TREES AND SHRUBS FORAGE IN THE EASTERN DEMOCRATIC REPUBLIC OF THE CONGO: DETERMINANTS OF UTILISATION, NUTRITIVE VALUE AND EFFECT OF SUPPLEMENTATION ON THE LACTATION PERFORMANCE OF CROSSBRED COWS

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Trees and Shrubs Forage in the Eastern Democratic Republic of the Congo: Determinants of Utilisation, Nutritive Value and Effect of Supplementation on the Lactation Performance of Crossbred Cows

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

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DEDICATION

To Aurélie Magaly Maheho Mangaza, my beloved wife and dear friend,

Daurel Sylvie Salima Baruani, my daughter

Vincent de Paul Baruani, my father

For your love, care, support, protection, and prayers,

May God Almighty bless you Plentifully.

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ABBREVIATIONS AND ACRONYMS

ADF	Acid Detergent Fibre
ADL	Acid Detergent Lignin
ANFs	Anti-Nutritional Factors
CP	Crude Protein
DM	Dry matter
DMI	Dry Matter Intake
DRC	Democratic Republic of the Congo
EE	Ether extract
IITA	International Institute of Tropical Agriculture
INERA	National Institute for Agricultural Study and Research (Institut National pour l'Etude et la Recherche Agronomiques)
ME	Metabolisable Energy
NDF	Neutral Detergent Fibre
OM	Organic Matter
SCFA	Short-Chain Fatty Acids
SSA	Sub-Saharan Africa
CT	Condensed Tannins
TEPH	Total Extractable Phenolics
TET	Total Extractable Tannins

ABSTRACT

Smallholder dairying is particularly important as milk produced provides nutrients and income to the households. Its expansion is thus desirable in alleviating poverty and enhancing food and nutrition security. Despite its importance, feed quantity and quality (protein and energy levels) are inadequate and rarely meet the nutrient requirements of lactating crossbred cows in Kalemie and Kabare territories, in the eastern Democratic Republic of the Congo (DRC). Milk production of cows fed on Guatemala grass (*Tripsacum andersonii* J.R. Gray), commonly established grass in the study area, is likely to be limited by low dry matter intake due to the low protein content. Thus, requiring supplementation which is not a common practice for most smallholder farmers due to the high price of concentrates. There is a need to provide alternative feed resources to increase milk production. This study aimed to evaluate the socio-economic factors determining the utilisation of trees and shrubs (TS) as livestock feeds by smallholder cattle farmers, assess the chemical composition and *in vitro* gas production of the most preferred TS, as well as to investigate the effects of supplementing Guatemala grass with Leucaena (*Leucaena leucocephala* (Lam. De Wit) or cassava (*Manihot esculenta* Grantz) leaves as nitrogen sources on lactation performance of Holstein Friesian x Ankole crossbred cows. Integrated approaches were used in this study, including household surveys and nutritional analysis of eight most preferred TS. In addition, an experiment was conducted to assess the effect of supplementing Guatemala grass with Leucaena or cassava on dairy cattle milk productivity. Results indicated that thirty-six (36) TS were used by farmers in Kalemie compared to 26 TS in Kabare. Factors such as gender, group membership, ownership of indigenous cattle, ownership of improved cattle, milk production perception, milk sales, milk price, legume production, crop residue usage, and farmer location positively and significantly ($p<0.05$) influenced the use of TS. The finding also revealed that the crude protein content of the eight most preferred TS ranged from 217.28 g kg^{-1} DM to 416.91 g kg^{-1} DM, while *in vitro* organic matter digestibility ranged from 31.3% to 44.6%. Supplementing Guatemala grass with dried Leucaena or cassava leaves increased ($p<0.05$) total dry matter intake by 20% and 26%, respectively. Cows supplemented with dried Leucaena resulted in high ($p<0.05$) milk production (6.83 kg) and milk fat (38.44g) than dried cassava (6.13 kg) and (28.17g), respectively. However, dried cassava supplementation increased ($p<0.05$) milk protein, lactose, and non-fat solids contents compared to dried Leucaena. It can be concluded from this study that 63% of farmers used TS as livestock feeds. Notably, leaves from the eight most preferred TS had high CP content, which suggests their suitability and potential for use as protein supplements for low-quality feeds. Dried Leucaena or cassava leaves incorporated at 20% into the dairy diet increased milk production and improved milk quality. This implies that Leucaena and cassava, which are easily established and found in abundance in Eastern DRC, can be used as protein sources for Holstein Friesian x Ankole crossbred cows in smallholder farming systems with limited incomes. The findings from this study provide relevant insights into informing policy formulation and implementation that promote the use of TS fodder to improve smallholder dairy production.

CHAPTER ONE

INTRODUCTION

1.1 Background

Population growth, urbanisation, shifts in dietary preferences, and increasing consumer demand for livestock products are re-defining livestock production systems globally (Food and Agriculture Organization, 2020). In 2019, the United Nations estimated that by 2050 the world population would increase from 7.7 to 9.7 billion people, where Sub-Saharan Africa (SSA) would account for almost double growth (from 1.1 to 2.1 billion people) (United Nations, 2020). Consequently, the demand for food, specifically animal protein in SSA, is expected to double by 2050 (Maina et al., 2020). A similar trend is observed in the Democratic Republic of the Congo (DRC), where the human population is expected to double from 90 million to 200 million by 2050 (United Nations, 2020). This population growth raises a concern about the capability of SSA countries such as DRC to meet the dietary needs of its people, yet livestock production in this region is yet to be optimised (Food and Agriculture Organization, 2020). Urbanisation is also rapidly increasing, and 75% of the population is expected to live in urban areas by the year 2050, making SSA the fastest urbanising region (United Nations, 2020). The urban populace adopts new eating behaviours characterised by consuming more animal protein and eating more of their food away from home (Maina et al., 2020; Steinfeld et al., 2006). This anticipated high demand for livestock-derived foods represents exciting market opportunities for smallholder farmers to increase milk production, thus contributing to food security and poverty alleviation.

In SSA, livestock is a predominant resource to rural smallholder households and is the main source of income, food, and nutritional needs, employment, insurance, a store of wealth, and social safety nets and manure for soil fertilisation (Food and Agriculture Organization, 2020; The World Bank, 2021). In DRC, the current national livestock population is estimated at 4.11 million head of goats, 1.21 million head of cattle, 0.99

million head of pigs, 0.91 million head of sheep, and 18.56 million head of poultry (National Institute of Statistics, DRC, 2020). Indeed, the national livestock population is in decline due to the recurrent wars, conflicts, and looting that the country experiences and which disrupt its development (Cox, 2012). Notwithstanding, cattle farming accounts for 11 per cent of the national potential of 40 million head of livestock, contributing 9.2 per cent of the country's agricultural gross domestic product (GDP) (National Investment Promotion Agency, DRC, 2022). In the mixed farming systems of Eastern DRC, smallholder farmers mostly raise cattle of local breeds such as Ankole and N'dama, with a stronger predominance of the Ankole cattle and, to a lesser extent, crossbreds and exotic breeds such as Holstein Friesian, Brown Swiss, and Jersey sourced from neighbouring countries (Rwanda, Uganda, Tanzania, Burundi). The average range of milk production is 1.7 litres to 4.6 litres per cow per day (Kibwana et al., 2012; Kumwimba et al., 2016; Mugumaarhahama et al., 2021).

Despite this contribution and favourable environmental conditions, the current livestock output remains far below the country's demand. This low milk production is associated with many complex and inter-related factors such as feed scarcity, the poor genetic potential of local breeds for functional traits, climate, widespread diseases, undeveloped marketing system, poor infrastructure, and war (Bisimwa et al., 2018; Cox, 2012; Kumwimba et al., 2016; Maass et al., 2012; Mugumaarhahama et al., 2021; Paul et al., 2016). Nonetheless, feed scarcity in terms of quality and quantity, as well as seasonal fluctuation, was identified as the most important constraint to livestock development and productivity in Eastern DRC (Bacigale et al., 2014; Katunga et al., 2014).

Livestock feeding systems in Eastern DRC are predominantly rain-fed, mainly from natural pastures, established grasses, and crop residues such as beans, bananas, maize, cassava, soybeans, and sugar cane. The commonly established pasture by farmers is Guatemala grass (*Tripsacum andersonii* J.R. Gray), as it's well adapted to the middle and highlands of the Eastern region of the DRC (Paul et al., 2016). Smallholder farmers rely on rain-fed fodder for feeding their livestock, which often fluctuates seasonally in quantity and quality (Maleko et al., 2018). Further, rapid human population growth, the subsequent reduction in land available for pasture production, and climate change negatively impact pasture productivity (Ayenew, 2019; Maina et al., 2020; Mugumaarhahama et al., 2021). Consequently, inadequate nutrition of cattle often culminates in substantial economic losses to the farmers due to low weight gain or milk production rates, poor body condition, reduced productive and reproductive performance, and susceptibility to pests and disease infestations (Henry et al., 2018). However, studies have been conducted to find alternative strategies to address feed quality and shortage throughout the year (Ayenew, 2019; Maina et al., 2020). Alternative conventional supplements such as concentrates and agro-industrial by-products in Eastern DRC are not readily available and, when available, are costly for most resource-poor smallholder farmers (Maass et al., 2012; Mutwedu et al., 2022).

In response to this challenge, there is a need to provide alternative cheap-to-produce and locally available feed resources to supplement the feeds produced on smallholder farms. In this regard, both the national (such as the National Institute for Agricultural Study and Research, INERA) and transnational (for example, the International Centre for Tropical Agriculture, CIAT; World Agroforestry Centre, ICRAF; and International Livestock Research Institute, ILRI) research organisations and development discourse have, over the past decades, advocated for the utilisation of trees and shrubs to enhance the nutritional resource base and as a sustainable intensification of livestock strategy in the SSA countries (Katunga, 2013; Wambugu et al., 2011).

Trees and shrubs are instrumental in delivering the triple-win strategy of enhancing livestock productivity, mitigating harsh climate in pastoral and agro-pastoral areas, and improving food security and rural livelihoods (Henry et al., 2018; Notenbaert et al., 2017). This strategy is attributed to their multiple roles in contributing to the welfare of the cattle farming communities (by providing fuelwood, construction materials, shade, and veterinary medicine); and in mitigating climate change (through biological nitrogen fixation, carbon sequestration, and reduction of greenhouse gas emissions) (Ayenew, 2019; Brandt et al., 2020; Pello et al., 2021). Trees and shrubs are highly valued because of their high volume of biomass production, nutritional value, and adaptation to poor soil and harsh climatic conditions (Barnes et al., 2021; Maina et al., 2020; Pello et al., 2021). Integrating trees and shrubs into animal diets improves palatability, feed intake, digestibility, and lactation performance (Ayenew, 2019; Juma et al., 2006; Derero & Kitaw, 2018; Osuga et al., 2011). This represents an opportunity for smallholder farmers to increase milk production to meet high market demand for dairy products due to the human population growth, urbanisation, and increased income in SSA countries (Steinfeld et al., 2006).

Given the benefits of the trees and shrubs in the tropics, efforts are being made to increase their uptake among the resource-poor smallholder farmers as livestock feeds (Franzel et al., 2014; Wambugu et al., 2011). However, their utilisation by the smallholder farmers for cattle feeding has proven unsatisfactory. For instance, Roothaert and Franzel (2001) found that in Kenya, farmers have integrated about 160 species of trees and shrubs within the farming systems across the farm boundaries, within the food crops, grazing land, and at the homestead. The preference for the trees and shrubs among the smallholder farmers was based on palatability, ability to satisfy hunger, and contributions to animals' overall health. Paul et al. (2020) focused on farmers' adoption of improved forages in dairy production systems in Tanzania. They reported that the recognised ecological benefits, labour costs, and positive community attitude influenced the adoption potential of the farmers. Although the benefits of trees and shrubs such as Leucaena (*Leucaena leucocephala* Lam de Wit) and cassava (*Manihot esculenta* Crantz) are well known and used by smallholder farmers in the tropics (Franzel et al., 2014; Roothaert & Franzel, 2001; Wambugu et al., 2011; Wanapat et al., 2011), the studies focusing on the utilisation of Leucaena or cassava as cattle feeds, notably in the DRC context, remain a significant literature gap.

In Eastern DRC, Leucaena and cassava can be used as alternative protein supplements to Guatemala grass as they have the potential to improve feed intake and digestibility and increase and enhance milk quality and production of dairy cows. For instance, Leucaena is a plant that potentially improves soil fertility, introduced to Eastern DRC 20 years ago. It is mostly used in soil fertility management as a source of green manure. The plant has the propriety of colonizing a wide range of soils due to its early year-round flowering and fruiting, abundant seed production, self-fertility, seed coat, and ability to regrow after burning or on being cut. These characteristics make the plant survive and multiply on farms, thus availing its resources all year round, which can be used in supplementing ruminants. Leucaena leaves are highly palatable, digestible (50% to 70%), and nutritious (22% to 40% of CP) (Katunga et al., 2014). These good nutritional characteristics make the leaves suitable for supplementation in ruminant diets and have been shown to increase milk production, fat, and protein contents (De Angelis et al., 2021). Besides the Leucaena trees, cassava is also grown in the Eastern DRC for its roots which constitute a staple food for more than 70% of the population, and its leaves are consumed throughout the year as a vegetable (Munyahali et al., 2017). However, for household consumption, most farmers (80%) cut only the young leaves without petiole to avoid fibrous stuff, leaving the other parts of the leaves as mulch or lost during root harvest (Munyahali et al., 2017). Wanapat et al. (2011) reported that cassava leaves at any stage of growth can still have good levels of protein (>14%), vitamins, minerals, low condensed tannins (1.5% to 4%); and can be used as a source of nutrients to dairy animals after removing the hydrocyanic acid (HCN) content.

1.2 Problem statement

Milk is a source of macro and micronutrients that improve the nutritional status of the African population, particularly children (Food and Agriculture Organization, 2021). It is also vital for food and nutrition security and poverty alleviation through income generation for poor smallholder farmers (Maass et al., 2012). In DRC, the demand for milk and milk products will continue to increase due to population growth, economic growth, and urbanisation (United Nations, 2020). Therefore, improving sustainable livestock production, including increasing milk production, is desirable in alleviating poverty and enhancing food security.

The most limiting factor for increased milk production in cows is mainly low protein and energy levels. To meet these requirements, lactating cows need a high nutrient intake, and milk production potential is reduced when these are not met. High nutrient intake can only be attained if cows achieve high dry matter (DM) intake. However, milk production of cows fed on rain-fed fodder such as Guatemala grass is likely limited by low DM intake due to the low crude protein content (Heuzé et al., 2015; Maleko et al., 2022). Thus, requiring supplementation which is not common practice for most smallholder farmers in Eastern DRC due to the high price of concentrates. In addition, the culture of production and conservation of fodder (such as hay and silage) for feeding cows is not common. Using Leucaena or cassava as alternative protein supplements to Guatemala grass would be an attractive option.

However, little information exists on the production of trees and shrubs (Barnes et al., 2021; Katunga et al., 2014; Muoni et al., 2019), but none to determine the factors underlying the use of trees and shrubs as livestock feeds. There is also limited information on the chemical composition and *in vitro* gas production of trees and shrubs fed to livestock. Information on the use of Leucaena or cassava in the diets of Holstein Friesian x Ankole crossbred cows is less documented, which constitutes an obstacle to its use. This study therefore aimed to improve the lactation performance of Holstein Friesian x Ankole crossbred cows in the Eastern DRC through improved feed quality and feeding management.

1.3 Rationale of the study

This work aimed at generating new information on innovative feed utilisation and feeding strategies to address feed quality and dry season feed gaps in smallholder dairy cattle farms. This included selecting and utilising trees and shrubs fodder leaves to supplement local pastures and crop residues in the diet of crossbred cows. This agricultural technology will have an impact on reducing overreliance and lack of concentrates, increasing dairy production, and reducing production costs. This information is of critical importance to many stakeholders, including smallholder farmers and policymakers, as it will assist in the planning and designing of appropriate intervention strategies for facilitating sustainable smallholder dairy cattle productivity in DRC.

1.4 Research questions

1. What factors determine the utilisation of trees and shrubs as livestock feeds by smallholder cattle farmers in Eastern DRC?
2. What are the chemical composition and *in vitro* gas production of trees and shrubs utilised by smallholder cattle farmers in Eastern DRC?
3. What are the feed intake, milk production, and composition of lactating Holstein Friesian x Ankole crossbred cows fed on Guatemala grass (*Tripsacum andersonii*) supplemented with dried Leucaena (*Leucaena leucocephala*) or cassava (*Manihot esculenta*) leaves as nitrogen sources?

1.5 Null Hypothesis

1. The socio-economic factors determining the utilisation of trees and shrubs as livestock feeds do not vary among smallholder cattle farmers in Eastern DRC.
2. The chemical composition and *in vitro* gas production of trees and shrubs utilised by smallholder cattle farmers do not vary in Eastern DRC.
3. The feed intake, milk production, and milk composition of lactating Holstein Friesian x Ankole crossbred cows fed on Guatemala grass (*Tripsacum andersonii*) supplemented with dried Leucaena (*Leucaena leucocephala*), or cassava (*Manihot esculenta*) leave as nitrogen sources do not vary.

1.6 Objectives of the study

1.6.1 Overall objective

This study aimed at determining the socio-economic factors influencing the utilisation of trees and shrubs forages, their nutritive value, and their effect on the lactation performance of crossbred cows in the Eastern Democratic Republic of the Congo.

1.6.2 Specific objectives

1. To evaluate the socio-economic factors determining the utilisation of trees and shrubs as livestock feeds by smallholder cattle farmers in Eastern DRC.
2. To determine the chemical composition and *in vitro* gas production of trees and shrubs utilised by smallholder cattle farmers in Eastern DRC.
3. To investigate the effects of supplementing Guatemala grass (*Tripsacum andersonii*) with dried Leucaena (*Leucaena leucocephala*) or cassava (*Manihot esculenta*) leaves as nitrogen sources on feed intake, milk production, and composition of lactating Holstein Friesian x Ankole crossbred cows.

1.7 Significance of the study

Dairy cattle transform poor-quality feed raw materials into useful human products (milk, meat, manure, and leather). Raising dairy cattle has become popular in SSA countries such as DRC and is one of the main ways to achieve the Sustainable Development Goals by 2030 through improving food security and income generation for smallholder cattle farmers (Marivoet et al. 2020). Nevertheless, low milk production is commonly reported. The situation is mainly caused by the inadequacy of feed in terms of quality and quantity. In response to this challenge, there is a need to provide alternative feed resources that are inexpensive to produce and locally available to supplement the pastures in the grazing fields and the feeds produced at the smallholder farm level. This study was designed to generate information that will contribute to managing the shortage of dairy feed. This was achieved through (a) the evaluation of the socio-economic factors determining the utilisation of trees and shrubs as livestock feeds by smallholder cattle farmers in Eastern DRC; (b) the evaluation of the chemical composition and *in vitro* gas production of trees and shrubs utilised by smallholder cattle farmers and (c) the investigation of the effects of supplementing Guatemala grass with Leucaena or cassava leaves as nitrogen sources on feed intake, milk production and milk composition of lactating Holstein Friesian x Ankole crossbred cows. The findings of this study provided insights into selecting and scaling up the most valuable tree and shrub technologies to improve cattle nutrition, enabling policymakers (governmental and non-governmental organisations) and farmers to design appropriate intervention strategies to improve livestock productivity and serve as a benchmark for future research. Furthermore, scientifically generated information is useful in developing livestock feeds and feeding management policies.

1.8 Scope and limitation of the study

This study targeted smallholder cattle farmers in Kalemie territory, Tanganyika province, and Kabare territory, South-Kivu province in Eastern DRC. The study faced the coronavirus pandemic crisis, which disrupted the research plan. A significant constraint was the unavailability of a large herd of crossbred cows of similar characteristics for use in the feeding experiment.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter presents a synthesis of literature deemed relevant to the study of lactation performance of crossbred cows fed on pastures supplemented with trees and shrubs fodders utilised by smallholder farmers. The literature offers support and guidance and indicates the extent of what has been done; thus, it serves to identify potential gaps in the literature and offers a starting point for this study. Section 2.2 presents livestock production in the Democratic Republic of the Congo. Section 2.3 presents the decision-making of agricultural technologies. Section 2.4 presents the nutritional and feeding impact of using trees and shrubs as livestock feeds. Finally, the last section, 2.5, presents a summary and research gaps in the chapter.

2.2 Livestock production in DRC

In DRC, the agricultural sector is dominated by a smallholder farming system, with more than 70% of its population living in rural areas and involved in agricultural production, both crops, and livestock. The agricultural sector contributes 45.7% of the Gross Domestic Product (GDP) (Ministry of Agriculture, 2018), while the livestock sector accounts for 9.2%. According to DRC's National Institute of Statistics report (2020), the national livestock population was estimated at 4.11 million head of goats, 1.21 million head of cattle, 0.99 million head of pigs, 0.91 million head of sheep, and 18.56 million head of poultry. These figures are in decline due to the recurrent wars and looting that have taken place in the country (Cox, 2012). Table 2.1 presents the different livestock species population trends between 2015 and 2019. Approximately 95% of the cattle population is indigenous (Ankole and N'dama). The grasslands and savannahs are capable of supporting 40 million head of cattle, but only 11% of cattle are explored. Few large companies in DRC raise indigenous beef cattle (N'dama) and improved crossbred (Afrikander and Bonsmara) in ranch systems on large grazing areas for meat production (Moula et al., 2013). Most of the livestock is kept in traditional systems such as pastoral transhumance and agro-pastoralism, which contribute to enhanced agricultural productivity, improved rural livelihoods, and income generation (Bacigale et al., 2018; Maass et al., 2012).

Table 2.1: Livestock population (heads) of the DRC between 2015-2019 (National Institute of Statistics, DRC, 2020)

Species	Years				
	2015	**2016**	**2017**	**2018**	**2019**
Cattle	1,005,384	1,020,959	1,080,993	1,144,766	1,211,912
Goats	4,093,457	4,095,348	4,101,065	4,105,026	4,111,782
Sheep	909,514	909,664	910,103	911,243	912,789
Pigs	994,569	985,541	988,947	992,322	995,584
Poultry	20,349,615	18,389,907	18,395,826	18,443,470	18,558,293

In Eastern DRC, Mugumaarhahama et al. (2021) characterised smallholder cattle production systems into three categories based on herd size and landholding. The first category is the most common and includes 70.80% of farmers raising on average small herds of 6 cattle of local breeds such as Ankole and N'dama cattle, with the predominance of the Ankole cattle, which is characterised by low milk production (1.8 litres per day), in the herding system. The basic feeding resources are mainly forage grazed in community pastures and fallow land. Farmers in this category hold small plots of land (less than 5 ha) on which they grow fodder grasses (Guatemala and Napier), trees and shrubs, and food crops. In the second category, some farmers have small plots (<5 ha) and others large plots (>5 ha), but all farmers (20.63%) have average herd sizes of 45 cattle consisting of local breeds, which are raised in herding system and producing an average of 1.7 litres per day. Farmers also exploit community pastures, fallow land, and roadside fodder for animal feeding. The third category includes farmers (8.57%) with large cattle herds (78 cattle) of local, crossbred, and exotic breeds (Holstein Friesian and Brown Swiss) raised freely in the fenced paddocks on large plots (>5 ha) at high altitudes. Introducing crossbred, exotic breeds and feed supplements improved milk production (4.6 litres per day). However, all three categories of cattle farming face numerous constraints (such as feed scarcity, the poor genetic potential of local breeds, climate, widespread diseases, undeveloped marketing system, poor infrastructure, and war) which prevent smallholder farmers from achieving a satisfactory standard of living (Bisimwa et al., 2018; Cox, 2012; Kumwimba et al., 2016; Maass et al., 2012; Mugumaarhahama et al., 2021; Paul et al., 2016).

Feed scarcity in terms of quality and quantity, as well as seasonal fluctuation, was identified as the most important constraint to livestock development and productivity in the Eastern DRC (Bacigale et al., 2014; Katunga et al., 2014). For instance, in Kenya, smallholder farmers use crop residues, purchase off-farm feeds, use public land for grazing, or use concentrates to address feed quality and shortage (Lukuyu et al., 2009). However, most strategies could oblige smallholders to spend money on cattle feeding, thus increasing milk production costs. The adoption of less expensive techniques such as the use of trees and shrubs to supplement grasses has been suggested as alternative feed resources to increase milk production (Abdulrazak et al., 2000; Osuga et al., 2008). The next section discusses the process of adopting new agricultural technologies.

2.3 Decision-making of new agricultural technologies

The individual decision of a farmer to utilise trees and shrubs as new agricultural technology can be modelled in a random utility framework, which is a common approach to analysing innovation adoption under uncertainty and risks (Marra et al., 2003). Previous studies showed that risk and uncertainty play an important role in adopting new agricultural technologies. Jera and Ajayi (2008) showed that agroforestry fails to be taken up by the poorest of the poor, whose main priority is to get food on the table and who cannot afford to take risks by investing time and labour in new technologies which have uncertain benefits in the long term. The expected utility framework model assumes that adoption decisions are based on the maximisation of the expected utility or profit subject to farmer resource constraints. As profit is a function of the farmer's choice of new technology, such as trees and shrubs, in each period, maximising profit depends on the farmer's binary choice from a set of alternatives (yes/no). Among the important results of the theory is that the correlation of outputs under alternative technologies is crucial to determining adoption rates.

However, the variables such as knowledge, perception, and attitude have been shown to have a key influence on decision-making on adopting new agricultural technologies. Meijer et al. (2015) reported that farmers know about the existence of a new technology, how to apply it, and the outcomes in terms of products, production, potential benefits, risks, and costs. The information an individual has about new technology forms the basis of the perceptions and attitudes this individual develops toward the technology. In Kenya, Roothaert and Franzel (2001) assessed farmers' knowledge and perception of tree and shrub species. The authors found that 90% of farmers in Kenya have integrated about 160 species of trees and shrubs within the farming systems across the farm boundaries, within the food crops, grazing land, and at the homestead. The preference for the trees and shrubs among the smallholder farmers was based on palatability, ability to satisfy hunger, and contributions to animals' overall health. Mekoya et al. (2008) found that farmers generally positively perceived multipurpose fodder trees for their feed value and contribution to soil conservation. However, agronomic problems constrained adoption (low biomass, short life, incompatibility to cropping system and adaptability), low multipurpose value, and land shortage. They recommended that farmers be involved at all project design and implementation stages to enhance adoption.

The agroforestry adoption studies have also sought to explain the adoption by looking at external variables (gender, age, marital status, income, education, assets) with a strong focus on socio-economic factors. Ajayi et al. (2003) found that farmer awareness of the technology, membership in farmers' group, wealth status, landholding size, modem farm inputs, possession of oxen, and cash crop production influenced farmers' decision to adopt fertiliser tree-based agroforestry in Zambia. An econometric model was used to analyse the factors determining farmers' adoption of alley farming in Southwest Cameroon (Adesina et al., 2000). The authors showed that adoption was higher for male farmers, with contacts with extension services and farmers belonging to the farmer's group. Krause et al. (2007) analysed smallholder farmers' decisions regarding integrating woody plants in Ethiopia. They found that the resource-base and personal characteristics of the farmers were the major decision-making determinants. In Zimbabwe, Jera and Ajayi (2008) assessed the potential of adopting fodder bank technology to improve livestock production and income generation for smallholder farmers. The findings showed that dairy herd size, land holding size, membership of the dairy association, and agro-ecological potential were the key factors influencing farmers' adoption of fodder banks. In Tanzania, Matata et al. (2010) found that information on improved farming, farmer participation in improved farming, membership of farm groups, and contact with extension significantly influenced the adoption of improved fallows among smallholder farmers. In contrast, marital status, formal education, and regular off-farm income had not influenced the adoption.

In Rwanda, Ndayambaje et al. (2012) found that the gender of household head (with a female predominance of 57%), the number of salaried members of the households, the amount of on-farm fuelwood, the number of meals per day, the geographical location of the household, and the selling of tree products to be the factors determining tree planting of farms. Pello et al. (2021) evaluated the factors influencing the adaptation to climate change through agroforestry technology in Kenya. The results indicated that the total yield for maize crop, farm size, extension frequency, off-farm income, access to training, access to credit, access to transport facilities, group membership, access to market, gender, distance to nearest trading centre, and household education level had a significant effect on the adoption of agroforestry technologies. Barnes et al. (2021) explored the drivers behind the adoption of legumes by developing an indicator of household legume cultivation from a survey of small-scale farm households in Kenya and DRC. The empirical framework indicated a limited influence of agro-ecological zones and formal institutions on the uptake of new technology. The factors such as age, income, and gender positively influenced the adoption process.

2.4 Nutritional and feeding impact of trees and shrubs on dairy cows

2.4.1 Nutritional composition of trees and shrubs

The browse trees and shrubs provide endless fodder throughout the year due to their root system, penetrating deep into the soil, growing even in dry conditions, and keeping the leaves green (Osuga et al., 2008). Trees and shrubs are rich in CP, vitamins, and minerals and tend to be more digestible than natural pastures and crop residues (Ayenew, 2019; Juma et al., 2006). Table 2.2 illustrates the potential nutrients of the most adopted trees and shrubs by smallholder farmers compared to Guatemala grass (*Tripsacum andersonii*), a common grass established and used in mixed farming systems of the Eastern DRC.

Table 2.2: Nutritional value (g kg^{-1} DM) of Guatemala grass and most adopted fodder trees

Species	DM	CP	NDF	IVODM (%)	References
Tripsacum andersonii	220	88.0	724	59.9	Heuzé et al. (2015)
Tripsacum andersonii	157	163	606	n.d	Perera and Perera (1994)
Tripsacum andersonii	163	153	623	n.d	Perera and Perera (1994)
Tripsacum andersonii	186	133	654	n.d	Perera and Perera (1994)
Leucaena leucocephala	280	220	221	58.8	Rashid et al. (2021)
Calliandra calothyrsus	283	282	455	38.0	Kaitho et al. (1993)
Leucaena leucocephala	350	288	350	n.d	Tshibangu et al. (2014)
Leucaena leucocephala	293	195	319	64.2	Katunga et al. (2014)
Leucaena leucocephala	183	201	538	62.7	Katunga et al. (2014)
Calliandra calothyrsus	295	237	416	56.6	Katunga et al. (2014)

DM, dry matter; CP, crude protein; NDF, neutral detergent fiber; IVODM, *in vitro* organic digestible matter; n.d, not determined.

The fluctuation in the nutritional composition of Guatemala grass shown in Table 2.1 can be explained by plant and environmental factors. The nutritional quality of plants tends to degrade with maturity, which is also associated with a decrease in the proportion of leaves relative to stems, reducing forage digestibility and intake. In ruminants, there is a positive relationship between the rate of feed digestion and feed intake. The neutral detergent fibre (NDF) is the primary chemical composition of feed that determines the digestion rate (Van Soest et al., 1991). Perera and Perera (1994) reported that the CP content of Guatemala grass decreased as the plant tended to mature while NDF content increased. For instance, grass harvested at eight weeks of age had a high CP content (163 g kg^{-1} DM) and low NDF (606 g kg^{-1} DM) compared to grass harvested at 12 weeks of age which had low CP (133g kg^{-1} DM) and high NDF (654 g kg^{-1} DM). In Eastern DRC, Paul et al. (2016) reported that Guatemala grass was well adapted to the middle and highland farming systems. The authors also reported that farmers preferred Guatemala grass because it was drought resistant and provided digestible forage during the dry season when Napier grass lost its forage quality.

Studies have shown that integrating trees and shrubs into animal diets improves palatability, feed intake, digestibility, and lactation performance (Ayenew, 2019; Derero & Kitaw, 2018; Osuga et al., 2011). Osuga et al. (2011) reported that goats fed chopped Rhodes grass hay and maize bran *ad libitum* and then supplemented with *Berchemia discolo*r and *Zizyphus mucronata* increased total DM intake and nitrogen intake. The authors found that the increased DM intake was likely due to increased microbial activity associated with a high rumen ammonia concentration. Nevertheless, the crude protein concentration in tropical pastures would vary between 30 and 200 g kg^{-1} DM, and the digestibility of DM varies between 30 and 70 % (Kebread et al., 2005). Norton (1994) reported that the minimum ammonia level to support optimal microbial activity ranges from 60-80 mg nitrogen per litre with an average of 70 mg nitrogen. A low nitrogen value is associated with a depressed appetite and decreased animal feed intake. Nitrogen deficiency in the rumen limits microbial fermentation, reducing feed intake (Forbes, 2007). The additional nitrogen source to a protein-deficient diet allows a faster rate of microbial fermentation and the disappearance of rumen materials, leading to a higher intake. Trees and shrubs contain tannins that affect palatability, feed intake, and animal performance, as discussed in the sub-section below.

2.4.2 Anti-nutritional factors

Trees and shrubs produce chemical compounds, especially tannins, that are not directly involved in the plant growth but act as deterrents to microbes, insects, and herbivore animals (Ebrahim & Negussie, 2020). Tannins form complexes with proteins, minerals, amino acids, and polysaccharides, thus reducing nutrient digestibility and feed intake, thus affecting livestock performances (Aganga & Tshwenyane, 2003). Tannins are classified into condensed tannin (CT) and hydrolysable tannin (HT). CT and HT have beneficial and harmful effects depending on their concentration and nature, besides other factors such as animal species, animal physiological state, and browse forage composition (Makkar, 2003). The toxicity of HT occurs when degraded products in the rumen, such as polyhydroxy-alcohol and various phenolic acids, are absorbed and loaded into the bloodstream beyond the capacity of the liver to detoxify (Makkar, 2003).

The effect of CT on dry matter intake depends on the type of ruminants. For instance, goats can consume a plant with a higher level of CT than sheep and cattle. Cattle select familiar plants and avoid those containing toxic secondary compounds (Ebrahim & Negussie, 2020). High condensed tannin levels reduce the feed intake of forages in three ways (Kumar & Vaithiyanathan, 1990). (1) decrease dry matter digestibility of forage in the rumen by reacting with the outer cell layer of the gut and thereby reducing the permeability of the gut wall, which gives signals of physical distention. (2) reduce the release of the hormones cholecystokinin and bombesin, which delay the release of gastrin and pancreatic enzymes as well as gallbladder contraction, thus suppressing the feed intake. (3) The decrease in intake is also due to the unpalatability of the forage. Plant tissue tannins precipitate salivary proteins, causing an astringent taste in the mouth. Derix (2017) reported that CT concentration in browse forages approximated at 0.5% is sufficient to destabilise the bloat proteins, and the concentration varying between 2% and 4% forms a tannin-protein complex, which is beneficial for livestock. Tannin-protein complexes bypass rumen protein breakdown and then hydrolyse in the small intestine to produce amino acids the host animal needs. Osuga et al. (2011) found that goats supplemented with browse forages containing moderate levels of CT (20.2-34.8 g kg^{-1} DM) increased total dry matter and nitrogen intake, which resulted in increased live weight gains. Ebrahim and Negussie (2020) reported that high concentrations of CT, between 5% and 9%, form complexes with proteins, carbohydrates, and minerals that cannot be hydrolysed in the small intestine, thus increasing nutrient wastage. Tannins-carbohydrate complexes delay the ruminal fermentation process, reducing feed intake and producing volatile fatty acids (propionate, butyrate, and acetate). CT values greater than 9% have been reported to be toxic and potentially fatal to animals (Makkar, 2003). The author mentioned that the adverse effects of tannins-rich feed do not reflect their toxic potential, but rather the toxicity results from the remaining tannins or degraded products not detoxified by the liver of the animal.

2.4.2.1 Beneficial effect of CT on the prevention of pathogen colonisation

The presence of unbound CT in the ruminant digestive system binds to the brush border of the epithelial layer of the intestine, then either impairs nutrient absorption that occurs via the brush borders or prevents its colonisation by pathogenic bacteria (Derix, 2017). Molan et al. (2002) reported less weight loss in animals infested with *Trichostrongylus circumcincta* and *T. colubriformis* fed a diet containing high levels of CT. The authors reported that the anthelmintic effect against *Trichostrongylus circumcincta* and *T. colubriformis* could be explained by the fact that CT impaired the development of eggs into L3 larvae and could inhibit egg hatching. The development of these anthelminthic was inhibited when animals were fed *Lotus pedunculatus* at the concentration of 200µg/mL of CT compared to *L. corniculatus, Hedysarum coronarium,* and *Onbrychus vicifolia* (at the concentration of 400µg/mL of CT). Although these properties of condensed tannins could be explored as feed additives to control and prevent problems such as diarrhoea caused by *Cryptosporidium parvum*, more research is still needed.

2.4.3 Feeding impact of trees and shrubs on dairy cows

The feed provided to cows is distributed among the various physiological requirements such as maintenance, activity, pregnancy, milk production, and body condition gain (Kibwana et al., 2012; Muinga et al., 1993). Regarding nutritional factors, protein, and energy are the limiting factors in milk production. For example, a lactating dairy cow needs a ration comprising at least 10 MJ kg^{-1} DM of metabolisable energy and a CP value ranging from 100 to 160 g kg^{-1} DM (National Research Council, 2001). To meet these requirements, cows need a high nutrient intake, and milk production potential is reduced when these are not met. The high nutrient intake can only be achieved if cows achieve high DM intake. Consequently, milk production of cows fed tropical forages is likely limited by low DM intake due to the low protein content (Ayenew, 2019; Derero & Kitaw, 2018; Muinga et al., 1993; Osuga et al., 2011).

2.4.3.1 Factors affecting feed intake

Feed intake represents the amount of feed consumed by an animal during a given period with free access to food. The DM intake is critical as it establishes the amount of nutrients an animal has for health, production, and reproduction. Therefore, it is essential to match feed intake to the required production, as low feed intake leads to lower production, while high feed intake leads to excess fat deposits and the wastage of nutrients. The feed intake is influenced by animal, plant, and environmental factors.

The animal factor, such as the capacity of the rumen to contain fodder, determines the feed intake in ruminants. Animals have a limited rumen capacity, which means that forages of low digestibility will take a long time to be digested, filling the stomach and limiting feed intake (Forbes, 2007). Stomach filling also stimulates tension receptors and mechanoreceptors in the reticulum and cranial rumen to send satiety signals to the medulla oblongata's gastric centre, reducing feed intake (Allen, 1996). The gestation of animals tends to increase feed intake to meet maternal and foetal requirements until the end of gestation. However, foetal and abdominal cavity sizes increase and decrease, respectively, as the animal tends to parturition, reducing feed intake. Dairy cows are in high demand for energy to meet the peak of milk production during the postpartum period, resulting in a negative energy balance, in which case the animals mobilise their body reserve and lose their body weight, followed by a decrease in appetite, which also reduces feed intake (Allen, 1996).

Environmental factors such as high ambient temperature have been reported to depress cattle feed intake. However, heat causes the rostral cooling centre of the hypothalamus to stimulate the medial satiety centre and inhibit the lateral appetite centre, which decreases feed intake and hence milk production (Fuquay, 1981). The high temperature is pronounced in exotic breeds and may stop feed intake and rumination when the ambient temperature exceeds 40 ºC. Feed intake has also been depressed by infectious, parasitic, and metabolic diseases. For instance, helminth infestation has been reported to cause a depression in feed intake through the continued stimulation of gut wall receptors by parasites, decreasing plasma protein concentration. This amino acid deficiency has been assumed responsible for reducing feed intake (Forbes, 2007).

2.4.3.2 Impact of trees and shrubs on dairy milk production and milk quality

Supplementing natural pastures with trees and shrubs fodders increases the total nitrogen supply to rumen microorganisms and provides the small intestine with non-degradable amino acids (Abdulrazak et al., 1997). Increased nitrogen sources have been reported to contribute to increased live-weight gains and milk production in goats (Osuga et al., 2011). Milk production of 5.1, 5.4, 5.5, and 6.5 kg day^{-1} from crossbred cows was reported with Napier grass basal diet alone, Napier grass supplemented with 1 kg of *L. leucocephala*, 2 kg of *L. leucocephala*, and 2 kg of *L. leucocephala* together with 1 kg DM of maize bran, respectively (Muinga et al., 1995). Supplementation of Friesian dairy cows with 1.5 kg day^{-1} of *Acacia boliviana* and *L. leucocephala* increased milk production by 5-16%, greater than Rhodes grass, a control diet (Maasdorp et al., 1999). Juma et al. (2006) reported that the dairy cows fed Napier grass and supplemented with *Gliricidia sepium*, *Clitoria ternatea,* and *Mucuna pruriens* as a nitrogen source increased daily milk production by 20%, 27.5%, and 32.5%, respectively. Flores-Cocas et al. (2021) reported higher milk fat content for cows fed on *Pennisetum purpureum* and *Leucaena leucocephala* than cows provided a high proportion of molasses or rice polishing. This result was consistent with the fact that high fibre in the diets such as trees and shrubs leads to an increase in the molar proportion of acetate in the rumen. Since milk fat is synthesised in the mammary gland from acetate, the concentration of milk fat is directly affected by the concentration of ruminal acetate and its flux to the mammary gland (Wanapat et al., 2018).

2.5 Summary and Research gaps

The literature reviewed and presented in this chapter has established a demand for livestock products (milk and meat) due to human population growth, urbanisation, and changing consumer food preferences. This high demand for milk and livestock products represents attractive market opportunities for smallholder farmers to increase milk production, thus contributing to food security and poverty alleviation. It is further noted that in Eastern DRC, Guatemala grass is the primary source of feeds for crossbred cows. Guatemala grass has been reported to have low crude protein and energy levels necessary to meet the dry matter intake required by lactating cows. Alternative concentrate supplementation is not common practice in the study area due to the high price. Trees and shrubs such as Leucaena and cassava were found to be attractive protein supplements to Guatemala grass for the resource-poor smallholder farmers.

However, the literature reveals that the benefits of fodder trees and shrubs are well known and used by smallholder farmers in the tropics, but their adoption is not widespread. For instance, in the Eastern DRC, the factors determining the use of trees and shrubs as livestock feeds are poorly understood. There is also limited information on the chemical composition and *in vitro* gas production of trees and shrubs fed to livestock. Information on the use of Leucaena or cassava in the diets of Holstein Friesian x Ankole crossbred cows is less documented, which constitutes an obstacle to its use.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter presents information on the study area and site, materials, and methods used to achieve the objectives of the study. First, it describes the study site, data, and sample used, followed by the analysis tools and respective statistical packages. Next, the chapter highlights the economic model, the standard laboratory procedures, and the experimental design used to achieve the objectives of the study, which were (i) to evaluate the factors determining the utilisation of trees and shrubs as livestock feeds by smallholder cattle farmers, (ii) to evaluate the nutritional composition and *in vitro* gas production of trees and shrubs utilised by smallholder cattle farmers, and (iii) to investigate the effects of supplementing Guatemala grass with Leucaena or cassava leaves on feed intake, milk production, and milk composition of lactating Holstein Friesian x Ankole crossbred cows. The first objective is analysed using the probit regression model; the second is analysed using one-way analysis of variance, and the third is analysed using two-way repeated measures of analysis of variance. These models are described in detail in the following paragraphs of this chapter.

3.2 Study area

The study was conducted in the territories of Kalemie and Kabare in Eastern DRC (Figure 3.1). Territories were purposefully selected based on favourable farming conditions for livestock combined with a growing demand for meat and milk, the adoption of dairy cattle farming, high human population densities (Marivoet et al. 2020), and proximity to research centres, both local (for example, National Institute for Agricultural Study and Research, INERA) and transnational (for example, International Institute of Tropical Agriculture, IITA) that promote uptake of trees and shrubs such as Leucaena and cassava among smallholder farmers. Within the territory level, a multistage sampling technique was used to select groups[1] and smallholder cattle farmers. In the first stage, 17 groups were selected from two territories based on the intensity of cattle farming, road access, and absence of conflict or violence. In Kalemie territory, five out of seventeen groups that fulfilled the criteria were selected, including Moni, Kasanga-Mtoa, Miketo, Mugonda, and Tumbwe-fief. In Kabare territory, twelve out of seventeen groups were selected, including Bugobe, Bugorhe, Bushwira, Bushumba, Cirunga, Irhambi-Katana, Kagabi, Luhihi, Miti, Mudaka, Mudusa, and Mumosho. In the second and last stage, a simple random sampling technique was used to select the smallholder cattle farmers (survey respondents).

Kalemie territory is located in the province of Tanganyika. It covers an area 30,512 km^2 with an estimated 707,021 populations (Development Indicator Analysis Unit, 2020). It stretches along the Western shore of Lake Tanganyika, which forms the border between the DRC, Burundi, Tanzania, and Zambia. Its altitude varies from sea level at about 700 metres in Kalemie town to around 2,667 metres in Kabobo massif, comprising mountain ranges in the Northwest on the border with the province of South-Kivu (Plumptre et al., 2008). Kabare territory located in the province of South-Kivu covers 1,960 km^2 with an estimated population of 868,616; on the Western shore of Lake Kivu, which forms the border between DRC and Rwanda (Development Indicator Analysis Unit, 2020). Its altitude varies between 1,460 metres at sea level up to 3,000 metres on the high mountain plateaus. The average altitude is 2,225 metres. The two territories have a similar agro-ecological zone characterised by the high-altitude of volcanic mountain ranges in the East and Northeast of the DRC, which have a very high population density. The landscape is that of the tropical rainforests characterised by two rainy seasons (between March and May and between September and December), followed by two short dry seasons (between June and August and January and February). The average temperature varies between 24 and 25°C; variability is limited throughout the year.

[1] In Democratic Republic of Congo, administrative units are, from superior to inferior, Province, Territory, Chiefdom, Groups, and villages.

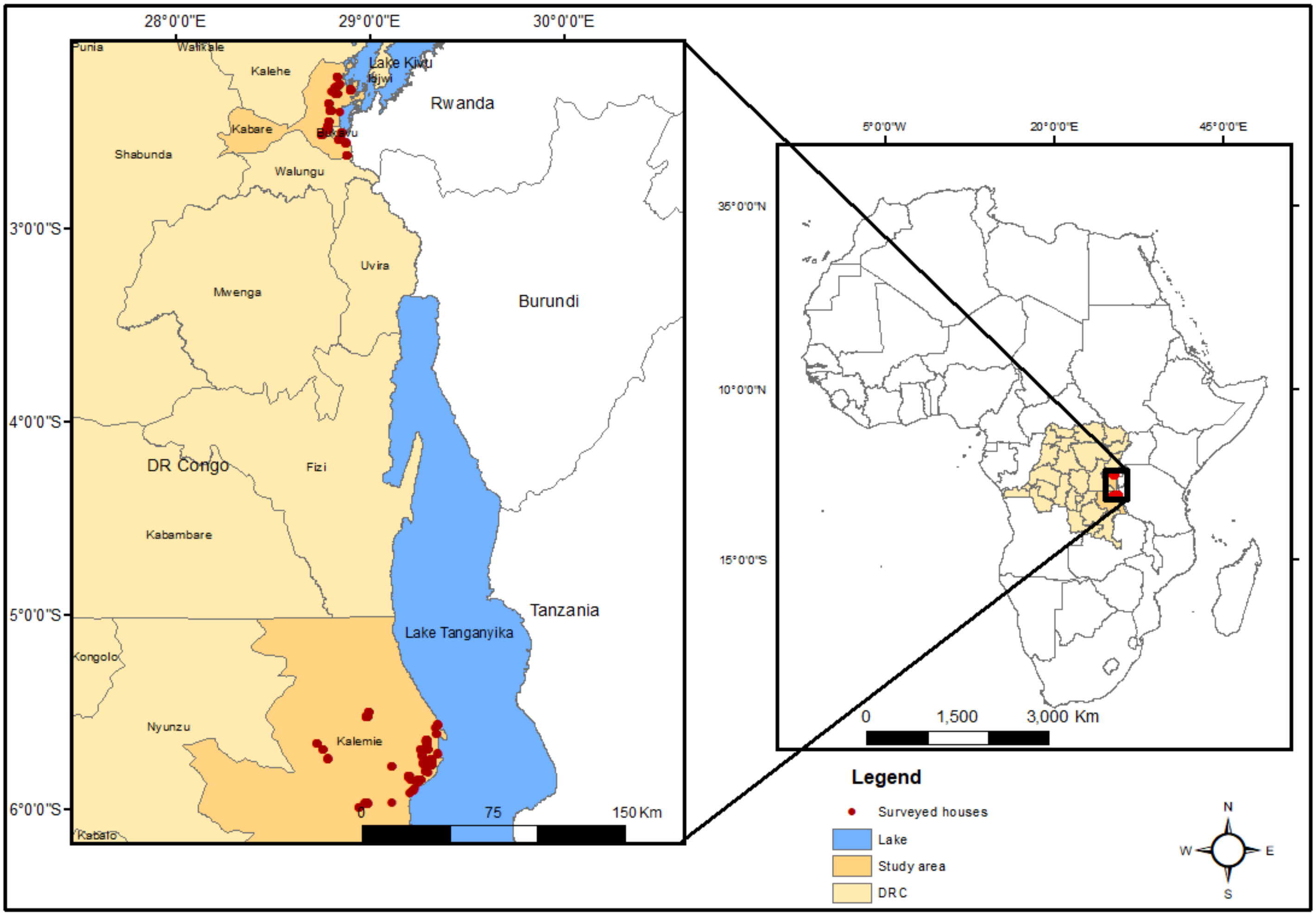

Figure 3.1: Map of the study area, Eastern DRC. Map made using shape files from the common geographical reference (http://www.rgc.cd)

Agro-ecological conditions are favourable to growing a wide variety of staple crops such as cassava, beans, rice, bananas, soybeans, cowpea, and sweet potatoes as well as cash crops such as coffee, tea, cocoa, and sugar cane (Karume et al., 2022). The average annual minimum and maximum temperatures in Kalemie are between 18 °C and 32 °C, respectively, while in Kabare, they are 12.6 °C to 24.4 °C. The average annual rainfall in Kabare is higher (1897 mm) compared to Kalemie (999 mm) (Development Indicator Analysis Unit, 2020).

In Kalemie and Kabare territories, smallholder cattle farmers raise indigenous breeds such as Ankole and N'dama cattle with predominance of the Ankole cattle, which is characterised by low milk production in the extensive system (transhumant pastoralists and agro-pastoralists) (Mugumaarhahama et al., 2021).

3.3 Ethical considerations

All Animal Care and Use procedures were conducted following the guidelines set by the Bureau of Livestock and Fisheries Inspection of South-Kivu Province in the Code of Practice for Care and Use of Animals for Experimental Purposes and have been reviewed and approved by the Ethics Committee on the Use of Animals for Research, under license number 55.00/99/IPPEL/SK/2021 (see Appendix 1).

3.4 Evaluate the socio-economic factors determining the utilisation of trees and shrubs as livestock feeds by smallholder cattle farmers in the Eastern DRC

3.4.1 Determination of sample size

The criterion for enrolling smallholder cattle farmers in the study was the possession of at least one head of cattle. Lists of all smallholder cattle farmers in each territory, which the territorial livestock officers compiled, served as a sampling frame for this study. The target sample frame was determined using equation 1 (Fischer et al., 1991).

$$\mathrm{n} = \frac{Z^2}{L^2} PQ \qquad (1)$$

where: n is the desired sample size; Z^2 is the normal distribution value at a 95% level of confidence (given as 1.96); P is the ratio of the estimated target population to have at least one head of cattle (assumed at 0.5 if unknown); Q is the target proportion of the population without having one head of cattle (1- P); L is margin error (estimated at 0.0345 to increase the accuracy of the target population) (Angelsen et al., 2011).The sample size was calculated by substituting for the values: n= $1.96^2 x \frac{(0.5\ x\ 0.5)}{0.0345^2} = 807$. Data on 805 households, including 400 households from Kalemie and 405 households from Kabare, were considered for the study after a cleaning process.

3.4.2 Study design and data collection

A cross-sectional survey was conducted on a random sample of 807 smallholder cattle farmers using a well-structured and pre-tested questionnaire (Appendix 2) in May and June 2021. The questionnaire was designed by conducting an exhaustive literature review to extract all the variables related to using trees and shrubs as livestock feeds. Then the variables were transformed into re-testable questions (Kothari, 2004). Pilot tests were conducted twice on the same ten respondents to evaluate the questionnaire for relevance, design, clarity, interpretation, completeness, and time taken per interview. To ensure the internal consistency of the questionnaire, the responses were subjected to a reliability test using the Cronbach test (Kothari, 2004). The scores below 0.7 were identified and modified.

The interviews were conducted in Swahili or French languages, and the results were translated into English. The survey captured cattle farmer-related variables, including socio-economic characteristics, livestock feeds, feeding management, trees and shrubs, and specific information regarding farmers' knowledge, production, importance, perceptions, preferences, and the utilisation of cattle feeds prior to the interviews. All interviewers were either research technicians or university students doing internships at INERA in the territories of Kalemie and Kabare. In each territory, the same interviewers participated at all sites. Questions were administered to the person responsible for cattle farming, usually the household head, within an average of 45 minutes. Data were recorded on tablet devices by the interviewers. Each interviewer was able to administer eight questionnaires per day.

Cattle farmers were asked to mention all trees and shrubs consumed by cattle, goats, and sheep. The trees and shrubs were identified by their local names and botanical names, which were cross-checked in botanical books using photos from the field (Latham et al., 2021a,b), and unrecognised species were identified at the Natural Science Research Centre (CRSN-Lwiro), located 45.3 km North of Bukavu City in South-Kivu Province, DRC. The most cited trees and shrubs were considered as the most preferred species by farmers as livestock feeds. The survey also captured the edible parts consumed by the animals, the period of the year they provide such fodder to the animals, the niche of production, and other roles played by trees and shrubs. The number of animals owned by farmers was converted into a tropical livestock unit (TLU) using the conversion factors of 0.7 for cattle and 0.1 for sheep and goats (Maass et al., 2012).

3.4.3 Conceptual framework

This study underpins the theory of household utility maximization (Singh et al., 1985) to develop a conceptual framework that explores households' motivations and constraints to the utilisation of trees and shrubs as livestock feeds, as presented in Figure 3.2. In the framework, the household context variables include demographics, institutional, livestock farm and farming, livestock product marketing, livestock feed production, feeding factors, tree and shrub production, perceptions, knowledge, and preferences.

The household context interacts with the perceived costs and benefits of trees and shrubs alongside the influence of intervening variables (including the legal and policy framework and intervention of agricultural research organisations). It is hypothesized that households will utilise trees and shrubs as livestock feeds if the benefits derived from utilisation outweighs its associated costs. Household utilisation of trees and shrubs as livestock feeds is expected to improve livestock productivity (with respect to reproductive and productive performance), sustainability, and household welfare (in regard to incomes and food security).

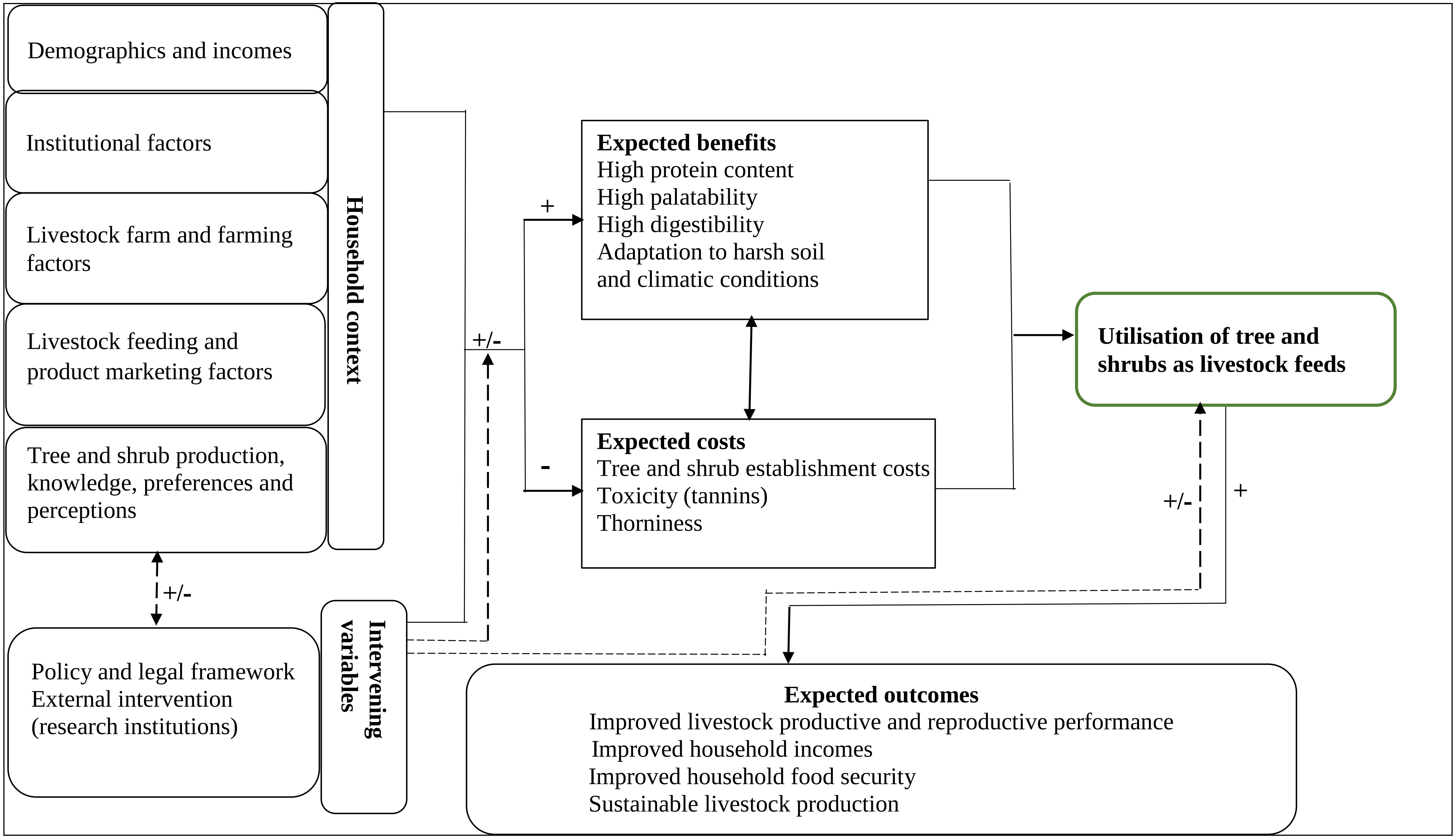

Figure 3.2: Conceptual framework of the socio-economic factors determinants of the use of trees and shrubs as livestock feeds

3.4.4 Analytical framework and variables

The smallholder farmer's choices are based on their perceived utility, that is, if the expected net benefits of trees and shrubs (B^{AF}) are greater than the expected payoffs of the alternative feed sources (C^{AF}), as shown in equation (2).

$$(B^{TS} - C^{TS}) \geq (B^{AF} - C^{AF}) \quad (2)$$

Where $(B^{TS} - C^{TS})$ are the benefits of trees and shrubs (B^{TS}) including low cost of production, drought resistance, animal satiation, and improved milk production and costs or setbacks of trees and shrubs (C^{TS}) such as toxicity and thorniness. While $(B^{AF} - C^{AF})$ denotes the benefits of alternative feeds (B^{AF}) and their associated costs (C^{AF}) (Franzel et al., 2014; Kiptot & Franzel, 2012). The comparative equation (2) underpins the theory of utility maximisation, which assumes that when an economic agent (individual or household) faces a choice among two or more alternatives, the agent will select an alternative that yields the highest utility (Singh et al., 1985). If the difference in the expected net benefits for the two livestock feeding regimes is denoted by π, as shown in equation (3), then a household will utilise trees and shrubs forages if $\pi>0$ and vice versa (Singh et al., 1985).

$$(B^{TS} - C^{TS}) - (B^{AF} - C^{AF}) > \pi \quad (3)$$

where π is the latent variable representing the differences in benefits and costs associated with the utilisation of trees and shrubs forages and alternative feeds. The specification presented in equation (3) implies that determinants that raise π will enhance the utilisation of trees and shrubs fodder and vice versa. The empirical modelling of a household choice of trees and shrubs fodder can be denoted by a binary latent variable (Y) such that:

$$Y_i = \begin{cases} 1 \text{ if } \pi_i = \pi_i + \varepsilon = (B^{TS} - C^{TS}) - (B^{AF} - C^{AF}) \geq 0 \\ 0, \text{otherwise} \end{cases} \quad (4)$$

where ε denotes the standard error term, equation (4) can be estimated using probit regression analysis to determine the factors influencing the propensity to utilise trees and shrubs as livestock feeds. The magnitude π is presumed to be highly heterogeneous depending on various contextual specific household factors, including gender, age, differential information, knowledge asymmetries, cattle production systems and capacities, farming experiences, incomes, and liquidity constraints (Poole, 2017). The empirical specification for equation (4) is expressed in equation (5).

$$Y_i = \phi\left(\beta_0 \sum_{n}^{m} \beta_j X_{ni}\right) + \varepsilon \qquad (5)$$

where ϕ is the cumulative standard normal distribution function, X is a vector of factors hypothesised to affect the choice of tree and shrub fodder as livestock feeds, including attributes such as age, gender, and education level, as shown in Table 4.1.

3.5 Determine the chemical composition and *in vitro* gas production of trees and shrubs utilised by smallholder cattle farmers in the Eastern DRC

3.5.1 Sample collection and preparation

Trees and shrubs were prioritized based on the presence of the species in both Kalemie and Kabare territories, resource constraints, and farmer preferences (see Table 4.5). Species such as *Tephrosia vogelii* (Hook. f) and *Albizia gummifera* (C.A. Sam), listed in Table 4.5, were excluded from the nutritional analyses due to budgetary constraints and lack of a sufficient quantity of samples needed to perform all chemical analyses. *Persea americana* (Mill) was intentionally replaced by *Sesbania sesban* (L.) to not promote competition between humans and livestock, as the tree is mainly cultivated for its fruits which provide food and a source of income to the smallholder farmers. Browse samples from eight selected trees and shrubs, including *Vernonia amygdalina* (Del.), *Erythrina abyssinica* (Lam.), *Calliandra calothyrsus* (Meisn.), *Leucaena leucocephala* (Lam De Wit), *Sesbania sesban* (L.), *Mangifera indica* (L.), *Tithonia diversifolia* (Hemsl. A. Gray), and *Ficus glumosa* (Delile) were collected during the end of the rainy season (May and June). Representative leaf samples for each species were collected from ten random trees and shrubs, composited, and dried under shade, and ground using a mill to pass through a 1 mm sieve. Approximately 100 g of milled samples of each species were packed separately in plastic containers for further analysis of chemical composition at the Animal Nutrition Laboratory of Egerton University, Nakuru, Kenya.

3.5.2 Chemical composition and *in vitro* gas production analysis

Dry matter (DM), ash, organic matter (OM), nitrogen, and ether extract (EE) content of trees and shrubs samples were determined in triplicate according to the procedures of the Association of Official Analytical Chemists (AOAC, 2000). Nitrogen (N) content was determined following the Kjeldahl method, and the crude protein (CP) content was estimated by multiplying the N content by 6.25. Neutral detergent fibre (NDF), acid detergent fibre (ADF), and acid detergent lignin (ADL) were analysed sequentially in triplicate according to the procedures of Van Soest et al. (1991). Hemicellulose content was calculated as the difference between NDF and ADF, whereas cellulose content was between ADF and ADL. Phenolics were extracted using 70% aqueous acetone according to the procedures of Makkar (2003). The total extractable phenolics (TEPH) concentration was calculated using the regression equation of the tannic acid standard in duplicate, as described by Abdulrazak and Fujihara (1999). Total extractable tannins (TET) and condensed tannins (CT) were measured and computed as leucocyanidin equivalent (Abdulrazak & Fujihara, 1999).

In vitro gas production was performed according to Menke and Steingass (1988) method using rumen liquor obtained from three mature sheep with a live weight of 27 ± 20 kg. Donor sheep were fed *ad libitum* Rhodes grass hay (*Chloris Gayana*) mixed with molasses and supplemented with 2 kg of commercial dairy concentrate twice daily. Mineral licks (Maclick mineral brick, COOPER-BRANDS LTD, Kenya) containing 85% Sodium, 5% Calcium, 2.5% Phosphorous, 1% Magnesium, 0.33% Zinc, 0.2% Copper, 0.2% Manganese, 0.015% Iodine, and 0.0015% Selenium were purchased from a local supplier. Mineral licks and freshwater were provided *ad libitum* to maintain a stable environment before collecting the rumen liquor. Rumen liquor was collected at 8:00 a.m. before morning feeding by a vacuum pump through a stomach tube, mixed, strained through four layers of cheesecloth, and kept at 39 °C under a carbon dioxide (CO_2) atmosphere.

Approximately 200 mg of sample (milled through a 1 mm sieve) were weighed into 100 ml calibrated glass syringes in triplicate. A 30 mL mixture of rumen liquor and buffer in a 1:2 ratio was added to the 100 mL calibrated glass syringes pre-warmed to 39 °C. Vaseline oil was applied to the pistons to ease movement and prevent gas leakage. Syringes were pre-warmed at 39 °C before adding 30 mL of rumen liquor and buffer mixture (1:2 ratio) into each syringe. Three blank syringes containing rumen liquor without feed samples were included as controls. All syringes were incubated in a water bath maintained at 39 °C and periodically agitated. Gas production readings were recorded at 0 and after 3, 6, 12, 24, 48, 72, and 96 hours of incubation. Gas production characteristics were estimated by fitting the average gas volumes to the exponential equation (6) of Ørskov and Mcdonald (1979) using the Neway-Excel computer program (Macaulay Institute, Aberdeen, UK).

$$\mathrm{G = a + b\,(1 - e^{-ct})} \qquad (6)$$

where G is the gas production (mL/200 mg DM) at time t, a is gas production (mL) from immediately soluble fraction, b is gas production (mL) from insoluble fraction, $a + b$ is gas production from potential degradable fraction (mL), c is the rate constant of gas production per hour (h), t is the incubation time in hours, and e is the exponential constant (2.718).

In vitro gas production parameters were used to estimate organic matter digestibility (OMD) (Menke & Steingass, 1988), metabolisable energy (ME) (Makkar & Becker, 1996), and short-chain fatty acids (SCFA) (Makkar, 2005) using the models shown in the equations below:

$$\mathrm{OMD\ (\%) = 14.88 + 0.889\ G + 0.45\ CP + 0.0651\ CA} \qquad (7)$$

$$\mathrm{ME\ (MJ/kg) = 2.20 + 0.136\ G + 0.057\ CP} \qquad (8)$$

$$S\mathrm{CFA\ (mmol/L) = 0.0222\ G - 0.00425} \qquad (9)$$

where G is gas production after 24 hours (G, mL), CP, crude protein content (% DM), and CA, crude ash content (% DM).

3.6 Investigate the effects of supplementing Guatemala grass with dried Leucaena or cassava leaves as nitrogen sources on feed intake, milk production, and composition of lactating Holstein Friesian x Ankole crossbred cows

3.6.1 Experimental site

The experiment was conducted at the Catholic University of Bukavu research farm in Kabare, South-Kivu province, DRC. The site is at 2º 17' S and 28º 49' E and lies 1,650 meters above sea level. The farm receives an average annual rainfall of 1224 mm; the average minimum and maximum temperatures are 12.5°C and 24.6°C, respectively, with an average of 18.4°C.

3.6.2 Criteria used to include Leucaena and cassava in the experiment

In Kalemie and Kabare territories, Leucaena and cassava are abundant and easily established by smallholder farmers. Leucaena was introduced for soil fertility management as a source of green manure (Muoni et al., 2019). Given the favourable climate conditions in the study area, Leucaena grows very quickly to form dense and homogenous thickets that are difficult to control once established. Invaded areas become unusable and inaccessible along with most other vegetation, posing a threat to local biodiversity. The use of this shrub by smallholder farmers as livestock feeds, as shown in Table 4.5, is one of the most effective management measures to control the invasion of the plant. Cassava is also grown for its roots in the study area as a staple food for the population (Munyahali et al., 2017). The DRC government has identified cassava and dairy cattle as a priority and profitable value chains to promote in Kalemie and Kabare territories (Marivoet et al. 2020). This government effort has resulted in high production of cassava roots, cuttings, and leaves. However, cassava leaves are less consumed, left in the fields as green manure. This woody shrub with compound leaves and tender twigs was reported to have a good level of proteins (Wanapat et al. 2018). Although cassava was not reported by smallholder farmers during the surveys in the study area and was not assessed for its nutritive value, its year-round availability motivated the choice to include it in the feeding experiment with the aim of promoting it as livestock feeds.

3.6.3 Forage preparation

Leucaena and cassava leaves were hand-harvested during the rainy season from smallholder farmers' fields in Uvira territory, South-Kivu province, DRC. Plant production conditions are fairly similar in most smallholder systems, ensuring minimum variation in the characteristics of the harvested herbages. Ten tons of fresh leaves of Leucaena regrowth of about four months old were cut and dried under shade. Then tons of cassava leaves came from plants that were about ten months old. The cassava leaves were harvested and dried in the sun for three days to reduce the hydrocyanic acid (HCN) content (Wanapat et al., 2000). The dried leaves were put into dried sacks and stored properly for feeding. Three hundred kilograms of fresh brewers' spent grain (BSG) were purchased every three days from a local brewing factory (Bralima, Bukavu, DRC) and fed to cows to stimulate forage consumption. Minerals licks (Mineral block, Royal ILAC, Turkey) containing 37.79% Sodium, 1.96% Calcium, 0.32% Magnesium, 0.105% Iron, 0.023% Zinc, 0.018% Copper, 0.015% Manganese, 0.0015% Cobalt, 0.00099% Iodine, and 0.00049% Selenium were purchased from a local supplier in Bukavu, DRC. Two hundred kilograms of fresh Guatemala grass regrowth of about five months old were collected daily from the Catholic University of Bukavu farm, chopped using a manual chaff cutter to a particle length of about 30-50 mm, and used in the experiment.

3.6.4 Animals, experimental design, and treatments

Three lactating Holstein Friesian x Ankole crossbred cows were selected from a cattle herd grazing on natural pasture and randomly assigned to three dietary treatments in a 3 x 3 Latin square design. All cows had similar lactation characteristics since they were in early lactation, and third parity, initial milk production was approximately 4± 1.2 kg/cow/day with 24 ± 9.02 days-in milk. The average body weight of cows was 359 ± 24 kg, and they were four years old (Table 3.1).

Table 3.1: Lactation characteristics of experimental cows

Characteristics	Cows				
	1	2	3	Mean	SEM
Initial body weight (kg)	325	406	346	359.00	24.00
Initial milk production (kg)	2.3	5.8	3.9	4.00	1.20
Days-in milk (day)	42	14	16	24.00	9.02
Age (years)	4	4	4	4	0.00
Lactation stage	Early	Early	Early		
Parity	Third	Third	Third		
Pedigree	Crossbred	Crossbred	Crossbred		

SEM, standard error of the means; Pedigree, crossbred from Holstein Friesian x Ankole

The experiment lasted 45 days, divided into three 15–day experimental periods, which were periodized into 1 to 10-day (diets adaptation periods) and 11 to 15-day (data collection). The experimental animals were fed fresh Guatemala grass, which was provided *ad libitum* as a basal diet. All animals were supplemented with a 1.25 kg DM fresh brewers' spent grain. This diet served as the control treatment. All cows were supplemented with dried Leucaena or cassava leaves at the inclusion rate of 20% of basal diet intake. The supplement was offered twice daily after milking (at 8:00 a.m. and 4:00 p.m.). The control diet was offered after consuming the supplements and added in the afternoon to ensure availability. All cows were housed in well-ventilated stalls and fed individually. The animals had free access to fresh water and mineral licks. All animals were sprayed weekly with a Norotraz 12.5% EC Amitraz (Norbrook Kenya Limited, Kenya) and Lava 100 EC Dichlorvos (Agritab Rwanda Limited, Rwanda) to control ticks and were dewormed with an Albendazole tablet (ModHike Private Limited, India) at the beginning of the experiment to control helminth.

3.6.5 Sampling procedures, data collection, and chemical analysis

Feed offered and refusals were measured daily throughout the experimental period to determine daily dry matter intake. Leucaena, cassava, brewers' spent grain, and Guatemala grass was sampled daily throughout the experimental period, compounded, and then shade-dried for subsequent chemical analysis at the Animal Nutrition Laboratory of the Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya. The samples were determined for dry matter (DM), ash, crude protein (CP), ether extract (EE), and crude fibre (CF) according to methods described by Abdulrazak and Fujihara (1999). Cows were hand-milked in the presence of their calves, and calves were fed using the bucket. Milk production was collected daily in the metal bucket and weighed individually using the Camry scale (Camry company, Zhongshan, China). Milk samples were composited daily from morning and afternoon milking, refrigerated in an ice-packed cooler, and then stored. The milk samples were then analysed for milk composition (fat, protein, lactose, solids not-fat content) at the Microbiology Laboratory of the Université Evangélique en Afrique, Bukavu, DRC, using the Milk Analyser Lactostar 3510 (Funke Gerber, Berlin, Germany).

3.7 Statistical analysis

After data collection, all tablet devices were synchronised with the Kobotoolbox platform server through an internet connection to upload all filled forms to the server (KoBoToolbox, 2020). An excel spreadsheet with data was then downloaded from the Kobotoolbox platform server, verified for input errors, and coded. The data was checked and cleaned to ensure consistency for any missing variables and outliers. Computation of statistical descriptions (means, frequencies) and inferential statistics, including the t-tests, was used to explore the correctness of the data and any underlying patterns in the dataset. Data analysis was executed with STATA software, version 16 (StataCorp, 2019). The independent variables were tested for multicollinearity using variance inflation factors (VIF). Unless otherwise indicated, the significance level was set at $p<0.05$. The probit regression analysis was used to assess the likelihood of independent variables determining the utilisation of trees and shrubs as livestock feeds. The average marginal effects were estimated to determine the contribution of the independent variables to the probability of utilisation of trees and shrubs.

All data on chemical composition, *in vitro* gas production, and animal feeding trials were statistically analysed using R software for windows, version 4.1.3 (R Core Team, 2022). Data on proximate, tannins, fibre, and *in vitro* gas production were subjected to a one-way analysis of variance in a completely randomised design using the statistical model presented in equation (10). The difference in the chemical composition of forages between territories was tested using an independent t-test.

$$Y_{ij} = \mu + S_i + \varepsilon_{ij} \quad (10)$$

where Y_{ij} = i …8, j =1…3; μ, overall mean; S_i, fixed species effect; $\mathcal{E}_{ijt}$ random residual error.

Data on feed intake, milk production, and milk composition were analysed for two-way repeated measures of analysis of variance (ANOVA) using the statistical model presented in equation (11). The results were expressed as means with a corresponding standard error of the means (SEM), representing the pooled SEM. Tukey's multiple comparisons test assessed significant differences between means after a significant F-test. These differences were considered significant at $p<0.05$.

$$Y_{ijt} = \mu + C_i + P_j + T_t + \varepsilon_{ijt} \quad (11)$$

Where Y_{ijt} = i … 3, j = 1 … 3, t = 1 …3; μ, overall mean; C_i, fixed cow effect; P_j fixed period effect; $T_{t,}$ fixed treatment effect; $\mathcal{E}_{ijt}$ random residual error.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results and discussion based on the specific objectives of the study. The first specific objective was to assess the socio-economic factors determining the use of trees and shrubs as livestock feeds, the second objective was devoted to determining the chemical composition and *in vitro* gas production of trees and shrubs preferred by farmers, and finally, the last objective was to investigate the effect of supplementing Guatemala grass with dried Leucaena and cassava leaves as nitrogen sources on feed intake, milk production and composition of lactating Holstein Friesian x Ankole crossbred.

4.2 Evaluate the socio-economic factors determining the utilisation of trees and shrubs as livestock feeds by smallholder cattle farmers in the Eastern DRC

4.2.1 Socio-economic characteristics of the smallholder farmers in the study area

The descriptive statistics for the smallholder cattle farmers are presented in Table 4.1. Most of the sampled household heads were males (83%) and married (89%), having a mean of eight household adult equivalent members and four dependents. The majority of the household heads were of middle age (45 years), having attained primary school education. This concurs with the findings of Mutwedu et al. (2022), who reported that most farmers involved in livestock were married men aged between 41 to 60 years with a primary school education level. Twenty-six per cent of households depended on mixed crop and livestock production for their livelihoods, earning a mean income of United States Dollars per month (USD) 65.18. Forty percent of the households were in either social or economic groups on social networks.

Table 4.1: Descriptions and descriptive statistics of the sampled households

Variable	Descriptions and measurement	Pooled sample Mean/proportion	Users (1) n=511	Non-users (0) (n=294)	Difference (1)-(0)
Location	Location of household head (0=Kabare;1=Kalemie)	0.50	0.55	0.41	-3.85***
Gender	Gender of household head (0=female;1=male)	0.83	0.85	0.80	-1.94*
Age	Age of year of household head (HH (years)	44.76	43.81	46.40	2.25**
Marital status	Marital status of the HH (1=married; 0=otherwise)	0.89	0.90	0.88	-0.94
Education level	Education level of the HH (1= primary 2= secondary 3= university	1.18	1.16	1.20	0.66
Household size	Household members above 18 years old (Number)	7.63	7.70	7.51	-0.72
Dependant size	Number of household members below 18 years	3.86	3.98	3.65	-1.68
Household income source	1= crop-livestock 0= livestock only	0.26	0.29	0.22	-2.01*
Monthly income	Household monthly income (USD)	65.18	68.88	58.74	-2.51**
Group membership	Membership in a social or economic group (1=Yes)	0.40	0.42	0.36	-1.69
Land size	Household land size holding (hectares)	1.34	1.33	1.35	0.14
Land tenure	Tenure of landholding (0=none 1=customary 2=purchased)	0.92	0.89	0.99	2.03
Livestock farming experience	Years of livestock farming	13.23	13.12	13.44	0.34
Cattle farming purpose	Purpose of cattle farming (1=income source 0=otherwise)	0.71	0.74	0.65	-2.68***
Cattle holding	Number of cattle (Tropical livestock units, TLU)	11.41	13.11	8.44	-4.14***

Improved cattle holding	Number of improved cattle (TLU)	0.10	0.12	0.05	-2.50**
Goats TLU	Number of goats (TLU)	0.22	0.20	0.25	2.12**
Sheep TLU	Number of sheep (TLU)	0.05	0.05	0.05	0.33
Meat production	Livestock reared for meat production purposes (1=yes)	0.04	0.03	0.06	2.16**
Milk production	Livestock reared for milk production purposes (1=yes)	0.70	0.79	0.54	-7.66***
Milk production quantity	Milk production per day (litres)	4.31	4.90	3.30	-3.44***
Milk sales	Milk sales per day (Litres)	2.90	3.42	1.99	-3.80***
Milk price	Price of milk per litre (USD)	0.31	0.36	0.23	-3.83***
Cattle feeding system	Cattle feeding system (0=Zero grazing; 1=Grazing)	0.84	0.84	0.84	-0.18
Grass production	Household produces grass (1=Yes)	0.37	0.35	0.39	1.31
Grass production area	Grass production area (hectares)	0.04	0.05	0.03	-1.19
Legume production	Household produces legumes (1=Yes)	0.17	0.23	0.08	-5.33***
Legume production area	Legume production area (hectares)	0.03	0.04	0.01	-2.47**
Crop residue usage	Household uses crop residues (1=yes)	0.53	0.52	0.53	0.26
Feed conservation	Household conserves feeds (1=yes)	0.12	0.12	0.12	-0.01
Tree and shrub usage	Household utilises trees and shrubs as cattle feed (1=yes)	0.63	-	-	-
Tree and shrub production	Household produces trees and shrubs	0.44	0.69	0	-25.37***

***p<0.01, **p<0.05, *p<0.1;

TLU=Tropical livestock units; USD=United States dollars

The majority of the households (92%) had a customary tenure form of landholding with a mean land size of 1.3 hectares. The observation of the landholding size is consistent with the rising trends of sub-divisions of land in SSA (Food and Agriculture Organization, 2021). The Food and Agriculture Organization (2021) report underlines that the trend will negatively affect farmers' production of livestock feeds. The results obtained showed that the farmers from the study had a mean livestock farming experience of 13 years in livestock farming. This experience would have implications for utilising trees and shrubs in cattle feeding. The results showed that most of the farmers had higher tropical livestock units of cattle (11.41 units), followed by goats (0.22 units) and sheep (0.05 units). However, cases of improved cattle were low (0.10 units). This finding falls within the range of 4.41 to 31 TLU of cattle reported by Mugumaarhahama et al. (2021) and Maass et al. (2012) in Eastern DRC. This low number of tropical livestock units in the study area can be due to pressure on natural resources, high population density, poverty, and the consequences of recent violent conflicts (Cox, 2012; Maass et al., 2012; Mugumaarhahama et al., 2021).

The majority of the farmers reared cattle for income generation (71%), mostly for milk production (70%), and less for meat production purposes (4%). The farmers produced an average of 4 litres of milk per day, allocating 3 litres for sale at USD 0.31 per litre. Apportioning 75% of the milk produced to sales is consistent with the farmers' economic mission of cattle production.

In terms of the feeding systems, the majority of the farmers (84%) practised extensive grazing, with about 37% of the households producing grass and about 17% producing legumes. Farmers allocated slightly more land to grass production (0.04 hectares) than legumes (0.03 hectares). An observation on the utilisation of crop residues is consistent with the predominating trend of the smallholders' dependence (in this case, 53%) on crop residues, including maize, beans, and sugarcane, in cattle feeding. These results are consistent with the observation of Paul et al. (2020), who reported that in Northern Tanzania, farmers kept large local cattle herd sizes, few improved breeds, daytime grazing, widespread crop residue feeding, and low productivity. Few farmers (12%) practised feed conservation innovations such as hay and silage. The observation was in line with Notenbaert et al. (2017), who attributed the low uptake of conservational technologies to a lack of technical know-how and access to or unaffordability of the required ingredients. More information on the sampled households is presented in Table 4.1. The high dependence on crop residues and low uptake of conservation strategies highlight the need to supplement locally produced feeds. Over 63% of the farmers utilised trees and shrubs for feeding their cattle, with about 44% of households cultivating them within their farms.

The mean differences following an independent t-test among the tree and shrub users and non-users are summarised in Table 4.1. There were significantly more farmers in Kalemie (55%) utilising trees and shrubs as cattle feeds than in Kabare (41%). The majority of the tree and shrub user households were male-headed and significantly younger than the non-users. Although not significantly different, the tree and shrub users were more educated and had a higher number of household adult equivalent members and dependants than the non-users. A significantly higher number of tree and shrub users (29%) reported mixed crop and livestock farming as their source of income than the non-users (22%) and consequently earned significantly higher monthly income (USD 68.88) than the non-users (USD 58.74). Although not significant, more tree and shrub users (42%) reported having membership in a social or economic group than the non-users (36%). There were no significant differences between the tree and shrub users and non-users regarding the size of land owned and livestock experience. However, there were significant differences ($p<0.01$) between the tree and shrub users and non-users regarding the cattle owned, where the users owned more cattle (13.11 units) than non-users (8.44 units). Similarly, users of trees and shrubs own significantly more improved cattle breeds (0.12 units) than non-users (0.05 units).

The tree and shrub users produced significantly more milk (4.90 litres per day) than the (3.30 litres per day) non-users. Correspondingly, the users sold more milk (3.42 litres per day) at a higher price of USD 0.36 per litre than (1.99 litres per day) the non-users who sold a litre at USD 0.23. Milk production and higher sales would incentivise the farmers to utilise trees and shrubs to enhance productivity and income. Results further showed that there were no significant differences between the household production of grasses and the grass production area.

However, more tree and shrub non-users used grass in cattle feeding than users. The tree and shrub users allocated significantly more land to grass production (0.05 hectares) than (0.03 hectares) to the non-users. More tree and shrub users (23%) produced legumes than (0.08%) non-users. There were no significant differences in the usage of crop residues and feed conservation. The tree and shrub users produced their fodder by cultivating the trees and shrubs on-farm the (69%), while the non-users barely produced any fodder on the farm. This attitude would be attributed to the transhumance nature of the cattle producers hereof, who lack land tenure for tree and shrub cultivation. Overall, there were significant differences between the tree and shrub users and non-users on numerous variables. Therefore, it qualified for the econometric estimation of the dataset to determine the factors influencing the utilisation of trees and shrubs as cattle feeds.

4.2.2 Farmer production of trees and shrubs

Table 4.2 presents the results attributes considered in the utilisation of trees and shrubs among the cattle smallholders. The farmers cultivated the trees and shrubs along the farm boundaries (12.5%), homestead compound (4.6%), within food crops (2.1%), within grazing land (0.1%), and off-farm (0.5%). There were more farmers in Kabare who preferred cultivating the trees and shrubs along the farm boundaries (24.2%), contrary to Kalemie (0.8%). In contrast to the farmers in Kalemie, the farmers in Kabare planted trees and shrubs within food crops (3.2%) and grazing land (0.2%). This result is consistent with that of Mugumaarhahama et al. (2021), who reported that land shortage is one of the major constraints farmers face in Kabare due to population growth pressure and proximity to Bukavu town city, thus pushing farmers to cultivate trees and shrubs alongside food crops.

Table 4.2: Farmer utilisation of trees and shrubs

Utilisation	Pooled sample (%)	Kabare (n=405) (%)	Kalemie (n=400) (%)
Parts utilised as livestock feeds			
Leaves only	41.4	27.9	55.0
Leaves and twigs	18.3	25.4	11.0
Leaves and pods	0.7	1.2	0.3
Fruits and pods	0.2	0.5	0
Season of tree and shrub usage			
Throughout the year	38.0	33.6	42.5
Dry season	23.9	21.2	26.5
Rainy season	1.6	2.2	1.0
Production of trees and shrubs			
Farm boundary	12.5	24.2	0.8
Homestead compound	4.6	9.1	1.0
Within food crops	2.1	3.2	0
Within grazing land	0.1	0.2	0
Off-farm	0.5	0.7	0.3
Other usages of trees and shrubs			
Soil fertilization	33.0	29.4	36.8
Soil erosion prevention	32.4	32.1	32.8
Fuel wood	38.0	23.0	53.3
Wind breaks	26.0	21.5	30.5
Construction materials	30.8	21.0	40.8
Live fence	18.5	17.0	20.0
Human medicinal purposes	18.4	6.9	30.0
Animal medicinal purposes	28.2	17.3	39.3
Environmental protection	20.7	22.2	19.3

The trees and shrubs served multipurpose functions to the cattle farmers, including fuelwood (38%), soil fertilisation (33%), provision of construction materials (30.8%), veterinary medicine (28.2%), live fences (18.5%), and human medicine purposes (18.4%). The results showed that the farmers in Kalemie utilised trees and shrubs more for some welfare purposes than in the Kabare location.

In all seasons, the farmers utilised trees and shrubs throughout the year, with farmers in Kalemie utilising more (42.5%) than their Kabare counterparts (33.6%). The trees and shrubs were also utilised more during the dry than the rainy seasons. This attitude is probably due to the abundance of other feed resources during the rainy season. Most farmers utilised leaves only in feeding their cattle, followed by the combinations of leaves and twigs, leaves and pods, and fruits and pods. This finding is consistent with Roothaert and Franzel (2001), who observed that preferred livestock feeding parts of trees and shrubs were twigs plus leaves.

4.2.3 Tree and shrub species utilised as cattle feeds in the study area

Farmers in Kalemie territory utilised more species (36) compared to their Kabare counterparts (26 species), as shown in Tables 4.3 and 4.4.

Table 4.3: Tree and shrub species utilised as cattle feeds in Kalemie territory

Species	Local name	Family name	Growth form	Preferred plant parts
Vernonia amygdalina Del.	Mubirizi	Asteraceae	Shrub	Leaves and twigs
Senna spectabilis (DC.) H.S.Irwin & Barneby	Kasha	Fabaceae	Tree	Leaves
Piliostigma thonningii (Schumarch.) Milne-Redh	Kifumbe	Fabaceae	Shrub	Fruits
Anisophyllea boehmii Engl.	Bukingwa	Anisophylleaceae	Tree	Leaves
Celtis mildbraedii Engl.	Mukore	Ulmaceae	Shrub	Leaves
Erythrina abyssinica Lam.	Kigowa	Fabaceae	Tree	Leaves
Leucaena leucocephala (Lam.) De Wit	Leucaena	Fabaceae	Shrub	Leaves and twigs
Mangifera indica L.	Hembe	Anacardiaceae	Tree	Leaves and twigs
Tephrosia vogelii Hook.f.	Bubaka	Fabaceae	Shrub	Leaves and twigs
Uapaca kirkiana Mull.Arg	Malobe	Phyllanthaceae	Tree	Leaves
Trema orientalis BLUME	Mwefu	Cannabaceae	Tree	Leaves
Tithonia diversifolia (Hemsl) A.Gray	Tithonia	Asteraceae	Shrub	Leaves and twigs
Annona senegalensis Pers	Kitobe	Annonaceae	Shrub	Leaves
Gmelina arborea Roxb.	Muticomite	Lamiaceae	Tree	Leaves
Albazia gummifera C.A.Sm.	Kashebeya	Fabaceae	Tree	Leaves
Moringa oleifera Lam.	Mutimaria	Moringaceae	Shrub	Leaves and twigs
Persea americana Mill.	Avoca	Lauraceae	Tree	Leaves
Calliandra calothyrsus Meisn.	Calliandra	Fabaceae	Shrub	Leaves and twigs
Eucalyptus globulus Labill.	Eucalyptus	Myrtaceae	Tree	Leaves

Psidium guajava L.	Pera	Myrtaceae	Tree	Leaves
Hymenocardia acida Tul.	Kapalaga	Phyllanthaceae	Shrub	Leaves
Ficus sycomorus L.	Mukuyu	Moraceae	Tree	Leaves
Sesbania sesban (L.) Merr.	Sesbania	Fabaceae	Shrub	Leaves and twigs
Dombeya rotundifolia Planch	Kakolokonde	Malvaceae	Tree	Leaves
Indigofera arrecta Hochst. ex A.Rich	Kabwebwe	Fabaceae	Shrub	Leaves
Harungana madagascariensis Poir	Musombosombo	Hypericaceae	Shrub	Leaves
Elaeis guinensis Jacq.	Ngazi	Arecaceae	Tree	Leaves
Chromolaena odorata (L) R.M.King & H.Rob.	Kitawala	Asteraceae	Shrub	Leaves
Ricinus communis L.	Magazya	Euphorbiaceae	Shrub	Leaves
Parinari curatellifolia Planch. ex Benth	Mukumu	Chrysobalanaceae	Shrub	Leaves
Ficus glumosa Delile	Kamimbi	Moraceae	Tree	Leaves
Vitex madiensis Oliv.	Mufutu	Lamiaceae	Tree	Leaves
Crotalaria spinosa Hochst.	Kansemene	Fabaceae	Shrub	Leaves
Protea madiensis Oliv.	Kagomba	Proteaceae	Shrub	Leaves
Lantana camara L.	Maviayakuku	Verbenaceae	Shrub	Leaves
Tetradenia riparia (Hochst.) Codd	Mulalavumba	Lamiaceae	Shrub	Leaves

Table 4.4: Tree and shrub species utilised as cattle feeds in Kabare territory

Species	Local name	Family name	Growth form	Preferred plant parts
Persea americana Mill.	Avoca	Lauraceae	Tree	Leaves
Calliandra calothyrsus Meisn.	Calliandra	Fabaceae	Shrub	Leaves
Tithonia diversifolia (Hemsl.) A.Gray	Tithonia	Asteraceae	Shrub	Leaves and twigs
Dracaena fragrans (L) Ker Gawl.	Kahari	Asparagaceae	Shrub	Leaves
Ficus glumosa Delile	Mutudu	Moraceae	Tree	Leaves
Vernonia amygdalina Del.	Mubirizi	Asteraceae	Shrub	Leaves and twigs
Leucaena leucocephala (Lam.) De Wit	Leucaena	Fabaceae	Shrub	Leaves
Cedrela serrulata Miq.	Ciharara	Meliaceae	Tree	Leaves
Morus nigra L.	Mangaka	Moraceae	Shrub	Leaves
Tephrosia vogelii Hook.f	Mulukuluku	Fabaceae	Shrub	Leaves
Mangifera indica L.	Hembe	Anacardiaceae	Tree	Leaves
Eucalyptus globulus Labill.	Eucalyptus	Myrtaceae	Tree	Leaves
Hibiscus rosa-sinensis L.	Hibiscus	Malvaceae	Shrub	Leaves
Albizia gummifera C.A.Sm.	Mushebeya	Fabaceae	Tree	Leaves
Cinchona officinalis L.	Quinquinat	Rubiaceae	Shrub	Leaves
Erythrina abyssinica Lam.	Cigoho	Fabaceae	Tree	Leaves
Grevillea robusta A. Cunn. ex R.Br.	Grevillea	Proteaceae	Tree	Leaves
Measopsis eminii Engl.	Mesopsis	Rhamnaceae	Tree	Leaves
Sesbania sesban (L.) Merr.	Munyegenyege	Fabaceae	Shrub	Leaves
Coffea arabica L.	Café	Rubiaceae	Shrub	Leaves

Psidium guajava L.	Pera	Myrtaceae	Tree	Leaves
Bridelia bridelifolia (Pax) Fedde	Mujimbu	Phyllanthaceae	Tree	Leaves
Ficus sycomorus L.	Mukuyu	Moraceae	Tree	Leaves
Rubus steudneri Schweinf.	Maflesi	Rosaceae	Shrub	Leaves
Fragaria ananassa (Weston) Duchesne ex Rozier	Fraise camerounaise	Rosaceae	Shrub	Leaves
Gliricidia sepium (Jacq.) Walp.	Acacia	Fabaceae	Shrub	Leaves

4.2.4 Farmers' most preferred tree and shrub species utilised for cattle feeding

Table 4.5 indicates the proportion of farmers who preferred tree and shrub species as their first choice. The species with at least 0.5% was therefore considered the most preferred.

Table 4.5: Tree and shrub species most preferred as cattle feeds

Species	Local name	Family names	Kalemie (%)	Kabare (%)
Vernonia amygdalina Del.	Mubirizi	Asteraceae	56.25	5.90
Persea americana Mill.	Avoca	Lauraceae	1.25	28.10
Calliandra calothyrsus Meisn.	Calliandra	Fabaceae	1.25	16.30
Tithonia diversifolia (Hemsl.) A. Gray	Tithonia	Asteraceae	2.25	13.10
Ficus glumosa Delile	Mutudu	Moraceae	0.50	8.10
Leucaena leucocephala (Lam.) De Wit	Leucaena	Fabaceae	3.75	5.70
Erythrina abyssinica Lam.	Cigoho	Fabaceae	4.75	0.50
Mangifera indica L.	Hembe	Anacardiaceae	3.50	1.00
Tephrosia vogelii Hook.f	Bubaka	Fabaceae	3.00	1.50
Albizia gummifera C.A.Sm.	Mushebeya	Fabaceae	1.75	0.70

Vernonia amygdalina (Del.) was the first most preferred species by the farmers in Kalemie (56.25%) than (5.90%) in Kabare. The tree is locally known as 'Mubirizi' and belongs to the Asteraceae family. It is one of the multipurpose trees that can rapidly grow, regenerate, and produce much biomass for forage (Kedir & Feki 2021). Evidence opines that supplementing *Vernonia amygdalina* in livestock feeding improves animal feed intake, nutrient digestibility, and body weight gain (Mengistu et al., 2020). The *Persea americana* (Mill.), locally known as the 'Avoca' tree, belongs to the family of Lauraceae and was the second most preferred tree, notably by the farmers of Kabare (28.10%) compared to those (1.25%) in Kalemie. The tree is a tropical fruit that thrives under harsh climatic conditions and is cultivated majorly for the production of fruits. Supplementing *P. americana* forage in livestock feeding has been shown to improve meat quality

(Leontopoulos et al., 2021). Calliandra (*Calliandra calothyrsus* Meisn.) was also utilised in Kabare (16.30%) and Kalemie (1.25%) by cattle farmers. The farmers cultivate Calliandra for fuelwood, shade, and ornamental purposes. According to Cook (2005), Calliandra increases the dry matter feed intake when fed to animals.

The *Tithonia diversifolia* is among the shrubs preferred and utilised by the farmers in Kabare (13.10%) than in Kalemie (3.25%) for cattle feeding. The farmers interviewed opined that *T. diversifolia* has several advantages, including high production, fast growth and regrowth after cutting, and tolerance to acidic soils. Research shows that *T. diversifolia* has high crude protein content and minerals as well as low fibre content, and its inclusion in livestock diets would boost nutrient intake and nutrient digestibility (Osuga et al., 2012; Mauricio et al. 2017; Sirait and Simanihuruk, 2021). *Ficus glumosa* (Delile) was mostly preferred by the farmers in Kabare (8.10%) than (0.50%) in Kalemie. Farmers in Kabare preferred *Leucaena leucocephala* compared to farmers in Kalemie. Farmers in Kalemie preferred *Erythrina abyssinica* and *Mangifera indica* (4.75% and 3.5%) compared to farmers in Kabare (0.50% and 1%), respectively. Similarly, farmers in Kalemie territory preferred *Tephrosia vogelii* and *Albizia gummifera* to farmers in Kabare.

4.2.5 Farmers' evaluation of trees and shrubs for cattle feeding

Farmers employed either animal-related criteria such as palatability, ability to improve animal satiation, growth, or productivity effects, or tree-related criteria, including compatibility with cultivated crops, drought resistance, improving soil fertility, and toxicity, as shown in Table 4.6, 4.7, and 4.8.

For the livestock-related criteria, the most mentioned attribute was the ability of the tree and shrub fodder to satisfy the hunger of the animal. The finding on animal satiation is consistent with the findings of Roothaert and Franzel (2001) in a study carried out in Kenya. The authors indicated that the farmers ranked animal satiation as the commonly used criteria to assess the quality of fodder. However, more farmers in Kalemie (63.5%) utilised the animal satiation criteria than (35.3%) in Kabare.

Table 4.6: Self-reported criteria farmers use to evaluate the tree and shrub forages as cattle feeds

Criteria	Pooled sample (n=805) (%)	Kabare (n=405) (%)	Kalemie (n=400) (%)
Livestock-related criteria (positive attributes)			
Animal satiation	49.3	35.3	63.5
Palatability	47.3	47.3	54.8
Improves animal health	34.4	27.7	41.3
Increased milk production (cows)	16.4	10.4	22.5
Improved growth	20.5	16.0	25.0
Improved meat production	10.9	1.2	20.8
Livestock-related criteria (Negative attributes/side effects)			
Cough	0.1	0.2	0
Diarrhoea	2.0	1.5	2.5
Loss of appetite	0.2	0	0.5
Bloat	0.7	1.5	0
Death	1.0	0.7	1.3
Tree-related criteria (positive attributes)			
Compatibility with cultivated crops	20.0	13.3	26.8
Drought resistance	50.8	40.7	61.0
Improves soil fertility	26.5	23.0	30.0
Tree-related criteria (negative attributes)			
Toxicity	5.8	4.7	7.0
Thorniness	1.1	0.2	2.0
Toxicity and thorniness	0.4	0	0.8

Farmers in Kalemie employed the attribute of palatability and ability of the fodder to improve animal health and production (in regards to milk, meat, and growth) compared to farmers in Kabare territory. The negative-related criteria, such as the ability of the trees to impose adverse health effects, were less observed than the positive livestock-related attributes. The tree and shrub fodder mostly caused diarrhoeas (2.0%), death (1.0%), bloat (0.7%), loss of appetite (0.2%), and cough (0.1%).

Cattle farmers from Kalemie territory reported using the tree criteria thereof compared to Kabare. Based on positive tree-related criteria, drought resistance was the most (50.8%) employed criteria, followed by the ability to improve soil fertility (26.5%) and compatibility with other crops (20.0%). Farmers reported negative tree-related criteria as toxicity (5.8%), thorniness (1.1%), and both toxicity and thorniness (0.4%). However, the farmers interviewed reported that the toxic substances contained in the tree and shrub fodder could provide beneficial anthelminthic effects to livestock.

Table 4.7 presents the rankings of the top four most preferred trees and shrubs by farmers (see Table 4.5) based on positive criteria related to livestock and trees (see Table 4.6). Farmers ranked the tree based on its ability to satisfy hunger, with the highest-ranking being *V. amygdalina* at 74.3%, while the lowest was *T. diversifolia* at 45.5%. The farmer’s assessment shows that *V. amygdalina* was highly ranked on improving palatability (84.3%), animal health (60%), and meat production (81.4%) compared to other highly preferred trees and shrub fodder. This choice of farmers could be explained by the fact that *V. amygdalina* has the advantage of being both fodder and medicinal plant to livestock. The result is consistent with that of Aderibigbe et al. (2022), who reported that *V. amygdalina* was active against adult bovine *Haemonchus placie* with an optimal lethality per fraction that kills 50% of worms of 6.51 mg/mL. Although smallholder cattle farmers in the study area claimed that *V. amygdalina* was effective as an anthelmintic, scientific information generated is not documented. Therefore, research should be conducted to determine the anthelmintic properties that should promote the use of this plant by cattle farmers in traditional animal health care. Similarly, *V. amygdalina* was also ranked as the most drought-resistant.

Table 4.7: Farmers' evaluation of the quality of the most preferred tree and shrub species

Criteria	Species			
	Vernonia amygdalina	*Persea americana*	*Calliandra calothyrsus*	*Tithonia diversifolia*
Livestock-related criteria				
Animal satiation	74.3	61.5	45.8	45.5
Palatability	84.3	66.7	66.7	72.3
Improves animal health	60.0	43.6	33.3	27.3
Increased milk production	12.9	15.4	20.8	9.1
Improved growth	20.0	23.1	20.8	45.5
Improved meat production	81.4	0	8.3	0
Tree-related criteria				
Compatibility with cultivated crops	17.1	15.4	25.0	9.1
Drought resistance	88.6	69.2	58.3	63.6
Improves soil fertility	34.3	10.3	62.5	27.3

Farmers ranked *C. calothyrsus* on its ability to improve milk productivity (20.8%), soil fertility, and the most compatible tree with cultivated crops. This result is consistent with that of Makau et al. (2020), who reported that farmers in Kenya increased daily milk production (from 6.39 to 7.39 litres) when they added 2kg DM of *C. calothyrsus* and Sesbania sesban to the daily ration of dairy cows. The last ranking was for *T. diversifolia*, which was reported to improve animal growth (45.5%). The result of this study corroborates those from the Caribbean region, which show that beef cattle achieved a higher growth rate of 512 g/day when supplemented with *T. diversifolia* compared to cattle on pastures (130 g/day) (Mauricio et al., 2017).

Table 4.8 presents the farmers' assessments on the ranking of the scores most preferred trees and shrubs. The scores were rated on a scale of 1 to 5, that is, 1 = bad, 2 = poor, 3=fair, 4=good, and 5=excellent. *C. calothyrsus* ranked highest in terms of growth; the second-rated tree was *V. amygdalina*, while *F. glumosa* had the lowest rating. *C. calothyrsus* had the highest ranking in regards to regrowth and drought resistance. Conversely, *F. glumosa* had the lowest rating on drought tolerance and the ability for regrowth. *V. amygdalina* was rated highly on compatibility when intercropped, while *C. calothyrsus* and *T. diversifolia* had zero ratings. *V. amygdalina* and *C. calothyrsus* had the highest rating on palatability, followed by *T. diversifolia* and *F. glumosa.*

Table 4.8: Farmers scoring the quality of the most preferred fodder tree and shrub species on selected criteria

Species	Growth	Regrowth	Drought resistance	Compatibility with crops	Palatability
Persea americana	2.56 (1.23)	2.95 (1.12)	3.33 (1.06)	1.85 (1.13)	3.51 (1.23)
Vernonia amygdalina	0.39 (1.11)	0.40 (1.15)	0.37 (1.11)	0.34 (1.00)	0.49 (1.39)
Calliandra calothyrsus	0.46 (1.14)	0.45 (1.12)	0.46 (1.44)	0	0.49 (1.21)
Tithonia diversifolia	0.11 (0.59)	0.09 (0.52)	0.11 (0.62)	0	0.10 (0.56)
Ficus glumosa	0.05 (0.39)	0.05 (0.40)	0.05 (0.42)	0.04 (0.34)	0.06 (0.47)

The figures in parentheses are the robust standard errors

4.2.6 Determinants of utilisation of trees and shrubs as cattle fodder

The study employed a probit model to estimate the factors that influence the decision of the farmers to utilise trees and shrubs as cattle feeds. The empirical model results and marginal effects are presented in Table 4.9. The log-likelihood ratio statistics, as presented by chi-square, were statistically significant ($p<0.001$). This significance ascertains that all the parameters modelled in the study were jointly significant in describing the dependent variable. Furthermore, the pseudo model square was 0.1546, which indicates that the independent variables jointly explain about 15% of the variation in the dependent variable.

Table 4.9: Probit model estimates on determinants of utilisation of trees and shrubs as cattle feeds

	Coefficient	SEM	AME	p-value
Gender	0.336**	0.140	0.106	0.017
Age	-0.002	0.005	-0.001	0.649
Marital status	-0.144	0.173	-0.045	0.404
Education level	-0.173***	0.066	-0.055	0.008
Household size adult equivalent	0.006	0.025	0.002	0.798
Dependant size	0.045	0.032	0.014	0.153
Household income source	0.077	0.137	0.024	0.576
Monthly income	0.001	0.001	0.000	0.494
Group membership	0.394***	0.122	0.124	0.001
Land size	-0.028	0.028	0.124	0.317
Livestock farming experience	0.001	0.005	-0.009	0.838
Cattle holding TLU	0.009*	0.005	0.003	0.087
Improved cattle holding	0.324**	0.158	0.102	0.041
Goats TLU	-0.299*	0.156	-0.094	0.056
Sheep TLU	-0.257	0.307	-0.081	0.402
Cattle farming purpose	0.088	0.110	0.028	0.427
Meat production	-0.161	0.260	0.168	0.537
Milk production	0.535***	0.142	-0.051	0.001
Milk production quantity	-0.064**	0.030	-0.020	0.031
Milk sales	0.076**	0.038	0.024	0.043
Milk price	0.225*	0.134	0.071	0.095
Grass production	-0.052	0.154	-0.016	0.737
Grass production area	0.216	0.302	0.068	0.474

Legume production	0.814***	0.173	0.256	0.001
Legume production area	0.156	0.414	0.049	0.706
Crop residue usage	0.674***	0.190	0.212	0.001
Feed conservation	0.021	0.169	0.007	0.901
Location	0.869***	0.235	0.274	0.001
Constant	-1.279***	0.347		0.001
The goodness of fit measures				
Prob > chi^2	0.001			
Pseudo R^2	0.1546			
LR chi^2 (28)	163.40			
Log-likelihood	-446.669			
Number of observations	805			

***p<0.01, **p<0.05, *p<0.1; SEM, standard error of means; AME=Average marginal effects

The results indicate gender differences in utilising the trees and shrubs technologies, with male farmers being more likely to use the technologies than females. In Eastern DRC, Mugumaarhahama et al. (2021) attributed this observation to less engagement of females in livestock farming. Further, Mutwedu et al. (2022) reported that this low commitment could be attributed to cultural beliefs and practices considering livestock farming is restricted to men as families look up to men for solutions for tackling whole family needs. This finding indicated the need to encourage women to adopt this sustainable agricultural practice through extension workers. Similar findings on the uptake of agroforestry were reported in Kenya and Malawi, and this was attributed to socio-economic inequalities and barriers which women face, including access to extension services, production, and market information (Maindi et al., 2020; Thangata et al., 2002). Nyberg et al. (2021) reported that female farmers in SSA are known to have less access to extension services, which may explain why male farmers in this study were likely to use more trees and shrubs fodder than female farmers. However, women farmers should therefore be specifically targeted based on their needs in the study area to increase the adoption of tree and shrub fodder. These findings are in line with the observations of Ayantunde et al. (2020), who reported that access to extension services increases farmers' likelihood of adopting agricultural technologies. The findings underline the importance of access to information in promoting the adoption of sustainable agricultural practices. It has been reported that the weak agricultural extension services in the DRC fail to deliver knowledge and technology to rural areas due to lack of coordination, lack of a unified and clear policy and mandate, lack of funding, ageing and low skills of agents, and lack of mobility and interactions of agents with key actors (Ragasa et al., 2016). Therefore, strengthening the agricultural extension services is critical for sustainable agricultural practices in the DRC. Effective extension systems are essential for disseminating proven agricultural technologies, off-farm testing and evaluation of the technologies, building the capacity of smallholder farmers, and linking farmers to appropriate development agencies and research institutions (Ayantunde et al., 2020).

The findings from this study showed that the level of formal education of cattle farmers was not a significant determinant in utilising tree and shrub innovations. This is because cattle farming in the study area is more traditional based on the culture of transmitting knowledge from generation to generation, which is important in deciding whether to use trees and shrubs, than on knowledge acquired through formal education. This result is consistent with Jera and Ajayi (2008), who opined that less-educated farmers gain experience through their involvement in agricultural work, and hence they could be well-informed on trees and shrubs fodder technologies. This finding could also be explained by the tendency of the more educated people to prefer off-farm employment compared to agriculture.

The findings on membership showed that belonging to a social or agricultural group increased the likelihood of utilising trees and shrubs technologies. Similar findings were reported by Pello et al. (2021) and Wambugu et al. (2011), who argued that group membership facilitates the flow, exchange, and sharing of information and experiences, incentivising the uptake of technologies. The households that owned higher tropical livestock units of indigenous cattle and their improved breeds were more likely to utilise tree and shrub fodder. This finding could be attributed to the increased demand for fodder to sustain the productivity of cattle (Kassie et al., 2018; Maina et al., 2020). However, goat ownership did not significantly affect the utilisation of trees and shrubs as did cattle. The unexpected negative effect could be explained by attributing less importance to goats than cattle. Farmers who perceived tree and shrub fodder could increase milk production were more likely to utilise the technology. This attitude implies that the farmers' perceived benefits of using trees and shrubs as fodder for livestock were high, consequently influencing the adoption decision. The farmers' high-value assignment would explain the finding on the positive attributes in evaluating the quality of the trees and shrubs. This finding is consistent with Meijer et al. (2015), who observed that farmers' prior knowledge of the benefits of technology creates a positive attitude towards the technology and increases the likelihood of adoption. Similarly, Barnes et al. (2021) observed that farmers adopted legume cultivation technology because it provided fodder to animals during periods of drought besides addressing other constraints, namely poor soil quality and limited access to chemical fertilisers. Therefore, trees and shrubs would be considered an attractive option for smallholder farmers in the coming decades.

Analysis of data obtained in the current study showed that an increase in one litre of milk per day is likely to decrease the probability of utilising trees and shrubs by 2%. This finding suggests that special attention should be paid to trees and shrubs fed to dairy cows. In Eastern DRC, the availability of concentrate feed remains limited and expensive when available (Maass et al., 2012, Mutwedu et al., 2022). High prices of feed drive up production costs, leading to high milk prices and making it inaccessible to poor rural households. The likelihood of farmers adopting trees and shrubs increased with milk sales and prices. The availability of a milk market in Eastern DRC should incentivise cattle farmers to increase milk production to meet the high market demand for dairy products through the use of trees and shrubs as a source of high-quality nutrients able to stimulate high milk production at a low cost thus lowering the milk price and increasing household access to the milk. Using trees and shrubs fodder in addition to natural pastures is a cheaper alternative for smallholder cattle farmers and consequently improves animal growth and lactation performance (Maasdorp et al., 1999; Osuga et al., 2011). Jera and Ajayi (2008) found that the adoption of tree-based fodder technology provided a market for smallholder dairy cows in Zimbabwe.

The results from this study highlight the effect of the agro-ecological zone in adopting this technology. Data analysis showed that farmers in Kalemie were more likely to use trees and shrubs than farmers in Kabare. In addition, the location influenced the preference for specific trees and shrubs by cattle farmers. For instance, 36 species were found in Kalemie compared to 26 from Kabare. The location further affected cattle feeding systems as it varied with the environment. For example, in Kalemie, cattle farmers kept high livestock units and depended on free-range pastures or transhumance that allowed them to get enough trees and shrubs fodder directly for their livestock.

Additionally, it was observed that in Kalemie, farmers relied on customary land tenure; that is, they have the right to own land temporarily. This system does not motivate them to develop sustainable agricultural practices such as planting trees and shrubs. Therefore, this regime does not promote good cohabitation between cattle keepers and crop farmers. Promoting the adoption of trees and shrubs in livestock production would have to be considered alongside revising the land tenure system in Kalemie.

Land scarcity and population pressure limit cattle farmers from accessing grazing pastures; therefore, using trees and shrubs is an alternative. This was evidenced by the findings from the Kabare area, which had a higher adoption level than Kalemie. Similar results were found in the South-Kivu province of the DRC by Bacigale et al. (2014) and Muoni et al. (2019). They reported that increasing land pressure and degradation have changed the context by reducing grazing land, subdividing farms, and increasing conflicts between cattle keepers and farmers, leading cattle farmers to rely on zero-grazing systems, tethering systems, collecting green forages from fields, and roadside systems for livestock feeding. Therefore, smallholder farmers require other sources for livestock feeds, and trees and shrubs are viable options. Besides higher adoption of trees and shrubs technologies in Kabare, farmers also used more exotic or introduced species (58%) than in Kalemie (12%). Mugumaarhahama et al. (2021) observed that in the South-Kivu province of the DRC, farmers used the little space they had for growing trees and shrubs species and food crops because of increased demographic growth, which has led to land scarcity. This finding shows the importance of taking into account the particularity of each agro-ecological zone in promoting the use of trees and shrubs to increase its dissemination and adoption among smallholder cattle farmers.

4.3 Determine the chemical composition and *in vitro* gas production of trees and shrubs utilised by smallholder cattle farmers in the Eastern DRC

4.3.1 Proximate composition of trees and shrubs species

The proximate composition of the eight selected species of trees and shrubs sampled in the study area is shown in Table 4.10. In Kalemie, the highest DM content was obtained in *F. glumosa* (959.83 g kg^{-1} fresh weight), and the lowest was found in *T. diversifolia* (925.17 g kg^{-1} fresh weight). In Kabare, the highest DM content was recorded in *M. indica* (951.00 g kg^{-1} fresh weight) and the lowest in *V. amygdalina* (912.00 g kg^{-1} fresh weight). The DM content of the fodder was significantly different ($p<0.05$) between the locations, where *V. amygdalina*, *E. abyssinica*, *S. sesban*, and *T. diversifolia* from Kalemie territory had higher DM content compared to those from Kabare territory.

The DM indicates the amount of feed nutrients other than water that is available to the animal, and the species with the highest content in this study were found to be *F. glumosa* found in Kalemie territory, while *F. glumosa*, *L. Leucocephala*, and *C. calothyrsus* found in Kabare territory.

The ash content of trees and shrubs forages varied from 41.38 g kg^{-1} DM in *S. sesban* to 139.66 g kg^{-1} DM in *T. diversifolia* for samples collected from Kalemie, while it was 46.47 g kg^{-1} DM in *L. leucocephala* to 162.65 g kg^{-1} DM in *T. diversifolia* for samples obtained from Kabare territory.

Table 4.10: Proximate composition of trees and shrubs leaves (g kg^{-1})

Species	Dry matter			Ash			Organic matter			Crude protein			Ether extract		
	Kalemie	Kabare	p value	Kalemie	Kabare	p value	Kalemie	Kabare	p value	Kalemie	Kabare	p value	Kalemie	Kabare	p value
V. amygdalina	930.33^{de}	912.00^{c}	0.000	118.92^{b}	121.14^{c}	0.196	806.38^{c}	801.51^{e}	0.724	341.91^{abc}	408.51^{a}	0.004	16.15^{cd}	17.31^{cd}	0.527
E. abyssinica	934.33^{cd}	929.50^{b}	0.008	133.83^{a}	90.33^{d}	0.002	809.29^{c}	845.53^{d}	0.003	305.65^{bc}	381.10^{a}	0.017	19.14^{cd}	29.00^{ab}	0.117
C. calothyrsus	946.00^{b}	946.00^{a}	1.000	81.91^{de}	62.84^{f}	0.000	868.51^{b}	886.55^{b}	0.001	360.77^{ab}	416.91^{a}	0.007	20.46^{cd}	10.65^{d}	0.004
L. leucocephala	941.33^{bc}	947.50^{a}	0.033	72.60^{e}	46.47^{g}	0.000	872.99^{b}	910.13^{a}	0.008	402.09^{a}	400.35^{a}	0.811	25.16^{c}	19.49^{c}	0.112
S. sesban	941.67^{bc}	929.17^{b}	0.000	41.38^{f}	65.43^{f}	0.000	902.70^{a}	868.37^{c}	0.000	285.06^{cd}	396.34^{a}	0.009	35.14^{b}	17.66^{cd}	0.002
M. indica	929.83^{de}	951.00^{a}	0.005	86.54^{d}	80.11^{e}	0.214	853.78^{b}	874.81^{bc}	0.011	217.28^{e}	270.36^{b}	0.045	24.15^{cd}	23.83^{bc}	0.875
T. diversifolia	925.17^{e}	915.00^{c}	0.008	139.66^{a}	162.65^{a}	0.000	795.95^{c}	766.17^{f}	0.000	333.16^{bc}	412.87^{a}	0.033	50.15^{a}	36.14^{a}	0.002
F. glumosa	959.83^{a}	947.67^{a}	0.108	101.87^{c}	148.71^{b}	0.000	862.05^{b}	811.14^{e}	0.000	229.90^{de}	301.15^{b}	0.018	15.16^{d}	33.99^{a}	0.000
SEM	2.22	3.11		6.50	8.30		7.58	9.57		13.00	11.42		2.36	1.80	
P-value	0.000	0.000		0.000	0.000		0.000	0.000		0.000	0.000		0.000	0.000	

SEM, standard error of the means;

^{abcdef} Means within columns with different superscripts differ at $p<0.05$);

p-value, independent t-test between Kalemie and Kabare territories

The highest ($p<0.05$) ash contents were recorded in *T. diversifolia* (162.65 g kg^{-1} DM) from Kabare and *T. diversifolia* (139.66 g kg^{-1} DM), and *E. abyssinica* (133.83 g kg^{-1} DM) from Kalemie territory. The finding of *T. diversifolia* in this study was higher than that of Wambui et al. (2006) (123.8 g kg^{-1} DM). However, the high ash content found in this study gives an overall representation of the mineral content in the forage that is essential for improving animal growth (Ravhuhali et al., 2022).

The organic matter (OM) contents of trees and shrubs fodders ranged from 795.95 g kg^{-1} DM in *T. diversifolia* to 902.70 g kg^{-1} DM in *S. sesban* from Kalemie, while it was 766.17 g kg^{-1} DM in *T. diversifolia* to 910.13 g kg^{-1} DM in *L. leucocephala* from Kabare. The lower OM content of *T. diversifolia* observed in the study area of this study is due to its higher ash content. Forages from Kabare had higher ($p<0.05$) OM contents than those from Kalemie territory. In this study, *S. sesban* from Kalemie and *L. leucocephala* from Kabare had the highest ($p<0.05$) OM contents. The OM range of *S. sesban* in this study (868.37-902.70 g kg^{-1} DM) was comparable to what was reported by Gebreyowhans and Zegeye (2018) (947.90 g kg^{-1} DM).

The CP content of the forages ranged from 217.28 g kg^{-1} DM in *M. indica* to 402.09 g kg^{-1} DM in *L. leucocephala* from Kalemie, while it ranged between 270.36 g kg^{-1} DM in *M. indica* to 416.91 g kg^{-1} DM in *C. calothyrsus* from samples obtained in Kabare. Samples from Kabare territory had the highest ($p<0.05$) CP content in all trees and shrubs forages than those from Kalemie, except for *L. leucocephala*. This result can be explained by agronomic practices and climate factors such as rainfall which indirectly influence the CP content of the plant through its growth. For instance, at the onset of the rainy season, young plants contain high content of crude protein and energy, but these nutrient components decrease as the plant matures due to increased cell walls (cellulose, hemicellulose, and lignin). In the present study, *L. leucocephala* (400.35 kg^{-1} DM) and *C. calothyrsus* (416.91 g kg^{-1} DM) obtained from Kabare had higher ($p<0.05$) content of CP than those reported by Katunga et al. (2014) within the same province of the South-Kivu. All the trees and shrubs forage in this study had a CP content above the minimum threshold required for optimal rumen function and feed intake (70 mg kg^{-1} DM of nitrogen). Therefore, they have the potential to be used as sources of protein to supplement poor-quality feeds such as crop residues and natural pastures, especially during the dry season when the quality and quantity of grasses are limited (Bayissa et al., 2022; Derero & Kitaw, 2018; Osuga et al., 2012).

In Kabare territory, land for fodder production is scarce. This has led to the reliance on planting/intercropping improved trees and shrubs such as *C. calothyrsus*, *L. leucocephala*, *S. sesban*, and *F. glumosa* to increase biomass production for animal feed by the smallholder cattle farmers. Conversely, Kalemie territory has abundant land, making farmers opt for a transhumance production system. In addition, the presence of organizations working in the agricultural sector in the Kabare territory for several decades has created a positive attitude on smallholder farmers to adopt improved trees and shrubs fodder compared to Kalemie (Katunga et al. 2014). These findings agree with Mutwedu et al. (2022), who observed similar trends between the provinces of Tanganyika and South-Kivu.

The ether extract (EE) of trees and shrubs varied from 15.16 g kg^{-1} DM in *F. glumosa* to 50.15 g kg^{-1} DM in *T. diversifolia* for samples obtained from Kalemie, while it did so between 10.65 g kg^{-1} DM in *C. calothyrsus* to 36.14 g kg^{-1} DM in *T. diversifolia* from samples obtained from Kabare territory. The species samples, such as *C. calothyrsus*, *S. sesban*, and *T. diversifolia* from Kalemie, had higher ($p<0.05$) EE content than those from Kabare.

4.3.2 Fibre composition of trees and shrubs species

The neutral detergent fibre (NDF) content of trees and shrubs ranged from 365.03 g kg^{-1} DM in *C. calothyrsus* to 690.31 g kg^{-1} DM in *E. abyssinica* for samples obtained from Kalemie territory. Whereas in Kabare, the lowest content was recorded in *C. calothyrsus* (265.14 g kg^{-1} DM) and the highest in *E. abyssinica* (579.85 g kg^{-1} DM) and *L. leucocephala* (577.88 g kg^{-1} DM). In this study, the highest ($p<0.05$) NDF content was recorded in *E. abyssinica* for samples obtained from Kalemie territory (Table 4.11). This could be due to the intensity of solar radiation, and the lesser amount of rainfall resulted in faster maturation during the dry season, which could result in higher cell wall contents than for samples obtained from Kabare, where the rainy season is longer. The range of NDF content (265.14 to 690.31 g kg^{-1} DM) in this study was within the critical level of 550 to 600 g kg^{-1} DM, which is the critical value above which voluntary feed intake and feed conversion efficiency have been reported to decrease due to longer rumination time (Bayissa et al., 2022). The range of NDF in this study was slightly lower than the 319-726 g kg^{-1} DM reported by Katunga et al. (2014).

The acid detergent fibre (ADF) content of trees and shrubs samples ranged from 248.05 g kg^{-1} DM in *S. sesban* to 518.82 g kg^{-1} DM in *E. abyssinica* for samples obtained from Kalemie and from 166.92 g kg^{-1} DM in *T. diversifolia* to 424.24 g kg^{-1} DM in *M. indica* for samples obtained from Kabare territory. The ADF results of this study were similar to the 317- 472 g kg-1 DM range reported by Bayissa et al. (2022). The lower ADF value in this study could be a sign of better digestibility than in other browse forages.

The acid detergent lignin (ADL) content of trees and shrubs species ranged from 74.59 g kg^{-1} DM in *S. sesban* to 427.49 g kg^{-1} DM in *M. indica* for samples obtained from Kalemie, while it was between 20.98 g kg^{-1} DM in *C. calothyrsus* to 462.40 g kg^{-1} DM in *M. indica* for samples obtained from Kabare. Lignin is a compound that attributes strength and resistance to plant tissue, thereby limiting the ability of the rumen micro-organisms to digest the cell wall polysaccharides. These become digestible once the lignin is removed (Osuga et al., 2012). Therefore, trees and shrubs with higher lignin contents could have a lower digestibility than those with low contents.

The hemicellulose content of trees and shrubs species ranged from 50.25 g kg^{-1} DM in *V. amygdalina* to 228.56g kg^{-1} DM in *S. sesban* for samples collected from Kalemie. While for samples collected from the Kabare area, the range varied from 67.74 g kg^{-1} DM in *C. calothyrsus* to 286.70 g kg^{-1} DM in *T. diversifolia*.

Table 4.11: Fibre composition of trees and shrubs leaves (g kg^{-1} DM)

Species	Neutral detergent fibre			Acid detergent fibre			Acid detergent lignin			Hemicellulose			Cellulose		
	Kalemie	Kabare	p value	Kalemie	Kabare	p value	Kalemie	Kabare	p value	Kalemie	Kabare	p value	Kalemie	Kabare	p value
V. amygdalina	495.32^{c}	490.57^{b}	0.459	455.07^{b}	414.57^{a}	0.016	139.35^{c}	46.57^{d} ^{e}	0.024	50.25^{d}	76.01^{d}	0.059	355.98^{ab}	444.01^{ab}	0.025
E. abyssinica	690.31^{a}	579.85^{a}	0.000	518.82^{a}	407.89^{ab}	0.000	381.20^{ab}	183.58^{b}	0.173	171.49^{ab}	171.96^{c}	0.973	309.11^{ab}	396.27^{abc}	0.514
C. calothyrsus	365.03^{f}	265.14^{d}	0.000	256.03^{e}	197.40^{d}	0.042	184.03^{bc}	20.98^{e}	0.000	109.01^{cd}	67.74^{d}	0.154	181.00^{bc}	244.16^{d}	0.002
L. leucocephala	486.62^{cd}	577.88^{a}	0.004	270.14^{de}	268.74^{c}	0.856	105.89^{c}	107.15^{cd}	0.900	216.47^{a}	309.14^{a}	0.003	380.72^{ab}	470.73^{a}	0.009
S. sesban	476.60^{cde}	507.44^{b}	0.000	248.05^{e}	269.05^{c}	0.003	74.59^{c}	74.59^{d} ^{e}	1.000	228.56^{a}	238.38^{b}	0.144	402.02^{a}	432.85^{abc}	0.118
M. indica	448.82^{de}	508.00^{b}	0.010	295.74^{cd}	424.24^{a}	0.000	427.49^{a}	462.40^{a}	0.202	153.07^{bc}	83.76^{d}	0.006	21.33^{c}	45.60^{e}	0.103
T. diversifolia	436.56^{e}	453.61^{c}	0.391	330.21^{c}	166.92^{d}	0.000	219.78^{abc}	82.70^{c} ^{de}	0.001	106.36^{cd}	286.70^{a}	0.000	216.79^{abc}	370.91^{bc}	0.004
F. glumosa	586.33^{b}	510.11^{b}	0.004	512.68^{a}	370.72^{b}	0.000	383.69^{ab}	153.72^{bc}	0.000	73.65^{d}	139.39^{c}	0.045	202.64^{abc}	356.39^{c}	0.005
SEM	19.57	19.43		22.50	20.13		29.89	27.72		13.19	19.04		28.14	27.69	
P-value	0.000	0.000		0.000	0.000		0.000	0.000		0.000	0.000		0.000	0.000	

SEM, standard error of the means;

^{abcdef} Means within columns with different superscripts differ at $p<0.05$);

p-value, independent t-test between Kalemie and Kabare territories

The average cellulose content of trees and shrubs species ranged from 21.33 g kg^{-1} DM in *M. indica* to 402.02 g kg^{-1} DM in *S. sesban* for samples collected from Kalemie, while it was 45.60 g kg^{-1} DM in *M. indica* to 470.73 g kg^{-1} DM in *L. leucocephala*.

4.3.3 Tannin compounds of the trees and shrubs species

The results of the tannin composition of trees and shrubs leaves of samples collected from Kalemie and Kabare territories are presented in Table 4.12. The condensed tannins (CT) content of trees and shrubs fodders ranged from 25.47 g kg^{-1} DM in *V. amygdalina* and *S. sesban* to 121.80 g kg^{-1} DM in *C. calothyrsus* for samples collected from Kalemie, while it was 34.77 g kg^{-1} DM in *V. amygdalina* to 68.31 g kg^{-1} in *M. indica* for samples collected from Kabare. *C. calothyrsus*, *L. leucocephala*, and *M. indica* from Kalemie were higher in CT contents ($p<0.05$) than those from Kabare, except for *S. sesban*. Trees and shrubs have been reported to contain high phenolic compounds and tannins (Osuga et al., 2006). These compounds tend to limit their use, particularly as protein supplements, because tannins decrease feed intake, impair feed digestibility, and are toxic to rumen microbes.

The CT content of trees and shrubs has been described as ranging from low (<30 g kg^{-1} DM), medium (40-60 g kg^{-1} DM) to high (>60 g kg^{-1} DM) (Rakhmani et al., 2005). Low to moderate concentration of CT has been reported to exert beneficial effects on protein digestion by passing rumen degradation, thereby increasing amino acid absorption in the small intestine and improving animal performance (Osuga et al., 2011). Results from this study indicate that species such as *V. amygdalina, S. sesban, F. glumosa, T. diversifolia*, and *E. abyssinica* found in Kalemie, and all trees and shrubs forage found in Kabare can exert these benefits as they contain low and moderate levels of CT. In contrast, high concentrations of CT in the diet reduce voluntary feed intake, digestive efficiency, and animal productivity. This study revealed that *C. calothyrsus, M. indica*, and *L. leucocephala* obtained from Kalemie territory contained higher ($p<0.05$) levels of CT than those from Kabare. The CT content of *C. calothyrsus* in the present study was in the range of 82.06 to 131 g kg^{-1} DM reported by Rakhmani et al. (2005) and is lower than that determined by Rira et al. (2021) of 361 g kg^{-1} DM.

Table 4.12: Tannin compounds of trees and shrubs leaves (g kg^{-1} DM)

Species	Condensed tannins			Total extractable Tannins			Total extractable phenolics		
	Kalemie	Kabare	p value	Kalemie	Kabare	p value	Kalemie	Kabare	p value
V. amygdalina	25.47^{f}	34.77^{d}	0.067	5.28^{c}	9.13^{abc}	0.304	32.65^{ab}	32.03	0.889
E. abyssinica	61.80^{cd}	62.67^{ab}	0.933	6.46^{c}	2.43^{c}	0.219	37.06^{ab}	34.77	0.815
C. calothyrsus	121.80^{a}	66.16^{ab}	0.015	22.34^{ab}	18.25^{a}	0.468	37.48^{ab}	34.05	0.284
L. leucocephala	80.58^{bc}	41.69^{cd}	0.007	8.80^{c}	15.54^{ab}	0.106	30.80^{ab}	34.38	0.719
S. sesban	25.47^{f}	53.02^{bc}	0.005	9.12^{c}	8.14^{bc}	0.607	31.28^{ab}	33.48	0.554
M. indica	86.28^{b}	68.31^{a}	0.006	8.44^{c}	10.43^{abc}	0.371	42.50^{a}	24.08	0.033
T. diversifolia	48.08^{de}	37.85^{d}	0.079	13.76^{bc}	7.35^{bc}	0.074	19.95^{b}	21.81	0.368
F. glumosa	33.84^{ef}	37.09^{d}	0.090	29.32^{a}	2.58^{c}	0.004	20.28^{b}	20.60	0.914
SEM	8.30	3.46		2.12	1.42		2.12	1.76	
P-value	0.000	0.000		0.000	0.002		0.013	0.090	

SEM, standard error of the means;

^{abcdef} Means within columns with different superscripts differ at $p<0.05$);

p-value, independent t-test between Kalemie and Kabare territories

Calliandra is widely used as a supplemental source of protein by smallholder farmers in animal production in many Sub-Saharan African countries (Franzel et al., 2014). The digestibility of Calliandra may be affected by the levels of CT due to its ability to bind proteins, which reduces the digestibility of the feed. Therefore, Calliandra can be used in animal nutrition in a mixture with other feeds, especially those rich in nitrogen, to dilute the anti-nutritive activity of tannins. It can also be reduced by treatments such as drying the forages.

Additionally, the CT content of Calliandra can vary within the species, and its composition depends on the region and growing season (Premaratne & Perera, 1999). However, in Eastern DRC, the type of Calliandra accessions introduced and used by smallholder farmers and its tannin levels are less documented. It is recommendable that research be carried out to determine the tannins levels.

The total extractable tannins (TET) ranged from 5.28 g kg^{-1} DM in *V. amygdalina* to 29.32 g kg^{-1} DM in *F. glumosa* samples collected from Kalemie and 2.43 g kg^{-1} DM in *E. abyssinica* to 18.25 g kg^{-1} DM in *C. calothyrsus* in samples collected from Kabare territory. The total extractable phenolics (TEPH) varied from 19.95 g kg^{-1} DM in *T. diversifolia* to 42.50 g kg^{-1} DM in *M. indica* in samples obtained from Kalemie, while it was between 20.60 g kg^{-1} DM in *F. glumosa* to 34.77 g kg^{-1} DM in *E. abyssinica* in samples collected from Kabare. The results of TET were within the range of 0.6 to 38.50 g kg^{-1} DM reported by Osuga et al. (2006), and the range of 11.8 to 52.3 g kg^{-1} DM of TEPH reported by the same author was comparable to the result of this study.

4.3.4 *In vitro* gas production profile of trees and shrubs species

The results of *in vitro* gas production of trees and shrubs species are presented in Table 4.13. At 24 hours of incubation, gas production in the rumen liquor ranged from 1.06 mL/200 mg DM in *L. leucocephala* to 17.42 mL/200 mg DM in *M. indica* in samples collected from Kalemie territory. In contrast, it ranged between 0.70 mL/200 mg DM in *C. calothyrsus* and 17.01 mL/200 mg DM in *V. amygdalina* samples collected from Kabare territory. This study revealed that *M. indica* samples obtained from Kalemie and

V. amygdalina samples from Kabare produced a higher ($p<0.05$) amount of gas at 24 hours than other species.

The gas production of *M. indica* (17.01 mL/200 mg DM) from this study was very low compared to the 51.8 mL/200 mg DM of that of Hernández et al. (2015). The high content of NDF could explain this difference in gas production (see Table 4.11) and condensed tannins (see Table 4.12) found in *M. indica* compared to 358 g kg^{-1} DM and 43.5 g kg^{-1} DM, respectively, for NDF and CT content reported by Hernández et al. (2015), which could reduce forage digestibility, thereby reducing gas production. Similarly, Ebrahim and Negussie (2020) reported that high concentrations of CT above 5% form indigestible complexes with carbohydrates which consequently delay the ruminal fermentation process, reducing the production of volatile fatty acids.

Gas production from the immediate soluble fraction (a) of trees and shrubs ranged from -0.45 mL/200 mg DM in *S. sesban* to 1.88 mL/200 mg DM in *F. glumosa* from samples collected from Kalemie. While samples were obtained from Kabare, gas production from immediate soluble fraction was the highest ($p<0.05$) in *M. indica*.

Gas production from an insoluble fraction (b) of trees and shrubs fodders was the highest ($p<0.05$) in *L. leucocephala* (21.0 mL/200 mg DM) from samples collected from Kalemie and *T. diversifolia* (30.9 mL/200 mg DM) from samples collected from Kabare. The potential gas production (a+b) was the highest ($p<0.05$) in *L. leucocephala* (20.80 mL/200 mg DM) from samples collected from Kalemie and *T. diversifolia* (30.95 mL/200 mg DM) from samples collected from Kabare. The rate of gas production (c) in this study ranged from 0.01 mL h^{-1} in *L. leucocephala* to 2.74 mL h^{-1} in *M. indica* for samples collected from Kalemie, whereas it ranged between 0.01 mL h^{-1} in *C. calothyrsus* to 0.17 mL h^{-1} in *S. sesban* for samples collected from Kabare.

Table 4.13: Gas production of trees and shrubs leaves(mL/200 mg DM)

Species	24			a			b			c			a+b		
	Kalemie	Kabare	p value	Kalemie	Kabare	p value	Kalemie	Kabare	p value	Kalemie	Kabare	p value	Kalemie	Kabare	p value
V. amygdalina	9.34[b]	17.01[a]	0.014	0.24[ab]	0.98[ab]	0.377	5.13[b]	5.60[b]	0.657	0.12	0.13[ab]	0.809	5.37[b]	6.58[b]	0.071
E. abyssinica	2.13[c]	2.14[d]	0.181	0.33[ab]	0.37[ab]	0.942	4.00[b]	5.95[b]	0.041	0.03	0.22[ab]	0.699	4.33[bc]	6.32[b]	0.018
C. calothyrsus	11.57[b]	0.70[d]	0.008	0.79[ab]	0.05[b]	0.046	3.18[bc]	16.38[ab]	0.339	0.12	0.01[b]	0.001	3.98[bcd]	4.43[bc]	0.419
L. leucocephala	1.06[c]	1.40[d]	0.734	-0.23[b]	-0.19[b]	0.889	21.03[a]	6.37[b]	0.000	0.01	0.02[ab]	0.240	20.80[a]	6.19[b]	0.000
S. sesban	1.41[c]	3.51[cd]	0.184	-0.45[b]	0.01[b]	0.270	4.96[b]	3.13[b]	0.118	0.06	0.17[a]	0.265	4.51[bc]	3.15[c]	0.261
M. indica	17.42[a]	5.94[c]	0.001	1.32[ab]	1.93[a]	0.380	2.90[bcd]	2.00[b]	0.408	2.74	0.10[ab]	0.368	4.22[bcd]	3.93[bc]	0.468
T. diversifolia	9.00[b]	1.81[d]	0.001	1.83[a]	0.03[b]	0.019	0.64[d]	30.92[a]	0.000	2.43	0.02[b]	0.356	2.47[d]	30.95[a]	0.000
F. glumosa	8.31[b]	10.83[b]	0.081	1.88[a]	0.76[ab]	0.184	1.01[cd]	3.06[b]	0.026	0.05	0.12[ab]	0.307	2.89[cd]	3.81[bc]	0.030
SEM	1.16	1.14		0.21	0.17		1.28	2.31		0.43	0.02		1.18	1.82	
P-value	0.000	0.000		0.002	0.009		0.000	0.003		0.528	0.010		0.000	0.000	

SEM, standard error of the means;

[abcd] Means within columns with different superscripts differ at $p<0.05$);

p-value, independent t-test between Kalemie and Kabare territories

Gas production results from the fermentation of the feed into short-chain fatty acids (SCFA) and carbon dioxide released from the buffering of SCFA produced by a bicarbonate buffer (Osuga et al., 2007). Therefore, the differences in gas production among trees and shrubs obtained in this study could be due to the amount of fermented substrate and the SCFA produced during substrate fermentation. Differences in rates and potential gas production of trees and shrubs from this study could be related to the differences in their chemical composition, particularly CP, fibre, and condensed tannins.

Furthermore, metabolisable energy (ME), *in vitro* organic matter digestibility (OMD), and short-chain fatty acids (SCFA) were estimated based on the gas produced at 24 hours of incubation (see Table 4.14). Samples of *C. calothyrsus* and *M. indica* obtained from Kalemie had higher ($p<0.05$) ME than other species. While the highest ($p<0.05$) ME for samples obtained from Kabare was reported in *V. amygdalina* (4.04 MJ kg^{-1} DM). These higher ME of *C. calothyrsus*, *M. indica*, and *V. amygdalina* could be explained by the high amount of SCFA produced as well as their high *in vitro* organic gas digestibility. These results are consistent with those of Kedir and Feki (2021) and Mengistu et al. (2020), who reported that the increased ME and *in vitro* OMD of forages were related to high CP content, moderate fibre, and condensed tannins.

Table 4.14: Metabolisable energy (MJ kg^{1}), *in vitro* organic matter digestibility (%), and short-chain fatty acids (mmol kg^{1}) of tree and shrub leaves

Species	Metabolisable energy			Organic matter digestibility			Short-chain fatty acids		
	Kalemie	Kabare	p value	Kalemie	Kabare	p value	Kalemie	Kabare	p value
V. amygdalina	2.58^{bc}	4.04^{a}	0.011	34.16^{bc}	44.55^{a}	0.009	0.20^{b}	0.38^{a}	0.014
E. abyssinica	2.03^{c}	2.46^{c}	0.016	31.34^{c}	34.48^{bc}	0.022	0.04^{c}	0.04^{d}	1.000
C. calothyrsus	3.63^{a}	2.47^{c}	0.016	41.90^{a}	34.65^{bc}	0.018	0.25^{b}	0.02^{d}	0.008
L. leucocephala	2.44^{bc}	2.47^{c}	0.827	34.36^{bc}	34.43^{bc}	0.955	0.02^{c}	0.03^{d}	0.709
S. sesban	1.82^{c}	2.53^{bc}	0.036	34.74^{bc}	34.74^{bc}	1.000	0.03^{c}	0.07^{cd}	0.189
M. indica	3.61^{a}	2.35^{c}	0.009	40.67^{a}	32.82^{c}	0.013	0.38^{a}	0.13^{c}	0.001
T. diversifolia	3.12^{ab}	2.60^{bc}	0.009	38.82^{ab}	36.03^{bc}	0.032	0.20^{b}	0.04^{d}	0.001
F. glumosa	2.44^{bc}	3.19^{b}	0.015	33.25^{bc}	38.98^{b}	0.011	0.18^{b}	0.24^{b}	0.082
SEM	0.14	0.12		0.82	0.79		0.03	0.03	
P-value	0.000	0.000		0.000	0.000		0.000	0.000	

SEM, standard error of the means;

^{abcd} Means within columns with different superscripts differ at $p<0.05$);

p-value, independent t-test between Kalemie and Kabare territories

4.3.5. Association among nutritive factors of the trees and shrubs species

Table 4.15 provides a relationship of all nutritional components of eight trees and shrubs. Dry matter content of the species was negatively and significantly ($p<0.05$) correlated with crude protein, metabolisable energy, organic matter digestibility, and short-chain fatty acids. In contrast, it was positively correlated with neutral detergent fibre, acid detergent fibre, and acid detergent lignin. The growth process of plants can explain this variation in nutritive values. For instance, at the early stage of growth, plants are vegetative, have high CP and energy, and are more digestible than mature plants with a high cell wall content (cellulose, hemicellulose, and lignin) increased. The results also showed that CP was negatively and significantly ($p<0.05$) correlated with NDF (26%), ADF (46%), and ADL (75%) while positively correlated with ME and OMD. NDF content also was negatively correlated with ME, *in vitro* OMD, and SCFA. Findings from this study showed a medium overall nutritional value of eight trees and shrubs and were consistent with Derero and Kitaw (2018) and Osuga et al. (2005).

Table 4.15: Pearson's correlation coefficient among nutritional components across all species, *N=48*

	DM	Ash	OM	CP	EE	NDF	ADF	ADL	Hemicellulose	Cellulose	ME	OMD	SCFA
DM	1												
Ash	-0.45[a]	1											
OM	0.65[a]	-0.95[a]	1										
CP	-0.40[a]	-0.04	-0.08	1									
EE	-0.27	0.36[b]	-0.36[b]	-0.09	1								
NDF	0.04	0.17	-0.13	-0.26	-0.01	1							
ADF	0.15	0.31[b]	-0.25	-0.46[a]	-0.21	0.68[a]	1						
ADL	0.30[b]	0.14	-0.02	-0.75[a]	-0.03	0.38[a]	0.55[a]	1					
Hemicellulose	-0.15	-0.21	0.17	0.31[b]	0.27	0.28	-0.51[a]	-0.28	1				
Cellulose	-0.29[b]	-0.03	-0.06	0.61[a]	0.03	0.27	-0.12	-0.79[a]	0.48[a]	1			
ME	-0.33[b]	0.29[b]	-0.33[b]	0.08	0.04	-0.33[b]	0.05	-0.03	-0.32[b]	-0.19	1		
OMD	-0.37[b]	0.21	-0.27[b]	0.13	0.17	-0.40[a]	-0.20	-0.18	-0.20	-0.08	0.95[a]	1	
SCFA	-0.20	0.31[b]	-0.32[b]	-0.36[b]	-0.02	-0.15	0.26	0.27	-0.52[a]	-0.38[a]	0.86[a]	0.79[a]	1

[a] Correlation is significant at the 0.01 level; [b] Correlation is significant at the 0.05 level;

DM, dry matter; OM, organic matter; CP, crude protein; EE, ether extract; NDF, neutral detergent fibre; ADF, acid detergent fibre; ADL, acid detergent; ME, metabolisable energy; OMD, organic matter digestibility; SCFA, Short chain fatty acids

4.4 Investigate the effects of supplementing Guatemala grass with dried Leucaena or cassava leaves as nitrogen sources on feed intake, milk production, and composition of lactating Holstein Friesian x Ankole crossbred cows

4.4.1 Health of the cows

All cows remained healthy throughout the experiment.

4.4.2 Chemical composition of the feedstuff used in the experiment

The results for the chemical composition of the feedstuff tested in this experiment are shown in Table 4.16.

Table 4.16: Chemical composition of the feedstuff (g kg^{-1} DM) used in the experiment

Parameters	Guatemala	Brewers' spent grain	Leucaena	Cassava
Dry matter	888.31	902.38	905.12	893.44
Ash	90.60	32.86	116.39	108.85
Organic matter	797.71	785.99	872.26	784.59
Crude protein	109.30	85.05	300.88	216.76
Ether extract	73.28	12.40	53.21	60.66
Crude fibre	127.50	45.70	129.46	95.23

The organic matter content of the diets ranged from 784.59 g kg^{-1} DM in cassava to 872.26 g kg^{-1} DM in Leucaena. The CP content of Guatemala grass (109.30 g kg^{-1} DM) in this study was higher than 69.00 g kg^{-1} DM reported by Nivyobizi et al. (2010) and 89.00 g kg^{-1} DM reported by Mtengeti et al. (2006). This content was, however, comparable to the 117.90 g kg^{-1} DM reported by Maleko et al. (2022). The plant and environmental factors can explain the fluctuation in the nutritional composition of Guatemala grass (Perera & Perera,1994). The nutritional quality of plants tends to degrade with maturity, which is also associated with a decrease in the proportion of leaves relative to stems, reducing forage intake. Perera and Perera (1994) reported that the CP and NDF content of Guatemala grass decreased and increased, respectively, when plants tended to mature. That is, grass harvested at eight weeks of age had a high CP content and low NDF compared to grass harvested at 10 and 12 weeks of age which had low CP and high NDF. The CP content of dried Leucaena was at 300.88 g kg^{-1} DM, which was higher than that of cassava. This trend was similar for ash, organic matter, and crude fibre. Conversely, cassava had a higher ether extract content (60.66 g kg^{-1} DM) than (53.21 g kg^{-1} DM) Leucaena. The dried cassava leaves ether extract was comparable to the 59-62 g kg-1 DM range reported by Wanapat (2003). Leucaena and Guatemala grass had respective crude fibre (CF) levels of 129.46 g kg^{-1} DM and 127.50 g kg^{-1} DM, which were higher than cassava at 95.25 g kg^{-1} of the dry matter.

4.4.3 Feed intake

Cows fed on the control diet consumed an average of 7.87 kg DM of Guatemala grass compared to 6.84 kg and 7.37 kg DM consumed by cows supplemented with Leucaena and cassava, respectively (Table 4.17). Leucaena and cassava supplements significantly ($p<0.001$) decreased the DM intake of Guatemala grass. This can be explained by the bulkiness of the forages, leading to the substitution effect. Cows consumed all the 1.25 kg DM of the brewers' spent grain offering. Cows consumed similar amounts of dried Leucaena and cassava. The mean daily CP supplement intake was 0.98 kg for Leucaena compared to 0.78 kg for cassava. The mean total dry matter intake (DMI) per cow for the control diet was 9.12 kg and which significantly increased ($p<0.001$) with supplementation of Leucaena and cassava by 20% and 26%, respectively. These positive effects of Leucaena and cassava supplementation on total DMI could be attributed to its palatability and high CP content, which improved the feed intake of the animal (Wanapat et al, 2018; Stifkens et al., 2022).

Cassava results match that of Wanapat et al. (2018), who reported that the total DMI in lactating crossbred cows was higher due to the good palatability of cassava silage, which would be comparable to the dried cassava leaves used in this study. The results for dried Leucaena leaves supplementation also agree with those of Stifkens et al. (2022), who reported the increment in dry matter intake of beef steers on the Rhodes grass basal diet coupled with supplementation of an increased proportion of Leucaena hay.

Table 4.17: Mean daily intake (kg) for Holstein Friesian x Ankole crossbred cows fed Guatemala grass supplemented with dried Leucaena and cassava leaves

Parameters	Treatments			SEM	P-value
	Control	Leucaena	Cassava		
DM intake (kg day^{-1})					
Guatemala grass	7.87^{a}	6.84^{c}	7.37^{b}	0.18	0.000
Brewers' spent grain	1.25	1.25	1.25	0.00	-
Supplements	0.00^{b}	2.83^{a}	2.83^{a}	0.20	0.000
Total	9.12^{c}	10.92^{b}	11.45^{a}	0.24	0.000
OM intake (kg day^{-1})					
Guatemala grass	7.07^{a}	6.14^{c}	6.62^{b}	0.16	0.000
Brewers' spent grain	1.09	1.09	1.09	0.00	-
Supplements	0.00^{c}	2.73^{a}	2.49^{b}	0.18	0.000
Total	8.16^{b}	9.97^{a}	10.20^{a}	0.22	0.000
CP intake (kg day^{-1})					
Guatemala grass	1.07^{a}	0.93^{c}	1.01^{b}	0.02	0.000
Brewers' spent grain	0.12	0.12	0.12	0.00	-
Supplements	0.00^{c}	0.98^{a}	0.78^{b}	0.06	0.000
Total	1.19^{c}	2.03^{a}	1.91^{b}	0.06	0.000

SEM, standard error of means; means within columns with different superscripts differ at $p<0.05$);

4.4.4 Milk production and milk composition

Feeding the cows on the control diet resulted in a mean daily milk production per cow of 5.96 kg. Supplementing the cows with dried cassava and Leucaena leaves increased this amount by 3% and 15% of daily milk production. Nevertheless, there were no significant differences in milk production between cows fed the control diet and those supplemented with dried cassava leaves, despite their high CP content and total DMI level (Table 4.18).

Table 4.18: Mean daily milk production (kg) and milk composition (g) of Holstein Friesian x Ankole crossbred cows fed Guatemala grass supplemented with dried Leucaena and cassava leaves

Parameters	Treatments			SEM	P-value
	Control	Leucaena	Cassava		
Milk production (kg day^{-1})	5.96^{b}	6.83^{a}	6.13^{b}	0.44	0.000
Milk composition (g)					
Fat	29.89^{b}	38.44^{a}	28.17^{b}	1.40	0.002
Protein	38.43^{a}	33.28^{b}	38.53^{a}	0.68	0.000
Lactose	56.11^{a}	48.26^{b}	56.79^{a}	1.00	0.000
Solids-not-fat	101.27^{a}	89.23^{b}	102.41^{a}	1.61	0.000

SEM, standard error of means; means within columns with different superscripts differ at $p<0.05$);

The results on milk production from this study were higher than those reported by Kumwimba et al. (2016) in Kalemie (1.8-2.4 kg day^{-1}) and Mugumaarhahama et al. (2021) in Kabare (1.7-4.6 kg day^{-1}). This production was, however, within the range of 4.6-15.7 kg day^{-1} for Holstein Friesian x Ankole reported by Manzi et al. (2022) in three different agro-ecological zones of Rwanda. The reason for increased milk production (up to 15.7 kg day^{-1}) in Rwanda was that farmers invested in commercial concentrates for their dairy cattle (Manzi et al., 2022). Nevertheless, milk production from this study remains below the potential milk production of 15-20 kg day^{-1} reported for Holstein Friesian x Zebu crossbred cows in Eastern Africa regions (Maleko, 2020).

Contrary, Wanapat et al. (2018) reported an increase in milk production when crossbred cows were supplemented with different levels of cassava top silage. This difference in milk production can be attributed to animal pedigree, climate, diseases, and diet. With regard to the diet, the anti-nutritional content of cassava leaves (condensed tannins and hydrocyanic acid), their stage of maturity, means of supplementation, and the amount added would affect this milk production. For instance, the means of supplementation in this study were different from those of Wanapat et al. (2018). This study used dried cassava leaves, while Wanapat et al. (2018) supplemented cows with top silage. It has been reported that silage plays a critical role in reducing anti-nutritional contents and improving the feed quality of tree and shrub legumes (Balehegn et al., 2021), which could increase milk production in this study. The concentrations of 50 to 90 g kg^{-1} DM of condensed tannins have been reported to form complexes with protein, reducing nutrient digestibility and feed intake, thus affecting livestock performances (Aganga & Tshwenyane, 2003; Ebrahim & Negussie, 2020).

The current study recorded the highest milk production when Guatemala grass was supplemented with dried Leucaena leaves. This result confirms the high forage value of this species (Maasdorp et al., 1999; Muinga et al., 1995). Protein has been reported to be an important factor in maintaining the rumen environment of animals, thus stimulating DM intake and digestibility (Nguyen et al., 2017). Therefore, supplementing Leucaena with a higher CP content (300.88 g kg^{-1} DM) in this study resulted in an improved intake of Guatemala grass, leading to high milk production. The milk composition of cows fed a control diet was similar to that of cows supplemented with dried cassava leaves treatment but significantly different ($p<0.05$) from cows supplemented with dried Leucaena leaves (see Table 4.18). The milk fat content was higher from cows fed basal diet plus dried Leucaena leaves supplement than for the control diet and those on dried cassava leaves. The mean value of milk fat in this study was lower than that obtained by Nugroho et al. (2019). This higher milk fat content from cows supplemented with dried Leucaena leaves could be attributed to its high crude fibre content (Table 4.16), which increases the molar proportion of acetate and butyrate in the rumen. Acetic and butyric acids are known as precursors of milk synthesis (Flores-Cocas et al., 2021). Additionally, supplementing cows with dried Leucaena leaves in this study is also beneficial in maintaining crude fibre levels in the rumen.

The milk protein, lactose, and solids not-fat contents of cows fed on the control diet and cows supplemented with dried cassava leaves were higher than those from cows supplemented with dried Leucaena leaves. Since cows supplemented with dried Leucaena or cassava leaves consumed additional CP of 0.98 kg and 0.78 kg, respectively, it was expected that the lesser increase in milk protein and lactose contents would be realised from cows supplemented with dried Leucaena leaves. Unexpectedly, higher milk protein contents were recorded from cows supplemented with cassava leaves as well as from the control diet. In this study, dried Leucaena leaves had higher CP content which would help in the supply of amino acids and indirectly supported milk protein synthesis, thus increasing milk protein content. Kakengi et al. (2001) reported similar results, whose supplementation of Leucaena to grazing crossbred cows increased milk production, weight gain, and enhanced milk composition but had no significant effect on milk protein. The milk lactose content from cows fed a basal diet and supplemented with dried Leucaena leaves in this study was similar to that of Osorio et al. (2016). Findings from this study showed that supplementing Guatemala grass with dried Leucaena leaves on lactose content followed the same trend as milk production. It has been reported that lactose content in the milk is nearly stable and is, therefore, crucial for the volume of produced milk in the udder (Osorio et al., 2016). Lactose acts as a water binder; more lactose synthesised leads to more amount of milk production. Milk production depends on the mammary synthesis of lactose because its osmoregulation of milk induces mammary absorption of water. Thus, the rate of lactose synthesis in the epithelial cells of the mammary gland serves as a major factor influencing milk volume production (Osorio et al., 2016).

CHAPTER FIVE

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the summary of the findings of this study. It highlights the conclusions for descriptive and economic model results, chemical composition and *in vitro* gas production of selected eight trees and shrubs, and the effects of supplementing Guatemala grass with dried Leucaena or cassava leaves on feed intake, milk production, and milk composition of Holstein Friesian x Ankole crossbred cows. The policy implications and further research recommendations are also provided.

5.2 Summary

The results revealed that farmers used thirty-six (36) trees and shrubs in Kalemie compared to 26 trees and shrubs in Kabare for animal fodder. Farmers employ experience-based perceptions to evaluate the suitability of trees and shrubs for fodder based on animal (palatability, ability to improve animal satiation, growth or productivity) and tree (compatibility with cultivated crops, drought resistance, improvement of soil fertility and toxicity) related criteria. The results of the probit regression analysis indicated that 63% of cattle farmers used trees and shrubs as livestock feeds. Factors such as gender, group membership, ownership of cattle, ownership of improved cattle, milk production perception, milk sales, milk price, legume production, crop residue usage, and farmer location positively and significantly ($p<0.05$) influenced the utilisation of trees and shrubs as livestock feeds. Conversely, education level, goat ownership, and milk quantity produced negatively and significantly ($p<0.05$) affected the utilisation of trees and shrubs.

The results of this study revealed that the crude protein content of most eight trees and shrubs ranged from 217.28 g kg^{-1} DM to 416.91 g kg^{-1} DM, which was above the minimum threshold of 70 g/kg DM required for optimal rumen function and feed intake. While the neutral detergent fibre content ranged from 265 to 690 g/kg DM, which was also within the critical level of 550-600 g/kg DM, which is the critical value above which feed intake and feed conversion efficiency decreased due to longer rumination time. All species from Kabare and except *C. calothyrsus, L. Leucocephala,* and *M. indica* from Kalemie, had low (<40 g/kg DM) or moderate (40-60 g/kg DM) levels of condensed tannins. When these trees and shrubs are supplemented to livestock, low or moderate levels of condensed tannins could benefit protein digestion while increasing its outflow from rumen, thereby increasing amino acid absorption in the small intestine, thus improving animal performance. *In vitro* organic matter digestibility of the eight most preferred species ranged from 31.3% to 44.6%, while metabolisable energy ranged from 1.82 MJ kg^{-1} DM to 4.04 kg^{-1} DM.

Results of animal feeding experiments revealed that supplementing Guatemala grass with dried Leucaena or cassava leaves increased ($p<0.05$) total dry matter intake by 20% and 26%, respectively. Dried Leucaena leaves supplementation resulted in higher milk production ($p<0.05$) than the dried cassava when fed to Holstein Friesian x Ankole crossbred cows. The milk fat content from cows supplemented with dried Leucaena leaves was higher ($p<0.05$) than those supplemented with dried cassava leaves. The milk protein, lactose, and non-fat solids contents from cows supplemented with dried cassava leaves were higher ($p<0.05$) than those of dried Leucaena.

5.3 Conclusion

Sixty-three percent (63%) of smallholder cattle farmers used trees and shrubs as livestock feeds. Thirty-six (36) trees and shrubs were used by farmers in Kalemie against 26 trees and shrubs in Kabare. Socio-economic factors such as gender, group membership, ownership of cattle, ownership of improved cattle, milk production perception, milk sales, milk price, legume production, crop residue usage, and farmer location positively and significantly influenced the use of trees and shrubs as livestock feeds. Conversely, education level, ownership of goat, and the quantity of milk produced negatively and significantly affected the utilisation of trees and shrubs.

The leaves of the eight most preferred trees and shrubs species by smallholder farmers had high crude protein content, above the minimum threshold required for optimal rumen function and feed intake. This suggests their suitability and potential as protein supplements for low-quality feeds.

Dried leaves of Leucaena or cassava incorporated at the rate of 20% in dairy feed increased milk production and improved milk quality.

5.4 Recommendations

a) Policymakers should train both male and female farmers on the benefits of using trees and shrubs to increase and promote their adoption. Considering positive socio-economic factors when scaling up and promoting the use of trees and shrubs will likely increase its adoption among farmers.

b) Smallholder cattle farmers in the study area can use the leaves of the eight most preferred trees and shrubs species as suitable and potential protein supplements for low-quality feeds.

c) Leucaena and cassava, which are easily established and abundant in Kalemie and Kabare territories of the Eastern DRC, can be used as protein sources for Holstein Friesian x Ankole crossbred cows.

5.4 Suggestions for further research

Further studies should aim to assess the nutritional quality of the remaining trees and shrubs species not covered by this study and to assess their supplement effects in the diet of crossbred cows. The lactation performance of Holstein Friesian x Ankole crossbred cows should also be determined by supplementing Guatemala grass with a combination of Leucaena and cassava leaves. Research can also be conducted to determine the anthelmintic properties of *V. amygdalina* on livestock.

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APPENDICES

Appendix 1: Ethical Approval

REPUBLIQUE DEMOCRATIQUE DU CONGO
PROVINCE DU SUD-KIVU
INSPECTION PROVINCIALE DE PECHE ET ELEVAGE

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N°55.00/.99..... /IPPEL/SK/2021 **Bukavu, le** 15 DECEMBRE 2021

Barwani Kichochi Didier
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NAIROBI

Objet : **Autorisation de Recherche par l'Inspection Provinciale de Pêche et Elevage**

Cher Monsieur Barwani

Nous nous référons à votre proposition de maîtrise soumise à notre bureau et à votre lettre de demande d'autorisation datée du 13 Décembre 2021, nous avons examiné votre demande d'autorisation de recherche dans la province du Sud-Kivu sur les performances de lactation des vaches laitières hybride nourries par les fourrages naturels et complétées avec des plantes fourragères sélectionnées dans l'Est de la République Démocratique du Congo.

Le protocole proposé et le nombre de vaches à utiliser dans l'étude satisfait aux normes minimales des lignes directrices du Règlement de l'Inspection de Pêche et Elevage.

Nous vous donnons par la présente l'approbation de poursuivre le projet tel que décrit dans la proposition soumise.

Cordialement

Dr. Vincent MUHIGIIRHWA SANGWA
Inspecteur Provincial de Pêche et Elevage

RREPUBLIQUE DEMOCRATIQUE DU CONGO INSPECTION PROVINCIALE DE PECHE ET ELEVAGE PROVINCE DU SUD-KIVU

Appendix 2: Household Survey Questionnaire

Introduction and consent

Hello, my name is Didier Barwani, a Masters student from Jomo Kenyatta University of Agriculture and Technology (JKUAT), undertaking a study to improve the lactation performance of dairy cows by improving feed quality and feeding management through the use of tree and shrub fodder. You, as one of the farmers and as the primary decision maker, have been identified as one of the respondents. All your answers will be completely confidential and used only for academic purposes. Participation in this exercise is voluntary; you can choose not to participate. You have the right to ask questions at the end of the interview.

SECTION A: HOUSEHOLD LOCATION

	Item	Response		Item	Response
A1	Name of the enumerator		**A7**	Province	
A2	Household ID		**A8**	Territory	
A3	Survey Date		**A9**	Chiefdom	
A4	GPS Longitude		**A10**	Group	
A5	GPS Latitude		**A11**	Village	
A6	GPS Altitude		**A12**	Axe	

SECTION B: CHARACTERISTICS OF HOUSEHOLD HEAD

Gender of household 0.Male 1.Female	Age of the household head (years)	Level of education 1.None 2.Primary 3.Secondairy 4.University 5.Others	Marital status 1.Married 2.Divorced/ Separated 3.Widowed 4. Never married	Main source of income 1.Livestock only 2.Crop-livestock 3.Off-farm activity	Household size (number)
B1	**B2**	**B3**	**B4**	**B5**	**B6**
Female 1-17 years (number)	Female 18-45 years (number)	Female 46-60 years (number)	Female above 60 years (number)	Male 1-17 years (number)	Male 18-45 years (number)
B7	**B8**	**B9**	**B10**	**B12**	**B13**
Male 46-60 years (number)	Male above 60 years (number)	Monthly revenue (USD)	Member of cooperative 0.No 1.Yes	Area of the activity	Own land 0.No 1.Yes
B14	**B15**	**B16**	**B17**	**B18**	**B19**

Land size owned (ha)	Land owned process 1.Customary chief 2.Land rent 3.Land registry service	Land acquisition cost/ha (USD)			
B20	**B21**	**B22**			

SECTION C: LIVESTOCK, LIVESTOCK FEEDS AND FEEDING SYSTEMS

C1	How long have you been practising cattle farming (years)?	
C2	The primary purpose for cattle farming 1.milk 2.manure 3.saving 4.family subsistence	
C3	Main targeted livestock product 1.milk 2.meat 3.others (specify)	
C4	Main destination of livestock product 1.consumption 2.sales 3.others (specify)	
C5	Number of cattle owned	
C6	Number of bulls owned	
C7	Number of improved bulls	

C8	Origin of improved bulls 1.project 2.purchased 3.other (specify)	
C9	Number of cows	
C10	Number of improved cows	
C11	Origin of improved cows 1.project 2.purchased 3.other (specify)	
C12	Number of heifers	
C13	Number of improved heifers	
C14	Origin of improved heifers 1.project 2.purchased 3.other (specify)	
C15	Number of steers	
C16	Number of improved steers	
C17	Origin of improved steers 1.project 2.purchased 3.other (specify)	
C18	Number of female calves	
C19	Number of male calves	
C20	Number of lactating cows	
C21	Number of improved lactating cows	
C22	Quantity of milk produced by improved lactating cows (litre/day)	
C23	Number of improved lactating cows at 1-3 month stage	
C24	Number of improved lactating cows at 4-7 month stage	
C25	Number of improved lactating cows above 7 month stage	
C26	Number of local lactating cows	
C27	Quantity of milk produced by local lactating cows (litre/day)	
C28	Number of local lactating cows at 1-3 month stage	

C29	Number of local lactating cows at 4-7 month stage	
C30	Number of local lactating cows above 7 month stage	
C31	Milking method 1. hand-milk 2. Other (specify)	
C32	Times of milking per day 1.one 2.two 3.other (specify)	
C33	Time of milking 1.morning 2.evening 3.other (specify)	
C34	Quantity of milk produced in morning/cow (litre)	
C35	Total quantity of milk produced in the morning (litre)	
C36	Quantity of milk consumed in the morning (litre)	
C37	Quantity of milk sold in the morning (litre)	
C38	Price of milk in the morning (USD/litre)	
C39	Quantity of milk produced in the evening/cow (litre)	
C40	Total quantity of milk produced in the evening (litre)	
C41	Quantity of milk consumed in the evening (litre)	
C42	Quantity of milk sold in the evening (litre)	
C43	Price of milk in the evening (USD/litre)	
C44	Number of pregnant cows	
C45	Number of pregnant cows at 0-3 months	
C46	Number of pregnant cows at 4-6 months	
C47	Number of pregnant cows at 7-9 months	
C48	Breeding method 1.natura 2.artificial insemination	
C49	Number of goats	

C50	Number of sheep	
C51	Feeding systems 1.grazing 2.zero-grazing 3.other (specify)	
C52	Size of grazing land set aside for livestock (ha)	
C53	Livestock fed with grasses 0.No 1.Yes	
C54	Feeding grass period 1.dry season 2.wet season 3.other (specify)	
C55	Species of grass 1.napier 2.guatemala 3.other (specify)	
C56	Land allocated to grow grass (ha)	
C57	Livestock fed with legumes 0.No 1.Yes	
C58	Feeding legume period 1.dry season 2.wet season 3.other (specify)	
C59	List legume species	
C60	Type of legume 1.local 2.Improved	
C61	Who introduced improve legume? 1.NGOs 2.other (specify)	
C62	Land allocated to grow legume (ha)	
C63	Feed livestock with crop residues 0.No 1.Yes	
C64	Feeding crop residues period 1.dry season 2.wet season 3.other (specify)	
C65	Treating crop residue 0.No 1.Yes	
C66	Treating method 1.chop 2.grind 3.silage 4.other (specify)	
C67	Type of crop residue 1.maize 2.cassava 3.bean 4.other (specify)	
C68	Homemade feed 0.No 1.Yes	

C69	Composition of the ration 1.grass 2.other (specify)	
C70	Dietary supplement 0.No 1.Yes	
C71	Type of supplement (specify)	
C72	Do prophylaxis 0.No 1.Yes	
C73	Type of prophylaxis 1.vaccination 2.other (specify)	

SECTION D: TREE AND SHRUB INVENTORY AND THEIR USES

D1	Do feed livestock with tree and shrub 0.No 1.Yes	
D2	***If No, ends interview***	
D3	List species used	
D4	Type of species 0.local 1.Improved	
D5	Who introduced improve species? 1.NGOs 2.other (specify)	
D6	List species fed to cattle	
D7	List species fed to goats	
D8	List species fed to sheep	
D9	List preferred species	
D10	Animal criteria:1. satisfies animal hunger 2. improves animal health 3. improves cow milk production 4. palatable 5. improves meat production 6. improves growth 7.other (specify)	
D11	Plant criteria:1.drought resistance 2.compatible with other crops 3.improves soil fertility 4.no dropping leaves 5.other (specify)	

D12	Score of the preferred species from 1 to 5 (1.poor 2.medium 3.good 4.very good 5.excellent) using 6 parameters (1.growth after establishment 2.regrowth 3.palatable 4.compatible with other crops 5.improves health 6.drought resistant)	
	e.g. avoca (1.6)	
D13	Feeding tree period 1.dry season 2.wet season 3.other (specify)	
D14	Edible parts fed to cattle 1.leaf only 2.leaf and twig 3.fruit or pod 4.other (specify)	
D15	Edible parts fed to goats 1.leaf only 2.leaf and twig 3.fruit or pod 4.other (specify)	
D16	Edible parts fed to sheep 1.leaf only 2.leaf and twig 3.fruit or pod 4.other (specify)	
D17	Role of trees and shrubs (*multiple responses allowed*) 1.soil fertiliser 2. protection against erosion 3.fuelwood 4. windbreaks 5. construction materials 6.live fence 7.human medicine 8.veterinary medicine 9.environmental conservation 10.other	
D18	Do you grow trees and shrubs? 0.No 1.Yes	
D19	Type of niche 1.external farm boundary 2.within home compound 3.within food crops 4.within grazing land 5.off-farm	
D20	List species grew on the external farm boundary	

D21	List species are grown within the home compound	
D22	List species are grown within food crops	
D23	List species are grown within grazing land	
D24	List species are grown off-farm	
D25	Propagation method 1.seeds 2.cuttings 3.roots 4.other (specify)	
D26	Management of cutting 1.coppice at knee height 2.coppice above 1m 3.pollard branches and leaf stem 4.cut soft twigs 5.browsing 6.other (specify)	
D27	Do tree attack by pests 0.No 1.Yes	
D28	List attacked species	
D29	Type of pests	
D30	Do tree attack by disease 0.No 1.Yes	
D31	List attacked species	
D32	Type of diseases	
D33	Other problems 1.toxicity 2.thorniness 3.other (specify)	
D34	Side effects of toxicity on animal	
D35	List toxic species	
D36	List species with thorniness	
	End of the interview and thank the farmer	

Appendix 3: List of publications

Peer-reviewed articles

Barwani, D. K., Bacigale, S. B., Kibitok, N. K., Webala, A. W., Gicheha, M. G., Katunga, D. M., & Osuga, I. M. (2022). Nutritional characterization of eight trees and shrubs used as livestock feeds in the Eastern Democratic Republic of the Congo. *Livestock Research for Rural Development*, 34(10).

Barwani, D. K., Bacigale, S. B., Ayagirwe, R. B. B., Gicheha, M. G., Katunga, D. M., & Osuga, I. M. (2023). Effect of dried *Leucaena leucocephala* and *Manihot esculenta* forage supplementation on feed intake, milk production and milk composition of Holstein Friesian x Ankole crossbred cows. *Livestock Research for Rural Development*, 35(4).

Submitted manuscript

Barwani, D. K., Maindi, C. N., Bacigale, S. B., Gicheha, M. G., Katunga, D. M., & Osuga, I. M. Smallholder cattle farmers' perceptions and utilisation of trees and shrubs as livestock feeds in the Eastern Democratic republic of the Congo. Submitted to *International Journal of Agricultural Sustainability*.