (Girelli *et al*., 2021). Generally, the addition of herbs to the rations of ruminants has positive effects on rumen fermentation and digestibility (Tawab *et al*., 2020). The result shows that forage chicory has the highest CP (224.1 g/kg DM) which is within the range reported by Laws and Genever (2016). While sweet sorghum silage has the least CP (81.1 g/kg DM). This crude protein was higher than that reported by Ren *et al*. (2014). The lower CP could be as a result of the higher fibre content in sweet sorghum silage diet. The crude protein of sweet sorghum silage was higher than the minimum CP content of 7% in roughages that is considered an essential requirement for optimal rumen microbial fermentation activity. It can also be observed that its combination with sweet sorghum silage at different levels improves the CP of these ingredients. The protein in forage chicory is a high-quality nutrient containing many diverse amino acids, nine essentials for humans and animals. Therefore, it is suitable as a protein source for dairy goats.

The result shows that forage chicory has an ash content of (173.1 g/kg DM), which is higher than that reported by Wang and Cui (2011). While sweet sorghum silage has a lower ash content (115.8 g/kg DM), which is lower than that reported by De Oliveira *et al*. (2021). The ash content in the diets increased depending on the level of supplementation with T4 (121.4 g/kg DM) recording the highest ash content. The crude fibre improves the diet's palatability, making it highly acceptable to the dairy goats. It also enhances chewing, rumination, and saliva production in ruminant animals, which helps maintain the rumen pH and normal function. Regarding CF content, the forage chicory value obtained here (113.8 g/kg DM) was much lower than that explored by Jangra and Madan (2018). Sweet sorghum silage has a higher CF content (295.8 g/kg DM), which is lower than that reported by Jalajakshi *et al*. (2018). The variation in forage chicory and sweet sorghum silage used in this study might result from different stages and seasons of harvest, soil type, post-harvesting treatment, drying method, and agro-climatic conditions.

The digestibility coefficients of forages with high concentrations of neutral detergent fibre (NDF) are lower than those of forages with lower fibre content. It should be noted that forage chicory had a low NDF intake (337.7 g/kg DM). This measure is the primary predictor of rumen fill and voluntary intake. However, it tends to remain rather stable. As the ADF increases, the forage becomes less digestible since it measures the forage's least digestible component. Forage chicory had a low ADF intake (353.5 g/kg DM). Therefore, forage chicory supplementation at various levels was found to reduce NDF and ADF levels. These findings were in contrast with those of Niderkorn *et al.* (2019). However, sweet sorghum silage had a higher NDF intake (647.0 g/kg DM) and ADF intake (419.5 g/kg DM). These results were higher than those of Ren *et al*. (2014).

Condensed tannins, phenolic compounds, and saponins are among the few anti-nutritional agents found in sweet sorghum silage and forage chicory. For instance, according to Nwafor *et al*. (2017), ruminants whose diets contain tannins and other anti-nutritional components at high intake rates have decreased feed intake, poor rumen metabolism, and dry matter digestibility issues. There have been reports of animals losing weight, becoming poisonous, and even dying. Saponins and condensed tannins are responsible for nutritional absorption reduction, growth impairment, and mucosal toxicity, according to the previous research. They also mentioned that ruminants had experienced haemolytic action and bloat as a result of these anti-nutritional elements.

A low concentration of condensed tannins (1.0 g/kg DM) was found in forage chicory and sweet sorghum silage (0.3 g/kg DM), according to these results, but the CT in the diets varied from 0.3 g/kg DM to 0.9 g/kg DM. These levels are below the harmful threshold (50 g/kg DM) for animal consumption as well as protecting proteins from rumen breakdown (Addisu, 2016). It was concluded that forage-fed ruminants could benefit from using forage containing condensed tannins in specific quantities to improve protein digestion and animal productivity. This would lead to more environmentally friendly methods of managing certain diseases that occur during grazing.

The total extractable tannins in forage chicory (4.0 g/kg DM) were higher than what was indicated by Iqbal *et al*. (2021), while the total extractable phenolics (20.1 g/kg DM) were lower than what was reported by Nwafor *et al*. (2017). The total extractable tannins in sweet sorghum silage (2.7 g/kg DM), and total extractable phenolics (22.6 g/kg DM) were high than that recorded by Khosravi *et al*. (2018). Glycosidic chemicals called saponins are present in the majority of plant species. They have a bitter taste and can cause foaming. Saponins contain anti-fungal and anti-carcinogenic properties. The results demonstrated that the saponins content of forage chicory was higher (3.3 g/kg DM) compared to what had been found by Abbas *et al*. (2015). Additionally, it was observed that when supplementation levels increased, so did the levels of TEPH, TET, and saponins in the treatment diets.

Gas production is a function and mirror of degradable carbohydrates and therefore the amount of gas produced depends on the nature of the carbohydrates. The gas volume is a good parameter from which to predict digestibility, fermentation end products and microbial protein synthesis of the substrate by rumen microbes in the *in vitro* system (Olusola *et al*., 2022). Fermentation and *in vitro* gas production showed a great deal of variation. According to the findings, T4 (10.81, 11.36) produced the most gas production at 24 and 48 hours thus indicating highest digestibility in the rumen. T1 (4.63, 8.22) produced the least gas production at 24 and 48 hours thus indicating least digestibility in the rumen. The observed low gas production in T1 could be attributed to the high cell wall content from sweet sorghum silage. Akinfemi *et al*. (2010) reported that the lignification of cell wall limits the function of rumen microbial flora. This is an indication of lower energy loss to ruminants.

Blümmel and Fernandez-Rivera (2002) used OMD% to calculate the metabolic energy (ME). T1 had the least 3.56 ME (MJ/Kg DM) while T4 recorded the highest 4.76 ME (MJ/Kg DM). The energy level was positively correlated with the supplementing rate. Supplementation enhanced the diets' supply of metabolizable energy, as shown above. This is because microorganisms in the rumen need energy to synthesize proteins. Getachew *et al*. (2002) reported the close association between SCFA and gas production *in vitro* that uses the relationship between SCFA and gas production to estimate the SCFA production from gas values, which is an indicator of energy availability to the animal. T4 (0.24) had the highest SCFA and this could be associated with the highest gas production and metabolizable energy while T1 (0.10) had the least SCFA due to a lower absolute gas production, which was most evident during the first 24 h of incubation.

3.6 Conclusion

Findings of this study indicate that sweet sorghum silage and forage chicory have the nutritive potentials as ruminant feeds. More so, the *in vitro* degradability study determines the nutritive value of sweet sorghum silage and forage chicory. Also, it identifies differences among their potential digestibility and energy contents. Therefore, the dietary treatment with 30% forage chicory supplementation indicated the highest nutritional value and digestibility.

3.7 Recommendation

Based on the nutritional composition reported in this study, forage chicory can be recommended as a potential protein supplement for ruminants offered low-quality forages.

CHAPTER FOUR

EFFECT OF SUPPLEMENTING SWEET SORGHUM (*SORGHUM BICOLOR* (L) MOENCH) SILAGE DIET WITH FORAGE CHICORY (*CICHORIUM INTYBUS* (L.) ON THE PERFORMANCE OF DAIRY GOATS

Abstract

Poor-quality pastures and cereal crop residues cannot sustain effective animal production or even support maintenance when fed alone, particularly during the dry season. This is because of their inherent nutrient deficiencies, hence the need for supplementation. Therefore, a study was conducted to evaluate the effect of supplementing sweet sorghum (*Sorghum bicolor* (L.) Moench) silage diet with forage chicory (*Cichorium intybus* (L.) on the performance of dairy goats. Twelve (12) Toggenburg dairy goats with same body weight (38.7 ± 9.7 kg), same parity and mid stage of lactation aged between 18-24 months were selected using a simple random technique from Tatton Agriculture Park. They were randomly assigned to four dietary treatments at supplementation levels of 0, 10, 20 and 30% and replicated three times in a completely randomized design (CRD. The feeding trial lasted for ten weeks, two weeks for the adaptation period and eight weeks for measurement. Data were analysed by the general linear model of the analysis of variance (ANOVA) using the statistical analysis system SAS version 9.4. The significant differences in means were separated using Tukey's Honestly Significant Difference test at ($P<0.05$). The results indicated that dry matter intake, average daily gain, and milk yield were significantly different at ($p<0.05$). In milk composition, there were no significant difference in T1, T2 and T3, T4 of fats and protein at ($p>0.05$). However, there was a significant difference in T3 from T1 and T2. There was no significant difference ($p>0.05$) in lactose and total solids of T2, T3 and T4. The supplementation with forage chicory increased dry matter intake from (0.86 kg DM/day to 1.60 kg DM/day), average daily gain (21.61 g/day to 164.88 g/day), and milk yield (1.13 L/day to 3.34 L/day). In conclusion, dairy goats' productive performance was enhanced when fed a diet that included 30% forage chicory. Furthermore, combining forage chicory with a basal diet of sweet sorghum silage increases feed utilization in the dairy goats.

4.1 Introduction

One aspect of livestock management that affects animal performance is feeding. Improved feeding to meet the nutritional needs of the animals can enhance livestock productivity threefold (Kahi & Wasike, 2019). Small ruminants, like all other animals, need to be provided with proper amounts of all the nutrients necessary for optimum production.

However, deficiencies of protein and energy are the main nutritional factors limiting the productivity of the dairy goats. Usually, a minimum crude protein content of 7% in roughage is considered an essential requirement for optimal rumen microbial fermentation activity in the animal (Ngila *et al*., 2016). Therefore, an active microbial population in the rumen is essential to digesting and extracting the nutrients contained in the fibrous feedstuffs.

However, minimal precipitation during the dry season limits pasture growth, preventing significant growth and plant biomass production. The majority of accessible forage feed resources, including standing hay, dry grass, and crop residues such as cereal stover and straw, have relatively poor nutritional value due to changes in chemical composition and morphology (Kemboi, 2018). As a result, these feeds exhibit a high degree of lignification, high cell-wall content, low organic matter digestibility, and low crude protein (less than 7%), resulting in decreased ruminal growth and digestion (Kashongwe *et al*., 2017). This inhibits the animal's ability to absorb protein and energy. Furthermore, these nutritional characteristics tend to depress dry matter digestibility, restricting voluntary feed intake, resulting in low production and reproductive performance, a slow growth rate, loss of body condition, and a higher susceptibility to diseases and parasites.

To address the nutritional issues of dairy goats and ensure a consistent supply of feed all year round, it is essential to make good use of alternative feed resources like sweet sorghum through silage making and supplementation with forage chicory. Worldwide, sweet sorghum can be grown in a variety of climates and soil types, including tropical, subtropical, temperate, and semi-arid zones. As a result of its ability to withstand dry conditions, it is called "the sugarcane of the desert" (Olugbemi, 2017). Sweet sorghum as an excellent photosynthetic capacity, high biomass yield potential, high sugar yield, and poor grain yields. It is desirable as a component of animal feed due to its high crude protein, moderate structural carbohydrate, and lignin content (Ren *et al*., 2021). The high concentration of water-soluble carbohydrates (WSC) in sweet sorghum is what gives it its high-energy content (Pecka-Kiełb *et al*., 2021). Since this variety of sorghum has a higher WSC content and a dry matter yield that is comparable to that of forage sorghum, it could be a viable alternative for making high-quality silages. Therefore, adding forage chicory to sweet sorghum silage can boost livestock productivity.

Forage chicory is an herb, and there is growing evidence that herbs can be high-yielding and a beneficial source of highly palatable and nutritious feed for livestock. Although forage chicory has a long history in agriculture, its use as a modern cattle feed crop is relatively new. Forage chicory contains a high crude protein content (16–27%) as well as high mineral and trace element concentrations, which have a significant impact on both animal production and quality as well as animal health (Nwafor *et al*., 2017). Therefore, this study aimed to evaluate the effect of supplementing sweet sorghum (*Sorghum bicolor* (L.) Moench) silage diet with forage chicory (*Cichorium intybus* (L.) on the performance of dairy goats.

4.2 Materials and Methods

4.2.1 Study site

This research was conducted at Tatton Agriculture Park (TAP) in Egerton University, Njoro. The University is located in Njoro Sub-County of Nakuru County. Positioned at an elevation of 1,800 meters above sea level, the location is approximately 0°22'11.0 "S, 35°55'58.0" E (Longitude: 35.932779; Latitude: -0.369734). The average temperature is 17-22 °C, although it may drop to 11 °C from July to August when the temperature drops to that magnitude. In short and long seasons, the average yearly rainfall is 1,200±100 mm. According to Egerton Station (2019), the prolonged rain begins in March and continues until July, whereas the short rain begins in October and ends in December.

4.2.2 Experimental animals

The experimental animals for this study consisted of twelve (12) Toggenburg dairy goats with initial weights of (38.7 ± 9.7 kg), same parity and mid stage of lactation aged between 18-24 months. Each goat's initial weight was determined by averaging it over three days. The dairy goats were chosen from Tatton Agriculture Park using a simple random sampling procedure.

4.2.3 Experimental diets

The basal diet comprised of sweet sorghum (*Sorghum bicolor* (L.) Moench) silage with forage chicory (*Cichorium intybus* (L.) as a supplement. Sweet sorghum was planted in Tatton Agriculture Park. A mounted forage harvester was used to cut sweet sorghum in the hard dough stage into 2 cm size and then put in AgroZ silage bags with dimensions of 1 meter by 2.5 meters. To ensure airtightness, the upper portion of the silage bags were tightly fastened and stored in a clean, dry store at room temperature with plenty of ventilation in Tatton Agriculture Park. Forage chicory was also grown in Tatton Agriculture Park and was harvested two days earlier, spread in the shade to dry, and measured before being fed daily to the dairy goats. The experimental diets consisted of T1 (0%) as the control comprising of sweet sorghum silage and plus chicory included at three levels T2 (10%), T3 (20%) and T4 (30%) (Table 4.1). The experimental diets was an estimated daily dry matter intake of 4% of the dairy goats' live body weight. The supplement diets were fed at 10, 20, and 30% of the expected daily DM intake, whereas the basal diet was provided *ad libitum*.

Table 4.1: Mixed proportions of forage chicory and sweet sorghum silage at different levels for the diets

	Dietary Treatments			
	T1 (Control) (0%)	T2 (10%)	T3 (20%)	T4 (30%)
Forage chicory	(0%)	(10%)	(20%)	(30%)
Sweet sorghum silage	(100%)	(90%)	(80%)	(70%)

4.2.4 Experimental design

The experimental design was completely randomized design (CRD) replicated three times from the four dietary treatments. The dietary treatments were as shown in Table 4.1. The animals were housed in individual cages that were slatted and well ventilated. The cages were disinfected prior to the introduction of the dairy goats and were cleaned in the morning and afternoon for the entire duration of the experiment. The dairy goats were weighed using a weigh band and subsequently rated based on their weight before the commencement of the feeding trial. The dairy goats were sprayed and dewormed to control ectoparasites and endoparasites. The four dietary treatments were allocated to the animals in a randomized manner. The animals were fed on the experimental diets twice daily, in the morning at 08:00 hr and in the afternoon at 14:00 hr. The supplements were prioritized in the feeding followed by the basal diet. In the afternoon diet (14:00 hr), the basal diet was offered to the experimental animals concerning the 08:00 hr basal diet intake. There was unlimited access to water and mineral licks. The feeding trial lasted for ten weeks, including two weeks of adaptation and eight weeks of measurement.

4.2.5 Data collection

Milk was collected twice daily, in the morning at 6:00am and in the afternoon at 6:00pm, and the quantity was recorded. Milk samples from the dairy goats were retrieved from all the treatments during the last week of data collection. The milk was analyzed for lipids, total solids, protein, and lactose using ultra scan milk analyzer at Egerton University's Animal Nutrition Laboratory. Feed offered and refusals from the the previous day's feed were collected, weighed using a digital weigh scale (with an accuracy of ±1 g) and recorded every day. Feed dry matter intake (FDMI) was calculated by the difference between feed offered and refusal. Weekly body weight measurements were taken following an overnight fast until the experiment was completed. Weekly weight gain was calculated by the difference between weekly weight recorded and the initial weight recorded.

4.3 Statistical analysis

The values of the measured parameters (DMI, ADG, milk yield, and milk composition) were determined by analysis of variance (ANOVA) using the general linear model (GLM) procedure of statistical analysis system (SAS, 2013) version 9.4 following a completely randomized design. Significant differences in means were separated using Tukey's HSD Test at (p< 0.05). The statistical model:

$Y_{ij} = \mu + \tau_i + \varepsilon_{ij}$

where:

Y_{ij} = is the response variable

μ = the overall mean

τi= effect of the feed of the i^{th} treatment, i= {1, 2, 3, 4}

ε_{ij} = random error associated with Y_{ij}

4.4 Results

The experimental diets' values for dry matter intake (DMI), weight gain, average daily gain (ADG), milk yield, and milk composition are shown in Table 4.2. The dry matter intake (DMI) exhibited a significant increase (p<0.05) because of supplementation. T4 had the DMI of 1.60kg/day whereas T1 showed the lowest DMI at 0.86kg/day. The increased DMI with supplementation from 10-30% was due to the improved level of CP because of supplementation. In terms of weight change, there were significant (p<0.05) differences in average daily gain (ADG) across the treatments. Supplemented dairy goats showed higher ADG compared to non-supplemented. Treatment four (30% supplementation level) recorded the highest ADG of 164.88g/day while the non- supplemented diet (T1) recorded the least ADG of 21.61g/day. The milk yield showed a significant increase (p<0.05) because of supplementation. T4 had the highest milk yield of 3.34l/day whereas T1 showed the lowest milk yield of 1.13l/day. In milk composition, there were no significant differences (p>0.05) in T1, T2 and T3, T4 of fats and protein. There were no significant differences (p>0.05) across the treatments of lactose and in the treatments of T2, T3, and T4 of total solids. Supplemented dairy goats showed higher fats, total solids, protein, and lactose as compared to non-supplemented.

Table 4.2: Dry matter intake, weight gain, average daily gain, milk yield, and milk composition of dairy goats fed on sweet sorghum silage supplemented with forage chicory at different levels

Dietary treatment					
Parameter	T1	T2	T3	T4	P-value
DMI (Kg/day)	0.86± 0.02[a]	1.26± 0.02[b]	1.50± 0.02[c]	1.60± 0.03[d]	<.0001
Initial body weight (Kg)	37.40±1.39[a]	35.70±1.44[a]	38.70±5.60 [a]	37.80±3.81[a]	0.9533
Final body weight (Kg)	38.61±1.26[a]	39.87±1.22[a]	45.66±5.45[a]	47.03±4.11[a]	0.4066
Total WC (Kg)	1.21±0.29[a]	4.17±0.28[b]	6.96±0.15[c]	9.23±0.39[d]	<.0001
ADG (g/day)	21.61±5.21[a]	74.41±4.94[b]	124.23±2.76[c]	164.88±7.02[d]	<.0001
Milk yield (L/day)	1.13± 0.04[a]	1.97± 0.06[b]	2.75± 0.05[c]	3.34± 0.07[d]	<.0001
Milk Composition					
Fats	3.18±0.07[a]	3.29±0.08[a]	3.51±0.10[b]	3.64±0.03[b]	<.0001
Total solids	11.17±0.38[a]	11.34±0.14[b]	11.70±0.13[b]	12.10±0.14[b]	0.0193
Protein	3.03±0.05[a]	3.14±0.02[a]	3.63±0.10[b]	3.97±0.07[b]	<.0001
Lactose	4.05±0.32[a]	4.20±0.29[a]	4.57±0.21[a]	4.70±0.47[a]	0.0573

[a, b, c, d] Means in a row with different superscripts significantly differ at ($p<0.05$). SEM=Standard Error of the Mean. DMI=Dry Matter Intake. ADG=Average Daily Gain. WC=Weight Change.

4.4 Discussion

4.4.1 Voluntary feed intake

An animal's feed intake and digestibility determine the feed's production performance. There was a significant increase in DMI when the dairy goats were supplemented with forage chicory. Dairy goats whose primary diet consisted of only sweet sorghum silage recorded the least DMI of 0.86 kg/day while T4 recorded the highest DMI of 1.60 kg/day. Additionally, the supplemented groups exhibited a greater DMI than the control group. These results were lower than those obtained by Niderkorn *et al.* (2019). The lower DMI could be attributable to the diet's higher fiber content, while the increased DMI could be related to the addition provision of rumen-degradable nitrogen supplied by the addition of forage chicory. This increases the activity of bacteria in the rumen, which improves organic matter digestibility and, as a result, feed intake (Soliman *et al.*, 2016).

Similarly, the increased feed intake by the dairy goats could be attributed to the palatability of forage chicory in diets containing it as compared to diets lacking it. This is in agreement with the findings obtained by Perović *et al.* (2021) who noted that forage chicory has a diverse range of nutrients, such as fibre, vitamins, and minerals. Forage chicory's high nutritional content is likely to fulfil the nutritional needs of the dairy goats. The non-supplemented dairy goats had the highest NDF that led to the decreased feed intake as compared to the supplemented dairy goats that had the lowest NDF levels. This is because the level of NDF in an animal ration typically affects their feed consumption as it brings about a faster rumen fill. It also implies that the supplemented dairy goats had a higher feeding value than non-supplemented dairy goats. This is because of the high proportion of cell wall contents that is a good index of the nutritional value of a feed.

4.4.2 Average daily gain

There was a significant increase in average daily gain with supplementation. The dairy goats whose diet consisted of only sweet sorghum silage (T1) recorded the least ADG of 21.61 g/day, while T4 recorded the highest ADG of 164.88 g/day. These findings are consistent with the findings of Mahmoud (2021), who found that Balady dairy goats fed on forage chicory had the highest weight gain and average daily gain. This is could be because of the higher protein and energy levels from forage chicory supplementation that caused the enhanced weight gain thus high ADG in the dairy goats. In addition, the enhanced dry matter intake could increase weight gain efficiency in dairy goats as indicated by high DMI (1.60 kg/day) resulting in high ADG (164.88 g/day). The dairy goats used in this experiment were of mid lactation hence did not lose weight as opposed to early stage of lactation.

4.4.3 Milk yield

The milk yield of supplemented dairy goats was higher than those of non-supplemented dairy goats. Treatment four (30% supplementation level) had the highest milk yield of 3.34l/day whereas T1 had the lowest milk yield of 1.13l/day. These results are consistent with those of El-Basiony *et al*. (2015), who observed that using forage chicory as an additive in dairy goat diets improves nutrient digestion and increased milk quantity. Forage chicory has low dry matter content, which indicates rapid digestion. As a result, including chicory in the diet may help with rapid rumen clearance, allowing for more dry matter intake and, thus, more milk production. Similarly, the increased milk yield could be attributed by the low fibre content in forage chicory diets that might have allowed for increased digestibility and intensity of fermentation in the rumen, enhancing DM intake and the supply of nutrients required for milk production. These results are consistent with those of Minneé *et al*. (2017), who found that cows fed chicory-based diets produced significantly more milk than cows fed grass-based diets (18.8 versus 9.8 l/cow/day). Furthermore, Di Grigoli *et al*. (2012) supported these findings, emphasizing forage's chicory ability to provide a long-term, high-quality herb and its positive effect on dairy performance in grazing sheep. While Hutton *et al*. (2011) observed that chicory-containing diets improved milk production in grazing sheep. In addition, Mangwe *et al*. (2024) reported that chicory inclusion diets slightly increased milk yield by 0.62kg/cow/ day compared to control diets of grasses.

4.4.4 Milk composition

The inclusion of forage chicory to sweet sorghum silage improved milk composition including fat, total solids, protein, and lactose percentages. Treatment four recorded the highest fats (3.64%), total solids (12.10%), protein (3.97%), and lactose (4.70%) while T1 recording the least fats (3.18%), total solids (11.17%), protein (3.03%), and lactose (4.05%). These findings were consistent with those of El-Basiony *et al*. (2015), who observed that using forage chicory as an additive in dairy goat diets improved milk quality. Furthermore, Mahmoud *et al*. (2021) reported that adding herbs to diets improved the fatty acid composition of milk. Similarly, Laws and Genever (2013) stated that experiments with dairy cows in the southern hemisphere and the United States demonstrated that grazing forage chicory increased milk solid yields in comparison to more common grass types.

4.5 Conclusion

Findings from this study indicate that sweet sorghum silage supplemented with forage chicory improved feed intake, weight gain, average daily gain, milk production, and milk composition of dairy goats. This is because of the the low fibre content in forage chicory diets that might have allowed for increased digestibility and intensity of fermentation in the rumen, enhancing DM intake and the supply of nutrients required for milk production. Therefore, it could be concluded that 30% forage chicory addition into sweet sorghum silage could be useful as it improved feed intake, weight gain, average daily gain, milk production and its composition of dairy goats.

4.6 Recommendation

Based on the findings of this study, a 30% forage chicory supplement to sweet sorghum silage can be recommended to improved performance of dairy goats.

CHAPTER FIVE

INCOME OVER FEED COST OF DAIRY GOATS FED ON SWEET SORGHUM (*SORGHUM BICOLOR* (L) MOENCH) SILAGE SUPPLEMENTED WITH FORAGE CHICORY (*CICHORIUM INTYBUS* (L.)

Abstract

Income over feed cost (IOFC), also known as return over feed (ROF), measures dairy herd feed efficiency and profitability. To be successful, farmers should monitor and make decisions based on income over feed costs (IOFC). However, monitoring IOFC over a certain time period can determine if feed costs are in accordance with current milk production or whether ration and feed management strategies are currently effective. Therefore, a study was conducted to determine the income over feed cost of dairy goats fed on sweet sorghum (*Sorghum bicolor* (L) Moench) silage supplemented with forage chicory (*Cichorium intybus* (L). Twelve (12) Toggenburg dairy goats with same body weight (38.7 ± 9.7 kg), same parity and stage of lactation aged between 18-24 months were selected using a simple random technique from Tatton Agriculture Park. They were randomly assigned to four dietary treatments at supplementation levels of 0, 10, 20 and 30% and replicated three times in a completely randomized design (CRD). The feeding trial lasted for ten weeks, two weeks for the adaptation period and eight weeks for measurement to determine the income over feed cost (IOFC). Data were analysed by the general linear model of the analysis of variance (ANOVA) using the statistical analysis system SAS version 9.4. The significant differences in means were separated using Tukey's Honestly Significant Difference test at ($P<0.05$). Results showed that there was no significant difference ($p>0.05$) in IOFC of T1, T2, and T3, T4 emphasizing that a 10% supplementation level may be economically comparable to a 20% supplementation level. However, IOFC of T3 was significantly different ($P<0.05$) from IOFC of T1 and T2. In addition, IOFC of T1 and T2 were significantly different ($p<0.05$) from those of T3 and T4. The supplementation with forage chicory increased IOFC among the treatments with T4 (165.50) recording the highest IOFC whereas T1 (59.51) recording the least IOFC. In conclusion, T3 (20% supplementation level) could be more economically viable because of its less feed cost associated with its production hence more income was generated as compared to T4 (30% supplementation level) that required more feed cost of production in order to achieve the same results.

5.1 Introduction

Kenya's dairy industry is one of the most important sectors of the economy, as well as the largest in Sub-Saharan Africa, accounting for 8% of GDP (Odero-Waitituh, 2017). The country remains one of Africa's top milk producers, accounting for 30–40% of Africa's 5% of global milk production (KNBS, 2019). The livestock sub-sector in Kenya accounts for around 12% of GDP and 40% of agricultural GDP (Behnke & Muthami 2011). According to Kenya Dairy Board estimates, milk production from livestock was 5.2 billion litres annually. Cow milk accounted for the largest part (75%), followed by goat milk (273,000 metric tons) and camel milk (1,165,000 metric tons) (KDB, 2019). Kenya's annual milk and dairy product consumption per capita, which now stands at 110 litres of liquid milk equivalent, is predicted to double to 220 litres by 2030.

The productivity of the subsector has been consistent but has not successfully addressed the disparity in national milk demand (Kahi & Wasike, 2019). According to Ogola *et al*. (2010), the ever-changing demand and supply in different ecological zones, along with the underdeveloped dairy goat and products market, causes prices to fluctuate, which in turn affects gross and net margins from selling goat milk. Feed costs are the most important component of dairy production, accounting for 50% to 60% of overall production costs (FAO, 2014). The milk-to-feed price ratio has fallen in recent years, and feed costs may now account for 70% or more of total milk production expenses (Beck *et al*., 2016). According to Ferreira (2015), there is a direct correlation between feed costs and milk output, although the profitability of milk production may not always be influenced by feed costs. Factors such as feed accessibility, feed pricing, and diet nature influence the expenses associated with feeding (Alqaisi *et al*., 2019).

Farmer profitability depends on reducing milk losses. The cost of milk, the cost of purchased feed, the cost of labour, and the production of crops and forages are the threats that the dairy industry faces including those that could reduce or increase costs to its financial health. Numerous hazards associated with the dairy industry in Kenya result in high cost of production and low yield (Prakash *et al*., 2017). It is critical for a farmer to track his production costs in order to determine whether he is making a profit. However, determining the expenses and revenues of milk production is not as straightforward as determining the milk price. Milk production costs and profitability can be influenced by factors influencing the price of milk at the farm gate in the countryside of Kenya (Ssekibaala, 2019). Farmers' decisions on how to produce and market their goods lead to low output and increased costs of production.

Income for a dairy producer can be difficult to predict because milk and feed markets are continuously changing and this is exacerbated with the ever-changing prices of fuel, fertilizers, and crop seeds. Thus, producers should monitor profit margins rather than milk income or feed costs to predict profitability (Buza *et al*., 2015). Milk production is often monitored because higher milk production equates to higher milk income. However, monitoring gross milk income per dairy goat alone does not provide a good estimate of cash flow or profitability, especially when feed costs are high. Therefore, dairy enterprises continue to exhibit dismal profitability and face significant production costs.

The calculation of monetary and economic costs, particularly in the context of milk production, serves as a crucial indication for ensuring the sustainability of dairy farming. Additionally, it provides a means of assessing the overall economic competitiveness of both the factor and product markets, both at the local and worldwide levels (Hemme *et al*., 2014). According to Koonawootrittriron *et al*. (2012), in order to maintain competitiveness, dairy organizations and farmers should make efforts to decrease expenses at the farm level. In order to maintain profitability, it is imperative for farmers to engage in the monitoring and decision-making process, with a primary focus on the income over feed cost (IOFC). Income over feed cost is a gross margin concept that might serve as an initial indicator to assess the feasibility of feeding management in the near term. Income over feed cost (IOFC), also known as return over feed (ROF), measures dairy herd feed efficiency and profitability.

Income over feed cost (IOFC) is determined by subtracting the feed costs linked to milk production from the total revenue earned from milk sales within a given time period (Connor, 2015). The farm's break-even point in terms of feed and marginal milk can be determined using IOFC. Additionally, it aids in the computation of optimal utilization of both on-farm and purchased ingredients, as well as in the formulation of feeding and herd management strategies. Income over feed cost can be utilized to assess both nutrition and pasture management. According to Ferreira and Teets (2020), IOFC monitoring on a monthly basis can reveal whether feed expenditures are reasonable in relation to milk output or if feed and ration management strategies are yielding the desired results. Therefore, this study assesses the income over feed cost of dairy goats fed on sweet sorghum (*Sorghum bicolor* (L) Moench) silage supplemented with forage chicory (*Cichorium intybus* (L).

5.1 Materials and methods

5.1.1 Study site

This research was conducted at Tatton Agriculture Park (TAP) Egerton University in Njoro. The University is located in Njoro Sub-County of Nakuru County. Positioned at an elevation of 1,800 meters above sea level, the location is approximately 0°22'11.0 "S, 35°55'58.0" E (Longitude: 35.932779; Latitude: -0.369734). The average temperature is 17-22 °C, although it may drop to 11 °C from July to August when the temperature drops to that magnitude. In short and long seasons, the average yearly rainfall is 1,200±100 mm. According to Egerton Station (2019), the prolonged rain begins in March and continues until July, whereas the short rain begins in October and ends in December.

5.2.2 Experimental animals

The experimental animals for this study consisted of twelve (12) Toggenburg dairy goats with initial weights of (38.7 ± 9.7 kg), same parity and mid stage of lactation aged between 18-24 months. Each goat's initial weight was determined by averaging it over three days. The dairy goats were chosen from Tatton Agriculture Park using a simple random sampling procedure.

5.2.3 Experimental diets

The basal diet comprised of sweet sorghum (*Sorghum bicolor* (L.) Moench) silage with forage chicory (*Cichorium intybus* (L.) as a supplement. Sweet sorghum was planted in Tatton Agriculture Park. A mounted forage harvester was used to cut sweet sorghum in the hard dough stage into 2 cm size and then put in AgroZ silage bags with dimensions of 1 meter by 2.5 meters. To ensure airtightness, the upper portion of the silage bags were tightly fastened and stored in a clean, dry store at room temperature with plenty of ventilation in Tatton Agriculture Park. Forage chicory was also grown in Tatton Agriculture Park and was harvested two days earlier, spread in the shade to dry, and measured before being fed daily to the dairy goats. The experimental diets consisted of T1 (0%) as the control comprising of sweet sorghum silage and plus chicory included at three levels T2 (10%), T3 (20%) and T4 (30%) (Table 5.1). The experimental diets was an estimated daily dry matter intake of 4% of the dairy goats' live body weight. The supplement diets were fed at 10, 20, and 30% of the expected daily DM intake, whereas the basal diet was provided *ad libitum*.

Table 5.1: Mixed proportions of forage chicory and sweet sorghum silage at different levels for the diets

	Dietary Treatments			
	T1 (Control) (0%)	T2 (10%)	T3 (20%)	T4 (30%)
Forage chicory	(0%)	(10%)	(20%)	(30%)
Sweet sorghum silage	(100%)	(90%)	(80%)	(70%)

5.2.4 Experimental design

The experimental design was completely randomized design (CRD) replicated three times from the four dietary treatments. The dietary treatments were as shown in Table 5.1. The animals were housed in individual cages that were slatted and well ventilated. The cages were disinfected prior to the introduction of the dairy goats and were cleaned in the morning and afternoon for the entire duration of the experiment. The dairy goats were weighed using a weigh band and subsequently rated based on their weight before the commencement of the feeding trial. The dairy goats were sprayed and dewormed to control ectoparasites and endoparasites. The four dietary treatments were allocated to the animals in a randomized manner. The animals were fed on the experimental diets twice daily, in the morning at 08:00 hr and in the afternoon at 14:00 hr. The supplements were prioritized in the feeding followed by the basal diet. In the afternoon diet (14:00 hr), the basal diet was offered to the experimental animals concerning the 08:00 hr basal diet intake. There was unlimited access to water and mineral licks. The feeding trial lasted for ten weeks, including two weeks of adaptation and eight weeks of measurement.

5.2.2 Data collection

Feed costs associated with milk production and income from milk sales were collected from the feeding experiment conducted for eight (8) weeks and recorded for analysis.

5.3 Data analysis

To determine revenues from milk production, the quantity of milk produced by each goat and period was multiplied by Ksh 150 per litre of milk. Feed costs were determined from the dry matter intake obtained from 4% of the live body weight (38.7 ± 9.7 kg) of each dairy goat, then multiplied by 100, 90, 80, 70% sweet sorghum silage levels and 0, 10, 20, 30% forage chicory levels. The results obtained were divided by the DM of each basal and supplement and later multiplied by Ksh 13.50 for one kilogram of the basal diet and Ksh 200 for one kilogram of the supplement. The following formula, provided by Connor (2015), was used to ascertain the income over feed cost (IOFC).

$$\text{Income over feed cost (IOFC)} = \frac{\text{Milk yield (litres)} \times \text{Milk price per litre} - \text{Cost of feed per goat}}{\text{Number of goats}}$$

The values generated from the formula above were subjected to analysis of variance (ANOVA) using the general linear model (GLM) procedure of statistical analysis system (SAS,

2013) version 9.4. Significant differences in means were separated using Tukey's HSD Test at (p< 0.05). The statistical model:

$Y_{ij} = \mu + \tau_i + \varepsilon_{ij}$

Where:

Y_{ij} = is the response variable

μ = the overall mean

τi= effect of the feed of the i^{th} treatment, i= {1, 2, 3, 4}

ε_{ij} = random error associated with Y_{ij}

5.4 Results

The IOFC exhibited a significant increase (p<0.05) as a result of supplementation as shown in Table 7. T4 had the highest IOFC of Ksh 165.50 whereas T1 showed the lowest IOFC of Ksh 59.51. In addition, an increase in the supplementation level generated more income as compared to feed cost associated with its production.

Table 5.2: Income over feed cost (IOFC) for each dietary treatment

	Income over feed cost (IOFC) Ksh
T1	59.51 ± 2.07^a
T2	72.99 ± 4.02^a
T3	150.65 ± 2.54^b
T4	165.50 ± 5.51^b
p-value	<.0001

$^{a, b, c}$ Means in the same column with different superscripts differ significantly at (p< 0.05).

5.5 Discussion

The findings indicate that there was a significant increase in IOFC when dairy goats were fed with forage chicory. The dairy goats fed on sweet sorghum silage only recorded the lowest IOFC of Ksh 59.51, while T4 recorded the highest IOFC of Ksh 165.50. These findings were consistent with the previous research conducted by Muktiani *et al*. (2019), who found that increasing protein, energy content in Ettawa crossbred goat diets improved IOFC, and cost-effectiveness can positively influence the economic performance of livestock. There was no significant difference in IOFC between T1 and T2, despite the additional 10% experimental diet in T2. This suggests that the incremental increase in the experimental diet did not have a notable impact on the economic value generated in terms of income over feed costs. Similarly, T3 and T4, which received different levels of dietary supplementation from T1 and T2, also did not exhibit a significant difference in IOFC. This implies that increasing the experimental diet from 20% to 30% did not result in a noticeable change in the economic viability of the livestock production system, as measured by the IOFC.

In addition, IOFC of T3 was significantly different from IOFC of T1 and T2. This suggested that an increase in the experimental diet generated more income as compared to feed cost associated with its production. However, there was a noteworthy distinction between the IOFC of T1 and T2 compared to IOFC of T3 and T4 signifying that a moderate level of supplementation (10% and 20%) might be more economically viable. This finding agrees with the previous research conducted by Buza *et al*. (2015) on the impact of dietary supplementation on IOFC in dairy cows. The IOFC of T3 (20% supplementation level) was more economically viable. This is as a result of its less feed cost associated with its production as compared to T4. Additional supplementation does not proportionately lead to an increase in IOFC. This is because of a plateau in IOFC suggesting a possibility of a diminishing return. Also, this is because of the animal's threshold above which it cannot utilize any additional supply of the nutrients.

5.6 Conclusion

Findings from this study indicate that sweet sorghum silage supplemented with forage chicory improved IOFC. This is because more income from the dietary treatments was generated as compared to feed cost associated with its production. Therefore, it could be concluded that 20% supplementation level could be more useful because of its less feed cost associated with its production compared to 30% supplementation level that required more feed cost of production in order to achieve the same results.

5.7 Recommendation

Based on the findings of this study, IOFC of 20% supplementation level could be recommended because of its less feed cost associated with its production compared to IOFC of 30% supplementation level that required more feed cost of production in order to achieve the same result.

CHAPTER SIX

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1 General discussion

This research discusses the nutritional composition and potential benefits of incorporating forage chicory into dairy goat diets. The experimental diets tested had varying levels of crude protein (CP), with values ranging from 81.1 to 138.7 g/kg of dry matter (DM). Forage chicory, with its high CP content of 224.1 g/kg DM, stands out as a valuable protein source, which can enhance the nutritional quality of feed, especially when used in combination with low-quality roughages or crop residues such as cereal stover and straw. This strategy could be particularly beneficial during the dry season when higher-quality forages are less available, helping to maintain or improve animal performance. Additionally, the diets' crude fibre (CF) levels ranged from 295.8 to 323.8 g/kg DM, which supports digestive health in ruminants. Supplementing with forage chicory also led to a slight increase in acid detergent lignin (ADL) content, which ranged from 50.6 to 51.8 g/kg DM. This increase in ADL may affect the digestibility of the diet, though it might also contribute to better rumen function by slowing down digestion slightly, allowing for improved nutrient absorption over time. Overall, the inclusion of forage chicory offers a balanced approach to enhance protein intake and fibre content in the diets of dairy goats.

There is a nutritional comparison between forage chicory and sweet sorghum silage in terms of fibre, shedding light on forage chicory's advantages as a feed component for dairy goats. Forage chicory exhibits a lower neutral detergent fibre (NDF) content of 337.7 g/kg DM and acid detergent fibre (ADF) content of 353.5 g/kg DM compared to sweet sorghum silage, which has higher NDF and ADF values (647.0 and 419.5 g/kg DM) respectively. This lower fibre content in forage chicory suggests that it may enhance digestibility in dairy goats, as its cell wall structure could be more conducive to digestion. Consequently, both NDF and ADF levels in the diet tended to decline with forage chicory supplementation, indicating improved feed utilization. In addition, sweet sorghum silage and forage chicory had beneficial secondary compounds such as condensed tannins, saponins, and total extractable phenolics and tannins that stay within safe intake thresholds. The supplementation of forage chicory supported improved digestion and animal performance without posing risks to intake or health.

Forage chicory's inclusion in sweet sorghum silage not only enhanced the digestibility and gas production of the feed but also provided crucial energy for microbial activity in the rumen. The gas production levels increased with forage chicory supplementation during fermentation thus indicating the digestibility potential. This gas is a byproduct of organic matter (OM) fermentation, as explained by Blümmel and Fernandez-Rivera (2002), and reflects how efficiently the feed is broken down in the rumen. Additionally, the estimated energy contents ranged from 3.56 to 4.76 MJME/kg DM with energy levels increasing alongside the rate of forage chicory supplementation. This is valuable for rumen microbes, which require adequate energy to support microbial protein synthesis. The energy released through OM fermentation not only supports microbial health but also contributes to better nutrient absorption and animal performance.

The supplementation with forage chicory increased dry matter intake from 0.86 kg/day to 1.60 kg/day. Supplementation improved the rumen environment by enhancing rumen microbial activity, which resulted in improved digestibility and intake of digestible nutrients, hence increased weight gain thus high average daily gain, milk yield and its composition. Sweet sorghum silage alone when fed to dairy goats had a higher fiber content that filled the rumen more quickly and hence reduced feed intake leading to low weight gain hence low average daily gain, milk yield and its composition. In addition, low crude protein of sweet sorghum silage did not provide sufficient nutrients for optimum growth and production of the dairy goats thus leading to low weight gain hence low average daily gain, milk yield and its composition.

Forage chicory supplementation on sweet sorghum silage had an impact on income over feed costs (IOFC) in the dairy goats, showing that forage chicory significantly boosted the economic returns. Sweet sorghum silage when fed to dairy goats alone showed low income over feed cost (IOFC) while with forage chicory supplementation at different levels increased the income over feed cost (IOFC). This is because more income was generated as compared to the feed costs associated with its production.

Sweet sorghum silage should be incorporated in the diets of the dairy goats as compared to maize plant that most farmers do rely on in Kenya. This is because; maize plant is less economical as compared to sweet sorghum. Maize plant can be harvested once in one production cycle while sweet sorghum can be harvested 3-4 times in one production cycle. Sweet sorghum is more drought tolerant compared to maize. In addition, the cost of production of sweet sorghum is 50% cheaper than the cost of maize production. Sweet sorghum contains greater water-soluble carbohydrates (WSC) which might allow the production of high-quality silages without the need to add the expensive molasses that is normally used in maize silage. Sweet sorghum also has high sugar content making it a perfect crop for ensiling. This is because it supports improved fermentation and provides more energy in support of milk synthesis or body weight gain. The incorporation of forage chicory with sweet sorghum silage to the dairy goats is important because both forage chicory and sweet sorghum silage fits in well with the need to grow climate smart forage in this era of climate change in order to boost ruminant production. In addition, sweet sorghum silage with forage chicory supplementation will improve the performance of dairy goats, which were best suited as their requirements are low.

6.2 Conclusions

i. Supplementation of sweet sorghum silage with forage chicory improved the nutritive content, *in-vitro* digestibility and fermentation characteristics.
ii. Supplementation of sweet sorghum silage with forage chicory improved the performance of the dairy goats (feed intake, average dairy gain, milk yield, and milk composition).
iii. Supplementation of sweet sorghum silage with forage chicory increased the income over feed cost.

6.3 Recommendations

i. Forage chicory has a high protein content thus can be used to alleviate the protein deficiencies in dairy goats fed on poor quality forage.
ii. Forage chicory can be used as a protein supplement to improve feed intake, average daily gain, milk yield, and milk composition of dairy goats fed on poor quality forage.
iii. The income over feed cost (IOFC) of sweet sorghum silage and forage chicory should be calculated in order to determine if the two feeds are economically viable to the dairy goat farmers.

6.4 Areas of further research

i. Forage chicory contains inulin content that has a beneficial effect on the probiotic intestinal flora. Therefore, further investigation is needed in this inulin content in improving milk yield and milk composition of dairy goats.
ii. More research is needed on the nutrient composition especially minerals, amino acids and vitamins of the various diets of sweet sorghum silage and chicory.

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APPENDICES

Appendix A: Abstract of published paper on objective one of this thesis

Nutritional Evaluation and *In-Vitro* Organic Matter Digestibility of Sweet Sorghum (*Sorghum Bicolor* (L.) Moench) Silage and Chicory (*Cichorium Intybus* (L.)

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ABSTRACT

Chemical composition and *in vitro* organic matter digestibility were evaluated in twelve diets consisting of sweet sorghum silage supplemented with 0, 10, 20, and 30% levels of chicory. The *in vitro* gas production properties, polyphenols, saponins, and chemical composition were determined. SAS software (version 9.4) was used to analyze the data using the general linear model of ANOVA. Significant means were separated using Tukey's Honestly Significant Difference Test at ($p<0.05$). The addition of chicory levels to the diets led to a significant rise ($p<0.05$) as per the chemical composition results. T4 (30% chicory) recorded the highest amount of ash (121.4 g/kg DM), CP (138.7 g/kg DM), CF (323.8 g/kg DM), EE (30.6 g/kg DM), ADL (51.8 g/kg DM), CT (0.9 g/kg DM), TEPH (51.3 g/kg DM), SAP (5.7 g/kg DM), and TET (22.2 g/kg DM) while T1 recorded the lowest. The decrease ($p<0.05$) in dry matter digestibility can be explained by the addition of chicory levels to the diets, which dramatically reduced both the NDF and ADF. Therefore, the NDF and ADF levels of chicory were lower than those of sweet sorghum silage. The CT in the diets varied from 0.3 to 0.9 g/kg DM. This is less than what has been reported to be harmful to an animal's intake (50 g/kg DM). It was evident that T4 was more digestible than T1 based on the *in vitro* gas production (ml/200 mg DM) at 24 and 48-hour incubation periods, which was considerably higher ($p<0.05$) in T4 and lower in T1. Chicory could be used as a protein supplement for ruminants, especially dairy goats, as shown by its comparatively high CP of 224.1 g/kg DM.

Keywords: Crude protein, dairy goats, forage, milk, proximate

Appendix B: NACOSTI permit

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REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

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Date of Issue: **17/July/2023**

RESEARCH LICENSE

This is to Certify that Miss.. Christine Kerubo Onkeo of Egerton University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Nakuru on the topic: PERFORMANCE OF LACTATING DAIRY GOATS FED ON BASAL SWEET SORGHUM (Sorghum bicolor (L.) Moench) SILAGE SUPPLEMENTED WITH CHICORY (Cichorium intybus (L.) for the period ending : 17/July/2024.

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Appendix C: Research ethics clearance

EU/RE/DIR/009

Approval No. UISERC/APP/237/2023

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TEL: (051) 2217808
FAX: 051-2217942

P. O. BOX 536
EGERTON

EGERTON UNIVERSITY INSTITUTIONAL SCIENTIFIC AND ETHICS REVIEW COMMITTEE

EU/RE/DIR/009
Approval No. EUISERC/APP/237/2023 ***3rd May 2023***

Christine Kerubo Onkeo
Department of Animal Sciences
Egerton University
P.O. Box 536-20115
Egerton
Telephone: 0724661215
E-mail: onkeoc@yahoo.com

Dear Christine,

RE: ETHICAL APPROVAL: PERFORMANCE OF LACTATING DAIRY GOATS FED ON BASAL SWEET SORGHUM (kinyaruka) SILAGE SUPPLEMENTED WITH CHICORY (Cichorium intybus (L.)

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/237/2023.*** The approval period is ***3rd May, 2023 –4th May, 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 affect 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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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.

EGERTON UNIVERSITY
Date. 03/05/2023
RESEARCH ETHICS

Prof. Raphael M. Ngure

CHAIRMAN, EGERTON UNIVERSITY INSTITUTIONAL SCIENTIFIC AND ETHICS REVIEW CTTEE

RMN/BK/

Appendix D: Research pictorial

Chicory in the nursery bed **Chicory in the field after transplanting**

Sweet sorghum in the field **Harvested sweet sorghum**

Mounted forage harvester cutting sweet sorghum to small pieces

Performing chemical analyses in the lab **Dairy goats feeding on the experimental diets**

Appendix E: ANOVA tables

The GLM Procedure

Dependent Variable: ASH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1.10182500	0.36727500	14.11	0.0076
Error	8	0.20820000	0.02602500		
Corrected Total	11	1.31002500			

R-Square	Coeff Var	Root MSE	ASH Mean
0.841072	1.378532	0.161323	11.70250

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Trt	3	1.10182500	0.36727500	14.11	0.0076

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Trt	3	1.10182500	0.36727500	14.11	0.0076

The GLM Procedure

Dependent Variable: CP

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	52.61669167	17.53889722	220.62	<.0001
Error	8	0.63600000	0.07950000		
Corrected Total	11	53.25269167			

R-Square	Coeff Var	Root MSE	CP Mean
0.988057	2.535779	0.281957	11.11917

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Trt	3	52.61669167	17.53889722	220.62	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Trt	3	52.61669167	17.53889722	220.62	<.0001

The GLM Procedure

Dependent Variable: CF

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	21.57909167	7.19303056	226.97	<.0001
Error	8	0.25353333	0.03169167		
Corrected Total	11	21.83262500			

R-Square	Coeff Var	Root MSE	CF Mean
0.988387	0.584972	0.178022	30.43250

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Trt	3	21.57909167	7.19303056	226.97	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Trt	3	21.57909167	7.19303056	226.97	<.0001

The GLM Procedure

Dependent Variable: EE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	2.34180000	0.78060000	25.59	0.0010
Error	8	0.24406667	0.03050833		
Corrected Total	11	2.58586667			

R-Square	Coeff Var	Root MSE	EE Mean
0.905615	7.033544	0.174666	2.483333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Trt	3	2.34180000	0.78060000	25.59	0.0010

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Trt	3	2.34180000	0.78060000	25.59	0.0010

The GLM Procedure

Dependent Variable: NDF

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	711.3358333	237.1119444	651.42	<.0001
Error	8	2.9119333	0.3639917		
Corrected Total	11	714.2477667			

R-Square	Coeff Var	Root MSE	NDF Mean
0.995923	1.118048	0.603317	53.96167

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Trt	3	711.3358333	237.1119444	651.42	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Trt	3	711.3358333	237.1119444	651.42	<.0001

The GLM Procedure

Dependent Variable: ADF

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	894.5040917	298.1680306	161.17	<.0001
Error	8	14.8002000	1.8500250		
Corrected Total	11	909.3042917			

R-Square	Coeff Var	Root MSE	ADF Mean
0.983724	4.837688	1.360156	28.11583

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Trt	3	894.5040917	298.1680306	161.17	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Trt	3	894.5040917	298.1680306	161.17	<.0001

The GLM Procedure

Dependent Variable: ADL

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	8.73446667	2.91148889	7.00	0.0207
Error	8	3.32953333	0.41619167		
Corrected Total	11	12.06400000			

R-Square	Coeff Var	Root MSE	ADL Mean
0.724011	14.66203	0.645129	4.400000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Trt	3	8.73446667	2.91148889	7.00	0.0207

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Trt	3	8.73446667	2.91148889	7.00	0.0207

The GLM Procedure

Dependent Variable: CT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.00009167	0.00003056	1.22	<0.001
Error	8	0.00020000	0.00002500		
Corrected Total	11	0.00029167			

R-Square	Coeff Var	Root MSE	CT Mean
0.314286	5.607477	0.005000	0.089167

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Trt	3	0.00009167	0.00003056	1.22	<0.001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Trt	3	0.00009167	0.00003056	1.22	<0.001

The GLM Procedure

Dependent Variable: TEPH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	16.40526667	5.46842222	39.70	0.0002
Error	8	1.10200000	0.13775000		
Corrected Total	11	17.50726667			

R-Square	Coeff Var	Root MSE	TEPH Mean
0.937055	11.32696	0.371147	3.276667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Trt	3	16.40526667	5.46842222	39.70	0.0002

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Trt	3	16.40526667	5.46842222	39.70	0.0002

The GLM Procedure

Dependent Variable: SAP

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.44629167	0.14876389	35.49	0.0006
Error	8	0.03353333	0.00419167		
Corrected Total	11	0.47982500			

R-Square	Coeff Var	Root MSE	SAP Mean
0.930113	20.39152	0.064743	0.317500

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Trt	3	0.44629167	0.14876389	35.49	0.0006

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Trt	3	0.44629167	0.14876389	35.49	0.0006

The GLM Procedure

Dependent Variable: TET

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1.20436667	0.40145556	5.01	0.0423
Error	8	0.64160000	0.08020000		
Corrected Total	11	1.84596667			

R-Square	Coeff Var	Root MSE	TET Mean
0.652431	15.23925	0.283196	1.858333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Trt	3	1.20436667	0.40145556	5.01	0.0423

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Trt	3	1.20436667	0.40145556	5.01	0.0423