Ensilability of Forage Cover Crops and Smallholder Farmers' Knowledge, Attitudes and Practices Regarding their use within Conservation Agriculture in Okhahlamba Local Municipality, KwaZulu Natal

By

SIKHO KAMVA CEMBI

(220088496)

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School of Agriculture and Science

College of Agriculture, Engineering and Science

University of KwaZulu-Natal

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Supervisor

Dr NR Mkhize

Co-Supervisor (s)

Prof PF Scogings and Prof TJ Tjelele

Declaration

I, **Sikho Kamva Cembi**, hereby declare that the dissertation entitled "**Ensilability of Forage Cover Crops and Smallholder Farmers' Knowledge, Attitudes and Practices Regarding their use within Conservation Agriculture in Okhahlamba Local Municipality, KwaZulu Natal**" is my original work. This study was conducted by me between March 2024 and June 2026. All sources consulted have been properly acknowledged and properly referenced. I further confirm that this dissertation has not been submitted for any degree at any other institution by myself or any other person.

Student: Sikho Kamva Cembi (220088496)

Signature  Date: 02 June 2026

Approved by:

Dr NR Mkhize Signature  Date: 15 June 2026

Prof PF Scogings Signature  Date: 23 June 2026

Prof TJ Tjelele Signature  Date: 23 June 2026

Dedication

This work is dedicated to the memory of my late grandmother, Mamchenge. Although she is no longer here to witness this milestone, her presence remains deeply felt. I am confident that she would have been proud of the academic journey I have undertaken and how much I have grown.

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General Abstract

The sustainability of smallholder farming systems in South Africa is increasingly threatened by climate variability, declining soil fertility, and seasonal feed shortages. Conservation Agriculture (CA) and improved forage conservation strategies have been identified as important approaches for improving resilience, productivity, and livestock nutrition. Forage cover crops (CCs) play an important role in CA and integrated crop–livestock systems. This study addressed two interrelated objectives: (1) to assess the knowledge, attitudes, and practices of smallholder farmers regarding the use and preservation of forage CCs for CA in Okhahlamba Local Municipality, KwaZulu-Natal, and (2) to evaluate the effect of dry matter (DM) content on fermentation characteristics, chemical composition, aerobic stability, and *in sacco* DM degradability of sorghum and pearl millet silages.For the first objective, a quantitative cross-sectional survey was conducted among 50 smallholder farmers who attended a Farmers' Day workshop in Bergville. A structured questionnaire was administered to collect information on farmers' demographic characteristics, knowledge of forage CCs, CA, and forage preservation, attitudes towards CC cultivation and silage production, and practices related to CC cultivation, forage preservation, and livestock feeding. The questionnaire was pre-tested and translated into IsiZulu to facilitate data collection. Data were analysed using descriptive statistics, Pearson's chi-square tests, and Spearman's rank-order correlation. Farmers demonstrated moderate knowledge of CCs and CA, but substantial knowledge gaps were observed regarding silage production and forage preservation. Although respondents expressed positive attitudes towards the benefits of CCs for soil improvement, crop productivity, and livestock production, perceptions of silage production were predominantly negative, and adoption of forage CCs for silage was low. Lack of knowledge, insufficient training, limited access to equipment and other resources, and financial constraints were identified as major barriers to adoption. Knowledge was weakly but significantly positively associated with practices ($r = 0.325$, $p < 0.05$), whereas attitudes were not significantly associated with practices. These findings indicate that improving farmers' knowledge and addressing resource and training constraints may be important for strengthening the adoption of forage CCs and their preservation. However, the low use of forage CCs for silage also highlights the need to evaluate the technical suitability of these forages for conservation, particularly through optimisation of DM content. For the second objective, an experimental study was conducted using a randomised complete block design to evaluate sorghum and pearl millet silages prepared at four target DM levels (25%, 30%, 35%, and 40%) using wheat bran as an absorbent. The effects of target DM on chemical composition, fermentation characteristics, aerobic stability, and *in sacco* DM degradability were evaluated. Data were analysed using one-way analysis of variance, with regression analysis used

to assess responses to increasing DM levels. Increasing DM significantly increased CP concentration and reduced fibre fractions ($p < 0.05$) in both silages. However, higher DM levels were associated with reduced lactic acid concentrations and increased pH ($p < 0.05$), indicating less intensive fermentation at higher DM levels. Despite these differences, all treatments achieved excellent fermentation quality based on Fleig scores (>80). Lower DM levels (25%–<30%) resulted in greater *in sacco* DM disappearance at 72 h ($p < 0.05$), whereas moderate DM levels (30%–35%) resulted in higher effective degradability. Aerobic stability was not significantly affected by DM level, with all silages remaining stable under aerobic conditions. A target DM range of 30%–35% provided a favourable balance between fermentation quality, chemical composition, and ruminal degradability of sorghum and pearl millet silages. Overall, the findings demonstrate that although farmers showed a moderate understanding of forage CCs and CA, important knowledge and implementation gaps remain, particularly regarding forage preservation. Optimising silage DM to approximately 30%–35%, together with targeted training, practical demonstrations, and improved access to resources, could support the effective use and conservation of forage CCs and contribute to more resilient smallholder crop–livestock systems in Bergville, Okhahlamba Local Municipality.

Keywords: Biomass conservation, farmer perceptions, fermentation quality, forage utilisation, nutrient dynamics, *Pennisetum glaucum*, ruminal digestion, *Sorghum bicolor*

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List of abbreviations

A	Fraction of DM (%) lost during washing
AA	Acetic Acid
ADF	Acid Detergent Fibre
ADL	Acid Detergent Lignin
AOAC	Association of Official Analytical Chemists
AS	Aerobic Stability
B	Fraction of DM (%) degraded
C	Rate of Degradation(h^{-1})
CA	Conservation Agriculture
CCs	Cover crops
Cell	Cellulose
CFU	Colony Forming Units/Gram
CP	Crude Protein
DM	Dry Matter
ED	Effective Degradability
FS	Flieg Score
Hemi	Hemicellulose
IVDMD	In *Vitro* Dry Matter Degradability
KZN	KwaZulu-Natal
LA	Lactic Acid
LAB	Lactic Acid Bacteria
MW	Pearl Millet-Wheat Bran
MY	Mould and Yeast
NDF	Neutral Detergent Fibre
PA	Propanoic Acid
SA	South Africa
SW	Sorghum-Wheat Bran
TDM	Target Dry Matter
WB	Wheat bran

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CHAPTER 1: GENERAL INTRODUCTION

1.1. Background

Agriculture has long been a fundamental pillar of human civilisation, providing food and sustaining livelihoods across generations (Araújo et al., 2021). Over time, agricultural systems have evolved in response to changing environmental conditions and the increasing demands of a growing global population (Gyamfi et al., 2024). By 2050, the global population is projected to reach approximately 9.7 billion, increasing from about 8.0 billion in 2022, with most of this growth expected to occur in developing regions, particularly sub-Saharan Africa and South Asia (Wheeler and von Braun, 2013; Liper et al., 2014). In these regions, agriculture remains a central component of economic activity and a primary source of employment while being dominated by smallholder farming (Wheeler and Von Braun, 2013; Abdul Rahman et al., 2024). However, a substantial proportion of the population continues to experience food insecurity, highlighting the urgent need to improve agricultural productivity and sustainability. Climate change further exacerbates these challenges by directly impacting agricultural productivity through increased soil erosion, soil fertility depletion, and more frequent droughts and floods (Lavudya et al., 2024; Yang et al., 2024). Consequently, crop productivity and the sustainability of farming systems are increasingly under pressure.

South Africa is particularly vulnerable to climate change because of its strong reliance on rainfed agriculture and its limited adaptive capacity (Palmer and Ainslie, 2006; Olabanji et al., 2021). These constraints increase risks to agricultural production and highlight the need for farming systems that can maintain productivity under variable climatic conditions. Conservation agriculture has been widely recognised as a sustainable approach with the potential to address these challenges (Kassam et al., 2009). Conservation agriculture is based on three core principles: (1) minimal soil disturbance, (2) permanent organic soil cover, and (3) crop rotation and diversification (Thierfelder and Wall, 2011). Together, these principles improve soil fertility, reduce erosion, and improve system resilience (Twomlow et al., 2008).

Within CA systems, cover crops support all three principles. Firstly, their residues remain on the soil surface after termination, reducing the need for tillage and supporting minimal soil disturbance (Hobbs et al., 2008). Secondly, they provide continuous soil cover, which helps reduce erosion and conserve soil moisture (Dabney et al., 2007). Thirdly, they increase crop diversity when included in crop rotations or intercropping systems, thereby improving system resilience (Snapp et al., 2005; Finney and Kaye, 2016). As a result, cover crops have become an integral component of CA systems. Common cover crop species include legumes such as clover and vetch, grasses such as rye and oats, and brassicas such as radish and mustard (Fernando and

Shrestha, 2023; Salisu et al., 2025). These species have been documented to improve soil fertility (Kaye and Quemada, 2017), reduce soil erosion (Kasper and Singer, 2011), suppress weeds (Osipitan et al., 2018), and enrich overall soil health and productivity. Among the forage CCs used in CA systems, sorghum and pearl millet have gained increasing attention because of their drought tolerance, adaptability to marginal environments, and ability to produce substantial biomass under low-input conditions (Shrestha et al., 2023; Abreha et al., 2022; Cruz et al., 2025). Beyond their role in soil protection and system diversification, these crops are also important forage resources for livestock production. Sorghum and pearl millet can produce relatively high quantities of palatable forage and provide a source of energy and nutrients for ruminants, making them suitable for integration into crop–livestock systems (Dunjana et al., 2022; Daduwal et al., 2024). Their ability to maintain forage production under water-limited conditions is particularly valuable in smallholder systems, where livestock depend heavily on locally produced feed and where climatic variability can reduce the availability of conventional forage resources.

The importance of these benefits is particularly evident in KwaZulu-Natal (KZN), which has experienced prolonged droughts, erratic rainfall patterns, and extreme temperatures in recent years (Sikhakhane, 2025; Singh, 2025; Mabaso, 2026). Because smallholder farming systems in the province depend largely on rainfed agriculture, they are highly vulnerable to these climatic stresses (Ndlovu et al., 2021). Consequently, many farmers have experienced crop failures, declining livestock productivity, water shortages, and increasing food insecurity (Ndlovu et al., 2021). Farmers in northern KZN have also reported reduced crop yields and livestock performance, forcing many households to rely increasingly on purchased food (Maziya et al., 2024).

In response, smallholder farmers have adopted CA practices to improve soil health and stabilise production (Mthethwa et al., 2022; Maziya et al., 2024). However, despite the recognised benefits of cover crops, their adoption of these species within the CA system remains limited (Ndah et al., 2014; Lee and Gambiza, 2022). Low adoption has been linked to limited knowledge and training, inadequate extension support, resource constraints, and uncertainty about the benefits of cover crops (Lee and Gambiza, 2022). These constraints may limit the contribution of cover crops to climate-resilient farming systems in KZN.Although forage cover crops can be grown to support the principles of CA, they can also provide a valuable source of livestock feed. In integrated crop–livestock systems, cover crops provide supplementary forage during winter and early spring when forage availability is limited (Janhi et al., 2019; Paye et al., 2022). This dual role is particularly important in smallholder farming systems, where seasonal feed

shortages can frequently limit livestock productivity and are further exacerbated by climate variability. However, the forage provided by cover crops is not always available when feed shortages occur (Cooke et al., 2025). Hence, it is vital to preserve surplus forage from cover crops for use during periods when feed resources are limited (Balegeh et al., 2021)

Among the available preservation methods, ensiling is widely recognised as an effective technique for conserving forage and maintaining its nutritional value (Sahoo, 2018). By preserving nutrients in moist forage under anaerobic conditions, ensiling provides a sustainable means of supplementing ruminant diets during dry seasons and other periods of feed scarcity (Sahoo, 2018; Wróbel et al., 2025). Nevertheless, the success of the ensiling process largely depends on the dry (DM) content of the forage at ensiling. Dry matter is a key determinant of silage quality because it influences microbial activity, fermentation patterns, nutrient preservation, and digestibility in livestock (Muck, 2010). At low DM levels, excessive fermentation and nutrient losses through effluent may occur, whereas very high DM levels can reduce compaction and increase the risk of aerobic spoilage (Wróbel et al., 2025). Therefore, achieving an optimal DM range is essential to maximise nutrient preservation, support desirable fermentation, and improve silage stability and feeding value.

Despite the recognised importance of DM content in silage production, limited research has examined its effects on the fermentation quality, nutrient preservation, and digestibility of ensiled cover crops. This information is needed to optimise the use of cover crop biomass, particularly because ensiling can preserve forage that might otherwise be underutilised or lost after the growing season (Van Vlierberghe et al., 2022.The successful adoption of cover crops and their use for silage production depends not only on technical feasibility but also on farmers' knowledge, attitudes, and practices. Knowledge influences farmers' awareness and understanding of these technologies, while attitudes affect their willingness to adopt them and their perceptions of associated risks and benefits (Knowler and Bradshaw, 2007; Sarma et al., 2025). Farmers' practices reflect their capacity to implement these technologies effectively. Assessing these factors is therefore important for understanding the adoption and utilisation of cover crops within smallholder farming in KZN. Accordingly, this study aimed to assess the ensilability of forage cover crops and evaluate farmers' knowledge, attitudes, and practices regarding their use within CA systems. By addressing both technical and socio-economic factors, the study contributes to improved feed security, sustainable livestock production, and the effectiveness of CA systems among smallholder farmers in KZN.

1.2 Problem statement

Conservation agriculture is increasingly promoted as a climate adaptation strategy, together with

forage-based approaches that improve livestock feed availability. However, the adoption of cover crops within these systems remains limited despite their recognised agronomic benefits and potential contribution to livestock production. In addition, the use of cover crops as a reliable source of high-quality preserved feed under local conditions has not been adequately explored. This limits their contribution to improving feed availability and livestock productivity, particularly in smallholder farming systems that frequently experience seasonal feed shortages. A major technical challenge relates to the uncertainty surrounding the optimal dry matter (DM) content required to produce high-quality silage from cover crops. Dry matter plays a central role in silage quality because it influences microbial activity, fermentation processes, nutrient preservation, and digestibility (Borreani et al., 2018). However, the optimal DM range that best supports desirable fermentation characteristics, nutrient retention, and feeding value has not been clearly established, particularly under smallholder farming conditions in KZN. Consequently, the efficient utilisation of cover crop biomass as a dependable livestock feed resource remains uncertain.

Beyond the technical aspects, the success of cover crop silage systems also depends on farmer-level factors. The adoption of these practices is influenced by farmers' knowledge, attitudes, and practices. However, there is still a limited understanding of how these socio-economic factors interact with the technical knowledge of silage systems to shape awareness, acceptance, and actual use within CA systems in KZN. This creates a gap between what is technically possible and what is practically adopted in real farming systems. Overall, there is a lack of integrated research that combines both the optimisation of cover crop silage production, particularly in relation to DM content, and the socio-economic factors that influence farmer adoption. Addressing this gap is important for improving the use of cover crop biomass, strengthening feed availability during periods of scarcity, and supporting more resilient and sustainable smallholder livestock production systems.

1.3 Justification

The sustainability of livestock production systems depends strongly on the continuous availability of nutritious forage (Guyader et al., 2016). In KZN, smallholder livestock systems are increasingly affected by climate variability, which reduces grazing availability and intensifies seasonal feed shortages. These constraints limit livestock productivity and threaten household food security. As a result, there is a growing need for practical and locally relevant feed conservation strategies. Conservation agriculture is widely promoted as a climate-smart approach for improving soil health, enhancing productivity, and strengthening system resilience under variable climatic conditions (Hailu and Teka, 2024). Within these systems,

cover crops are mainly used for soil-related functions. However, they also produce biomass that has potential value as livestock feed (Teague, 2018). When preserved through ensiling, this biomass can extend feed availability beyond the growing season and reduce seasonal feed gaps.

In addition, Smit et al. (2021) demonstrated that cover crops can provide livestock feed while maintaining the benefits of CA and further indicated that the effective utilisation of their biomass requires additional research. This highlights the need to investigate factors that influence the quality and utilisation of cover crop silage, particularly DM content. Since DM plays a critical role in fermentation, nutrient preservation, and overall feed value, generating information on optimal DM levels is essential for improving the use of cover crop biomass as livestock feed. Such information could support the development of more reliable feed resources for smallholder farmers and increase feed availability during periods of forage scarcity.

In addition to technical constraints, adoption is influenced by farmer-level factors such as knowledge, attitudes, and practices. These factors shape how farmers understand, evaluate, and apply new agricultural technologies (Meijer et al., 2015). However, there is limited understanding of how they influence the adoption of cover crop silage systems in KZN. This creates a gap between research findings and practical on-farm implementation. Addressing both the technical constraints and socio-economic factors is therefore vital. This study generates evidence to improve the use of cover crops as livestock feed and to support more informed decision-making among smallholder farmers.

1.2. Aim and objectives

This study aimed to assess the ensilability of forage cover crops and evaluate farmers' knowledge, attitudes, and practices regarding the use of cover crops within conservation agriculture systems in Okhahlamba local Municipality, KwaZulu-Natal.

The specific objectives were:

1. To assess the knowledge, attitudes, and practices of smallholder farmers regarding the use and preservation of forage cover crops for conservation agriculture in Okhahlamba local municipality, KwaZulu-Natal.
2. To evaluate the effect of dry matter on the fermentative characteristics, chemical composition, and *in sacco* DM degradability of sorghum and pearl millet silage.

1.3. Hypotheses

1. Farmers' knowledge and attitudes will influence their practices related to the use and preservation of forage cover crops within CA systems.

2. Increase in the dry matter content of sorghum and pearl millet silages from 25% to 40% will improve silage quality by enhancing nutrient profiles (higher crude protein, lower fibre fractions) and promoting desirable fermentation characteristics (lower pH, higher lactic acid).

1.4. Thesis outline

This introductory chapter has set the scene for the subject of the succeeding chapters.

Chapter 2 discusses the importance of livestock production in South Africa under changing climatic conditions and examines the principles of CA. The chapter further explores the role of sorghum and pearl millet as forage cover crops within conservation agriculture systems, with emphasis on their forage potential, nutritive value, and suitability for forage preservation. Their potential as climate-resilient forage resources for smallholder farming systems is also discussed.

Chapter 3 focuses on the social component of the study. It assesses the knowledge, attitudes, and practices of smallholder farmers regarding the use and preservation of forage cover crops within CA systems in KZN.

Chapter 4 presents the technical component of the study and examines the factors affecting the ensilability and quality of sorghum and pearl millet forage used as cover crops. Specifically, it evaluates the effects of different dry matter (DM) levels on silage fermentation characteristics, chemical composition, aerobic stability, and in sacco dry matter degradability. The chapter therefore assesses how adjustment of DM content influences both the fermentation quality and nutritive utilisation of the resulting silages.

Chapter 5 provides a summary and interpretation of the findings from both the social and technical components of the study. The chapter discusses the implications of the results for the use of forage cover crops in CA. It further highlights the potential contribution of sorghum and pearl millet cover crops to improving livestock feed availability and enhancing the sustainability of smallholder farming systems in KZN.

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CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

Livestock farming is an important component of the agricultural sector and has significant potential to improve livelihoods within smallholder farming systems across South Africa (Meissner et al., 2013; Zansti, 2021). In these systems, ruminant livestock production is a major enterprise because it provides meat and milk for food security while also supporting income generation and employment (Herrero et al., 2013; Anim-Jnr et al., 2023). However, the productivity and profitability of ruminant systems largely depend on adequate animal nutrition. Feed costs can account for up to 70% of total production expenses in ruminant enterprises (Bach, 2012), which poses a major challenge for resource-limited smallholder farmers operating under extensive or semi-intensive systems. Consequently, these farmers mainly rely on natural forages, crop residues, and communal grazing lands as primary feed resources (Simbaya, 2002; Bogale et al., 2008; Duguma et al., 2021). However, these feed resources are generally low in nutritional value and are strongly affected by seasonal fluctuations, particularly during the dry season when forage quantity and quality decline sharply (Gelhaus et al., 2016).

To address seasonal feed shortages and improve livestock productivity, some smallholder farmers have adopted high-quality forages such as legumes (Medicago sativa, Vigna unguiculata), improved grasses (*Cynodon dactylon*, *Lolium multiflorum*, *Festuca arundinacea*, *Lolium perenne*), and brassicas (*Brassica rapa*, *Brassica acephala*) (Muoni et al., 2019; Herforth et al., 2025; Mandiriza-Mukwirimba et al., 2016). These forage species can improve nutrient intake and animal performance (Truter et al., 2015). However, their cultivation is often limited by high input requirements, including fertiliser, irrigation, and labour costs, which are generally unaffordable for many smallholder farmers (Giller et al., 2009). In addition, their growth and productivity are highly vulnerable to climatic variability, particularly prolonged droughts and erratic rainfall (Hart et al., 2022; Dubeux et al., 2024).

Climate change is further intensifying these challenges across much of Africa through increasingly unpredictable weather patterns, including more frequent droughts and erratic rainfall (Batisani and Yarnal, 2010). These conditions threaten forage production and worsen the imbalance between forage supply and livestock feed demand, especially during the dry season. Furthermore, water scarcity in arid and semi-arid regions limits the successful production of conventional forages (Bondaruk et al., 2022; Piri et al., 2025). This highlights the

urgent need to identify and promote alternative forage crops that are both climate-resilient and nutritionally adequate.

Pearl millet and sorghum are important forage crops in many arid and semi-arid regions because they can tolerate low rainfall, high temperatures, and poor soil fertility (Chaturvedi et al., 2023). Both crops are recognised for their good nutritional value (Bhattarai et al., 2019). Pearl millet generally has a higher leaf-to-stem ratio, lower lignin content, higher crude protein concentration, and better digestibility than sorghum and maize (Harinarayana et al., 2005; Kumar et al., 2019). In addition, pearl millet is rich in essential minerals such as calcium and phosphorus, while its oxalic acid concentration remains within safe limits. Unlike sorghum, pearl millet can be grazed or harvested at almost any stage of growth, making it a flexible forage option for year-round use. Although pearl millet is often considered nutritionally superior, both pearl millet and sorghum can be conserved during summer for feeding during winter when forage quality and availability decline.

Forage conservation is an important strategy for reducing seasonal feed shortages and maintaining livestock productivity (Balehegn et al., 2022). Studies have shown that pearl millet and sorghum can be preserved as hay, silage, foggage and crop residues (Moyer et al., 2004; Hassanat et al., 2007; Amer et al., 2012; Brunette et al., 2014). Among these methods, silage is the most widely used because it preserves forage through fermentation under anaerobic conditions (Wilkinson and Rinne, 2018). Therefore, understanding the ensiling characteristics of these forage crops is important for improving silage quality, digestibility, and animal performance. Improved forage preservation can ultimately support livestock productivity and farmer livelihoods within smallholder farming systems.

In addition to their forage value, sorghum and pearl millet are also important in Conservation agriculture systems because of their adaptability to harsh environmental conditions and their ability to improve soil health, promote biodiversity, and reduce soil erosion (Slakie, 2013; Cruz et al., 2025). In conservation agriculture, cover crops are mainly grown to protect and improve soil quality rather than for harvest (Hobbs et al., 2008; Smith et al., 2021). Sorghum and pearl millet are considered suitable cover crops because of their favourable agronomic characteristics and weed suppression ability (Trezzi et al., 2004). Therefore, this review evaluates the potential of sorghum and pearl millet as alternative forage crops by examining their nutritional value, forage conservation potential, particularly silage production, and their role as cover crops in conservation agriculture systems. The overall aim is to determine how

these crops can contribute to improved livestock productivity among smallholder farmers in South Africa.

2.2. Livestock production in South Africa

The livestock sector plays an important role in the global food system by contributing to food security, poverty reduction, and agricultural development (Amejo et al., 2018). It is one of the fastest-growing agricultural subsectors, particularly in southern african developing countries, where it contributes about 33% of agricultural GDP (Thornton et al., 2010). In Southern Africa, cattle, sheep, and goats are the dominant livestock species because of their economic value and contribution to rural livelihoods (Otte and Chilonda, 2003; Erdaw et al., 2023). These animals mainly depend on extensive grazing systems, with large areas of land used globally for livestock production (Michalk et al., 2019).

In South Africa, smallholder farmers manage a large proportion of agricultural land and make an important contribution to national food production (Cafer et al., 2018). Livestock production in these systems is mainly divided into small-scale commercial and communal farming systems (Palmer and Ainslie, 2006). Small-scale commercial farmers are generally market-oriented and use moderate levels of technology and external inputs (Ainslie, 2005), whereas communal farmers mainly practice subsistence farming with limited use of technology. According to Statistics South Africa (2024), most provinces experienced a decline in cattle numbers between 2011 and 2022, except for North West and Mpumalanga. Farmers identified several constraints to livestock production, including water shortages, limited grazing land, livestock theft, movement restrictions, and animal diseases (Ngoshe et al., 2022). These challenges particularly affect emerging farmers and contribute to persistent inequalities within the livestock sector. Despite these constraints, communal livestock farming remains important in provinces such as KwaZulu-Natal, Eastern Cape, and Limpopo, where many households depend on cattle, goats, and sheep for livelihoods (FAO, 2006). KwaZulu-Natal, in particular, has a high number of households farming goats because goats are widely used in cultural and traditional ceremonies, creating a strong local demand for goat production (Khowa et al., 2023).

Despite the importance of livestock production, poor-quality feed remains one of the major challenges affecting animal productivity (Kamalzadeh et al., 2008). The main feed resources, natural pastures and crop residues, are generally low in digestibility and nutrient content (Kubkomawa et al., 2015; Bhandari, 2019). In addition, seasonal feed shortages, limited access to agro-industrial by-products, and the high cost of concentrate feeds make it difficult to meet

the nutritional requirements of livestock (Rusdy et al., 2016; Alimi et al., 2024). Although improving production efficiency is central to livestock enterprise development, long-term sustainability requires careful evaluation of animal nutrition and performance to support productivity.

Table 2.1 Number of agricultural households grouped by number of cattle, sheep, and goats farmed in South Africa

	Cattle			Sheep			Goats		
Province	**0-10**	**11-100**	**+100**	**0-10**	**11-100**	**+100**	**0-10**	**11-100**	**+100**
Western Cape	1 701	1 864	824	1 332	1 861	2 252	1 048	901	287
Northern Cape	5 082	3 884	444	4 893	6 573	1 395	5 697	7 903	382
KwaZulu-Natal	97 625	59 592	2 248	20 320	9 871	633	103 249	78 439	1 378
North west	28 967	22 306	1922	18 508	16 613	700	26 411	27 887	572
Eastern Cape	109 358	51 276	5 204	46 488	88 325	16 463	85 661	79 073	2260
Limpopo	53 547	34 639	1085	18 300	8 105	436	63 242	42 331	467
Mpumalanga	30 206	21 026	1 002	4,945	2509	456	27 489	15 062	176
Free State	13 194	7 365	1 807	3 810	3 932	1 646	3 239	1 826	135
Gauteng	4 267	4 371	728	2 854	2 524	441	4 457	3 275	233
Total	**343 947**	**206 323**	**13016**	**116 510**	**126 510**	**24 422**	**320 493**	**256 697**	**5 890**

Source: STATS SA (2024), Census 2022, Agriculture household

2.2.1. Livestock nutrition

Ruminants play an important role in supporting the livelihoods of smallholder farmers, particularly in developing countries (Pulina et al., 2017). They provide milk, meat, draught power, and manure for crop production, while also serving as a source of income and financial security under difficult economic and environmental conditions (Smith et al., 2013). Globally, ruminants contribute substantially to human food supply systems by producing nearly all milk and about 29% of total meat production (Gerber et al., 2013; Guyader et al., 2016). In many low-input production systems, especially among smallholder farmers, ruminants mainly depend on natural pastures and crop residues as feed resources. However, these feed sources are often inadequate to support optimal animal productivity because feed intake and animal performance largely depend on forage quality and availability (Mertens, 1994; Konlan, 2018).

In rangeland systems, feed intake by grazing ruminants commonly declines during the dry season when forage quantity and quality become insufficient to meet animal nutritional requirements (Pulina et al., 2017). In addition, accurately determining feed intake and diet selection remains challenging because of variations in animal behaviour and feed resources under both grazing and indoor feeding systems (Osoro et al., 2013; Mkhize et al., 2014). Climate change has further intensified these challenges by negatively affecting agricultural production and forage systems worldwide (Ahmed et al., 2022). Extreme temperatures and erratic rainfall patterns frequently reduce crop growth and productivity (Raza et al., 2019; Giridhar et al., 2015). These impacts are particularly severe in tropical regions where rainfed agriculture dominates, and farming systems are highly dependent on climatic conditions. Climate change affects plant growth through morphological, physiological, and biochemical disruptions that ultimately reduce crop productivity (Chadalavada et al., 2021; Raza et al., 2019).

Beyond crop production, climate change has also reduced forage quality and livestock productivity, particularly in tropical and subtropical regions (Bhiya, 2018). These regions contain large grazing areas and support many food-insecure populations, yet they are expected to experience increasing temperatures and scarcity. Such conditions reduce forage biomass and lower nutritional quality by decreasing crude protein content and digestibility (Henry et al., 2018). Increasing rainfall variability further threatens the sustainability of livestock production systems (Alemayehu et al., 2025).

High-quality forages such as legumes and temperate grasses are rich in nutrients, particularly crude protein, but they generally require high water availability for optimal growth (Annicchiarico et al., 2015). Consequently, their productivity is highly vulnerable to climate change. Therefore, there is an urgent need to identify and promote climate-resilient forage species with high nutritional value and rapid growth potential to help smallholder farmers maintain livestock productivity under increasingly unpredictable climatic conditions. Such species must combine resilience, productivity, and nutritive quality to sustain ruminant performance and support the long-term viability of smallholder and communal livestock systems under increasingly unpredictable climatic conditions.

2.3. Forage production

Ruminant productivity depends largely on the availability and quality of forage, especially in extensive and semi-extensive farming systems. Globally, forage lands occupy about 27% of the Earth's land surface and 71% of agricultural land, highlighting their importance in livestock production and food security (FAO, 2008). In many developing countries, including South Africa, forage availability is highly seasonal and unevenly distributed, resulting in persistent feed shortages for grazing animals. These challenges are more severe in communal farming systems, where overgrazing and limited management resources reduce pasture productivity (Snyman et al., 2005). These lands include natural grasslands, permanent pastures, and cultivated forage systems used within crop rotations (Humphreys et al., 2014).

Grasslands contain many forage species suitable for livestock production in tropical and subtropical regions, although only a small proportion has been commercially developed (Hanson and Ellis, 2020). Natural and improved pastures provide the main grazing resource during the growing season, while cultivated forages are often conserved as hay or silage for periods of feed shortage. Improving pasture management is therefore essential to boost forage productivity, nutritive value, and grazing efficiency, which ultimately supports better livestock performance (Boval and Dixon, 2012).

The growing demand for animal-source foods, driven by rapid population growth, has increased pressure on available land resources (Teferedegne et al., 2000). At the same time, grazing areas continue to decline because of expanding settlements, crop production, mining, forestry, and conservation activities. In densely populated regions, many farmers can no longer rely solely on natural grasslands and must increasingly use alternative feed resources such as cultivated forages, crop residues, agro-industrial by-products, and concentrate feeds (Rusdy et al., 2016). Under these conditions, the cultivation of high-yielding and drought-

tolerant forage crops such as sorghum and pearl millet are becoming an important strategy for sustaining livestock productivity in land-constrained farming systems (Rusdy et al., 2016).

2.3.1. Characteristics of climate-resilient forage crops

2.3.1.1. Sorghum

Sorghum (*Sorghum bicolor* [L.] Moench) is a tropical cereal crop widely grown in semi-arid regions because of its strong tolerance to heat, drought, and variable climatic conditions (Rao et al., 2015). It is the fifth most cultivated cereal crop globally and serves both food and feed purposes depending on regional needs (Hariprasanna et al., 2017). Globally, sorghum is an important cereal crop used for both grain and fodder production under irrigated and rainfed conditions (Chadalavada et al., 2021). In many parts of Africa and Asia, sorghum is an important staple food crop that contributes to food security, whereas in more industrialised countries, it is mainly produced as livestock and poultry feed (Léder, 2004). Major sorghum-producing regions include India, Pakistan, Thailand, China, Australia, and the drier parts of Argentina and Brazil (Mundia et al., 2019; Davoudkhani et al., 2025).

Sorghum productivity is influenced by factors such as cultivar type, nutrient availability, irrigation, planting density, climate, pest incidence, and management practices (Bhattarai et al., 2020). Although sorghum production has declined in parts of Asia and the Americas, cultivated area and yields have increased in Africa over the past decade (FAOSTAT, 2012). Despite these regional differences, sorghum remains highly adaptable and can grow under diverse environmental conditions (Schittenhelm et al., 2014; Rattunde et al., 2021).

The crop performs well in both tropical and temperate climates, under rainfed or semi-arid conditions, and across a wide range of soils and altitudes (Mwamahonje et al., 2024). It can tolerate soils with pH levels between 5.0 and 8.5 and germinates best at temperatures ranging from 10°C to 35°C (Panico et al., 2020). Its short growth cycle, low input requirements, high tillering ability, and high biomass production make sorghum particularly suitable for marginal and resource-limited farming systems (Yadav et al., 2024)

Sorghum is cultivated on both commercial and smallholder farms in several provinces of South Africa, including the Free State, Limpopo, Mpumalanga, North West, Gauteng, and KwaZulu-Natal (Grain SA, 2014). Planting usually takes place between October and January, depending on rainfall availability. Sorghum is mainly grown under dryland conditions, which account for about 99% of the cultivated area nationally (Haarhoff, 2020). Its widespread production in the western parts of the country is largely due to its strong tolerance to arid and

semi-arid environments. In many tropical regions, more than 70% of the grain produced is consumed by humans, while part of the crop is specifically cultivated as livestock fodder, especially in areas with limited forage availability. Sorghum forage is commonly used as green fodder during the growing season and later as stover after harvest. In tropical production systems, nearly 90% of sorghum is grown without inorganic fertilisers because many smallholder farmers cannot afford external inputs (Weltzien et al., 2018; Dunjana et al., 2022). Consequently, production often relies on residual soil fertility and limited applications of organic amendments (Malobane et al., 2020; Mokgehle et al., 2024). These low-input requirements, together with its drought tolerance and adaptability, make sorghum an important crop for resource-constrained farming systems.

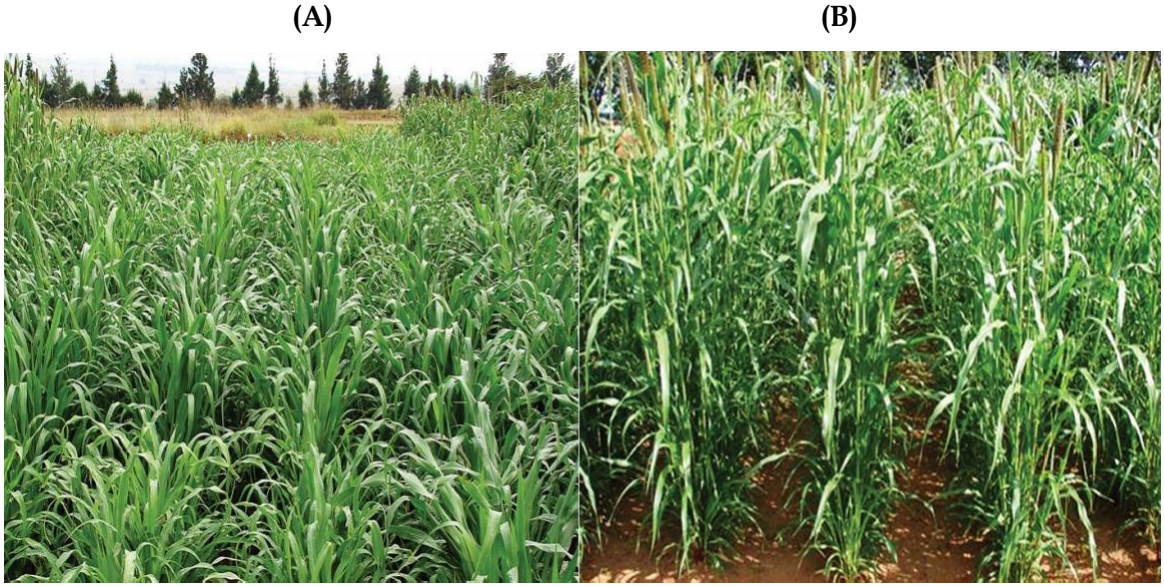

Figure 2.1 Sorghum forage at grazing height stage (A) and early flowering stage (B) (*Source: Grain SA,2014).*

2.3.1.2 Pearl millet

Pearl millet (*Pennisetum glaucum [L.]* R. Br.) is a warm-season annual cereal crop known for its exceptional tolerance to drought, high temperatures, and low soil fertility (Khairwal et al., 2007; Singh et al., 2017). Originating in West Africa, it later spread to India and other semi-arid regions, where it is now widely cultivated. Among domesticated cereals, pearl millet is one of the most drought- and heat-tolerant crops and requires relatively little water for growth (Serba et al., 2020; Shrestha et al., 2023). These characteristics make it the second most widely grown millet crop globally after sorghum (Haussmann et al., 2012).

Pearl millet is an important crop for food and livelihood security, particularly among resource-poor farmers in arid and semi-arid regions. It is used for food, livestock feed, forage,

fodder, brewing, building material, and biofuel production (Daduwal et al., 2023; Satyavathi et al., 2024). Globally, the crop is cultivated on approximately 27–30 million hectares and serves as a staple food for millions of people, especially in Africa and India (Satyavathi et al., 2024). Over time, Africa's contribution to global pearl millet production has increased considerably (FAOSTAT, 2012). In India, the crop is grown for both grain and fodder, while in many African countries, its stover is commonly used as livestock feed (Koli et al., 2018; Boote et al., 2022). As a C4 crop, pearl millet possesses strong climate-resilient traits that enable it to tolerate drought, salinity, high temperatures, low soil fertility, and acidic or alkaline soils (Al-Farsi, 2006; Krishnan et al., 2006). It can survive in regions receiving less than 250 mm of annual rainfall, where many other cereal crops fail to produce grain (Srivastava et al., 2020). Its efficient photosynthetic system, high biomass production, and low input requirements make it particularly suitable for smallholder and low-input farming systems in marginal environments (Bandyopadhyay et al., 2017).

(A) **(B)**



Figure 2.2: Pearl millet forage at the grazing height stage(A) and flowering stage(B) (*Source: Grain SA,2014*)

In South Africa, pearl millet is mainly cultivated in Limpopo, KwaZulu-Natal, and the Free State, with planting commonly taking place between October and November. Under favourable conditions, hybrids can produce yields of 3–4 t/ha (Ausiku, 2025). The crop is often intercropped or rotated with legumes and other cereals because it performs well under unreliable rainfall and limited agricultural inputs (Waddington et al., 2010). Similar to

sorghum, pearl millet is generally grown under low-input conditions with little or no fertiliser application, particularly in regions receiving 400–500 mm of annual rainfall (Nagarajan et al., 2005).

Beyond grain production, both sorghum and pearl millet have considerable potential as forage crops for ruminant livestock because of their adaptability, biomass production, and ability to perform under harsh environmental conditions. Evaluating their nutrient composition and forage quality is therefore important for improving feed formulation, livestock productivity, and smallholder farming systems while reducing risks such as poor feed quality and mycotoxin contamination (Musidzaramba et al., 2025).

2.3.2. Nutritive value of forage sorghum and millet

Forage quality is an important determinant of ruminant growth, productivity, and overall animal performance because it influences nutrient intake, digestion, and nutrient utilisation (Paterson et al., 1994; Beever and Mould, 2000). It is determined by several characteristics, including nutrient composition, digestibility, intake potential, and the presence of antinutritional factors (Minson, 2012; Carlier et al., 2009). In sorghum and pearl millet, forage quality can vary according to cultivar, stage of maturity, growing environment, soil fertility, and agronomic management practices such as irrigation and fertiliser application. Therefore, reported nutritive values should be interpreted in relation to the conditions under which the forage was produced and harvested.

The variation in chemical composition among sorghum and pearl millet cultivars is evident from the literature summarised in Table 2.2. Reported CP concentrations in Sorghum ranged from 7.2% DM in Sorghum Evergreen PS BMR to 14.5% DM in the Piper cultivar, whereas pearl millet CP ranged from 7.51% DM in IP22269 to 16.1% DM in CON PM (Table 2.2). Similarly, NDF concentrations ranged from 38.14 to 64.2% DM among the reported sorghum cultivars and from 43.25 to 68.2% DM among pearl millet cultivars (Table 2.2). These differences indicate substantial variation in the nutritive characteristics of the forage materials reported across studies. However, such differences cannot be attributed exclusively to cultivar because the studies were conducted under different geographical, climatic, soil, and management conditions and may have used forage harvested at different stages of maturity. Nevertheless, the observed variation demonstrates that cultivar and production environment are important considerations when evaluating sorghum and pearl millet as forage resources for livestock.Fibre concentration is particularly important because it influences both forage digestibility and voluntary feed intake. The ADF concentration

reported for sorghum ranged from 32.19 to 38.0% DM, while pearl millet ranged from 27.90 to 44.9% DM (Table 2.2). Lower concentrations of NDF and ADF are generally associated with greater digestibility and potential intake, whereas high concentrations of structural carbohydrates can limit forage utilisation and consequently animal performance (McDonald et al., 2021; Oh et al., 2016). Lignin further restricts the microbial degradation of cell-wall carbohydrates and is therefore negatively associated with fibre digestibility (Stypinski et al., 2024). Reported ADL concentrations ranged from 2.7 to 6.5% DM in sorghum and from 3.1 to 4.9% DM in pearl millet (Table 2.2), although lower lignin concentrations have also been reported for some pearl millet cultivars (Mustafa et al., 2004). Collectively, these differences reinforce the importance of considering cultivar and production conditions when assessing the feeding value of these forage crops.

Dry matter concentration also showed considerable variation among the cultivars for which DM was reported in Table 2.2. Sorghum DM ranged from 21.6 to 36.1% of fresh matter, while pearl millet ranged from 22.4 to 30.1% of fresh matter (Amer et al., 2012; Neto et al., 2017; Oskey, 2020). This variation is important not only from a nutritional perspective but also for forage conservation because DM concentration strongly influences the ensilability and fermentation of forage. Forages harvested at excessively low DM may contain high levels of moisture, increasing the risk of undesirable fermentation and nutrient losses, whereas excessively high DM can restrict compaction and reduce the removal of oxygen during ensiling. Consequently, differences in DM among cultivars and production environments may influence the suitability of sorghum and pearl millet for silage production.

The variation in DM reported among studies may arise from differences in cultivar characteristics, climatic conditions, soil properties, agronomic management, and particularly stage of harvest. Thus, the DM values reported in Table 2.2 should not be interpreted as a single representative DM range for all sorghum or pearl millet forage. Rather, they demonstrate that the DM concentration of these crops can vary substantially depending on the cultivar and conditions under which they are produced. This variation is particularly relevant in smallholder farming systems, where forage production is often dependent on local rainfall patterns and where access to irrigation and other production inputs may be limited.Establishing the DM characteristics and nutritive value of sorghum and pearl millet produced under local conditions is therefore important when considering their use as both forage cover crops and conserved livestock feed. This provides a basis for investigating how manipulation of DM concentration can influence the fermentation quality, chemical composition, and utilisation of these forages during silage production.

Overall, sorghum and pearl millet share many similar nutritional characteristics because they belong to the same grass family. Both forages are considered nutritionally balanced and are increasingly used as alternatives to maize silage in ruminant production systems (Brunette et al., 2014; Bhattarai et al., 2019). Since these crops can be conserved using different forage preservation methods, it is important to evaluate which techniques are most effective for maintaining forage quality and supporting optimal livestock performance.

Table 2.2 Chemical composition of sorghum and millet forage cultivars (% DM)

Cultivar	DM	CP	Ash	NDF	ADF	ADL	REFERENCES
Sorghum							
BRS 655	29.04	10.22	9.58	38.14	-	-	Neto et al. (2017)
Grazer N	21.6	13.7	11.7	62.6	36.2	2.70	Colombo et al. (2007)
BRS 610	22.89	9.51	9.16	46.54	-	-	Neto et al. (2017)
Nicole	24.9	12.3	11.2	62.9	38.0	3.00	Colombo et al. (2007)
Piper	24.9	14.5	10.4	64.2	37.9	3.50	Colombo et al. (2007)
Sorghum Evergreen PS	-	7.5	-	63.5	37.5	-	Getachew et al. (2016)
Sorghum Evergreen PS BMR	-	7.2	-	59.3	33.8	-	Getachew et al. (2016)
CFSH-30	36.1	10.8	4.6	60.8	35.9	6.5	Amer et al. (2012)
Millet							
CFPM101	30.1	10.2	6.4	68.2	44.9	4.9	Amer et al. (2012)
IP17862	-	9.91	9.10	43.25	28.15	-	Animasaun et al. (2018)
NGB00551	-	10.35	9.60	43.70	30.12	-	Animasaun et al. (2018)
IP22269	-	7.51	8.91	40.25	27.30	-	Animasaun et al. (2018)
AVKAB 19	-	11.87	-	57.9	30.1	3.6	Vinutha et al. (2021)
BMR	23.9	15.5	11.0	58.1	33	3.10	Oskey (2020)
CON PM	22.4	16.1	10.8	56.9	32.6	3.17	Oskey (2020)
Milkon	-	9.25	-	62.2	30.6	4.3	Vinutha et al. (2021)
IP3122	-	9.63	8.86	43.55	27.90	-	Animasaun et al. (2018)

Note: DM: dry matter; CP: crude protein; NDF: neutral detergent fibre; ADF: acid detergent fibre; ADL: acid detergent lignin.

2.4. Forage conservation

Forages are essential for livestock production, particularly in smallholder farming systems where animals mainly depend on natural pastures and grasslands (Rao et al., 2015; Tulu et al., 2023). They enable ruminants to convert fibrous plant material into valuable products such as milk and meat, which contribute to human nutrition (Oltjen and Beckett, 1996). However, forage availability and quality often decline during dry seasons due to changes in rainfall and temperature. To address seasonal feed shortages, farmers conserve forage through methods such as haymaking, silage, and foggage (Kubkomawa et al., 2019). In South Africa, haymaking and ensiling are the main forage conservation methods (Rotz and Shinners, 2020). Although silage production has increased in recent years, haymaking remains widely used because it is easier to transport and market (Shinners, 2010).

Hay is a widely used forage conservation method in which grass or legumes are cut, dried, and stored for livestock feeding. In South Africa, legume hay such as lucerne generally has higher crude protein content than grass or cereal hay (Muller, 2017). Hay production differs across regions, with winter rainfall areas mainly producing oat, barley, and triticale hay, while summer rainfall regions rely more on lucerne and grasses such as teff and African lovegrass (Scholtz et al., 2009). Sorghum and pearl millet can also be used for hay production, although pearl millet is often preferred because of its finer stems and faster drying rate (DA et al., 1989). Successful haymaking depends on proper management practices, including cutting height, drying, wilting, baling, and storage conditions, all of which influence nutrient preservation and forage quality (Lehmkuhler, 2019; Rotz and Shinners, 2020). Research has shown that appropriate cutting height and shorter storage periods help maintain higher crude protein content and digestibility (Zamudio et al., 2024). Proper drying is also important to prevent mould growth and spoilage. Although hay is an effective preservation method, smallholder farmers often struggle to adopt it because machinery, fertiliser, and storage infrastructure are expensive. As a result, many farmers rely on lower-cost forage conservation methods such as foggage.

Foggage, also known as standing hay, is a traditional forage conservation method widely used in low-input farming systems. It involves allowing forage to remain standing in the field for grazing during periods of feed shortage (Engelbrecht, 2002; Corbett et al., 1957). Foggage reduces the need for purchased feeds, labour, and machinery, making it a cost-effective option for smallholder farmers. However, it is generally used as a supplement rather than a replacement for conserved forages such as hay or silage, especially during early winter

(Brockett, 1983). Sorghum can be conserved successfully as foggage, and studies have shown that sorghum foggage may provide better winter feed value than sorghum silage under certain conditions (Goto et al., 1987). Despite these advantages, sorghum contains cyanogenic compounds that can produce prussic acid, particularly under stress conditions such as drought, frost, or excessive nitrogen fertilisation, posing a risk of toxicity to livestock (Al-Beiruty et al., 2020; Tewe et al., 2023). In addition, the quality of foggage declines as forage matures and undergoes weathering during winter, resulting in nutrient losses and leaf shedding (Engelbrecht, 2002). Compared with foggage, silage is a more controlled preservation method with lower nutrient losses, although wilting before ensiling is still recommended to help reduce prussic acid risk in sorghum (Manzoor et al., 2021).

2.4.1. Silage

Silage is a moist, acidic, fermented feed produced by preserving freshly harvested forage under anaerobic conditions (McDonald et al., 2021). The process of producing silage is known as ensiling, while the structure or container in which the forage is preserved is referred to as a silo. A wide range of crops can be ensiled, although grasses, legumes, and whole cereal crops, particularly maize and wheat, are commonly used for silage production (McDonald et al., 2021; Wilkinson and Rinne, 2018). The primary objective of ensiling is to preserve forage by promoting desirable microbial fermentation and restricting the activity of microorganisms responsible for nutrient deterioration. Successful preservation therefore depends on both the characteristics of the forage and the management of the ensiling process (da Silva et al., 2017).

Maize silage is widely used as a forage source for dairy cattle because of its high biomass production, energy content, and suitability for ensiling (Wei et al., 2018; Goyal and Tiwana, 2016). However, sorghum and pearl millet have also been investigated as alternative forage crops for silage production and can provide suitable feed resources for ruminants under conditions where maize production may be constrained (Brunette et al., 2014; Colombini et al., 2012). Ensiling provides an effective method of conserving surplus sorghum and pearl millet forage for use when fresh forage availability is limited. Compared with haymaking, silage production can allow large quantities of forage to be conserved rapidly and can reduce dependence on favourable weather conditions during the preservation process (Charmley, 2001; Wilkinson et al., 2003). However, producing high-quality silage requires a series of appropriately managed steps. The ensiling process begins with harvesting the forage at an appropriate stage of maturity, followed where necessary by DM adjustment, chopping, filling, compaction, and sealing. Once oxygen is excluded, the forage undergoes a

sequence of biological phases consisting of an initial aerobic phase, an anaerobic fermentation phase, a stable storage phase, and finally a feed-out phase when the silo is opened. The outcome of each stage influences the fermentation quality, nutrient preservation, and stability of the final silage.

2.4.1.1. The Ensiling process

Grasses should be harvested at the early vegetative stage, typically around 60 days, when they contain the highest levels of nutrients. This timing is crucial because preserved grasses, such as hay and silage, generally have lower nutrient content than fresh pasture. Additionally, maximising nutrient retention during the harvesting and preservation process is essential (Shinoda et al., 1999). After harvesting, the grass should be chopped to a length of 1-2 cm, either manually or using machinery. According to Sun et al. (2020), grasses chopped to 1-2 cm exhibited better preservation characteristics compared to those chopped to 4-5 cm. Precisely, the shorter-chopped grass demonstrated lower pH values, higher levels of lactic acid, and improved aerobic stability.

The next step should be wanting to preserve the grass through natural fermentation in the achievement of anaerobic conditions. Anaerobioses can be archived in many ways, but the most efficient one is to store the plant material in an appropriately sealed container. In such an environment, the oxygen trapped within the plant material is quickly consumed by the plant's respiratory enzymes (Tikwayo, 2016). According to Mciteka (2008), when oxygen remains in contact with herbage for an extended period, microbial aerobic activity occurs, leading to the breakdown of the forage into spoiled, unappetising, and sometimes toxic components.

During the ensiling process, bacteria ferment plant-derived sugars into volatile fatty acids (VFAs), a biochemical reaction that requires energy (Wilkinson et al., 2003). This fermentation results in a reduction in pH and an increase in lactic acid concentration. According to Thomas (2013), there is a positive correlation between the initial population of bacteria at the onset of ensiling and the rate at which pH declines. For optimal fermentation to occur rapidly and extensively, the forage must contain high levels of fermentable carbohydrates, possess low buffering capacity, have a moderate DM content (typically between 30–40%), and be inoculated with a sufficient population of lactic acid bacteria before ensiling (Kumar et al, 2019).

High-quality silage is primarily achieved when lactic acid is the predominant fermentation acid produced, as it is the most efficient acid in reducing pH and accelerating the fermentation

process (Nkosi, 2010; Meeske et al., 1993). Fast fermentation results in better nutrient retention within the silage. The fermentation process typically takes between 10 days and 3 weeks to complete. While fermentation does not improve the nutritive value of the silage, it may improve digestibility, although this is often accompanied by energy losses (da Silva et al., 2017). Efficient fermentation cannot occur if the forage's DM content is too high, as this inhibits sufficient pH reduction (Driehuis et al., 2000).

During anaerobic conditions, fermenting microorganisms multiply and convert water-soluble carbohydrates (WSC) into organic acids through fermentation (Weinberg and Muck, 1996). The main acids produced during the ensiling process are lactic, acetic, butyric, and propionic acids. After the forage is stacked and sealed to exclude air, the ensiling process can be divided into four distinct stages, as outlined by Weinberg and Muck (1996):

Aerobic phase: In the first few hours after the silo is sealed, two key enzymatic processes occur in the plant material: respiration and proteolysis. During respiration, plant sugars are fully broken down into carbon dioxide and water, consuming oxygen and producing heat. At the same time, proteolysis breaks down proteins into amino acids and ammonia through proteases (McDonald et al., 1991). The loss of sugars at this stage is critical, as they serve as the main substrate for lactic acid bacteria to produce the acids that preserve the forage. This initial phase relies heavily on proper compaction and sealing of the silo.

Fermentation phase: Once the oxygen in the silo is depleted, anaerobic bacteria begin to grow. They ferment plant sugars into lactic acid, acetic acid, alcohol, and other organic acids. These acids reduce the pH from around 6 to below 5.5. This fermentation phase typically lasts between 3 and 5 days.

Stable phase: At this stage, the silo is regarded as stable, characterised by reduced pH levels and minimal biological activity. Most microorganisms are no longer present, with only acid-tolerant enzymes such as proteases and carbohydrases, along with low populations of *Lactobacillus buchneri*, remaining active.

Feed out phase: This stage begins when silage is exposed to air. Under these conditions, dormant yeasts and molds become active, facilitating the production of clostridial bacteria. As these bacteria multiply, they degrade fermentable sugars and convert lactic acid into butyric acid, leading to an increase in pH. The resulting decrease in lactic acid concentration contributes to significant DM losses and negatively impacts both the intake and palatability of the silage for ruminants.

2.4.1.2 Ensiling characteristics of climate-resilient forage crops

pH

pH is a critical parameter in evaluating fermentation and serves as a primary indicator of silage quality. According to Bernardes et al. (2019), well-preserved silage typically has a pH range of 3.80–4.20, while poorly preserved silages exhibit pH values between 4.90 and 5.60 (McDonald et al., 1991). Additionally, Brunette et al. (2014) reported a pH range of 3.72–4.47 for mature pearl millet, while Pinho et al. (2015) found a pH range of 3.93–4.23 for various sorghum cultivars. Ward et al. (2001) found that forage millet silage has a higher pH and a lower lactic acid concentration than sorghum silage.

2.4.1.3 Dry matter content of forages

Dry matter is defined as the portion of forage that remains after complete removal of moisture, encompassing essential nutrients such as proteins, lipids, carbohydrates (including soluble sugars), and minerals. The DM content of a plant is strongly influenced by its developmental stage, with higher concentrations generally observed during the flowering phase compared to the mature stage (Waldren et al., 1979; Anjum et al., 2017). For silage, a minimal moisture level is required for lactic acid bacteria to thrive and ferment soluble sugars into by-products such as lactic acid, which in turn reduces the pH of the plant material and inhibits undesirable organisms such as mould, yeast, and spoilage bacteria (Woolford, 1998). Wilkinson and Rinne. (2017) reported that DM content is inversely proportional to crude protein and directly proportional to fibre content in forages. The DM content of pearl millet forage ranges from 11.9% to 32.4% (Brunette, 2014), while sorghum forage exhibits similar values, ranging between 15.73% and 38.7%DM (Colombo et al., 2007; Kung et al., 2018).

Several studies have shown that both forages possess relatively low moisture content compared to other grasses, making them suitable for ensiling. Amer et al. (2012) investigated the ensilability of forage sorghum and pearl millet at different DM levels—36.1% DM for sorghum and 30% DM for pearl millet. Both forages demonstrated good preservation characteristics, with silage pH values remaining below 4.20, indicating successful fermentation at these respective DM levels. Although increasing the maturity stage at harvest improves DM content, it often results in reduced nutritional quality (Tolera et al., 1998). Therefore, determining the optimal harvest window requires a balance between achieving adequate DM content for effective preservation and minimising losses in forage nutritive value.

2.4.1.4 Lactic acid

Lactic acid is regarded as the main fermentation acid in most successful silages. It was initially proposed that lactic acid production is primarily associated with non-spore-forming bacteria, commonly referred to as Lactic Acid Bacteria (LAB**)**, due to their fermentative nature, where they primarily convert a variety of carbohydrates into lactic acid (Okoye et al., 2023). The accumulation of lactic acid lowers the pH of the silage, thereby preventing the growth of harmful microorganisms, such as moulds and spoilage bacteria (Driehuis et al., 2001). This acidification also inhibits enzymes responsible for feed degradation, thus helping preserve the nutritional quality of the feed (Kung et al., 2018; Ávila and Carvalho, 2020; Ridwan et al., 2024). In addition to these preservative effects, lactic acid contributes to the production of volatile compounds that can increase the palatability of silage, increasing animals' appetite and improving the overall energy value of the feed. For well-preserved silages of pearl millet and sorghum, lactic acid concentrations typically range from 3.33% to 8.5% (Messman et al., 1992; Ward et al., 2001; Amer and Mustafa, 2010; Amer et al., 2012). Notably, Amer and Mustafa (2010) reported that pearl millet silage, which had a higher concentration of water-soluble carbohydrates, exhibited a lactic acid concentration that was 7% higher than that found in corn silage.

2.4.1.5. Lactic acid bacteria

Lactic acid bacteria are Gram-positive, microaerophilic, non-spore-forming bacteria that occur as cocci or rods (Kim et al., 2021). They are mainly associated with the genera *Lactobacillus* and *Bifidobacterium*, which are widely recognised and commonly used as probiotics in feed formulations, dairy products, and beverages (Guo et al., 2022). During fermentation, LAB degrade plant biomass into lactic acid and other beneficial organic acids, with their primary role being the conversion of WSC into these fermentation end products (Kim et al., 2021; Akhtar et al., 2025). Natural LAB populations vary across forage species. Meeske et al. (1993) reported LAB counts of 7.2 log CFU/g FM in sorghum silage. In contrast, Tahir et al. (2025) observed higher counts (8.91 log CFU/g FM) in sweet sorghum silage, likely due to its inherently high WSC concentration, which promotes favourable fermentation. For pearl millet, Ashbell and Weinberg (2000) recorded LAB populations of 5.7 log CFU/g FM in silage wilted for two days, whereas Zhao et al. (2024) reported 6.80 log CFU/g FM in mature pearl millet silage.

2.4.1.6. Yeast and Molds

These are eukaryotic microorganisms, facultative anaerobes that rely on organic matter for nutrition and are commonly found in silages (Suntaram et al., 2024). They tend to grow in

areas where small amounts of oxygen are present and can contribute to both aerobic and anaerobic spoilage during fermentation (Li et al., 2018). As undesirable epiphytic microbes, they may reduce the nutritional value of the silage and negatively affect animal health or milk production (Oude Elferink et al., 2000). Their numbers can reach up to 10^7 CFU/g during the early weeks of ensiling, although they usually decline with long-term storage. Zhao et al. (2024) reported yeast counts of 3.31 log CFU/g at the milk stage of whole-plant pearl millet silage, while Khota et al. (2017) found higher levels, 5.71 log CFU/g, in sorghum silage. To limit the growth of such undesirable microorganisms, proper ensiling practices that minimise oxygen exposure (such as effective compaction and sealing of the silo) should be followed, along with the use of additives that inhibit aerobic spoilage.

2.4.1.7 Aerobic stability

Aerobic stability refers to the length of time silage remains cool and unspoiled once it is exposed to air (Kung Jr et al., 2010). After a silo is opened, oxygen allows yeasts, aerobic bacteria, and moulds to oxidise fermentation acids and other compounds, initiating spoilage (Wilkinson and Davies, 2013). This aerobic deterioration can lead to significant nutrient losses and reduced feed quality. Therefore, improving the aerobic stability of silages is essential to reduce spoilage and ensure safe, toxin-free feed for ruminants (Wilkinson and Davies, 2013). A wide range of aerobic stability values has been reported for pearl millet silage, varying from 18 to 156 hours (Hassanat et al., 2006; Amer and Mustafa, 2010). Harvesting pearl millet at the vegetative stage, rather than at heading, has been shown to reduce aerobic stability by up to 95% (Brunette et al., 2014). Several studies have also studied the aerobic stability of sweet sorghum (Nkosi et al., 2012; Chen et al., 2019; Tahir et al., 2025), which is often attributed to its relatively high concentration of WSC. However, Weinberg et al. (2011) noted that the factors influencing the aerobic stability of sorghum silages are still not well understood.

2.4.1.8 Wheat bran as an absorbent

Absorbents are a type of silage additive used to reduce moisture content by taking up excess water. When applied to forages with low DM levels, they can improve silage quality and help prevent nutrient losses during ensiling (Kordi and Naserian, 2020). Wheat bran, a by-product of the wheat milling process, is valued for its relatively high protein content (17.89%–19.21%) (Yi et al., 2023; Fávaro et al., 2025) and its rich fibre profile, making it a useful feed ingredient. According to Mirshahi et al. (2025), wheat bran can be used as a silage additive and may serve as a practical strategy for enhancing the nutritional value of silages produced from other low-DM by-products. Previous studies have demonstrated that high-quality, well-fermented silage with an optimal pH can be produced using wheat bran as an absorbent (Nkosi et al.,

2010).

2.4.1.9 The use of additives to improve fermentation

To improve the quality of silage fermentation, various additives have been developed. In recent years, biological additives (inoculants) have become increasingly popular as silage preservatives. These inoculants are applied to forage to increase organic-acid production and quickly lower the silage pH from about 6.5 to 3.5 (Kim et al., 2021). The use of homofermentative LAB inoculants accelerates the fermentation process and suppresses the growth of pathogenic microorganisms. Blajman et al. (2018) reported that LAB inoculation reduces undesirable yeast and mould growth, improves aerobic stability, and increases LAB populations in corn silage. However, the effectiveness of inoculation depends greatly on the specific strains used during fermentation. Molasses is another widely used silage additive. Beyond its role in silage preservation, molasses stimulates rumen microbial activity, thereby improving the digestibility of low-quality forage and increasing DM intake (Mordenti et al.,2021). Man and Winterson. (2002) found that adding molasses enhances fermentation and that even low inclusion levels can support the preservation process and reduce ensiling losses in cassava and gliricidia top silages. Additionally, adding 3–4% molasses is sufficient to achieve the desired reduction in silage pH (Arbabi and Ghoorchi, 2008).

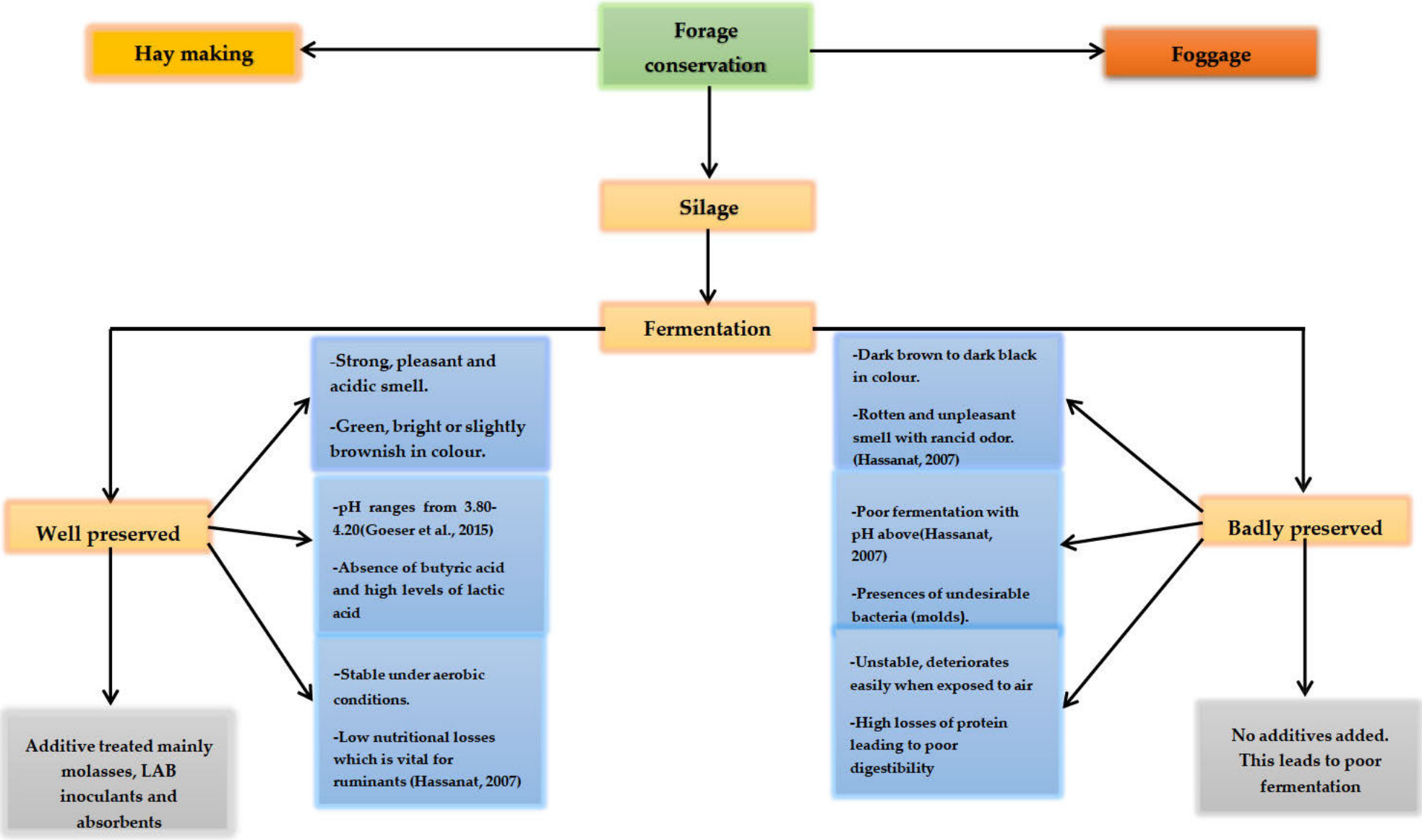

Figure 2.3 A diagram showing methods of forage preservation, with a focus on silage production and the associated fermentation process

2.5 In *sacco* DM degradability of climate-resilient forage crops

The *in sacco* (nylon-bag) technique is widely used to rank feeds according to the rate and extent of degradation of DM, organic matter, nitrogen, and fibres. In this method, as described by Osuji et al. (1993), nylon mesh bags (6.5 × 14 cm; 30–50 µm pore size) containing a known quantity of feed are placed in the rumen of a fistulated animal for predetermined incubation periods, typically ranging from 6 to 120 hours. After removal, the bags are washed, dried, and weighed to determine nutrient degradability based on the loss of material during rumen incubation. Published data on the *in sacco* DMD of pearl millet and sorghum silage remain limited. Amer et al. (2010) reported a 48hr DMD of 62.3%, whereas Kochapakdee et al. (2004) found a 72hr DMD of 80.9% for millet. For comparison, McQuiston et al. (2017) observed a 72hr DMD of 54.2% in forage sorghum silage, while Thomas et al. (2013) reported a 72hr DMD of 72.7% for sorghum silage. According to Nozière and Michalet-Doreau (2000), degradation rates increase with finer particle size, and results vary depending on the duration of rumen exposure and the nature of the feed. Numerous kinetic studies of nitrogen disappearance using this technique have contributed to the development of modern feeding systems for evaluating ruminant nutrient and protein requirements.

2.6. Potential of sorghum and pearl millet as cover crops in conservation agriculture

2.6.1 Roles of cover crops in conservation agriculture

Conservation agriculture is a sustainable farming system that aims to improve long-term productivity, profitability, and food security while conserving natural resources (Jayaraman et al., 2021). It is founded on three interconnected principles: minimum mechanical soil disturbance, permanent soil cover, and crop diversification through rotations or intercropping (Chatterjee et al., 2021; Francaviglia et al., 2023). Together, these practices improve soil health, conserve water, improve biodiversity, and promote more efficient use of natural resources, ultimately supporting stable and sustainable agricultural production.

Cover crops are a key component of conservation agriculture because they provide important agronomic and environmental benefits beyond cash crop production. They help reduce soil erosion, improve soil organic matter, suppress weeds, and enrich soil fertility (Shelton et al., 2018; Scavo et al., 2022). Common cover crops include legumes, grasses, herbs, and brassicas. Leguminous species such as vetch (*Vicia L.*), pea (*Pisum L.*), and clover (*Trifolium L.*) contribute nitrogen to the soil through biological nitrogen fixation (Ward et al., 2012). Grass cover crops are mainly valued for erosion control and high biomass production, while grasses and brassicas also assist in scavenging residual soil nitrogen and suppressing weeds (Thapa et al.,

2018). Brassicas such as radish (*Raphanus sativus*) further improve soil structure and reduce compaction through their deep taproot systems (Cofer, 2019). Among the grasses, sorghum and pearl millet are widely used as cover crops because of their adaptability to harsh environmental conditions and their ability to produce large amounts of biomass.

2.6.2. Role of sorghum and pearl millet as cover crops

Sorghum and pearl millet are annual summer grasses, similar to maize, that are commonly planted around October as summer cover crops. These species are well adapted to dryland conditions and can grow successfully in both low- and high-fertility soils. Their tolerance to drought and low input requirements allows them to produce good-quality forage, with crude protein levels ranging from 9% to 13%DM, even under minimal fertiliser application (Gerber et al., 2006). In addition, their extensive root systems and dense leaf cover help suppress weeds, protect the soil surface, and reduce problems associated with root-feeding nematodes (Guerena et al., 2006). Both crops are also capable of producing large amounts of biomass, making them valuable for both livestock forage and soil cover within conservation agriculture systems.

Despite these agronomic and environmental benefits, the adoption of sorghum and pearl millet as cover crops among smallholder farmers remains limited. Many farmers have little awareness of their broader benefits beyond forage production and basic soil cover (Roesch-McNally et al., 2017). Limited access to information, training, and extension support often restricts farmers' understanding of how cover crops can improve soil fertility, moisture conservation, weed control, and long-term farming sustainability (Manono et al., 2025; Mendi and Matiwane, 2025). In addition, challenges such as seed costs, inconsistent biomass production, and weed management further constrain adoption (Roesch-McNally et al., 2017). Hence, improving farmer knowledge and access to technical support is essential for promoting the successful use of cover crops in smallholder farming systems.

2.7. Summary

Livestock production plays an important role in supporting food security, income generation, and rural livelihoods in South Africa, particularly within smallholder and communal farming systems. However, productivity is often constrained by high feed costs, seasonal forage shortages, and the poor nutritional quality of natural pastures and crop residues. These challenges are becoming more severe due to climate change, which increases drought frequency, rainfall variability, and temperature extremes, resulting in reduced forage availability and quality.

Sorghum and pearl millet have emerged as promising alternative among a host of forage crops because of their drought tolerance, adaptability to marginal environments, and ability to produce satisfactory biomass under low-input conditions. Both crops possess good nutritional value and can serve as viable alternatives to conventional forage crops in resource-constrained production systems. Furthermore, these crops have considerable potential as conserved forages because they can be preserved as hay, foggage, or silage. Among these preservation methods, silage is widely regarded as the most effective for maintaining forage quality and ensuring feed availability during periods of shortage. Successful ensiling of sorghum and pearl millet depends on factors such as DM, fermentation characteristics, microbial activity, and aerobic stability, all of which influence the nutritional value and utilisation of the ensiled forage. In addition to their value as livestock feed, sorghum and pearl millet can contribute to conservation agriculture through soil protection, weed suppression, and improvements in soil health. Their ability to function as both forage and cover crops provides opportunities to improve the sustainability of crop–livestock systems. Nevertheless, wider adoption remains constrained by limited smallholder farmers' awareness, inadequate extension support, and resource limitations. Overall, these crops offer considerable potential to strengthen livestock production and improve the resilience of smallholder farming systems under changing climatic conditions.

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CHAPTER 3: Knowledge, Attitudes, and Practices of smallholder farmers on using and preserving Forage Cover crops for Conservation Agriculture in Okhahlamba Local Municipality, KwaZulu-Natal

3.1. Abstract

Rapid population growth in South Africa (SA) is placing increasing tension on agricultural systems, intensifying the need for sustainable and efficient farming practices. Conservation agriculture (CA) has emerged as a viable approach to address these challenges, with forage cover crops (CCs) offering dual benefits for soil health and livestock feed, particularly when preserved as silage. This study evaluated the knowledge, attitudes, and practices of smallholder farmers regarding the use and preservation of forage CCs within CA systems in Okhahlamba Local Municipality, KwaZulu-Natal (KZN). A quantitative cross-sectional survey was conducted among 50 smallholder farmers attending a Farmers' Day workshop in Bergville. While the sample size was limited and may not be fully representative of all smallholder farmers in the province, the study provides useful preliminary insights into knowledge, attitudes, and practices regarding forage CCs within CA systems. Data were analysed using descriptive statistics, chi-square tests, and Spearman's correlation. The results indicated that farmers had a moderate understanding of CCs and CA, but notable knowledge gaps existed in silage production and reasons for forage preservation. Although respondents recognised the benefits of CCs for soil improvement, crop yields, and livestock productivity, perceptions of silage were largely negative. Almost all respondents (98%) had never used forage CCs for silage. Despite generally positive attitudes toward CCs and CA practices, their adoption remained low. Key barriers included limited knowledge, inadequate training, restricted access to resources, and financial constraints. A significant positive relationship was found between knowledge and practices (r=0.325, p<0.05). Attitudes showed no significant association with practices (r=0.180, p>0.05), suggesting that knowledge is a more influential driver of adoption than perception. These findings highlight the importance of strengthening extension services and training programmes to improve the adoption of forage CCs among smallholder farmers in KZN.

Keywords: Silage; farmers' perceptions; technology adoption; sustainable agriculture; extension services; livestock feed; soil improvement; cover crops

3.2. Introduction

By 2050, global agricultural production is projected to increase by more than 55% in response to rapid population growth and rising food demand (Kim and Guha-Sapir, 2012; Stamoulis and Hemrich, 2016; Nkonki-Mandleni et al., 2022). This growing demand is placing increasing pressure on agricultural systems, making sustainable agriculture a critical priority. Addressing this challenge requires the identification and adoption of practices that support sustainable intensification. Within this context, Conservation Agriculture (CA) has emerged as a promising model for promoting sustainable agriculture. It seeks to address critical issues such as soil degradation caused by the depletion of organic matter and nutrients, while also reducing labour demands in conventional farming practices (African Conservation Tillage Network, 2008). A key component of CA is the use of cover crops (CCs), which are grown primarily to maintain and improve soil quality rather than for direct economic return (Wendling et al., 2017; MacLaren et al., 2019). These crops support sustainable farming by reducing soil erosion, improving soil structure, increasing organic matter, enhancing nutrient retention, suppressing weeds, and promoting biodiversity in agro-ecosystems (Quintrell et al., 2022).

In practice, CCs are grown during the fallow period between two successive main cash crops (Hallama et al., 2019), where they utilise residual soil nutrients that might otherwise be lost (Quintrell et al., 2022). Their growth is carefully managed and terminated either before or shortly after the establishment of the following crop, thus preventing competition for essential resources such as water, light, and nutrients (Rosa et al., 2021). Beyond these agronomic functions, CCs are also increasingly recognised for their role in supporting integrated crop–livestock systems (Carvalho et al., 2018; Swanepoel and Smit, 2024). Certain species, particularly legumes and brassicas, can function as dual-purpose crops by contributing to soil improvement while also providing valuable forage to livestock during periods of scarcity (Wyffells et al., 2021; Bracey et al., 2022). Moreover, they can be utilised beyond grazing through conservation as silage. Previous studies have incorporated them into forage systems such as maize–grass–legume intercrops, where they improved silage yield and improved the feed nutritive value (Pariz et al., 2020; Paye et al., 2022; Kühling et al., 2023).

Despite these well-documented benefits, adoption of CA and cover cropping remains relatively low among smallholder farmers in South Africa (Nkonki-Mandleni et al., 2022). This is particularly significant in the KwaZulu-Natal (KZN) Province. This Province accounts for the country's highest proportion of agricultural households (23%) (Statistics South Africa,

2016) and therefore represents a substantial share of smallholder farming activity (Ntshangase et al., 2018; Nkonki-Mandleni et al., 2022). Their adoption is largely constrained by limited access to resources, inadequate extension services, and insufficient knowledge or training in sustainable farming practices (Lee and Gambiza, 2022; Maziya et al., 2024). Although CA and cover cropping offer considerable agronomic and livestock benefits, their widespread adoption remains limited by persistent socio-economic and institutional barriers (Kassam et al., 2019). These constraints underscore the need for targeted capacity-building and resource-support initiatives to boost adoption among smallholder farmers (Food and Agriculture Organisation, 2017; Kassam et al., 2022).

In particular, there is limited information on smallholder farmers' knowledge, attitudes, and practices regarding the use and preservation of forage CCs. Assessing these aspects is critical, as they provide insights into the factors that influence the adoption of agricultural technologies. Knowledge shapes farmers' awareness and understanding, attitudes reflect their perceptions and willingness to adopt innovations, and practices reflect actual implementation. Understanding these dimensions is particularly important in the context of integrated crop–livestock systems. Therefore, this study aimed to assess the knowledge, attitudes, and practices of smallholder farmers regarding the use and preservation of forage CCs for CA in Okhahlamba Local Municipality of the KZN Province. In line with the study objectives, it was hypothesised that farmers' knowledge and attitudes regarding the use and preservation of forage CCs within CA systems are positively associated with their practices.

3.3. Methods and Materials

3.3.1. Ethical consideration

Ethical approval to conduct the study was granted by the Humanities and Social Sciences Ethics Committee of the University of KwaZulu-Natal (Certificate No.: HSSREC/00008455/2025). Before data collection, the purpose and objectives of the study were clearly explained to all prospective participants. Those who indicated willingness to participate were provided with an informed consent form outlining the voluntary nature of the study, as well as assurances of confidentiality and anonymity. Participants were informed that their involvement was entirely voluntary and that they could withdraw from the study at any stage without any consequences.

3.3.2. Study area and design

The study was conducted in October 2025 at the Bergville Community Hall (28°44'0"S, 29°21'30"E), located within the Okhahlamba Local Municipality under the uThukela District

Municipality in the KZN Province, South Africa. Data were collected during the third annual Farmers' Day workshop organised by the Department of Agriculture, Land Reform and Rural Development in collaboration with the Agricultural Research Council. The workshop primarily focused on cover cropping and CA practices, to provide practical knowledge and exposure to smallholder farmers from Bergville and surround rural communities within the district. It forms part of an ongoing programme aimed at building farmers' capacity in these practices, meaning that participants had prior and continued exposure to the concepts assessed in this study.

The study population comprised smallholder farmers who participated in the workshop. Although some attendees were employed as extension officers or officials within the Department of Agriculture, they were also actively involved in smallholder farming. Therefore, their inclusion in the study was deemed appropriate, as they met the criteria defining the target population. Before data collection, participants were informed about the purpose of both the workshop and the research study. The objectives of the questionnaire were clearly explained, including its structure, content, and relevance to the study. This briefing ensured that participants understood the nature of their involvement before completing the questionnaire.

3.3.3. Data collection

A structured questionnaire was developed as the primary data collection instrument for this study. The questionnaire was pre-tested among Master of Science in Agriculture students in the Department of Animal and Poultry Science at the University of KwaZulu-Natal, South Africa, to assess clarity, relevance, and consistency of the questions. The questionnaire was originally developed in English; however, during data collection, it was translated into IsiZulu to accommodate participants who were not proficient in English. The study targeted 100 participants who were expected to attend the Farmers' Day workshop; however, only 50 participants attended the event, and all of them were included in the study. Therefore, the study constituted a census of all workshop attendees. Although the sample size of 50 respondents is quite small, it aligns with similar field-based studies conducted in constrained conditions such as workshops and training events (Malterud et al., 2016; Vasileiou et al., 2018).

The research adopted a quantitative cross-sectional survey design. This design was appropriate as it facilitated the collection of numerical data from smallholder farmers at a single point in time during the workshop. The cross-sectional approach provided a snapshot of farmers' knowledge, perceptions, attitudes, and practices regarding cover cropping and CA

within the study area (Panagakou et al., 2009). The design was further considered suitable because the study aimed to describe existing conditions and examine relationships among variables without manipulating the research environment (Bryman et al., 2007). The questionnaire was divided into four sections. Section A collected demographic information of the respondents. Section B focused on respondents' knowledge of CCs, preservation of CCs, and the role of CCs in CA. Section C examined respondents' attitudes toward and adoption of practices related to CCs and their preservation within CA systems. Section D assessed farmers' practices regarding cover cropping, preservation techniques, and their application in CA.

3.3.4. Sampling procedure

The study employed a non-probability convenience sampling approach (Luschei and Hammond, 2009). This method was considered appropriate because data were collected during a Farmers' Day workshop, where participants were selected based on their availability and willingness to participate. At the time of the study, there was no comprehensive sampling frame of all smallholder farmers within the district, making probability sampling impractical. Furthermore, the workshop provided direct access to the target population, namely smallholder farmers who had been exposed to training on cover cropping and CA. Given the limited time and logistical constraints associated with conducting research during a one-day event, convenience sampling enabled efficient and practical data collection (Maliba, 2024). Although this approach does not provide every member of the broader farming population with an equal chance of selection, all 50 workshop attendees were included in the study (Khapayi and Celliers, 2016). However, the findings were interpreted with caution, as the results did not fully generalise to all smallholder farmers in the district and the province.

3.3.5. Knowledge, attitudes, and practices indices

Knowledge indices were computed by awarding +1 point for each correct response and −1 point for each incorrect response. The aggregate score was then used to classify respondents' overall knowledge levels. A cumulative score of one or higher (≥1) was interpreted as indicating sufficient knowledge, whereas a score below zero (<0) was categorised as insufficient knowledge regarding CCs and CA. Attitude indices were developed using a Likert-scale instrument, a widely recognised psychometric approach for assessing attitudes, opinions, and perceptions. In this study, participants rated their level of agreement with statements related to CC cultivation, silage production, and CA practices on a five-point scale ranging from "Strongly Disagree" to "Strongly Agree." The use of the Likert scale enabled the

generation of reliable estimates of respondents' attitudes toward cover cropping and CA systems. A mean score greater than 3 was interpreted as indicating a positive attitude, whereas a mean score less than 3 was interpreted as indicating a negative attitude. A composite practice index was constructed by assigning numerical scores to respondents' reported behaviours regarding CC cultivation, silage production, and livestock practices. The summed scores were used to categorise farmers into low, moderate, and high levels of practice adoption. Table 3.1 presents the knowledge, attitude, and practice statements and questions that were administered to farmers during the survey.

3.3.6. Data analysis

Data collected through questionnaires were first coded in Microsoft Excel to facilitate quantitative analysis. The coded data were then analysed using IBM SPSS Statistics software (Version 30; IBM Corp., Armonk, NY, USA). Descriptive statistics were employed to summarise the frequency distributions of categorical variables. The reliability of the attitude-related Likert-scale items was assessed using Cronbach's alpha. A coefficient value above 0.70 was regarded as acceptable, indicating adequate internal consistency of the items measuring farmers' attitudes toward cover cropping and CA. Spearman's rank-order correlation(r)was applied to assess the relationships among farmers' knowledge, attitudes, and practices related to cover cropping, silage production, and CA. Additionally, Pearson's chi-square tests(X^2) were performed to assess the associations between respondents' demographic characteristics and their knowledge of forage CCs, the preservation of CCs, and CA. Results were considered statistically significant at $p < 0.05$.

Table 3.1 Statements and questions administered to farmers during the survey (Adapted from Khapayi and Celliers, 2016).

Questions and statements
Knowledge
Are you familiar with the term "forages"?
Do you understand the meaning of the word "Cover Crops"?
Are you familiar with the difference between Cover Crops and forages?
Do you understand the meaning of the word silage?
Are you familiar with methods used to preserve forage Cover Crops?
Do you know how the silage-making process is carried out?
Are you aware that legumes can serve as Cover Crops?

Are you aware that grasses can function as Cover crop?

Are you aware that brassicas can be used as Cover crop?

Do you understand the meaning of the word "Conservation Agriculture"?

Are you aware of the Conservation Agriculture practices?

Attitudes

Are cover crops important for promoting sustainable agriculture?

Does planting Cover crops provides significant benefits for livestock production?

Does using Cover crops as forage is important for livestock feeding systems?

Can silage produced from Cover crops be beneficial for livestock?

Does the use of Cover crops contribute to improved soil productivity?

Can Cover crops increase soil water retention?

Can Cover crops promote greater biodiversity within farming systems?

Can the use of Cover crops lead to increased crop yields?

Can Cover crops play a significant role in reducing soil erosion?

Are you willing to participate in workshops and training programs to improve my understanding of CA practices.

Do some Cover Crops, such as legumes, help add nitrogen to the soil, improve fertility for subsequent crops.

Can Cover crops can outcompete weeds for resources, reducing the need for herbicides and manual weeding.

Do you believe that making silage decreases the nutritive value of forage.

Do you believe that feeding silage has negative effects on livestock health and performance.

Do you believe that livestock benefit from silage during dry or feed-scarce seasons.

Do you believe that silage can reduce feed costs during winter.

Do you believe that forage Cover crops can be successfully preserved as silage.

Practices

Cultivation of Cover crops in my farm.

Use Cover crops as a feed source for my livestock.

Incorporate forage Cover crops alongside other crops in my farming system.

Crops often cultivated.

Feeds commonly used.

Challenges in the silage-making process.

Used Cover crops for silage before.

Years of experience in the use of CCs.

Agricultural practices are often used.

Forages often used as CCs.

3.4. Results

3.4.1 Socio-demographic information of the respondents

Table 3.2 presents the socio-demographic characteristics of the 50 smallholder farmers who participated in this study. The majority of the respondents were male (74%), while females accounted for 26% of the farmers. Regarding age distribution, most respondents (56%) were older than 40 years, whereas the lowest proportion (12%) fell within the 20–30-year age group. In terms of educational attainment, more than half of the respondents (54%) had a tertiary education, followed by those with secondary education (26%). With respect to farming practices, the majority of respondents (74%) were engaged in subsistence farming, while only one respondent (2%) practised commercial farming.24% of the respondents were communal farmers. More than half of the respondents (52%) were unemployed, while 24% were extension officers and 20% were government department officials. Fifty-four percent of the respondents were single, whereas 46% were married. In terms of land ownership, the majority of respondents (54%) owned less than one hectare of land, while only a small proportion (4%) owned more than 20 hectares.

Table 3.2 Demographic characteristics of the respondents

Variable	Category	Frequency(*n*=50)	Percentage (%)
Age (Years)	20-30	6	12
	31-40	16	32
	>40	28	56
Gender	Male	37	74
	Female	13	26
Race	Black	50	100
Educational status	No formal education	5	10
	Primary level	5	10
	Secondary level	13	26
	Tertiary level	27	54
Type of farming	Commercial	1	2
	Subsistence	37	74
	Communal	12	24
Occupation	Unemployed	26	52
	Extension officer	12	24
	Department official	10	20
	Other	2	4
Marital status	Single	27	54
	Married	23	46
Land size (Ha)	1>	27	54
	1-20	21	42
	>20	2	4

3.4.2. Demographic characteristics of respondents and their knowledge of forages, CCs, and the differences between them

Table 3.2 presents the demographic characteristics of the respondents and their knowledge of forages, CCs, and the differences between the two. The results indicate that age, gender, occupation, and marital status did not significantly influence respondents' knowledge of forages, CCs, or the differences between them ($p > 0.05$). However, a relatively higher proportion of male respondents demonstrated knowledge of forages (11/37), CCs (29/37), and the differences between them (9/37) compared to female respondents. Respondents aged over 40 years exhibited the highest level of knowledge regarding CCs (18/28) and the

differences between them (9/50). Respondents with no formal education had the lowest level of knowledge of forages and CCs (0/5), with education level being a significant determinant of knowledge of CCs (X^2=8.42, p< 0.05). Subsistence farmers showed the highest level of knowledge of CCs (27/37) and the differences between them (6/37). Farming type was also found to significantly influence knowledge of the differences between forages and CCs (X^2=6.42, p < 0.05). Regarding employment status, unemployed respondents demonstrated the highest level of knowledge of both forages (13/26) and CCs (21/26), while married respondents showed the lowest level of knowledge of forages (5/23). Land size also appeared to influence knowledge of forages and CCs (p > 0.05), with farmers owning less than one hectare of land demonstrating the highest level of knowledge of both forages (7/50) and CCs (17/50) compared to other land categories.

3.4.3. Demographic characteristics of respondents and knowledge of various types of CCs

Table 3.2 shows the demographic characteristics of respondents and their knowledge of different types of CCs. Age, gender, educational status, type of farming, occupation, and land size did not significantly influence farmers' knowledge of CCs (p>0.05). However, male farmers demonstrated slightly higher knowledge of various CCs compared to females. Farmers aged above 40 years showed greater knowledge than younger age groups. Respondents with no formal education knew legumes (5/5) and brassicas (5/5). Most subsistence (19/37) and communal farmers (7/12) had high knowledge of legumes. Extension officers showed strong knowledge of grasses (7/12) and legumes (7/12). In contrast, most unemployed farmers lacked knowledge of brassicas (12/26). Marital status significantly influenced farmers' knowledge of brassicas (X^2=4.43, p<0.05). Farmers with less than one hectare of land had better knowledge of legumes (15/27), grasses (13/27), and brassicas (12/27) than those with more than 20 hectares.

Table 3.3 Demographic characteristics of respondents and their knowledge of forages, CCs, and the differences between them

Variable	Category	Frequency (*n=50*)	Knowledge of forages		X^2	Sig.	Knowledge of CCs		X^2	Sig.	Difference between CCs and forages		X^2	Sig
			No	Yes			No	Yes			No	Yes		
Age (Years)	20-30	6	3	3			0	6			6	0		
	31-40	16	9	7			4	12			13	3		
	>40	28	24	4	5.04	0.080	10	18	3.23	0.199	19	9	3.15	0.207
Gender	Male	37	26	11			8	29			28	9		
	Female	13	12	1	2.56	0.110	6	7	2.87	0.090	10	3	0.00	0.93
Educational status	No formal education	5	5	0			4	1			4	1		
	Primary level	5	5	0			2	3			3	3		
	Secondary level	13	10	3			3	10			8	5		
	Tertiary level	27	18	9	4.45	0.216	5	22	8.42	0.03	23	4	3.46	0.32
Type of farming	Commercial	1	0	1			0	1			0	1		
	Subsistence	37	28	9			10	27			31	6		
	Communal	12	9	3	0.36	0.85	4	8	0.57	0.75	7	5	6.45	0.04
Occupation	Unemployed	26	13	13			5	21			21	5		
	Extension officer	12	3	9			4	8			6	6		
	Department official	10	1	9			3	7			9	1		
	Other	2	0	2	6.97	0.07	2	0	6.324	0.097	2	0	6.48	0.091
Marital status	Single	27	20	7			8	19			21	6		
	Married	23	18	5	0.12	0.73	6	17	0.078	0.78	17	6	0.10	0.75
Land size (Ha)	1>	27	20	7			10	17			23	4		
	1-20	21	17	4			4	17			15	6		
	>20	2	1	1	1.08	0.58	0	2	2.75	0.26	0	2	7.82	0.02

Significant at $p<0.05$. CCs-cover crops.

Table 3.4 Demographic characteristics of respondents and their knowledge of various types of CCs

Variable	Category	Frequency (*n=50*)	Legumes act as CC		X^2	Sig.	Grasses act as a CC		X^2	Sig.	Brassicas act as a CC		X^2	Sig.
			No	Yes			No	Yes			No	Yes		
Age (Years)	20-30	6	4	2			5	1			4	2		
	31-40	16	9	7			10	6			9	7		
	>40	28	11	17	2.16	0.35	11	17	4.89	0.087	16	12	0.21	0.89
Gender	Male	37	19	18			20	17			21	16		
	Female	13	5	8	0.64	0.42	6	7	0.24	0.624	8	5	0.09	0.76
Educational status	No formal education	5	0	5			2	3			0	5		
	Primary level	5	2	3			2	3			3	2		
	Secondary level	13	5	8			4	9			8	9		
	Tertiary level	27	17	10	7.64	0.05	18	9	5.26	0.154	18	9	7.81	0.50
Type of farming	Commercial	1	0	1			0	1			1	0		
	Subsistence	37	18	19			20	17			22	15		
	Communal	12	5	7	1.165	0.58	6	6	1.165	0.558	6	6	1.07	0.56
Occupation	Unemployed	26	12	14			13	13			14	12		
	Extension officer	12	5	7			5	7			9	3		
	Department official	10	6	4			7	3			5	5		
	Other	2	1	1	0.81	0.85	1	1	1.86	0.603	1	1	1.92	0.50
Marital status	Single	27	11	16			14	13			12	15		
	Married	23	13	10	1.24	0.27	12	11	0.001	0.98	17	6	4.43	0.035
Land size (Ha)	1>	27	12	15			14	13			15	12		
	1-20	21	10	11			11	10			12	9		
	>20	2	2	0	2.305	0.316	1	1	0.00	0.98	2	0	1.52	0.48

Significant at $p<0.05$. CCs -cover crops.

3.4.4. Demographic characteristics of respondents and their understanding of silage and reasons for crop preservation

Table 3.4 presents the demographic characteristics of respondents and their understanding of silage, as well as their knowledge of the reasons for crop preservation. The results indicate that gender, educational status, type of farming, marital status, and land size did not significantly influence respondents' understanding of silage or their knowledge of the reasons for crop preservation ($p > 0.05$). The majority of respondents across all age groups demonstrated a lack of knowledge regarding silage. However, age significantly influenced respondents' knowledge of the reasons for crop preservation ($X^2 = 6.13$, $p < 0.05$). Most male respondents showed a lack of knowledge of silage (31/50), while respondents with tertiary education demonstrated slightly higher knowledge of the reasons for crop preservation (9/27) compared to other education levels. In terms of farming type, the majority of subsistence (28/37) and communal farmers (10/12) lacked knowledge of silage and the silage-making process. Occupation significantly influenced respondents' knowledge of the reasons for crop preservation ($X^2 = 12.81$, $p < 0.05$), with most unemployed farmers showing a lack of understanding of silage (22/26). Additionally, farmers with less than one hectare of land lacked knowledge of silage, the silage-making process, and the reasons for crop preservation.

3.4.5. Demographic characteristics of respondents and their knowledge of CA practises

Table 3.5 presents the demographic characteristics of respondents and their knowledge of CA and its practices. The results show that gender, type of farming, occupation, marital status, and land size did not significantly influence farmers' knowledge of CA practices ($p > 0.05$). However, age had a significant effect on farmers' knowledge of CA ($X^2 = 6.95$, $p < 0.05$) and CA practices ($X^2 = 8.01$, $p < 0.05$), with farmers aged over 40 years demonstrating higher levels of knowledge compared to younger age groups. A large proportion of male respondents lacked knowledge of and its practices. Farmers with tertiary education had significantly higher knowledge of CA ($X^2 = 8.33$, $p < 0.05$) and its practices compared to respondents with lower levels of education. The majority of subsistence (20/37) and communal farmers (20/37) did not have knowledge of CA and CA practices. Extension officers generally demonstrated better knowledge of CA (5/12) and its practices (8/12), while most Department of Agriculture officials showed comparatively lower levels of knowledge (9/10). Farmers cultivating between 1 and 20 hectares had better knowledge of CA (12/21) and its practices (12/21) compared to the groups, whereas those farming on less than one hectare mostly lacked knowledge of CA (17/27) and related practices (16/27).

Table 3.5 Demographic characteristics of respondents and their understanding of silage and reasons for crop preservation

Variable	Category	Frequency (*n=50*)	Understand the meaning of "silage"		X^2	Sig.	The Silage-making process is carried out		X^2	Sig.	Reasons for preserving CCs and other crops		X^2	Sig
			No	Yes			No	Yes			No	Yes		
Age (Years)	20-30	6	3	3			5	1			2	4		
	31-40	16	13	3			15	1			12	4		
	>40	28	23	5	3.12	0.210	25	3	0.56	0.755	23	5	6.13	0.04
Gender	Male	37	31	6			33	4			28	9		
	Female	13	8	5	2.77	0.07	12	1	0.10	0.75	9	4	0.21	0.65
Educational status	No formal education	5	5	0			5	0			5	0		
	Primary level	5	4	1			5	0			5	0		
	Secondary level	13	12	1			12	1			10	3		
	Tertiary level	27	18	9	4.94	0.173	23	4	1.88	0.58	17	10	5.28	0.152
Type of farming	Commercial	1	0	1			0	1			0	1		
	Subsistence	37	28	9			32	5			26	11		
	Communal	12	10	2	0.58	0.74	12	0	1.95	0.378	11	1	5.06	0.80
Occupation	Unemployed	26	22	4			24	2			22	4		
	Extension officer	12	9	3			12	0			10	2		
	Department official	10	6	4			7	3			3	7		
	Other	2	2	0	3.128	0.36	2	0	6.15	0.10	2	0	12.81	0.005
Marital status	Single	27	19	8			24	3			18	9		
	Married	23	20	3	1.991	0.158	21	2	0.081	0.77	19	4	1.65	0.20
Land size (Ha)	1>	27	20	7			23	4			19	8		
	1-20	21	17	4			20	1			16	5		
	>20	2	1	1	0.91	0.633	1	1	1.558	0.459	1	1	0.940	0.625

Table 3.6 Demographic characteristics of respondents and their knowledge of CA practises.

Variable	Category	Frequency (*n=50*)	Knowledge of CA		X^2	Sig.	Knowledge of CA practices		X^2	Sig.
			No	Yes			No	Yes		
Age (Years)	20-30	6	2	4			2	4		
	31-40	16	10	6			10	6		
	>40	28	12	16	6.95	0.031	11	17	8.01	0.018
Gender	Male	37	20	17			20	17		
	Female	13	8	5	0.21	0.64	7	6	0.00	0.99
Educational status	No formal education	5	5	0			5	0		
	Primary level	5	2	3			2	3		
	Secondary level	13	4	9			4	9		
	Tertiary level	27	17	10	8.33	0.04	17	10	10.5	0.015
Type of farming	Commercial	1	0	1			0	1		
	Subsistence	37	20	17			20	17		
	Communal	12	7	5	0.86	0.648	6	6	0.93	0.63
Occupation	Unemployed	26	13	13			13	13		
	Extension officer	12	5	7			4	8		
	Department official	10	9	1			9	1		
	Other	2	1	1	6.10	0.16	1	1	7.46	0.059
Marital status	Single	27	17	10			16	11		
	Married	23	11	12	1.15	0.28	11	12	0.65	0.41
Land size (Ha)	1>	27	17	10			16	11		
	1-20	21	9	12			9	12		
	>20	2	1	1	3.57	0.18	1	1	3.05	0.22

Significant at $p<0.05$; CA-conservation agriculture

3.4.6. Respondents' perceptions of CC benefits for agriculture and livestock

The results of respondents' perceptions regarding the benefits of CCs for agriculture and livestock production are presented in Table 3.6. The reliability analysis showed a Cronbach's alpha coefficient of 0.70 for the attitude scale, indicating acceptable internal consistency.

Overall, respondents demonstrated positive attitudes toward the benefits of CCs for agriculture and livestock. Among the statements, the importance of planting CCs for livestock production recorded the highest mean score (Mean = 3.90, SD = 1.11), indicating strong agreement among respondents. This was followed by incorporating CCs with other crops as beneficial for the farming system, which had a mean score of 3.50 (SD = 1.11). The importance of CCs for promoting sustainable agriculture recorded the lowest mean score (Mean= 3.26, SD = 0.853), although it still reflected a positive perception among respondents.

Table 3.7 Respondents' perceptions of CCs benefits for agriculture and livestock (*n*=50)

Statements	Mean	SD	Interpretation
Cover crops are important for promoting sustainable agriculture.	3.26	0.853	Positive
Incorporating forage CCs with other crops is beneficial for my farming system.	3.50	1.11	Positive
Planting CCs provides significant benefits for livestock production.	3.90	1.11	Positive
Cover crops are beneficial for maintaining and promoting CA.	3.86	0.881	Positive

SD = standard deviation

3.4.7. Respondents' perceptions of silage and its effects on livestock

Table 3.7 presents the results of respondents' perceptions of silage and its effects on livestock. Overall, respondents demonstrated negative perceptions toward silage. The statement that feeding silage has negative effects on livestock health and performance recorded the highest mean score (Mean = 2.88, SD = 0.895). In contrast, the statements that livestock benefit from silage during dry or feed-scarce seasons (Mean = 1.76, SD = 0.902) and that silage can reduce feed costs during winter (Mean = 1.64, SD = 1.005) recorded the lowest mean scores. These mean values below 2 indicate strongly negative perceptions among farmers regarding the benefits of silage.

Table 3.8 Respondents' perceptions of silage and its effects on livestock (*n*=50)

Statements	Mean	SD	Interpretation
I believe that making silage decreases the nutritive value of forage.	2.58	1.108	Negative
I believe that feeding silage has negative effects on livestock health and performance.	2.88	0.895	Negative
I believe that livestock benefit from silage during dry or feed-scarce seasons.	1.76	0.902	Negative
I believe that silage can reduce feed costs during winter.	1.64	1.005	Negative

SD = standard deviation

3.4.8. Perceptions of respondents on CC benefits for CA

The perceptions of respondents regarding the benefits of CCs for CA are presented in Table 3.8. Overall, respondents demonstrated positive attitudes toward all CA-related statements. The statement that the use of CCs contributes to improved soil productivity recorded the lowest mean score (Mean = 3.96, SD = 1.04), although it still reflected a positive perception among respondents. In contrast, respondents' willingness to participate in workshops and training programs to improve their understanding of CA practices (Mean = 4.52, SD = 1.21) and the perception that CCs can outcompete weeds for resources, thereby reducing the need for herbicides and manual weeding (Mean = 4.66, SD = 0.68) recorded the highest mean scores. These mean values above 4.50 indicate strongly positive attitudes among farmers toward these CA practices.

Table 3.9 Perceptions of respondents on CC benefits for CA (n=50)

Statements	Mean	SD	Interpretation
The use of CCs contributes to improved soil productivity.	3.92	1.04	Positive
Cover crops increase soil water retention.	3.74	1.06	Positive
The use of CCs leads to increased crop yields.	3.85	1.23	Positive
Cover crops play a significant role in reducing soil erosion.	4.00	1.22	Positive
I am willing to participate in workshops and training programs to improve my understanding of CA practices.	4.52	1.21	Positive
Cover crops can outcompete weeds for resources, reducing the need for herbicides and manual weeding.	4.66	0.68	Positive
Some CCs, such as legumes, help add nitrogen to the soil, improving fertility for subsequent crops.	3.96	1.245	Positive

SD= Standard deviation

3.4.9. Association between educational status, type of farming, and land size of respondents and the categorised practice score for the use of CCs for livestock and CA

The association between educational status, type of farming, and land size of respondents and their categorised practice level regarding the use of CCs for livestock and CA is presented in Table 3.9. The results indicate that educational status, type of farming, and land size did not have a statistically significant effect on practice level ($p > 0.05$). With respect to educational status, the majority of farmers exhibited low practice levels across most categories: no formal education (4 /5), primary education (3/5), and secondary education (7 /13). In terms of farming type, most subsistence farmers demonstrated low practice levels (19 /27), whereas the majority of communal farmers recorded high practice levels. Regarding land size, farmers with less than one hectare of land predominantly exhibited low practice levels (15/27). In contrast, those with land sizes between 1 and 20 hectares generally demonstrated moderate practice levels (8/21).

Table 3.10 Association between educational status, type of farming, and land size of respondents and the categorised practice score for the use of CCs for livestock and CA

Variables	Practice level (*n*=*50*)			Total	X^2	*p*-Value
	Low	Moderate	High			
Education status						
No formal education	4	0	1	5		
Primary level	3	1	1	5		
Secondary level	7	3	3	13		
Tertiary level	8	10	9	27	6.37	0.385
Type of farming						
Subsistence	19	10	8	37		
Communal	3	4	5	12		
Commercial	0	0	1	1	5.48	0.241
Land size (Ha)						
1>	15	4	8	27		
1-20	7	8	6	21		
20>	0	2	0	2	8.97	0.062

X^2- Chi-square values. Significant at $p<0.05$

3.4.10. Use of forage CCs for silage and challenges affecting the adoption of CCs and CA practices among respondents

Table 3.10 presents the results on the use of forage CCs for silage and the challenges affecting the adoption of CCs and CA practices among respondents. The findings indicate that the vast majority of farmers (98%) have never used forage CCs for silage production. Regarding challenges encountered in the silage-making process, most respondents identified a lack of knowledge (72%) and inadequate access to equipment and resources (72%) as the primary constraints. Concerns related to nutritive value were reported as the least significant challenge (26%). In terms of the adoption of forage CCs, more than 60% of farmers reported facing challenges, with lack of training and workshops (74%) and insufficient financial support (76%) being the most prominent barriers. Similarly, for the adoption of CA practices, financial costs were most frequently cited (74%) as a major constraint, while resistance to change was reported as the least significant challenge (34%).

Table 3.11 Use of forage CCs for silage and challenges affecting the adoption of CCs and CA practices among respondents

Variables	Frequency (*n*=50)	Percentage (%)
Used forage CCs for silage before		
Yes	1	2
No	49	98
Challenges faced in the silage-making process		
Lack of knowledge	36	72
Nutritive value concerns	13	26
Labour availability	15	30
Negative equipment and resources	36	72
Challenges faced in the adoption of forage CCs		
Training and workshops	37	74
Seed availability	33	66
Financial support	38	76
Challenges faced in the adoption of CA practices		
Resistant to change	17	34
Lack of knowledge	37	74
Financial costs	37	74
Labour availability	21	42

Figure 3.1 illustrates the CC species most commonly used by farmers. The results show that oat grass was the most frequently used species (50%), followed by ryegrass (46%). Turnip and cowpea were each used by 30% of the farmers. Additionally, 26% of respondents reported that they did not use any CC species.

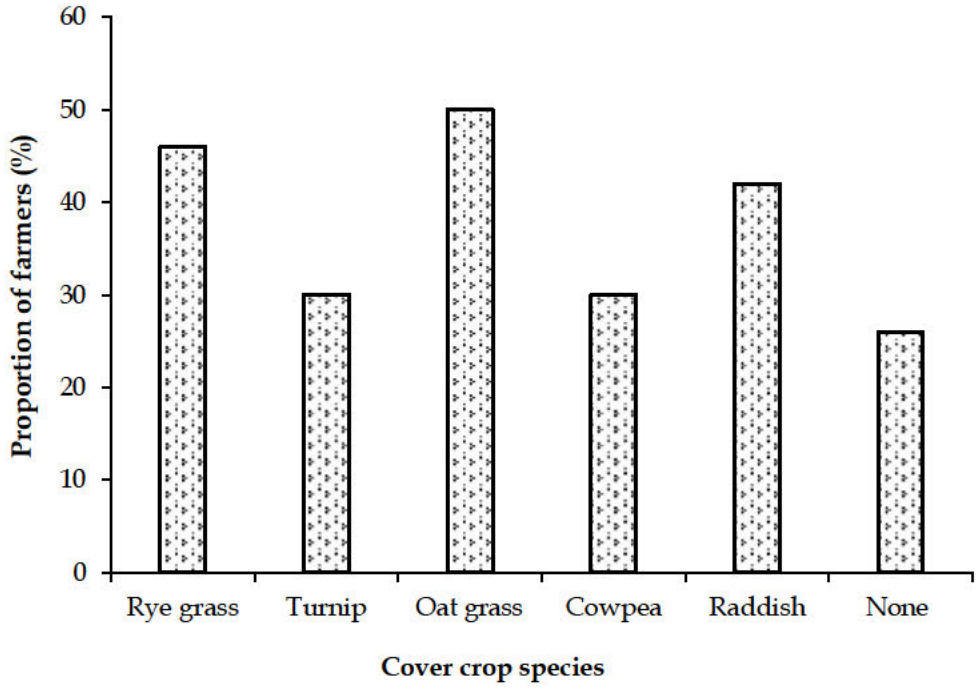

Figure 3.1 Cover crop species mostly used by farmers (*n*=50)

Figure 3.2 presents the types of crops predominantly cultivated by farmers. The results indicate that summer crops were the most commonly planted, reported by 50% of the respondents, followed by annual crops at 46%. Winter crops and fodder crops were each cultivated by 30% of the farmers. Perennial crops were the least commonly grown, reported by only 4% of respondents. Moreover,16% of the farmers indicated that they did not cultivate any crops.

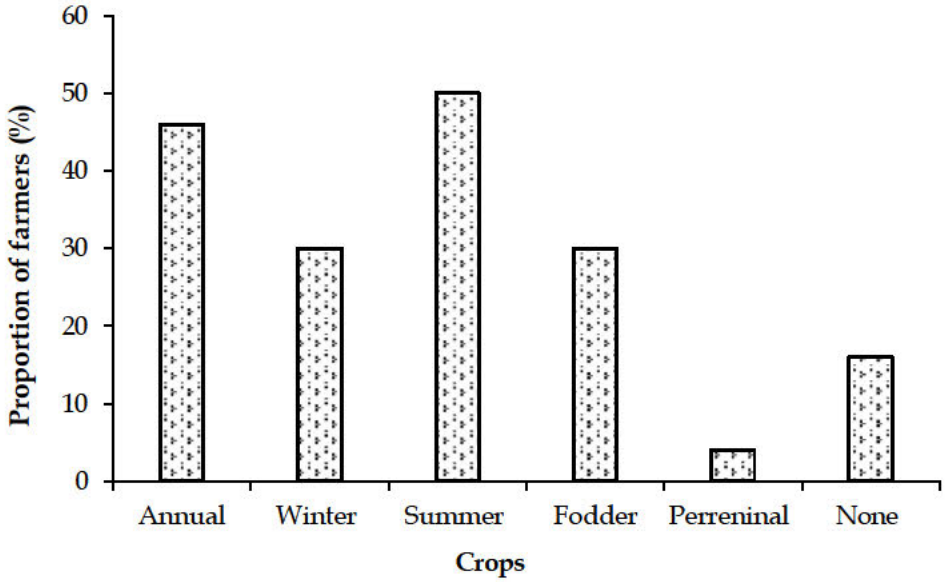

Figure 3.2 Types of crops mostly planted by farmers (*n*=50)

Figure 3.3 presents the common feed resources predominantly used by farmers. Grazing was the most widely utilised feed resource, reported by 90% of respondents, followed by maize at 78%. Molasses was used by 50% of the farmers, while hay and forages were each utilised by 32% of respondents.

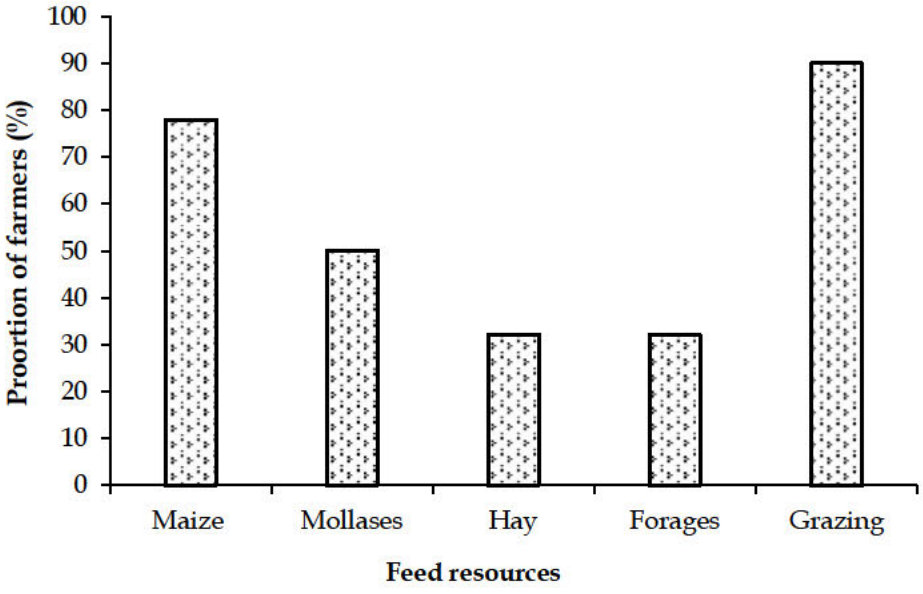

Figure 3.3 Common feed resources mostly used by farmers (*n*=50)

Spearman's rank correlation was performed to examine the relationships among knowledge, attitudes, and practices related to forage CC use and preservation for CA, as shown in Table 3.11. The findings revealed a weak yet statistically significant positive association between knowledge and practices (r = 0.325, p <0.05), indicating that increased knowledge is linked to better practices. In contrast, no significant relationship was observed between knowledge and attitudes (r = 0.005, p >0.05), suggesting that these variables are not associated. Similarly, although a positive relationship was found between attitudes and practices (r = 0.180), it was not statistically significant (p >0.05).

Table 3.12 Spearman's rank correlation(r) of knowledge, attitudes, and practices related to forage CC use and preservation within CA systems

	Correlation Coefficient (p-value)		
	Knowledge	**Attitudes**	**Practices**
Knowledge	1.00	0.005(0.972)	0.325(0.021)
Attitudes	0.005(0.972)	1.00	0.180(0.211)
Practices	0.325(0.021)	0.180(0.211)	1.00

Significant at p<0.05

3.5. Discussion

This study investigated the knowledge, attitudes, and practices of smallholder farmers regarding the use and preservation of forage CCs within CA systems in KZN. Studies that simultaneously examine these three interrelated dimensions remain limited. The findings highlight the need for targeted awareness and intervention strategies to address existing knowledge gaps and strengthen adoption among smallholder farming communities in the region. The results further revealed a positive association between farmers' knowledge and their practices, supporting the study's hypothesis. This finding aligns with Splijer et al. (2023), who reported that farmers with higher levels of knowledge are more likely to adopt sustainable agricultural practices. Similarly, knowledge has been identified as a key determinant of adoption, as it improves farmers' understanding, reduces uncertainty, and increases confidence in implementing new practices (Sarma et al., 2023; Mulugeta et al., 2024). These findings highlight the importance of strengthening extension services and training programmes to improve the adoption of forage CCs among smallholder farmers.

However, the study did not support the hypothesis that farmers' attitudes towards the use and preservation of forage CCs within CA systems are positively associated with their practices. Although the majority of farmers showed positive attitudes towards the benefits of CCs and CA, these perceptions did not translate into actual practice. This gap between attitude and practice may be attributed to several constraints commonly faced by smallholder farmers, including limited financial resources and inadequate access to inputs and equipment required for effective implementation. In addition, smallholder farmers may be reluctant to adopt new practices due to uncertainty about outcomes, as their livelihoods depend on stable production systems. Similar studies have shown that even when farmers are motivated, the absence of adequate support systems can hinder adoption, resulting in many remaining non-adopters despite holding positive attitudes (Ayim et al., 2020; Rizzo et al., 2023). These findings suggest that interventions to improve adoption should go beyond awareness and attitudes and instead address structural and resource-related constraints.

3.5.1. Knowledge

Demographic variables were assessed for their association with knowledge of forage CCs, silage, and CA practices. Most demographic variables showed limited association with knowledge of CCs and forages. However, respondents older than 40 years demonstrated relatively higher knowledge than younger respondents. This pattern is consistent with Albizua et al. (2021) and Tamako et al. (2022), who reported that farmer knowledge can develop through continuous interaction, observation, and experience within farming systems. The higher knowledge observed among older farmers may therefore reflect the accumulation of practical farming experience over time and the transfer of knowledge through interactions within farming communities and across generations. However, the present study did not directly assess intergenerational knowledge transfer, and this interpretation should therefore be considered cautiously.

Male respondents reported higher levels of knowledge of forages and CCs than female respondents, although these differences were not statistically significant. This pattern may reflect differences in farming roles and exposure to agricultural information, as previous studies have reported gender differences in access to extension services and agricultural information (Ragasa et al., 2013; Ge et al., 2023; Timalsina et al., 2026). However, lower observed knowledge among female respondents should not be interpreted as evidence that women are less knowledgeable or unwilling to participate in CC and CA practices. Participation may also be influenced by individual preferences, household responsibilities, perceived relevance of the practices, social and cultural roles, and access to opportunities for

practical engagement. These factors were not directly measured in the present study and therefore cannot be established as explanations for the observed pattern. Nevertheless, the findings highlight the importance of ensuring that extension and training opportunities are accessible to both men and women. Further research should examine the specific factors influencing women's willingness, motivation, and ability to participate in forage CC and CA practices, rather than assuming that differences in participation are solely attributable to information or resource constraints.

Educational status appeared to positively influence knowledge of CCs, as respondents with tertiary education showed higher levels of awareness. This finding agrees with previous studies, which indicate that higher education improves farmers' ability to access informationand understand agricultural innovations (Mdoda, 2020; Nassar et al., 2025). Similarly, Myers and Wilson. (2023) found that higher levels of formal education are linked to greater adoption of CCs.Since some respondents had lower levels of education, this suggests a need for more inclusive extension strategies. To encourage wider adoption of CCs, extension services should simplify information and focus on practical, demonstration-based approaches instead of relying on technical language. Similar to overall knowledge of CCs, knowledge of different CC species was also moderate, with education showing a positive association, particularly with knowledge of legumes compared to other species. Studies in Sub-Saharan Africa indicate that farmers are generally more familiar with legumes because they are strongly promoted through extension systems and are directly linked to household food use as well as soil fertility improvement (Vanlauwe et al., 2019; Breen et al., 2024). However, adoption studies suggest that the lower use of brassicas and grasses does not necessarily indicate a lack of awareness, but rather reflects the stronger emphasis placed on legumes within extension programs (Lee and Gambiza, 2022). This suggests that when all CC species are promoted equally, overall knowledge of different CC types is likely to improve.

Silage is an important livestock feeding practice involving the preservation of green fodder through fermentation, ensuring a continuous supply of feed during dry periods (Harrison et al., 2003). The findings of this study indicate low levels of knowledge and adoption of silage and forage preservation among smallholder farmers across all demographic variables, suggesting a limited understanding of both the concept and its importance. Although younger farmers and extension officers showed slightly higher levels of awareness, these differences were not sufficient to alter the overall pattern of low knowledge and limited adoption. However, existing literature suggests that low uptake of silage practices is not solely due to a

lack of knowledge but is also influenced by constraints such as inadequate training, limited access to appropriate equipment, and weak extension support services (Kule et al., 2025; Maiyo et al., 2026). In contrast, evidence from Honduras demonstrates that smallholder farmers were able to successfully adopt silage production following targeted training and participatory extension programs (Reiber et al., 2013). This highlights the critical role of effective knowledge transfer and strong support systems in improving adoption rates.The moderate level of knowledge of CA and CA practices among smallholder farmers suggests that understanding is unevenly distributed across demographic categories. Higher knowledge levels observed among younger farmers and extension officers may be attributed of improved access to information through mobile technologies, as well as their direct involvement in training and farmer support activities (Simpson and Calitz, 2014; Khwidzhilli et al., 2025).In contrast, lower levels of knowledge among communal and subsistence farmers may be linked to their strong focus on food crop and livestock production, particularly maize and vegetables, which are essential for household consumption (Giller et al., 2009; Muoni et al., 2024).

This production focus limits their exposure to CA systems, thereby reducing both knowledge and adoption of CA practices. Furthermore, farmers owning 1–20 hectares of land demonstrate relatively higher levels of knowledge compared to those with smaller landholdings. This is likely because they are often semi-commercial producers who are more market-oriented and therefore more receptive to productivity-enhancing technologies such as CA, especially through extension services (Maake et al., 2022; Ngaiwi et al., 2023). Their larger landholdings also allow for experimentation with new practices without compromising household food security. To address these differences, extension services should move away from targeting farmers based on land size alone (Ringo et al., 2024). Instead, they should adopt inclusive, group-based, and participatory training approaches to ensure wider access to knowledge and promote more unbiased adoption of CA practices.

The observed knowledge gaps among Department officials and extension officers regarding silage, CCs, and CA may be attributed to differences in training, specialisation, and exposure to specific agricultural practices within the Department. In some cases, extension officers may not receive regular refresher training on emerging agricultural innovations, leading to limited knowledge in areas such as forage preservation and CA-related practices (Dimitrov, 2025; Hangula et al., 2026). This highlights the need for the Department to strengthen capacity-building initiatives through regular and targeted workshops. Such training would equip extension officers and officials with up-to-date knowledge and practical skills before they

engage with smallholder farmers (Raidimi and Kabiti, 2019). This would improve the quality of information dissemination and boost the adoption of improved agricultural practices at the farmer level.

3.5.2. Attitudes

The moderately positive attitudes of smallholder farmers toward CCs in relation to livestock production and sustainable agriculture indicate a high level of perceived usefulness, which may encourage adoption behaviour. Farmers expressed strong agreement that CCs provide significant benefits for livestock production and contribute to the maintenance and promotion of CA. Previous studies indicate that smallholder farmers tend to prioritise immediate production-related benefits such as livestock productivity, income generation, and food security over long-term sustainability outcomes (Rapiya et al., 2025; TM et al., 2026). This is because adoption decisions are largely influenced by perceived usefulness and observable farm-level benefits (Chatterjee et al., 2022), while permanent ecological gains such as soil sustainability are less visible and therefore less strongly valued.

The negative perceptions of silage observed among smallholder farmers may be attributed to limited knowledge and inadequate training in silage-making practices. Silage production involves technical processes such as fermentation, proper storage, and moisture control, which require a certain level of skill and understanding (Oude Elferink et al., 2000). When farmers lack this knowledge, they are more likely to perceive the practice as complex and risky, leading to uncertainty and negative attitudes (Maina et al., 2021; Kule et al., 2025). In addition, the absence of visible success among peers further reinforces these perceptions, as farmers tend to rely on observed outcomes within their communities when evaluating new technologies. For instance, Maiyo et al. (2026) found that when successful examples are lacking, silage is often regarded as unreliable and unrewarding. Moreover, limited exposure to practical demonstrations, coupled with weak extension support systems, constrains farmers' ability to build confidence in the practice.

The positive attitudes expressed by farmers suggest that they strongly believe in the benefits of CCs within CA systems and are willing to adopt these practices. This may be attributed to their exposure to ongoing training initiatives, as this was the third annual workshop. As a result, some farmers may have already observed the practical benefits of CCs in their own fields, which likely influenced their agreement with the statements. In particular, strong agreements with the statement that CCs outcompete weeds for resources and reduce the need for herbicides and manual weeding may reflect farmers' direct experiences. This finding is

supported by Sithole and Olorunfemi. (2024), who reported that smallholder farmers in SA hold strong beliefs regarding the weed suppression benefits of CCs. Similarly, Phophi et al. (2017) found that smallholder farmers in KZN rely on CCs for weed control, especially because herbicides are often expensive and less accessible. Furthermore, farmers' willingness to attend training shows they value knowledge for improving agricultural practices. Farmers are likely motivated to attend such programs because they perceive CA practices to be effective and beneficial. This aligns with the findings of Ntshangase et al. (2018), who reported that access to training is a key factor influencing the adoption of CA, as it equips farmers with the required skills and knowledge to improve their farming practices.

3.5.3. Practices

Although educational status, land size, and type of farming did not influence practice levels, a large proportion of farmers fell within the low practice category. This suggests that, although the use and preservation of forage CCs within CA systems are being adopted, their application is still at a developmental stage rather than being fully integrated into farming systems. This finding is consistent with findings of Ntshangase et al. (2018), who reported that CA practices in KZN remain at early stages of adoption. Similarly, Muzangwa et al. (2017) found that many smallholder farmers implement only selected components of CA rather than adopting the system as a whole. The limited level of adoption may be attributed to several challenges faced by farmers, including inadequate access to training and workshops, limited financial support, and a lack of knowledge. Addressing these constraints could improve farmers' capacity to implement CA practices more effectively and may lead to increased adoption levels among smallholder communities.

Grazing was the main feed source for livestock, while forages were used less, and smallholder farmers mostly planted summer crops. This is consistent with findings that smallholder farmers in SA primarily rely on natural rangelands for livestock feeding due to their low cost and availability (Lamega et al., 2021). In contrast, the adoption of improved forages remains limited despite their benefits, mainly due to constraints such as limited resources, land availability, and technical knowledge (Paul et al., 2020). Despite these constraints, forage CCs were moderately used, with oats being used by about half of the farmers. This preference may be attributed to the fact that oats are highly palatable to livestock due to their leafy structure (Zhang et al., 2023) and provide higher nutritive value compared to many grasses during winter (Lee, 2018; Barsila, 2018). However, 26% of farmers reported not using any CCs, and nearly all farmers (98%) indicated that they had never used CCs for silage. These relatively low adoption levels, particularly for silage use, suggest that farmers may have limited

awareness and knowledge of using CCs for silage production. Therefore, there is a need to improve farmer education and training, specifically on the benefits and techniques of silage making from CCs, to boost its adoption.

3.6. Conclusion and Recommendations

The study examined the knowledge, attitudes, and practices of smallholder farmers regarding the use and preservation of forage CCs within CA systems in Okhahlamba Local Municipality, KZN. The findings revealed that farmers possessed a moderate level of knowledge of forage CCs and CA. However, their knowledge of silage production and preservation techniques was relatively low. The study further showed that knowledge significantly influences farmers' practices, indicating that increased knowledge contributes to improved implementation of forage CC practices. Although farmers expressed positive attitudes toward the benefits of CCs and their role in CA, these attitudes did not consistently translate into practice. Interestingly, almost all respondents (98%) had never used forage CCs for silage, and many exhibited negative attitudes toward this practice. This is largely due to the uncertainty about its outcomes and a lack of confidence in its effectiveness. Overall, the level of practice among farmers was low, with only a few demonstrating moderate levels, suggesting that the adoption of forage CCs is still at a developmental stage. Several key barriers to adoption were identified, including limited access to training, inadequate financial support, lack of equipment and resources, and insufficient extension services. To improve the implementation of these practises, the following recommendations are proposed:

- ✓ Strengthen capacity of extension personnel: Improve knowledge among extension officers and Department of Agriculture officials through regular (e.g., monthly) training workshops to keep them up to date with the latest agricultural innovations before engaging with smallholder farmers.
- ✓ Establish demonstration sites: Develop demonstration plots to showcase the implementation of forage CCs within CA systems, allowing farmers to observe practical benefits under real field conditions.
- ✓ Promote farmer-to-farmer learning: Encourage exchange visits and knowledge sharing among farmers from different districts to facilitate the spread of practical experiences and successful practices.
- ✓ Promote intergenerational knowledge exchange: Develop farmer-to-farmer learning, mentorship, and practical training programmes that encourage older and more experienced farmers to share their knowledge and practical experience of forage cover crops and conservation agriculture with younger farmers. This may help

preserve existing farming knowledge while improving the understanding and adoption of forage CC practices among younger farmers.

- ✓ Provide financial and resource support: Support farmers with essential resources such as tractors, water, seeds, labour, and access to land to improve the successful implementation of forage CC practices.
- ✓ Develop targeted education programs: Design and implement training programs focused on the importance of forage CCs, particularly their use in silage production, and clearly demonstrate how farmers can benefit from these practices.
- ✓ Demonstrate silage production and use: Conduct practical demonstrations on harvesting, chopping, and ensiling both winter and summer forage CCs, followed by feeding trials, so that farmers can directly observe the benefits for livestock.

To further advance this research, future studies should investigate these three interrelated dimensions across different regions of KZN and other provinces in SA. Although some studies have examined the adoption of CA among smallholder farmers in KZN limited research has focused on the use and ensiling of forage CCs in SA.

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CHAPTER 4: Effect of Dry Matter on Fermentative characteristics, Chemical composition, and *In sacco* dry matter degradability of Sorghum and Pearl millet Silage

4.1. Abstract

Ensiling is an important forage preservation technique used to ensure a continuous supply of ruminant feed under increasingly variable climatic conditions. However, silage quality is strongly influenced by forage dry matter (DM) content and the use of absorbents during ensiling. This study evaluated the effects of different DM levels adjusted with wheat bran (WB) on the fermentation characteristics, chemical composition, aerobic stability, and in sacco DM degradability of sorghum and pearl millet silages. Sorghum bargrazer and pearl babala millet were grown under dryland conditions without fertiliser or weeding and harvested at the vegetative stage (68 days after planting). The forages were chopped and mixed with WB using the Pearson Square method to obtain target DM levels of 25%, 30%, 35%, and 40%. Increasing DM content significantly increased crude protein concentration ($p < 0.05$) and reduced neutral detergent fibre and acid detergent fibre contents in both silages. Higher DM levels reduced lactic acid concentration and slightly increased pH, indicating less intensive fermentation. Nevertheless, all silages achieved excellent fermentation quality according to Fleig scores. Lower DM silages (25–<30%) exhibited higher *in sacco* DM disappearance at 72 h, whereas moderate DM levels (30–35%) resulted in greater effective degradability. Aerobic stability was not influenced by DM level, with all silages remaining stable during aerobic exposure. Regression analysis identified crude protein ($p < 0.05$), lactic acid ($p < 0.05$), and degradation parameters as significant predictors of target DM ($p < 0.05$). Although silages at 40% DM had the highest nutrient concentrations and 25% DM promoted more extensive fermentation, DM levels between 30% and 35% provided the most favourable balance between fermentation quality, nutrient preservation, and ruminal degradability in both sorghum and pearl millet silages

Keywords: Aerobic stability; anaerobic fermentation; forage preservation; ruminal degradability; wheat bran; yield optimisation

4.2. Introduction

Effective forage conservation is essential in Southern Africa due to the pronounced seasonality in forage availability caused by climatic variability (Palmer and Ainslie, 2006; Batisani and Yarnal, 2010). These fluctuating conditions frequently result in inadequate feed supplies in rangelands for ruminant livestock during both the dry and rainy seasons. In South Africa, ensiling is widely used to stabilise forage supply and mitigate seasonal shortages of green biomass fodder (Balehegn et al., 2021). The ensiling process involves the anaerobic fermentation of fresh forage by lactic acid bacteria (LAB) (Bai et al., 2021; Kaewpila et al., 2021). During fermentation, LAB produce organic acids, mainly lactic acid, which reduce silage pH and inhibit undesirable microorganisms (Oude Elferink et al., 2000; McDonald et al., 2021). However, successful ensiling is strongly influenced by several management factors, with dry matter (DM) content at ensiling being one of the most important. Since DM content is a major determinant of fermentation quality, feed intake, and animal productivity (Guo et al., 2013), inappropriate moisture levels can impair fermentation and increase nutrient losses during ensiling (Hu et al., 2009). Therefore, proper management of forage DM content is essential to achieve favourable fermentation, maintain nutritive value, and improve digestibility under increasing climatic variability.

Sorghum [*Sorghum bicolor* (L.) Moench] and pearl millet [*Pennisetum glaucum* (L.) R. Br.] are annual C_4 forage grasses recognised for their tolerance to drought, heat, and nutrient-poor soils (Bhattarai et al., 2020; Bani Hana et al., 2022). These characteristics make them suitable for silage production in water-scarce regions. Their high biomass yield, efficient water use, and ability to maintain growth under drought and other environmental stresses enable them to remain productive under conditions where traditional silage crops such as maize may underperform (Salama et al., 2020; Nematpour et al., 2021; Zampaligré et al., 2022). In addition, both forages generally ferment well, achieving desirable pH and lactic acid concentrations, and are increasingly considered alternatives to maize silage in South African livestock systems (Cattani et al., 2017; Bernard and Tao, 2020; Lv et al., 2023). Nevertheless, achieving consistent silage quality in these forages requires appropriate DM concentrations at ensiling. Maintaining optimal DM levels is therefore important, as concentrations between 30–50% generally support efficient fermentation and minimise nutrient losses (Wróbel et al., 2025). Low DM (<30%) may cause excessive effluent losses and poor fermentation, while high DM (>50%) may reduce compaction and increase aerobic spoilage (Wróbel et al., 2025). Although recommended DM ranges for silage production have been established, there is still limited information on the DM level that

best supports silage quality, nutritive value, and degradability in sorghum and pearl millet silage.

Previous studies report that DM affects fermentation and nutrient composition, but findings remain inconsistent for sorghum and pearl millet. For instance, sorghum silage at lower DM levels often shows stronger fermentation, with lower pH and higher organic acid production, whereas higher DM levels tend to improve nutrient retention (Kharazian et al., 2024; Oliveira et al., 2024). Similarly, pearl millet silage can ferment effectively across a range of DM levels, although results vary for protein content and digestibility (da Silva et al., 2025; Souza et al., 2023). These contrasting findings suggest that acceptable silage quality can be achieved across different DM levels, but the optimum range that balances fermentation quality, nutrient preservation, and degradability has not yet been clearly established. To overcome moisture-related limitations, management practices such as wilting and the use of absorbents are commonly used to adjust forage moisture and improve silage quality (Fransen and Strubi, 1998; Wilkinson and Rinne, 2018).

Wheat bran (WB), a common agricultural by-product, is widely used as an absorbent in high-moisture silage systems due to its ability to reduce moisture while improving nutritional value (Yi et al., 2023). Wheat bran contains relatively high crude protein content and moderate fibre levels, making it a valuable energy and nutrient source for ruminants (Yi et al., 2023). Despite its recognised potential, limited studies have examined how DM adjustment using WB affects fermentation quality, nutrient composition, and ruminal degradability in sorghum and pearl millet silages. Therefore, this study aimed to address this knowledge gap by evaluating the effect of DM content on the fermentation quality, nutritional value, and *in sacco* DM degradability of sorghum and pearl millet silages. It was hypothesised that increasing DM from 25% to 40% would improve silage quality through increased crude protein and reduced neutral detergent fibre and acid detergent fibre concentrations. Higher DM concentrations (35-40%DM) were also expected to improve fermentation characteristics through lower pH and higher lactic acid concentrations. Lastly, lower DM silages (25–30%) were expected to show higher DM disappearance after 72 hours of rumen incubation because their fibre components are more slowly degraded by microbes over time. These trends are anticipated in both forage species, with similar patterns but minor differences in magnitude between sorghum and pearl millet.

4.3. Materials and Methods

4.3.1. Site description

The experiment was conducted at the Agricultural Research Council (ARC-AP) Animal

Production Range and Forage Science located in Cedara Research Station (S29° 32′ 15.33″, E30° 16′ 09.19″), which is situated in the uMgungundlovu District Municipality, approximately 16 km from Pietermaritzburg in the KwaZulu-Natal Midlands, South Africa. The study area receives an average annual rainfall of about 900 mm and is positioned at approximately 1076 m above sea level (KwaZulu-Natal Department of Agriculture and Rural Development, Cedara Research Station fact sheet, 2024). The soils are acidic, with soil pH (KCl) ranging from 3.9 to 5.0 and acid saturation up to 60% in unlimed soils. The frost period averages 75 days per year with a minimum temperature of 9.4 °C and a maximum temperature of 22.3 °C.

4.3.2. Planting and experimental design

Two forage species (Sorghum bargrazer and Pearl babala millet) were grown under similar soil and management conditions. Seeds of the sorghum and pearl millet cultivars used in this study were purchased from Barenbrug South Africa and were supplied by the ARC-AP. Germination tests were first conducted to confirm seed viability before planting. Planting took place in October 2024 after land preparation using a no-tillage system, and seeds were sown by hand using the broadcasting method and then lightly covered with soil to ensure adequate seed-to-soil contact. The experiment followed a randomised complete block design (RCBD) with a total of 48 plots. Each plot measured 12 m² (6 × 2 m), resulting in a total experimental area of 576 m². The design consisted of three blocks, each containing 16 plots, of which eight were planted with sorghum bargrazer and eight with pearl babala millet. For the silage experiment, forage from all sorghum plots was harvested and combined into a single composite batch, and the same procedure was applied to all pearl millet plots before chopping and treatment formulation. The forages were grown under dryland conditions, without irrigation, weeding, or fertiliser application throughout the study period.

4.3.3. Silage making

Forages were harvested in December 2024 (68 days after planting) at the vegetative growth stage using a hand-cutting method at an approximate height of 1.0–1.3 m (Alatürk, 2024). Following harvest, the material was manually chopped to an approximate length of 2.0–2.25cm (Zheng et al., 2022) in preparation for treatment formulation. Wheat bran used in the mixtures was sourced from Agrimark South Africa agricultural supplies. The study aimed to achieve different DM levels using the forages and WB. Proportions of each forage and WB required to achieve the target DM (TDM) level were calculated using the Pearson Square method as described by Pearson (1909). The mixtures were adjusted to obtain TDM concentrations of 25%, 30%, 35%, and 40% in fresh matter basis (FM). The resulting treatments

were as follows: sorghum–WB at 25% DM (SW25), 30% DM (SW30), 35% DM (SW35), and 40% DM (SW40); and pearl millet-WB at 25% DM (MW25), 30% DM (MW30), 35% DM (MW35), and 40% DM (MW40). Molasses was added at 5% to improve fermentation. Each TDM level within a forage was treated as a separate experimental group for analysis. Approximately 750 g of each thoroughly mixed treatment was packed into 1 L Mason glass experimental jars with airtight lids. Treatments were replicated 3 times, and mixtures were hand-compacted to expel as much air as possible. The jars were then kept at room temperature (22–25 °C) and were opened after a 90-day ensiling period. Upon opening, the upper 2 cm of visibly spoiled silage was removed and discarded. The remaining material from each jar was transferred into labelled aluminium trays, and after all three jars for the treatment had been emptied, the contents were thoroughly mixed pending chemical analysis.

4.3.4. Chemical analysis

For chemical analysis, both pre-ensiling and post-ensiling samples were oven-dried at 60 °C for 48 hours to determine DM content. The dried samples were then ground using a fitted Ultra Centrifugal Mill ZM 300 (Retsch GmbH, Haan, Germany) with a 1-mm sieve in preparation for further analyses. Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were analysed using an ANKOM2000 Fibre Analyser (ANKOM Technology, Macedon, NY, USA). Acid detergent lignin (ADL) was determined using the 72% H_2SO_4 method described by Van Soest et al. (1991). Hemicellulose (Hemi) and cellulose (Cell) contents were calculated as NDF minus ADF, and ADF minus ADL, respectively, following the approach of Javier-Astete et al. (2021). For ash determination, one gram of sample was placed into a pre-weighed crucible and combusted in a muffle furnace (Carbolite AAF 1100, Carbolite Gero, Hope Valley, UK) at 550 °C (AOAC,2005). Total nitrogen content of the samples was determined using a LECO TruSpec N nitrogen analyser (LECO Corporation, St. Joseph, MI, USA) following the Dumas combustion method (AOAC, 2005; method 990.03). Crude protein (CP) content was subsequently calculated by multiplying the nitrogen percentage by 6.25.

4.3.5. Ensiling characteristics

The pH of the silage was measured by diluting 25 g of each sample with 100 ml of distilled water, blending the mixture for 2 minutes, and filtering it through MN615 (90 mm) filter paper (Macherey–Nagel). The pH of the filtrate was then determined using a CRISON micro 2000 pH meter. Acetic acid (AA) and propionic acid (PA) were quantified using gas chromatographic analysis, which was performed using an Agilent Technologies system (Agilent 6890N GC-FID, Model G1530N; Serial No. CN10739015, USA). Lactic acid (LA) concentration was measured using the gas chromatography method as described by Doms (1974). Silage quality was evaluated using Fleig score (FS) data, and the FS was calculated according to the formula reported by Denek et al. (2004):

Flieg score = 220 + (2 × DM% - 15) - 40 × pH

4.3.6. Aerobic stability

The aerobic stability (AS) of the silages was evaluated following the procedure of Ranjit and Kung (2000). After opening the silos, the contents were thoroughly mixed, and 1 kg of silage from each treatment was placed into separate 1-L metal containers, with three containers prepared per treatment. A digital probe thermometer was inserted into the centre of every container to record silage temperature at hourly intervals. The trial was conducted under controlled laboratory conditions at a constant ambient temperature of 25 °C ± 0.8. The temperatures of both the silage and the surrounding environment were monitored continuously for 5 days (120 hours). Aerobic deterioration was considered to have begun when the silage temperature exceeded the ambient temperature by more than 2 °C.

4.3.7. Microbial analysis

Microorganism counts in the silages were determined using the plate count method described by Yamamoto et al. (1986). One gram of fresh silage was homogenised with 9 mL of quarter-strength Ringer's solution (0.85% NaCl) to obtain a 10^{-1} dilution. The mixture was blended for 2 minutes using a Kenwood laboratory blender (Kenwood, Havant, Hampshire, UK) and then serially diluted in sterile Ringer's solution from 10^{-1} to 10^{-6} for lactic acid bacteria (LAB) and from 10^{-1} to 10^{-3} for mould and yeast. Lactic acid bacteria were cultured on MRS (de Man, Rogosa, and Sharpe) agar, while yeasts and moulds were cultured on Rose Bengal Chloramphenicol agar. From each dilution, 100 µL was aseptically inoculated onto the surface of the appropriate agar medium using the spread plate technique. All plates were prepared in triplicate. Lactic acid bacteria plates were incubated at 30°C for 24 hours, whereas yeast and mould plates were incubated at 30°C for 48 hours. Following incubation, colonies were

counted and recorded as viable microorganisms (colony-forming units per gram, CFU/g). Final counts were expressed on an FM basis and converted to logarithmic (log_{10}) values.

4.3.8. In *sacco* DM degradability

The experiment was conducted in June 2025 at the Livestock Department of the University of KwaZulu-Natal Research Farm (Ukulinga), South Africa (28°24' E; 30°24' S). The study employed the nylon bag technique described by Osuji et al. (1993). Ethical approval was obtained from the University's Animal Ethics Committee (Ref: AREC/00007767/2024). Two rumen-fistulated Jersey cows with a mean body weight of 550 ± 45 kg were used as experimental animals. Silage samples of about 2.5 g were prepared in triplicate. Each sample was placed in a nylon bag measuring 6.5 × 14 cm with a mesh size of 30–50 µm. The bags were sealed and incubated in the rumen for 0, 6, 12, 24, 48, and 72 hours. The cows had continuous access to kikuyu grass, lucerne hay, and water. After each incubation period, the bags were removed, rinsed, and washed under running water for 10 minutes before being placed in a washing machine for three 15-minute cycles. The bags were then air-dried and later oven-dried at 60°C for 48 hours. Once dried, the bags were weighed to determine the remaining residue. Zero-hour bags were treated in the same manner but were not incubated in the rumen. Dry matter disappearance (DMD) was calculated using the method outlined by Orskov et al. (1979).

DMD (%) = (Initial weight – Final weight/ Initial weight) × 100

The nonlinear parameters a, b, and c for DM were modelled using the exponential equation as described by Orskov and McDonald (1979):

$P = a + b (1 – e^{-ct})$

Where P represents the degradability of DM at time t, a is the fraction of DM lost during washing, b is the fraction of DM slowly degraded, and c is the rate of DM degradation (h^{-1}). The Effective degradability (ED) was calculated using the formula described by Ørskov and McDonald (1979), where k = 0.05:

$ED = a + (b. c)/ (k + c)$

4.4. Statistical analysis

All data were analysed using SPSS statistical software (Version 30; IBM Corp., Armonk, NY, USA). Before analysis, the assumptions of normality and homogeneity of variances were evaluated using the Shapiro–Wilk test. Data were subsequently analysed using the General Linear Model (GLM) procedure. One-way analyses of variance (ANOVA) were performed separately for each forage type, such that sorghum and pearl millet silage mixtures were analysed independently. For each forage, the four TDM levels (25%, 30%, 35%, and 40%) constituted the treatment groups used to assess the effect of DM content on silage chemical composition, fermentation characteristics, AS, and *in sacco* DM degradability at both pre-ensiling and post-ensiling stages. Linear regression analysis was performed to examine the relationships between TDM levels and chemical composition, fermentation characteristics, and degradation parameters at the post-ensiling stage for both silage mixtures. When significant differences were detected, treatment means were separated using Tukey's *post hoc* test. Statistical significance was declared at $p < 0.05$.

4.5. Results

The chemical composition of the silage raw materials is presented in Table 4.1. Wheat bran had the highest DM (88.30% FM) and CP content (19.90% DM) compared to sorghum and pearl millet. Sorghum recorded the highest NDF content (64.85% DM), followed by pearl millet (59.37% DM), while WB had the lowest value. Similarly, sorghum (43% DM) and pearl millet (34.73% DM) exhibited higher ADF contents compared to WB (18.76% DM). Wheat bran had the highest ADL content (3% DM) as well as hemicellulose content (26.99% DM). Pearl millet recorded the highest ash content (10.76%DM) among the three raw materials.

Table 4.1 Mean(±SEM) chemical composition of raw materials used

Variables	Sorghum	Pearl millet	Wheat bran
Dry Matter (%FM)	23.20±0.87	18.87±0.40	88.30±0.15
Crude protein (%DM)	9.8±0.16	10.99±0.26	19.20±0.13
Neutral detergent fibre (%DM)	64.85±0.41	59.37±0.62	45.74±0.23
Acid detergent fibre (%DM)	43±1.3	34.73±0.43	18.76±0.42
Acid detergent lignin (DM%)	2.83±0.45	2.35±0.29	3±0.7
Ash (DM%)	9.36±0.21	10.76±0.19	6.47±0.41
Hemicellulose (DM%)	21.86±0.90	24.63±0.90	26.99±0.54
Cellulose (DM%)	40.16±1.78	32.38±0.45	15.77±0.55

4.5.1. Chemical composition of forage- WB mixed silages at pre-ensiling

Table 4.2 presents the chemical composition of the forage–WB mixed silage before ensiling. For SW, increasing TDM levels resulted in significant increases in DM content ($F_{(3,8)}$ =149.12; p<0.05) and CP ($F_{(3,8)}$ =14.38; p<0.05). Neutral detergent fibre ($F_{(3,8)}$ =19.06; p<0.05) and ADF ($F_{(3,8)}$ =24.01; p<0.05) also differed significantly among TDM levels. In contrast, ash ($F_{(3,8)}$ =0.86; p>0.05) did not significantly affect TDM levels. For MW, increasing TDM levels similarly resulted in increased DM content ($F_{(3,8)}$ =106.44; p<0.05) and increased CP ($F_{(3,8)}$ =183.36; p<0.05) but were associated with decreased NDF ($F_{(3,8)}$ =2.43; p>0.05). Ash ($F_{(3,8)}$ =3.77; p>0.05) and Hemicellulose ($F_{(3,8)}$ =2.285; p>0.05) did not significantly affect TDM.

4.5.2. Chemical composition of forage- WB mixed silages at post-ensiling

For SW, increasing TDM levels resulted in a significant increase in DM content ($F_{(3,8)}$ =55.16; p<0.05) and a slight decrease in CP ($F_{(3,8)}$ =40.17; p<0.05) compared to pre-ensiling. Neutral detergent fibre ($F_{(3,8)}$ =50.388; p<0.05) and ADF (F (3,8) =24.889; p<0.05) were significantly affected by TDM levels, whereas ADL ($F_{(3,8)}$ =1.04; p>0.05) did not affect TDM. Ash ($F_{(3,8)}$ =19.89; p>0.05) also showed variation with TDM levels, with SW25 having the highest value. For MW, increasing TDM levels led to a significant increase in DM content ($F_{(3,8)}$ =84.54; p<0.05) and a slight decrease in CP ($F_{(3,8)}$ =46.32; p<0.05) compared to pre-ensiling. However, all fibre fractions, including NDF ($F_{(3,8)}$ =3.91; p>0.05), ADF ($F_{(3,8)}$ =2.08; p>0.05), and ADL ($F_{(3,8)}$ =0.45; p>0.05), did not show significant changes with TDM levels. The results of the chemical composition of forage -WB mixed silage at post-ensiling are presented in Table 4.3

4.5.3. Ensiling characteristics of forage-WB mixed silage

Increasing TDM resulted in a significant rise in pH (p<0.05) and a significant reduction in LA content (p<0.05), as presented in Table 4.3. Mould and yeast counts were low, remaining below 5 CFU/g for both SW and MW silages. Lactic acid bacteria, AA, and PA did not show significant changes (p>0.05) in either forage mixture. Fleing scores, however, differed significantly (p<0.05) with increasing TDM for both SW and MW, with all silage mixtures being classified as excellent.

Table 4.2 Mean results (±SEM) chemical composition of forage- WB mixed silages at pre-ensiling

			Variables (%DM)						
Mixtures	**TDM (%)**	**DM (%FM)**	**CP**	**NDF**	**ADF**	**ADL**	**Ash**	**Hemi**	**Cell**
SW	25	24.56±0.89^{a}	14.14±0.16^{a}	53.98±0.67^{b}	27.27±0.47^{d}	2.26±0.23^{a}	9.08±0.43	26.71±0.31^{a}	25.01±0.69^{b}
	30	29.28±0.39^{b}	15.10±0.87^{ab}	48.05±1.01^{a}	22.75±0.59^{a}	2.34±0.11^{a}	8.67±0.47	25.29±0.49^{a}	20.41±0.58^{a}
	35	34.08±0.08^{c}	16.04±0.42^{bc}	49.37±0.50^{a}	22.97±0.13^{a}	2.65±0.13^{ab}	8.03±0.38	26.40±0.26^{a}	21.80±0.20^{a}
	40	38.90±0.27^{d}	16.16±0.25^{c}	51.23±0.83^{b}	24.91±0.57^{c}	3.11±0.13^{b}	7.65±1.15	28.62±0.29^{b}	21.88±0.22^{a}
	***p*-value**	<0.001	<0.001	<0.001	<0.001	0.014	0.499	0.001	<0.001
MW	25	25.44±0.37^{a}	14.60±0.05^{a}	55.87±0.76	27.27±0.47^{c}	2.26±0.23^{a}	9.90±0.24	28.60±0.45	25.01±0.69^{b}
	30	30.60±0.86^{b}	15.56±0.11^{b}	54.27±1.06	22.76±0.59^{a}	2.34±0.12^{a}	9.47±0.13	31.51±0.86	20.41±0.57^{a}
	35	36.59±0.73^{c}	16.50±0.06^{c}	51.74±1.17	22.97±0.28^{a}	2.66±0.13^{ab}	8.89±0.32	28.77±2.43	20.30±0.19^{a}
	40	42.41±0.83^{d}	16.80±0.02^{c}	50.72 ±1.61	24.91±0.31^{b}	3.16±0.11^{b}	8.83±0.31	25.80±1.62	21.80±0.21^{a}
	***p*-value**	<0.001	<0.001	0.140	<0.001	0.014	0.059	0.156	<0.001

Note: Target DM (TDM), Sorghum-WB (SW), Pearl millet-WB (MW). Means within the same column with different superscript letters for each mixture differ significantly at $p < 0.05$

Table 4.3 Mean results (±SEM) chemical composition of forage- WB mixed silages at post -ensiling

			Variables (%DM)						
Mixtures	**TDM (%)**	**DM (%FM)**	**CP**	**NDF**	**ADF**	**ADL**	**Ash**	**Hemi**	**Cell**
SW	25	24.43±0.80^{a}	13.48±0.05^{a}	48.59±0.21^{c}	27.12±0.09^{c}	2.13±0.28	9.71±0.11^{c}	21.48±0.19	24.91±0.26^{c}
	30	29.00±0.62^{b}	14.91±0.01^{b}	45.75±0.38^{b}	24.30±0.60^{b}	2.21±0.26	8.79±0.13^{b}	21.44±0.52	22.09±0.44^{b}
	35	34.16±1.21^{c}	15.01±0.18^{b}	42.40±0.78^{a}	22.58±0.44^{ab}	2.51±0.11	8.55±0.29^{ab}	19.82±0.80	20.07±0.34^{b}
	40	38.83±0.20^{d}	15.94±0.26^{c}	40.40±0.50^{a}	19.90±0.94^{a}	2.57±0.13	7.89±0.23^{a}	20.49±0.46	17.33±0.91^{a}
	***p*-value**	<0.001	<0.001	<0.001	<0.001	0.423	<0.001	0.165	<0.001
MW	25	25.82±1.06^{a}	14.48±0.14^{a}	43.24±1.75	25.00±1.45	2.48±0.36	9.15±0.42^{bc}	18.23±0.40	22.52±1.09^{b}
	30	31.66±0.47^{b}	15.50±0.07^{b}	39.89±0.40	23.80±0.49	2.79±0.45	9.44±0.36^{c}	16.09±0.39	21.0±0.51^{ab}
	35	37.45±0.88^{c}	15.60±0.08^{b}	41.68±0.10	23.83±0.96	3.35±0.94	7.94±0.05^{ab}	17.85±0.92	20.48±0.28^{ab}
	40	43.57±0.78^{d}	16.40±0.14^{c}	39.10±0.54	21.78±0.39	3.02±0.36	7.79±0.09^{a}	17.31±0.84	18.75±0.52^{a}
	***p*-value**	<0.001	<0.001	0.055	0.181	0.723	0.007	0.214	0.027

Note: Target DM (TDM), Sorghum-WB (SW), Pearl millet-WB (MW). Means within the same column with different superscript letters for each mixture differ significantly at $p < 0.05$

Table 4.4 Mean results (±SEM) fermentative characteristics of forage- WB mixed silages

Mixtures	TDM (%)	pH	LA (%DM)	LAB (logCFU/g)	MY (CFU/g)	AA (%DM)	PA (DM%)	FS	Classification
SW	25	3.98±0.03^{a}	7.06±0.08^{b}	7.95±0.03	<5	2.12±0.02	0.34±0.006	86.21±0.47^{a}	Excellent
	30	4.02±0.01^{ab}	5.85±0.02^{ab}	7.97±0.02	<5	2.79±0.03	0.36±0.006	98.61±2.84^{a}	Excellent
	35	4.04±0.02^{ab}	5.67±0.57^{a}	7.89±0.05	<5	2.53±0.25	0.35±0.003	91.98±3.21^{a}	Excellent
	40	4.08±0.01^{b}	5.08±0.01^{a}	7.85±0.07	<5	2.40±0.14	0.35±0.008	116.65±2.07^{b}	Excellent
	***p*-value**	0.044	0.008	0.417		0.133	0.237	0.001	
MW	25	4.02±0.04^{a}	6.90±0.05^{a}	7.90±0.06	<5	1.75±0.68	0.36±0.01	88.39±3.80^{a}	Excellent
	30	4.27±0.02^{a}	4.99±0.08^{b}	7.76±0.13	<5	2.37±0.34	0.48±0.04	97.25±1.53^{a}	Excellent
	35	4.27±0.01^{a}	4.40±0.01^{c}	7.76±0.13	<5	2.23±1.81	0.37±0.009	108.84±1.55^{b}	Excellent
	40	4.52±0.02^{b}	3.58±0.03^{d}	7.64±0.04	<5	1.49±0.95	0.36±0.01	110.55±1.97^{b}	Excellent
	***p*-value**	<0.001	<0.001	0.570		0.500	0.062	<0.001	

Note: Target DM (TDM), Sorghum-WB (SW), Pearl millet-WB (MW**)**, Lactic acid bacteria (LAB), Acetic acid (AA), Propanoic acid (PA), Fleig score (FS), Mould and yeasts (MY), Colony forming unit per gram (CFU/g), Lactic acid (LA). Means within the same column with different superscript letters for each mixture differ significantly at $p < 0.05$

4.5.4. *In sacco* DM disappearance of forage-WB mixed silages

The *in sacco* DM disappearance of sorghum–WB mixed silage, as illustrated in Figure 4.1, showed only minor variations among the different TDM levels. At 0 hours of incubation, SW25 exhibited the lowest DM disappearance (33.98%; $F_{(3,8)}$ =20.19; p<0.05), yet it demonstrated the highest disappearance at 72 hours (82.63%; $F_{(3,8)}$ =10.63; p<0.05) relative to the other TDM levels. The SW40 level displayed the greatest DM disappearance at 6 hours (53.93%; $F_{(3,8)}$ 7.63=; p<0.05), but its DM disappearances showed a slight reduction at 24 hours (76.41%; $F_{(3,8)}$ =6.58; p<0.05) compared with the other TDM levels. By 72 hours, SW25 again recorded the highest DM disappearance (84.72%; $F_{(3, 8)}$ =11.23; p<0.05), followed closely by SW30 (83.64%; $F_{(3,8)}$ =10.23; p<0.05).

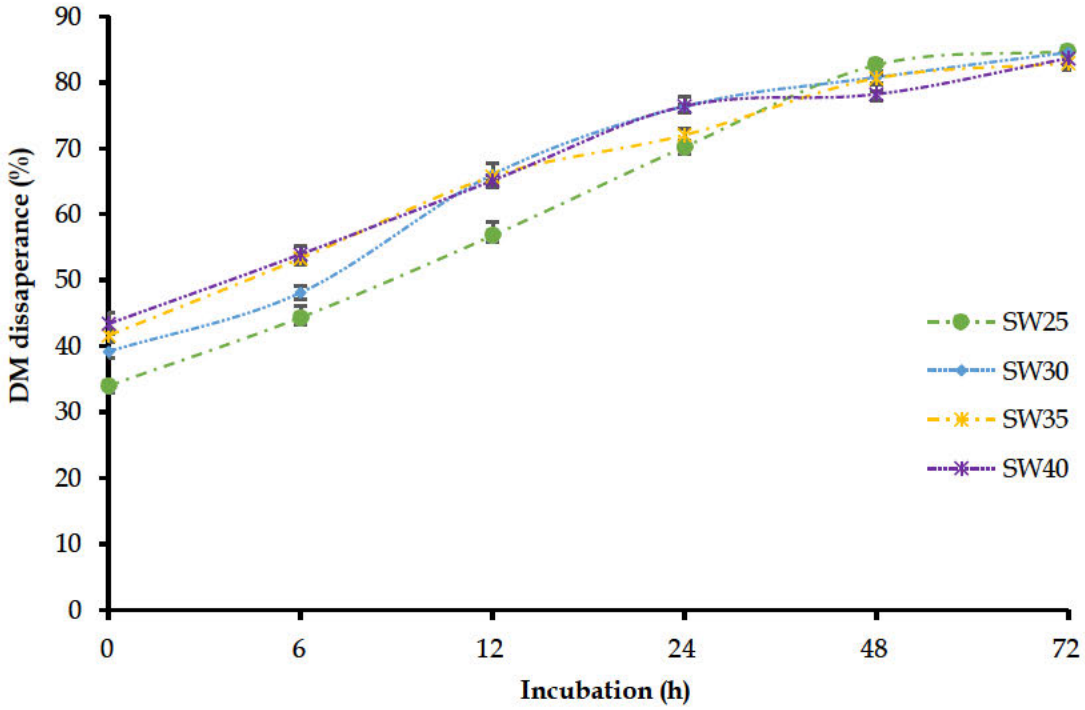

Figure 4.1 *In sacco* DM disappearance of sorghum -WB mixed silage

The *in sacco* DM disappearance of pearl millet–WB mixed silage is presented in Figure 4.2. Similar to the sorghum–WB silage, the pearl millet–WB TDM levels showed only slight variation in DM disappearance across incubation times. At 0 hours, MW25 recorded the lowest DM disappearance ($F_{(3,8)}$ =5.84; p<0.05), but its disappearance increased steadily and reached the highest value among all TDM levels at 72 hours ($F_{(3,8)}$ =7.39;

p<0.05). In contrast, MW35 showed the highest DM disappearance at 12 hours ($F_{(3,8)}$ =8.69; p<0.05), yet by 72 hours it had the lowest DM disappearance (84.54%) compared with the other TDM levels. Overall, the pearl millet–WB silage exhibited higher DM disappearance than the sorghum–WB silage at both 0 and 72 hours of incubation (p< 0.05).

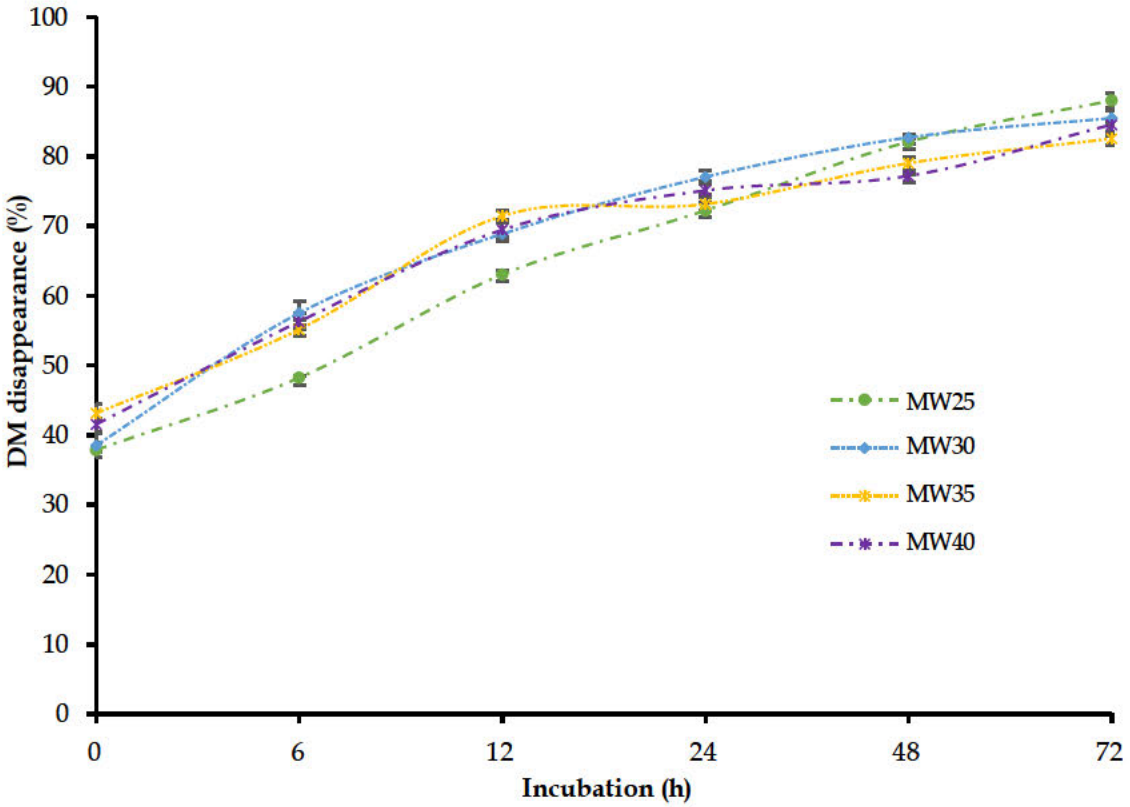

Figure 4.2 *In sacco* DM disappearance of pearl millet-WB mixed silage

4.5.4. Degradation parameters of forage-WB mixed silages

The degradation parameters of the forage–WB mixed silages are presented in Table 4.5. TDM levels had a significant effect on parameters A ($F_{(3,8)}$ =27.79; p<0.05), B ($F=_{(3,8)}$ =61.61; p<0.05) and ED ($F_{(3,8)}$ =12.43; p<0.05) for SW and on A ($F_{(3,8)}$ =6.726; p<0.05), B ($F=_{(3,8)}$ =31.45; p<0.05) and ED ($F_{(3,8)}$ =14.356; p<0.05) for MW. Parameter C was not influenced by TDM level in SW ($F_{(3,8)}$ =1.76; p>0.05). The lowest proportion of DM lost during washing was observed in SW25 (32.78%; $F_{(3,8)}$ =27.79; p <0.05), whereas SW40 (43.39%DM) exhibited the highest loss. For fraction B, which represents the slowly degraded DM, SW25 (54.63%; $F_{(3,8)}$ =61.61; p<0.05) showed the highest degradability. Effective degradability was highest in MW30 (69.79%), with MW35 (68.64%) showing the next highest value.

Table 4.5. Degradation parameters of forage-WB mixed silages

Mixtures	TDM (%)	A	B	C	ED
SW	25	32.78±0.07^{a}	54.63±0.55^{c}	0.04±0.003	61.03±0.85^{a}
	30	36.88±1.04^{b}	47.47±0.90^{b}	0.06±0.004	66.11±0.41^{b}
	35	40.72±0.77^{bc}	41.42±1.12^{a}	0.09±0.029	68.32±1.82^{b}
	40	43.39±1.17^{c}	38.87±0.78^{a}	0.06±.0.01	67.09±0.58^{b}
	***p*-value**	<0.001	<0.001	0.232	0.002
MW	25	37.48±0.05^{a}	51.14±0.42^{c}	0.04±0.01^{a}	64.75±0.31^{a}
	30	38.71±1.20^{ab}	45.72±0.86^{b}	0.08±0.01^{ab}	69.79±0.72^{b}
	35	42.64±1.02^{b}	37.70±2.1.61^{a}	0.09±0.009^{b}	68.64±0.54^{b}
	40	41.12±0.69^{ab}	40.69±0.94^{a}	0.08±0.008^{a}	68.58±0.65^{b}
	***p*-value**	0.014	<0.001	0.037	0.001

Note: Target DM (TDM), Sorghum-WB (SW), Pearl millet-WB (MW). Fraction of DM (%) lost during washing (A), Fraction of DM (%) slowly degraded (B), Rate of degradation of DM (h^{-1}) (C), Effective degradability (ED). Means within the column with different superscript letters for each mixture differ significantly at $p< 0.05$.

4.5.4. Aerobic stability of forage-WB mixed silages

After 90 days of ensiling, the silages were evaluated for AS. The effects of the TDM levels on AS are presented in Figures 4.3 and 4.4. Temperature changes in the forage–WB mixed silages were monitored over five days following exposure to air. Throughout the monitoring period, none of the treatments exhibited temperatures exceeding the ambient room temperature of 25 °C. As expected, all treatments showed a decline in temperature within the first 24 hours after opening, reflecting the initial release of fermentation heat. After 72 hours, silage temperatures continued to decrease slightly across all treatments. Among them, the SW25 treatment recorded the lowest temperature (23.4 °C) at 72 hours, indicating comparatively greater AS relative to the other treatments.

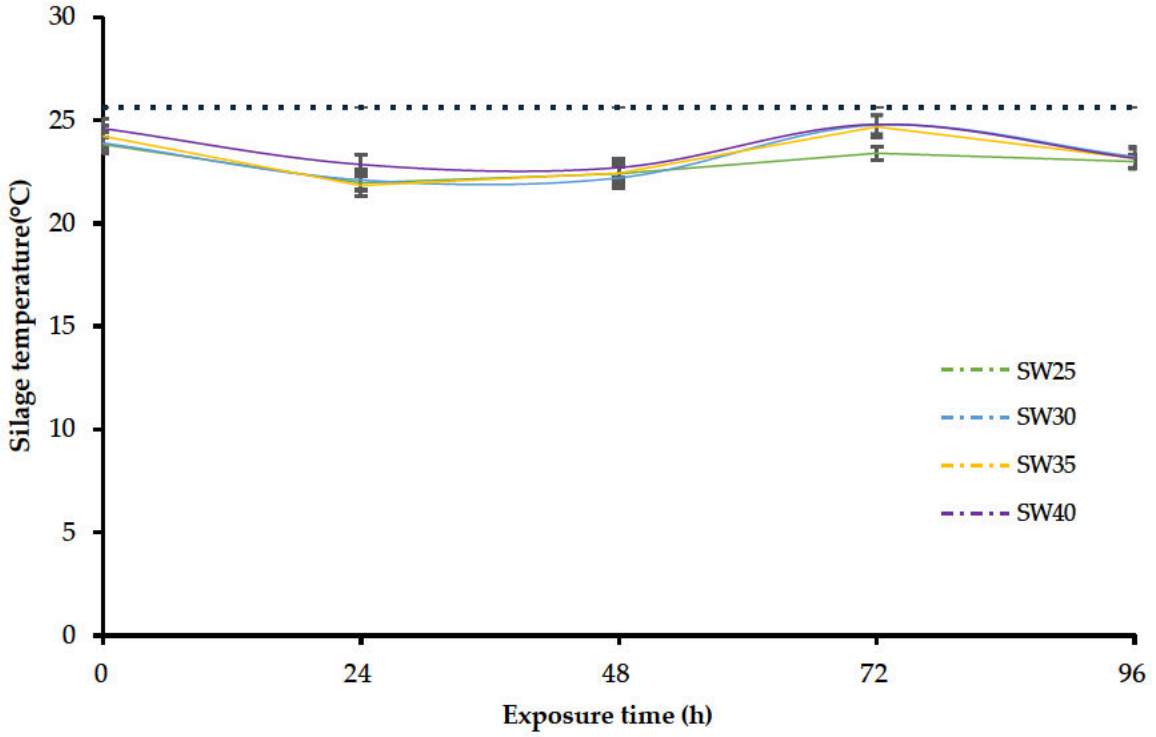

Figure 4.3 Temperature dynamics of sorghum-WB mixed silage treatments exposed to air over five days

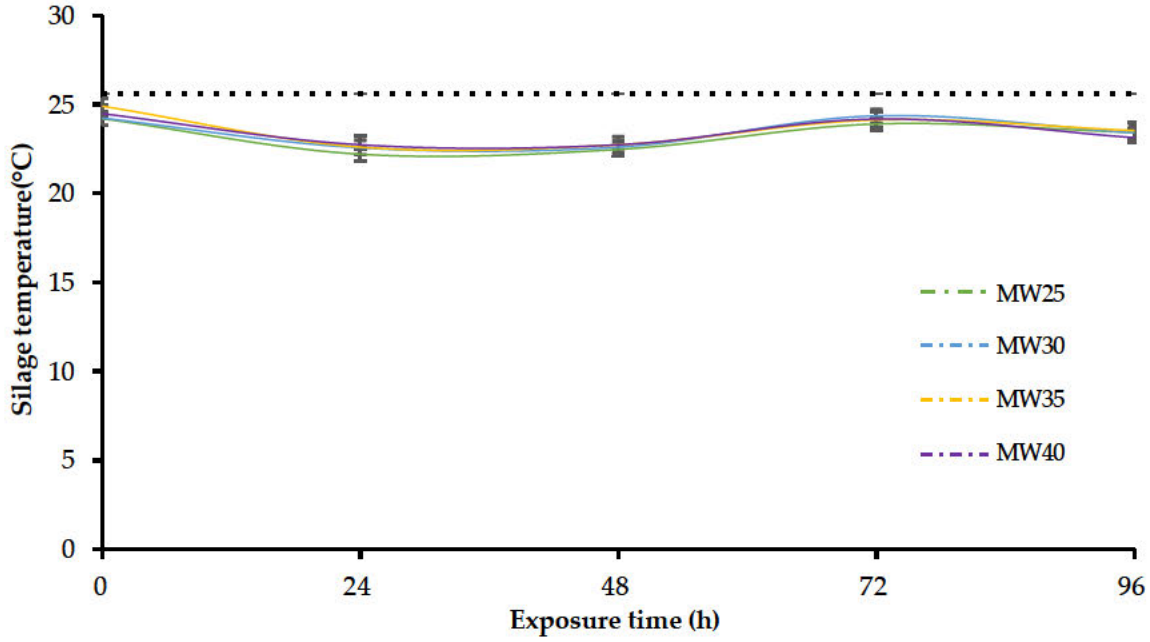

Figure 4.4 Temperature dynamics of pearl millet-WB mixed silage treatments exposed to air over five days

Regression analysis showed that TDM was strongly associated with most nutritional variables (Table 4.6). Dry matter (R^2=0.953) and CP (R^2=0.857) increased significantly with TDM, while fibre components (NDF and ADF) and ash decreased (p<0.05). Among ensiling characteristics, pH increased slightly, whereas LA (R^2=0.860) decreased with increasing TDM (p<0.05). However, LAB, AA, and fermentation products showed no significant relationships (p>0.05). For degradation parameters, A and ED increased, while B decreased with TDM (p<0.05).

Table 4.6 Regression model for predicting TDM from nutritive value, ensiling characteristics, and degradation parameters of sorghum–WB mixed silage at post-ensiling

Factor	Y-Variables	Formulae	*p*-value	R^2
	Chemical composition			
TDM	DM	4.082x+19.628	**<0.001**	0.953
	CP	0.756x+12.970	**<0.001**	0.857
	NDF	-2.789x+51.260	**<0.001**	0.941
	ADF	-2.331x+29.306	**<0,001**	0.896
	ADL	0.162x+1.955	0.091	0.260
	Hemi	-0.458x+21.954	0.100	0.990
	Ash	-0.570x+10.163	**<0.001**	0.843
	Cell	-2.494x+12.970	**<0.001**	0.924
	Fermentative characteristics			
TDM	pH	0.026x+3.970	**<0.001**	0.463
	LA	-0.654x+7.399	**<0.001**	0.860
	LAB	-0.038x+8.016	0.105	0.377
	FS	7.441x+78.982	0.064	0.461
	AA	-0.225x+3.736	0.687	0.029
	PA	0.004x+0.345	0.343	0.150
	Degradation parameters			
TDM	A	3.567x+29.525	**<0,001**	0.905
	B	-5.333x+58.930	**<0,001**	0.922
	C	0.009x+0.040	0.257	0.126
	ED	2.039x+60.540	**<0,001**	0.556

R^2- Regression coefficient

Regression analysis showed that TDM was significantly related to most nutritive variables in MW silage (Table 4.7). Dry matter (R^2=0.969) and CP (R^2=0.849) increased with TDM (p<0.05), while ADF and ash decreased (p<0.05). NDF showed a decreasing trend, but it was not significant, and ADL and hemicellulose were also not affected (p>0.05). For ensiling

characteristics, pH (R^2=0.842) increased, and LA (R^2=0.931) decreased significantly with increasing TDM (p<0.05), whereas LAB and AA were not significantly influenced (p>0.05). For degradation parameters, A and ED increased with TDM, while fraction B decreased (p<0.05).

Table 4.7 Regression model for predicting TDM levels from chemical composition, fermentative characteristics, and the degradation parameters of pearl millet–WB mixed silage at post-ensiling

Factor	Y-Variables	Formulae	*p*-value	R^2
	Chemical composition			
TDM	DM	5. 904x+19. 870	**<0.001**	0.969
	CP	0.581x+14. 066	**<0.001**	0.849
	NDF	-1. 064x+43. 641	0.053	0.326
	ADF	-0. 964x+26. 017	**0.033**	0. 379
	ADL	0.216x+2. 374	0.357	0.085
	Hemi	-0.100x+17. 624	0.785	0.008
	Ash	-0.560x+9. 987	**0.005**	0.570
	Cell	-1. 181x+14. 066	**0.002**	0.641
	Fermentative characteristics			
TDM	pH	0.108x+4. 033	**0.001**	0.842
	LA	-1. 065x+7. 624	**<0. 001**	0.931
	LAB	-0. 078x+7. 967	0.138	0.327
	FS	6. 687x+85. 751	**<0. 001**	0.944
	AA	0.115x+2. 121	0.852	0. 006
	PA	-0. 010x+0. 421	0.639	0.039
	Degradation parameters			
TDM	A	3. 567x+29. 525	**<0. 001**	0.989
	B	-5. 333x+58. 930	**<0. 001**	0.922
	C	0.009x+0.040	0. 257	0.126
	ED	2. 039x+60. 540	**0.005**	0.556

R^2- Regression coefficient

4.5 Discussion

4.5.5. Chemical composition

The study evaluated the effect of DM levels using sorghum and pearl millet as biological replicates, with WB incorporated as an absorbent to achieve the targeted DM concentrations. To date, studies investigating the effect of DM using these two closely related forage species remain limited. Sorghum and pearl millet exhibited largely similar nutritional composition, fermentative characteristics, and degradability responses across treatments. This similarity may be attributed to their comparable physiological and biochemical properties, as both species belong to the Poaceae family and share related forage quality characteristics (Cai et al., 2020; Guzmán-Ochoa and Felipe-Victoriano, 2026). The study supported the hypothesis that increasing DM from 25% to 40% improves silage quality, as evidenced by higher CP concentrations and reduced NDF and ADF losses in both sorghum and pearl millet silages. Crude protein increased from 13% to 16% DM in both forages, while CP losses after 90 days of ensiling remained minimal, which indicated effective nitrogen preservation during fermentation. Moreover, all the CP levels across genotypes exceed the minimum requirement of 7–8% needed for effective rumen function in cattle (NASEM, 2021; Erickson et al., 2024).

The observed improvement in CP is likely associated with the inclusion of WB, which may have increased nutrient retention during ensiling. This finding is consistent with Kordi and Naserian. (2012) who reported that increasing WB inclusion improved CP concentration in citrus pulp silage. Similarly, Yi et al. (2023) demonstrated that WB inclusion at 30–40% DM significantly increased CP content in amaranth silage, highlighting its role in improving silage nutritive value across different forage types. The relatively small CP losses observed in both silages may be explained by the functional properties of WB during fermentation. Wheat bran contains a fibrous structure capable of physically entrapping soluble nitrogen fractions, thereby reducing their diffusion into effluent and limiting their degradation into fermentation by-products (Gül, 2023). The NDF (39–48%DM) and ADF (19–27%DM) values observed in both silage studies fall within ranges generally considered indicative of good-quality forage for ruminants (Harper and McNeill, 2015; Van Soest et al., 2020; Wrobel et al., 2026). Moderate NDF concentrations support rumen function and chewing activity without reducing feed intake (Schulze et al., 2014; Harper and McNeill, 2015). Low ADF concentrations are linked to better digestibility and higher energy availability (Raffrenato, 2011). Together, these fibre characteristics improve nutrient use, rumen fermentation, and animal performance in lactating dairy cattle (Weiss et al., 1989). Neutral detergent fibre and ADF losses, particularly in SW silages, are supported by previous studies reporting that WB inclusion and ensiling

processes can modify fibre composition (Wagali et al., 2023; Mu et al., 2023). Beyond serving as an absorbent, WB may amplify microbial activity during ensiling, promoting partial breakdown of fibre components and contributing to reduced NDF and ADF concentrations (Nkosi et al., 2015; Mu et al., 2023). These findings suggest that WB improved not only CP content, but also the overall fibre quality of the silages.

The consistent and statistically significant increase in DM across treatments confirms that the Pearson Square method was effective for silage formulation. Although the exact target DM values were not fully achieved, the measured DM showed a clear progressive increase that closely followed the intended levels of 25%, 30%, 35%, and 40%. Small deviations between targeted and actual DM are expected under practical conditions due to natural variation in forage moisture, mixing uniformity, and sampling procedures, as also reported by Karma et al. (1983). Despite these variations, WB inclusion effectively contributed to achieving the desired DM trend across treatments (Perim et al., 2014). Regarding the ash, both forage mixtures had ash contents of 7–10%DM, consistent with reported values for high-quality sorghum and pearl millet silages (Bishnoi et al., 1993). This range indicates adequate mineral content and falls within normal forage quality levels, with no evidence of soil contamination (Hoffman, 2005; Collin et al., 2017). It was evident in the present study that increasing WB levels improved DM, CP, and fibre fractions, resulting in the 40% DM treatments having the highest overall nutritive value.

4.5.6. Fermentative characteristics

Evaluating silage quality involves several fermentation parameters, with DM content playing a critical role in influencing fermentation dynamics and feed quality (Wróbel et al., 2025). Contrary to the study hypothesis that increasing DM would improve LA production and reduce pH, the present findings showed that lower DM silages promoted more intensive fermentation due to greater moisture availability and accentuated microbial activity. The decline in LA concentration with increasing DM suggests that higher DM levels restricted lactic acid bacterial fermentation by reducing moisture content and water activity within the silage. Under drier conditions, microbial activity and substrate availability are limited, which reduces the conversion of water-soluble carbohydrates into LA (Xu et al., 2024). In addition, WB may have further absorbed available moisture, contributing to reduced bacterial activity and lower LA production at 35-40% DM. These findings are supported by those of Khota et al. (2017) and Tabacco et al. (2011), who reported higher LA concentrations in lower DM sorghum silages compared to higher DM treatments. Similarly, Amer et al. (2012)

demonstrated that adequate moisture levels (68–73%) in sorghum and pearl millet silages are essential for optimal LA production. Despite these trends, all observed values remained within the range reported for well-preserved grass and cereal silages (McDonald et al., 1991; Weinberg and Muck, 1996; Zanine et al., 2016). The increasing pH observed in this study can be attributed to the reduction in LA levels, as LA is the primary driver of silage acidification (Kintl et al., 2023). Sorghum showed higher LA levels and lower pH values than pearl millet, which is likely due to its greater content of water-soluble carbohydrates that provide more substrate for LAB fermentation. In spite of these differences, all silages remained within the optimal fermentation pH range of 3.8–4.2 (McDonald et al., 1991). High DM silages also remained within the acceptable pH range of 4.3-4.70 (Weinberg and Muck, 1996; Franco and Rinne, 2023), indicating acceptable preservation quality across MW treatments.

These consistently high LAB counts were similarly reported by Basmacioğlu et al. (2002) and Filya. (2003) in maize and sorghum silages, indicating that strong LAB populations can be maintained across different DM levels. In addition, molasses supplementation has been shown to promote LAB growth and reduce spoilage activity (Liu et al., 2020; Luo et al., 2021), which is consistent with the low yeasts and moulds counts (<5 CFU/g) observed in the present study. All silages recorded temperatures below ambient during the five-day aerobic exposure, indicating good AS. This stability may be linked to the moderate AA production findings shown in the study, which has been reported to inhibit yeasts and moulds and improve AS (Danner et al., 2003). However, Mpanza and Mani. (2023) noted that a four to five-day exposure period may be insufficient to fully assess AS and recommended including microbial and pH measurements to better explain temperature changes. Despite this limitation, all silages were classified as excellent based on FS, although the higher values in the 35–40% DM treatments were mainly influenced by their higher DM content. Overall, the 25–30% DM silages showed the best fermentation quality, as indicated by lower pH, higher LA production, and stronger LAB activity.

4.5.7. *In sacco* DM degradability

Dry matter disappearance increased with rumen incubation time in both pearl millet and sorghum silages, showing continuous microbial breakdown of nutrients. The results support the hypothesis that silages with lower DM levels (25–30%) would have higher *in sacco* DM disappearance at 72 h. As shown in Figures 4.1 and 4.2, the 25–30% DM treatments had greater disappearance than the higher DM levels, likely due to improved fermentation under higher moisture conditions. Although limited studies exist on this specific comparison, the values

observed were higher than those reported by Costa et al. (2016) and Maria Silva Alencar et al. (2023) for sorghum silage at 72 hours of incubation. The higher DM disappearance in low DM silages can be explained by more extensive fermentation, which weakens plant cell walls and improves microbial access to fibre fractions in the rumen (Li et al., 2018; Piltz et al., 2022). In contrast, higher DM silages retain more rigid structural components due to restricted fermentation, which limits long-term fibre degradation even though they may contain more rapidly soluble nutrients at the start. In addition, the improved ruminal degradation rates may be related to the low ADL fractions (<3.5%) observed in the silages (Van Soest et al., 2020). Lignin limits fibre digestion by forming a barrier around plant cell wall carbohydrates, reducing microbial attachment and slowing enzymatic breakdown (Jancik et al., 2011; Fukushima et al., 2021).

Our findings showed that the fraction of DM lost during washing increased with increasing DM concentration, while the fraction that was slowly degraded decreased in both silage mixtures. Similar trends were observed for sorghum and pearl millet silages, although minor differences occurred in the slowly degradable fraction. The fraction lost during washing was higher than the values reported by Costa et al. (2016) for sorghum silage and Brunette et al. (2014) for pearl millet silage. This may be attributed to the physical characteristics of WB, which possesses a porous and finely textured structure with a large surface area that allows water to rapidly penetrate and remove soluble nutrients during the washing phase of the nylon bag procedure. In addition, the fine particle size of WB may have increased the physical loss of particles through the nylon bag pores (Osuji et al., 1993). Low-DM silages (25–30% DM) contained lower levels of WB and therefore had greater proportions of forage stem fibre and cell wall components, which contributed to a larger slowly degradable fraction. This explains why the 25% DM silages showed greater DM degradability after 72 h of incubation (Figure 4.1 and 4.2), as more material remained available for gradual microbial degradation over time.

Despite the reduction in the slowly degradable fraction, increasing WB inclusion up to 35% DM improved ED in both silages. The ED values observed in the present study (61–70%) indicate moderate-to-high ruminal nutrient availability and were higher than values reported in previous *in sacco* studies on sorghum, pearl millet, and grass silages (Valentin et al., 1999; Brunette et al., 2014; Costa et al., 2016). Although pearl millet silage showed slightly higherDM degradability and ED values than sorghum silage, WB inclusion and early harvesting at the vegetative stage likely contributed to the improved degradation characteristics observed in both silages.

4.5.8. Regression

The regression analysis demonstrated that TDM was a major predictor of chemical composition and *in sacco* DM degradability parameters, whereas its influence on fermentative characteristics varied between SW and MW silages. Increasing TDM increased CP and soluble nutrient fractions while reducing fibre components, indicating improved nutrient density and ruminal nutrient accessibility. These findings agree with De Boever et al. (1993) and Liu and Han. (2006), who reported that CP and fibre fractions are reliable indicators of silage nutritive value. In SW silage, NDF and ADF were strong predictors of TDM, whereas these relationships were weaker in MW silage. This may be attributed to the lower fibre concentrations and greater leaf-to-stem ratio of pearl millet compared to sorghum, which reduces the contribution of fibre fractions to TDM prediction (Cruz et al., 2025). The reduction in fibre fractions with increasing TDM decreased the slowly degradable fraction and shifted the silage from fibre-rich material toward a more rapidly degradable and nutritionally accessible feed.This was further supported by the increase in ED, which indicated improved ruminal nutrient availability as TDM increased. However, limited published information on ruminal degradation parameters of SW and MW silages restricted direct comparisons with previous studies. Regarding fermentation, increasing TDM slightly reduced fermentation intensity, suggesting that higher-DM silages underwent less extensive fermentation. Despite this, silage preservation remained acceptable across treatments. Overall, the results indicated that 30–35% DM provided the most favourable balance between nutrient preservation, fermentation quality, and ruminal degradability, even though 25% DM showed greater fermentative material and 40% DM exhibited greater rapidly available nutrients.

4.6. Conclusion and Recommendations

The study evaluated the effects of different target dry matter (TDM) levels, adjusted using wheat bran (WB), on the chemical composition, fermentative characteristics, aerobic stability, and in sacco dry matter degradability of sorghum and pearl millet silages. The Pearson Square method successfully achieved the targeted DM levels of 25, 30, 35, and 40%, demonstrating that WB can be used as a practical absorbent to adjust the DM content of high-moisture forage before ensiling. Increasing TDM resulted in clear changes in the chemical composition of both silages. Dry matter and crude protein increased with increasing TDM, while fibre fractions, particularly NDF and ADF, generally increased with greater inclusion of maize stover or dry material. The 40% DM silages generally had the highest DM and nutrient concentrations, indicating greater nutrient density at higher DM levels. The fermentation characteristics also responded to changes in TDM. Lower DM silages, particularly those prepared at 25%, generally showed more favourable fermentation characteristics, as reflected by greater lactic acid production and lower pH. This indicates that the higher moisture content at lower TDM levels provided more favourable

conditions for fermentation. In contrast, increasing TDM reduced the extent of fermentation, although all treatments produced acceptable fermentation characteristics and achieved good Fleig scores. These findings demonstrate that increasing DM does not necessarily result in improved fermentation and that the relationship between DM content and silage quality depends on the balance between moisture availability and fermentation conditions.

Target DM also affected ruminal dry matter disappearance and degradability. Dry matter disappearance at the different incubation periods generally increased with increasing TDM, while the 25% DM treatment showed the highest disappearance at 72 h. The rapidly degradable fraction, slowly degradable fraction, potential degradability, and effective degradability also differed among TDM levels. The 25% DM treatment generally showed greater ruminal degradability, whereas intermediate DM levels, particularly 30–35%, provided a more favourable balance between degradability, nutrient preservation, and fermentation quality. Although differences were observed between sorghum and pearl millet, the two forages generally showed similar responses to changes in TDM, indicating that DM adjustment using WB had consistent effects across both forage types. Aerobic stability was not significantly affected by TDM. None of the silages exceeded ambient temperature during the five-day observation period, indicating that all treatments remained relatively stable following exposure to air. However, the 25% DM silage generally maintained lower temperatures during the later stages of aerobic exposure, suggesting differences in post-opening temperature development among treatments.

The study was limited to the evaluation of DM disappearance and overall DM degradability and did not determine the ruminal degradation characteristics of individual nutrients such as crude protein and fibre fractions. Future studies should therefore evaluate CP and NDF degradability to provide a more comprehensive understanding of how DM adjustment using WB affects ruminal nutrient utilisation. Aerobic stability should also be monitored for periods longer than five days, with changes in temperature and DM losses recorded throughout the exposure period to provide a better assessment of storage stability after silo opening. In addition, feeding trials should be conducted using the 30–35% DM silages under South African production conditions to determine their effects on voluntary DM intake, palatability, nutrient utilisation, and animal performance, including average daily gain.

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CHAPTER 5: GENERAL DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

5.1. General discussion

Climate change and increasing feed shortages continue to threaten the sustainability of smallholder farming systems in South Africa due to declining rainfall, increasing climate variability, and reduced feed availability for livestock. Similar findings were reported by Lamega et al. (2021) and Zwane and Mthembu. (2017) in KZN, where declining rainfall and increasing climate stress reduced grazing availability for smallholder farmers. Under these conditions, practices that improve soil productivity while supporting livestock feeding are becoming increasingly important. This dissertation demonstrated that forage CCs can contribute to both objectives within CA systems. Assis et al. (2017) and Achray et al. (2023) also reported that sorghum and pearl millet can be used as forage CCs in CA systems and are suitable for silage production under climate-stressed conditions. Furthermore, Lee and Gambiza. (2022) reported that smallholder farmers' knowledge and perceptions are important for the successful implementation and adoption of these practices. By combining social and technical approaches, this study provided insight into both the practical challenges affecting adoption and the potential value of forage CCs as conserved livestock feed.

Chapter 3 findings suggest that smallholder farmers are generally aware of the benefits associated with CA and forage CCs. However, awareness and positive perceptions do not always lead to adoption. Similar findings were reported in KZN, where farmers had knowledge of CA practices, but adoption and implementation remained low (Ntshangase et al., 2018; Zaca et al., 2023). The low use of silage and forage preservation practices observed in this study suggests that practical and technical challenges are still major barriers within smallholder farming systems. Although farmers may understand the importance of forage conservation for livestock feeding, many still lack the technical skills, confidence, and resources needed to implement these practices successfully (Balehegn et al., 2022). These findings highlight the need for improved farmer training and extension support to encourage the successful integration of forage CCs into smallholder crop–livestock systems (Andersson and D'Souza, 2014).

In this dissertation, sorghum and pearl millet were used as forage CCs because of their high biomass yield and agronomic characteristics that can help mitigate climate change challenges. These crops are similar in many aspects and are increasingly being used as alternatives to maize silage in dairy production systems (Marsalis et al., 2010). In Chapter 4, both crops showed good nutritional value despite being grown under dryland conditions without fertiliser application and with minimal weed management, as also reported by Bhattarai et al. (2020). This suggests

that sorghum and pearl millet can produce good-quality forage under low-input conditions. The crops were also produced under no-tillage conditions, further demonstrating the potential effectiveness of CA systems. When grazed at the vegetative stage, sorghum and pearl millet provided adequate CP and fibre levels that support rumen function, animal growth, and livestock production in sheep and cattle (Legodimo et al., 2016). These characteristics make them suitable forage crops for improving livestock feed availability while also supporting soil conservation in smallholder farming systems in South Africa.

This chapter also demonstrated the importance of proper forage management during preservation. Achieving suitable DM levels before ensiling was necessary to maintain favourable fermentation and forage use characteristics (Borreani et al., 2018). Sorghum and pearl millet showed improved nutritional quality with increasing DM content, suggesting that WB inclusion not only adjusted DM levels but also improved the nutritive value of the silages. Similar findings were reported by Yi et al. (2023) and Gül. (2022), who observed increased CP and reduced fibre concentrations in caramba and amaranth silages. However, increasing DM content also resulted in higher pH and lower LA concentrations. Although these findings differed from those reported by Keskin and Aktanbaş .(2025), the Fleig score indicated that all silages were of excellent quality. All silages were therefore classified as well-preserved, with pH values below 4.5 and LA concentrations greater than 4%DM, which are considered desirable characteristics of good-quality grass silage (Kung et al., 2018; Piltz et al., 2022). The improved nutritive value and early harvesting stage also contributed to high DM disappearance and ED. These values were higher than those reported by Amer et al. (2010) for pearl millet silage. These findings emphasise that successful forage preservation depends not only on crop selection but also on appropriate harvesting and ensiling management practices. Therefore, technical knowledge is an important factor influencing the quality and utilisation of conserved forage in smallholder farming systems.

5.2. Conclusion and recommendations

Overall, the dissertation highlights that the successful use of forage CCs depends on both biological potential and farmer capacity. While the technical results confirmed that high-quality silage can be produced from sorghum and pearl millet, the survey findings showed that adoption may remain limited without adequate training and support. Therefore, improving farmer knowledge and strengthening extension services will be essential for increasing the use of forage CCs and forage preservation technologies in KZN. Integrating these practices into smallholder CA systems could improve feed security, support livestock productivity, and

improve the resilience of farming systems under changing climatic conditions. The study further recommends that similar research should be conducted in other climate-vulnerable provinces of South Africa to support the wider adoption of forage CCs and forage preservation practices among smallholder farmers.

This study had several limitations that should be considered when interpreting its findings. For the farmer survey, the study was conducted among 50 smallholder farmers who attended a Farmers' Day workshop in Bergville, KwaZulu-Natal, rather than the initially targeted 100 farmers. The participants were therefore not randomly selected from all smallholder farmers in the Okhahlamba Municipality, which limits the generalisability of the findings to the wider smallholder farming population in the municipality and other areas of KwaZulu-Natal. In addition, the cross-sectional nature of the survey provides a snapshot of farmers' knowledge, attitudes, and practices at the time of data collection and does not capture changes in these factors over time or following training and extension interventions. The technical experiments were also conducted under specific research-station conditions, with sorghum and pearl millet grown under dryland, no-tillage conditions and with minimal input. Consequently, the results may differ under other soil types, climatic conditions, management practices, and farmer production systems.

The silage experiments evaluated a limited range of target DM levels and used wheat bran specifically as the DM-adjusting absorbent; therefore, the findings may not be directly applicable to other DM-adjustment materials or forage combinations. Furthermore, the *in sacco* experiment assessed overall DM disappearance and degradability but did not determine the ruminal degradation of individual nutrients such as crude protein and fibre fractions. Although aerobic stability was assessed, the evaluation was limited to five days after silo opening and therefore did not determine longer-term stability or nutrient losses during prolonged exposure to air. Finally, no animal feeding trial was conducted to validate whether the differences observed in silage chemical composition, fermentation characteristics, and ruminal DM degradability translate into differences in voluntary feed intake, palatability, nutrient utilisation, or animal performance. Therefore, further research under diverse smallholder farming conditions, together with longer-term aerobic stability assessments, nutrient-specific ruminal degradation studies, and controlled animal feeding trials, is required to strengthen the practical application and broader relevance of these findings.

5.3. References

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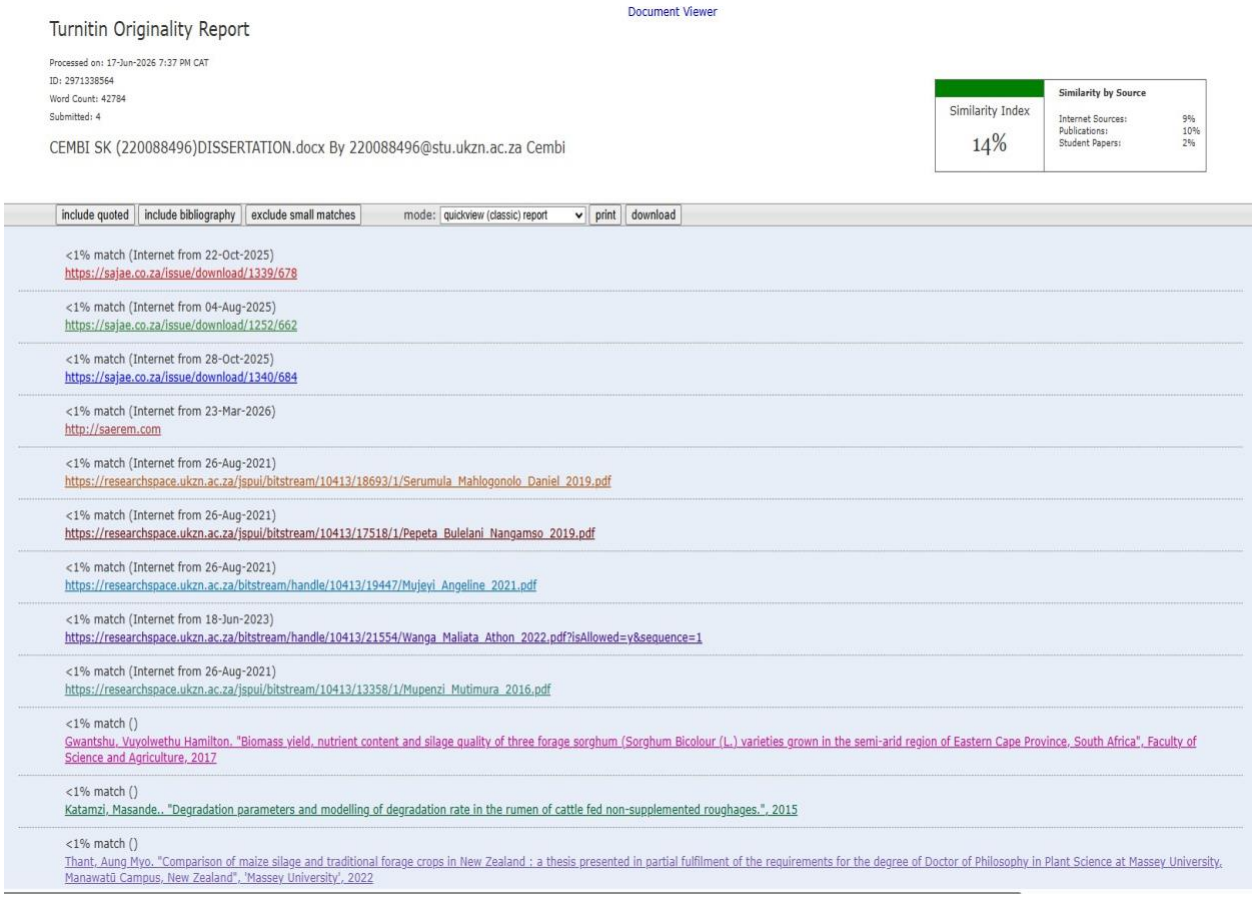
Appendix 1: **Similarity Report**



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Appendix 2: **Humanities and Social Science Research Ethics Committee Approval**

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

30 May 2025

Sikho Kamva Cembi (220088496)
School of Agri Earth & Env Sc
Pietermaritzburg Campus

Dear SK Cembi,

Protocol reference number: HSSREC/00008455/2025
Project title: Knowledge, attitudes, and practices of smallholder farmers on using and preserving forage cover crops in KwaZulu-Natal.
Degree: Masters

Approval Notification – Expedited Application

This letter serves to notify you that your application received on 28 March 2025 in connection with the above, was reviewed by the Humanities and Social Sciences Research Ethics Committee (HSSREC) and the protocol has been granted **FULL APPROVAL**.

Any alteration/s to the approved research protocol i.e. Questionnaire/Interview Schedule, Informed Consent Form, Title of the Project, Location of the Study, Research Approach and Methods must be reviewed and approved through the amendment/modification prior to its implementation. In case you have further queries, please quote the above reference number.

PLEASE NOTE: Research data should be securely stored in the discipline/department for a period of 5 years.

Incidents of adverse events and serious adverse events (AEs and SAEs) should be reported in writing to HSSREC, the study sponsors, and any regulatory authority (where appropriate), within 7 working days of the occurrence for local sites and 14 days for all other South African sites.

This approval is valid until 30 May 2026.
To ensure uninterrupted approval of this study beyond the approval expiry date, a progress report must be submitted to the Research Office on the appropriate form 2 - 3 months before the expiry date. A close-out report to be submitted when study is finished.

HSSREC is registered with the South African National Health Research Ethics Council (REC-040414-040).

Yours sincerely,

[redacted]

Doctor Shamila Naidoo (Senior Deputy Chair)

/nng

Appendix 3: **Animal Research Ethics Approval**

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

12 December 2024

New Application	
Protocol Reference number:	AREC/00007767/2024(00025948)
Project title:	**Suitability of a selected suite of Forages used as Cover Crops: Biomass, Chemical Composition, Digestibility, and Grazing Preferences**
Main Applicant and School:	Mr Simphiwe Samkelo Mthembu (224132084) Mr Sikho Kamva Cembi (220088496) School of Agriculture Earth & Environmental Sciences

Dear Mr Mthembu and Mr Cembi,

Regarding your revised application received on 11 November 2024, the UKZN Animal Research Ethics Committee (AREC) has accepted the documents submitted, and **FULL APPROVAL** for the protocol was granted at the quorate committee meeting of 04 December 2024.

About your approved protocol, please note:

1. All correspondence with the AREC about this protocol must be accompanied by the full reference number.
2. Any alterations to the approved protocol (e.g. title, location, methods, research team) must be reviewed and approved through an official amendment application, via the RIG system, prior to its implementation.
3. Any Veterinary and Para-Veterinary procedures must be conducted by a SAVC registered veterinarian/para-veterinarian or SAVC authorized person, and their details must be logged with the AREC if it changes during the approval period.
4. The AREC may actively monitor research, ask further questions, request additional information, or require modification on welfare grounds. If animal welfare is compromised in any way, the AREC may suspend the study/withdraw approval.
5. The research team must declare any adverse or serious adverse event(s) to the AREC via the RIG system as soon as possible but no later than **48 hours** after the event.
6. Research data should be securely stored in the discipline/school for a period of 5 years.
7. The approval is valid for one year from the date of issue. If the project is continuing, a renewal application must be submitted to the AREC at least **30 days before the expiration date if a timeline extension is applied for**, and **60-90 days ahead of the expiration date if amendments are included in the renewal application**. If work is completed at the end of the approval period, a close-out report must be submitted. Renewals/close-out reports are submitted via the RIG system.

I take this opportunity to wish you all the best with your study.

Yours faithfully

[redacted]

Dr Dalene Vosloo, PhD, Pr. Sci. Nat.
Chair: Animal Research Ethics Committee
/kr

cc Supervisor: Dr Ntuthuko Raphael Mkhize
cc Ukulinga Farm Manager: Mr Mangesh Deepa

The UKZN AREC is registered with the SA National Health Research Council (Reg. No. AREC-200111-006; Expires on 31/12/2027) in accordance with the National Health Act (No 61 of 2006) and conforms to the guidelines of the Department of Health (DOH2015) and SANS10386:2021. The UKZN AREC has an active US NIH OLAW assurance (Reg. No. F18-00371; Expires on 31/12/2027).

Animal Research Ethics Committee (AREC)
Ms Karen Reinertsen (Administrator)
Westville Campus, Govan Mbeki Building
Postal Address: Private Bag X54001, Durban 4000
Telephone: +27 (0) 31 260 8850 **Facsimile:** +27 (0) 31 260 4609 **Email:** animalethics@ukzn.ac.za
Website: http://research.ukzn.ac.za/Research-Ethics/Animal-Ethics.aspx

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