Acta Universitatis Agriculturae Sueciae

Doctoral Thesis No. 2025:57
Faculty of Veterinary Medicine and Animal Science

Milk Matters. Linking dairy cow feed to milk yield and quality, and child undernutrition in Northern Rwanda

Marie Anne Mukasafari

Milk matters. Linking dairy cow feed to milk yield and quality, and child undernutrition in Northern Rwanda

MARIE ANNE MUKASAFARI

Faculty of Veterinary Medicine and Animal Science

Department of Applied Animal Science and Welfare

Uppsala

SLU

SWEDISH UNIVERSITY
OF AGRICULTURAL
SCIENCES

DOCTORAL THESIS

Uppsala 2025

Acta Universitatis Agriculturae Sueciae
2025:57

Cover: The landscape of the Northern Province, Rwanda (photo: Horacio Gonda)

ISSN 1652-6880
ISBN (print version) 978-91-8124-041-2
ISBN (electronic version) 978-91-8124-087-0
https://doi.org/10.54612/a.406abvn25e

Swedish University of Agricultural Sciences, Department of Applied Animal Science and Welfare, Uppsala, Sweden

Print: SLU Grafisk service, Uppsala 2025

Milk matters. Linking dairy cow feed to milk yield and quality, and child undernutrition in Northern Rwanda

Abstract

Stunting, a form of chronic undernutrition in children, is a major public health concern worldwide. Livestock can play a crucial role in reducing stunting by supplying nutrient-dense animal-source foods needed for child growth and development. This thesis aimed to study the association between keeping a lactating cow and the prevalence of stunting in smallholder households in the Northern Province of Rwanda by looking at feeding and milking practices, milk yield and quality, and the association between keeping a lactating cow and stunting in young children. A cross-sectional study involving 601 smallholder households was conducted during November-December 2021. Most households had at least one type of livestock, and 156 owned cows, mostly crossbreeds, that were lactating at the moment of the visit. All cows were fed according to a cut-and-carry system, mostly with roadside native vegetation, crop residues, and cultivated grasses. Most of the feed resources were of poor nutritional quality, characterized by low protein, high fibre, and low energy contents. Milk yield was low, on average 4 L/cow/day. Cow's breed, parity, stage of lactation, body condition, and milking frequency affected milk yield. Around 34% of the milk samples had somatic cell counts above 300,000 cells/ml indicating the presence of intra-mammary infections, and 13% of the samples had antibiotic residues. Prevalence of stunting in children ranged from 10.4 to 50.0%, with a mean of 27.3%. Owning a lactating cow showed a tendency to reduce stunting, while poultry keeping was significantly associated with a lower prevalence of stunting. However, the consumption of milk or eggs was not associated with stunting. Factors that were associated with stunting included sex of the child (girls less than boys), birth weight and breastfeeding; body mass index and level of education of the mothers; household economy and food security, gender of the household head (men more than women), and the presence of a kitchen garden. Improving animal husbandry would result in more milk of better quality, both to be consumed or sold, and in reduced prevalence of stunting and improved household livelihoods.

Keywords: feed resources, feed composition, lactating cow, zero-grazing, East Africa, poverty, animal-source foods, child stunting

Mjölk spelar roll. Samband mellan mjölkkors foder, mjölkavkastning och mjölkkvalitet samt undernäring hos barn i norra Rwanda

Sammanfattning

Kronisk undernäring och hämmad tillväxt (eng. stunting) hos barn är ett stort folkhälsoproblem i stora delar av världen. Att hålla livsmedelsproducerande djur kan spela en roll för att minska barnens undernäring genom tillgång till de näringsrika, animaliska livsmedel som behövs för barns tillväxt och kognitiva utveckling. Syftet med avhandling var att studera sambandet mellan att hålla mjölkkor och förekomsten av hämmad tillväxt hos barn i hushåll i norra provinsen i Rwanda genom att titta på kornas tillgång till foder, mjölkningsmetoder, mjölkavkastning och kvalitet, samt förekomsten av undernäring hos små barn. En studie med 601 hushåll genomfördes under november och december 2021. De flesta hushållen hade minst ett djurslag av livsmedelsproducerande djur, och 156 ägde kor, mestadels korsningsdjur, som var lakterande vid besökstillfället. Alla kor utfodrades enligt ett "cut-and-curry"-system, mestadels skördat från vägkantens inhemska vegetation, rester från grödor och odlat gräs. De flesta foderslagen var av dålig näringskvalitet, med lågt protein- och energiinnehåll och högt fiberinnehåll. Mjölkavkastningen var låg, i genomsnitt 4 l/ko/dag. Cirka 34 % av mjölkproverna hade förhöjda celltal, (över 300 000 celler/ml) vilket tyder på förekomst av juverinflammation, och 13 % av proverna innehöll antibiotikarester. Förekomsten av undernäring hos barn varierade från 10,4 till 50,0 %, med ett medelvärde på 27,3 %. Att äga en lakterande ko visade en tendens att minska undernäring, medan hållning av fjäderfän var signifikant associerat med en lägre prevalens hämmad tillväxt. Konsumtion av mjölk eller ägg var dock inte associerat med undernäring. Faktorer som var negativt associerade med hämmad tillväxt hos barn inkluderade barnets kön (mindre vanligt hos flickor än hos pojkar), födelsevikt och amning, mödrarnas BMI och utbildningsnivå, hushållets ekonomi och livsmedelssäkerhet, hushållets överhuvud (mer hos män än kvinnor) samt förekomsten av en köksträdgård. Att förbättra djurhållningen skulle leda till mer mjölk av bättre kvalitet, både för hushållsbruk och försäljning, därmed förbättra hushållens försörjning och minska förekomsten av undernäring.

Nyckelord: foderresurser, fodersammansättning, lakterande kor, Östafrika, småbönder, animaliska livsmedel, hämning av barns tillväxt

Dedication

To my beloved family. I love you so much!

"Education is not the learning of facts, but the training of minds to think"
Albert Eistein

Contents

List of publications 9

List of tables 11

List of figures 13

Abbreviations 15

1. Introduction 17

2. Background 19

2.1 The contribution of dairy cattle to household food insecurity 20

2.2 Feeds and feeding practices, milk yield, and quality in East African countries 21

2.2.1 Animal feed resources at smallholder farms 21

2.2.2 Feeding practices and milk yield 23

2.3 Milking practices and milk handling in East African countries 24

2.4 Animal-source foods and chronic undernutrition in children 26

3. Aim and objectives 29

4. Materials and methods 31

4.1 Data collection processes 31

4.1.1 Description of the study area and participant enrolment (Papers I, III, and IV) 31

4.1.2 Questionnaire design and data collection methods (Papers I, III, and IV) 32

4.1.3 Stunting measurement (Paper IV) 34

4.1.4 Individual animal observation (Paper III) 34

4.2 Feed and milk sampling 34

4.2.1 Feed samples collection (Paper I) 34

4.2.2 Milk collection (Paper III) 34

4.3 Samples analysis 35

4.3.1 Feed samples (Paper I) 35

4.3.2 Milk samples (Paper III) 35

4.4 Systematic review (Paper II) 35

4.5 Statistical analysis 35
4.6 Ethical considerations (Papers I, III, and IV) 36

5. Results 37
5.1 Household characteristics 37
5.2 Feed resources used by smallholder farmers (Papers I and II) .. 38
5.2.1 Feeds resources in the Northern Province of Rwanda (Paper I) 38
5.2.2 Feed resources in East African Countries (Paper II) 39
5.3 Feeding practices and milk yield (Paper II) 40
5.4 Farm management practices and their effect on milk yield and quality (Paper III) 41
5.5 Livestock keeping and child stunting (Paper IV). 43
5.6 Other factors contributing to stunting in children (Paper IV) 44

6. Discussion 45
6.1 Effects of farm management practices on milk yield and quality 45
6.1.1 Feeds and feeding lactating dairy cows 45
6.1.2 Milk yield and quality 48
6.2 Linking livestock keeping to stunting among young children 49
6.3 A multidisciplinary approach to tackle child undernutrition 51

7. Conclusions and future perspectives 53
7.1 Conclusions 53
7.2 Future perspectives 54

References 57

Popular science summary 69

Populärvetenskaplig sammanfattning 71

Incamake (Kinyarwanda) 73

Acknowledgements 75

List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I. **Mukasafari M.A.**, Mutimura M., Wredle E., Gonda H.L. (2025). Nutritional quality of feed resources used by smallholder dairy farmers in the Northern Province of Rwanda. *Tropical Animal Health and Production,* 57(301). https://doi.org/10.1007/s11250-025-04562-w

II. **Mukasafari M.A.**, Mpatswenumugabo J.P., Mutimura M., Ndahetuye J.B., Wredle E., Båge R., Gonda H.L. Feed resources, feeding practices, and milk production at smallholder dairy farms in East African Countries: A Systematic Review (*submitted*).

III. **Mukasafari M. A.***, Mpatswenumugabo J. P.*, Ndahetuye J. B., Wredle E., and Båge R. (2025). Management factors affecting milk yield, composition, and quality on smallholder dairy farms. *Tropical Animal Health and Production,* 57(41). https://doi.org/10.1007/s11250-025-04294-x

IV. **Mukasafari M.A.***, Rinda D.*, Wredle E., Båge R., Matsiko E., Elfving K., Gonda H.L. Livestock ownership and child stunting: Insights from a cross-sectional study in the Northern Rwanda (manuscript)

*Joint first authorship

Papers I and III are reproduced with the permission of the publishers.

The contribution of Marie Anne Mukasafari to the papers included in this thesis was as follows:

I. Participated in planning the study design. Collected, sorted feed samples, performed laboratory analysis, wrote the manuscript, and was a corresponding author. All activities completed in this paper were supported by supervisors.

II. Planned the aim of the review together with the co-authors. Contributed to reviewing papers, data retrieval, and presentation. Wrote the manuscript with inputs from co-authors and supervisors.

III. Planned the study together with the co-author and supervisors. Contributed to the collection, preparation, and part of the data analysis. Together with co-author, I participated in writing the paper with regular inputs from supervisors and co-author.

IV. Was involved in study planning, as well as data collection, cleaning and curation. Wrote the manuscript, and everything was carried out under the guidance of my supervisors.

List of tables

Table 1. Overview of the methodology used, and the data collected in the studies included in the thesis... 31

Table 2. Nutrient composition of feed resources used by smallholder dairy farmers in East African Countries (Paper II)... 40

Table 3. Mean comparison in relation to daily milk yield (L/cow/day) of dairy cows in the Northern Province of Rwanda. 42

Table 4. Milk yield, composition, somatic cell counts (SCC), and antibiotic residues at smallholders' dairy farms in the Northern Province of Rwanda. 43

Table 5. Prevalence of stunting in relation to livestock ownership among smallholder farmers in the Northern Province of Rwanda.......................... 44

List of figures

Figure 1. Livestock keeping at smallholder dairy farms in Northern Rwanda. 26

Figure 2. Map of study sites, Northern Province, Rwanda. 33

Figure 3. Cattle fed natural pasture under a zero-grazing system at smallholder dairy farm in Northern Rwanda. 38

Figure 4: Crude protein, neutral detergent fibre, and metabolisable energy contents in feed resources used by smallholder dairy farmers (Paper I)... 39

Abbreviations

ADF	Acid detergent fibre
ASF	Animal-source foods
CP	Crude protein
DHS	Demographic and Health Survey
EAC	East African countries
FAO	Food and Agriculture Organisation of the United Nations
HAZ	Height for age z-Score
LMICs	Low-middle-income countries
ME	Metabolisable energy
MINAGRI	Ministry of Agriculture and Animal Resources
NDF	Neutral detergent fibre
NISR	National Institute of Statistics of Rwanda
OMD	Organic matter digestibility
RDDP	Rwanda Dairy Development Project

1. Introduction

Agriculture, which encompasses both crop and livestock production, plays a critical role in the economies of sub-Saharan Africa, serving as the primary source of livelihood for majority of the rural population, particularly smallholder farmers (FAO, 2024). Despite its centrality, the sector is characterised by low productivity and limited returns, which constrain its potential to drive economic growth. The underperformance of agriculture has contributed to persistent poverty and food insecurity across this region compared to other regions in the developing world (Amejo et al., 2018). Indeed, the rapid population growth often outpaces economic gains, making it difficult for countries to reduce poverty in a significant way. In rural areas, where most of the poor reside, limited access to markets, agricultural inputs, and social services further compounds the problem (McMahon, 2016).

In developing countries, such as Rwanda, smallholder dairy farmers form the backbone of the local dairy sector and make substantial contributions to rural livelihoods. Many households rely on milk not only as a source of nutrition, especially for children and vulnerable family members, but also as a source of income when production exceeds their household requirements (Flax et al., 2023a). Despite its potential, milk yields from smallholder dairy farms remain relatively low (Duguma, 2022), which limit its access and affordability particularly in rural areas (Zerfu et al., 2024). Low milk yields among smallholder dairy farmers are predominantly caused by poor feeding practices, inadequate veterinary care of the dairy cows, and improper farm management (Terefe & Walelegne, 2024). Various initiatives in East Africa Countries (EAC), including the Rwanda Dairy Development Project (RDDP) which supports livestock farmer field schools (L-FFS) (RDDP, 2016) and the Wakulima Self-Help Group Dairy (WSHGD) in Kenya (VanLeeuwen et al., 2012), aim to improve rural livelihoods by increasing milk yield and promoting better feeds, feeding and management practices. However, the adoption of improved dairy technologies among poor-resource farmers remains low due to limited access to quality inputs and services, weak extension support, and high costs. Such constraints not only hinder productivity but also contribute to low accessibility and consumption of animal-source foods (ASF). Insufficient ASF intake can result in moderate to severe, and in some cases chronic undernutrition, with young children being among the most vulnerable (McMahon, 2016; Zerfu et al., 2024).

Undernutrition, manifested as stunting, is a persistent challenge in many developing countries where it contributes considerably to child mortality and impaired development (Hetherington et al., 2017). Stunting, defined as a low height-for-age z-score (HAZ), often results from chronic nutrient deprivation during the critical first 1,000 days of life (González-Fernández et al., 2024). A key contributor to these conditions is the low consumption of ASF (Zerfu et al., 2024). Animal-source foods such as milk, meat, and eggs are rich in nutrients essential for physical growth, cognitive development, immune support, and bone health. Most children in households with dairy animals are expected to have better dietary diversity and nutritional outcomes (Dumas et al., 2018), however, this may not always be the case. When milk is not consumed within the home it may be due to either low availability or because it must be sold to meet another essential household need (Flax et al., 2021). In households without livestock, low consumption of ASF is often driven by a limited awareness of their nutritional benefits and/or by their high cost (Zerfu et al., 2024).

To address stunting in Rwanda, different programmes such as *shisha kibondo* (feel the goodness); *One Cup of milk per child school feeding initiative; Orora Wihaze activity* (promoting livestock rearing), and *kitchen garden (akarimak'igikoni)* have been implemented (USAID, 2020; World Bank, 2021). Despite these efforts, the national prevalence of stunting remains high at 33.1%, although there has been a decline (RDDP, 2023).

The Northern Province of Rwanda, characterised by subsistence farming, has been identified as one of the country's hunger hotspots with the highest rate of child stunting at 41% (National Institute of Statistics of Rwanda, 2021). Defining possible strategic interventions requires greater knowledge about the management of dairy cows, milking routines, and milk handling at the household level, as well as the impact of owning a lactating cow on the occurrence of stunting among young children.

2. Background

Rwanda is a small, landlocked country in East-Central Africa, covering approximately 26,338 km^2, making it one of the smallest countries in mainland Africa. Despite its small size, Rwanda has a relatively large and growing population, estimated at around 13 million people in 2022 (annual growth rate of 2.3%), with a population density of over 532 people/km^2, making it one of Africa's most densely populated countries (NISR, 2023). Known as the "*Land of a Thousand Hills,*" Rwanda's landscape is characterised by rolling hills, valleys, and mountains, including the Virunga volcanic range in the northwest that is part of the country's highest elevations. The Northern Province is mountainous and fertile, whilst the eastern part of Rwanda is flatter and contains savannahs and wetlands. Water bodies, including Lake Kivu along the western border and numerous rivers covering 8% of the country's total surface area, play an integral role within the ecosystem and livelihoods. Rwanda has a temperate tropical highland climate, with temperatures generally ranging between 16°C and 28°C.

Rwanda's economy has grown consistently throughout the past two decades, supported by political stability and driven by sectors such as agriculture and services (MINAGRI et al., 2018; Lokuruka, 2020). Agriculture remains the foundation of the rural economy, employing 69% of the population (MINAGRI, 2025), and livestock play a key role in enhancing food security and household incomes. Despite this economic progress, poverty majorly persists notably in rural areas. In 2013/14, poverty rates in the Western and Northern provinces were 45.2% and 46.1%, respectively, both of which surpass the national average of 39% (MINAGRI et al., 2018). Consequently, around one in three children under five years of age are stunted (33%), with a higher prevalence across the Northern province (41%; National Institute of Statistics of Rwanda 2021).

2.1 The contribution of dairy cattle to household food insecurity

In many rural areas of low- and middle-income countries, smallholder farmers raise livestock primarily to meet their household's nutritional needs, as opposed to commercial purposes (Headey et al., 2018). In subsistence farming systems, livestock help mitigate the risks from seasonal crop failures by diversifying livestock production, enabling the recycling of crop residues as animal feed and providing manure that can be used as fertiliser in crop production (Amejo et al., 2018).

Research across Sub-Saharan Africa suggested that livestock ownership is associated with improved child health outcomes (Dumas et al., 2018; Hetherington et al., 2017). Households that own livestock, notably dairy animals, often have greater access to ASF which contributes to diet diversification and reduces the risk of child undernutrition (Rawlins et al., 2014). Moreover, livestock-derived income strengthens household purchasing power and thus facilitates access to healthcare, education, and a variety of nutritious foods (Flax et al., 2023a). A review focusing on developing countries reported that livestock represents an asset for wealth accumulation as animals can be sold to generate income or serve as an investment during times of need, such as illness or drought (Herrero et al., 2012).

In Rwanda, cattle symbolise wealth and are traditionally used as part of dowries in weddings. However, the 1994 genocide severely impacted the livestock sector, with about 90% of small ruminants and 80% of the cattle population eradicated (Habiyaremye et al., 2021). This devastation disrupted agricultural livelihoods, food production, and rural economies. To support recovery, and improve social cohesion and food security the Rwandan government launched the *Girinka* programme ("*One Cow per Poor Family Program*") in 2006 (RGB, 2018). By providing a dairy cow to poor households, the programme aims to improve household nutrition through access to milk and milk products, whilst promoting agricultural productivity and income generation through the sale of surplus milk and manure for farming (Flax et al., 2021; Habiyaremye et al., 2021). Livestock can also enhance farm productivity through draft power for land preparation, and income generation through sales (Herrero et al., 2012).

2.2 Feeds and feeding practices, milk yield, and quality in East African countries

Over the past two decades, the dairy sector in EAC has experienced remarkable growth, becoming an important driver of improved food security and livelihoods for many rural households (Bingi & Tondel, 2015). However, in most poor-resource farms, daily milk production is still insufficient, often ranging between 1 to 5 L/cow/day (Kamanzi & Mapiye, 2012; Manzi et al., 2020). This low milk yield is primarily caused by poor farm management practices, scarcity of local resources (land and capital), and socio-economic factors (VanLeeuwen et al., 2012; Shiferaw et al., 2018). The shortage of quality feed resources remains one of the primary constraints for to livestock production (Balehegn et al., 2020).

2.2.1 Animal feed resources at smallholder farms

Smallholder farmers in EAC rely on natural pastures, cultivated forages, crop residues (Kamanzi & Mapiye, 2012; Duguma et al., 2017; Matovu & Alçiçek, 2023), and, to a small extent, fodder trees and agro-industrial by-products (Duguma et al., 2017; Shiferaw et al., 2018). The availability of these feeds varies depending on the local conditions, seasonal changes, and land access. Natural pasture refers to the native grasses and other vegetation that naturally grow in the environment without significant human intervention on fallow land and uncultivated public areas such as roadsides, steep and rocky hills, riparian areas, bushlands, and forest reserves (Kamanzi & Mapiye, 2012; Bedada et al., 2021). In addition, forages such as Napier grass (*Cenchrus purpureus*) and *Brachiaria* hybrids, among others, are the most cultivated species. Leguminous fodder crops such as *Desmodium* spp., Lablab (*Lablab purpureus*), Calliandra (*Calliandra calothyrsus*), and Leucaena (*Leucaena leucocephala*) are also grown in certain areas (Maleko et al., 2018; Mutimura et al., 2015). However, land constraints, access to seeds, and the lack of knowledge regarding on how to crop forages limit the availability of cultivated grasses and legumes.

Different crop residues such as maize and sorghum stover, banana leaves and pseudo-stems, bean straw, sorghum haulms, and rice and wheat straw, to name few, are also commonly used as feed sources (Mutimura et al., 2015; Yami et al., 2013). The variations in their use are mainly determined by the type of crops grown, agroecological conditions, and seasons. When abundant, feed can be conserved, but limited technical skills in conservation methods hinder their adoption practices (Duguma et al., 2017).

Aside from the availability, the nutritional quality of the available feeds poses a significant challenge in smallholder systems (Lukuyu et al., 2011). Although the chemical composition of feed resources varies widely, tropical grasses, present in natural pastures as well as cultivated, ones are characterised by relatively low crude protein (CP) (on average around 3-8% on DM basis) and high fibre contents (up to 80% on DM basis) (Mamo et al., 2023; Njau et al., 2013). Crude protein contents above 7% are required to sustain proper rumen microbial activity (Van Soest, 1982; Chalchissa et al., 2014; Mamo et al., 2023). Similar chemical compositions can be found in most of the available crop residues, with CP contents as low as 2.4% and neutral detergent fibre (NDF) contents as high as 74.2% in oat straw (Ashagrie et al., 2023). The NDF contents can be used to indicate the nutritional quality of feed, with values below 45% considered high quality, between 45 and 65% as medium quality, and above 65% as low quality (Singh & Oosting, 1992). Low CP contents and high fibre contents correlate with low metabolisable energy (ME) contents. Thus, on average, ME content is around 6-7 MJ/kg DM in natural and cultivated grasses, and most crop residues (Chalchissa et al., 2014; Mutimura et al., 2015; Katongole et al., 2016). Among the species present in natural pastures in EAC, *Cyperus* had the lowest ME content (4 MJ/kg DM) (Katongole et al., 2016; Mutimura et al., 2015) whilst Bermuda grass (*Cynodon dactylon L.*) had the highest (8.3 MJ/kg DM) (Gobena et al., 2022). Cultivated grasses, such as *Brachiaria* and Napier grass, had ME contents of 6 and 8 MJ/kg DM, respectively (Chalchissa et al., 2014; Mutimura et al., 2015). Animals that consume diets with low ME contents (<5 MJ/kg DM) may not meet their energy requirements, resulting in poor body condition scores, reduced growth rates, and low milk yields and reproductive performances (Terefe & Walelegne, 2024). Factors affecting forage chemical composition, and hence the nutritional value, include the growth stage and seasonality, among others. As forages mature, grasses in particular, their fibre content increases whilst CP content and digestibility decrease (Njau et al., 2013). Mamo et al. (2023) reported that natural pastures have a lower NDF content during the wet season compared to the dry season, reflecting seasonal fluctuation in forage quality.

Legume plants, on the other hand, have a higher nutritive value due to their higher CP content and relatively lower fibre content. Examples of these are *Desmodium uncinatum*, lucerne (*Medicago sativa*), and lablab (*Lablab purpureus*) (Mazimpaka et al., 2017; Crovetto et al., 2021), and among fodder trees, flat top acacia (*Acacia abissinica*), *Leucaena,* and tree lucerne (*Cytisus proliferus*) (Klapwijk et al., 2014; Tefera et al., 2019; Fekade et al., 2021).

Whilst feed availability and quality impact milk yield by providing the necessary nutrients for production, farmers' feeding practices are also immensely important (Kashongwe et al., 2017b; Khan et al., 2009).

2.2.2 Feeding practices and milk yield

It is common practice for smallholder dairy farmers to keep one or a few more cows confined and/or in small plots of land of less than 1 hectare (Techno-serve, 2008). In EAC, cattle may freely graze, usually on natural pastures when land is available, although this practice is restricted in Rwanda (Techno-serve, 2008; RDDP, 2016). Due to land scarcity, many farmers practice zero- or partial-grazing (Kamanzi & Mapiye, 2012; Bosire et al., 2019). In zero-grazing systems, cows are confined to stalls and are fed through cut-and-carry practices, whilst in partial-grazing systems, cows are confined but allowed to graze, usually tethered, for a few hours a day. Partial- and zero-grazing do not necessarily result in a high milk yield, as the feed supply, in terms of both quantity and quality, is a determining factor of milk production (Gillah et al., 2014). In EAC, traditional feeding systems (free, partial, or zero-grazing) often fail to meet the nutritional needs of dairy cattle, especially during the dry seasons or at the peak of lactation, resulting in low milk yields.

The choice of feed resources used by farmers largely depends on availability, seasonal changes, and feed costs (Kamanzi & Mapiye, 2012; Duguma, 2016). The inclusion of legumes plants may be a good alternative to increase both herbage mass and quality. Indeed, Kabirizi et al. (2013) reported an 80% increase in milk yield when cows were fed Napier grass sown together with centro legume and *Brachiaria* hybrid cv Mulato sown together with *Clitoria* sp, compared to cows fed a monoculture of Napier grass. Similarly, Mutimura et al. (2018) reported increased milk yield when dairy cows fed on Napier grass were supplemented with *Desmodium distortum*, a forage legume. An alternative to combat the low nutritional quality of the available feed resources, whenever possible, is practicing supplementation. For instance, Njau et al. (2013) and Lukuyu et al. (2011) observed that cows free grazing on natural pastures produced about 1.8 to 3.0 L/cow/day, respectively. In contrast, 12 L/cow/d was produced when supplementation occurred with either planted forages such as Napier grass or purchased concentrates, hay, or crop residues. Nalubwama et al. (2016) reported that crossbred lactating dairy cows grazing part-time on natural pastures with crop residues supplementation produced a lower milk yield (3 L/cow/d) than similar cows managed in a zero-grazing system fed predominantly Napier grass supplemented with crop residues and maize bran (6.5 L/cow/d). Supplementing basal diets with higher quality feeds can enhance dairy cattle productivity and milk supply (Khan et al., 2009; Kashongwe et al., 2017b), and crucially, livelihoods (Zerfu et al., 2024).

Methods to improve the nutritive value of poor-quality forages include, among others, physical treatments, such as the chopping of hay or crop residues, as well as chemical treatments like urea (Duguma et al., 2017). Chopping high fibrous feeds may result in an increased feed intake, and thus in an increased supply of nutrients despite a slight decrease in digestibility because of the lower retention time of the feed in the rumen. Tirusew et al. (2023) reported that when cows were supplemented with urea-molasses-treated bamboo leaves, milk yield increased by 40% compared to cows supplemented with untreated bamboo leaves (6.3 vs 4.4 L/cow/d, respectively). Moreover, treating low nutritive feed such as wheat straw with urea has been shown to sustain milk yield, although only to a certain extent (Kashongwe et al., 2017a). In households with limited access to feed resources, wheat straw can help to maintain milk production by serving as a basic roughage source during feed shortages. However, the adoption of such simple and cost-effective technologies is often constrained by limited access to extension services, lack of knowledge, and financial barriers (Balehegn et al., 2021). The same could be said about using forage conservation methods, such as hay or silage.

2.3 Milking practices and milk handling in East African countries

Hygienic practices at the farm level play a critical role in influencing both milk yield and quality. Gillah et al. (2014) reported that in Tanzania, 77% of farmers kept their cattle in unhygienic environments (Figure 1), increasing the risk of contamination and udder infections. Lack of knowledge about milking hygiene and udder health combined with poor practices such as using dirty utensils and unwashed hands contributes to mastitis and milk contamination, making milk unsafe for consumption and shortening its shelf life (Oloo et al., 2023; Terefe & Walelegne, 2024). Limited awareness regarding mastitis detection and its impact on milk quality can lead to milk from infected cows coming into contact with other milk, increasing the risk of contamination (Nyokabi et al., 2021). The consumption of milk with intra-mammary infections poses a serious health risk, since potential pathogens could cause several diseases, e.g., chronic reactive arthritis, meningitis, and miscarriage (Mor-Mur & Yuste, 2010; D'Angelo et al., 2022).

Another important aspect to consider is the use of antibiotics and the presence of their residues in milk. Misuse of antibiotics in humans and animals presents a serious threat to health by contributing to a rise in antimicrobial resistance (Bednarski & Kupczyński, 2024). A study by Nyokabi et al. (2021) noted that most smallholder farmers lack training on animal husbandry, milk safety, and antibiotic use and withdrawal in instances where sick animals require treatment. The authors highlighted that the income from selling milk often collides with the need to discard milk with antibiotic residues (Nyokabi et al., 2021). The consumption of milk containing antibiotic residues can fuel the development of antibiotic resistance (Virto et al., 2022). A review focusing on low- and middle-income countries (Zerfu et al., 2023) found that in 86% of the examined studies households owning cattle have a negative association with smallholders' health outcomes, including increased infection and morbidity.

It is important to ensure that milk remains clean, safe, and of good quality until it is consumed. Milk may be stored in unclean or open containers or left at room temperature for long periods before consumption, providing favourable conditions for bacterial growth (Mpatswenumugabo et al., 2023).

Figure 1. Livestock keeping at smallholder dairy farms in Northern Rwanda.

(Photo: Mukasafari)

2.4 Animal-source foods and chronic undernutrition in children

Stunting, defined as the impaired growth and development in children as a consequence of long-term undernutrition and repeated infections during early childhood, is a widespread problem across LMICs, (González-Fernández et al., 2024). Globally, an estimated 150.2 million children under the age of five are affected by stunting (UNICEF, 2025). In Rwanda the prevalence of stunting has decreased from 37.9% in 2017 (Akombi et al., 2017) to 33.1% in 2020 (RDDP, 2023), but remains above the global target of 23.2% by 2025 (UNICEF, 2025).

Stunting often commences with poor maternal nutrition during pregnancy and is exacerbated by inadequate infant and young child feeding practices (De Onis & Branca, 2016). Inadequate maternal nutrition can lead to intrauterine growth restriction and a low birth weight, rendering children more vulnerable to infections and undernutrition. Limited dietary diversity and a low intake of nutrient-rich foods, including ASF, further contributes to the high rates of stunting among children (Headey et al., 2018). A review focusing on LMICs indicated that livestock ownership can enhance ASF consumption, thereby improving child nutritional outcomes (Chen et al., 2021). For instance, households in Rwanda participating in the *Girinka programme* are reported to have higher dairy consumption (Flax et al., 2021; Rawlins et al., 2014). Additionally, a study across seven Sub-Saharan Africa countries found a strong association between ASF consumption and a reduction in child stunting (Headey et al., 2018).

Whilst breast milk is the primary source of nutrition for infants, it becomes insufficient beyond six months of age or when the mother does not produce enough milk at any stage of breastfeeding, making it essential to introduce complementary foods, such as milk, eggs, meat, and fish (National Institute of Statistics of Rwanda 2021). The consumption of ASF provides essential, bioavailable nutrients that are critical for child growth and development (Beal et al., 2023). For instance, whole milk is rich in protein, calcium, vitamin B12, and zinc, which supports growth and brain development (Yisak et al., 2024). Studies have shown that children in dairy-farmer households experience improved health indicators compared to those without access to milk, with milk consumption being positively associated with improved HAZ-scores (Hetherington et al., 2017; Herrero et al., 2023). Milk also supports maternal health by aiding foetal development and bone strength during pregnancy, as well as breast milk quality during breastfeeding (Marangoni et al., 2018).

Although ASF are important for enhancing human nutrition, they can also pose health risks when contamination occurs during production, handling, or preparation (Chen et al., 2021). Inadequate hygiene and poor food safety practices increase the risk of foodborne illnesses, such as diarrhoea and other infections (Zerfu et al., 2023; Garcia et al., 2023). It has been reported, for instance, that poultry ownership could intensify health risks for children when birds are kept in close proximity to living areas and young children ingest poultry faeces (as seen in Figure 1) (Zerfu et al., 2023).

Chen et al. (2021) highlighted the role of gender in improving nutrition through livestock ownership. Gender imbalance in household decision-making can limit women's ability to allocate resources toward purchasing or keeping ASF for home consumption. When men control household decisions, income from livestock or milk sales is often prioritised for other expenditures whereas women are more likely to use these resources to improve family nutrition (Chen et al., 2021; Flax et al., 2023b). Evidence also indicates that children in households with female or joint livestock ownership tend to have better nutrition than those from households where men alone own livestock (Zerfu et al., 2023).

It has become increasingly evident that improving livestock production through better feeding, farm hygiene, and management can increase the availability of safe ASF for household consumption (Terefe & Walelegne, 2024). Any increase in the production of ASF can also strengthen a household’s livelihood by ensuring surplus production for market sales whilst keeping enough ASF for family nutrition.

3. Aim and objectives

This thesis aimed to investigate how lactating dairy cows are fed, their milk yield and milk handling, and the association between keeping a lactating cow and the occurrence of stunting in young children at smallholder farms in the Northern Province of Rwanda.

The specific objectives were:

- to evaluate the nutritional quality of the feed resources commonly used by the smallholder dairy farmers in the Northern Province of Rwanda,

- to systematically review existing literature on the nutritional quality of available feeds and feeding practices and milk yield of lactating cows at smallholder dairy farms in the EAC,

- to gain knowledge on cow´s housing, milking practices, and milk yield, composition, and quality at the smallholder dairy farms in the Northern Province of Rwanda,

- to assess the role of lactating dairy cows and livestock keeping in association to dietary diversity and the occurrence of stunting in young children at the smallholder farmers in the Northern Province of Rwanda.

Results of this work are expected to be used in the definition of possible interventions that would help enhance the livelihood of the smallholder's households.

4. Materials and methods

An overview of the experiments and papers included in the present doctoral project is presented in Table 1.

Table 1. Overview of the methodology used, and the data collected in the studies included in the thesis.

Study	Methodology	Data type collected
Paper I	Cross-sectional, feed analysis	Household characteristics, feed chemical composition, gas production, organic matter digestibility, and metabolisable energy
Paper II	Systematic review	PRISMA* protocol, feed chemical composition, feeding practices, and milk yield
Paper III	Cross-section study, milk analysis	Household characteristics, farm management practices, milk yield, composition, handling and hygiene.
Paper IV	Cross-sectional, child height	Household characteristics, livestock keeping and stunting in young children.

*Preferred Reporting Items for Systematic reviews and meta-Analyses

4.1 Data collection processes

4.1.1 Description of the study area and participant enrolment (Papers I, III, and IV)

The study was conducted in the five districts of the Northern Province of Rwanda: Burera, Gakenke, Gicumbi, Musanze, and Rulindo (Figure 2). The study was performed as part of a big interdisciplinary project, named *"Undernutrition programme focusing on children and mothers*". To determine the sample population, the study employed a multi-stage sampling strategy (see Utumatwishima et al., 2024). In the first stage, 137 out of 2,744 villages were selected using a geospatial grid-based approach (Figure 2). In the second stage, 630 households were systematically selected, including 178 households with lactating cows. In the final stage, village leaders and community health workers helped to identify households with children aged between 1 to 36 months and their mothers. Households containing a sick child, or mothers aged under 18 or too unwell to answer questions were excluded. During data cleaning, 29 households were excluded due to lack of critical information; among them, 22 had lactating cows. The final sample size consisted of 601 households, 156 of which owned lactating cows.

4.1.2 Questionnaire design and data collection methods (Papers I, III, and IV)

Data was collected using a web-based sampling tool developed through the Internet-based Management System for Environmental Protection and Disaster Risk Management (iMSEP) (Mansourian et al., 2023). This system was designed and implemented by members of the "*Interdisciplinary Undernutrition Programme*" with a geographical information system (GIS) expertise which facilitated efficient and standardised data collection.

The cross-sectional survey was conducted in late November to December 2021. Data collection teams were organised according to expertise, with one group focusing on child and maternal health, and the other on animal production and veterinary aspects. Digital questionnaires were integrated into an Android-based mobile GIS app, enabling geo-coded data collection in the field. Twelve trained enumerators, six doctoral students, and one postdoctoral researcher used GPS-enabled tablets to record household locations whilst collecting data through interviews, taking children's anthropometric measurements and blood samples, and collecting animal feed and milk samples.

The questionnaire was comprised of eleven sections, with the first ten covering socio-demographic and economic status, dietary diversity, human health, domestic violence. The final section gathered information on dairy farm management practices, veterinary extension services, and other related practices.

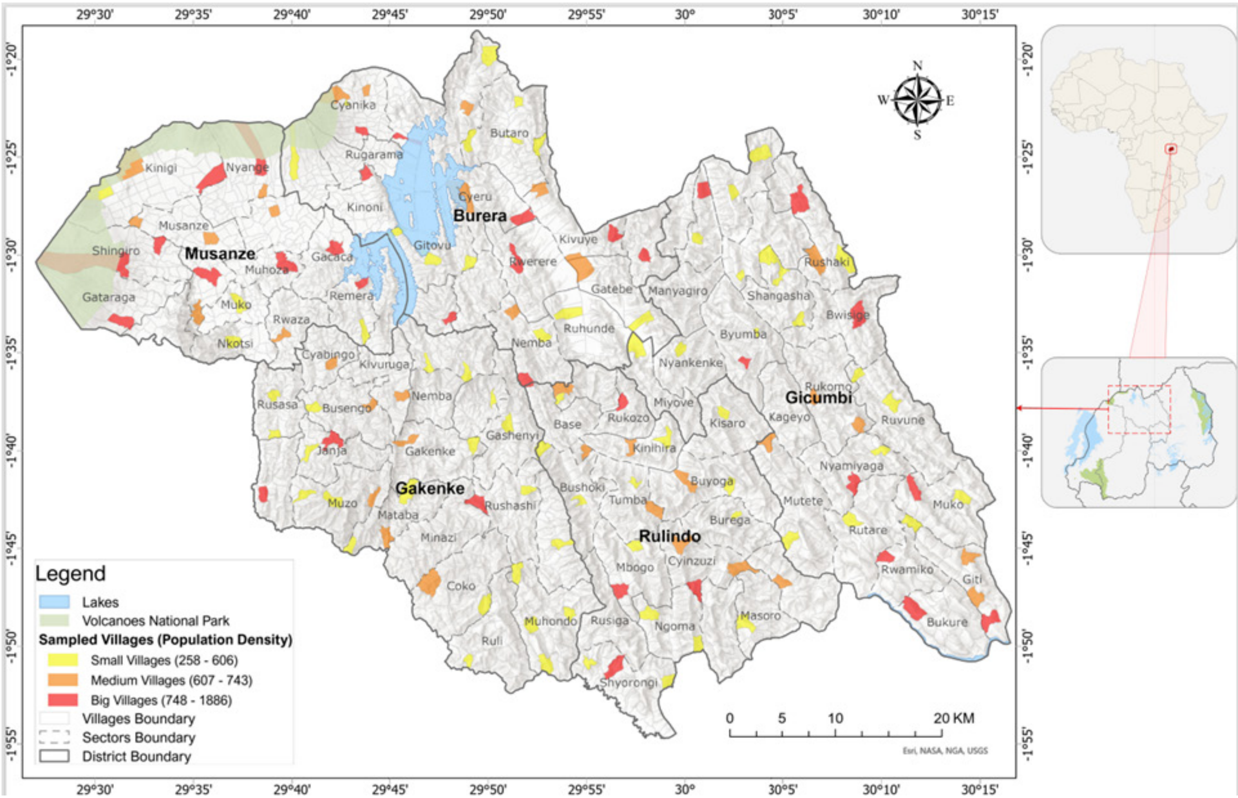


Figure 2. Map of study sites, Northern Province, Rwanda.

Edited by Kagoyire Clarisse

4.1.3 Stunting measurement (Paper IV)

Children's height was measured using a ShorrBoard, with recumbent length taken for children under 2 years of age and standing height for those over 2 years of age. Stunting was assessed using height-for-age z-scores (HAZ), calculated based on demographic and health survey (DHS) standards. Children whose HAZ fell below -2 standard deviation (SD) from the median, based on the World Health Organisation (WHO) child growth standards, were classified as stunted (WHO and UNICEF, 2019).

4.1.4 Individual animal observation (Paper III)

Primary data on animal and environmental variables was collected through a structured, hard-copy observational questionnaire. Information included cow breed and age, body condition score (BCS), estimated animal weight, parity, stage of lactation, calving interval, and average daily milk yield per cow. Milking hygiene conditions were assessed, with particular attention given to udder cleanliness.

4.2 Feed and milk sampling

4.2.1 Feed samples collection (Paper I)

A total of 218 feed samples, each about 0.5 kg, were collected from the feeding troughs or the floor, depending on the farmers' feeding practices. Samples were stored in paper envelopes at room temperature for several days before being air dried at Busogo Campus, University of Rwanda. At the end of collection period, samples were analysed at Rubona Station laboratory of the Rwanda Agriculture and Animal Resources Development Board (RAB).

4.2.2 Milk collection (Paper III)

Milk samples, collected directly from milk storage containers, were immediately placed in a cooling box at 4°C and subsequently transported to the district hospital and stored at −20°C. Prior to analysis, milk samples were transferred to the Busogo campus, University of Rwanda, for storage at −80°C.

4.3 Samples analysis

4.3.1 Feed samples (Paper I)

Feed samples were analysed for crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), and ash, as described in Paper 1. For the estimation of organic matter digestibility (OMD) and metabolisable energy (ME) content, samples were analysed following the protocol for *in vitro* gas production over a 72 hr period (Menke et al., 1979; Osuji et al., 1993). Rumen fluid was collected 15 minutes post-slaughter from cattle at the Huye district slaughterhouse, Rwanda.

4.3.2 Milk samples (Paper III)

Milk samples were analysed for nutrient composition, somatic cell count (SCC), and antibiotic residues. Milk composition was analysed with a Lactoscan Milk Analyser (Milkdata.in, Bangalore, India). The SCC was analysed on-farm using a DeLaval cell counter (DeLaval International AB, Tumba, Sweden). Antibiotic residues were tested using the Delvotest SP-NT kit (DSM, Delft, the Netherlands).

4.4 Systematic review (Paper II)

The systematic review followed PRISMA guidelines (Moher et al., 2015). Peer-reviewed articles published in English between 2010 and 2024 were retrieved from Scopus and Web of Science using Boolean operators ('AND', 'OR') and truncation (*) with relevant keywords. Title, abstract, and full texts were screened by all co-authors, with disagreements resolved through discussion until a consensus was achieved. Studies that did not report data on feed chemical composition or feeding practices linked to milk yield were excluded from the review. Data was compiled in Excel, categorised, and average chemical composition values were calculated for commonly reported feed resources.

4.5 Statistical analysis

Data on chemical composition and *in vitro* gas production in Paper I were subjected to analysis of variance (ANOVA; proc GLM, SAS, version 9.4, SAS Institute Inc., Cary, NC, USA). Differences among means were evaluated by the student-Newman-Keuls (SNK) test at a 5% significance level. In Paper III, a multivariate analysis of variance (MANOVA) was conducted using R software to evaluate the relationships between independent variables and outcomes (milk yield, milk composition, somatic cell count (SCC), and antibiotic residues). Pillai’s Trace was applied to assess the overall effect and partial eta squared was used to determine the effect size for any identified significant associations. In Paper IV, data were statistically analysed by chi-square test, with a level of significance set at $p<0.05$ (proc FREQ, SAS, version 9.4, SAS Institute Inc., Cary, NC, USA).

4.6 Ethical considerations (Papers I, III, and IV)

This research project, identified as project number: 11277, has received ethical approval from the Institutional Research Ethics Review Board (IRB) of the College of Medicine and Health Sciences at the University of Rwanda (reference No: 181/CMHS IRB/2021) (Kagoyire et al., Preprint). Before data collection began, all participants were informed about the study's purpose, procedures, potential risks, and benefits. Prior to participating in the research, each participant signed a written consent form. Participants were assured of their right to participate voluntarily, withdraw at any time, or decline participation without facing any consequences.

5. Results

This section provides a summary of the household characteristics and presents the main findings from in studies in Papers I to IV.

5.1 Household characteristics

The survey showed that 92% of the household heads were male, a stark contrast to the male 8% that were female. Livestock ownership was common, with 84% of households owning at least one species of livestock. Landholding sizes were generally small, with 70% of households being landless, 25% owning between 1 to 5 ha, and only 2% owning more than 5 ha. Most householders practiced mixed crop-livestock farming and, due to limited land, zero-grazing emerged as the predominant feeding practice (Figure 3). Majority of the households (84%) earned less than 36,000 Rwandan francs per month (approximately 27 USD: September 2024) and few (21.9%) had reached secondary level of education.

Figure 3. Cattle fed natural pasture under a zero-grazing system at smallholder dairy farm in Northern Rwanda.

(Photo: Mukasafari)

5.2 Feed resources used by smallholder farmers (Papers I and II)

5.2.1 Feeds resources in the Northern Province of Rwanda (Paper I)

A total of 20 different feeds were identified. Feeds were classified into four categories: roadside vegetation, cultivated grasses, crop residues, and fodder trees. No farmer used concentrates or industrial by-products. Across all districts, 51% of the farmers used roadside vegetation, followed by cultivated grasses (45%), and crop residues (23%). The use of fodder trees was very low (2.3%) and exclusive to households in Musanze district. It was observed that 85% of the feeds were fed to cows together with other feeds, whilst 15% were fed alone. The chemical composition of the reported feeds varied significantly ($p<0.05$) (Figure 4).

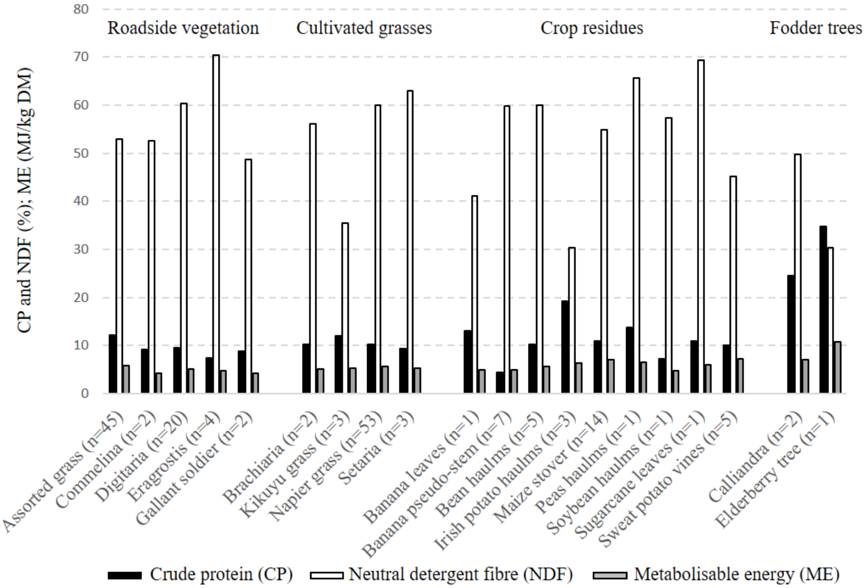


Figure 4: Crude protein, neutral detergent fibre, and metabolisable energy contents in feed resources used by smallholder dairy farmers (Paper I).

On average, roadside vegetation and cultivated grasses had similar contents of CP, NDF, and ME (9.4 and 10.5%; 57.0 and 53.6 %; 4.8 and 5.4 MJ/kg DM, respectively). Crop residues showed more variable chemical composition, with Irish potato haulms having the highest CP content (19.2%) and the lowest NDF content (30.3%). Fodder trees, on the other hand, had high CP and ME contents, on average 29.7% and 8.9 MJ/kg DM, respectively, and a relatively low NDF content, on average 40.1%.

5.2.2 Feed resources in East African Countries (Paper II)

In the literature review (Paper II), 147 feed types were reported. They were grouped into six categories (Table 2). Natural grasses and forbs were the most reported feeds (n=41), followed by crop residues (n=29), cultivated grasses (n=26), fodder trees (n=23), agro-industrial by-products (n=22), and concentrates (n=6) (data not presented here). The feeds displayed substantial variations in chemical composition which are summarised in Table 2 based on the different feed categories (see Paper II for more detailed information).

On average, natural grasses and forbs, cultivated grasses and crop residues had low CP and ME contents and high NDF contents. In contrast, fodder trees, agro-industrial by-products, and commercial concentrates, possessed a higher nutritional quality.

Table 2. Nutrient composition of feed resources used by smallholder dairy farmers in East African Countries (Paper II)

Feeds resources (# of feed resources)	**Feed composition, mean (SD)**			
	CP %	**NDF** %	**ADF** %	**ME** (MJ/kg DM)
Natural grass and forbs (n=36)	7.5 (2.6)	66.6 (9.8)	45.4 (5.5)	6.7 (0.7)
Cultivated grass (n=10)	8.8 (3.7)	62.7 (10.1)	45.6 (6.2)	6.6 (0.4)
Crop residues (n= 17)	7.2 (3.8)	59.6 (15.0)	45.9 (10.3)	7.0 (1.7)
Fodder trees (n= 16)	19.6 (5.4)	46.2 (12.7)	30.9 (9.5)	8.1 (1.3)
Agro-industrial byproducts (n=14)	19.7 (7.9)	42.3 (15.4)	19.6 (11.8)	10.7 (9.1)
Concentrates (n= 6)	16.1 (3.3)	37.3 (10.2)	18.7 (7.8)	10.3 (1.3)

SD= standard deviation, CP=crude protein, NDF= neutral detergent fibre, ADF= acid detergent fibre, ME= metabolisable energy, DM= dry matter

Among natural grasses and forbs, the species with the highest CP content, and lowest NDF content were *Tribulus terrestris* (14.2%), *Cyperaceae sp.* (13.6%), and *Tithonia diversifolia* leaf (16.6%). For cultivated forages the legumes *Desmodium uncinatum* (15.9%) and *Medicago sativa* (19.9%) had the highest CP and lowest NDF contents. Fodder trees with a high CP content were *Maytenus arbutifolia* (27%) *and Cytisus proliferus* (24.4%), as well as the legume trees *Acacia abyssinica* (24.4%) and *Leucaena diversifolia* (23.3%). Reported agro-industrial by-products, were derived from breweries, oil seeds (sunflower and linseed) and cereal grain milling (wheat and maize).

5.3 Feeding practices and milk yield (Paper II)

The literature review (Paper II) involved a total of 22 papers that discuss the feeding strategies used by smallholder dairy farmers across EAC and their impact on milk yield. The strategies were broadly categorised into traditional feeding practices and improved feeding practices (including certain interventions). In EAC, natural grasses and forbs were the primary basal diet used by most farmers. In addition, it was reported that around 40% of the farmers used improved grasses and crop residues, mostly maize stover, as well as a small amount of concentrates during milking. Zero- and partial-grazing systems were the most reported feeding practices. Under traditional feeding systems, milk yield ranged from 1.8 to 10.4 L/cow/d. In contrast, studies where improved feeding practices were tested reported higher milk yields, ranging from 3.0 to 16.0 L/cow/d. The use of intercropping grasses and legumes, as well as the use of homemade supplements, provides farmers with the opportunity of increasing milk yields at a low cost (Kabirizi et al., 2013; Gakige at al., 2020; Crovetto et al., 2021).

Alongside feeding practices, factors such as seasonality, cow genetics, and stage of lactation were also found to influence milk yield (Klapwijk et al., 2014; Mazimpaka et al., 2017; Maleko et al., 2018; Gakige et al., 2020; Tadesse et al., 2022).

5.4 Farm management practices and their effect on milk yield and quality (Paper III)

Among the surveyed smallholders, only 21.1% had experience in rearing dairy cattle and 59.2% kept farm records. Most of the cows were crossbreed (87.5%), followed by Ankole cattle (7.9%). Farmers kept their cows in a zero-grazing system, with none practicing free grazing, and only 15% practicing partial-grazing (Paper III). Collected or purchased forages were used by 55% of farmers. Hand milking was universal and 88.5% of the farmers practiced some form of hygiene routine by washing hands and udders with clean water, whilst 1.9% did not employ any hygiene measures. Mastitis screening was practiced by 63.8% of farmers.

Milk yield was significantly ($p<0.05$) influenced by breed, body condition score (BCS), parity, and milking frequency, but not stage of lactation (Table 3). Milk yield was higher for cows with a good body score than those with a moderate or poor body score. Crossbreed cows produced more milk than Ankole cows. Multiparous cows had a higher milk yield than primiparous ones. Milking twice a day instead of just once resulted in a higher milk yield.

Table 3. Mean comparison in relation to daily milk yield (L/cow/day) of dairy cows in the Northern Province of Rwanda.

Variable (N=150)	**Means** (SD)	***p-value***
Body condition score		*<0.001*
Good	5.4 (2.6) [a]	
Moderate	3.8 (1.9) [b]	
Poor	2.3 (1.3) [c]	
Breed		*<0.001*
Ankole	1.9 (1.1) [b]	
Crossbreed	4.1 (2.1) [a]	
Friesian	8.0 (2.8) [a]	
Jersey	6.0 (2.4) [a]	
Parity		*0.002*
Primiparous	3.9 (2.2) [b]	
Multiparous	4.9 (2.6) [a]	
Stage of lactation		*0.287*
Early (1-100 days)	3.8 (1.9)	
Middle (101-200 days)	3.8 (2.2)	
Advanced (>200 days)	4.5 (2.7)	
Milking frequency		*<0.001*
Once	3.5 (2.0) [b]	
Twice	5.1 (2.4) [a]	

[a, b, c] Means values within columns with different superscripts differ significantly at $p<0.05$.

Milk yield, composition and somatic cell count (SCC) varied widely (Table 4). A high percentage (34%) of the milk samples originated from cows with udder infections and 12.9% of the samples tested positive for antibiotic residues.

Table 4. Milk yield, composition, somatic cell counts (SCC), and antibiotic residues at smallholders' dairy farms in the Northern Province of Rwanda.

	Descriptive statistics			
Variables	**Minimum**	**Mean**	**Maximum**	**SEM**
Milk yield (L/cow/d)	0.5	4.0	12.0	0.19
Fat (%)	1.1	3.1	8.1	0.10
Protein (%)	2.0	3.3	4.8	0.03
Lactose (%)	3.2	5.0	6.7	0.33
Solids no fat (%)	6.7	9.2	12.3	0.06
Density (kg/m^3)	1,022	1,033	1,045	0.20
SCC* (cells/ml)	101,000	470,908	2,516,000	44,888
	Positive		**Negative**	
Antibiotics residues, n (%)	19 (12.9)		128 (87.0)	

SEM: standard error of the mean, * SCC values classified as <300,000 cells/ml are acceptable (65.8% of samples), and >300,000 cells/ml not acceptable (34.2% of samples) (COMESA, 2006)

5.5 Livestock keeping and child stunting (Paper IV).

The percentage of young, stunted children on average 27.3% (SD= 3.16), was similar across the different districts of the Northern Province of Rwanda, irrespective of the size of the households (the number of people/household).

Majority of the households (84%) had at least one species of livestock, and a few (4%) kept more than 4 different species of livestock. During data collection, 26.2% of households owned lactating cows, and 38.9% kept non-lactating cattle, either a bull or a non-lactating cow (information not recorded) (Table 5). Among those owning dairy cows, 59% kept them for the purpose of obtaining milk for both home consumption and commercial, whilst 41% kept them primarily for home consumption only. Other livestock species included pigs, poultry, goats, sheep, and rabbits, owned by 18.6, 20.8, 20.1, 14.9, and 7.1% of households, respectively.

There were no significant associations (p>0.05) between the ownership of lactating cows, cattle, pigs, goats, sheep, or rabbits and the occurrence of stunting in children (Table 5). However, there was a tendency (p= 0.0776) for households that possess lactating cows to have a 25% lower prevalence of child stunting. On the other hand, poultry ownership was significantly associated with a 40% lower stunting rate (p=0.0081) in households with poultry compared to those without. However, neither milk nor egg consumption showed a significant association with stunting (p>0.05).

Table 5. Prevalence of stunting in relation to livestock ownership among smallholder farmers in the Northern Province of Rwanda.

		Total		No-stunting		Stunting		Chi-q	*P=*
		n	%	n	%	n	%		
Any livestock	No	96	16.2	68	70.8	28	29.2	0.1871	*0.6653*
	Yes	496	83.8	362	73.0	134	27.0		
Lactating cows	No	437	73.8	309	70.7	128	29.3	3.1141	*0.0776*
	Yes	155	26.2	121	78.1	34	21.9		
Non-lactating cattle	No	363	61.3	268	73.8	95	26.2	0.6731	*0.4120*
	Yes	229	38.7	162	70.7	67	29.3		
Pigs	No	482	81.4	344	71.4	138	28.6	2.0912	*0.1482*
	Yes	110	18.6	86	78.2	24	21.8		
Poultry	No	469	79.2	329	70.1	140	29.9	7.0179	*0.0081*
	Yes	123	20.8	101	82.1	22	17.9		
Goats	No	473	79.9	345	72.9	128	27.1	0.1091	*0.7412*
	Yes	119	20.1	85	71.4	34	28.6		
Sheep	No	504	85.1	369	73.2	135	26.8	0.5722	*0.4494*
	Yes	88	14.9	61	69.3	27	30.7		
Rabbits	No	557	94.1	402	72.2	155	27.8	1.0151	*0.3137*
	Yes	35	5.9	28	80.0	7	20.0		

n: number of households.

5.6 Other factors contributing to stunting in children (Paper IV)

There was a lower prevalence (p=0.0003) of stunting among children in households with kitchen gardens (24.3%) versus those without (41.8%). Birth weight was significantly and inversely associated with stunting (p=0.017) with stunting rates 16.6 and 24.5% higher among children with low and very low birth weights, respectively, compared to those with a normal birth weight. The incidence of stunting was higher (p<0.001) for 2-3-year-old children (36.6%) than younger children (10.7%). Breastfeeding was associated with a 37% reduction in stunting, with stunting prevalence observed at 38.7% among non-breastfed children compared to 24.3% among breastfed children. The proportion of stunting was found to be higher for male children than female children (p<0.001; 34.1 and 22.2%, respectively). Maternal education level was inversely associated with stunting, with 41% of children with uneducated mothers being stunted compared to 28% among those whose mothers attended primary or secondary education.

6. Discussion

In spite of recent progress, stunting among small children remains a serious public health concern in Rwanda, affecting a substantial proportion of children under five years of age, particularly those from the poorest households (RDDP, 2023). A better understanding on how feeding and milking practices affect milk production and quality, and child nutrition at smallholder dairy farms is critical to address undernutrition in children.

6.1 Effects of farm management practices on milk yield and quality

6.1.1 Feeds and feeding lactating dairy cows

In this thesis, around 70% of the visited households were landless as a consequence of land scarcity, forcing farmers to manage their livestock under a zero-grazing, stall-feeding, system (Papers I and II; Kamanzi & Mapiye, 2012; Duguma et al., 2017). Under zero-grazing conditions in low-income settings, farmers feed their cattle with whatever feeds is available, regardless of the nutritional quality, mostly harvested from roadside areas, communal lands, crop residues, or by purchasing cultivated forages. A total of 20 different feeds were used by the smallholder dairy farmers (Paper I). None of the farmers supplemented their cows' diets with either agro-industrial by-products or concentrates. However, it should be noted that the sampling of the feeds was performed on a single occasion and therefore does not represent all the feeds that farmers may have been used throughout the whole year in different seasons. Sample collection took place during the transition from the short rainy season to the short dry season (November to December), a period characterised by limited rainfall. During this time, certain farmers rely on crop residues for their cattle to compensate for the scarcity of fresh forage; similar to what was reported by Mutimura & Everson (2011). Despite this limitation, the feeds reported in Paper I were similar to those documented in South-western Rwanda (Klapwijk et al., 2014) and other East African countries (Paper II; Kiggundu et al., 2014; Maleko et al., 2018; Mamo et al., 2023; Mutimura et al., 2015).

Most of the feeds possessed a poor nutritional quality, characterised by relatively low CP and ME, and high NDF contents(Paper I). Assorted grass and Napier grass were the most commonly used feed resources. However, Napier grass samples had a relatively high fibre content of and low protein content. This suggests that there is room to improve its nutritional quality, as well of the other cultivated grasses, by cutting it in an earlier growth stage (Mutimura et al., 2017) and feeding it fresh or conserving it as hay or silage (Balehegn et al., 2021). Although the majority (85%) of feeds were fed together with others (Paper I), this was most likely because of a shortage of feeds rather than an attempt to achieve a more balanced diet. Most of the farmers, nearly 80%, did not possess any knowledge about managing and feeding lactating cows (Paper III). Possible ways of improving the nutritional quality of the diets for dairy cows may involve comprise the inclusion of high-quality feed resources such as fodder trees (Papers I and II), and legume plants (Paper II). Aside from few crop residues, none of the farmers fed their animals legumes (Paper I). The introduction of species such as tree lucerne (*Cytisus proliferus*), characterised by high CP and low NDF contents, is an alternative to explore, carrying the additional advantage of being a perennial N-fixing and soil restoring species (Wocheslånder et al., 2016; Tefera et al., 2019; Paper II). However, an important aspect to consider is the presence of toxins and/or anti-nutritional substances that are most common in legumes and trees (Van Soest, 1982). The cropping of grass-legume mixtures has been consistently linked to increased milk yield. For instance, Kabirizi et al. (2013; Paper II) reported an 80% increase in milk yield when cows were fed grasses sown together with legumes compared to cows fed a monoculture of grass as a consequence of an increased herbage mass with a higher CP content. However, land shortage remains a significant challenge as many smallholder farmers prioritise land for food crops, leaving insufficient space for forage production (Kamanzi & Mapiye, 2012; Tefera et al., 2019). Nonetheless, integrating forage crops with food crops through intercropping, planting high-yielding fodder species along field boundaries or on marginal lands, and growing multipurpose fodder trees that require less space would help to increase the availability of feed resources (Balehegn et al., 2020). Another effective strategy would be to promote community-based fodder production, where farmers collaborate to grow and manage fodder on communal or underutilised land (Balehegn et al., 2020; Kamanzi & Mapiye, 2012).

Another alternative, for certain households, would be the use of homemade supplements, which may allow farmers to increase milk yields at a low cost (Gakige et al., 2020; Paper II); or, for instance, to treat fibrous feed resources, low in CP, with urea (Tirusew et al., 2023; Paper II). None of the visited farmers practiced any form forage conservation (Paper I). Ineffective feed conservation strategies further exacerbate seasonal feed gaps (Nyokabi et al., 2022). There is a need to promote feeding conservation practices to enhance productivity and resilience (Bosire et al., 2019). Unfortunately, farmers frequently lack the knowledge, skills, and equipment to effectively preserve feed through silage or hay-making techniques (Duguma & Janssens, 2016). A review by Balehegn et al. (2022) highlighted the importance of practical, community-based approaches in promoting forage conservation among smallholder farmers. The authors emphasised that hands-on training on demonstration farms, supported by cooperatives and strengthened through farmer-to-farmer learning and participatory extension methods, can build confidence, enhance knowledge exchange, and increase the adoption of improved technologies to address feed scarcity (Balehegn et al., 2022). In a Kenyan study, Sakwa et al. (2021) demonstrated that training farmers on feed conservation practices and ratio formulation resulted in an 18 to 31% increase in milk yield.

In addition to feed resources, the quantity and quality of the water supply is crucial to sustain milk synthesis (Amenu et al., 2013). In the current thesis, most farmers (92%) stated that they provide their cows with water (data not presented). Unfortunately, no information was retrieved about how much and how often the cows were supplied with water. The poor nutritional quality of most of the available feed resources, together with a possible inadequate supply of feed and water, may explain, at least in part, the low milk yields reported by the farmers (Paper III).

6.1.2 Milk yield and quality

In the present thesis, milk yields were low, on average 4 L/cow/d, ranging between 0.5 to 12 L/cow/d (Paper III) which is well within the range of milk yields reported in EAC (Paper II). Poor animal management practices, such as insufficient feed, minimal disease control, poor housing, low water availability, and poor hygiene, are most likely the causes for the low recorded milk yields, as most of the visited farmers had no previous experience in rearing dairy cattle. Unfortunately, because no data on feeding management, amount and frequency of feeding, for instance, was collected, these factors could not be included in the data analysis referring to milk yield and composition (Paper III). However, there was an association between BCS and milk yield, suggesting that better fed cows were able to produce more milk than poorer fed ones.

Most of the farms, 87.5%, had crossbreed cows, 4.6% had exotic breeds, and 7.9% had Ankole cattle. Native Ankole cattle produced less milk than the other breeds possibly due to its lower genetic potential for milk synthesis (Duguma, 2020; Manzi et al., 2020), although this was not assessed under directly comparable management and feeding conditions (Paper III). Whilst this fact may encourage farmers to look for cattle with a higher genetic potential for milk yield, it is worth noting that higher genetic potential necessitates higher nutritional requirements (Oloo et al., 2023).

Good practices at milking in relation to udder health are also vital. Although 89% of households reported washing the udder before milking (Paper III), the use of poor-quality water to clean cow udder and milking utensils can increase the risk of contamination to other animals or post-milk contamination if not properly managed (Nyokabi et al., 2021). In this thesis (Paper III), 34.2% of the milk samples had a SCC above 300,000 cells/ml, i.e. were unacceptable for drinking or delivery to a milk collection centre in the Rwandan context (COMESA, 2006). Intra-mammary infections are considered the most common reason for increased SCC in milk. Oloo et al. (2023) reported that mastitis-affected cows, indicated by a high SCC, often produce milk contaminated with pathogens which reduces its shelf life. Milk is a product that spoils rapidly without proper hygiene, making strict cleanliness essential to maintain its safety and quality (Nyokabi et al., 2021; Terefe & Walelegne, 2024).

The relatively high level of antibiotic residues in the milk samples (Paper III) was most likely due to ongoing or recent treatments for intra-mammary infections or other diseases, as reviewed by Virto et al. (2022). Most farmers in this thesis did not keep records, which could be one reason why they may milk cows under treatment without respecting milk withdrawal times. A previous study in Rwanda revealed that 97.4% of farmers used antibiotics on-farm and nearly 60% of farmers bought antibiotics without a veterinary prescription (Manishimwe et al., 2017). Routine testing for SCC and antibiotic residues on the farm and at milk collection centres is important to ensure high quality and safety of raw milk to safeguard consumers. Considering that farmers often ignore the mandatory withdrawal period, it is crucial to highlight the risks of consuming and selling milk with antibiotic residues. At the same time, it is necessary to reinforce the controls leading to the compulsory discard of milk containing antibiotics (Nyokabi et al., 2021).

Proper animal keeping management, including adequate nutrition, shelter, hygiene, and healthcare, would increase both the quantity and quality of the milk, ultimately helping to secure smallholders' livelihoods.

6.2 Linking livestock keeping to stunting among young children

In this thesis, the prevalence of stunting among young children was similar across districts in the Northern Province, averaging at 27.3% and thereby slightly exceeding the mean global value of 23.2% (UNICEF, 2025). There was, however, a much higher prevalence in different clusters, as observed in boys (34.1%) and in children born with a low weight (50.0%) (Paper IV).

Among the various livestock species, only owning poultry was significantly associated with a lower occurrence of stunting, which agrees with the observations compiled in the review by Zerfu et al. (2023). Keeping a lactating cow only showed a tendency of being positively associated with reduced stunting. Dror & Allen (2014) and Mosites et al. (2017) reported a positive association between child growth and dairy consumption. However, in the present thesis (Paper IV), with the exception livestock ownership, the consumption of either eggs or milk by small children did not exhibit any association with stunting. Even when it was expected that dairy production would relate to dairy consumption, smallholders can sell part of the produced ASF, which is reflected by the fact that the proportion of households with children consuming milk was numerically lower than those with a lactating cow (23.0 *vs* 26.2 %, respectively). The same effect was observed for eggs.

Whilst 20.8% of the households had chickens, eggs were consumed by children at only 4.6% of the households. Selling ASF for income generation may reduce the amount available for household consumption, particularly children (Flax et al., 2023a,b). However, the data on food consumption by children in the present study refers to a short period of time using a 24-hour recall period. It is worth noticing that livestock keeping, including cattle, may also have a negative effect on stunting (Zerfu et al., 2023). Negative effects of livestock on stunting predominantly due to infection diseases and/or parasites transmitted from livestock to humans. By keeping livestock in close contact (also seen in this thesis, Figures 1 and 3), with their manure, as well as ASF consumption, could result in the transmission of zoonotic pathogens and other illness through contaminated food, air, and water sources (Zambrano et al., 2014; Zerfu et al., 2023). As, farmers keep their livestock close to their steady home. A study on children aged 12-59 months reported a significant association between a contaminated household environment and an increased risk of stunting (40% of stunted children came from a highly contaminated household) (Fregonese et al., 2017). A review by Mpatswenumugabo et al. (2023) highlighted that zoonotic diseases pose a significant health risks, particularly in EAC where raw milk consumption is common. Certain populations such as pregnant women and children, are the most vulnerable since potential pathogens can cause several diseases aside from food poisoning (D'Angelo et al., 2022; Mpatswenumugabo et al., 2023).

Nonetheless, associations between animal keeping and stunting should not be exclusively considered as causative, as the occurrence of stunting in children arises from a constellation of different factors (Paper IV).

Gender differences were evident, with boys being more affected than girls. This is likely linked to both biological vulnerability and gender-related caregiving practices (Thurstans et al., 2020).

Furthermore, it was observed that children born with low and very low weight, as well as those that were not breastfed, had a stunting prevalence almost double that of children born with a normal weight or those were breastfed. The importance of good maternal health during pregnancy and during the 6 months post-partum in the prevention of stunting has been well-documented (Hadi et al., 2021; Halli et al., 2022).

6.3 A multidisciplinary approach to tackle child undernutrition

Undernutrition is a complex issue affecting millions of children under five years of age worldwide. It is caused by insufficient intake or absorption of nutrients, leading to poor growth, low weight, weakened immunity, and, in severe cases, increased risk of illness or death. Forms of undernutrition include *stunting* (low height for age), *wasting* (low weight for height), and being *underweight* (low weight for age) (Akombi et al., 2017).

Multiple factors contribute to undernutrition, including inadequate diets, poor health services, and socio-economic conditions (Utumatwishima et al., 2024; Ndagijimana et al., 2025). Numerous studies have investigated the causes of stunting, concluding that a multidisciplinary approach is essential to effectively reduce any form of undernutrition (Akombi et al., 2017; Utumatwishima et al., 2024; Zerfu et al., 2023). The current `undernutrition sub-programme´, which this thesis is part of, integrates diverse disciplines such as public health, gender and social sciences, agricultural practices (including livestock), and geospatial information technology. The aim is to identify possible causes of undernutrition among young children at smallholder households in the Northern Province of Rwanda to address the problem more effectively and holistically.

The multidisciplinary approach of the sub-programme aligns with recommendations from Kanmodi et al. (2024), who emphasised the need to consider the multiple factors that influence child nutrition, from individual characteristics to socio-economic, cultural, and environmental contexts. As part of the `undernutrition sub-programme´, this thesis sought to understand how livestock feeding practices, and milk yield and quality, relate to child stunting.

7. Conclusions and future perspectives

7.1 Conclusions

This thesis aimed to investigate feeding practices for lactating dairy cows, their milk yield and handling, and the association between owning a lactating cow and the occurrence of stunting in young children at smallholder farms in the Northern Province of Rwanda. Although most smallholder farmers were landless, 65 % owned cattle and most owned at least one species of livestock. At the time of the survey, a quarter of the households possessed a lactating cow, managed under a zero-grazing system. Beyond the main findings presented above, several additional conclusions emerged from this thesis:

- Available feed resources used by farmers consisted, predominantly, of roadside vegetation, crop residues, and in lesser extent, cultivated grasses. Most of these feeds were generally of poor nutritional quality, characterized by low protein, high fibre, and low energy contents. None of the farmers practiced feed conservation or utilised commercial or agro-industrial by-products as supplements.

- The review study revealed that East African farmers utilised a variety of feed resources, largely consistent with those previously described. Reported feeding systems comprised either traditional or improved practices, with specific interventions being common in improved systems. Milk yields were consistently lower in traditional feeding systems compared with improved feeding practices.
- Majority of the lactating cows were crossbreeds, whilst less than 10% were Ankole. Milk yield, which averaged only 4 L/cow/day,

was influenced by factors such as breed, parity, stage of lactation, and milking practices. Low yields were most likely due to limited availability and poor quality of feed resources, coupled with limited knowledge on feeding lactating cows (the amount, frequency, and even water supply), with almost 80% of the farmers lacking proper management skills.

- A third of the cows had impaired udder health indicated by high somatic cells counts in milk, which affect milk production and quality, and 13% of the milk samples contained antibiotic residues. Consumption of milk from cows with intra-mammary infections, represents a considerable public health risk. Misuse of antibiotics, as well as consuming milk with antibiotic residues, can contribute to the development of antibiotic resistance in both cows and humans.
- The prevalence of stunting among young children was on average 27.3%, ranging from 10% to 50%. Ownership of a lactating dairy cow was not associated with milk consumption and only showed a weak tendency to influence stunting prevalence, while poultry keeping was strongly associated with a reduced risk of stunting.
- Other factors that were significantly associated with child stunting, included child sex and birth weight, breastfeeding, child age, level of education of the mother, household economy and food security, sex of the household head and the presence of a kitchen garden.

A more in-depth analysis of the collected data, taking advantage of the multidisciplinary nature of the current, overall research programme on undernutrition, would provide greater insights into the associations between livestock keeping and child undernutrition. Unfortunately, the cross-sectional design of the present thesis restricts the ability to draw causal conclusions.

7.2 Future perspectives

Undernutrition among children remain a persistent problem in many low-income countries where it contributes significantly to impaired development and child mortality. An important contributor to undernutrition is the low, or null, consumption of ASF, such as meat, milk, and eggs. In rural areas, livestock keeping at smallholder farms has been associated with a higher consumption of ASF and a lower prevalence of stunting in children.

However, overpopulation, land scarcity, and low availability of feed resources, among other factors, preclude an increased ASF production.

Simple practices though challenging to be achieved, have proven to have the potential of improving the nutritional quality of low-quality basal diets. These include harvesting forages at an early growth stage, intercropping with legume species and/or supplementing the basal diets with resources such as fodder trees or homemade concentrates based on locally available and affordable feed resources. Though easy to say, any intervention will face a challenge regarding its adoption. Local farmers must be included in the decision making and design of potential interventions. Promoting community-based fodder production, where farmers collaborate to grow and manage fodder on communal land, could be a viable strategy to overcome the shortage of available feed resources. If the availability of feed resources is increased, both in quantity and quality, and feeding practices are improved, there is room for an increased supply of milk in a relativity short period.

Considering that most farmers lacked any knowledge about managing lactating cows, there is a need for a more active advisory service to train smallholder farmers on animal keeping management including nutrition, shelter, milking routines, hygiene and healthcare. Such actions would increase the quantity and quality of the milk and thus help to enhance smallholders' livelihoods and tackle the high prevalence of stunting in children.

Child undernutrition, the ultimate issue that the programme seeks to address, is undoubtedly an immensely challenging and complex problem to tackle. The preliminary results of this thesis underline, among other factors, the importance of breastfeeding, birth weight, sex of the child, and the mother's nutrition and education level. Given its multifaceted nature, the multidisciplinary approach of the project would certainly provide the necessary information for designing effective future interventions that consider the context of the Northern Province of Rwanda and other similar regions or settings.

Capacity building, such as training of local trainers, it is a way to facilitate positive change. Community-based actions, involving locals, may also be an interesting approach to solve common problems.

References

Akombi, J. B., Agho, E. K., Merom, D., Renzaho, M. A., & Hall, J. J. (2017). Child malnutrition in sub-Saharan Africa: A meta-analysis of demographic and health surveys (2006-2016). *PLOS ONE*, *12*(5), e0177338. https://doi.org/https://doi.org/10.1371/journal. pone.0177338

Amejo, G. A., Gebere, M. Y., & Kassa, H. (2018). Integrating crop and livestock in smallholder production systems for food security and poverty reduction in sub-Saharan Africa. *African Journal of Agricultural Research*, *13*(25), 1272–1282. https://doi.org/10.5897/ajar2018.13020

Amenu, K., Markemann, A., Roessler, R., Siegmund-Schultze, M., Abebe, G., & Valle Zárate, A. (2013). Constraints and challenges of meeting the water requirements of livestock in Ethiopia: Cases of Lume and Siraro districts. *Tropical Animal Health and Production*, *45*, 1539–1548. https://doi.org/10.1007/s11250-013-0397-0

Ashagrie, A. K., Feyissa, F., Kebede, G., Faji, M., Mohammed, K., Mengistu, G., Kitaw, G., Dejene, M., Geleti, D., Minta, M., Rios, E. F., Balehegn, M., & Adesogan, A. T. (2023). Enhancing dairy productivity through best bet feeding interventions under smallholders in the central highlands of Ethiopia. *Frontiers in Animal Science*, *4*(1118437). https://doi.org/10.3389/fanim.2023.1118437

Balehegn, M., Ayantunde, A., Amole, T., Njarui, D., Nkosi, B. D., Müller, F. L., Meeske, R., Tjelele, T. J., Malebana, I. M., Madibela, O. R., Boitumelo, W. S., Lukuyu, B., Weseh, A., Minani, E., & Adesogan, A. T. (2021). Forage conservation in sub-Saharan Africa: Review of experiences, challenges, and opportunities. *Agronomy Journal*, *114*, 75–99. https://doi.org/10.1002/agj2.20954

Balehegn, M., Duncan, A., Tolera, A., Ayantunde, A. A., Issa, S., Karimou, M., Zampaligré, N., André, K., Gnanda, I., Varijakshapanicker, P., Kebreab, E., Dubeux, J., Boote, K., Minta, M., Feyissa, F., & Adesogan, A. T. (2020). Improving adoption of technologies and interventions for increasing supply of quality livestock feed in low- and middle-income countries. *Global Food Security*, *26*(100372). https://doi.org/10.1016/j.gfs.2020.100372

Beal, T., Gardner, C. D., Herrero, M., Iannotti, L. L., Merbold, L., Nordhagen, S., & Mottet, A. (2023). Friend or Foe? The Role of Animal-Source Foods in Healthy and Environmentally Sustainable Diets. *Journal of Nutrition*, *153*, 409–425. https://doi.org/10.1016/j.tjnut.2022.10.016

Bedada, K. W., Kechero, Y., & Janssens, G. P. J. (2021). Seasonal and agro-ecological associations with feed resource use and milk production of ranging dairy cows in the Southern Ethiopian Rift Valley. *Tropical Animal Health and*

Production, *53*(411). https://doi.org/10.1007/s11250-021-02867-0
Bednarski, M., & Kupczyński, R. (2024). Factors Affecting Milk Productivity, Milk Quality and Dairy Cow Health. *Animals*, *14*(3707). https://doi.org/10.3390/ani14243707
Bingi, S., & Tondel, F. (2015). Recent developments in the dairy sector in Eastern Africa. *European Centre for Development Policy Management*, *78*. http://ecdpm.org/wp-content/uploads/BN-on-dairy-sector-in-EA_final1.pdf
Bosire, C. K., Rao, J., Muchenje, V., Van Wijk, M., Ogutu, J. O., Mekonnen, M. M., Auma, J., Lukuyu, B., & Hammond, J. (2019). Adaptation opportunities for smallholder dairy farmers facing resource scarcity: Integrated livestock, water and land management. *Agriculture, Ecosystems and Environment*, *284*(106592). https://doi.org/10.1016/j.agee.2019.106592
Chalchissa, G., Mekasha, Y., & Urge, M. (2014). Feed resources quality and feeding practices in urban and peri-urban dairy production of Southern Ethiopia. *Tropical and Subtropical Agroecosystems*, *17*, 539–546.
Chen, D., Mechlowitz, K., Li, X., Schaefer, N., Havelaar, A. H., & McKune, S. L. (2021). Benefits and Risks of Smallholder Livestock Production on Child Nutrition in Low- and Middle-Income Countries. *Frontiers in Nutrition*, *8*(751686). https://doi.org/10.3389/fnut.2021.751686
COMESA. (2006). *East Africa Standard, Raw Cow Milk- Specification*. 457. https://ia802900.us.archive.org/18/items/eas.67.2006/eas.67.2006.pdf
Crovetto, G. M., Magnoli, F., Chiaravalli, M., Njeru, T., Gitau, J. W., & Colombini, S. (2021). Nutritive value of forages and diets in some small-scale dairy farms in Kiambu County, Kenya in the short rains season. *Tropical Grasslands-Forrajes Tropicales*, *10*(1), 69–77. https://doi.org/10.17138/TGFT(10)69-77
D'Angelo, L., Paradiso, R., Alfano, D., Riccardi, M. G., Borriello, G., & Galiero, G. (2022). First Report on Abortion Caused by Salmonella enterica subsp. enterica Serovar Enteritidis in Water Buffalo (Bubalus bubalis). *Frontiers in Veterinary Science*, *9*(July). https://doi.org/10.3389/fvets.2022.894154
De Onis, M., & Branca, F. (2016). Childhood stunting: A global perspective. *Maternal and Child Nutrition*, *12*, 12–26. https://doi.org/10.1111/mcn.12231
Dror, D. K., & Allen, L. H. (2014). Dairy product intake in children and adolescents in developed countries: Trends, nutritional contribution, and a review of association with health outcomes. *Nutrition Reviews*, *72*(2), 68–81. https://doi.org/10.1111/nure.12078
Duguma, B. (2020). Productive and reproductive performance of crossbred and indigenous dairy cows at smallholdings in selected towns of Jimma Zone, Ethiopia. *Animal Production Science*, *61*, 92–100. https://doi.org/10.1071/AN19380
Duguma, B. (2022). Farmers' perceptions of major challenges to smallholder dairy farming in selected towns of Jimma Zone, Oromia Regional State, Ethiopia: possible influences, impacts, coping strategies and support required. *Heliyon*, *8*(e09581). https://doi.org/10.1016/j.heliyon.2022.e09581
Duguma, B., Dermauw, V., & Janssens, G. (2017). The assessment and the farmers'

perceived ranking of feed resources and coping strategies with feed scarcity in smallholder dairy farming in selected district towns of Jimma Zone, Ethiopia. *Tropical Animal Health and Production*, *49*, 923–935. https://doi.org/10.1007/s11250-017-1274-z

Duguma, B., & Janssens, G. P. J. (2016). Assessment of feed resources, feeding practices and coping strategies to feed scarcity by smallholder urban dairy producers in Jimma town, Ethiopia. *SpringerPlus*, *5*(717). https://doi.org/10.1186/s40064-016-2417-9

Dumas, S. E., Kassa, L., Young, S. L., & Travis, A. J. (2018). Examining the association between livestock ownership typologies and child nutrition in the Luangwa Valley, Zambia. *PLOS ONE*, *13*(2), e0191339. https://doi.org/10.1371/journal.pone.0191339

FAO, IFAD, UNICEF, WFP, & WHO. (2024). In Brief to The State of Food Security and Nutrition in the World 2024 – Financing to end hunger, food insecurity and malnutrition in all its forms. *Rome, FAO*. https://doi.org/https://doi.org/10.4060/cd1276en

Fekade, M., Bayissa, M., & Nurfeta, A. (2021). Nutritive value of major browse species in east dembia district, central gondar, Ethiopia. *Agricultural Science Digest*, *41*(1), 76–80. https://doi.org/10.18805/ag.D-192

Flax, V. L., Ouma, E. A., Baltenweck, I., Omosa, E., Girard, A. W., Jensen, N., & Dominguez-Salas, P. (2023b). Pathways from livestock to improved human nutrition: lessons learned in East Africa. *Food Security*, *15*, 1293–1312. https://doi.org/10.1007/s12571-023-01382-4

Flax, V. L., Ouma, E. A., Schreiner, M. A., Ufitinema, A., Niyonzima, E., Colverson, K. E., & Galiè, A. (2023a). Engaging fathers to support child nutrition increases frequency of children's animal source food consumption in Rwanda. *PLoS ONE*, *18*(4), e0283813. https://doi.org/10.1371/journal.pone.0283813

Flax, V. L., Ouma, E., Izerimana, L., Schreiner, M. A., Brower, A. O., Niyonzima, E., Nyilimana, C., Ufitinema, A., & Uwineza, A. (2021). Animal source food social and behavior change communication intervention among girinka livestock transfer beneficiaries in rwanda: A cluster randomized evaluation. *Global Health: Science and Practice*, *9*(3), 640–653. https://doi.org/10.9745/GHSP-D-21-00082

Fregonese, F., Siekmans, K., Kouanda, S., Druetz, T., Ly, A., Diabaté, S., & Haddad, S. (2017). Impact of contaminated household environment on stunting in children aged 12-59 months in Burkina Faso. *Journal of Epidemiology and Community Health*, *71*, 356–363. https://doi.org/10.1136/jech-2016-207423

Gakige, J. K., Gachuri, C., Butterbach-Bahl, K., & Goopy, J. P. (2020). Sweet potato (Ipomoea batatas) vine silage: A cost-effective supplement for milk production in smallholder dairy-farming systems of East Africa? *Animal Production Science*, *60*, 1087–1094. https://doi.org/10.1071/AN18743

Garcia, S. N., Mpatswenumugabo, J. P. M., Ntampaka, P., & Nandi, S. (2023). A one health framework to advance food safety and security : An on- farm case

study in the Rwandan dairy sector. *One Health*, *16*(January), 1–37. https://doi.org/10.1016/j.onehlt.2023.100531
Gillah, K. A., Kifaro, G. C., & Madsen, J. (2014). Effects of management practices on yield and quality of milk from smallholder dairy units in urban and peri-urban Morogoro, Tanzania. *Tropical Animal Health and Production*, *46*, 1177–1183. https://doi.org/10.1007/s11250-014-0624-3
Gobena, G., Urge, M., Hundie, D., & Kumsa, D. (2022). Identification and evaluation of agro-ecological variation in dry matter yield and nutritional values of local grasses used as livestock feed in Adola Reedde, Guji Zone, Ethiopia. *Journal of Applied Animal Research*, *50*(1), 369–379. https://doi.org/10.1080/09712119.2022.2080212
González-Fernández, D., Williams, T. S., Vaivada, T., & Bhutta, Z. A. (2024). Early Growth and Impacts on Long-Term Neurodevelopment and Human Capital. *Annals of Nutrition and Metabolism*, *0*(0), 1–14. https://doi.org/10.1159/000540874
Habiyaremye, N., Ouma, E. A., Mtimet, N., & Obare, G. A. (2021). A Review of the Evolution of Dairy Policies and Regulations in Rwanda and Its Implications on Inputs and Services Delivery. *Frontiers in Veterinary Science*, *8*(611298). https://doi.org/10.3389/fvets.2021.611298
Hadi, H., Fatimatasari, F., Irwanti, W., Kusuma, C., Alfiana, R. D., Ischaq Nabil Asshiddiqi, M., Nugroho, S., Lewis, E. C., & Gittelsohn, J. (2021). Exclusive breastfeeding protects young children from stunting in a low-income population: A study from eastern indonesia. *Nutrients*, *13*(12), 1–14. https://doi.org/10.3390/nu13124264
Halli, S. S., Biradar, R. A., & Prasad, J. B. (2022). Low Birth Weight, the Differentiating Risk Factor for Stunting among Preschool Children in India. *International Journal of Environmental Research and Public Health*, *19*(3751). https://doi.org/10.3390/ijerph19073751
Headey, D., Hirvonen, K., & Hoddinott, J. (2018). Animal sourced foods and child stunting. *American Journal of Agricultural and Applied Economics*, *100*(5), 1302–1319. https://doi.org/10.1093/ajae/aay053
Herrero, M., Grace, D., Njuki, J., Johnson, N., Enahoro, D., Silvestri, S., & Rufino, M. C. (2012). The roles of livestock in developing countries. *Animal*, *7*(Suppl.1), 3–18. https://doi.org/10.1017/S1751731112001954
Herrero, M., Mason-D'Croz, D., Thornton, P. K., Fanzo, J., Rushton, J., Godde, C., Bellows, A., de Groot, A., Palmer, J., Chang, J., van Zanten, H., Wieland, B., DeClerck, F., Nordhagen, S., Beal, T., Gonzalez, C., & Gill, M. (2023). Livestock and Sustainable Food Systems: Status, Trends, and Priority Actions. *Science and Innovations for Food Systems Transformation*, 375–399. https://doi.org/10.1007/978-3-031-15703-5_20
Hetherington, J. B., Wiethoelter, A. K., Negin, J., & Mor, S. M. (2017). Livestock ownership, animal source foods and child nutritional outcomes in seven rural village clusters in Sub-Saharan Africa. *Agriculture and Food Security*, *6*(9), 1–11. https://doi.org/10.1186/s40066-016-0079-z

Kabirizi, J., Ziiwa, E., Mugerwa, S., Ndikumana, J., & Nanyennya, W. (2013). Dry season forages for improving dairy production in smallholder systems in Uganda. *Tropical Grasslands-Forrajes Tropicales*, *1*, 212–214. https://www.tropicalgrasslands.info/index.php/tgft/article/view/TGFT%281%29212-214/52

Kamanzi, M., & Mapiye, C. (2012). Feed inventory and smallholder farmers' perceived causes of feed shortage for dairy cattle in Gisagara District, Rwanda. *Tropical Animal Health and Production*, *44*, 1459–1468. https://doi.org/10.1007/s11250-012-0087-3

Kanmodi, K. K., Amzat, J., & Aminu, K. (2024). Theories, determinants, and intervention models and approaches on inequalities of undernutrition amongst under fives: A literature review. *Health Science Reports: Narrative Review*, *7*(e2078). https://doi.org/https://doi.org/10.1002/hsr2.2078

Kashongwe, B. O., Bebe, B. O., Migwi, P. K., & Onyango, T. A. (2017a). Integrating Characterization of Smallholders' Feeding Practices with On-Farm Feeding Trials to Improve Utilization of Crop Residues on Smallholder Farms. *Advance in Agriculture*, *2017*(6952407), 7. https://doi.org/https://doi.org/10.1155/2017/6952407

Kashongwe, O. B., Bebe, B. O., Matofari, J. W., & Huelsebusch, C. G. (2017b). Effects of feeding practices on milk yield and composition in peri-urban and rural smallholder dairy cow and pastoral camel herds in Kenya. *Tropical Animal Health and Production*, *49*, 909–914. https://doi.org/10.1007/s11250-017-1270-3

Katongole, C. B., Kabirizi, J. M., Nanyeenya, W. N., Kigongo, J., & Nviiri, G. (2016). Milk yield response of cows supplemented with sorghum stover and Tithonia diversifolia leaf hay diets during the dry season in northern Uganda. *Tropical Animal Health and Production*, *48*, 1463–1469. https://doi.org/10.1007/s11250-016-1119-1

Khan, M. J., Peters, K. J., & Uddin, M. M. (2009). Feeding Strategy For Improving Dairy Cattle Productivity In Small Holder Farm In Bangladesh. *Bangladesh Journal of Animal Science*, *38*(1 & 2), 67–85. https://doi.org/10.3329/bjas.v38i1-2.9914

Kiggundu, M., Kabi, F., Mette, V., Nalubwama, S. M., & Odhong, C. (2014). Management and use of dairy cattle feed resources on smallholder certified organic pineapple farms in Central Uganda. *Journal of Agriculture and Environment for International Development*, *108*(2), 207–225. https://doi.org/10.12895/jaeid.20142.253

Klapwijk, C. J., Bucagu, C., van Wijk, M. T., Udo, H. M. J., Vanlauwe, B., Munyanziza, E., & Giller, K. E. (2014). The "One cow per poor family" programme: Current and potential fodder availability within smallholder farming systems in southwest Rwanda. *Agricultural Systems*, *131*, 11–22. https://doi.org/10.1016/j.agsy.2014.07.005

Lokuruka, N. I. M. (2020). Food and Nutrition Security in East Africa (Rwanda, Burundi and South Sudan): Status, Challenges and Prospects. In *Food Security*

in Africa. https://doi.org/10.5772/intechopen.95037
Lukuyu, B., Franzel, S., Mudavadi, P. O., & Duncan, A. J. (2011). Livestock feed resources: Current production and management practices in central and Northern rift valley provinces of Kenya. *Livestock Research for Rural Development*, *23*(5). https://www.researchgate.net/publication/287168075
Maleko, D., Ng, W. T., Msalya, G., Mwilawa, A., Pasape, L., & Mtei, K. (2018). Seasonal variations in the availability of fodder resources and practices of dairy cattle feeding among the smallholder farmers in Western Usambara Highlands, Tanzania. *Tropical Animal Health and Production*, *50*, 1653–1664. https://doi.org/10.1007/s11250-018-1609-4
Mamo, B., Mengistu, A., & Shenkute, B. (2023). Feed Resources Potential, and Nutritional Quality of Major Feed Stuffs in the Three Agro-Ecological Zone of Mixed Farming System in Arsi Zone, Ethiopia. *Asian Journal of Research in Animal and Veterinary Sciences*, *6*(3), 241–252. https://doi.org/10.9734/ajravs/2023/v6i3251
Manishimwe, R., Nishimwe, K., & Ojok, L. (2017). Assessment of antibiotic use in farm animals in Rwanda. *Tropical Animal Health and Production*, *49*(6), 1101–1106. https://doi.org/10.1007/s11250-017-1290-z
Mansourian, A., Matchanov, M., Farnaghi, M., & Pilesjö, P. (2023). iMSEP: a GIT-based digital solution for disaster management. In *Hydro-Meteorological Hazards, Risks, and Disasters* (pp. 323–334). https://doi.org/10.1016/B978-0-12-819101-9.00012-1
Manzi, M., Rydhmer, L., Ntawubizi, M., D', C., Hirwa, A., Karege, C., & Strandberg, E. (2020). Milk production and lactation length in Ankole cattle and Ankole crossbreds in Rwanda. *Tropical Animal Health and Production*, *52*, 2937–2943. https://doi.org/10.1007/s11250-020-02311-9
Marangoni, F., Pellegrino, L., Verduci, E., Ghiselli, A., Bernabei, R., Calvani, R., Cetin, I., Giampietro, M., Perticone, F., Piretta, L., Giacco, R., La Vecchia, C., Brandi, M. L., Ballardini, D., Banderali, G., Bellentani, S., Canzone, G., Cricelli, C., Faggiano, P., … Poli, A. (2018). Cow's Milk Consumption and Health: A Health Professional's Guide. *Journal of the American College of Nutrition*, *38*(20124). https://doi.org/10.1080/07315724.2018.1491016
Matovu, J., & Alçiçek, A. (2023). Feed resources used for small ruminant nutrition in Sub-Saharan Africa: a case study of Uganda. *Tropical Animal Health and Production*, *55*(377). https://doi.org/10.1007/s11250-023-03781-3
Mazimpaka, E., Mbuza, F., Michael, T., Gatari, E. N., Bukenya, E. M., & James, O. A. (2017). Current status of cattle production system in Nyagatare District-Rwanda. *Tropical Animal Health and Production*, *49*, 1645–1656. https://doi.org/10.1007/s11250-017-1372-y
McMahon, K. (2016). Herding Livestock Programs toward Nutrition: A Critical Analysis with a Focus on Rwanda's Feed the Future Dairy Program. In *Global Food Security Project* (Issue November, 2016). https://doi.org/https://doi.org/10.21955/gatesopenres.1115405.1
Menke, K. H., Raab, L., Salewski, A., Steingass, H., Fritz, D., & Schneider, W.

(1979). The estimation of the digestibility and metabolizable energy content of ruminant feedingstuffs from the gas production when they are incubated with rumen liquor in vitro. *Journal of Agriculture Science, Cambridge*, *93*, 217–222. https://doi.org/https://doi.org/10.1017/S0021859600086305

MINAGRI. (2025). *Ministry of Agriculture and Animal Resources: Annual Report 2023/2024*. https://www.minagri.gov.rw/index.php?eID=dumpFile&t=f&f=113084&token=834276a7fcb9607d03f1a4828041c9ff44b20b5a

MINAGRI, NISR, WFP, UNICEF, EU, & USAID. (2018). Comprehensive Food Security and Vulnerability Analysis (CFSVA) Rwanda. In *Rome: World Food Programme* (Issue December, 2018). https://doi.org/https://docs.wfp.org/api/documents/WFP-0000103863/download/

Moher, D., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P., Stewart, L. A., & PRISMA-P, G. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Bio Medical Central Research*, *4*(1). https://doi.org/http://www.systematicreviewsjournal.com/content/4/1/1

Mor-Mur, M., & Yuste, J. (2010). Emerging bacterial pathogens in meat and poultry: An overview. *Food and Bioprocess Technology*, *3*(1), 24–35. https://doi.org/10.1007/s11947-009-0189-8

Mosites, E., Aol, G., Otiang, E., Bigogo, G., Munyua, P., Montgomery, J. M., Neuhouser, M. L., Palmer, G. H., & Thumbi, S. M. (2017). Child height gain is associated with consumption of animal-source foods in livestock-owning households in Western Kenya. *Public Health Nutrition*, *20*(2), 336–345. https://doi.org/10.1017/S136898001600210X

Mpatswenumugabo, J. P., Mukasafari, M. A., Ndahetuye, J. B., Wredle, E., & Båge, R. (2023). A systematic literature review of milk consumption and associated bacterial zoonoses in East Africa. *Journal of Applied Microbiology*, *134*, 1–13. https://doi.org/10.1093/jambio/lxad080

Mutimura, M., Cyprian, E., Idupulapati, M. R., & Ignatius, V. N. (2017). Effect of cutting time on agronomic and nutritional characteristics of nine commercial cultivars of Brachiaria grass compared with Napier grass during establishment under semi-arid conditions in Rwanda. *African Journal of Agricultural Research*, *12*(35), 2692–2703. https://doi.org/10.5897/ajar2017.12474

Mutimura, M., Ebong, C., Rao, I. M. and, & Nsahlai, I. V. (2015). Nutritional values of available ruminant feed resources in smallholder dairy farms in Rwanda. *Tropical Animal Health and Production*, *47*, 1131–1137. https://doi.org/10.1007/s11250-015-0839-y

Mutimura, M., Ebong, C., Rao, I. M., & Nsahlai, I. V. (2018). Effects of supplementation of Brachiaria brizantha cv . Piata and Napier grass with Desmodium distortum on feed intake, digesta kinetics and milk production in crossbred dairy cows. *Animal Nutrition*, *4*, 222–227. https://doi.org/10.1016/j.aninu.2018.01.006

Mutimura, M., & Everson, T. M. (2011). Assessment of livestock feed resource-use patterns in low rainfall and aluminium toxicity prone areas of Rwanda. *African Journal of Agricultural Research*, *6*(15), 3461–3469. https://doi.org/10.5897/AJAR10.315

Nalubwama, S., Kabi, F., Vaarst, M., Smolders, G., & Kiggundu, M. (2016). Cattle management practices and milk production on mixed smallholder organic pineapple farms in Central Uganda. *Tropical Animal Health and Production*, *48*(8), 1525–1532. https://doi.org/10.1007/s11250-016-1123-5

National Institute of Statistics of Rwanda, (NISR) [Rwanda], Ministry of Health Rwanda, (MOHR) [Rwanda], & ICF. (2021). *Rwanda Demographic and Health Survey 2019-20, Final Report. Kigali, Rwanda, and Rockville, Maryland, USA: NISR and ICF.* https://statistics.gov.rw/sites/default/files/documents/2025-01/Rwanda DHS 2019-20_Final report_N.pdf

Ndagijimana, A., Elfving, K., Umubyeyi, A., & Lind, T. (2025). Identification of amendable risk factors for childhood stunting at individual, household and community levels in Northern Province, Rwanda – a cross-sectional population-based study. *BMC Public Health*, *25*(1087). https://doi.org/10.1186/s12889-025-22329-8

NISR. (2023). National Institute of Statistics of Rwanda: The Fifth Rwanda Population and Housing Census, Main Indicators Report, February 2023. https://statistics.gov.rw/publication/main_indicators_2022

Njau, F. B. C., Lwelamira, J., & Hyandye, C. (2013). Ruminant livestock production and quality of pastures in the communal grazing land of semi arid central Tanzania. *Livestock Research for Rural Development*, *25*(8). https://doi.org/https://www.researchgate.net/publication/255965191

Nyokabi, N. S., Luning, P. A., Phelan, J. E., Creemers, J., Lukuyu, B., Bebe, B. O., & Oosting, S. J. (2022). Intra-annual variation in feed and milk composition in smallholder dairy farms in Kenya. *NJAS: Impact in Agricultural and Life Sciences*, *94*(1), 137–155. https://doi.org/10.1080/27685241.2022.2135391

Nyokabi, S., Luning, P. A., de Boer, I. J. M., Korir, L., Muunda, E., Bebe, B. O., Lindahl, J., Bett, B., & Oosting, S. J. (2021). Milk quality and hygiene: Knowledge, attitudes and practices of smallholder dairy farmers in central Kenya. *Food Control*, *130*, 108303. https://doi.org/10.1016/j.foodcont.2021.108303

Oloo, R. D., Ojango, J. M. K., Ekine-Dzivenu, C. C., Gebreyohanes, G., Mrode, R., Mwai, O. A., & Chagunda, M. G. G. (2023). Enhancing individual animal resilience to environmental disturbances to address low productivity in dairy cattle performing in sub-Saharan Africa. *Frontiers in Animal Science*, *4*(1254877). https://doi.org/10.3389/fanim.2023.1254877

Osuji, P. O., Nsahlai, I. V., & Khalili, H. (1993). Feed evaluation: ILCA Manual 5. In *(International Livestock Centre for Africa), Addis Ababa, Ethiopia*. https://doi.org/https://hdl.handle.net/10568/4491

Rawlins, R., Pimkina, S., Barrett, C. B., Pedersen, S., & Wydick, B. (2014). Got milk? The impact of Heifer International's livestock donation programs in Rwanda on nutritional outcomes. *Food Policy*, *44*, 202–213. https://doi.org/10.1016/j.foodpol.2013.12.003

RDDP. (2016). Rwanda Dairy Development Project: International Fund for Agricultural Development (IFAD): Investing in rural people. Detailed Design Report. In *East and Southern Africa Division Programme Management Department*. https://www.ifad.org/en/web/operations/-/project/2000001195

RDDP. (2023). Rwanda Dairy Development Project- Phase 2: Project Design Report Main report and annexes. In *East and Southern Africa Division Programme Management Department* (Issue Phase 2).

RGB. (2018). *Assesing Girinka Programme (2006-2016). Citizen perspectives. A publication of Rwanda Governance Board (RGB)*. https://doi.org/10.1044/leader.ppl.23062018.24

Sakwa, B., Ondiek, J., King'ori, A., & Ndambi, O. (2021). Effects of fodder conservation and ration formulation interventions on dairy performance in Kenya. *International Journal of Agricultural Research, Innovation and Technology*, *10*(2), 76–83. https://doi.org/10.3329/ijarit.v10i2.51580

Shiferaw, M., Asmare, B., Tegegne, F., & Molla, D. (2018). Farmers perception and utilization status of improved forages grown in the natural resource areas of northwestern Ethiopia. *Biodiversitas*, *19*(4), 1568–1578. https://doi.org/10.13057/biodiv/d190450

Singh, G. P., & Oosting, S. J. (1992). Nutritive value of straw. *NDRI-DCNO, Karnal-132001, Haryana, India*. https://library.wur.nl/WebQuery/wurpubs/fulltext/333874

Tadesse, A., Tesfay, Y., & Fievez, V. (2022). Exploring dietary quality characteristics related to milk yield of crossbred cows in Ethiopian smallholder farms: a clustering and multivariate analysis approach. *Tropical Animal Health and Production*, *54*(89). https://doi.org/10.1007/s11250-021-02874-1

Techno-serve. (2008). East Africa Dairy Development: The Dairy Value Chain in Rwanda Report, October 2008. In *East Africa Dairy Development Program*.

Tefera, S., Asmare, B., & Tegegne, F. (2019). Farmers' utilization practice, yield and chemical composition of selected improved forages grown in natural resource management areas of Farta District, South Gondar Zone, Ethiopia. *Cogent Food and Agriculture*, *5*(1686961). https://doi.org/10.1080/23311932.2019.1686961

Terefe, G., & Walelegne, M. (2024). Effect of feeds and hygienic practices on milk production and its nutritional and microbiological quality. *CABI Reviews*, *19*(1). https://doi.org/10.1079/cabireviews.2024.0017

Thurstans, S., Opondo, C., Seal, A., Wells, J., Khara, T., Dolan, C., Briend, A., Myatt, M., Garenne, M., Sear, R., & Kerac, M. (2020). Boys are more likely to be undernourished than girls: A systematic review and meta-analysis of sex differences in undernutrition. *BMJ Global Health*, *5*(e004030). https://doi.org/10.1136/bmjgh-2020-004030

Tirusew, S., Mekuriaw, Y., Ebro, A., Aranguiz, A. A., & Lee, J. V. D. (2023). Effect of urea-molasses-treated highland bamboo leaves supplementation on lactating crossbred dairy cows nutrient utilization, body weight,milk yield and its composition and economic performance under on-farm condition in Guagusa Shikudad district, Ethiop. *Veterinary Medicine and Science*, *9*, 2269–2277. https://doi.org/https://doi.org/10.1002/vms3.1241

UNICEF, WHO, & WBG. (2025). Levels and trends in child malnutrition. Joint Child Malnutrition Estimates. *UNICEF, WHO and the World Bank Group, July 2025*. https://doi.org/https://data.unicef.org/resources/jme/

USAID. (2020). Feed the future Rwanda, Orora wihaze activity: Understanding influences on demand for and consumption of animal-source foods: Insights from eight Rwandan Districts. https://doi.org/https://manoffgroup.com/wp-content/uploads/Rwanda-Orora-Wihaze-Consumption-Study-Report.pdf

Utumatwishima, J. N., Mogren, I., Umubyeyi, A., Mansourian, A., & Krantz, G. (2024). How do household living conditions and gender-related decision-making influence child stunting in Rwanda? A population-based study. *PLOS ONE*, *19*(3), e0290919. https://doi.org/10.1371/journal.pone.0290919

VanLeeuwen, J. A., Mellish, T., Walton, C., Kaniaru, A., Gitau, R., Mellish, K., Maina, B., & Wichtel, J. (2012). Management, productivity and livelihood effects on Kenyan smallholder dairy farms from interventions addressing animal health and nutrition and milk quality. *Tropical Animal Health and Production*, *44*, 231–238. https://doi.org/10.1007/s11250-011-0003-2

Van Soest, J. P. (1982). Nutritional Ecology of the Ruminant. 2nd Edition. Cornell University Press. 476 00.

Virto, M., Santamarina-García, G., Amores, G., & Hernández, I. (2022). Antibiotics in Dairy Production: Where Is the Problem? *Dairy*, *3*, 541–564. https://doi.org/10.3390/dairy3030039

WHO, & UNICEF. (2019). World Health Organisasion (WHO) and the United Nations Children´s Fund (UNICEF): Recommendations for Data Collection, Analysis and Reporting on Anthropometric Indicators in Children under 5 Years Old: Genev. In *Licence: CC BY-NC-SA 3.0 IGO. Switzerland*. https://iris.who.int/bitstream/handle/10665/324791/9789241515559-eng.pdf?sequence=1&isAllowed=y

Wocheslánder, R., Harper, R. J., Sochacki, S. R., Ward, P. R., & Revell, C. (2016). Tagasaste (Cytisus proliferus Link.) reforestation as an option for carbon mitigation in dryland farming systems. *Ecological Engineering*, *97*, 610–618. https://doi.org/10.1016/j.ecoleng.2016.10.039

World Bank. (2021). Diagnostic Note: Behavioral Insights to Prevent and Reduce Stunting in Rwanda. In *eMind, Behavior, and development Unit*. https://doi.org/https://documents1.worldbank.org/curated/en/099062923172030174/pdf/P16998800dbbd00fa0a4380cd1211e73aa6.pdf

Yami, M., Bedada, B., & Tekemedihin, T. (2013). Enhancing the productivity of livestock production in highland of Ethiopia: Implication for improved on-farm feeding strategies and utilization. *International Journal of Livestock Production*, *4*(8), 113–127. https://doi.org/10.5897/ijlp2012.0145

Yisak, H., Gedamu, D., & Ewunetei, A. (2024). Untimely Initiation of Whole Cow Milk, Stunting, and Related Factors in South Gondar, Ethiopia. *Pediatric Health, Medicine and Therapeutics*, *15*, 159–170. https://doi.org/10.2147/phmt.s454615

Zambrano, L. D., Levy, K., Menezes, N. P., & Freeman, M. C. (2014). Human diarrhea infections associated with domestic animal husbandry: A systematic review and meta-analysis. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, *108*, 313–325. https://doi.org/10.1093/trstmh/tru056

Zerfu, T. A., Nguyen, G., Duncan, A. J., Baltenweck, I., Brown, F., Iannotti, L. L., & McNeill, G. (2023). Associations between livestock keeping, morbidity, and nutritional status of children and women in low and middle-income countries: a systematic review. *Nutrition Research Reviews*, *36*, 526–543. https://doi.org/10.1017/S0954422422000233

Zerfu, T., Duncan, A., Baltenweck, I., & McNeill, G. (2024). Low awareness and affordability are major drivers of low consumption of animal-source foods among children in Northern Ethiopia: A mixed-methods study. *Maternal and Child Nutrition*, *21*(e13720). https://doi.org/10.1111/mcn.13720

Popular science summary

Globally, around 150 million children under five years of age suffer of chronic undernutrition. A form of chronic undernutrition, known as stunting, is characterised by impaired growth and development, and by a reduced cognitive function, limiting children's function and learning abilities. In countries like Rwanda, in East Africa, the prevalence of stunting in young children is high. In rural areas of Rwanda, 36% of children younger than 5 years suffer of stunting. After breastfeeding, animal-source foods like milk, eggs or meat, are a source of essential nutrients critical for child growth and development. At smallholder farms, keeping animals like cattle, goats, pigs, sheep, chickens or rabbits, has been associated with lower prevalence of stunting. The aim of this thesis was to study the association between keeping a lactating dairy cow and the prevalence of stunting in smallholder households in the Northern Province of Rwanda by looking at feeding and milking practices, milk yield and quality, and stunting in young children. In the Northern Province, most of the population practice subsistence farming and the prevalence of stunting is high (41%).

For collecting all necessary data, a total of 601 houses were visited on one occasion during November and December of 2021. At the moment of the visit, different questions covering aspects of demographics, household food security, socioeconomic status, mother and child health, food and water consumed, hygiene, type of animals kept, animal feeding and management, milking practices, and milk yield among others were collected. At the same time, from the 156 households with a lactating cow at the moment of the visit, samples of milk and feed were collected to be later analysed.

Majority of the households had only one cow, and almost all of the cows were permanently kept in small pens and fed manually. To feed their cows, farmers had to harvest herbage from public areas, like roadsides, and/or make

use of crop residues like banana leaves or maize stover, and in few cases, also cultivated grasses. All the available feeds were of poor nutritive quality. Not surprisingly, milk yield was on average low. It was also noticed that one third of the cows had some sort of udder infection (mastitis), and more than one tenth of the milk samples had antibiotics residues. It is worth to mention that the consumption of milk collected from mammary gland with infections, poses a health risk, since potential pathogens could cause several diseases, as well as that the consumption of milk containing antibiotic residues can contribute to the development of antibiotic resistance.

With regard to the association between animals keeping, as a source of animal-source food, and the prevalence of stunting in children, it was observed than only having chickens was associated with a reduced stunting, while owning a lactating cow was only weakly associated. That weak association could have been due to the fact that milk, though available, may not always be given to children but to be sold instead. No association were observed between consumption of milk or eggs and stunting. However, this observation should be taking with care as the information of food consumed by children referred to a short temporal window of 24 hours before the visit.

Besides animal keeping, there were many other factors associated with the prevalence of stunting. Variables that were positively associated with a lower level of stunting were birth weight, breastfeeding, and being a girl rather than a boy. For the mothers, it was observed that the level of education and the body index were positively related to a lower rate of stunting in children. Finally, analysis of household-related data, revealed that households in which the head was a man, as well as household´s economic status and food security were associated with a lower prevalence of stunting.

Stunting in children is a consequence of a constellation of factors, a multilayer problem that requires to be study under a multidisciplinary approach, as in the present case. This thesis is part of a bigger, ongoing project named "A*n interdisciplinary undernutrition programme, focusing on children and their mothers*". Further analysis of the collected data will allow the designing of different interventions to support children's growth and development, improve household livelihoods, and to ensure a better future for present generations, and those to come, in the rural areas of the Northern Province of Rwanda.

Populärvetenskaplig sammanfattning

Globalt sett lider cirka 150 miljoner barn under fem år av kronisk undernäring. En form av kronisk undernäring hos barn, kännetecknas av försämrad tillväxt och utveckling (eng. *stunting*), samt lägre kognitiv funktion, vilket begränsar barns funktion och inlärningsförmåga. I länder som Rwanda i Östafrika är förekomsten av hämmad tillväxt hos små barn hög. På landsbygden i Rwanda lider 36 % av barn yngre än 5 år av hämmad tillväxt. Näst efter amning är livsmedel av animaliskt ursprung, som mjölk, ägg eller kött, en källa till viktiga näringsämnen som är avgörande för barns tillväxt och utveckling. I fattiga hushåll som är småbönder har djurhållning som nötkreatur, getter, grisar, får, kycklingar eller kaniner förknippats med lägre förekomst av hämmad tillväxt. Syftet med denna avhandling var att studera sambandet mellan att hålla en lakterande mjölkko och förekomsten av hämmad tillväxthos småböndernas barn i norra provinsen i Rwanda genom att titta på utfodrings- och mjölkningsmetoder, mjölkavkastning och mjölkkvalitet, samt hämmad tillväxt hos små barn. I norra provinsen bedriver majoriteten av befolkningen självhushållsjordbruk och förekomsten av hämmad tillväxt är hög (41 %).

För att samla data besöktes totalt 601 hushåll vid ett tillfälle under november och december 2021. Vid besöket fick hushållets överhuvud svara på frågor om aspekter av demografi, hushållets livsmedelssäkerhet, socioekonomisk status, mors och barns hälsa, konsumerad mat och vatten, hygien, samt vilka djurslag som fanns i hushållet. Om det fanns en lakterande ko ställdes även frågor om djurens utfodring och skötsel, mjölkningsmetoder och mjölkavkastning bland annat. Samtidigt samlades mjölkprover och foderprover i 156 hushåll som hade en lakterande. Majoriteten av hushållen hade bara en ko, och nästan alla kor hölls permanent i små fållor och utfodrades manuellt. Bönderna skördade gräs från offentliga områden som vägkanter, och/eller använde rester från grödor som bananblad eller majsstrån, och i några fall även odlat gräs. Allt tillgängligt foder var av dålig näringskvalitet. Inte överraskande var mjölkavkastningen i genomsnitt låg. Det noterades också att en tredjedel av korna hade någon form av juverinflammation, och mer än en tiondel av mjölkproverna innehöll antibiotikarester. Konsumtion av mjölk från kor med juverinflammation kan utgöra en hälsorisk, eftersom mjölken kan innehålla sjukdomsalstrande bakterier, medan konsumtion av mjölk som innehåller antibiotikarester kan bidra till utveckling av antibiotikaresistens.

Beträffande sambandet mellan djurhållning och ha tillgång till animaliskt protein och förekomsten av hämmad tillväxt hos barn, observerades att enbart hållande av höns var kopplat till lägre förekomst av hämmad tillväxt, medan det endast var ett svagt samband till att äga en mjölkande ko. Det svaga sambandet kan ha berott på att mjölk, även om den är tillgänglig, inte alltid ges till barnen utan istället säljs. Inget samband observerades mellan konsumtion av mjölk eller ägg och hämmad tillväxt. Denna observation bör dock tas med försiktighet eftersom informationen om barns födointag avser ett kort tidsfönster dygnet före intervjun.

Förutom djurhållning fanns det många andra faktorer kopplade till förekomsten av hämmad tillväxt hos barn. Variabler som hade en positiv effekt på lägre förekomst av hämmad tillväxt var födelsevikt, amning och att vara flicka. Hos mödrarna observerades att utbildningsnivå och BMI var positivt relaterade till en lägre andel hämmad tillväxt hos barn. Slutligen visade en analys av hushållsrelaterad information att när överhuvudet var en man, och när hushållets ekonomi och livsmedelssäkerhet var bättre, var också förekomsten av hämmad tillväxt lägre.

Det är tydligt att hämmad tillväxt hos barn är ett komplext problem som beror på många faktorer och som kräver studier med ett tvärvetenskapligt tillvägagångssätt, som i det aktuella fallet. Denna avhandling är en del av ett större, pågående projekt "*Ett tvärvetenskapligt program mot undernäring, med fokus på barn och deras mödrar*". Vidare analys av den insamlade datan kommer att möjliggöra utformning av olika åtgärder för att stötta barns tillväxt och utveckling, för att säkerställa en bättre framtid för nuvarande och kommande generationer på landsbygden i den norra provinsen i Rwanda.

Incamake (Kinyarwanda)

Ku isi hose, abana bagera kuri miliyoni 150 bafite munsi y'imyaka itanu bafite ikibazo gikomeye cyo kubura intungamubiri igihe kirekire bikongera ibyago byo kurwara indwara zitandukanye. Imwe muri izo hari izwi nko kugwingira (stunting), igaragazwa no kudakura bihagije, kugira ubwonko budakora neza, bigabanya ubushobozi bwo kwiga no gukora. Mu bihugu byo muri Afurika y'Uburasirazuba, n'u Rwanda rurimo, iki kibazo kiracyagaragara mu bana bato. Mu cyaro cyo mu Rwanda, abana bangana na mirongo itatu na gatandatu ku ijana (36%) bari munsi y'imyaka itanu baragwingiye. Nyuma yo konka k'umwana, ibiryo bikomoka ku matungo nk'amata, amagi, cyangwa inyama, ni isoko y'intungamubiri z'ingenzi cyane mu mikurire y'umwana. Ubworozi bw'amatungo nk'inka, ingurube, ihene, intama, inkoko cyangwa inkwavu, bifitanye isano no kugabanya ibyago byo kugira abana bagwingiye. Intego y'ubu bushakashatsi yari ukureba niba kugira amatungo k'inka ikamwa, bifitanye isano no kugabanya kugwingira kw'abana mu miryango y'aborozi mu Ntara y'Amajyaruguru y'u Rwanda. Twari tugamije kureba uko inka igaburirwa, uko ikamwa, umusaruro w'amata, ubuziranenge bw'amata, n'uburyo abana bakura. Mu Ntara y'Amajyaruguru, abaturage benshi bakora ubuhinzi n'ubworozi buciriritse, kandi byagaragaye ko bafite abana benshi bagwingiye bagera kuli mirongo in ena rimwe ku ijana (41%).

Kugirango dufate aya makuru byimbitse, mu kwezi kw' Ugushyingo n'Ukuboza mu mwaka wa 2021, twasuye imiryango 601. Mu gihe twabasuye, twababajije ibibazo byerekeye imibereho y'umuryango, kwihaza mu biribwa, uko babona amafaranga bakoresha murugo, ubuzima bw'umubyeyi n'umwana, ibyo barya, isoko y'amazi n'isuku murugo. Ikindi twarebye ni ubwoko bw'amatungo bafite, ndetse n'abari bafite inka ikamwa babajijwe n'ibijyanye n'uburyo inka zitabwaho harimo kuzigaburira, uko ikamwa, umusaruro w'amata, n'ibindi. Icyo gihe kandi, imiryango 156 yari ifite inka zikamwa, hafashwe amata hamwe n'ibiryo by'izo nka kugira ngo bizakorerwe isuzumwa nyuma.

Imiryango myinshi yari ifite inka imwe ikamwa, zagaragaje ko inka hafi ya zose ziba mubiraro zikaba zigaburirwa ubwatsi. Aborozi benshi bakoresha ubwatsi bahiye ku ntanzi z'imihanda, mu mirima, n'ibisigazwa by'ibihingwa harimo amakoma cyangwa ibisigati by'ibigori ndetse rimwe na rimwe bakoresha ubwatsi buhingwa nk'urubingo. Ibiryo bihanbwa inka hafi ya byose bifite intungamubiri zidahagije. Ibi byatumye umukamo w'amata uba muke cyane. Byongeye kandi, hagaragaye ko kimwe cya gatatu cy'inka zari zirwaye ifumbi, naho kimwe cya cumi by'amata yarafite ibisigazwa by'imiti. Iyo abantu banyweye amata aturutse ku nka zifite uburwayi afite ingaruka ku buzima, naho kunywa amata arimo ibisigazwa by'imiti bishobora kugabanya ubushobozi bwo kuvurwa n'imiti igihe umuntu arwaye.

Ku bijyanye n'uko kugira amatungo bifitanye isano n'igwingira ry'abana, byagaragaye ko kugira inkoko bifitanye isano n'igabanuka ry'igwingira, mu gihe kugira inka ikamwa bifitanye isano nke cyane. Iyi sano nke ishobora guterwa n'uko amata aboneka ashobora kugurishwa aho kugaburirwa abana. Nta sano yabonetse hagati yo gukoresha amata cyangwa amagi n'igabanuka ry'igwingira. Ariko ibi bigomba kwitonderwa kuko amakuru y'ibyo abana barya yari ashingiye ku gihe gito cy'amasaha 24 mbere yo gusura iyi miryango.

Uretse amatungo, hari n'ibindi byinshi bifitanye isano n'igwingira ry'abana. Ibintu byagaragaye ko bigira uruhare mu kugabanya igwingira ku bana n'ibiro by'umwana yavukanye, harimo igihe amara yonswa, no kuba ar'umukobwa kurusha umuhungu. Ku babyeyi, impamyabumenyi y'abo n'ibiro bafite bifitanye isano n'igabanuka ry'igwingira ku bana. Ku miryango, abayobozi b'imiryango baba abagabo, umutungo w'umuryango, n'umutekano w'ibiribwa bifitanye isano n'igabanuka ry'igwingira ry'abana.

Igwingira mu bana ni ikibazo gikomoka ku mpamvu nyinshi zitandukanye kandi gisaba ko gisesengurwa mu buryo bwimbitse, nk'uko byagaragajwe muri ubu bushakashatsi. Ibyanditswe muriki gitabo ni igice cy'umushinga munini kandi ukiri gukorwa witwa "*Porogaramu ihuza abashakashatsi benshi barwanya imirire mibi, bagamije gufasha abana n'ababyeyi babo*,". Gusesengura neza amakuru yakusanyijwe bizafasha gukora gahunda zitandukanye zirimo gufasha abana gukura neza, guteza imbere imibereho y'imiryango, no kwiyubakira ejo hazaza heza h'abana n'ababyeyi batuye mu byaro by'Intara y'Amajyaruguru y'u Rwanda.

Acknowledgements

This work would not have been possible without the support of research institute and funding organisations among others. First, I would like to acknowledge the Swedish International Development Cooperation Agency (SIDA) for funding this study, through its collaboration with the University of Rwanda (grant No: 11277). I also thank the Rwanda Agriculture and Animal Resources Development Board (RAB) for granting permission to use their equipment for sample analysis.

The work described in this thesis was conducted in the department of Applied Animal Science and Welfare (THV) led by Ewa. I would like to extend my special thanks to the administrative staff and researchers from the former (HUV) and the current (THV) departments for their effort in ensuring that all departmental activities, including courses ran smoothly.

My deepest gratitude goes to my main supervisor, Horacio, for his steady support and encouragement throughout my studies. Your constructive feedback and genuine interest have been invaluable, helping me grow as a researcher and improved my writing skills. *Thank you*!

I am deeply grateful to all co-supervisors, Ewa, Renee, Mupenzi, and Baptiste, for unwavering support and guidance throughout this journey. Your encouragement, thoughtful feedback, and generosity with your time have been invaluable to my PhD work. Special thanks to Ewa for introducing me to the interdisciplinary Undernutrition program, where I learned to collaborate across disciplines. I also thank Anselme; although he did not continue with the project, his guidance during that time was appreciated.

Thanks to the team leaders in Rwanda and Sweden: Gunilla, Kristina, Theoneste, and Eric, for coordinating program activities and ensuring everything ran smoothly. I also appreciate the Rwanda project coordination team: Etienne, Aline, Peter, Claudine, Charles, Oreste, Edward, for their support with the administrative processes including, travel and fieldwork.

I am grateful to all the PhD students in the Undernutrition programme for your support during fieldwork, collaboration, among other activities, which made the process both productive and enjoyable. Special thanks to m co-authors Jean Pierre, Diane and Kristina for their valuable contributions. Grateful to Jean Pierre, my Agri-vet colleague, for his encouragement.

I thank all the study participants; without their contributions this thesis would not have been possible. I am also grateful to the RAB laboratory technicians, Corneil, Berthilda, and Vestine, for their valuable assistance with the laboratory analysis.

To my fellow PhD students, past (HUV) and present (THV) -Leo, Anna, Claire, Melania, Markos, Emy, Aprajita, Heidi, Hanna, Leonie, Ashwath, Pontus, Shouwen, Anica, Adnan, Nathaniel, Jhon, Arnold, Patience, and others, thank you for your solidarity! Your advice, laughter and shared frustrations have meant so much to me throughout this journey.

I am sincerely grateful to Johan K (HUV) and Sonia (THV) for their invaluable assistance with administrative matters and ensuring I have accommodation while in Sweden. I also warmly thank my friend, Talin, for her kindness and generously sacrificing her time for me. *Thank you!*

I thank other UR-SIDA colleagues at SLU, Olive, Leo, Christine, Patrick, Theoneste, Alice and Jeanine, for your companionship. Thank you, Gerald N., for your encouragement. *Mwarakoze!*

Outside of my PhD, I would like to thank my extended family for their constant encouragement, which gave me strength throughout this journey. Babyeyi beza, mama, mabukwe na databukwe, mwarakoze cyane kumba hafi. I am deeply grateful to the families of Mutembe, Mama Tessy (*my role models*), the late Martin, and Joseph S for providing the foundation that has shaped who I am today. My heartfelt thanks go to my twin sister Marie, all my siblings (Bere, Ino, Vicent….), sis Marietha, all cousins, in-laws Ngutete, Egidia, Ange, Egide, and many others, for their encouragement. Thanks to my young sister Bertha for always being there for my children. Emertha, warakoze cyane kwita ku bana mugihe ntarimpari.

Thanks to the most important people in my life, my husband Claude Sendex, and our children, Ethan, Jaden, and Declan, for their unwavering encouragement. Hubby, you made this journey so much smoother by caring of our children and allowing me to focus on my studies. *I love you dearly!*

I

Tropical Animal Health and Production (2025) 57:301
https://doi.org/10.1007/s11250-025-04562-w

REGULAR ARTICLES

Nutritional quality of feed resources used by smallholder dairy farmers in the Northern Province of Rwanda

Marie Anne Mukasafari[1,2] · Mupenzi Mutimura[3] · Ewa Wredle[2] · Horacio Leandro Gonda[2]

Received: 18 November 2024 / Accepted: 9 July 2025

Abstract

The study aimed to analyse both the type and quality of available feed resources used by smallholder dairy farmers in the Northern Province of Rwanda during the transition period from the short rainy season to the short dry season. A total of 218 feed samples were collected from 178 households. Twenty different feed types were identified and classified into: roadside vegetation (51%), cultivated grasses (45%), crop residues (23%), and cultivated trees (2%). Similar feeds from the same village and district were pooled, and the results from 175 feed samples were analysed for crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), and ash. Organic matter digestibility (OMD) and metabolisable energy (ME) content of the samples was calculated based on in vitro gas production at 24 h (GP_{24}). Among all feed resources used, 42, 32, 12, and 9% of the households, respectively, minimally used feed such as Napier grass, assorted grasses, *Digitaria*, and maize stover. The CP content varied ($p<0.0001$) between 4.4% in banana pseudo-stem and 34.8% in Elderberry tree. Only sweet potato vines, elderberry trees, and maize stover had significantly ($p<0.0001$) higher OMD than the other feeds. The ME values ranged from 4.2 to 10.7 MJ/kg DM, with the lowest values reported for roadside vegetation (*Commelina* and gallant soldier), and the highest for Elderberry tree. Possible interventions such as training farmers in forage management and optimising the use of available feed resources, along with supplementing of higher-quality feed, can escalate productivity.

Keywords East African countries · Forages · Crop residues · Fodder trees · Feed quality · Animal-source food

Introduction

Livestock products serve several important purposes, including their contributions to food security, economic development, and cultural practices with high income from sales of animal products globally (Flax et al. 2023). Livestock contribute around 13% and 28% of global calories and protein, respectively, through direct consumption of animal-source foods (ASF) such as meat, eggs, or milk and provide essential nutrients for meeting humans' nutritional requirements (McMahon 2016). Dairy products, for instance, are a valuable source of calcium, protein, and energy for young children, as well as pregnant or lactating women (McMahon 2016). Adequate intake of ASF, especially during pregnancy and the critical first 1000 days of life, has the greatest impact on children's future growth and overall well-being (Martorell 2017). In most low-income countries such as Rwanda, the *per capita* consumption of ASF remains low (Balehegn et al. 2020). In Rwanda, even a low consumption of milk and milk products of 7.5 kg/capita/year, represents the main contributor to the food supply among other animal products, followed by meat and fisheries (Rwanda Food Balance Sheets 2017–2021) (NISR 2023). In smallholder farms, the amount of milk consumed at the household level is dependent on the amount produced at the household. In Rwanda the Self-Sufficient Ratio (SSR), the proportion of food consumed by a household that are produced at the same household, for animal products is 93.6% (Rwanda Food Balance Sheets 2017–2021). In relation to the low consumption of

✉ Marie Anne Mukasafari
anne.mukasafari@slu.se

1 Department of Animal Production, University of Rwanda, Box 57, Nyagatare, Rwanda

2 Department of Applied Animal Science and Welfare, Swedish University of Agricultural Sciences, Box 7024, Uppsala 750 07, Sweden

3 Rwanda Agriculture and Animal Resources Development Board, Box 5016, Kigali, Rwanda

Published online: 18 July 2025

ASF, around 6.7% of children below the age of 5 experience chronic malnutrition with a 33.1% occurrence of stunting in Rwanda (National Institute of Statistics of Rwanda 2021).

It has been reported that milk yield at the majority of smallholder dairy farm is low, on average 3.2 L/cow/day (Kamanzi and Mapiye 2012; Klapwijk et al. 2014), limiting the availability of milk for human consumption, as well as the income of the household. Feed scarcity, both in terms of quantity and quality, is the main constraint that hinders livestock production (FAO 2018) as it limits the expression of the genetic potential of the livestock (Duguma 2020; Khan et al. 2009). In tropical countries, the availability of feed resources for livestock is highly dependent on climatic conditions including drought (Onono et al. 2013) and seasonality, particularly during the dry season (Kamanzi and Mapiye 2012; Bedada et al. 2021). Several studies have emphasised that factors such as forage types, phenological stage, and rainfall (Bezabih et al. 2014; Mutimura et al. 2017; Tefera et al. 2019), influence feed chemical composition, intake, digestibility, and therefore, milk production (Melaku et al. 2010; Kashongwe et al. 2017). During the dry season, feed resources are scarce and of low nutritional quality (Khan et al. 2009). In addition, animal breed can significantly affect milk yield, as Ankole crossbreds have the potential of producing more milk than pure Ankole (Manzi et al. 2020; Mukasafari et al. 2025).

A strategy to overcome feed shortage, and to subsequently improve animal productivity, is to cultivate improved forage varieties. However, the growing human population poses a significant challenge for poor smallholder farmers who face land shortage (Kamanzi and Mapiye 2012; Mutimura et al. 2019; Ndah et al. 2022). In addition, because many farmers are engaged in mixed crop-livestock production, a large portion of their land is usually allocated to crop production for human food, rather than for animal feed. Moreover, farmers have poor knowledge regarding pasture conservation and a lack of necessary facilities such as grass chopping and storage, as well as low accessibility to extension services (Kamanzi and Mapiye 2012; Ndah et al. 2022). Furthermore, limited land availability and restrictions on free grazing compel smallholder farmers to adopt zero grazing systems. While these systems allows for better control over feeding, require high input levels, particularly in terms of feeds which pose a significant challenge for resource-constrained households (Duguma 2022).

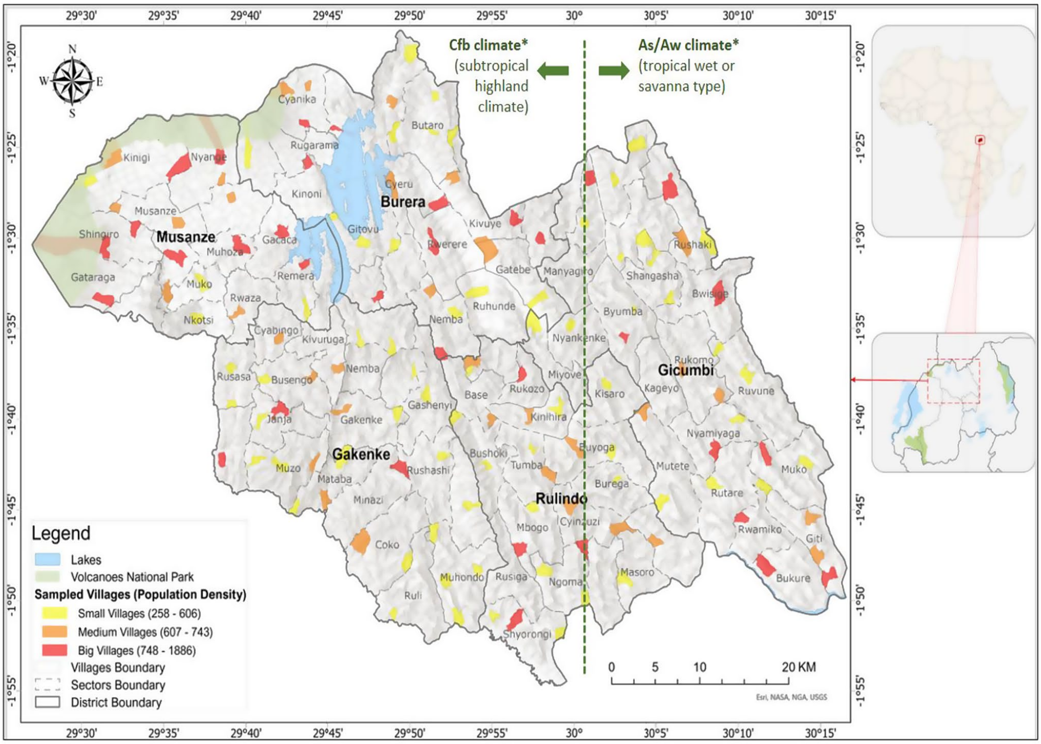
In East African countries, smallholder dairy farmers often rely solely on poor-quality natural forages and crop residues as basal diets for their dairy cattle. The limited availability of high-quality feed resources means that farmers are faced with the challenge of feeding their cattle, with whatever feed is accessible at minimal or no cost which typically results in very low productivity (Kamanzi and Mapiye 2012; Kashongwe et al. 2017). Majority of smallholder dairy farmers cannot supplement poor quality animal diets due to the shortage of quality feed and high cost of concentrates (Kashongwe et al. 2017). Efforts have been made to address feed scarcity and imbalanced diets to enhance animal performance (Khan et al. 2009) and to increase availability and consumption of ASF. To meet animal requirements, information regarding the nutritional value of the feed ingredients is needed (Khan et al. 2009). In Rwanda, information on the chemical composition of locally available feed resources for cattle is scarce. The current study aims to identify and evaluate the nutritional quality of locally available feed resources used by smallholder dairy farmers in northern Rwanda.

The present study is part of a bigger transdisciplinary project, which focuses on undernutrition in both children and their mothers. The project encompasses various fields of science including medicine and health sciences, agricultural and veterinary science, and geographical information systems by identifying a broader range of main risk factors contributing to stunting in children. Results of this study will enable opportunities for designing interventions and strategies aimed at improving feed management practices and, ultimately, enhancing the productivity and resilience of smallholder farmers in Rwanda, thereby addressing the issue of food insecurity.

Materials and methods

Study site

This study was conducted at smallholder farms in the Northern Province of Rwanda, occasionally referred to as the Buberuka agro-ecological zone. The province comprises five districts, namely Burera, Gakenke, Gicumbi, Musanze, and Rulindo, with a total surface of 3,276 km^2. According to the Köppen-Geiger climate classification, the district has areas being classified as a subtropical highland climate (Cfb), in Burera, Gakenke, Musanze, and Western part of Rulindo, while Gicumbi and Eastern part of Rulindo fall under the tropical wet or savannah climate (As/Aw) (Fig. 1). Rwanda generally experiences a bimodal rainfall pattern, resulting in four distinct seasons throughout the year, with the long rainy season from March to May, followed by a long dry season from June to mid-September. A shorter rainy season occurs from October to November, followed by a short dry season from December to February (https://www.expertafrica.com/rwanda/weather-and-climate). Northern Province has an estimated elevation of roughly 2,500 m above sea level, highest precipitation levels, cooler temperature averaging between 10 °C and 29 °C, and annual



(*) Climate zones according to **Köppen-Geiger** classification system (https://climateknowledgeportal.worldbank.org/country/rwanda)

As/Aw: Equatorial savanna with dry summer (As), or dry winter (Aw). Area characterized by all tewelve months having a mean temperature greater or equal 18°C and a summer month (As), or a winter month (Aw), with precipitation less than 60 mm.

Cfb: Warm temperate fully humid with warm summer. A climate where the coldest month is warmer than -3°C but colder than +18°C and precipitation is generally the same throughout the year.

(chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.globe.gov/documents/358135/359681/Koppen-Geiger+Guide)

Fig. 1 Map of the study sites, Northern Province, Rwanda (after edition by Kagoyire Clarisse)

rainfall ranging from 1,000 to 1,400 mm. The native vegetation in this zone includes mountain climate zone, forests, natural grasslands, and wetlands, however, extensive agricultural activities have transformed much of the landscape. The study area is characterised by steep slopes and agriculture is the primary livelihood practice. To control soil erosion and improve crop yields, radical terracing is widely practiced within these highlands.

Household selection and study design

The process of household selection involved multi-stage random sampling of villages and participants. In the first stage, 186 out of 2,743 villages were randomly selected using a geospatial grid system, representing 7% of all villages, followed by proportional sampling of households within each selected village (Utumatwishima et al. 2024). The number of households included in the study was estimated using the formula described by Kagoyire et al. (unpublished) after considering the proportion of stunting in the study area (41%; National Institute of Statistics of Rwanda 2021) (Eq. 1).

$$n = \frac{Z^2 \text{ x } p\,(1-p)}{\epsilon^{\,2}} \text{x DEFF} \tag{1}$$

Where: n is the sample size, Z is the z-score or the critical value associated with 95% confidence interval (1.96), p is the estimated proportion of stunting among children in the Northern Province (0.4), ε is the desired level of precision or margin of error (0.05), and DEFF is the design effect of 1.5

(to account for the increased variability that might be due to intra-cluster correlation).

The village leaders and Community Health Workers assisted in identifying households with mothers aged 18 and above, children between 1 months and 3 years of age, preferentially keeping a lactating cow. To guarantee the required sample size for the project on child undernutrition, if a household was unavailable on the day of data collection, a close neighbour was then selected provided that he/she had a similar living condition. A total of 630 households were initially interviewed; but 29 were excluded due to missing essential data. The final dataset included 601 households. Households were interviewed by using a comprehensive questionnaire, comprising a broader range of topics aimed to capture the various factors influencing child and maternal nutrition. The topics included were household characteristics; social support; reproductive history and antenatal care; child health; household dietary diversity; milk processing at the household; violence experience and controlling behaviour; mothers health; gender and decision-making in the household; and extensive agriculture and veterinary medicine. Data were collected only once at each household, from 29th November 2021 to 6th January 2022.

Feed sample collection and preparation

Among all households, 178 (30%) had at least one lactating cow. From those households, a total of 218 feed samples, each weighing around 0.5 kg on fresh basis, were collected. Most households visited used just one type of feed rather than two types (Table 1). After sampling and during working days, feed samples were kept in labelled paper envelopes and stored in nearby district health centres. During storage before drying, samples were allowed to wilt at room temperature avoiding any deterioration due to moist content. By the end of the week, samples were moved to an air-drying room at the University of Rwanda, Busogo Campus to be subsequently transferred to the Rwanda Agriculture and Animal Resources Development Board (RAB) laboratory at Rubona Station for chemical analysis. Feed samples were oven-dried at 65 °C until reaching a constant weight using electronic weighing scale (Adam Equipment.com; Model PW254: UK). Samples of the same feeds and from the same village were combined into one sample. After combining, a total of 175 out of 218 collected feed samples were ground to pass through a 1 mm sieve and kept in airtight containers until analysis (Table 1).

Table 1 Number of samples collected from the households with lactating cattle at different districts in the Northern Province of Rwanda

District	Household visited (n=178)	Feed samples collected (n=218)	Ratio of feeds used per household	Feed samples after combining (n=175)
Burera	32	40	1.25	34
Gakenke	18	27	1.50	18
Gicumbi	54	60	1.11	44
Musanze	40	52	1.30	42
Rulindo	34	39	1.15	37

Chemical analysis

All 175 combined samples were analysed for crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), and ash. Determinations of CP and ash were carried out according to AOAC (2023), and NDF and ADF fractions according to Goering and Van Soest (1970).

In vitro gas production

Prior to the in vitro gas production, feed samples were further grouped. Samples of the same feed resources from different districts were combined based on their NDF levels. This categorisation resulted in 43 out of 175 feed samples being selected for in vitro gas production.

Aliquots of 0.2 g of each sample were weighed into 100-mL airtight glass syringes in triplicate (Samco, Eterna-Matic, Italy). Within 2 h before each incubation, rumen fluid (RF) was collected from slaughtered cattle at Matyazo slaughterhouse in Huye district, Rwanda. Within 15 min after the animal was slaughtered, samples of RF were squeezed, transferred to a pre-warmed thermos, immediately sealed, and delivered to the laboratory. Upon arrival, RF was pooled and filtered using two layers of cheesecloth, then poured into pre-warmed buffer solutions prepared according to Osuji et al. (1993) in a ratio of 1:2 (v/v) with continuous CO_2 flushing. Using a veterinary drenching cannon (HSW, ROUX-REVOLVER, Germany), approximately 30mL of anaerobic buffered RF was pipetted and thoroughly poured into the glass syringes for incubation in an oven at 39 ± 1 ^{0}C for 72 h (Mammart, D_0606´: Model600, Germany). The gas production (GP) was visually recorded by reading the displacement of the plungers at different times of 0, 2, 6, 8, 12, 18, 24, 36, 48, 60, and 72 h. At each reading, syringes were gently shaken. Two to three blank syringes, containing only buffered rumen fluid were also incubated at each of the 4 runs.

Data handling

The collective gas produced was calculated for each glass syringe by computing the difference of gas recorded at a certain time (t_i) and an average of blank syringe (t_0). Cumulative gas production (GP) data were adjusted at the model proposed by Ørskov & Mcdonald. (1979) (Eq. 2):

$$GP\,(t) = a + b(1 - e^{-ct}) \quad (2)$$

Where: GP $_{(t)}$ is the cumulative gas produced at time *t*, '*a*' is gas produced by the soluble fraction (mL), '*b*' is gas produced by insoluble but potentially degradable feed, '*c*' is constant rate of GP (mL/h), and '*t*' is half-time of gas production (h). Organic matter digestibility (OMD) and metabolisable energy (ME) were estimated on the basis of the mean of gas volume produced at 24 h (G_{24}) according to Menke et al. (1979), as follows, Eqs. 3 and 4:

$$\mathrm{OMD}\,(\%) = 148.8 + 8.89\,\mathrm{GP}_{24} + 4.5\mathrm{CP} + 0.651\mathrm{A} \quad (3)$$

Where: G_{24} is the cumulative gas volume at 24 h after inoculation, CP is the crude protein (%), and A is the ash content (%).

$$\mathrm{ME}\left(\frac{\mathrm{MJ}}{\mathrm{kg}}\mathrm{DM}\right) = 2.2 + 0.136\,\mathrm{GP}_{24} + 0.057\mathrm{CP} + 0.0029\mathrm{CP}^2 \quad (4)$$

Where: G_{24} is the cumulative gas volume at 24 h after inoculation, and CP is the crude protein (g/kg DM).

Data analysis

Data on chemical composition and in vitro cumulative gas production were subjected to analysis of variance (ANOVA) using the Statistical Analysis System version 9.4 (SAS Institute Inc., 2016). Significant differences in feed composition parameters among continuous variables were addressed by using GLM procedures of SAS and differences among means were determined by the Student-Newman-Keuls (SNK) test at 5% significance level. The model used for the analyses of nutritional quality was: $Yij = \mu + bi + eij$ where Yij = mean for response variable; μ = overall mean; bi = the effect of the i^{th} feed samples and eij = effect of the random error of the i^{th} feed samples.

Results

Household characteristics

In the study area, 70% of the surveyed households were landless, with the highest number being in the Rulindo District (Table 2). A smaller number of households owned between 1 and 5 ha of land, particularly in the Musanze and Gakenke districts, while very few households owned more than 5 ha. Regarding livestock ownership, on average 64% of households owned cattle. The Gicumbi district had the highest number of households with cattle (76%). In addition to cattle, farmers also owned goats, poultry, pigs, and rabbits (Table 2). Households in the Gicumbi district commonly keep both goats and pigs, while in the Gakenke district, pigs were more common than in other districts. Most households across all five districts fall into the lowest income category 1(<36,000 Frw), with Gicumbi having the greatest percentage compared to Burera districts. A much smaller number of households fall into income category 2 and 3, while very few households reported being unsure of their income, with only 2% or less in most districts.

Feed types

In this study, a total of 20 different feeds were identified. However, only a few were used by a significant number of households. Thus, while Napier grass, assorted grass, *Digitaria*, and maize stover were used by 42, 32, 12, and 9% of households, respectively, all other feeds were used by just less than 5% of households (Table 3). Feed types were classified into four distinct categories, namely roadside vegetation, cultivated grasses, crop residues, and fodder trees. Among the districts, certain differences in the use of the available feed resources were observed. Across all districts, 51% of the farmers used roadside vegetation, followed by cultivated grasses (45%), and crop residues (23%) as their primary feed resources. The use of fodder trees was very low (2.3%), and exclusive for households in Musanze district. Farmers in Burera district used less roadside vegetation and more cultivated grasses than farmers in the other districts. The use of cultivated grasses was great in Burera and Gakenke districts, where nearly 75% of the households used Napier grass. Musanze was the district where the use of cultivated grasses was the lowest, and crop residues used was the greatest. Musanze, Burera, and Gicumbi exhibited a greater diversity of feed resources than Rulindo and Gakenke.

Within roadside vegetation, assorted grass was more frequently used in all districts except in Gakenke, at which *Digitaria* was most used. Napier grass was the most used of all cultivated grasses in all districts, and the only one used in Rulindo and Gakenke. Farmers in Gakenke use exclusively Napier grass, whereas those in Burera used Kikuyu grass, Napier grass, *Brachiaria*, and *Setaria*. Across all districts, common crop residues used were maize stover, sweet potatoes vines, banana pseudo-stem, and bean haulms. Musanze was the exception, where maize stover was used by almost 60% of the households that used crop residues, whilst in the other four districts maize stover was used by only a few households. Fodder trees were exclusively used in Musanze district but only by 10% of the households. Both species, *Calliandra* and Elderberry trees, were fed mixed with other feeds. Most of the different feeds were fed either alone or mixed with others in a similar proportion. Some exceptions

Table 2 Household social-economic characteristics in the Northern Province of Rwanda

Variable	District				
	Burera (n = 129)	Gakenke (n = 130)	Gicumbi (n = 144)	Musanze (n = 96)	Rulindo (n = 102)
Farm size (%)					
Unclassified	4	3	0	3	8
Landless	68	67	69	72	74
< 1 ha	6	5	10	6	7
1–5 ha	20	21	19	19	9
> 5 ha	2	4	2	0	2
Household with cow (%)	52	64	75	53	75
Household with other livestock (%)					
Goat	18	25	30	7	16
Poultry	18	22	28	16	22
Pig	16	36	12	13	21
Rabbit	3	6	6	2	16
Sheep	22	15	9	21	9
Feeding system for cattle (%)*					
Zero grazing	93	100	98	47	84
Semi-zero grazing#	7	0	2	50	16
Grazing	0	0	0	3	0
Major source of forage (%)*^					
Collected (n = 144)	100	94	92	83	94
Planted (n = 132)	79	100	94	57	94
Both practices (n = 86)	31	94	50	63	56
Household income category (%)##					
1	77	85	88	79	86
2	19	8	5	18	11
3	4	5	6	3	1
Dont know	0	2	1	0	2

*Frequency for those owning lactating cow; #Includes tethering; ^each variable was analysed individually; ##household income category: 1 = less than 36,000 Frw (Rwandan Francs); 2 = income between 36,000 to 99,000 Frw; 3 = above 100,000 Frw [1 USD = 1, 325 Frw] (September 2024)

were assorted grasses, Napier grass, and banana pseudo-stem, which were more commonly fed in combination with other feed.

Chemical composition of available feed resources

There was a noticeable variation in the chemical composition of the feed resources utilised by smallholder farmers (Table 4). The CP content ranged from 4.4% in banana pseudo-stem to 34.8% in Elderberry trees. Fodder trees consistently exhibited significantly ($p < 0.0001$) greater levels of CP content compared to other feed resources. There were no significant differences observed in CP content among feeds categorised in roadside vegetation and cultivated grasses. The CP content in crop residues was more variable, where Irish potato haulms had the greatest CP content ($p < 0.0001$). Concerning the average structural constituents, NDF was slightly greater in roadside vegetation especially in *Eragrostis* compared to gallant soldier. Despite numerical differences, there were no significant differences in the content of NDF among all feed resources except between *Eragrostis*, Irish potato haulms, and Elderberry trees. This was also observed for ADF, with the exception of Kikuyu grass which had a lower ADF content ($p < 0.001$) than *Eragrostis* and sugarcane leaves. The average ash content ranged from 6.3 to 23.1%, with gallant soldier having the greatest ash content among the feeds, which significantly surpassed that of *Eragrostis*. Among the 20 feed resources, only sweet potato vines, Elderberry trees, and maize stover had significantly ($p < 0.0001$) greater OMD compared to other feed resources (Table 5). Contrastingly, the lowest OMD value was observed in *Commelina*. The ME values ranged from 4.2 to 10.7 MJ/kg DM, with the lowest values reported in roadside vegetation, particularly in *Commelina* and gallant soldier. The ME values of Elderberry trees was significantly greater ($p < 0.0001$) than all other feed resources.

In vitro gas production

Total GP of the feed resources was significantly different ($p < 0.0001$) and ranged between 16.2 and 40.8 mL/0.2 g DM (Table 5). Gallant soldier, banana leaves, Irish potato haulms, soybean haulms, *Calliandra*, and Elderberry trees

Table 3 Locally available feed resources used by farmers during the period of short wet season in the Northern Province of Rwanda

Feed resources		Districts					% of HH	Fed as (% of HH)	
Common name	Scientific name	Burera 32 HH	Gakenke 18 HH	Gicumbi 54 HH	Musanze 40 HH	Rulindo 34 HH		Alone	Mixed
Roadside vegetation									
Assorted grass	NA	5	1	23	16	12	*32*	*37*	*63*
Commelina	*Commelina communis*	1	-	1	-	-	*1*	*50*	*50*
Digitaria	*Digitaria sp*	3	7	3	3	6	*13*	*36*	*64*
Eragrostis	*Eragrostis sp*	-	2	1	-	2	*3*	*60*	*40*
Gallant soldier	*Galinsoga parviflora*	1	-	-	4	-	*3*	*60*	*40*
% of households		*31*	*56*	*52*	*58*	*59*	-	-	-
Cultivated grasses									
Brachiaria	*Urochloa sp.*	1	-	-	1	-	*1*	*0*	*100*
Kikuyu grass	*Cenchrus clandestinus*	2	-	1	-	-	*2*	*33*	*67*
Napier grass	*Cenchrus purpureus*[#]	19	14	24	6	11	*42*	*38*	*62*
Setaria grass	*Setaria sp.*	2	-	-	1	-	*2*	*100*	*0*
% of households		*75*	*78*	*46*	*20*	*32*	-	-	-
Crop residues									
Banana leaves	*Musa sp.*	-	-	1	-	-	*1*	*0*	*100*
Banana pseudostem	*Musa sp.*	-	2	2	2	2	*5*	*25*	*75*
Bean haulms	*Phaseolus vulgaris*	-	-	2	1	2	*3*	*20*	*80*
Irish potato haulms	*Solanum tuberosum*	-	-	-	3	-	*2*	*100*	*0*
Maize stover	*Zea mays*	3	1	1	10	1	*9*	*56*	*44*
Peas haulms	*Lathyrus oleraceus*	1	-	-	-	-	*1*	*100*	*0*
Soybean haulms	*Glycine max*	1	-	-	-	-	*1*	*0*	*100*
Sugarcane leaves	*Saccharum officinarum*	-	-	-	-	1	*1*	*0*	*100*
Sweat potato vines	*Ipomoea batatas*	1	-	1	1	2	*3*	*60*	*40*
% of households		*19*	*17*	*13*	*45*	*24*	-	-	-
Fodder trees									
Calliandra	*Calliandra calothyrsus*	-	-	-	3	-	*2*	*0*	*100*
Elderberry	*Sambucus nigra*	-	-	-	1	-	*1*	*0*	*100*
% of households		*0*	*0*	*0*	*10*	*0*	-	-	-
Total feed types per district		12	6	11	13	9		-	-

[HH] households, [NA] not available, [–]Feed resources not used in the district, [#]Also known as *Pennisetum purpureum*

had lower GP (<25 mL/0.2 g DM; $p<0.001$) than all other feeds. Numerically, the greatest GP values (>35 mL/0.2 g DM) corresponded to assorted grass, Napier grass, banana pseudo-stem, maize stover, peas haulms, and sweet potato vines. Values of the constant rate of GP (C) ranged between 0.018 and 0.058 h, with the lowest value corresponding to banana leaves and the greatest to Elderberry tree. The time taken to achieve 50% of total GP ($T_{1/2}$) ranged between 13.9 and 36.8 h. Feeds that showed the shortest times and therefore, faster fermentation, were banana leaves, maize stover, and Elderberry tree, and the longer times corresponded to *Commelina* and *Brachiaria* (Table 5).

The cumulative gas production profile at different incubation time is displayed in Fig. 2. Across all feed categories, gas production started after initial incubation, and showed an increase between 24 h and 72 h.

Discussion

Rwanda is a landlocked country, located south of the Equator in East-Central Africa between latitudes 1°04' and 2°51' south and longitudes 28°45' and 31°15' east. The land has a total area of 26,340 km², with a population of approximately 14.5 million people, making it the most densely populated country in the world. A considerable share of the inhabitants (82%) belongs to the rural population. Mixed crop-livestock production is the predominant farming system in Rwanda wherein most of the crop residues used were directly obtained from farming activities or neighbours (Klapwijk et al. 2014). Due to land scarcity, free grazing is prohibited in the country. Instead, farmers across all districts practice zero grazing, especially in Gakenke, Gicumbi, and Burera. However, households in Musanze are the exception, where free grazing is still practiced. Farmers in the study area do not conserve feeds as hay or silage, rather, they rely on a cut-and-carry system to collect forages from their farms or

Table 4 Chemical composition of locally available feed resources used in smallholder dairy farms in the Northern Province of Rwanda

Feed resources (# of samples)	Feed composition parameters (%)			
	CP	NDF	ADF	Ash
Roadside vegetation				
Assorted grass (n=45)	12.2^{de}	52.9^{ab}	35.9^{abc}	16.3^{ab}
Commelina (n=2)	9.2^{de}	52.5^{ab}	30.2^{abc}	13.1^{ab}
Digitaria (n=20)	9.6^{de}	60.4^{ab}	38.6^{abc}	12.7^{ab}
Eragrostis (n=4)	7.4^{de}	70.4^{a}	45.5^{ab}	6.3^{b}
Gallant soldier (n=2)	8.8^{de}	48.7^{ab}	35.3^{abc}	23.1^{a}
Cultivated grasses				
Brachiaria (n=2)	10.3^{de}	56.1^{ab}	40.8^{abc}	17.4^{ab}
Kikuyu grass (n=3)	12.1^{de}	35.4^{ab}	21.5^{c}	16.2^{ab}
Napier grass (n=53)	10.2^{de}	60^{ab}	37.0^{abc}	16.4^{ab}
Setaria (n=3)	9.3^{de}	63^{ab}	37.9^{abc}	17.2^{ab}
Crop residues				
Banana leaves (n=1)	13.0^{de}	41.2^{ab}	34.1^{abc}	12.4^{ab}
Banana pseudo-stem (n=7)	4.4^{e}	59.9^{ab}	41.6^{abc}	14.2^{ab}
Bean haulms (n=5)	8.6^{de}	60^{ab}	40.6^{abc}	8.7^{ab}
Irish potato haulms (n=3)	19.2^{c}	30.3^{b}	25.9^{bc}	21.0^{ab}
Maize stover (n=14)	11.0^{de}	54.8^{ab}	34.5^{abc}	12.7^{ab}
Peas haulms (n=1)	13.8^{d}	65.6^{ab}	46.6^{ab}	7.9^{ab}
Soybean haulms (n=1)	7.3^{de}	57.4^{ab}	28.4^{abc}	8.2^{ab}
Sugarcane leaves (n=1)	10.9^{de}	69.3^{ab}	50.2^{a}	10.1^{ab}
Sweet potato vines (n=5)	10.1^{de}	45.1^{ab}	33.1^{abc}	12.7^{ab}
Cultivated trees				
Calliandra (n=2)	24.6^{b}	49.8^{ab}	35.5^{abc}	6.7^{b}
Elderberry tree (n=1)	34.8^{a}	30.4^{b}	25.2^{bc}	10.1^{ab}
RMSE	2.97	12.14	7.21	4.71
P-value	*0.0001*	*0.002*	*0.001*	*0.0001*

[a–e] Means with different superscripts in the column are significantly different at least at p<0.05. DM=Dry matter, CP=Crude protein, NDF=Neutral detergent fibre, ADF=Acid detergent fibre, n=number of feeds samples

other locations. To cope with the feed shortage, some farmers grow forages on terraces alongside their crops, though not all have adopted this practice (Kamanzi and Mapiye 2012).

This study aimed to generate information on the distribution and nutritional quality of locally available feed resources used by smallholder dairy farmers in the Northern Province of Rwanda. The available feeds utilised by smallholder farmers were grouped into four categories, namely: roadside vegetation, cultivated grass, crop residue, and fodder trees. Feeds reported in this study are similar to those found in Southwestern Rwanda (Klapwijk et al. 2014) and other East African countries (Kiggundu et al. 2014; Mutimura et al. 2015; Maleko et al. 2018; Mamo et al. 2023). Variation of available feed resources, both in quantity and quality, is dependent on various factors such as land owned to grow forages, seasonality, accessibility (Mutimura et al. 2019; Tefera et al. 2019; Fentahun et al. 2020), and forage phenological stage (Mutimura et al. 2015), among others. In East African countries, including Rwanda with its high population density, farmers face land shortage, which resultantly inhibits their ability to grow forages for their livestock. In our study, most farmers were landless, with some owning 1 to 5 ha of land. The lack of enough land causes most farmers in Rwanda, similar to many other developing countries, to prioritise growing food crops over forages (Gebremariam and Belay 2016), especially when food security is a major concern. If the opportunity of cultivating forages is there, it would occur on terraces alongside the crop-growing areas (Kamanzi and Mapiye 2012; Crovetto et al. 2022). It was found that Napier grass was the most commonly cultivated grass in Gicumbi compared to the other districts. Farmers generally prefer Napier grass due to its year-round yield, its ability to tolerate tropical conditions, reduce soil erosion, and its resilience (Khan et al. 2011). With regard to fodder trees, the least used feed resource as seen by Klapwijk et al. (2014), it can be said that they appear as a good protein rich supplementary feed.

Roadside vegetation and crop residues were the alternative feed resources collected in a cut-and-carry system from either their farms, communal lands, or roadsides. Among roadside vegetation, assorted grass and *Digitaria* were abundantly used as a feed across all districts. In the current study, data collection took place during the transition from the short rainy season to the short dry season (November to January), a period characterised by limited rainfall. Various researchers have reported that during the dry season, farmers predominantly rely on crop residues to feed their livestock (Kamanzi and Mapiye 2012; Fentahun et al. 2020; Mamo et al. 2023). This practice is common in many rural and peri-urban areas in East African countries, where farmers rely on both their own agricultural by-products and a collaborative community. In our study, maize stover was the most used crop residue by farmers in Musanze, as reported for Southern Rwanda (Kamanzi and Mapiye 2012). However, Kiggundu et al. (2014) and Klapwijk et al. (2014) reported that maize stover was the least used feed by farmers in their studies. This is likely due to the fact that, almost all of the maize stover was left in the fields after the harvest of the cob for mulching or used as firewood (Kiggundu et al. 2014). Similar to our findings, Klapwijk et al. (2014) highlighted that banana pseudo-stem was more frequently used than banana leaves. Further, in Uganda banana plantains are a staple food and their by-products, such as pseudo-stems and peels, are more commonly used than leaves (Lumu et al. 2013).

Unsurprisingly, the chemical composition of the different feed resources varied considerably. In general, values of CP and fibre in the current study were similar to those provided by Feedipedia (https://feedipedia.org), and other reports (Klapwijk et al. 2014; Mutimura et al. 2015; Crovetto et al. 2022). The CP content of roadside vegetation and cultivated

Table 5 In vitro gas production parameters, organic matter digestibility (OMD) and metabolisable energy (ME) of the feed resources used by smallholder farmers in the Northern Province of Rwanda

Feed resources	In vitro gas production parameters					
	GP_{72}	GP_{24}	C	$T_{1/2}$	OMD	ME
	mL/0.2 g DM	mL/0.2 g DM	mL/hr	hr	(%)	MJ/kg DM
Roadside vegetation						
Assorted grass	37.5^{abc}	20.5^{a}	0.02^{b}	27.9^{abcde}	37.6^{cde}	5.8^{cde}
Commelina	28.4^{abcdef}	8.3^{b}	0.02^{b}	36.8^{a}	27.8^{f}	4.2^{f}
Digitaria	32.5^{abcdef}	14.3^{ab}	0.02^{b}	31.0^{abcd}	33.9^{cdef}	5.1^{def}
Eragrostis	34.8^{abcd}	15.0^{ab}	0.02^{b}	33.6^{abc}	31.8^{def}	4.8^{ef}
Gallant soldier	20.0^{def}	14.5^{ab}	0.04^{ab}	22.1^{bcde}	29.1^{ef}	4.3^{f}
Cultivated grasses						
Brachiaria	35.0^{abcd}	14.5^{ab}	0.02^{b}	35.1^{ab}	34.0^{cdef}	5.1^{def}
Kikuyu grass	28.8^{abcdef}	14.7^{ab}	0.04^{ab}	28.6^{abcde}	34.4^{cdef}	5.3^{cdef}
Napier grass	39^{ab}	19.3^{ab}	0.02^{b}	26.2^{abcde}	37.3^{cde}	5.7^{cde}
Setaria grass	33.2^{abcde}	17.7^{ab}	0.03^{b}	27.6^{abcde}	35.8^{cdef}	5.4^{cdef}
Crop residues						
Banana leaves	18.7^{ef}	9.7^{b}	0.02^{b}	33.6^{abc}	31.3^{def}	4.9^{ef}
Banana pseudo-stem	37.4^{abc}	16.9^{ab}	0.03^{b}	21.2^{bcde}	34^{cdef}	5.0^{ef}
Bean haulms	39.6^{ab}	21.2^{ab}	0.02^{b}	26.1^{abcde}	36.8^{cde}	5.6^{cde}
Irish potato haulms	18.8^{ef}	14.3^{ab}	0.06^{a}	15.9^{e}	37.9^{cde}	6.3^{bcd}
Maize stover	43.6^{a}	28.9^{a}	0.04^{ab}	19.3^{cde}	46.1^{ab}	7.1^{b}
Peas haulms	31.5^{abcdef}	22.0^{ab}	0.05^{ab}	17.4^{de}	41.2^{bc}	6.5^{bc}
Soybean haulms	22.7^{cdef}	15^{ab}	0.05^{ab}	19.7^{cde}	32.1^{def}	4.8^{ef}
Sugarcane leaves	33.5^{abcde}	21.7^{ab}	0.05^{ab}	21.3^{bcde}	39.7^{cd}	6.1^{bcde}
Sweet potato vines	39.7^{ab}	29.2^{a}	0.05^{ab}	15.4^{e}	47.4^{ab}	7.2^{b}
Cultivated trees						
Calliandra	17.4^{f}	11.5^{ab}	0.02^{b}	17.9^{de}	37.5^{cde}	7.1^{b}
Elderberry tree	25.3^{bcdef}	21.7^{ab}	0.06^{a}	13.9^{e}	50.5^{a}	10.7^{a}
RMSE	4.99	5.9	0.01	4.91	5.14	0.64
P-value	<0.0001	0.008	<0.0001	0.0001	<0.0001	<0.0001

$^{a-f}$ Means with different superscripts in the column are significantly different at least at $p<0.05$; GP_{72}=total gas production at time 72 h; GP_{24}=gas production at 24 h; C=constant rate of gas production; $T_{½}$= time required to generate 50% of total GP

grasses was similar among the different species of forages, and above the minimum CP content capable of reducing rumen microbial activity (Van Soest 1994). The CP content of the most commonly used feed resources, Napier grass and assorted grass, falls within the range reported by Nyaata et al. (2000) in Kenya, although they were slightly greater than those reported by Mutimura et al. (2015). The CP content in banana pseudo-stem samples was the lowest of all feed resources, but greater than the value reported by Klapwijk et al. (2014) and similar to values found by Mutimura et al. (2015). In contrast to banana pseudo-stem, Irish potato haulms, with a CP content close to 20%, appeared to be a potential protein supplement in combination with other energy rich feeds. The same can be said for Elderberry and *Calliandra* trees which had a CP>20%. The greater CP contents in Elderberry tree, although lower than the one observed in the present study, were reported by Młynarczyk et al. (2018) and Castillo et al. (2019). Different CP content in samples of Elderberry tree can be explained by the fact that CP content differs among the different parts of the plant i.e., leaves, flowers, or fruits (Młynarczyk et al. 2018). Mutimura et al. (2015) and Klapwijk et al. (2014) also found a greater CP content in samples of *Calliandra* tree.

Assorted grass and Napier grass were, by far, the most commonly used feed resources within the categories of roadside and cultivated grasses, respectively. Assorted grasses were shown to have a numerically lower mean NDF content than Napier grass, as 67% of the samples collected had NDF content<60%, whilst 64% of the samples of Napier grass had an NDF content>57% (data not presented). This suggests that there is room for improving the nutritional quality of the cultivated Napier grass by cutting it at earlier stage of growth (Mutimura et al. 2017). The nutritional quality of forages decreases as they progress from the vegetative to the mature stage, with young forages being more digestible and greater in protein. As forages mature, fibre content increases, reducing DM intake, digestibility, and overall nutritive value for livestock (Mamo et al. 2023). In general terms, according to Kitaba and Tamir (2007), feed resources with an fibre content less than 45% can be classified as greater-quality, those with a content between 45% and 65%

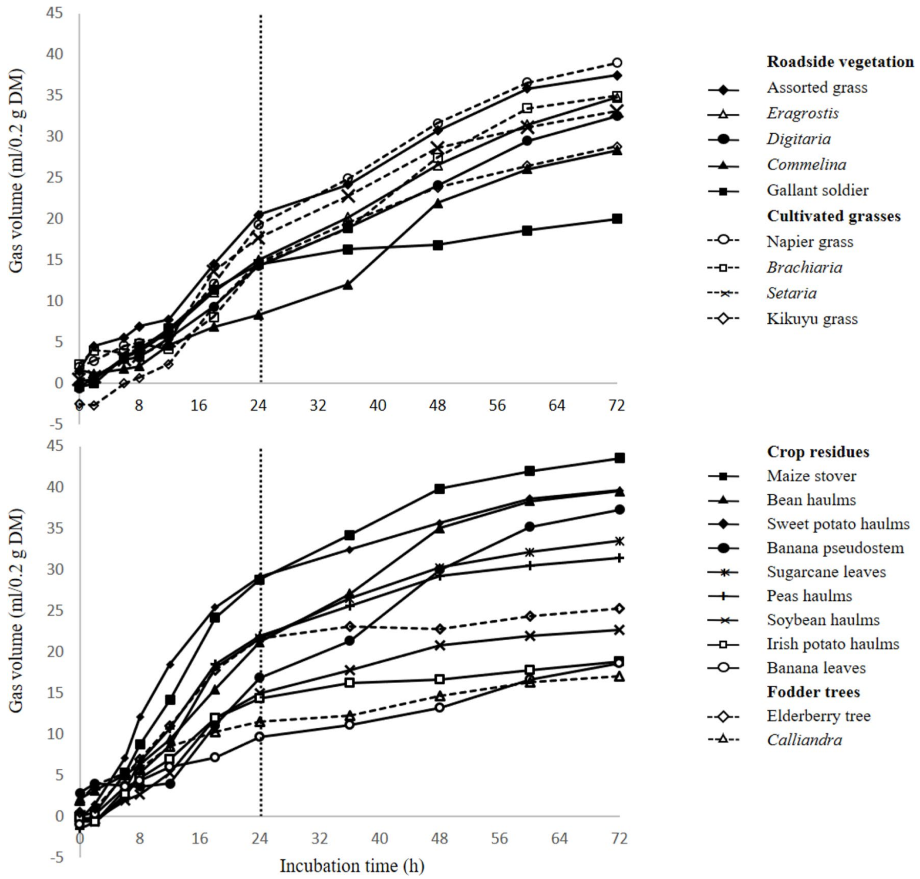


Fig. 2 In vitro gas production of feed resources used by smallholder farmers in the Northern Province of Rwanda incubated within 72 h

can be classified as medium-quality, and feeds with a fibre content > 65% can be considered to be of poor quality.

Mutimura et al. (2015), following the same protocol as in the current study but using a rumen fistulised cow as a donor of rumen fluid, reported a greater ME value, on average 14% greater, than those reported in this study for samples of *Commelina*, Napier grass, *Setaria*, banana leaves and pseudo stem, Irish potato haulms, sweet potato vines, and maize stover. Various factors such as the conditions on which rumen fluid was collected, and/or variation in the phenological stage of the feeds, could explain the observed differences (Sallam et al. 2007). Nonetheless, OMD and ME content were relatively similar among roadside vegetation and cultivated grasses. Among crop residues, maize stover and sweet potato vines had the greatest OMD and ME values. Across all feed resources, ME values of banana leaves, *Calliandra*, and *Commelina* were lower compared to the report in Sub Saharan Africa database (https://feedsdatabase.ilri.org/). The lowest ME values reported in these feeds may be explained by the method used for OMD determination. In the present study, OMD was based in gas production, and the presence of condensed tannins and other secondary metabolites in banana leaves and legumes can interfere with rumen microbial activity (Oliveira et al. 2014), reducing the amount of gas produced and, therefore, the calculated OMD. Similarly, phenolic compounds and tannins presents in Elderberry tree (Młynarczyk et al. 2018) may explain its low gas production. However, due to its high CP content, Elderberry tree has the highest OMD and ME values.

Even when the ME content of most of the feed resources used by smallholder dairy farmers is low, it could be argued that it is enough to sustain a slightly greater milk yield than the average of 3.5–5 L/cow/d (Kamanzi and Mapiye 2012; Mwendia et al. 2018; Mukasafari et al. 2025). It is possible that, not only could the quality of the feed resources be a limiting factor, but also the amount of feed that it is being offered to the cows is insufficient. Unfortunately, to our knowledge, there is no information within the literature about the amount of feed and the feeding practices, as frequency of feeding, usually used by the smallholder farmers, nor about the water supply in quantity and quality. Smallholder dairy farmers in East African countries face a major challenge of seasonal water shortages during the dry season, which restricts water availability for livestock and negatively affects the milk production of improved cattle breeds with greater water needs (Bosire et al. 2019).

Conclusions

In conclusion, this study presented valuable insights into both the availability and quality of local feed resources used by smallholder farmers in Northern Rwanda. Feeds distribution among smallholder dairy farms varies. Most farmers rely on roadside vegetation and cultivated grass fed either alone or in combination. All feed resources, except banana pseudo-stem, provide an amount of CP that does not limit microbial activity. However, ME content may be a limiting factor. Harvesting cultivated forages at early stage of growth would allow them to increase their ME and CP contents. Elderberry tree, *Calliandra*, and Irish potato haulms have the potential to be used as protein-rich supplements to improve the nutritional quality of low-quality basal diets, such as crop residues or roadside vegetation. To address the challenges linked to feed quantity and quality in smallholder farms, possible interventions such as training farmers in forage management and optimising the use of available feed resources, along with supplementing of greater-quality feed, can accelerate productivity. These efforts hold significant potential to enhance human well-being in the long-term.

Acknowledgements The authors gratefully acknowledge the Swedish International Development Cooperation Agency (SIDA) in collaboration with the University of Rwanda (UR) for its financial support (Grant number:11277). Thanks are extended to the Rwanda Agriculture and Animal Resources Development Board (RAB) for providing laboratory facilities. We heartfelt acknowledge the willingness of RAB laboratory technicians for their support during feed analysis.

Author contributions Marie Anne Mukasafari (DOI: https://orcid.org/0000-0002-6044-5197) Conceptualization, Methodology, Data collection, Writing – Original Draft. Mupenzi Mutimura (DOI: https://orcid.org/0000-0001-7019-4152) Conceptualisation, Methodology, Data analysis, and Review and Editing. Horacio Leandro Gonda (DOI: https://orcid.org/0000-0002-0452-8289) Conceptualisation, Methodology, and Review and Editing. Ewa Wredle (DOI: https://orcid.org/0000-0002-5252-9024) Wrote the project, Conceptualisation, Methodology. All authors have read and agreed to the final version of the manuscript.

Funding Open access funding provided by Swedish University of Agricultural Sciences. Swedish International Development Cooperation Agency (SIDA) funded this research work in partnership with the University of Rwanda (UR) (Grant number: 11277).

Data availability Original research data of this manuscript is available from the corresponding author on reasonable request.

Declarations

Ethical approval This research, conducted as part of the big project, was approved by the Institutional Review Board (IRB) of the College of Medicine and Health Sciences (CMHS) at the University of Rwanda, under Certificate Ref. No: 181/CMHS IRB/2021. Since no live animals were directly involved, ethical approval was not required for the analysis of feed composition.

Consent to participate Written informed consent was obtained from all individual participants included in the study.

Consent to publish We declare that all authors have read and agree with the final manuscript.

Conflict of interest The authors declare that they have no known conflict of interest.

References

AOAC (2023) AOAC Official Method 2001.11 Protein (crude) in animal feed, forage (plant tissue), grain and oilseeds: Block Digestion Method Using Copper Catalyst and Steam Distillation into Boric Acid First Action 2001. Official Methods of Analysis of AOAC International. https://doi.org/10.1093/9780197610145.003.1403

Balehegn M, Duncan A, Tolera A, Ayantunde AA, Issa S, Karimou M, Zampaligré N, André K, Gnanda I, Varijakshapanicker P, Kebreab E (2020) Improving adoption of technologies and interventions for increasing supply of quality livestock feed in low-and middle-income countries. Glob Food Sect. 26:100372

Bedada KW, Kechero Y, Janssens GPJ (2021) Seasonal and agro-ecological associations with feed resource use and milk production of ranging dairy cows in the Southern Ethiopian rift Valley. Trop Anim Health Prod 53:1–8

Bezabih M, Pellikaan WF, Tolera A, Khan NA, Hendriks WH (2014) Nutritional status of cattle grazing natural pasture in the mid rift Valley grasslands of Ethiopia measured using plant cuticular hydrocarbons and their isotope enrichment. Livest Sci 161:41–52

Bosire CK, Rao EJO, Muchenje V, Van Wijk M, Ogutu JO, Mekonnen MM, Auma JO, Lukuyu B, Hammond J (2019) Adaptation opportunities for smallholder dairy farmers facing resource scarcity: integrated livestock, water and land management. Agric Ecosyst Environ 284:106592

Castillo J, Benavides J, Vargas J, Avellaneda Y, García G (2019) Applied research on dairy cattle feeding systems in Colombian high tropics. Rev Cienc Agríc 36(2):108–122. https://doi.org/10.22267/rcia.193602.122

Crovetto GM, Magnoli F, Chiaravalli M, Njeru T, Gitau JW, Colombini S (2022) Nutritive value of forages and diets in some small-scale dairy farms in Kiambu county, Kenya in the short rains season. Trop Grassl 10(1):69–77. https://doi.org/10.17138/TGFT(10)69-77

Duguma B (2020) Productive and reproductive performance of crossbred and Indigenous dairy cows at smallholdings in selected towns of Jimma zone, Ethiopia. Anim Prod Sci 61(1):92–100. https://doi.org/10.1071/AN19380

Duguma B (2022) Farmers' perceptions of major challenges to smallholder dairy farming in selected towns of Jimma zone, oromia regional state, ethiopia: possible influences, impacts, coping strategies and support required. Heliyon 8(2022):e09581. https://doi.org/10.1016/j.heliyon.2022.e09581

FAO (2018) Ethiopia: Report on feed inventory and feed balance, 2018. Rome, Italy. 160 pages. Licence: CC BY-NC-SA 3.0 IGO

Fentahun S, Urge M, Mekuriaw Y (2020) Assessment of seasonality availability of livestock feed resources and feeding system in Bahir Dar Zuria district of Amhara region, Ethiopia. J Fish Livest Prod 8(1):293

Flax VL, Ouma EA, Baltenweck I, Omosa E, Girard AW, Jensen N, Dominguez-Salas P (2023) Pathways from livestock to improved human nutrition: lessons learned in East Africa. Food Sect. 15(5):1293–1312. https://doi.org/10.1007/s12571-023-01382-4

Gebremariam T, Belay S (2016) Livestock feed resources utilization practices in Tanqua-Abergelle district of tigray, Northern Ethiopia. Trop Anim Health Prod 48:1183–1190. https://doi.org/10.1007/s11250-016-1073-y

Goering HK, Van Soest PJ (1970) Forage fibre analyses (Apparatus, Reagents, Procedures, and Some Applications). USDA. Agricultural Research Service. Agricultural Handbook No. 379

Kamanzi M, Mapiye C (2012) Feed inventory and smallholder farmers' perceived causes of feed shortage for dairy cattle in Gisagara district, Rwanda. Trop Anim Health Prod 44(7):1459–1468. https://doi.org/10.1007/s11250-012-0087-3

Kashongwe OB, Bebe BO, Matofari JW, Huelsebusch CG (2017) Effects of feeding practices on milk yield and composition in peri-urban and rural smallholder dairy cow and pastoral camel herds in Kenya. Trop Anim Health Prod 49(5):909–914. https://doi.org/10.1007/s11250-017-1270-3

Khan MJ, Peters KJ, Uddin MM (2009) Feeding strategy for improving dairy cattle productivity in small holder farm in Bangladesh. Bangladesh J Anim Sci 38(1–2):67–85. https://doi.org/10.3329/bjas.v38i1-2.9914

Khan Z, Midega C, Pittchar J, Pickett J, Bruce T (2011) Push–pull technology: a conservation agriculture approach for integrated management of insect pests, weeds and soil health in Africa. Int J Agric Sustain 9(1):162–170. https://doi.org/10.3763/ijas.2010.0558

Kiggundu M, Kabi F, Mette V, Nalubwama S, Odhong C (2014) Management and use of dairy cattle feed resources on smallholder certified organic pineapple farms in central Uganda. J Agric Environ Int Dev 108(2):207–225. https://doi.org/10.12895/jaeid.20142.253

Kitaba A, Tamir B (2007) Effect of harvesting stage and nutrient levels on nutritive values of natural pasture in central highlands of Ethiopia. Agric Trop Subtrop 40(1):7–12. http://www.projects.its.czu.cz/ats/pdf_files/vol_40_1_pdf/KITABA.pdf

Klapwijk CJ, Bucagu C, van Wijk MT, Udo HMJ, Vanlauwe B, Munyanziza E, Giller KE (2014) The 'one cow per poor family'programme: current and potential fodder availability within smallholder farming systems in Southwest Rwanda. Agric Syst 131:11–22. https://doi.org/10.1016/j.agsy.2014.07.005

Lumu R, Katongole CB, Nambi-Kasozi J, Bareeba F, Presto M, Ivarsson E, Lindberg JE (2013) Indigenous knowledge on the nutritional quality of urban and peri-urban livestock feed resources in kampala, Uganda. Trop Anim Health Prod 45:1571–1578. https://link.springer.com/article/ https://doi.org/10.1007/s11250-013-0401-8

Maleko D, Ng WT, Msalya G, Mwilawa A, Pasape L, Mtei K (2018) Seasonal variations in the availability of fodder resources and practices of dairy cattle feeding among the smallholder farmers in Western Usambara highlands, Tanzania. Trop Anim Health Prod 50:1653–1664. https://doi.org/10.1007/s11250-018-1609-4

Mamo B, Mengistu A, Shenkute B (2023) Feed resources potential, and nutritional quality of major feed stuffs in the three agro-ecological zone of mixed farming system in Arsi zone. Ethiopia Asian J Res Anim Vet Sci 6(3):241–252. https://doi.org/10.9734/ajravs/2023/v6i3251

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

Martorell R (2017) Improved nutrition in the first 1000 days and adult human capital and health. Am J Hum Biol 29:e22952. https://doi.org/10.1002/ajhb.22952

McMahon K (2016) Herding livestock programs toward nutrition: a critical analysis with a focus on Rwanda's feed the future dairy program. Center for Strategic and International Studies. https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/161122_McMahon_HerdingLivestock_Web.pdf. Accessed 26 July 2021

Melaku S, Aregawi T, Nigatu L (2010) Chemical composition, in vitro dry matter digestibility and in sacco degradability of selected browse species used as animal feeds under semi-arid conditions in Northern Ethiopia. Agrofor Syst 80:173–184. https://doi.org/10.1007/s10457-010-9295-x

Menke KH, Raab L, Salewski A, Steingass H, Fritz D, Schneider W (1979) The Estimation of the digestibility and metabolizable energy content of ruminant feedingstuffs from the gas production when they are incubated with rumen liquor in vitro. J Agric Sci 93:217–222

Młynarczyk K, Walkowiak-Tomczak D, Łysiak GP (2018) Bioactive properties of Sambucus nigra L. as a functional ingredient for food and pharmaceutical industry. J Funct Foods 40:377–390. https://doi.org/10.1016/j.jff.2017.11.025

Mukasafari MA, Mpatswenumugabo JP, Ndahetuye JB, Wredle E, Båge R (2025) Management factors affecting milk yield, composition, and quality on smallholder dairy farms. Trop Anim Health Prod 57(2):1–12. https://doi.org/10.1007/s11250-025-04294-x

Mutimura M, Ebong C, Rao IM, Nsahlai IV (2015) Nutritional values of available ruminant feed resources in smallholder dairy farms in Rwanda. Trop Anim Health Prod 47:1131–1137. https://doi.org/10.1007/s11250-015-0839-y

Mutimura M, Ebong C, Rao IM, Nsahlai IV (2017) Effect of cutting time on agronomic and nutritional characteristics of nine commercial cultivars of Brachiaria grass compared with Napier grass

during establishment under semi-arid conditions in Rwanda. Afr J Agric Res 12(35):2692–2703. https://doi.org/10.5897/ajar2017.12474
Mutimura M, Ebong C, Rao IM, Nsahlai IV (2019) Seasonal variation of livestock feed resources in semi-arid and humid environments of Rwanda. East Afr Agric J 83(2):137–148. https://doi.org/10.1080/00128325.2019.1603578
Mwendia SW, Mwungu CM, Ng'ang'a SK, Njenga D, Notenbaert A (2018) Effect of feeding oat and Vetch forages on milk production and quality in smallholder dairy farms in central Kenya. Trop Anim Health Prod 50(5):1051–1057. https://doi.org/10.1007/s11250-018-1529-3
National Institute of Statistics of Rwanda, (NISR) [Rwanda], Ministry of Health Rwanda, (MOHR) [Rwanda], and ICF (2021) Rwanda Demographic and Health Survey 2019-20, Final Report. Kigali, Rwanda, and Rockville, Maryland, USA: NISR and ICF. https://statistics.gov.rw/sites/default/files/documents/2025-01/Rwanda_DHS_2019-20_FINAL_REPORT_N.pdf
Ndah HT, Schuler J, Nkwain VN, Nzogela B, Mangesho W, Mollel R, Loina R, Zander P, Paul BK (2022) Determinants for smallholder farmers' adoption of improved forages in dairy production systems: The case of Tanga region, Tanzania. Agron 12(2):305. https://doi.org/10.3390/agronomy12020305
NISR (2023) National Institute of Statistics of Rwanda: Rwanda Food Balance Sheets 2017–2021. https://www.afdb.org/sites/default/files/documents/publications/rwanda_food_balance_sheets_2017-2021_26jun2023_final.pdf Accessed 25 August 2024
Nyaata OZ, Dorward PT, Keatinge JDH, O'neill MK (2000) Availability and use of dry season feed resources on smallholder dairy farms in central Kenya. Agrofor Syst 50:315–331
Oliveira LN, Cabral Filho SLS, Geraseev LC, Duarte ER, Abdalla AL (2014) Chemical composition, degradability and methane emission potential of banana crop residues for ruminants. Trop Subtrop Agroecosystems 17(2):197–206
Onono JO, Wieland B, Rushton J (2013) Constraints to cattle production in a semiarid pastoral system in Kenya. Trop Anim Health Prod 45:1415–1422. https://doi.org/10.1007/s11250-013-0379-2
Ørskov ER, McDonald I (1979) The Estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. J Agric Sci 92(2):499–503. https://doi.org/10.1017/S0021859600063048
Osuji PO, Nsahlai IV, Khalili H (1993) Feed evaluation. ILRI [ILCA and ILCA (International Livestock Centre for Africa)], Addis Ababa, Ethiopia, (Vol. 5), PP 40
Sallam SMA, Nasser MEA, El-Waziry AM, Bueno ICDS, Abdalla AL (2007) Use of an in vitro rumen gas production technique to evaluate some ruminant feedstuffs. J Appl Sci Res 3(1):34–41
SAS Institute Inc (2016) SAS/CONNECT® 9.4 User ' s Guide, Fourth Edition. Cary, NC: SAS Institute Inc
Tefera S, Asmare B, Tegegne F (2019) Farmers' utilization practice, yield and chemical composition of selected improved forages grown in natural resource management areas of Farta district, South Gondar zone, Ethiopia. Cogent Food Agric 5(1):1686961. https://doi.org/10.1080/23311932.2019.1686961
Utumatwishima JN, Mogren I, Umubyeyi A, Mansourian A, Krantz G (2024) How do household living conditions and gender-related decision-making influence child stunting in rwanda?? A population-based study. PLoS ONE 19(3):e0290919. https://doi.org/10.1371/journal.pone.0290919
Van Soest PJ (1994) Nutritional ecology of ruminants. Cornell University Press

III

Tropical Animal Health and Production (2025) 57:41
https://doi.org/10.1007/s11250-025-04294-x

REGULAR ARTICLES

Management factors affecting milk yield, composition, and quality on smallholder dairy farms

Marie Anne Mukasafari[1,3] · Jean Pierre Mpatswenumugabo[2,3] · Jean Baptiste Ndahetuye[3] · Ewa Wredle[1] · Renée Båge[2]

Received: 6 January 2024 / Accepted: 17 January 2025 / Published online: 29 January 2025

Abstract

A cross-sectional study on 156 smallholder dairy farms in Rwanda was carried out to assess the association between farm management practices and milk yield and quality. A pre-tested questionnaire was used to collect data on cow characteristics and farm management practices. Milk yield was recorded at household level, milk composition was monitored using a Lactoscan device (Milk Analyzer). Somatic cell count (SCC) was determined using a DeLaval cell counter (DCC). A Delvotest SP-NT kit was used to determine antibiotic residues in raw milk. Most dairy cows were kept in zero-grazing system (84.6%) and most farmers had less experience of dairy production (78.2%). Mean daily milk yield was 3.9 L/cow and was associated with type of breed, milking frequency, stage of lactation, and parity. Mean milk content of protein, fat, lactose and solid non-fat, and density were normal and showed no association with different management practices. Based on SCC analyses, 65.8% of the milk samples with less than 300,000 cells/mL were graded as acceptable for delivery to a milk collection centre (MCC) and 12.9% of the samples tested positive for antibiotic residues. These findings suggest low milk yields on smallholder farms in Rwanda that are attributable to type of breed and prevalent high level mastitis, among other factors. The results also indicate possible non-compliance with withdrawal periods, resulting in antibiotic residues in milk, which has public health implications for consumers. Routine testing at MCC for both SCC and antibiotic residues is important for quality control.

Keywords Milk quality · Antibiotic residues · Feeding practices · Dairy cattle · Milking procedures

Introduction

Milk is a major animal-source food (ASF) that can play a crucial role in alleviating poverty and improving human nutrition, health and well-being (FAO et al. 2022). Milk is a highly nutritious and valuable source of fats, amino acids, minerals and vitamins that form part of the recommended daily intake for humans. Essential nutrients found in milk are known to be important for the growth and cognitive development and health maintenance of young children (McMahon 2016; Beal et al. 2023). ASF provides more essential nutrients like calcium, proteins and vitamin B12 than most plant-based sources, which can be particularly beneficial for young children and pregnant mothers (Beal et al. 2023). Milk yield, composition, and quality aspects are also important for the milk processing industry. However, with the increasing trend of the human population, particularly in sub-Saharan Africa, there has been a rise in the demand for ASF as reported by Bateki et al. (2020). The insufficient consumption of ASF, such as milk, has been linked to high incidences of stunting in young children (McMahon 2016). In order to meet the demand for milk and prevent stunting, both milk quality and production must improve. In tropical regions, however, the productivity of dairy cattle remains low. This is primarily due to the scarcity of feed, both in terms of quantity and quality, particularly during the dry season. In sub-Saharan Africa, feeding strategies heavily rely on natural pastures

Marie Anne Mukasafari and Jean Pierre Mpatswenumugabo contributed equally to this study and should be considered co-first authors.

✉ Jean Pierre Mpatswenumugabo
jean.pierre.mpatswenumugabo@slu.se

1 Department of Applied Animal Science and Welfare, Swedish University of Agricultural Sciences, Box 7024, 750 07 Uppsala, Sweden

2 Department of Clinical Sciences, Swedish University of Agricultural Sciences, Box 7024, 750 07 Uppsala, Sweden

3 Department of Veterinary Medicine, University of Rwanda, Box 57, Nyagatare, Rwanda

during the wet season, followed by the utilization of crop residues and green forages without supplements decrease dairy performance (Duguma and Janssens 2016; Ramírez-Rivera et al. 2019). Water scarcity and drought in tropical harsh conditions adversely affects milk yield, composition and quality by reducing intake and interfering with their metabolism due to heat stress (Hernández-Castellano et al. 2019).

Milk composition and quality are also influenced by several factors, such as animal breed, stage of lactation, parity (Gustavsson et al. 2014), and management practices such as feeds and feeding system (Kashongwe et al. 2017; Mayberry et al. 2017). In tropical countries, local breeds produce less milk compared to improved crossbreeds of pure and local cattle (Ramírez-Rivera et al. 2019; Bateki et al. 2020). This observation is consistent with findings from Rwanda, where the local Ankole breed produces less milk than improved crossbreeds (Manzi et al. 2020). However, the performance of improved breeds in tropical regions is often affected by unpredictable weather conditions, such as drought and high temperatures, which can reduce feed intake and overall productivity. Milk production is influenced by the animal health status. Intramammary infections, manifested as high SCC levels, reduce milk yield as a result of subclinical or clinical mastitis (Hagnestam-Nielsen et al. 2009). Milk quality is also negatively affected by mastitis when its causing pathogens attack and reduce numbers in milk producing cells in the mammary gland, e.g. according to Ma et al. (2000), intramammary infections affect milk quality by increasing proteolysis and lipolysis of milk components, thus reducing its shelf-life. Farm hygiene also has an impact on milk quality, with poor cleaning of cow shelters increasing infection pressure on the farm, therefore, disease incidence (Garcia et al. 2023) and affecting udder health (Ndahetuye et al. 2020b).

Furthermore, potential pathogens associated with intramammary infections, such as *Staphylococcus* spp., *Escherichia coli*, *Campylobacter jejuni* etc., can cause food poisoning (Petzer et al. 2017) and a number of health hazards such as chronic reactive arthritis (Mor-Mur and Yuste 2010), meningitis and abortions (D'Angelo et al. 2022). Antibiotics are often used to lower SCC in herds with udder health problems, posing a risk of the presence of antibiotic residues in ASF if withdrawal times are not respected (Alves et al. 2020). A recent study confirmed problems with antibiotic residues in ASF as a result of misuse of antimicrobials in animals (Chowdhury et al. 2021). Health risks associated with antibiotic residues in milk include development of antimicrobial resistance (AMR), hypersensitivity reactions, and cancer (Rahman et al. 2021). Developing countries are at greater risk than developed countries due to poor detection facilities, lack of proper monitoring systems and permissible thresholds for antimicrobial residues in foods (Pokharel et al. 2020). Poor antimicrobial stewardship programmes and lack of knowledge about appropriate antimicrobial use among smallholder farmers in developing countries are the main causes of high levels of antibiotic residues in ASF (Chattopadhyay 2014).

Enhancing the quality of dairy production in smallholder farms within tropical regions presents one of the most fundamental challenges in livestock management. The gaps in dairy nutrition, breeding, health, and farm management practices vary among smallholder farmers across different production systems and countries (Hernández-Castellano et al. 2019). Addressing these gaps requires a deeper understanding of the management practices associated with milk production and quality. However, information on the effects of management practices on milk yield, composition, and quality among smallholder dairy farms is the case in many African countries, is still lacking. The aim of this study was therefore to identify dairy farm management practices affecting milk production, composition, and quality on smallholder dairy farms in Rwanda.

Material and methods

Study design and study area

The study formed part of a large interdisciplinary research project to combat under-nutrition in children under 3 years and their mothers in the highlands of Northern Province, Rwanda (Fig. 1). Rwanda is located in Subsaharan Africa at 121 km south of the equator, within the Tropic of Capricorn, 1416 km to the west of the Indian Ocean, and 1250 km to the east of the Atlantic Ocean (Rwanda Directorate General of Immigration and Emigration 2016). The Northern province lies at around 2,500 m above sea level and enjoys the coolest weather and most abundant precipitation of all provinces in Rwanda (MINALOC 2021). However, according to the Rwanda Demographic Survey, the province has the highest rate (41%) of stunting in children under 5 years (NISR 2021). A survey, field observations, and laboratory analyses were used in this study to collect relevant information about management factors associated with milk composition and quality on smallholder farms.

Household selection and smallholder dairy farm identification

Household recruitment was done based on a sampling frame provided by the Ministry of Health. This comprised a list of all households with a child below the age of 3 and a mother aged 18 years and above from each village. One day before the field visit, village leaders and community health workers were contacted by phone to inform them

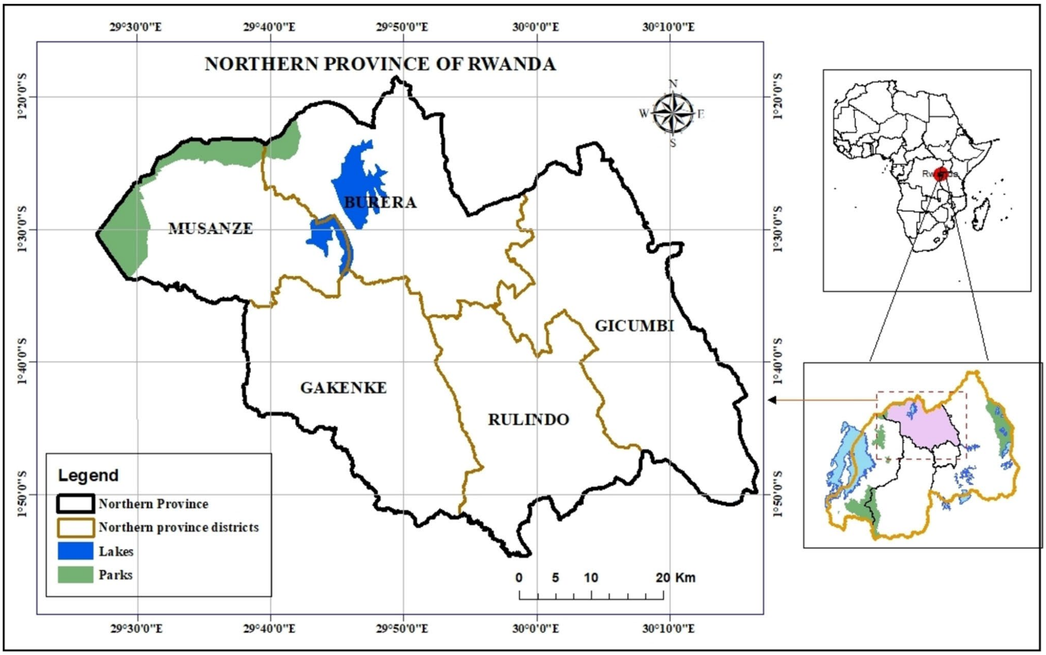


Fig. 1 Administrative map showing the Northern Province, Rwanda

about the study. On the day of data collection, village leaders and community health workers assisted in randomly selecting households to ensure representativeness of the sample size. Briefly, the number of households chosen from each village was determined proportionally to its size. In total, 601 households fulfilled the selection criteria and 156 (26%) of these had lactating cows and were included in the current analysis.

Farm characteristics and managment factors

A structured questionnaire was designed, pre-tested and adapted. It was installed on an android platform (tablets) to facilitate data collection, storage and quality checks. Prior to data collection, the survey questionnaire was pre-tested on 15 households, of which 6 had lactating cows, and minor adjustments were made. The questionnaire contained an initial section asking for basic household data and another section focusing on feeding practices, milk yield, animal health, milk handling practices, record keeping etc. In addition, field observations were conducted by two of the authors (MAM and JPM) on animal hygiene, milking procedures, milking place and cow body condition score (BCS), as indicated in Table 1.

Milk sampling and analyses

It was initially hypothesized that some farmers would have more than one lactating cow at the time of data collection. Based on this assumption, collecting bulked milk samples was anticipated. However, during data collection, we discovered that all participating households had only one lactating cow at the time of the study. Therefore, milk was directly collected from the on-farm milk storage container in 15-mL sterile screw-top tubes that were placed in a cool box (at 4 °C), stored at −20 °C in a freezer at the district hospital until the end of the week and later transported to the University of Rwanda, Busogo campus, for storage at −80 °C for three months until laboratory analyses.

Milk samples were analysed for SCC immediately upon sampling on the farm, using a portable DeLaval cell counter (DCC) (DeLaval International AB, Tumba, Sweden). The results were obtained in cells/μL and converted into cells/mL (Kandeel et al. 2018).

For laboratory analyses, frozen milk samples were thawed and kept at room temperature for around 20–30 min before analysis. For milk composition analysis, the tubes were shaken gently to avoid foam formation and any cream adhering to the tube was removed. Milk composition was analysed using a Lactoscan Milk Analyzer (Milkdata.in, Bangalore,

Table 1 Definition of variables used in multivariate analysis and other farm management practices adopted by smallholder dairy farmers in the study area

Variable name	Definition
Response variable	
Milk composition	Continuous variable: fat (%), lactose (%), protein (%),solids-non-fat (SNF) (%) and density (kg/m^3)
Milk yield	Continuous variable, number of liters of milk produced per cow/day
Somatic Cell Count (SCC)	Continuous variable, number of inflammatory cells per milliliter of milk (cell/mL)
Antibiotic residues	Binary variable, 0 = absence of antibiotic residues in milk, 1 = presence of antibiotic residues in milk
Independent variables	
Household land size	The total land owned by farmers is measured in hectares (Ha). Individuals who did not possess land of their own were categorized as landless, indicating that they were renting their agricultural plots
Farm herd size	The number of total cows per farmer, including calves and bulls
Keeping farm records	The practice by which farmers keep records of farm activities including animal treatment, milk yield, fertility among others
Feeding system	Categorical variable, 1 = Zero grazing: animals are kept in a shed and feeding by cutting and carrying forage and crop residues to the cows, 2 = open grazing: animals freely graze on individual or communal grazing lands, 3 = Semi-grazing which is a hybrid between open-grazing and zero-grazing where animals are kept in a shed but also allowed to graze on nearby land part of the time
Source of forage	The source of forages refers to where farmers get grasses to feed their cows. Some farmers were (1) purchasing forages from neighbours, (2) collecting forages along roadsides or other areas accessible to them, or (3) purchasing and collecting at the same time
Screening for mastitis	Binary variable, 1 = Yes: those who screen for subclinical mastitis, 0 = No: those who do not screen
Source of veterinary services	Categorical variable, 1 = Private Veterinarians: these veterinarians operate independently and have mobile clinics. They offer veterinary services on-call to farmers, 2 = Sector Animal Resources Officer (SARO): these are government officials who occasionally provide veterinary services to farmers, 3 = Farmer Treatment: some farmers opt to treat their own animals, either due to financial constraints or limited access to veterinary services in their area
Previous experience in farming practice	Binary variable, 1 = Yes: those who have been practicing dairy farming at least for three (3) years, 0 = No: those who started dairy farming within the last 3 years
Breed	Categorical variable, 1 = Ankole: a local zebu breed, characterized by low milk yield, 2 = crossbred: a result of crossing the local breed with pure breed (Ankole x Holstein–Friesian/Jersey), 3 = purebred: Holstein–Friesian or Jersey cows
Parity	Categorical variable, 1 = Primiparous: cows that have calved between 1 – 2 times, 2 = Multiparous: cows that have calved > 2 times
Body condition scores (BCS)	Categorical variable, 1 = Backbone prominent (poor); 2 = backbone visible (moderate); 3 = hipbone visible faintly (good); 4 = hipbone not visible (fat); 5 = hipbone showing fat deposit (very fat)
Stage of lactation	Categorical variable, 1 = Early stage: cows that calved within the last 2 months, 2 = middle stage: cows that calved within the last 2 to 6 months, 3 = cows that calved within > 6 months
Milking procedures	Milking procedures refer to the methods farmers employ when milking their cows. These included: 1 = Washing hands before milking; 2 = washing the udder with clean water; 3 = teat dipping (before/after milking); 4 = None (when no pre-milking procedure is done)

India). Prior to analysis, the machine was calibrated using ultra-high-temperature (UHT) milks with known high and low fat content. The analysis included fat (%), protein (%), solids-non-fat (SNF) (%), density (kg/m^3) and lactose (%), and was performed according to the manufacturer's instructions.

Before antibiotic residue testing, the milk samples were gently homogenised in an electrical vortex machine. Testing was performed with a Delvotest SP-NT kit (DSM, Delft, the Netherlands) according to the manufacturer's instructions. Positive and negative controls were prepared as described previously (Ondieki et al. 2017). For each milk sample (or control), a total of 100 µL milk was placed on the surface of the agar. The plates were then sealed, placed in a water bath and incubated at 64 ± 2 °C for 3 h. Test results were interpreted visually as 'negative' (yellow agar) or 'positive' (purple agar).

Statistical analysis

Survey responses were extracted from the survey software and exported to an Excel worksheet (Excel, 2016, Microsoft Corp.). Each response was then assigned a categorical code for subsequent descriptive statistical analysis (Table 1). Results for SCC, milk composition, and antibiotic residue tests were recorded in the same worksheet to facilitate inferential statistical analysis. Cleaned data were exported to R version 4.3.3 (R Core Team, Vienna, Austria) for descriptive and multivariate analyses. Descriptive analyses focused on the percentages of each variable. Multivariate analysis of variance (MANOVA) tests were conducted to identify any potential associations between outcome variables and independent variables, with statistical significance set at $p < 0.05$. Preliminary statistical analysis involved formulating relevant hypotheses related to dependent variables, including milk yield, milk composition, antibiotic residues and SCC and checking for important assumptions. The following formula, modified from previous reference (James et al. 2023), was used to construct the MANOVA models in R.

$$Y_i = x_{i},_1\beta_1 + x_{i},_2\beta_2 + \cdots + x_{i,d}\beta_d + e_i = \beta^T x_i + \varepsilon_i$$

where $i = 1, \ldots, n$ has $m \geq 2$ response variables $Y_1, \ldots, Y_m$ and d predictor (independent) variables $X_1, X_2, \ldots, X_d$. Furthermore, β_1 through β_d are the unknown coefficients for the predictor variables. Response variables in each model were combined by *cbind()* function to create Y_i matrices.

For the Model 1, Y_1 is milk yield and Y_2 is milk composition (fat, protein, lactose, SNF and density) whereas X_1 through X_8 are stage of lactation, milking frequency, breed, parity, BCS, feeds, SCC and feeding systems, respectively. In this model, SCC values were categorized into categorical variables based on the threshold stated in East African Community Standards, where SCC < 300,000 cells/mL is deemed acceptable and higher values are deemed unacceptable (COMESA 2006). For the Model 2, Y_1 is antibiotic residues and Y_2 is SCC whereas X_1 through X_7 are stage of lactation, milking frequency, breed, parity, screening for subclinical mastitis, source of veterinary services and feeding system, respectively. To evaluate the possibility of multicollinearity among independent variables, a Pearson correlation analysis was conducted for all independent variables. There was a weak positive correlation between milking frequency and stage of lactation (=0.022). However, since stage of lactation did not demonstrate statistical significance in the full model ($p = 0.855$), it was excluded from the subsequent analysis.

Initial analysis comprised a full model to assess any association between response variables and independent variables. In the subsequent phase, a multivariate pairwise comparison analysis was conducted considering independent variables that had a significant association with milk yield. Pillai's Trace test was selected for its robustness (Warne 2014) in determining the influence of each independent variable on the outcome variable. Both Pillai's Trace and partial eta squared (η^2_p) tests were used to evaluate the magnitude of within and between subjects for each independent variable and the proportion of the total variance in the dependent variables (Lakens 2013; Richardson 2011).

Results

Farm characteristics and management practices

Descriptive characteristics on the participating smallholder dairy farmers and management practices are presented in Table 2. Over two-thirds (67.1%) of the smallholder farmers were landless, with no possibility to grow forages, and hence most (92.3%) depended on forages collected in different places, such as communal land, open space, playgrounds etc. Most farmers kept their cattle within the homestead and average cattle ownership was around two per farm. A majority of the farms (87.3%) had crossbreed cows and exotic breeds were only kept by 4.6% of the farms. Less than 60% of the farmers kept records, which mainly consisted of fertility records, while 41% did not keep any records. Although nearly 80% had no previous experience in animal rearing, most had adopted some good milking practices at farm level, such as screening for mastitis (62.2%) using California Mastitis Test (CMT) and washing hands and cow udder before milking (92.9%) (Table 2).

Somatic cell count and antibiotic residues

The mean SCC count was 470,907 cells/mL milk (Table 3) while 34.2% of milk samples had SCC above 300,000 cells/mL, and 19 samples (12.9%) tested positive for antibiotic residues. There were no associations between management practices and SCC or antibiotic residues. However, the distribution of SCC levels according to cow age showed that 77.7% of cows with SCC < 300,000 cells/mL were younger than 6 years, compared to 22.3% that were older than 6 years. A similar pattern was observed in cows with SCC > 300,000 cells/mL.

Management factors associated with milk yield and milk compostion

Results from Model 1, which included milk yield and milk composition, demonstrated that milking frequency, breed, parity, and body condition score (BCS) were statistically significant ($p < 0.05$). By splitting the R output, it was found that all these variables were only associated with milk yield at various levels (see Table 4). BCS was highly associated with milk yield ($p = 0.001$), followed by breed ($p = 0.002$), milking frequency ($p = 0.005$) and parity showed a weaker relationship with milk yield ($p = 0.02$). Milking twice resulted in a higher milk yield (5.05L ± 2.43, $p < 0.001$) compared to milking once (3.54L ± 1.98), whereas the Ankole breed was associated with a lower overall mean milk yield (1.88L ± 1.11,

Table 2 Farm management practices and their respective percentages in the study area ($n = 156$)

Variable	Percentage of farmers
HH land size	
Landless	67.1
1–5 Hectares	29.5
> 5 Hectares	3.4
HH herd size	
1–2 cattle	79.9
3–5 cattle	20.1
Keeping farm records	
Yes	59.2
No	40.8
Feeding system	
Zero grazing	84.2
Semi-zero grazing	15.8
Source of forages	
Purchase	3.8
Collect	40.4
Both	55.8
Screen for mastitis	
Yes	63.8
No	36.2
Source of veterinary services	
Private veterinarians	63.2
Sector Animal Resources Officer (SARO)	32.2
Treatment by the farmer	4.5
Previous experience in rearing dairy cattle	
Yes	21.1
No	78.9
Cow breed	
Ankole (local breed)	7.9
Cross-breed	87.5
Friesian	1.3
Jersey	3.3
Parity	
Primiparous	86.2
Multiparous	13.8
Body condition score (BCS)	
Good	26.3
Moderate	62.5
Poor	11.2
Stage of lactation	
Early (1–2 months)	26.3
Middle (2–6 months)	52.6
Advance (7 months and over)	21.1
Milking procedures	
Washing hands before milking	5.8%
Washing the udder with clean water	88.5%
Teat dipping	3.8%
None	1.9%

Table 3 Summary statistics for milk yield, composition, and somatic cell counts

Descriptive statistics				
Variables	Minimum	Mean	Maximum	SEM
Milk yield (L/cow/day)	0.5	4.0	12.0	0.19
Fat (%)	1.1	3.1	8.1	0.10
Protein (%)	2.0	3.3	4.8	0.03
Lactose (%)	3.2	5.0	6.7	0.33
Solid not fat (%)	6.7	9.2	12.3	0.06
Density (Kg/m3)	1,022	1,033	1,045	0.20
Somatic cell count (cell/mL)	101,000	470,908	2,516,000	44,888

SEM standard error of the mean

Table 4 Assessment of association between farm management practices and milk yield and composition

Independent variable	Pillai value	F-value	df (num, den)	*p*-value
Stage of lactation	0.99	0.7	(18, 390)	0.771
Milking frequency	0.13	32.7	(6, 128)	***0.005***
Breeds	0.29	22.7	(18, 390)	***0.002***
Parity	0.11	225.4	(6, 128)	***0.023****
Body condition score	0.22	27.1	(12, 258)	***0.002***
Feed used	0.17	1.0	(24, 524)	0.506
SCC groups	0.18	13.6	(18, 390)	0.149
Feeding system	0.06	12.7	(6, 128)	0.276

SCC somatic cell count; *df* degrees of freedom; *num* numerator; *den* denominator, *** (<0.001); ** (0.01); *(0.05)

$p < 0.001$) compared to other breeds. Similarly, good BCS was associated with higher milk yield (5.36L ± 2.60, $p < 0.001$) compared to moderate and poor BCS ($p > 0.05$), while multiparous cows produce more milk (4.98L ± 2.56, $p = 0.002$) than primiparous cows (Fig. 2).

Multivariate pairwise comparison analysis, combined with effect size determination showed that each independent variable influenced the outcome at different levels. Milking frequency was highly associated with milk yield ($p = 0.002$). Mean milk yield from Ankole breed was statistically different ($p = 0.002$) from other breeds, whereas differences between other breeds were not significant ($p > 0.05$). While parity had shown positive influence on milk yield, multivariate pairwise comparisons did not show any difference between the two groups ($p = 0.08$). This significance might have happened by chance (Mordkoff 2019), since the Pillai's Trace = 0.08 (Table 5). Results from Model 2 revealed that none of the independent variables was associated with SCC or antibiotic residues ($p > 0.05$).

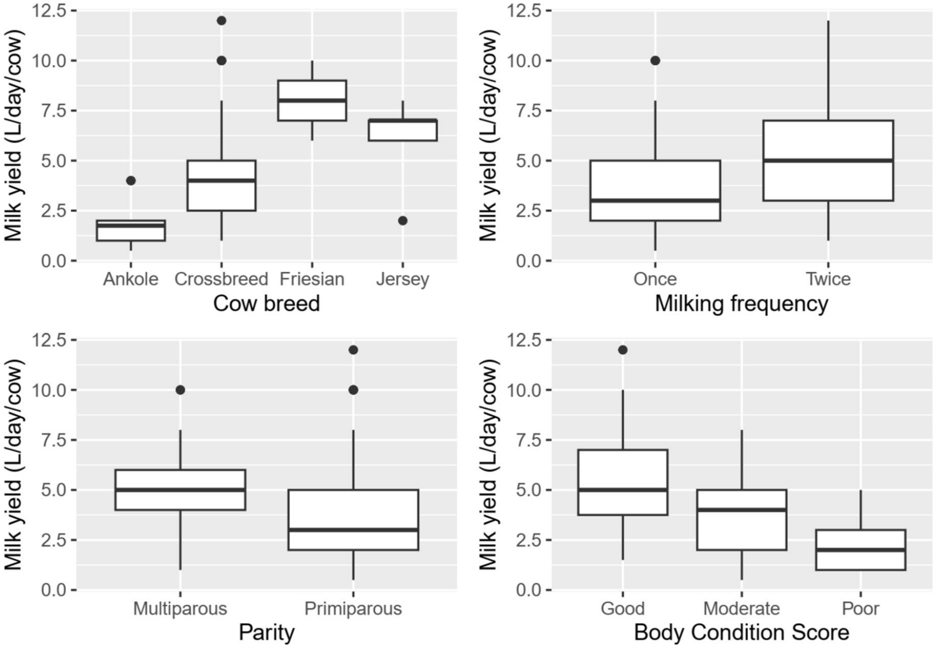


Fig. 2 Average daily milk yield associated with breed, milking frequency, parity, and BCS ($p < 0.05$)

Table 5 Determination of effect size of management factors associated with milk yield by multiple group comparisons analysis

Independent variable	Pillai value	F-value at df(6,128)	p-value	η^2_p	95% CI
Milking frequency				0.10	[0.01, 1.00]
Once—twice	0.15	3.8	***0.002*****		
Breeds				0.07	[0.00, 1.00]
Ankole—Crossbreed	0.14	3.5	***0.017****		
Ankole—Friesian	0.15	3.9	***0.007****		
Ankole—Jersey	0.14	3.7	***0.012****		
Crossbreed—Friesian	0.09	2.3	0.202		
Crossbreed -Jersey	0.08	1.8	0.533		
Friesian—Jersey	0.07	1.8	0.575		
Parity				0.11	[0.01, 1.00]
Primiparous vs multiparous	0.08	1.908	0.084		
Body condition score				0.09	[0.01, 1.00]
Good—moderate	0.19	5.2	***< 0.001*******		
Good—poor	0.22	6.2	***< 0.001*******		
Moderate—poor	0.09	2.2	0.125		

df degrees of freedom; η^2_p partial eta squared; *CI* confidence interval, *** (< 0.001); ** (0.01); *(0.05)

Discussion

This study examined associations between prevalent management practices such as milking frequency, stage of lactation among the others on smallholder dairy farms in Rwanda, and milk quality and yield. Milk yield was found to be associated with factors such as cow breed, milking frequency, BCS and parity. Milk SCC were high, suggesting that some lactating cows had subclinical intramammary infections. Others had apparently been diagnosed with clinical mastitis and were undergoing antibiotic treatment, since 12.9% of milk samples tested positive for antibiotic residues.

Milk yield was positively associated with cow breed, where improved breeds produced more milk than the local breed, as found in previous studies in Ethiopia, Rwanda and Tanzania (Galukande et al. 2013; Gillah et al. 2014; Duguma 2020; Manzi et al. 2020). Breed was also associated with milk yield, but not with milk composition parameters, confirming previous findings (Sandoval-Castro et al. 2000; Wall and McFadden 2012). Poor animal management practices (such as insufficient and unbalanced diets, low disease control, poor housing, low water availability, and poor hygiene) are most likely the reason for the recorded low milk yield. It has been found that milking once a day dramatically reduces milk yield, by almost 22% of daily milk production (Stelwagen et al. 2013). Additionally, milk yield was associated with BCS and parity, which is in accordance with literature findings; cows with higher BCS produced more milk than those with low BCS, as expected (Roche et al. 2007) and multiparous cows produced more than primiparous cows, as found previously (Lee and Kim 2006). It has been suggested that the increase in milk yield in multiparous cows may be attributable to increasing cell development in the udder during subsequent pregnancies (Roche et al. 2007). This difference likely relates to the higher milk yield in multiparous cows (Azizi et al. 2009) and their distinct energy requirements for growth and lactation (Agnew and Yan 2000). Furthermore, cows with poor body conditions may not have sufficient energy reserves to extract nutrients from feed resources that support milk yield.

The average values of the milk composition parameters analysed were within the range reported in earlier studies conducted in Rwanda (Hirwa et al. 2017; Ayabagabo et al. 2021). However, Ayabagabo et al. (2021) observed greater fat content variations with season, associated with high fibre content in the feed, which increases acetate as well as volatile fatty acid content in milk. In the present study, milk lactose was not associated with feed/s used, feeding practices, breed, milking frequency, BCS or SCC, indicating that the farmers used similar farming practices. This is similar to findings in Kenya and Tanzania, but with higher values of milk composition parameters in different feeding systems, e.g. dairy cattle fed on Napier grass have a higher fat content in milk than those fed on natural pasture (Gillah et al. 2014; Kashongwe et al. 2017). Seasonal changes in the quantity and quality of feed and different agro-ecological zones can also affect milk yield and composition parameters (Hernández-Castellano et al. 2019; Ayabagabo et al. 2021). While this study did not examine the microbiological contamination of milk or the impact of psychrotrophic bacteria—biochemically active at low temperatures—on milk composition, previous research has demonstrated their effects on milk content through enzymatic activity (Hahne et al. 2019; Hu et al. 2018). The current findings showed that a few samples had very low fat and protein contents, at 1.1% and 2%, respectively, which may have been partly attributed to freezing temperatures and the influence of psychrotrophic bacterial activity on milk composition (Hu et al. 2018).

In contrast to previous findings (Stelwagen et al. 2013; Schwendel et al. 2015; Ramírez-Rivera et al. 2019), no relationship was found between milk yield and the feeds used, feeding system, or lactation stage. This could be partly explained by the fact that the majority of participating farmers (92.6%) use a cut-and-carry feeding system involving insufficient feeds of low quality, which results in low milk yield. This corroborates findings in a previous study by Maleko et al. (2018) that smallholder dairy farms in Tanzania that keep cows in a zero-grazing with cut and carry system have low milk productivity and poor milk composition. Similar to other tropical countries, land scarcity is the major contributing factor to feed shortage, as two-thirds of farmers are actually landless and cannot grow fodder in Rwanda (Kamanzi and Mapiye 2012). Additionally, most of our respondents had no previous experience of rearing dairy cattle, which might have contributed to low milk yield resulting from poor animal husbandry practices such as unbalanced diet, dirty shelters and disease. Lower milk yield means that farmers are unable to meet market demand (Nyamwaro et al. 2018), leading to lower consumption levels. In the present study, 34.2% of milk samples analysed had SCC above 300,000 cells/mL, i.e. were unacceptable for delivery to a milk collection centre in the Rwandan context (COMESA 2006). Intramammary infections are considered the most common reason for increased SCC in milk, but many other factors may contribute to high SCC. These include stage of lactation (in the beginning and in the end), parity, body condition, milking frequency and stress (Paape et al. 2007; Lianou et al. 2021). However, these factors were not associated with SCC in the present study. The high level of unacceptable SCC values obtained indirectly indicates a significant health risk to consumers. Consumption of milk with intramammary infections, indicated by high level of SCC, poses a public health risk, since potential pathogens such as *Staphylococcus* spp, *Escherichia coli*, *Campylobacter jejuni* etc., can cause several diseases other than food poisoning, e.g. chronic reactive arthritis (Mor-Mur and Yuste 2010), meningitis and abortion (D'Angelo et al. 2022).

The relatively high level of antibiotic residues in the milk samples analysed supports findings by other researchers (Alves et al. 2020) and could be due to ongoing or recent treatments for intramammary infections. Although we did not investigate whether the cows were undergoing certain treatments, recent studies have found that subclinical mastitis is one of the most common diseases affecting Rwandan dairy farms, with prevalence of more than 50% (Ndahetuye et al. 2020b; Mpatswenumugabo et al. 2017; Iraguha et al. 2015). In addition, the majority of farmers in our study did not keep records, which could be one reason why they may milk cows under treatment without respecting withdrawal times. It has been found that poor management practices and ineffective veterinary services lead to higher levels of antibiotic residues in milk (Rahman et al. 2021). A previous study in Rwanda revealed that 97.4% of farmers used antibiotics on-farm and nearly 60% of farmers bought antibiotics without a veterinary prescription (Manishimwe et al. 2017). However, we found no association with various management practices included in our statistical model. The proportion of samples with antibiotic residues in this study (12.9%) was around tenfold higher than in a previous study in Rwanda (1.3%) (Ndahetuye et al. 2020a). This difference might be due to the dilution effect, since in the current study milk samples were collected from individual cows, while Ndahetuye et al. (2020a) collected samples of bulk tank milk. When milk samples are pooled, the concentrations of antibiotic residues could be diluted to undetectable levels (Rahman et al. 2021). When individual milk samples are collected from each cow, milk from individual cows treated with antibiotics before sample collection may contain high levels of antibiotic residues (Rahman et al. 2021).

Poor detection facilities and lack of a proper monitoring system for antibiotic residues in foods prevent full assessment (Pokharel et al. 2020). The microbial-based detection method used in the present study is cost-effective and able to cover the entire antibiotic spectrum with a single test (Pikkemaat 2009). The detection rate (12.9%) was much lower than in a study in Ghana by Aning et al. (2007), who found antibiotic residues in 35.5% of samples from peri-urban areas, and in a study in Tanzania by Kurwijila et al. (2006), where 36% of milk samples tested positive for antibiotic residues. The presence of antibiotic residues in raw milk affects the quality of dairy products by reducing the growth of starter culture, milk curdling, and cheese ripening, as well as flavour production (Virto et al. 2022). There are also health risks associated with consumption of milk containing antibiotic residues, including the development of antimicrobial resistance, hypersensitivity reactions, toxicities and cancer (Rahman et al. 2021).

In conclusion, this study provided new information on management practices on smallholder dairy farms in Rwanda and their relationship with milk yield and quality. Since our findings corroborate with previous studies in developing countries, the current results can act as baseline information for policymakers and researchers, e.g. in risk analysis on public health threats associated with antibiotic residues in food. Milk yield was found to be associated with some management practices, so smallholder farmers in Rwanda need to be educated on best farming practices, including suitable feed rations and milking frequencies. Milk composition parameters were not associated with management practices, but routine analysis of milk composition parameters should be established to detect any milk adulteration. High levels of SCC and presence of antibiotic residues in milk suggest constant exposure of consumers, with potential health risks. Extension services should support farmers' cooperatives or smallholder farmers to improve feeding practices and exploit the production capacity of improved breeds. Routine testing for SCC and antibiotic residues at milk collection centres is important to ensure high quality and safety of raw milk and safeguard consumers. Finally, proper farm management would increase both the quantity and quality of cow milk, thus helping to meet increasing market demand and securing human livelihoods.

Study limitations

The study highlights several limitations that support the context of the findings and inform future research directions (Ross and Zaidi 2019). First, the cross-sectional design cannot establish direct causality between independent variables and milk yield, but existing literature supports these associations. Second, due to the study's involvement in a larger project on child undernutrition in Rwanda, milk samples were frozen for later molecular analysis in Sweden. Despite some values for fat and protein content falling below normal, mean values remained within range, suggesting minimal impact from freezing. Lastly, the sample size was limited to 156 households with lactating cows out of 601, to prevent bias in assessing child stunting. The current findings are relevant due to methodological reproducibility and consistency with previous studies. Therefore, future studies should use longitudinal designs and analyze milk content soon after milking, without freezing, to improve accuracy and causal understanding.

Acknowledgements The authors gratefully acknowledge the contribution of all participating farmers who voluntarily accepted to be part of this research. We also thank the community health workers and village leaders who helped us reach out to selected households.

Author contributions M.A. Mukasafari: Conceptualisation, Methodology, Investigation, Data Curation, Formal analysis, Writing—Original Draft. J.P. Mpatswenumugabo: Conceptualisation, Methodology, Investigation, Data Curation, Formal analysis, Writing—Original Draft. J.B. Ndahetuye: Conceptualisation, Supervision, Writing—Reviewing and Editing. E. Wredle: Conceptualisation, Supervision, Writing—Reviewing and Editing. R. Båge: Conceptualisation, Resources, Supervision, Writing—Reviewing and Editing.

Funding Open access funding provided by Swedish University of Agricultural Sciences. This material is based upon project work supported by the Swedish International Development Cooperation Agency (SIDA). Research Partnership 2019 – 2024, SIDA contribution No. 11277.

Data availability Not applicable. Data were not deposited in an official repository. No new datasets were created.

Declarations

Ethics approval This research was reviewed and approved by the College of Medicine and Health Sciences (CMHS) Institutional Review Board (IRB) of the University of Rwanda, with approval notice No. 181/CMHS IRB/2021.

Consent to participate Further approval was obtained from participants before their voluntary participation in the study by signing informed consent forms.

Consent for publication The manuscript is approved by all authors for publication.

Declaration of generative AI and AI-assisted technologies in the writing process The authors did not use any artificial intelligence-assisted technologies in the writing process.

Conflict of interest The authors declare no competing interests.

References

Agnew RE, Yan T (2000) Impact of recent research on energy feeding systems for dairy cattle. Livest Prod Sci 66(3):197–215. https://doi.org/10.1016/S0301-6226(00)00161-5

Alves JF, Paula GH, Silva RCF, Leão PVT, Leão KM, Nicolau ES, Silva MAP (2020) Residues of antibiotics in milk: persistence and quality interference. Can J Anim Sci 100(1):93–101. https://doi.org/10.1139/cjas-2018-0224

Aning KG, Donkor ES, Omore A, Nurah GK, Osafo ELK, Staal S (2007) Risk of exposure to marketed milk with antimicrobial drug residues in Ghana. Open Food Sci J 1(1):1–5. https://doi.org/10.2174/1874256400701011046

Ayabagabo J de D, Onjoro PA, Migwi PK, Dusingize MC (2021) Effects of nutrients supply on milk yield, composition, and enteric methane gas emissions from smallholder dairy farms in Rwanda. J Anim Sci Vet Med 6(2):93–104. https://doi.org/10.31248/jasvm2021.261

Azizi O, Kaufmann O, Hasselmann L (2009) Relationship between feeding behaviour and feed intake of dairy cows depending on their parity and milk yield. Livest Sci 122(2–3):156–161. https://doi.org/10.1016/j.livsci.2008.08.009

Bateki CA, van Dijk S, Wilkes A, Dickhoefer U, White R (2020) Meta-analysis of the effects of on-farm management strategies on milk yields of dairy cattle on smallholder farms in the Tropics. Animal 14(12):2619–2627. https://doi.org/10.1017/S1751731120001548

Beal T, Gardner CD, Herrero M, Iannotti LL, Merbold L, Nordhagen S, Mottet A (2023) Friend or foe? The role of animal-source foods in healthy and environmentally sustainable diets. J Nutr 153(2):409–425. https://doi.org/10.1016/j.tjnut.2022.10.016

Chattopadhyay MK (2014) Use of antibiotics as feed additives: a burning question. Front Microbiol 5(JULY):1–3. https://doi.org/10.3389/fmicb.2014.00334

Chowdhury S, Ghosh S, Aleem MA, Parveen S, Islam A, Rashid M, Akhtar Z, Chowdhury F (2021) Antibiotic usage and resistance in food animal production: what have we learned from Bangladesh ? Antibiotics 10(1032):1–14. https://doi.org/10.3390/antibiotics10091032

COMESA (2006) East African Standard: Raw cow milk – Specification. 457

D'Angelo L, Paradiso R, Alfano D, Riccardi MG, Borriello G, Galiero G (2022) First report on abortion caused by Salmonella enterica subsp. enterica serovar Enteritidis in water buffalo (Bubalus bubalis). Front Vet Sci9 (July). https://doi.org/10.3389/fvets.2022.894154

Duguma B (2020) Productive and reproductive performance of crossbred and indigenous dairy cows at smallholdings in selected towns of Jimma Zone, Ethiopia. Anim Prod Sci 61(1):92–100. https://doi.org/10.1071/AN19380

Duguma B, Janssens GPJ (2016) Assessment of feed resources, feeding practices and coping strategies to feed scarcity by smallholder urban dairy producers in Jimma town, Ethiopia. SpringerPlus 5(1). https://doi.org/10.1186/s40064-016-2417-9

FAO, IFAD, UNICEF, WFP, WHO (2022) The state of food security and nutrition in the world (SOFI) Report - 2022, WFP: World Food Programme, Italy. https://coilink.org/20.500.12592/vr7ntv. Accessed 25 Jan 2025

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

Garcia SN, Mpatswenumugabo JPM, Ntampaka P, Nandi S (2023) A one health framework to advance food safety and security: an on- farm case study in the Rwandan dairy sector. One Health 16(January):1–37. https://doi.org/10.1016/j.onehlt.2023.100531

Gillah KA, Kifaro GC, Madsen J (2014) Effects of management practices on yield and quality of milk from smallholder dairy units in urban and peri-urban Morogoro, Tanzania. Trop Anim Health Prod 46(7):1177–1183. https://doi.org/10.1007/s11250-014-0624-3

Gustavsson F, Buitenhuis AJ, Johansson M, Bertelsen HP, Glantz M, Poulsen NA, Lindmark Månsson H, Stålhammar H, Larsen LB, Bendixen C, Paulsson M, Andrén A (2014) Effects of breed and casein genetic variants on protein profile in milk from Swedish Red, Danish Holstein, and Danish Jersey cows. J Dairy Sci 97(6):3866–3877. https://doi.org/10.3168/jds.2013-7312

Hagnestam-Nielsen C, Emanuelson U, Berglund B, Strandberg E (2009) Relationship between somatic cell count and milk yield in different stages of lactation. J Dairy Sci 92(7):3124–3133. https://doi.org/10.3168/jds.2008-1719
Hahne J, Isele D, Berning J, Lipski A (2019) The contribution of fast growing, psychrotrophic microorganisms on biodiversity of refrigerated raw cow's milk with high bacterial counts and their food spoilage potential. Food Microbiol 79(2019):11–19. https://doi.org/10.1016/j.fm.2018.10.019
Hernández-Castellano LE, Nally JE, Lindahl J, Wanapat M, Alhidary IA, Fangueiro D, Grace D, Ratto M, Bambou JC, de Almeida AM (2019) Dairy science and health in the tropics: challenges and opportunities for the next decades. Trop Anim Health Prod 51(5):1009–1017. https://doi.org/10.1007/s11250-019-01866-6
Hirwa CD, Kugonza DR, Murekezi T, Rwemarika DJ, Kayitesi A, Musemakweri A, Shabariyo JP, Shombusho F, Manzi M, Safari T (2017) Management and phenotypic features of indigenous cattle in Rwanda. Int J Livest Prod 8(7):95–112. https://doi.org/10.5897/ijlp2017.0362
Hu J, Cai W, Wang C, Du X, Lin J, Cai J (2018) Purification and characterization of alkaline lipase production by Pseudomonas aeruginosa HFE733 and application for biodegradation in food wastewater treatment. Biotechnol Biotechnol Equip 32(3):583–590. https://doi.org/10.1080/13102818.2018.1446764
Iraguha B, Hamudikuwanda H, Mushonga B (2015) Bovine mastitis prevalence and associated risk factors in dairy cows in Nyagatare District, Rwanda. J S Afr Vet Assoc 86(1):1–6. https://doi.org/10.4102/jsava.v86i1.1228
James G, Witten D, Hastie T, Tibshirani R (2023) An introduction to statistical learning with applications in R, 2nd edn. Springer Science and Business Media
Kamanzi M, Mapiye C (2012) Feed inventory and smallholder farmers' perceived causes of feed shortage for dairy cattle in Gisagara District, Rwanda. Trop Anim Health Prod 44(7):1459–1468. https://doi.org/10.1007/s11250-012-0087-3
Kandeel SA, Megahed AA, Arnaout FK, Constable PD (2018) Evaluation and comparison of 2 on-farm tests for estimating somatic cell count in quarter milk samples from lactating dairy cattle. J Vet Intern Med 506–515. https://doi.org/10.1111/jvim.14888
Kashongwe OB, Bebe BO, Matofari JW, Huelsebusch CG (2017) Effects of feeding practices on milk yield and composition in peri-urban and rural smallholder dairy cow and pastoral camel herds in Kenya. Trop Anim Health Prod 49(5):909–914. https://doi.org/10.1007/s11250-017-1270-3
Kurwijila LR, Omore A, Staal S, Mdoe NSY (2006) Investigation of the risk of exposure to antimicrobial residues present in marketed milk in Tanzania. J Food Prot 69(10):2487–2492. https://doi.org/10.4315/0362-028X-69.10.2487
Lakens D (2013) Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. Front Psychol 4(NOV):1–12. https://doi.org/10.3389/fpsyg.2013.00863
Lee JY, Kim IH (2006) Advancing parity is associated with high milk production at the cost of body condition and increased periparturient disorders in dairy herds. J Vet Sci 7(2):161–166. https://doi.org/10.4142/jvs.2006.7.2.161
Lianou DT, Michael CK, Vasileiou NGC, Petinaki E, Cripps PJ, Tsilipounidaki K, Katsafadou AI, Politis AP, Kordalis NG, Ioannidi KS, Gougoulis DA, Trikalinou C, Orfanou DC, Fragkou IA, Liagka DV, Tzora A, Albenzio M, Mavrogianni VS, Caroprese MC, Fthenakis GC (2021) Extensive countrywide field investigation of somatic cell counts and total bacterial counts in bulk tank raw milk in goat herds in Greece. J Dairy Res 88(3):307–313. https://doi.org/10.1017/S0022029921000674
Ma Y, Ryan C, Barbano DM, Galton DM, Rudan MA, Boor KJ (2000) Effects of somatic cell count on quality and shelf-life of pasteurized fluid milk. J Dairy Sci 83(2):264–274. https://doi.org/10.3168/jds.S0022-0302(00)74873-9
Maleko D, Ng WT, Msalya G, Mwilawa A, Pasape L, Mtei K (2018) Seasonal variations in the availability of fodder resources and practices of dairy cattle feeding among the smallholder farmers in Western Usambara Highlands, Tanzania. Trop Anim Health Prod 50(7):1653–1664. https://doi.org/10.1007/s11250-018-1609-4
Manishimwe R, Nishimwe K, Ojok L (2017) Assessment of antibiotic use in farm animals in Rwanda. Trop Anim Health Prod 49(6):1101–1106. https://doi.org/10.1007/s11250-017-1290-z
Manzi M, Rydhmer L, Ntawubizi M, D'Andre Hirwa C, Karege C, Strandberg E (2020) Milk production and lactation length in Ankole cattle and Ankole crossbreds in Rwanda. Trop Anim Health Prod 52(6):2937–2943. https://doi.org/10.1007/s11250-020-02311-9
Mayberry D, Ash A, Prestwidge D, Godde CM, Henderson B, Duncan A, Blummel M, Ramana Reddy Y, Herrero M (2017) Yield gap analyses to estimate attainable bovine milk yields and evaluate options to increase production in Ethiopia and India. Agric Syst 155(July):43–51. https://doi.org/10.1016/j.agsy.2017.04.007
McMahon K (2016) Herding livestock programs toward nutrition: a critical analysis with a focus on Rwanda's feed the future dairy program. Washington, DC 20036. https://doi.org/10.21955/gatesopenres.1115405.1
MINALOC (2021) Government of Rwanda: xdministrative structure. Government of Rwanda. https://www.gov.rw/government/administrative-structure [2023–04–27]
Mordkoff JT (2019) A simple method for removing bias from a popular measure of standardized effect size: adjusted partial eta squared. Adv Methods Pract Psychol Sci 2(3):228–232. https://doi.org/10.1177/2515245919855053
Mor-Mur M, Yuste J (2010) Emerging bacterial pathogens in meat and poultry: an overview. Food Bioprocess Technol 3(1):24–35. https://doi.org/10.1007/s11947-009-0189-8
Mpatswenumugabo JP, Bebora LC, Gitao GC, Mobegi VA, Iraguha B, Kamana O, Shumbusho B (2017) Prevalence of subclinical mastitis and distribution of pathogens in dairy farms of Rubavu and Nyabihu Districts, Rwanda. J Vet Med 2017(1):8456713
National Institute of Statistics of Rwanda (NISR) (2021) Rwanda demographic and health survey 2019–20. Kigali, Rwanda and Rockville, Maryland, USA. https://www.statistics.gov.rw/publication/1724. Accessed 22 May 2022
Ndahetuye JB, Twambazimana J, Nyman A, Karege C, Tukei M, Ongol MP, Persson Y, Båge R (2020) A cross sectional study of prevalence and risk factors associated with subclinical mastitis and intramammary infections, in dairy herds linked to milk collection centers in Rwanda. Prev Vet Med 179(July 2019):105007. https://doi.org/10.1016/j.prevetmed.2020.105007
Ndahetuye JB, Artursson K, Båge R, Ingabire A, Karege C, Djangwani J, Nyman A, Ongol MP, Tukei M, Persson Y (2020a) MILK Symposium review : microbiological quality and safety of milk from farm to milk collection centers in Rwanda *. 9730–9739. https://doi.org/10.3168/jds.2020-18302
Nyamwaro SO, Mugabo J, Kalibwani R, Tenywa MM, Buruchara R, Fatunbi AO (2018) Innovation opportunities in milk production in Rwanda. FARA Res Rep 2(19):17. Retrieved from https://library.faraafrica.org/2021/01/21/. Accessed 20 Apr 2022
Ondieki GK, Ombui JN, Obonyo M, Gura Z, Githuku J, Orinde AB, Gikunju JK (2017) Antimicrobial residues and compositional quality of informally marketed raw cow milk, Lamu West Sub-County, Kenya, 2015. Pan Afr Med J 28(1):5. https://doi.org/10.11604/pamj.supp.2017.28.1.9279
Paape MJ, Wiggans GR, Bannerman DD, Thomas DL, Sanders AH, Contreras A, Moroni P, Miller RH (2007) Monitoring goat and sheep milk somatic cell counts. Small Rumin Res 68(2007):114–125. https://doi.org/10.1016/j.smallrumres.2006.09.014

Petzer IM, Karzis J, Donkin EF, Webb EC, Etter EMC (2017) Validity of somatic cell count as indicator of pathogen-specific intramammary infections. J S Afr Vet Assoc 88(1):1–10. https://doi.org/10.4102/jsava.v88i0.1465
Pikkemaat MG (2009) Microbial screening methods for detection of antibiotic residues in slaughter animals. Anal Bioanal Chem 893–905. https://doi.org/10.1007/s00216-009-2841-6
Pokharel S, Shrestha P, Adhikari B (2020) Antimicrobial use in food animals and human health: time to implement 'One Health' approach. Antimicrob Resist Infect Control 9(1):1–5. https://doi.org/10.1186/s13756-020-00847-x
Rahman MS, Hassan MM, Chowdhury S (2021) Determination of antibiotic residues in milk and assessment of human health risk in Bangladesh. Heliyon 7(8):e07739. https://doi.org/10.1016/j.heliyon.2021.e07739
Ramírez-Rivera EJ, Rodríguez-Miranda J, Huerta-Mora IR, Cárdenas-Cágal A, Juárez-Barrientos JM (2019) Tropical milk production systems and milk quality: a review. Trop Anim Health Prod 51(6):1295–1305. https://doi.org/10.1007/s11250-019-01922-1
Richardson JTE (2011) Eta squared and partial eta squared as measures of effect size in educational research. Educ Res Rev 6(2):135–147. https://doi.org/10.1016/j.edurev.2010.12.001
Roche JR, Lee JM, Macdonald KA, Berry DP (2007) Relationships among body condition score, body weight, and milk production variables in pasture-based dairy cows. J Dairy Sci 90(8):3802–3815. https://doi.org/10.3168/jds.2006-740
Ross PT, Zaidi NLB (2019) Limited by our limitations. Perspect Med Educ 8(4):261–264. https://doi.org/10.1007/s40037-019-00530-x
Rwanda Directorate General of Immigration and Emigration (2016) About Rwanda. Rwanda directorate general of immigration and emigration. http://www.rw.undp.org/content/rwanda/en/home/countryinfo.html. Accessed 12 Mar 2024
Sandoval-Castro CA, Anderson S, Leaver JD (2000) Production responses of tropical crossbred cattle to supplementary feeding and to different milking and restricted suckling regimes. Livest Prod Sci 66(1):13–23. https://doi.org/10.1016/S0301-6226(00)00164-0
Schwendel BH, Wester TJ, Morel PCH, Tavendale MH, Deadman C, Shadbolt NM, Otter DE (2015) Invited review: organic and conventionally produced milk-An evaluation of factors influencing milk composition. J Dairy Sci 98(2):721–746. https://doi.org/10.3168/jds.2014-8389
Stelwagen K, Phyn CVC, Davis SR, Guinard-Flament J, Pomiès D, Roche JR, Kay JK (2013) Invited review: reduced milking frequency: milk production and management implications. J Dairy Sci 96(6):3401–3413. https://doi.org/10.3168/jds.2012-6074
Virto M, Santamarina-García G, Amores G, Hernández I (2022) Antibiotics in dairy production: where is the problem? Dairy 3(3):541–564. https://doi.org/10.3390/dairy3030039
Wall EH, McFadden TB (2012) Triennial lactation symposium: a local affair: How the mammary gland adapts to changes in milking frequency. J Anim Sci 90(5):1695–1707. https://doi.org/10.2527/jas.2011-4790
Warne R (2014) A primer on multivariate analysis of variance (MANOVA) for behavioral scientists. Pract Assess Res Eval 19(1):17. https://doi.org/10.7275/sm63-7h70

Acta Universitatis Agriculturae Sueciae

Doctoral Thesis No. 2025:57

Stunting, chronic undernutrition in children, is of major concern in Rwanda. This thesis studied dairy cow feeding practices, milk yield and quality, and stunting in young children at smallholder farms in Northern Rwanda. Findings revealed that lactating cows were poorly fed, and that milk yield was low. Owning a lactating cow was not associated with stunting in children. Results of this thesis corroborated the multifactor nature of stunting occurrence and the need of studying it with a multidisciplinary approach.

Marie Anne Mukasafari received her doctoral education at the Department of Applied Animal Science and Welfare, SLU, Sweden. She has a MSc degree in Animal Production, Egerton University, Kenya, and a BSc degree in Veterinary Medicine, University of Rwanda, Rwanda.

Acta Universitatis Agriculturae Sueciae presents doctoral theses from the Swedish University of Agricultural Sciences (SLU).

SLU generates knowledge for the sustainable use of biological natural resources. Research, education, extension, as well as environmental monitoring and assessment are used to achieve this goal.

ISSN 1652-6880
ISBN (print version) 978-91-8124-041-2
ISBN (electronic version) 978-91-8124-087-0