ONLINE JOURNAL OF ANIMAL AND FEED RESEARCH

BOOKLET

Volume 14, Issue 6, November 2024

Online J. Anim. Feed Res., 14 (6): 347-423; November 30, 2024

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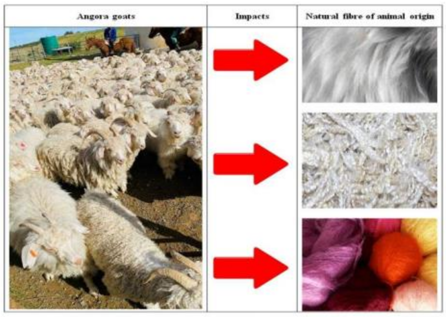
Review

Angora goats and mohair production in South Africa: a review

Mtenjwa B, Ikusika O, Mpendulo CT, and Gajana SC.



Mtenjwa B, Ikusika O, Mpendulo CT, and Gajana SC (2024). Angora goats and mohair production in South Africa: a review. Online J. Anim. Feed Res., 14(6): 347-357. DOI: https://dx.doi.org/10.51227/ojafr.2024.40

Online J. Anim. Feed Res., 14(6): 347-357, 2024; pii: S222877012400040-14
DOI: https://dx.doi.org/10.51227/ojafr.2024.40

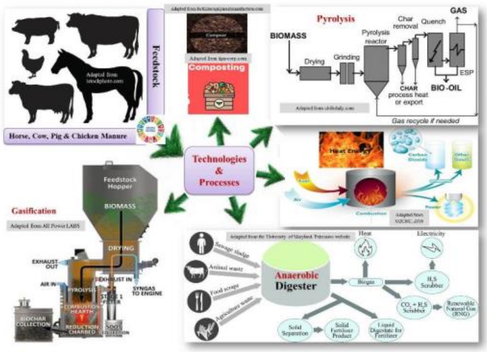
Abstract
This review summarises the properties, nutritional requirements, and production of a natural fibre called mohairs produced by Angora goats. One of the most valuable natural fibres is mohair, produced by Angora goats. Angora goats, also known as Ankara, have their origin in Asia Minor, but today, South Africa is home to over 23% of the global population of Angora goats, where it produces over 60% of the world's mohair, generating about 4 million kilograms annually. Eastern parts of South Africa account for over 72% of the total Angora goats in the country, hence producing the highest number of mohair. The physical properties of Angora mohair, such as lustre, non-inflammable, breathable, durability, elasticity, and resistance to soiling, make it unique and different from other natural fibres of other animal sources. These properties are affected by age, nutrition, and management. The role of nutrition is particularly crucial, as Angora goats require 3-4% of their body weight DM, whilst meat goats and lactating dairy goats require 3-5% and 4-6% of their body weight DM. When Angora goats were fed diets with 18% crude protein, mohair growth increased by about 33% annually compared to diets containing 12-15% CP, while feed intakes were the same. Also, copper, sulphur, molybdenum, and water intake affect the quality of mohairs. In conclusion, inadequate nutrition significantly impedes productivity and sustains financial losses. Hence, promoting sustainable farming practices is vital, investing in research to develop resilient grazing systems and drought-tolerant feed crops, and building capacity for small-scale farmers to improve mohar production and quality in South Africa.

Keywords: Angora goats, Mohair, Nutrition, Physical Properties, Processing.
[Full text-PDF]

Review

Value of horse manure for renewable energy production: anaerobic digestion, biogas generation, and contributions to sustainable development

Yildirim F and Açar Y.



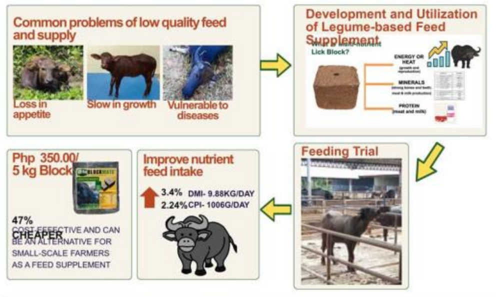
Online J. Anim. Feed Res., 14(6): 358-366, 2024; pii: S222877012400041-14
DOI: https://dx.doi.org/10.51227/ojafr.2024.41

Abstract
There are various methods like composting, combustion, gasification, pyrolysis, and anaerobic digestion to convert animal wastes that harm the environment into various bio-products. Horse manure containing lower ash and higher rate of lignin compositions can be potentially reuse as a valuable feedstock in anaerobic digestion method to produce nutrient-rich digestate (bio-fertilizer) clean and cheap biofuels, and bio-energy to replace the cost effective fossil fuels which not only make climate change but harms our health by generating toxic emissions and contamination of soil and water. Therefore, converting bio wastes into useful green resources especially using anaerobic co-digestion is necessary to reduce their adverse environmental impact and can contributes towards the achievement of sustainable development goals (SDGs) 2, 3, 5, 6, 7, 9, 12, 13 and 15. As can be seen today, various animal manure types have begun to be used in different situations for their green benefits. This review aimed to provide an overview of the transformation of horse manure into compost, biogas in terms of its preferability as a renewable energy source or a value-added product that mitigate the environmental problems and contribute to the SDGs specially 7, 9, 12, and 13. The potential of animal manure to produce biomaterials, organic acids, biofuels and bioenergy is clear. Therefore, bioprocesses or biorefineries using this biomass as raw material may be promising in the near future in the context of bioeconomy, may help increase renewable energy production and may become capable of promoting innovation that boosts the value of livestock-derived organic fertilizers. There are still needs to extend the development of technologies for converting on-site bio waste resources to useful forms, exploring new and safe biological conversion pathways and bio waste processing methods.
Keywords: Anerobic digestion, Bioenergy, Biogas production, Circular economy, Horse manure, Sustainable development goal
[Full text-PDF]

Effect of *Leucaena leucocephala*-based multi-nutrient lick blocks on the feed intake and growth performance of buffaloes

Llantada PLT, Castillo CI, Uy-De Guia MRD, Amido RD, Grospe VKA, Lavarias PJF, Gonzales EG, and Del Barrio AN.

Online J. Anim. Feed Res., 14(6): 367-375, 2024; pii: S222877012400042-14
DOI: https://dx.doi.org/10.51227/ojafr.2024.42



Llantada PLT, Castillo CI, Uy-De Guia MRD, Amido RD, Grospe VKA, Lavarias PJF, Gonzales EG, and Del Barrio AN. (2024). **Effect of *Leucaena leucocephala*-based multi-nutrient lick blocks on the feed intake and growth performance of buffaloes.** *Online J. Anim. Feed Res.*, 14(6): 367-375. DOI: https://dx.doi.org/10.51227/ojafr.2024.42

Abstract
Ruminant production in the Philippines is often hindered by limited access to high-quality feed, leading to suboptimal animal growth and productivity. To address these challenges, this study evaluated the locally made multi-nutrient lick block (MNLB) containing ipil-ipil (*Leucaena leucocephala*), a legume known for its nutritional value. A 30-day palatability test was conducted to assess the acceptability of the developed MNLB, using 5 male buffaloes with an average weight of 245 ± 5 kg. Additionally, a 90-day- feeding trial was carried out using 15 growing buffaloes (average age: 13.5 months, weight: 243.83 ± 5 kg), randomly assigned to three treatment groups: T1 or control (non-supplemented), T2 or commercial mineral block, and T3 or MNLB, to evaluate the growth performance, nutrient utilization, and economic viability of the legume-based MNLB. Results demonstrated that the MNLB was palatable to the animals, with an average daily consumption of 192.10 g/animal/day, providing adequate nutritional value to meet the buffaloes' daily requirements. Moreover, MNLB supplementation significantly enhanced dry matter (DM) and crude protein (CP) intake compared to control and commercial mineral block groups. The average DM intake for T3 was 9.88 kg, and the average CP intake was 1006 g, compared to T1 (9.56 kg DM intake and 983 g CP intake) and T2 (9.59 kg DM intake and 984 g CP intake). While the commercial mineral block showed positive results, the MNLB outperformed in terms of nutritional value. In terms of cost-effectiveness, the MNLB can serve as an alternative feed supplement for small- scale farmers, offering a lower- cost option compared to commercial feed supplements. The study concluded that the MNLB has potential as a practical solution to address the nutritional challenges faced by ruminant producers in resource-limited environments. By providing a nutrient-rich and safe feed supplement, the MNLB can contribute to improved animal health, productivity, and overall farm profitability.

Keywords: Legume, *Leucaena leucocephala*, Multi-nutrient supplementation, Ruminants, Urea based feed supplements, Water buffalo.

[Full text-PDF]

Research Paper

Occurrence and levels of aflatoxin contamination in poultry feed ingredients and layer mash in farms and feed mills in Ghana

Nkansah B, Adjorlolo L, Appiah-Opong R and Obese F.

Online J. Anim. Feed Res., 14(6): 376-382, 2024; pii: S222877012400043-14
DOI: https://dx.doi.org/10.51227/ojafr.2024.43

Nkansah B, Adjorlolo L, Appiah-Opong R and Obese F (2024). **Occurrence and levels of aflatoxin contamination in poultry feed ingredients and layer mash in farms and feed mills in Ghana.** *Online J. Anim. Feed Res.*, 14(6): 376-382. DOI: https://dx.doi.org/10.51227/ojafr.2024.43

Abstract
The study assessed the incidence and contamination levels of total aflatoxins (TAF) and aflatoxin B1 (AFB1) in feed ingredients and compound layer mash from six regions in Ghana. Thirty-five facilities comprising commercial poultry farms and feed mills were used in the study. There was 100% incidence of TAF and AFB1 in the samples of layer mash and feed ingredients (maize, soybean meal and wheat bran). The TAF of layer mash, maize and soybean meal (55.2, 54.0 and 47.6 µgkg-1, respectively) were significantly higher ($P < 0.05$) than TAF of wheat bran (28.6 µgkg-1). Most of the layer mash, soybean meal and wheat bran samples had TAF concentrations exceeding the US Food and Drug Administration (USFDA) maximum limit of 20 µgkg-1. Mean TAF concentrations in layer mash and maize samples were strongly and positively correlated ($r = 0.50$; $P < 0.018$). Layer mash, maize and soybean meal had significantly higher ($P< 0.05$) AFB1 concentrations (33.0, 35.1, 26.5 µgkg-1, respectively) when compared to wheat bran (13.8 µgkg-1). Most layer mash and maize samples exceeded the European Commission's maximum limits of 20 and 50 µgkg-1 respectively for AFB1. Mean AFB1 concentrations in layer mash and maize samples were strongly and positively correlated ($r = 0.54$; $P = 0.01$). High aflatoxins contamination of poultry feed is a persistent problem in Ghana. The use of toxin-binders, education of poultry farmers and feed millers on the implication of aflatoxins contamination in poultry feeds and the enforcement of regulation by Ghana's food and drugs authority is recommended.

Keywords: Aflatoxin B1, Compound feed, Maize, Soybean meal, Total aflatoxin, Wheat bran.

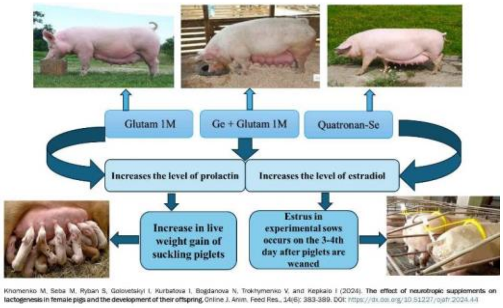
[Full text-PDF]

Research Paper

The effect of neurotropic supplements on lactogenesis in female pigs and the development of their offspring

Khomenko M, Seba M, Ruban S, Holovetskyi I, Kurbatova I, Bogdanova N, Trokhymenko V, and Kepkalo I.

Online J. Anim. Feed Res., 14(6): 383-389, 2024; pii: S222877012400044-14
DOI: https://dx.doi.org/10.51227/ojafr.2024.44



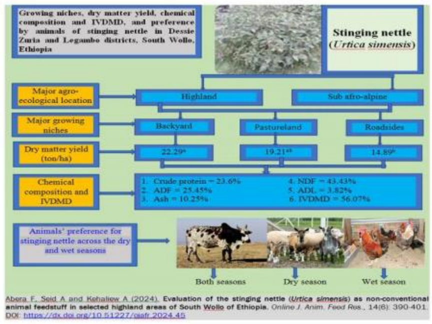
Abstract
The aim of study was to evaluate the influence of biologically active additives on the hormonal status of lactating sows and the absolute growth of suckling piglets. Glutam 1M, nanoaquachelates of germanium (NPs-Ge) and Quatronan-Se (Cu-NPs, Se-NPs, Cr-NPs, Ge-NPs, Mn-NPs) have been administered orally (lat. per os) for animals in different percentage doses and schemes. Five animals groups have been formed by the method of analogues: control (20 ml physiological solution) and four experimental (group M: 18 mg/kg Glutam 1M; group G18: 5 µg/kg Ge-NP + 18 mg/kg Glutam 1M; group G9: 5 µg/kg Ge-NP + 9 mg/kg Glutam 1M; and group Q: Quatronan-Se (0.02 ml/kg) administered for 14 days). Results showed positive effects of the use of supplements on prolactin secretion. Administration of 5 mg/kg live weight NPs-Ge for sows G18 and G9 for 4 days before the farrowing increased the level of prolactin in the blood serum. On farrowing day, the hormone level in these groups was 14.6 ng/ml (G18) and 13.42 ng/ml (G9), while in K and M groups it was 12.02 and 9.94 ng/ml, respectively. On the day of weaning, the highest prolactin content has been observed in the G18 group as 14.9 ng/ml. Also, suckling piglets from this group have had the highest growth during the studied period. During the entire suckling period, the growth of piglets in the G18 group was 3.65 kg and was higher compared to the K (2.94 kg), M (3.58 kg), G9 (3.31 kg) and Q (3.44 kg) groups. It's suggested that the scheme introduction of Germanium (5 mg/kg) additives, 4 days before and 10 days after farrowing + Glutam 1M (18 mg/kg) 3 days after farrowing is the most effective (group G18) in means of growth performance.

Keywords: Biologically active drugs, Glutam 1M, Prolactin, Hormone, Sows.

[Full text-PDF]

Research Paper

Evaluation of the stinging nettle (*Urtica simensis*) as non-conventional animal feedstuff in selected highland areas of South Wollo of Ethiopia



Abera F, Seid A and Kehaliew A.

Online J. Anim. Feed Res., 14(6): 390-401, 2024; pii: S222877012400045-14
DOI: https://dx.doi.org/10.51227/ojafr.2024.45

Abstract
This study assessed the use of stinging nettle as animal feed and evaluated its biomass yield and nutritional quality in Dessie Zuria and Legambo districts, Ethiopia. Data were collected from 384 randomly selected respondents and growing niches across 8 kebeles. Findings indicated a demand for 1935 tons of dry matter (DM), while available feed resources contributed only 915.41 tons of DM, highlighting a significant feed shortage. Stinging nettle, which remains vegetative in both wet and dry seasons, was identified as a potential supplementary feed. Over 77.86% of respondents reported that ruminants consume the leaves and stems, while 13.02% noted that chickens rarely use the leaves, and equines never consume any part of the plant. Cattle preferred stinging nettle in both seasons, but small ruminants showed preference only during the dry season, and chickens showed the least preference in the wet season. Most households (83.6-89.3%) treated the plant by wilting it for 2-6 hours, while others (4.40-10.16%) dry it, and the rest (4.69-9.89%) mix it with other feeds to minimize its stinging nature. Common growing niches for stinging nettle include backyards, pastureland, and roadsides, with the first producing a higher biomass yield of 22.29 tons/ha ($P<0.02$) than the roadsides (14.89 tons/ha), and the pastureland yielded intermediate biomass (19.21 tons/ha). Stinging nettle from pastureland niche had higher crude protein (CP, 25.26%) and in vitro dry matter digestibility (60.90%, $P<0.001$). The ash (7.90%), neutral detergent fiber (NDF, 39.74%), and acid detergent fiber (24.16%) contents were lower for samples taken from the pastureland niche. In conclusion, stinging nettle is suitable for supplementation due to its favorable nutritional qualities. Further studies, such as animal feeding trials and investigations into anti-nutritional factors, are needed for more detailed information on the use of the stinging nettle plant as an animal feedstuff.
Keywords: Agro-ecology, Biomass yield, Growing niche, Nutritional quality, Stinging nettle, Wilting.

[Full text-PDF]

Research Paper

Growth performance, haematological and serum biochemical indices of weaner pigs fed *Carica papaya* seed and leaf meal as dietary supplement

Nkwocha G, Ekenyem B, Anukam K, Adeolu A, Nwose R, Ahaotu E, Anosike F and Callistus M.

Online J. Anim. Feed Res., 14(6): 402-409, 2024; pii: S222877012400046-14
DOI: https://dx.doi.org/10.51227/ojafr.2024.46

Abstract
A 28-day feeding trial was carried out to evaluate the performance characteristics and hemato-biochemical parameters of weaner pigs fed graded levels of *Carica papaya* seed and leaf meal supplementation. A total of 36 cross-bred (Large white x Landrace) strains of weaner pigs of average initial weight of 8.86+0.10 kg were used for the study. Four treatment diets designated T1, T2, T3 and T4 replicated 3 times in a completely randomized design (CRD) were formulated to include the *Carica papaya* leaf and seed meal at 0, 1, 2 and 3% levels, respectively. Data were collected on daily feed intake (DFI), daily weight gain (DWG), feed conversion ratio (FCR), cost benefit analysis, hematological indices and serum biochemistry. The body weight gain of the weaner pigs was highest in T4 (3%) *Carica papaya* seed and leaf meal mix (CSLM) supplementation with the value of 353 g while the least value of 228 g was recorded by T2 which significantly differed (P<0.05) from the control group. Hemato-biochemical parameters showed significant differences (P<0.05) between treatments, indicating positive influence of CSLM on the investigated parameters. The blood urea nitrogen and creatinine, alkaline phosphatase, alanine aminotransferase and aspartate aminotransferase concentration increased as the dietary levels of CLSM increased in the diets. Based on the above findings, it is recommended that CLSM can be included at a level of 3% for optimum performance, hemato-biochemical stability and profit maximization.

Keywords: *Carica papaya*, Dietary supplementation, Haematology, Serum biochemistry, Weaner pigs, biochemistry, supplement

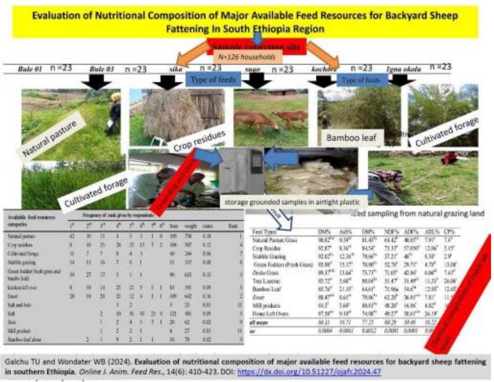
[Full text-PDF]

Research Paper

Evaluation of nutritional composition of major available feed resources for backyard sheep fattening in southern Ethiopia

Galchu TU and Wondater WB.

Online J. Anim. Feed Res., 14(6): 410-423, 2024; pii: S222877012400047-14
DOI: https://dx.doi.org/10.51227/ojafr.2024.47



Abstract
The study was conducted in the Bule district of Gedeo zone in southern Ethiopia to assess the available feed resources for sheep fattening and their chemical composition in backyard sheep fattening operations. A reconnaissance study identified the main sources of feed, followed by a multi-stage sampling procedure to select kebeles and households involved in sheep fattening. Six kebeles were specifically selected based on sheep population, experienced fatteners and accessibility. A total of 126 households were randomly selected for the study. The main food sources included natural pasture, stubble pasture, forage, bamboo leaves, enset (Ensete ventricosum), crop residues, desho grass (Pennisetum pedicellatum), tree alfalfa, kitchen residues and mill products. Feed samples were taken for laboratory analysis, and the average values for dry matter (88.3%), ash (10.71%), organic matter (77.25%), crude protein (11.21%), neutral detergent fibers (60.2%), and acidic detergent fibers yielded (39.42%) and acidic detergent lignin (10.22%). Tree alfalfa (26.06%), mill products (16.11%), green fodder (13.88%), and bamboo leaf (12.45%) had the highest crude protein content. Bamboo leaves (21.15%), forage (15.17%), and stubble pasture (12.36%) provided suitable ash levels for mineral intake. However, concerns arise regarding fiber content in crop residues, grazing practices, and bamboo leaf quality, affecting feed intake, digestibility, and absorption. Promising feeds such as alfalfa, mill products, and forage boost high protein content, but better fiber management is essential for feeds with excessive fiber. Tailored feeding strategies, enhanced feed conversion, and thorough training for sheep fatteners are pivotal to address these challenges.

Keywords: Bamboo leaf, Desho grass, Ensete ventricosum, Fattening, Feed Resource, Sheep.

[Full text-PDF]

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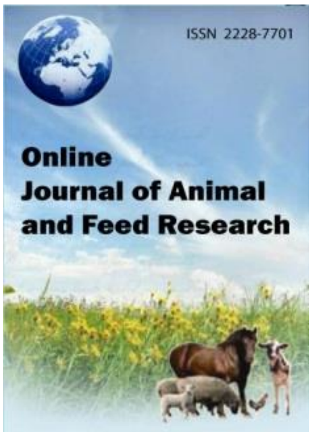

ISSN: 2228-7701

Frequency: Bimonthly

Current Issue: 2024, Vol: 14, No: 6 (November 30)

DOI Prefix: 10.51227

Publisher: SCIENCELINE

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2024 SCIENCELINE

Online Journal of Animal and Feed Research

Volume 14, Issue 6: 347-357; November 30, 2024

ISSN 2228-7701

DOI: https://dx.doi.org/10.51227/ojafr.2024.40

ANGORA GOATS AND MOHAIR PRODUCTION IN SOUTH AFRICA: A REVIEW

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Supporting Information

ABSTRACT: This review summarises the properties, nutritional requirements, and production of a natural fibre called mohairs produced by Angora goats. One of the most valuable natural fibres is mohair, produced by Angora goats. Angora goats, also known as Ankara, have their origin in Asia Minor, but today, South Africa is home to over 23% of the global population of Angora goats, where it produces over 60% of the world's mohair, generating about 4 million kilograms annually. Eastern parts of South Africa account for over 72% of the total Angora goats in the country, hence producing the highest number of mohair. The physical properties of Angora mohair, such as lustre, non-inflammable, breathable, durability, elasticity, and resistance to soiling, make it unique and different from other natural fibres of other animal sources. These properties are affected by age, nutrition, and management. The role of nutrition is particularly crucial, as Angora goats require 3-4% of their body weight DM, whilst meat goats and lactating dairy goats require 3-5% and 4-6% of their body weight DM. When Angora goats were fed diets with 18% crude protein, mohair growth increased by about 33% annually compared to diets containing 12-15% CP, while feed intakes were the same. Also, copper, sulphur, molybdenum, and water intake affect the quality of mohairs. In conclusion, inadequate nutrition significantly impedes productivity and sustains financial losses. Hence, promoting sustainable farming practices is vital, investing in research to develop resilient grazing systems and drought-tolerant feed crops, and building capacity for small-scale farmers to improve mohar production and quality in South Africa.

REVIEW
PII: S222877012400040-14
Received: February 19, 2024
Revised: October 29, 2024
Accepted: November 01, 2024

Keywords: Angora goats, Mohair, Nutrition, Physical Properties, Processing.

INTRODUCTION

The global goat population is around 1.2 billion, with Southern Africa having an estimated 35 million goats (Monau et al., 2020; Mthi et al. 2024). According to Mthi et al. (2024), South Africa is home to approximately 5.2 million goats, where they were domesticated. National Institute of Food and Agriculture (2022) stated that different goat breed types include Kalahari Red, Savanna, Nguni, Xhosa Lob-ear, Northern Cape Speckled, Kaokoland, Boer, Skilder goat, Saanen, British Alpine, Toggenburg, Non-descript, and Angora goats are found in South Africa. Nguluma et al. (2018) and Mataveia et al. (2021) reported that angora goats account for approximately 23% of the goat population in South Africa. Additionally, Turkey, Iran, China, the United States, and Australia are home to large populations of Angora goats.

Capra hircus ancryrensis, also known as Angora goats, originated from the district of Angora in Asia Minor and became established in Turkey, where they were called Ankara (Zehra and Çek, 2021). It produces the lustrous fibre known as mohair. It is widespread in many world countries, and many breeds have derived from it, including the Indian Mohair and the Soviet Mohair (Porter et al., 2016). In South Africa, Angora goats thrive in Eastern Cape Province and Karoo regions (Mpyana, 2019), which has become a significant economic contributor to goat production through mohair (Mataveia et al., 2021). Angora goat is a unique breed farmed for mohair, meat, milk, leather, and other social needs. Daskiran et al. (2018) reported that Angora goats are dual-purpose animals with small body frames and adapt quickly to poor environmental conditions compared to other breeds of goats.

Mpyana (2019) and Marius et al. (2021) asserted that South Africa produces approximately 60% of the world's mohair, generating about 4 million kilograms annually. Mohair is a gleaming fibre that is white, extraordinarily soft, and silky, possessing a natural brightness and shine. It is a breathable, moisture-wicking, strong, durable natural fibre resistant to soiling and wrinkling (Abdollahzadeh and Yousefi, 2014; Gericke et al., 2022). Mohair is flame and static-resistant; it does not encourage the growth of bacteria, making it an excellent choice for allergy sufferers compared to other fibres such as cotton and wool (Gericke et al., 2022; Shashikant and Singh, 2024). Gericke et al. (2022) stated that Mohair is smoother, shinier, more durable, and wrinkling-resistant than wool. Due to its characteristics, mohair is suitable for use in the textile sector, especially for making clothes, sweaters, drapes, socks, scarves, and other items.

Citation: Mtenjwa B, Ikusika O, Mpendulo CT, and Gajana SC (2024). Angora goats and mohair production in South Africa: a review. *Online J. Anim. Feed Res.*, 14(6): 347-357. DOI: https://dx.doi.org/10.51227/ojafr.2024.40

Angora breed of goats has different nutritional requirements in different physiological stages (Zehra and Çek, 2021). About 14 to 16% of crude protein content in the Angora goat diet is essential for growth and mohair production. Froghi and Hosaini (2012) and Zehra and Çek (2021) reported that inadequate protein results in coarse and brittle Angora fleece, which can lead to a lower quality. Similarly, when Angora goats do not receive enough energy from their diet, they might experience poor growth performance, and fleece may be affected. Insufficient calcium and phosphorus minerals in their diets lead to skeletal problems and reduced fertility (Froghi and Hosaini, 2012; Kumar, 2023).

MOHAIR PRODUCTION

Although South Africa is the largest producer of mohair globally, the country witnessed a decline in the Angora goat population between 2003 and 2015 (Mpyana, 2019), leading to a drop in mohair production from 12.2 to 2.23 million kilograms annually. This decline may be due to decreased profits from fluctuating costs of feed ingredients. Additional obstacles could involve a lack of functional local markets, insufficient financial support from the government, and inadequate infrastructure within the market (Mpyana, 2019; Marius et al., 2021). However, because of the recent increase in the demand for mohair in the global market, there has been an increase in the population of Angora goats in South Africa, leading to a 25% increase in mohair production (Gericke et al., 2022). Figure 1 shows the global mohair production by countries as reported by the South Africa Mohair Growers Association in September 2022 cited from Mohair South Affrica (2022).

Mohair quality

The age of Angora goats affects the quality of Mohair produced (Zehra and Cek, 2021), while Mpyana (2019) observed that as the Angora advanced in age, the quality of mohair produced declined, especially the fibre thickness, hardness, and lustiness. According to Zehra and Çek (2021), goats aged 3 to 5 years produce more low-quality mohair, whereas goats aged 1 to 2 years produce less low-quality Mohair. Zehra and Çek (2021) and Gericke et al. (2022) also reported that males produce more mohair than females. Mohair yields and quality depend largely on genetics composition, goat management, and, most importantly, nutritional factors (Zehra and Çek, 2021). Good management practice and balanced nutrition are essential for mohair growth and high-quality yields.

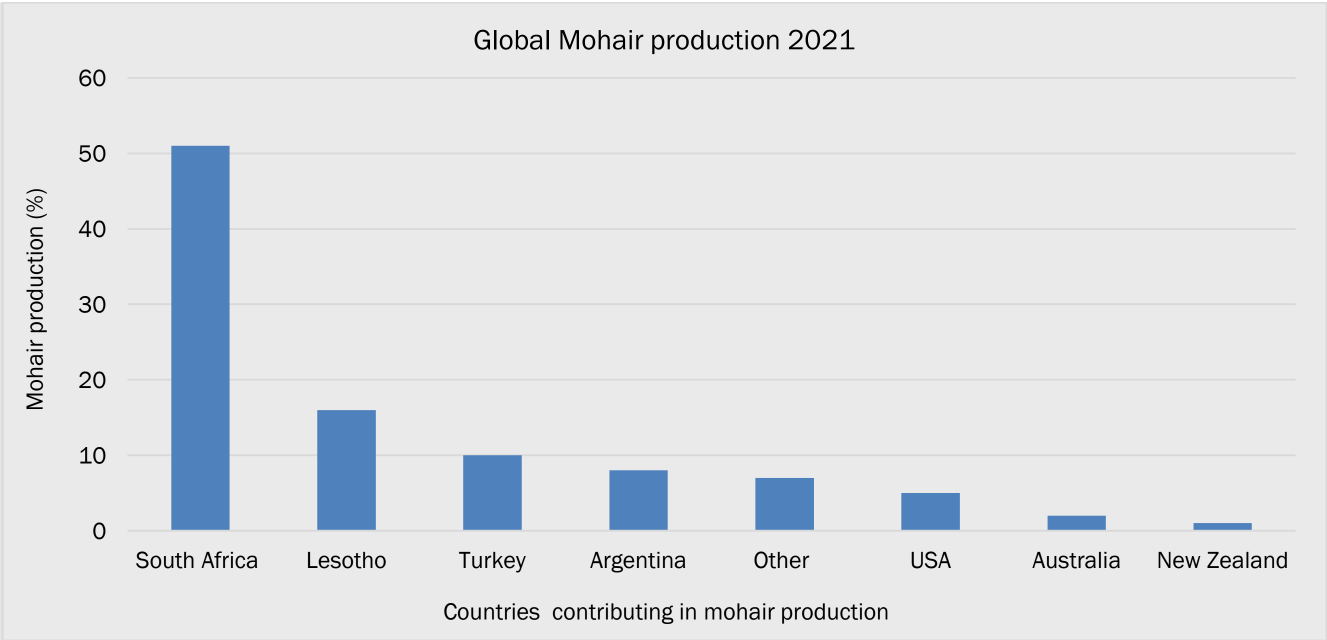

Figure 1. A bar graph showing global mohair production in 2021

Impact of mohair production on rural economy in South Africa

Mohair production in South Africa significantly contributes to rural income, particularly in the Eastern Cape Province, which is the heart of the global mohair industry (Mpyana, 2019). Over 800 farmers (communal and commercial) and their dependents, numbering around 30,000 people, benefit directly or indirectly from the mohair value chain (SA Farmers' Magazine, 2022). Hence, support rural livelihoods through farming, processing, and export-related activities.

Efforts to enhance income and participation among rural farmers include initiatives like the Mohair Empowerment Trust (MET), which collaborates with government entities to support emerging black farmers (SA Farmers' Magazine, 2023). This Trust allocated funds for farm infrastructure, Angora goats, and shearing equipment to improve productivity and market access for these rural farmers. Thereby integrating historically disadvantaged individuals into the commercial sector and promoting sustainable income generation (Marius et al., 2021). Similarly, in 2023, the Eastern Cape Development Corporation (ECDC) provided over R1 million to support emerging mohair farmers, which highlights the financial backing given to rural initiatives to uplift income levels. This funding helps farmers adopt best practices in animal care and fibre production, which, in turn, increases the marketability and profitability of their mohair (SA Farmers' Magazine, 2023)

Nutrition and feeding requirements of Angora goats

According to Froghi and Hosaini (2012), goats differ in breeds, which necessitates diverse dietary needs. Angora type of goats requires specific quantities of protein, energy, vitamins, and mineral elements to satisfy their nutritional requirements. These depend on the age, sex, breeding condition, and wellness state of the goat (Zehra and Çek, 2021). Illustratively, Mcgregor (2018) communicated that young goats in the growth phase demand additional protein compared to those matured ones; furthermore, pregnant or lactating goats require more energy and calcium. Hay or pasture is the most important source of nutrition for mohair goats (Zehra and Çek, 2021). In South Africa, most Angora strives better with Leucine hay than other types of hay (Mpyana, 2019; Nipane et al., 2023). Mamoon (2008) and Kumar (2023) reported that providing Angora goats with dry matter (DM) ranging from 3-4% of their body weight through pasture or hay is beneficial to their growth and overall productivity. It is suggested that the hay is of the highest quality as it should be free from contaminations such as moulds and dust and offer the right proportion of protein, energy, and fibre. Hay such as Alfafa, grass hay, oats hay, leucine and legume hay are good for mohair production (Mamoon, 2008; Nipane et al., 2023). The literature asserts that small ruminants may be best offered twice daily, once in the morning and another in the afternoon (Ikusika et al., 2019; Khaskheli et al., 2020). Inadequate nutrition is a crucial factor impeding productivity and sustaining financial losses most of the time. Nipane et al. (2023) delineated five critical elements in goat nutrition: water, proteins, minerals, vitamins, and energy (obtainable from fats and carbohydrates).

Dry matter

Dry matter is that part of a feed that does not contain liquid form or moisture (Cériac et al., 2019). More than that, the whole feed solids are composed of fibre, protein, and minerals. Rahman et al. (2020) noted that the dry matter content of feeds may be determined by subtracting the moisture value from the total weight of feed offered. DMI is measured by the portion of dry matter consumed by goats in a day (Rahman et al., 2020). Important determinants of a goat's dry matter requirements include age, weight, breed, and production environment. Nipane et al. (2023) noted that young and lactating goats have significantly higher DMI than other goats. Inadequate dry matter intake leads to poor performance and productivity (Zhang et al., 2011; Cériac et al., 2019). Inadequate Dry matter Intake may result in goats consuming fewer nutrients, negatively impacting mohair growth.

Angora goats require 3-4% of their body weight DM, whilst meat goats and lactating dairy goats require 3-5% and 4-6% of their body weight DM (Mamoon, 2008; Nipane et al., 2023). Too much dry matter, Copper, and Molybedum may result in poor mohair production and digestibility difficulties in goats (Zhang et al., 2011). Goats are estimated to consume DM ranging from 12-35% in forages and 86-92% in hay (Mamoon, 2008). Dry matter is directly proportional to protein and inversely proportional to the energy in a diet, which means that energy, milk yield, and body weight gains may estimate the DMI of goats (Nipane et al., 2023).

Energy

Meeting the energy needs of angora goats is essential as goats that are not adequately nourished show reduced growth and mohair output. Weather, activity level, pregnancy, and disease impact Angora goats' energy requirements (Hart, 2004; Froghi and Hosaini, 2012). According to Atiba et al. (2020), goats and sheep have nutritional needs distinct from those of larger animals such as cows and horses. Small ruminant animals are hindgut fermenters, indicating that they break down food in the cecum, a sizable pouch close to the start of the large intestine. A high-fiber diet with moderate levels of protein and fat is essential for small livestock (Nipane et al., 2023). A higher-quality diet is required for fat deposition because Angora stores a small amount of body fat (Froghi and Hosaini, 2012). Energy supplements may contain oats and barley. However, Mcgregor (2018) concluded that Angora goats fed hay, corn, and barley have a significant body weight gain but little change in mohair production. Australian results anticipated that when an Angora goat is fed energy and protein from 5 months old, it tends to gain about 3.6kg body weight, increased mohair production by about 20%, and mohair diameter by <1um (McGregor, 1998). Kids produced the most valuable and quality fibre. However, mohair diameter increases as the goat ages (McGregor, 1998).

Angora goats have higher energy requirements than other goat breeds (Mcgregor, 2018). This is because they grow more quickly than other breeds and produce mohair. Weight, age, and reproductive status influence the goat's required energy range. McGregor (2020) claimed that the energy requirements of young goats that are still growing and gaining weight are different from the needs of adult goats who are neither lactating nor about to give birth. Milking goats, the highest stage in the list, require more energy than any other stage to help maintain body condition and milk production.

When lactating, goats need approximately 30% more energy than non-lactating goats (Oliveira et al., 2021; Nipane et al., 2023). According to Gelayenew et al. (2016), angora goats are more vulnerable to nutritional stress because they store less body fat.

Protein

Angora goats with high mohair yields have higher protein requirements than other goat breeds (Froghi and Hosaini, 2012). Protein is necessary in the Angora goat's diet for mohair's growth, maintenance, and production (Nipane et al., 2023). If goats do not have sufficient protein, they can become weak and ill, and in extreme situations, they may die. Angora goats need between 14 and 16% protein in their dry matter consumption (Emeruwa, 2016). Environmental conditions, activity level, pregnancy, and disease impact Angora goats' protein requirements.

Protein is typically obtained from the hay or forage that the goats consume. Hay, legumes, alfalfa, barley, corn, oats, soya meal, peas, canola, and cottonseed meal are typical protein supplements that fulfil goats' protein needs (Mamoon, 2008; Chisoro et al., 2023; Nipane et al., 2023). According to Huston et al. (1971), cited from McGregor (1998) findings, when Angora goats were fed diets with 18% crude protein, mohair growth increased by about 33% annually compared to when fed diets containing 12-15% CP while feed intakes were the same. However, in other countries such as Australia, it is allowed only to feed Angora goats wheat with 12 to 14% CP (McGregor et al., 2012).

Determining protein quality relies on its amino acid profile and is crucial for achieving optimal productivity (Nipane et al., 2023). According to Froghi and Hosaini (2012) and Nipane et al. (2023), proteins' prime building block units generally comprise amino acids crucial for hair growth and protein synthesis. In an article published in 2018, the researcher Hobson (2018) highlighted how essential amino acids such as methionine and lysine are vital for goats' well-being. The potential for increasing mohair production by up to 20% exists through utilising rumen bypass proteins (Froghi and Hosaini, 2012). The diet needs to have a balance of protein and energy levels. The protein-to-energy ratio in goats is influenced by the type of hay, quantity of protein supplement, and level of exercise. Overall, if goats obtain enough amino acids, they can digest protein properly, leading to better productivity.

Vitamins

There is a lack of literature regarding this element related to Angora goats; however, like any other livestock, the well-being of the Angora goat influences mohair growth. Each vitamin plays a unique role in goats' performance and mohair production. Four vitamins are known as fat-soluble vitamins, i.e., A, D, E, and K, and water-soluble vitamins such as C and B complex are incredibly beneficial to health and fibre production (Froghi and Hosaini, 2012). Angora goats require vitamins for various purposes; all vitamins, with their unique purposes, contribute to quality mohair yields.

Skin, eye health, reproduction, and the coat of goats seem to benefit immensely from the favourable role that Vitamin A and Vitamin D play in research by Nipane et al. (2023). Also, conditions favourable for bone growth and mineral absorption are brought about by vitamin D supplementation. Vitamins can assist in ensuring that the goat is healthy, which might translate into better fiber production, especially mohair (Nipane et al., 2023; Ma et al., 2024). Table 1 below shows the estimated fat-soluble vitamin-required levels for goats.

Table 1 - Fat-soluble vitamin requirements levels of goats

Vitamin	Level
A	11.000 IU/Kg of feed
D	4,400 IU/Kg of feed
E	176 IU/Kg of feed
K	A well-functioning rumen cans synthesis sufficient levels.

Source: (Nipane et al., 2023)

Minerals

There are two main categories of essential minerals: macronutrients and micronutrients (Mamoon, 2008; Atiba et al., 2020). Froghi and Hosaini (2012) and Nipane et al. (2023) stated that macronutrients are needed in large quantities, while micronutrients are needed in small amounts in diets. The Angora goats require the intake of calcium, phosphorus, magnesium, copper, zinc, manganese, and selenium to stay healthy and give high-quality mohair. According to Hobson (2018) and Nipane et al. (2023), copper is one of the most essential minerals in mohair production. They both reported that including copper in the diets of Angora goats resulted in mohair and keratin production growth. In contrast, copper deficiency may make mohair weak, thin, or discoloured. Copper and Mo are reported to be essential minerals for mohair quality. However, a recommended percentage must be fed. Zhang et al. (2011) reported that feeding goats a feed containing 19 mg Cu per kg Dry matter in an experimental diet with 4, 75 mg/kg Cu, 0.16 mg of Mo, and Sulfur equal to 0.2 % can potentially revamp growth performance, fibre digestion, and mohair growth.

Zehra and Çek (2021) concluded that mohair quality is affected by Calcium, Magnesium, Sulfur, Iron, and Nitrogen content. Zinc and selenium are essential minerals that impact mohair quality by supporting hair and bones and enforcing muscles. Most of the time, there is a need to supply phosphorus supplements since phosphorus acts in cahoots with calcium to speed up the process of bone and enamel strengthening. Sodium resides in a water arrangement where the body is mainly in homeostasis. Each mineral uniquely impacts mohair production, and ensuring that Angora goats receive the correct proportion of minerals is crucial because an excess could be harmful (Froghi and Hosaini, 2012; Hobson, 2018). Table 2 below shows goat diets' estimated recommended micro and macro minerals quantities.

Table 1 - Estimated micro and macronutrient quantities in goat diets.

Micronutrients	Quantity (%)	Micronutrients	Quantity (ppm)
Calcium (Ca)	0.3-0.8	Iron (Fe)	50-1000
Phosphorus (P)	0.25-0.4	Selenium (Se)	0.1-3
Sodium (Na)	0.2	Manganese (Mn)	0.1-3
Potassium (K)	0.8-2.0	Iodine (I)	0.5-50
Chloride (Cl)	0.2	Molybdenum (Mo)	0.1-3
Sulfur (S)	0.2-0.32	Copper (Cu)	10-80
Magnesium (Mg)	0.18-0.4	Zinc (Zn)	40-500
		Cobalt (Co)	0.1-10

Source: Cited from Nipane et al. (2023)

Water

Sufficient water consumption is crucial for proper bodily functions like digestion, waste elimination, temperature control, and overall well-being (Nipane et al., 2023). Mpendulo et al. (2020) argue that water is essential for the digestion of feed and absorption of nutrients. Lower-quality diets increase water intake because goats must drink more to stay hydrated. Water is crucial for Angora goats as it is one of their most essential nutrients. Insufficient water can lead to dehydration in Angora goats, resulting in various health problems such as decreased food consumption and mohair production, and potentially leading to their demise (Michael, 2021).

Angora goats' water requirements vary according to their age, activity level, diet, and environmental conditions (Nipane et al., 2023). Water consumption increases in hot weather and when the goat's diet contains more dry matter (Michael, 2021). Goats weighing about 20 kg require about 700ml of water daily; however the abovementioned factors might influence the water intake (Nipane et al., 2023). Nipane et al. (2023) claim that goats consume about 3.5 litres of water for each litre of milk produced. Daramola and Adeloye (2009) and Nipane et al. (2023) reported that sufficient water intake is essential for healthy mohair growth; if an Angora goat does not get adequate water, it is likely to experience poor mohair growth, and its mohair tends to be dry and brittle. Excessive water intake may negatively impact mohair production by leading to soggy mohair, which is less desirable for processing and spinning (Schoeman and Visser, 1995). Despite all the factors affecting water intake, a goat must always have free-choice access to water. Table 3 below shows the estimated water consumption at different stages of goats per day; however, these can be affected by factors like temperatures, the water content in the feed, etc.

Table 2 - Estimated water consumption on different life stages of goat daily.

Different goat stages	Water consumption per day
Weaners	4-6 liters
Adult dry goat	5-7 liters
Doe with kid	5-10 liters

Source: (Nipane et al., 2023)

Physical properties of Mohair

Luster

Luster is the most noticeable feature, referring to a mohair's natural shine (Muthu and Gardetti, 2016; Mazinani and Rude, 2020). Luster is a characteristic that explains how light bounces off a fibre's exterior. Mohair is famous for its shiny, metallic look due to its high lustre. Mohair fibres are comparatively straight and flat, enabling uniform light reflection on the surface (Singh and Gaikwad, 2020). Mohair is also famous for its soft texture and resistance to pilling (Gericke et al., 2022). This characteristic is why mohair is often chosen for luxury clothing and fabrics.

Non-flammable

Shashikant and Singh (2024) claims that the slivers of mohair fibre turn into little ash beads if placed straight in the fire. In contrast, the combustion process will discontinue as soon as it is removed from the toxicity of fire. Whilst ignition temperature is the attribute that distinguishes mohair fibres from the wool of other animals, it is also known as the ultimate point at which the fibres start to burn. Mohair is more challenging to ignite and better than most synthetic materials when it tumbles because its flame spreads slowly and burns more excellently. However, fibres such as mohair need a higher temperature to ignite than other natural fibres such as cotton and wool above the ignition temperature (Gericke et al., 2022; Shashikant and Singh, 2024). Early teddy bears were crafted from mohair to prevent injuries due to their properties; mohair is also less likely to cause allergic reactions than other wool types (Shashikant and Singh, 2024). Mohair's elevated ignition point makes it an excellent option for clothing in dangerous settings like the military or fire department.

Style and character

Gericke et al. (2022) indicate that mohair is well renowned among fashion people for its rich and trendy appearance. Fibres are luxuriously smooth and very delicate, thus making mohair yarn classified as silk. Since the mohair comes in multiple colours, patterns, and textures, finding a style that matches one's preference is easy (McGregor, 2020; Shashikant and Singh, 2024). The mohair is all the more remarkable due to its halo or fuzzy outline, which makes it stand out from the rest with its unique look and texture. The fluffy look of the fabric is due to the twisted pattern of mohair fibres, which creates a halo effect by trapping air (Shashikant and Singh, 2024). Mohair is usually deemed a halo or bloom, the importance of which is a light and fluffy sensation. The fabric is very soft, and it has a halo or bloom. The crafting style has a significant impact on how the fibres are spun. This yarn creation's shape results from the fibre twist and air pockets formed (Gericke et al., 2022). This makes the mohair garments look elegant and incredible; therefore, the mohair materials are considered excellent for sweaters, scarves and other garments.

Breathable

The airflow permeability, the level that makes the clothes breathable, is an insightful aspect that helps prevent moisture accumulation. Cotton and mohair are two distinct fibres; however, like cotton, mohair is an incredibly breathable material that can absorb moisture and support airflow (Shashikant and Singh, 2024). Availing of these unique qualities of mohair, it is undoubtedly that they are perfect for producing healthy, relaxing wear and cooling materials such as summer wear and sportswear. The breathability of mohair prevents mildew and bacterial growth and aids in regulating body temperature, according to Gericke et al. (2022), Shashikant and Singh (2024). This is why mohair fibres can retain body heat in chilly temperatures and release moisture in hot weather, keeping you cosy at all times.

Durable

The mohair quality is the most prominent feature of this great material. It offers high strength and relatively durable quality. Mohair was pointed out by Shashikant and Singh (2024) as a fabric that is mainly well known for its superb resistance to wear and tear and for surviving multiple cycles through washing. This is attributed to the nature of the fibre, which consists of long, strong fibres entangled with each other. Due to its durability, mohair garments and fabrics can be expected to stay with proper care for longer. Mohair garments from certain textile manufacturers are also known to be long-lasting (Gericke et al., 2022; McGregor, 2020). Mohair's composition enables it to flex and turn without harm, affirming claims that it is the most rigid fibre compared to other animal fibres.

Elastic

Zehra and Çek (2021) highlighted that the elasticity of mohair is influenced by nutrition, and poor nutrition leads to decreased elasticity. Gericke et al. (2022) indicated that the spindle fibres of mohair are expected to stretch by an increment of 30 % along its length with a standard shape after that. As per Shashikant and Singh (2024), being elastic denotes the ability of a fibre to stretch itself and regain its normal state automatically. Mohair tends to possess a relatively high degree of elasticity, enabling it to stretch and regain its initial shape and form without decreasing either strength or appearance. This characteristic makes mohair an excellent option for clothing and textiles needing to preserve their shape long-term. This is a critical factor in why mohair is frequently utilised in knitwear, as it can regain its shape after being stretched while being knitted. Mohair apparel maintains its shape when worn (McGregor, 2020). According to Zehra and Çek (2021) results, mohair elasticity values peak when a goat is six months old and decrease as it grows.

Resistance to soiling

Mohair is recognised for its ability to resist getting dirty, making it less prone to staining than other materials (Shashikant and Singh, 2024). The mohair fibres have a smooth and tightly bound surface, hindering dirt and grime from sticking to the material (McGregor, 2020; Shashikant and Singh, 2024). This property means that mohair is easy to clean and maintain. Dust can be easily removed by brushing and shaking the fabrics.

Mohair Steps/stages in Mohair production

Mohair undergoes processing to guarantee top quality and the lack of impurities (Ghiţuleasa et al., 2013). The processed mohair can be twisted into thread and utilised to create various items. The Australian Mohair Marketing Organisation Ltd. (2020) stated that processing mohair is essential to ensure the end product's uniform texture and quality. In general, the processing of mohair allows for the production of unique and top-notch items that can be sold at a higher price. According to Frank et al. (2012), shearing is the initial stage in mohair processing, where the mohair is taken off the Angora goat. The following stages are sorting, carding, combing, and spinning. During shearing, a shearing comb is used to cut the mohair into long strips (McGregor, 2020). The cut mohair is gathered in big bags and categorised by colour and quality.

Classing/ Grading

Classing or grading refers to sorting mohair by quality and character in the industry. This process ensures that mohair of similar quality is spun together, producing a consistent yarn (Muthu and Gardetti, 2016). The classification process includes various steps such as visual examination, measuring fibre length and diameter, and analysing the characteristics of the fibre (Almeida et al., 2016). The mohair is segmented into various groups depending on its grade. Top-grade Mohair is commonly employed in upscale goods, whereas inferior mohair is frequently used for practical items. The price of mohair is affected by the grade it receives (AMMO Ltd, 2020). Grading is essential so buyers know what they're buying and can make informed decisions on the mohair's quality.

Scouring

Scouring mohair involves cleansing the fibre to eliminate natural oils and dirt (Almeida et al., 2016; AgriSETA, 2018). This method also assists in the softening of the mohair and simplifying its manipulation. Scouring mohair is comparable to wool processing, with some distinct variations noted (Almeida et al., 2016). Mohair is more prone to damage from heat and alkali, which is why it is usually scoured using gentler solutions and at a lower temperature. Another difference is that mohair is often scoured with a detergent called Lanasol, which is designed explicitly for delicate fibres like mohair (Morris, 2017). Zehra and Çek (2021) concluded that Angora goats aged six months have the highest clean mohair percentage compared to 2.5 years; this might be because six months kids have less environmental exposure, such as dust, plant material and other animals, etc.

Carding

Carding straightens the fibres and removes impurities (Muthu and Gardetti, 2016). It involves combing the mohair with a machine known as a carder. The carder divides and arranges mohair fibres in a uniform direction. Almeida et al. (2016) stated that this procedure eliminates any impurities in the mohair, such as plant material, dirt, and fragments. Carding helps smooth the mohair and even while preparing the fibres for the next stage (Almeida et al., 2016).

Combing

Both combing and carding are processes that prepare mohair for spinning, but they serve different purposes. Carding straightens the fibres and removes any debris or impurities while combing straightens them even more and removes all shorter, weaker fibres (Almeida et al., 2016). Combing produces a smoother, more uniform yarn than carding. Frank et al. (2012) highlighted that combing yields higher-quality yarn, but it takes longer and costs more money. Combing is a process that occurs after carding but before spinning (Muthu and Gardetti, 2016). Mohair is separated into individual fibres during combing, with the shorter fibres removed (Almeida et al., 2016). This procedure results in a yarn that is smoother and more consistent. Once the mohair has been combed, it is prepared for spinning by twisting it into yarn.

Spinning

According to Almeida et al. (2016) the thickness of the yarn is determined by the spinning process, which can vary from extremely fine to extremely thick and is carried out manually or using a spinning frame machine. Kosmovis et al. (2013), cited from Zehra and Çek (2021), stated that fibre thickness in male Angora goats between old one-year-old, six months, two years old, and 3 to 5 old, is 27.3, 2,4, 31,3, and 34,6 um, respectively. Hand-spun mohair tends to be pricier yet boasts a unique look and feel. The spinning frame twists carded mohair fibres to create a continuous yarn strand (Almeida et al. 2016). Different types of spinning exist, such as worsted spinning, as Frank et al. (2012) mentioned. This method of spinning yields a smooth, strong yarn suitable for a wide range of applications (Muthu and Gardetti, 2016). Another type of spinning is known as woollen spinning. This method produces a loftier, fuzzier yarn commonly used to knit sweaters and other garments (Almeida et al., 2016). Additionally, there are various spinning methods, such as ring spinning, which involves a ring-shaped device for twisting fibres, and air-jet spinning, which utilizes fast air jets. Once the yarn has been spun, it is then wound onto spools, where it is prepared for weaving or knitting various products.

Techniques used to make fabric for end products

Weaving

After being produced, mohair yarn can create different fabrics through weaving. The process of interlacing yarns to create fabric is known as weaving (Almeida et al., 2016). There are various classifications of weaving, such as plain weave, twill weave, and satin weave. The type of weave can impact how the fabric looks and feels, as well as its resilience and robustness (Ghiţuleasa et al., 2013). After being woven, the fabric can be utilized to create various items, such as garments, interior decorations, and industrial supplies (Gericke et al., 2022). One way to create a fluffy texture is by brushing the fabric, while another method to make it wrinkle-resistant is heat-setting. It is also possible to dye or print it to create patterns or designs (Almeida et al., 2016). Certain textiles may also undergo treatment using chemicals or other substances to become resistant to water and flames. Mohair fabric can be completed in various ways, depending on its intended use.

Knitting

Yarn can be machine-knitted into garment panels, whereas hand knitting comes in solid balls or skeins in various colours, textures, and blends (Almeida et al., 2016). Knitting involves creating a textile using mohair yarn by intertwining loops with knitting needles or a machine (Mazinani and Rude, 2020). There are two types of knitting: warp knitting and weft knitting. The most prevalent form of knitting is weft knitting, which creates fabrics like jersey, ribbing, and double knitting (Omer et al., 2024). Warp knitting is less prevalent, yet it produces textiles like tricot, milanese, and raschel. Both knitting methods can create a range of mohair clothing and accessories, according to Gericke et al. (2022). Knitting involves different stitches, such as garter stitch, stockinette stitch, and seed stitch. Certain stitches are more appropriate for creating specific types of clothing or desired outcomes. All of these elements contribute to the versatility of mohair for knitting.

Global future and prospects of Mohair

In March 2020, the Textile Exchange and the South African Mohair Industry established the Reandair Standard (RMS) to increase mohair (Elizabeth, 2023). South Africa's mohair demand in the past five years has grown (Saez, 2013). Angora goat population is reported to be increasing by Saez (2013) and Mataveia et al. (2021), which means mohair production is expected to grow in the coming years. Gericke et al. (2022) highlighted that mohair is highly resistant to abrasion. It can withstand enormous wear and tear without losing strength or shape, making mohair ideal for high-traffic areas like rugs and carpets. This might be why China is the largest market for South Africa's Mohair, as reported by Mohair South Africa (2022). Elizabeth (2023) reported that the South African mohair industry is working on the adverse effects of climate change and supports the idea of decreasing carbon emissions by at least 45% at the end of 2030, which will have a positive impact on land and have the potential to increase mohair production. Mohair is a renewable resource, making it a valuable fabric in growing demand.

CONCLUSION

South Africa is the world's leading mohair producer, contributing around 60% of global output. The country has earned a reputation for producing high-quality mohair due to its ideal climatic conditions, predominantly in the Karoo region, which provides the necessary arid environment for raising Angora goats. The industry supports thousands of farmers and workers, contributing significantly to the rural economy. However, inadequate nutrition is a significant factor that could impede the quantity and quality of mohair. This is because the Angora type of goats requires specific quantities of protein, energy, vitamins, and mineral elements to satisfy their nutritional requirements and to produce quality mohair. Therefore, promoting sustainable farming practices, investing in research to develop resilient grazing systems and drought-tolerant feed crops, building capacity for small-scale farmers, and developing innovative uses for mohair beyond traditional markets are some of the ways South Africa can maintain mohair global leadership.

DECLARATIONS

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Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Acknowledgments

The authors would like to acknowledge the Livestock and Pasture Science Department together with the Driefontein farm located in Somerset East.

Consent to publish

Not applicable.

Competing interests

The authors declare no competing interests in this research and publication.

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2024 SCIENCELINE

Online Journal of Animal and Feed Research

Volume 14, Issue 6: 358-366; November 30, 2024 ISSN 2228-7701

DOI: https://dx.doi.org/10.51227/ojafr.2024.41

VALUE OF HORSE MANURE FOR RENEWABLE ENERGY PRODUCTION: ANAEROBIC DIGESTION, BIOGAS GENERATION, AND CONTRIBUTIONS TO SUSTAINABLE DEVELOPMENT

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Supporting Information

REVIEW
PII: S222877012400041-14
Received: August 19, 2024
Revised: November 14, 2024
Accepted: November 15, 2024

ABSTRACT: There are various methods like composting, combustion, gasification, pyrolysis, and anaerobic digestion to convert animal wastes that harm the environment into various bio-products. Horse manure containing lower ash and higher rate of lignin compositions can be potentially reuse as a valuable feedstock in anaerobic digestion method to produce nutrient-rich digestate (bio-fertilizer) clean and cheap biofuels, and bio-energy to replace the cost effective fossil fuels which not only make climate change but harms our health by generating toxic emissions and contamination of soil and water. Therefore, converting bio wastes into useful green resources especially using anaerobic co-digestion is necessary to reduce their adverse environmental impact and can contribute towards the achievement of sustainable development goals (SDGs) 2, 3, 5, 6, 7, 9, 12, 13 and 15. As can be seen today, various animal manure types have begun to be used in different situations for their green benefits. This review aimed to provide an overview of the transformation of horse manure into compost, biogas in terms of its preferability as a renewable energy source or a value-added product that mitigate the environmental problems and contribute to the SDGs specially 7, 9, 12, and 13. The potential of animal manure to produce biomaterials, organic acids, biofuels and bioenergy is clear. Therefore, bioprocesses or biorefineries using this biomass as raw material may be promising in the near future in the context of bioeconomy, may help increase renewable energy production and may become capable of promoting innovation that boosts the value of livestock-derived organic fertilizers. There are still needs to extend the development of technologies for converting on-site bio waste resources to useful forms, exploring new and safe biological conversion pathways and bio waste processing methods.

Keywords: Anerobic digestion, Bioenergy, Biogas production, Circular economy, Horse manure, Sustainable development goal

INTRODUCTION

People have sought various methods to reduce the products that are formed as a result of the use of some resources or their need for them and that harm the environment. One of the most important of these methods has been to produce energy from unwanted products.

Today, the need for energy has increased with the increase in the human population and the development of industry and technology. In parallel with the increasing need for energy, the use of fossil resources is also increasing and this increase reveals environmental problems. Generating energy has been an effective choice for the disposal of both useful and unwanted waste products. People who have turned to alternative energy sources to reduce the environmental damage caused by animal waste in particular have tried to produce environmentally friendly and renewable energy sources. At this stage, biogas obtained from organic waste, which is important in the disposal of waste and is seen as environmentally friendly, has emerged as a renewable energy source (Canbaz and Bulut, 2021).

HORSE MANURE

Horse manure is not only rich in nitrogen, phosphorus and potassium but also rich in lignin compositions with a lower ash rate, can be considered as a potential feedstock in converting into bio-oil and solid fuel with high phenolic content (Chong et al., 2019). Processing and transporting horse manure is also easier because of low moisture and high solid content in comparision to dairy manure (Cross, 2017).

Animal manure exhibits a complex structure and can be classified as a lignocellulosic material (plant dry matter) (Hoyos-Seba et al., 2024). Horse manure is a heterogeneous wet mixture of bedding materials and feces (Da Lio et al., 2021). Horse manure is formed by mixing various amounts of feces, urine and various bedding materials (Eriksson et al., 2016). The amount of manure produced by animals is quite effective in the effects of care-feeding and the environment.

Citation: Yildirim F and Açar Y (2024). Value of horse manure for renewable energy production: anaerobic digestion, biogas generation, and contributions to sustainable development. *Online J. Anim. Feed Res*., 14(6): 358-366. DOI: https://dx.doi.org/10.51227/ojafr.2024.41

The amount of manure produced by horses varies between 9 and 29 m3/horse/year (Lundgren and Petterson, 2004), which corresponds to an average of 8-14 tons/horse/year of collectable wet manure (Cui et al., 2011). According to some researchers, horses produce 17 to 25 kg of feces and 8 to 10 kg of bedding materials per day, depending on their feed, bedding and cleaning systems (Böske et al., 2014; Wartell et al., 2012).

Horse manure can also be reused as a sustainable feedstock for pyrolysis, aimed to both waste treatment and useful end products derivation. The operating parameters, such as carrier gas flow rate (Ng et al., 2017), temperature (Cantrell et al., 2012), and microwave receptor proportion (Yerrayya et al., 2018) followed by process optimisation are main factors of pyrolysis process in the maximum yield (Mushtaq et al., 2015).

When horse manure is examined in terms of energy, it is more effective to be dry, which requires approximately 1.4 MJ of energy to completely dry 1 kg of wet manure. In the 6.1 MJ energy content provided by dry manure, the effectively useful part decreases to 4.7 MJ/kg. In addition, horse manure can provide 4.7 MJ/kg of energy production (Da Lio et al., 2021). The management of horse manure causes environmental problems when emissions occur during the decomposition of organic material, in addition to the non-recycling of nutrients (Eriksson et al., 2016).

The composition of the manure is diverse and depends on the type of animal and its feed (Orlando and Borja, 2020). Some researchers who have conducted research on horse manure have shown the analysis results in Table 1.

Table 1 - Some analysis values of horse manure

Proximate analysis	Ash (%)		Volatile matter (%)		Fixed carbon (%)		Nanda et al. (2016)
	16.70		64.80		10.10		
Ultimate analysis	C (%)	H (%)	O (%)	N (%)	S (%)	C/N (%)	Lee et al. (2021)
	43.00	5.70	49.50	1.00	0.80	43.00	
High Heating Value (HHV)	HHV (MJ/kg)						Da lio et al. (2021)
	17.50						
Chemical analysis	Cellulose (%)		Lignin (%)		Hemicellulose (%)		
	42.40		7.20		9.20		Lee et al. (2021)
	6.30		56.00		23.80		Chong et al. (2018)
	19.20		0.30		12.00		Juntupally et al. (2022)

Compost production

Due to its rich nutrient composition (potassium, nitrogen and phosphorus), manure has historically been utilized as a natural fertilizer and soil conditioner (Oenema et al., 2007). Managing a compost pile requires consideration of the carbon-nitrogen ratio, oxygen, moisture, and temperature. The C:N ratio of horse manure is typically 40:1 due to the large amount of bedding mixed into it, but it generally does not require additional nitrogen as long as it has sufficient moisture and oxygen. Typical horse stable waste tends to be dry. Since approximately 50% moisture content is required to create ideal conditions for compost microbes, horse manure may need to be soaked. It is also desirable to maintain a constant temperature of 130° to 150°F in the interior of the compost pile (Smith and Swanson, 2009). When considering the use of horse manure on agricultural land, it can be spread directly on agricultural land or spread after composting (Swinker et al., 1997). When the effects of spreading are examined, it provides nutrients, increases soil organic matter, improves water holding capacity and soil structure. However, ammonia and nitrates in horse manure can change soil-related ecosystems and pollute surface runoff waters and pose a risk to aquatic life. These disadvantages can be significantly reduced by composting horse manure before spreading on fields (Da Lio et al., 2021).

The physicochemical properties and energy content of various fertilizers are presented as; cow ≈ horse > sheep > poultry > pig manure, but this situation is still debated for different reasons (Hoyos-Seba et al., 2024). It is recommended to use horse manure as a biofertilizer on farms (Lundgren and Petterson, 2009). Because this manure has a lignocellulosic structure, it is suitable for composting (Rodhe et al., 2015; Airaksinen et al., 2001). Due to the high content of bedding material in horse manure, its spontaneous decomposition time is slow (Malgeryd and Persson, 2013). Horse manure without bedding material can be composted in a month, but the content of the bedding material slows down the composting process (Airaksinen et al., 2001). In addition, aeration and mixing should be done to accelerate the composting process in composting (Sindhöj and Rodhe, 2013). In general, the use of horse manure as a soil fertilizer after composting is considered beneficial in terms of improving soil quality. However, some metallic contents and especially nitrogen and phosphorus ratios may exceed those required for crop growth and may cause water pollution due to surface runoff (Eriksson et al., 2016). In addition, there are researchers who question the use of composted horse manure as fertilizer both economically and agriculturally (Lundgren and Petterson, 2009). It has also been reported that some grain farmers are reluctant to spread manure due to the potential for the formation of an undesirable weed (such as oats) in addition to the crop they plant when they spread horse manure on their fields (Da Lio et al., 2021).

Biogas production

Biogas is a colorless and flammable gas mixture formed as a result of the fermentation of organic substances such as animal and plant waste in airless environments, containing 60-70% methane, 30-40% carbon dioxide and small amounts of hydrogen sulfide, hydrogen, carbon monoxide and nitrogen (Gülen and Çeşmeli, 2012). Efforts to dispose of animal waste products have led people to research the use of these products in different areas. This section of this research addresses the use of manure obtained from horses in biogas production.

The European Union has adopted decisions to encourage waste-to-energy conversion in order to maximize its contribution to decarbonization and reduce waste production (European Commission, 2019). It has also enacted laws that force farmers to transport or treat excess manure obtained from animals (170 kg N/hectare/year) (European Commission, 1991). The interest in anaerobic digestion of horse manure and thus producing biogas has increased with the increasing interest in biogas as a renewable fuel (Eriksson et al., 2016). In studies conducted on horse manure, some researchers (Weiland et al., 2023) reported the obtained biogas and methane values as 185-115 (Day 16-LN kgVS−1) and 207-135 (Day 40-LN kgVS−1), respectively, while others reported 164 (LN kgVS−1) biogas and 277 (LN kgVS−1) methane (Kusch et al., 2008). These values are lower than the biogas energy values obtained from wheat straw (Bauer et al., 2009) (219-484 LN kgVS−1) but similar to the biogas energy values obtained from manure obtained from cows (De Bere, 2000; MarañóN et al., 2001; Saev et al., 2009) (103-184 LN kgVS−1). Ignition tests have shown that the only major limitation in manure combustion is the high moisture content (approximately 60%), and therefore research is being conducted to overcome the detrimental effect of high moisture content and, in particular, its removal efficiency (Da Lio et al., 2021). The economic viability of using horse manure as a substrate for biogas production depends on the availability of manure, the cost of transportation to the biogas plant and the amount of biogas obtained from the substrate, which is affected by the variability of the bedding materials used (Hadin and Eriksson, 2016). Using horse manure for biogas production instead of improper composting reduces its undesirable impact on the environment (Hadin et al., 2017).

ANAEROBIC DIGESTION AND CO-DIGESTION

Anaerobic digestion is an effective method of converting bio wastes like dairy and horse manure into useful forms, and the most common ways of renewable energy recovery (Mata-Alvarez et al., 2014; Mao et al., 2015), which can produce nutrient-rich digestate (bio-fertilizer), biogas and bio-energy simultaneously. There are wide substrates of municipal, agricultural, horticultural and industrial wastes available for anaerobic digestion (Li et al., 2015).

Although food waste with a high methane production potential can be an attractive feedstock for anaerobic digestion (Zhang et al., 2011), but often faces with some disadvantages like low pH, lack of certain nutrients and suboptimal carbon to nitrogen (C/N) ratio (Mata-Alvarez et al., 2014). Solutions were adopted to overcome the deficiencies of mono-digestion and improve the operational stability and economic viability of this method, for example anaerobic co-digestion or simultaneous anaerobic digestion of food waste plus other organic wastes (Hartmann and Ahring, 2005; Banks et al., 2011; Fang et al., 2011), like co-digesting food waste with cattle manure (Zhang et al., 2013) to provide good buffering capacity and favorably alter anaerobic digestion systems using the nutrient profile of manure (Mata-Alvarez et al., 2014).

Horse manure, is one of the major sources of animal manure in Türkiye. Although Kafle and Chen, (2016) reported that the biochemical methane potential of horse manure are the lowest in most cases compared to other livestock manures because of bedding materials (straw, woodchips, etc.) which have a high content of refractory organic compositions such as lignin and cellulose, but Yerrayya et al. (2018) and Mong et al. (2020) stated that the lower ash content and higher lignin compositions in horse manure makes it a potential feedstock to produce solid fuel and phenol-rich bio-oil with high phenolic content. Chong et al., (2019) also reported that the high volatile and low ash content in horse manure indicates the potential for bioenergy recovery. Miron et al. (2000) stated that lignin is one of factors limiting anaerobic digestion of lignocellulosic biomass due to surrounding the cellulose by lignin and preventing the accessibility of cellulose.

Therefore, the efficiency of co-digestion of food waste when mixtured with horse manure is limited because of the higher content of lignin. There are some physico-chemical pretreatment methods to destroy the structure of lignin and increase the digestibility of lignocellulose, improve the biochemical methane potential of lignocellulosic biomass, and reduce operating costs and energy of anaerobic digestion systems (Shahriari et al. 2013; Ma et al. 2011, Chekani-Azar et al. 2008). A cost-effective separate biological dissolution process has also been suggested for treating bio waste as a pre-treatment step, so that particles are microbiologically hydrolyzed and their size is reduced prior to anaerobic digestion (Gonzales et al., 2005). Zhang et al. (2017) anticipated that the overall performance of anaerobic digestion could be improved if the hydrolyzing and fermenting process of horse manure and food waste were conducted before methanogenesis within the same anaerobic digester.

The digestion and transport of large fibrous particles in manure or solid manures or other residues can cause pumps and pipes to choke and are limited in conventional anaerobic digesters. On the other hand, the transfer and digestion of large fibrous particles in manures are liable to cause technological issues like choking of pumps and pipes18, 19. For this reason, only liquid manures are commonly used in practical AD plants while the utilization of most of solid manures or other residues with fibrous materials is limited in conventional anaerobic digesters (Mönch-Tegeder et al., 2014).

Anaerobic co-digestion of food waste with livestock manure and sustainable development goals

The anaerobic digestion system is one of the important economies of bio wastes which connect the circular economy and bio-economy to sustainable development goals (SDGs) (Fagerström et al., 2018, Netherlands Enterprise Agency, 2021).

Anaerobic digestion convert disposable waste material into high-end outcomes such as biogas (60% methane and 40% carbon dioxide), and nutrient-rich digestate as bio-fertilizer (Holm-Nielsen et al., 2009 Appels et al., 2011 Lohani et al., 2015) which could be the sustainable future replacement for fossil fuels and is an excellent solution for the reduction of the toxic emissions and contamination of soil and water (Miller et al., 2020; Haltas et al., 2017; Labatut and Pronto, 2018). In addition, anaerobic digestion of biowastes contributes towards the achievement of sustainable development goals (SDGs) 2 (zero hunger), 3 (good health and well-being), 5 (gender equality), 6 (clean water and sanitation), 7 (affordable and clean energy), 9 (industries, innovation and infrastructure), 12 (responsible consumption and production),13 (climate action) and 15 (life on land) (Sarika, 2021; World Biogas Association, 2021).

Converting animal manure sources to biogas as renewable energy, which can be successfully done at domestic and industrial scales, can also positively impact sustainable development goals like 7, 9, 12, and 13 SDGs, especially SDGs 9 (innovation) and 13 (climate action) that require urgent implementation for protecting the global health. Shaibur et al. (2021) and Lohani et al. (2021) reported that small-scale biogas systems would contribute to SDGs 1, 3, 5, 7, 13, and 15. The SDGs 3, 4, 5 and 7 are highlighted by Rahman et al. (2019) for biogas implementation, while agriculture residue biogas was considered to SDG 6 by Orner et al. (2020). New method or guidelines are suggested by Obaideen et al. (2022) to enhance the contribution to the SDGs.

Livestock manure as a major issue for sustainable agricultural development can be contributed greatly to the development of some SDGs. Three main categories (reducing emissions to protect the environment, adapting to change, and financing adjustments) which are suggested by the treaties to achieve a zero greenhouse gas emissions (Subbarao et al., 2023) are achievable through the application of the technologies mentioned in Figure 1. The figure shows different processes and technologies of manure treatment using aerobic, anaerobic, and thermochemical pathways so that this optimizasion in the use of materials and energy is in line with SDGs (Hoyos-Seba et al., 2024).

Therefore, additional efforts are required to overcome the current climate change problem. One of most important efforts is to encourage greater use of existing technologies like those presented in Figure 1 to achieve sustainable development goals through valorization of livestock manure.

Gasification, combustion and pyrolysis of horse manure

The thermochemical biomass conversion process known as gasification offers non-oxidative conversion conditions with very low emissions of pollutants, making it a desirable technique for the production of energy and fuel (Ferdous et al., 2001, Tavasoli et al., 2009). Horse dung is a good candidate for catalytic gasification to produce H2-rich syngas, according to research by Nanda et al. (2016). A win-win-win situation, including the creation of biofuel (H2), waste management (manure remediation), and carbon sequestration (application of biochar), might be addressed by using horse manure in supercritical water gasification. Overall, the findings support the idea that using livestock manure in the waste-to-energy conversion process might yield a variety of renewable products with additional value (Nanda et al., 2016).

Horse manure burning directly could be a desirable alternative for combusting heat. Horse manure is rarely used as fuel for three reasons: (a) it is produced in fragmented, mostly small stables that rarely cooperate; (b) regulations vary from one country to another regarding whether or not manure qualifies as a waste or as a renewable fuel and whether it is eligible for renewable energy subsidies (Kusch, 2014); and (c) designing furnaces fed only horse manure is difficult because it needs to be customised for a very wet, heterogeneous, and potentially sticky feedstock (Da Lio et al., 2021). A research comparing horse manure samples of varied origins, management, and ages discovered that the heating values, ash, and melt temperatures were compatible with combustion, but the manure's relatively high moisture content prohibited it from burning (Da Lio et al., 2021).

Pyrolysis is the heat decomposition of a solid fuel in an inert, oxygen-free atmosphere, yielding a liquid or gaseous fuel and a solid residue known as char, which contains the fuel's ash and fixed carbon content (Soria-Verdugo, 2019). According to some recent studies, horse dung is a carbon-neutral biological waste that can be exploited for bioenergy production by microwave-assisted pyrolysis, with microwave pyrolysis producing up to 73.1 vol% of the syngas component (Mong et al., 2020).

Thermochemical conversion methods such as gasification, combustion, and pyrolysis present great opportunities for using horse dung as a viable feedstock for renewable energy production while also addressing waste management and contributing to carbon sequestration. Despite constraints such as high moisture content and regulatory barriers, novel techniques such as catalytic gasification and microwave-assisted pyrolysis have the potential to unlock a wide range of bioenergy products, thereby facilitating the transition to a more sustainable and circular economy.

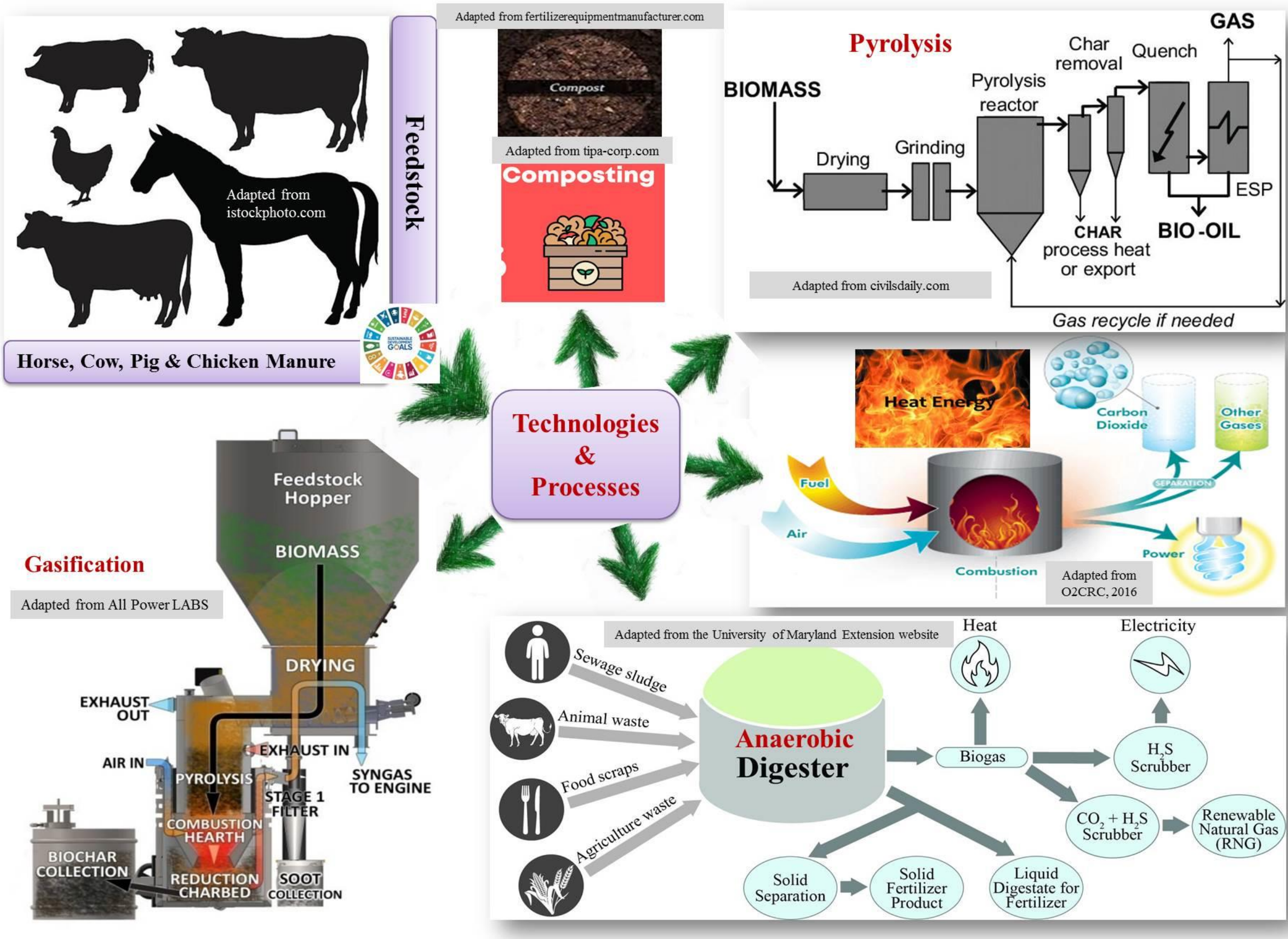

Figure 1 - Products made from various manure treatment technologies and processes.

CONCLUSION AND RECOMMENDATION

In the face of growing environmental challenges and the increasing energy demand, utilizing animal waste—especially horse manure—emerges as a promising solution to address both waste disposal and renewable energy generation. The potential of horse manure as a sustainable feedstock for biogas production, composting, and bioenergy recovery has been extensively explored, demonstrating its value not only as an organic fertilizer but also as a resource for generating clean energy. While its biochemical methane potential may be lower compared to other manures, recent advancements in anaerobic digestion, including co-digestion with food waste and the application of pre-treatment methods, show promise in improving its digestibility and energy yield. Furthermore, adopting biogas technology aligns with the European Union's renewable energy goals and sustainable development objectives, such as climate action, clean energy, and responsible consumption.

Despite the challenges associated with managing horse manure—such as high moisture content and slow decomposition due to bedding materials—innovative technologies offer opportunities to optimize its conversion into valuable byproducts, including biogas and biofertilizers. By enhancing the efficiency of anaerobic digestion systems and promoting horse manure in circular economy models, we can reduce harmful emissions, improve soil quality, and generate renewable energy that supports global sustainability goals. To fully realize the potential of horse manure, further research and technological advancements are needed to overcome existing barriers and scale these solutions. Ultimately, the valorization of animal waste through biogas production and other renewable energy pathways can be crucial in mitigating environmental impacts, fostering energy independence, and contributing to a more sustainable future.

DECLARATIONS

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Acknowledgements

The authors thank Y. Betül Apaydin for providing the resources in this research.

Competing interests

The authors declare no competing interests in this research and publication.

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2024 SCIENCELINE

Online Journal of Animal and Feed Research

Volume 14, Issue 6: 367-375; November 30, 2024

ISSN 2228-7701

DOI: https://dx.doi.org/10.51227/ojafr.2024.42

EFFECT OF *Leucaena leucocephala*-BASED MULTI-NUTRIENT LICK BLOCKS ON THE FEED INTAKE AND GROWTH PERFORMANCE OF BUFFALOES

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Supporting Information

RESEARCH ARTICLE
PII: S222877012400042-14
Received: September 04, 2024
Revised: November 21, 2024
Accepted: November 22, 2024

ABSTRACT: Ruminant production in the Philippines is often hindered by limited access to high-quality feed, leading to suboptimal animal growth and productivity. To address these challenges, this study evaluated the locally made multi-nutrient lick block (MNLB) containing ipil-ipil (*Leucaena leucocephala),* a legume known for its nutritional value. A 30-day palatability test was conducted to assess the acceptability of the developed MNLB, using 5 male buffaloes with an average weight of 245 ± 5 kg. Additionally, a 90-day-feeding trial was carried out using 15 growing buffaloes (average age: 13.5 months, weight: 243.83 ± 5 kg), randomly assigned to three treatment groups: T1 or control (non-supplemented), T2 or commercial mineral block, and T3 or MNLB, to evaluate the growth performance, nutrient utilization, and economic viability of the legume-based MNLB. Results demonstrated that the MNLB was palatable to the animals, with an average daily consumption of 192.10 g/animal/day, providing adequate nutritional value to meet the buffaloes' daily requirements. Moreover, MNLB supplementation significantly enhanced dry matter (DM) and crude protein (CP) intake compared to control and commercial mineral block groups. The average DM intake for T3 was 9.88 kg, and the average CP intake was 1006 g, compared to T1 (9.56 kg DM intake and 983 g CP intake) and T2 (9.59 kg DM intake and 984 g CP intake). While the commercial mineral block showed positive results, the MNLB outperformed in terms of nutritional value. In terms of cost-effectiveness, the MNLB can serve as an alternative feed supplement for small- scale farmers, offering a lower- cost option compared to commercial feed supplements. The study concluded that the MNLB has potential as a practical solution to address the nutritional challenges faced by ruminant producers in resource-limited environments. By providing a nutrient-rich and safe feed supplement, the MNLB can contribute to improved animal health, productivity, and overall farm profitability.

Keywords: Legume, *Leucaena leucocephala*, Multi-nutrient supplementation, Ruminants, Urea based feed supplements, Water buffalo.

INTRODUCTION

In developing countries like the Philippines, ruminant producers face considerable challenges due to the limited and inconsistent availability of high-quality animal feed (Liang and Paengkoum, 2019). The scarcity of nutrient-dense fodder compounded by seasonal fluctuations in forage quality, often leads to nutrient deficiencies, which hinder optimal animal growth, reproduction, and overall productivity. These challenges are particularly prevalent among smallholder farmers, who frequently rely on low-quality feed resources such as crop residues and poor-quality roughages, further exacerbating the issue of undernutrition in livestock (Choudhary et al., 2021).

To address the nutritional needs of ruminants, various feed supplementation strategies have been explored, with multi-nutrient blocks (MNBs) emerging as a widely adopted solution in many regions. MNBs are solidified blocks containing a mixture of nutrients such as urea (a source of non-protein nitrogen), molasses, di-calcium phosphate, vitamins, and minerals, all formulated to enhance rumen fermentation, improve digestion, and boost growth performance in ruminants (Khan et al., 2017; SungChinTial et al., 2023). The use of these blocks has been shown to stimulate microbial growth in the rumen, thereby improving the digestion of fibrous feeds and increasing nutrient absorption, which in turn enhances productivity, particularly in animals on low-quality diets (Reshi et al., 2022; Villanueva Pedraza et al., 2023).

Supplementing ruminant diets with multi-nutrient feed blocks has proven beneficial in improving various performance parameters. For instance, Kachhawaha et al. (2022) highlighted the positive effects of Multi-Nutrient Feed Blocks (MNFB) as a supplement for lactating buffaloes, resulting in improved milk yield, milk fat content, general health status, and reproductive performance. These findings (Kachhawaha et al. 2022; Reshi et al., 2022; Villanueva Pedraza et

Citation: Llantada PLT, Castillo CI, Uy-De Guia MRD, Amido RD, Grospe VKA, Lavarias PJF, Gonzales EG, and Del Barrio AN. (2024). Effect of *Leucaena leucocephala*-based multi-nutrient lick blocks on the feed intake and growth performance of buffaloes. *Online J. Anim. Feed Res.*, 14(6): 367-375. DOI: https://dx.doi.org/10.51227/ojafr.2024.42

al., 2023) underscore the potential of multi-nutrient supplementation in overcoming nutritional deficiencies and enhancing livestock productivity in resource-limited environments.

Despite the documented advantages of MNBs, their adoption among small-scale farmers in the Philippines remains limited. A key barrier to widespread use is the inclusion of urea, a non-protein nitrogen source that, while beneficial in controlled amounts, poses toxicity risks when consumed in excess. Urea poisoning is a significant concern, particularly in regions where farmers may lack the technical knowledge to manage proper dosing (Reshi et al., 2022; Gimelli et al., 2023). This fear of urea toxicity has led to low adoption rates, limiting the potential benefits of MNBs for improving ruminant nutrition in the country.

To mitigate the risks associated with urea, alternative feed formulations are being explored. One promising approach is the development of multi-nutrient lick blocks (MNLB) incorporating ipil-ipil (*Leucaena leucocephala*), a leguminous plant known for its high protein content. Ipil-ipil offers a safer, nutrient-rich alternative to urea, reducing the reliance on non-protein nitrogen while maintaining or enhancing the nutritional benefits of the supplement. By incorporating ipil-ipil, MNLBs can provide a more natural, balanced source of protein, which may lead to improved animal health and reduced risk of urea toxicity.

This study was conducted to evaluate the nutritional and economic benefits of a novel MNLB formulation that utilizes ipil-ipil as a key ingredient. Specifically, the research aimed to: 1) determine the nutritional composition of the MNLB, 2) assess its impact on the growth performance of water buffaloes through controlled feeding trials, and 3) evaluate its economic viability as a feed supplement for smallholder farmers. By addressing these objectives, this study seeks to contribute to the development of sustainable and innovative feed supplementation strategies that can help overcome the challenges faced by ruminant producers in the Philippines. Furthermore, it highlights the potential for locally sourced, high-protein leguminous plants to play a pivotal role in improving the productivity and profitability of ruminant farming in resource-limited environments.

MATERIALS AND METHODS

The study was conducted at the Gene Pool Farm of the Department of Agriculture- Philippine Carabao Center National Headquarters and Gene pool, Science City of Munoz, Nueva Ecija, to determine the effect of legume based multi-nutrient block on the growth performance of growing buffalo.

Preparation and mixing of MNLB

The preparation and mixing of MNLB were carried out following standard procedures to ensure consistency and accuracy of the final product. First, the ipil-ipil leaves were collected and sun-dried. Once dry, the leaves were milled to increase the surface area for better mixing. Before mixing with other ingredients, the urea was crushed or ground to increase its solubility. It was then added to molasses in a large basin or drum and mixed continuously until all the urea grains dissolved completely. In a separate container, the other ingredients such as rice bran, pulverized ipil-ipil, cement, salt, dicalcium phosphate, vitamins, and mineral mix were combined and mixed thoroughly. The two mixtures were then mixed together. Mixture 1 (molasses and dissolved urea) was added gradually to Mixture 2 (rice bran, ipil-ipil, cement, dicalcium phosphate, mineral mix, and salt) while continuously mixing until a homogeneous dough texture was achieved. The final mixture was weighed using a top-loading weighing balance, and about 5kg of the mixture was compacted using a customized fabricated molder (Figure 1) to produce MNLB of the desired shape and size. The blocks were then sun dried for 30 to 35 days (Figure 2). This method ensured the consistent composition of each block, enabling accurate dosing and efficient nutrient delivery to animals.


Figure 1 - Improvised molder for multi-nutrient lick block production


Figure 2 - Sun drying of MNLB for 30 to 35 days

Nutrient composition of MNLB

The chemical composition of the MNLB was analyzed through a series of tests. Initially, the samples from each treatment were oven-dried at 60 ℃ for 72 hours to remove moisture content (% MC). Subsequently, the temperature was raised to 135 ℃ for 2 hours to determine the % MC. The ash content (% Ash) and crude protein (CP) content (% CP) were then analyzed using the standard method of the Association of Official Analytical Chemists (AOAC, 1995). The dry matter (DM) content (% DM) was calculated by subtracting the % MC from 100%. Additionally, mineral analysis was conducted by sending MNLB samples to a third-party laboratory for analysis using Atomic Absorption Spectroscopy (Shimadzu Corp., Kyoto, Japan). This analysis determined the concentrations of essential minerals such as manganese (Mn), phosphorus (P), calcium (Ca), sodium (Na), copper (Cu), zinc (Zn), and selenium (Se). These analyses provided valuable insights into the nutritional content of the MNLB, guiding further improvements in its formulation and ensuring its efficacy as a feed supplement for water buffaloes.

Palatability test and evaluation of the effect of MNLB on growth performance of growing buffaloes

Palatability Test

Preliminary trials were conducted at Philippine Carabao Center National Headquarters and Gene Pool farm using animals ≥ 1 year old to assess the palatability of the MNLB (Figure 3). Five male buffaloes of similar age and average weight of 245 ± 5 kg were individually housed to accurately measure intake and preference. Each animal received the same diet of grass and concentrates twice daily along with MNLB. Clean and fresh drinking water was made available all throughout the experiment. The weight of blocks was recorded weekly to determine the average daily intake of animals for optimal MNLB consumption.

Figure 3 - Palatability and acceptability trial set-up.

Evaluation of the effect of MNLB on growth performance of growing buffaloes

Experimental animals and treatment

Fifteen apparently healthy, riverine type growing male buffaloes between 13-16 months old (average 13.56 months) and weighing approximately 243.83 ± 5 kg were selected for this experiment. The animals were randomly assigned to three treatments with five replicates per treatment: Treatment 1: Negative Control (no MNLB or commercial mineral block provided), Treatment 2: Positive Control (provided commercial mineral block, Red Rockies brand), and Treatment 3: Supplemented with MNLB.

Feeds and feeding management

The sample ration with a 65:35 forage-to- concentrate ratio for 14- month- old growing animals, averaging 250 kg body weight and targeting an average daily gain (ADG) of 500 grams, was formulated using the KBGAN iFEED© mobile app (Palacpac et al., 2024; Table 1). The initial weight, monthly and final weight of the animals were recorded to determine the total weight gained and the ADG. The selected growing buffaloes were fed a formulated ration consisting of Napier grass, rice straw, and concentrate feed to meet their daily nutritional requirements (Table 1) (Kearl, 1982) for a 90-day feeding trial period. Roughage was provided ad libitum in the morning for consumption throughout the day, while concentrate was given in the morning, before the roughage. The blocks were hung above the animals to allow for free licking while preventing overconsumption.

Table 1 - Formulated TMR ration (total mixed ration) based on the requirement of the animals

T3 Diet (feed materials)	DM (%)	CP (%)	TMR Ration (DM basis)		Fresh wt. (kg)
Napier grass	17	7.98	45.00		13.76
Grower concentrate	88	16.00	35.00		2.07
Rice straw	94.93	4.00	20.00		1.10
Total	-	-	100.00		16.93
Ration	**DM (kg)**	**CP (g)**	**TDN (kg)**	**Ca (g)**	**P (g)**
Requirement	5.90	604.00	3.55	15.00	12.00
Diet	5.90	689.56	3.61	31.12	21.54

Animal health, care, and management

The collection and testing of urine and fecal samples were conducted before and after the feeding trial to ensure that the animals remained healthy and free from health issues. Fecal and urine samples were analyzed at the Biosafety and Environment Section (BES) laboratory of PCC. All animals were given a 7-day adjustment period before the actual data collection. During this period, the animals were weighed, dewormed with Triclabendazole, and injected with Vitamin A, D, and E. Throughout the experiment, each animal was housed in an individual pen and provided with ad libitum access to clean and fresh drinking water.

Ethical approval

All experimental procedures, including animal maintenance and sample collection, were conducted following the guidelines of the ethical committee at the Philippine Carabao Center National Headquarters and Gene Pool with research code AN20002-ROG and as describe by the Animal Research: Reporting of In Vivo Experiments (ARRIVE) (Percie du Sert et al., 2020).

Collection of samples

Feed offered and refusal by each animal was collected and weighed daily. Approximately 200g samples of the collected feed were dried and ground for proximate analysis.

Cost and return analysis of MNLB production

The cost of producing MNLB was included to demonstrate the economic benefits of the products for dairy farmers as an alternative to commercially available mineral lick. The cost of the block was calculated based on 2021 prices of feed ingredients used.

Statistical analysis

The statistical analysis of our research involved performing appropriate tests to determine the significance of the differences in dependent variable(s) such as weight gain. We conducted tests for assumptions of normality (Shapiro-Wilk test) and homogeneity of variance (Levene's test). One-way ANOVA was used for normally distributed data, while the Kruskal-Wallis rank sum test was used for non-normally distributed data. Tukey's test was used for post-hoc comparisons following a significant one-way ANOVA, and the Bonferroni correction was applied for post-hoc comparisons following the Kruskal-Wallis test (P=0.05 and 0.1).

RESULTS AND DISCUSSION

Nutritional composition of MNLB

Laboratory analysis revealed that the MNLB used in the study contains 85.32% DM and 29.83% CP, surpassing the 17.2-17.6% CP reported by Muhammed (2016). The inclusion of ipil-ipil leaves and a minimal amount of urea contributed to the increased protein content (Sankar et al., 2020), enhancing the overall nutritional value of MNLB. This suggests its potential as a valuable protein source for ruminants in areas with limited access to high-quality feeds and forages. On the other hand, Table 2 demonstrates that the developed MNLB had higher levels of sodium (5,487.76 mg/kg), calcium (49,968.77 mg/kg), selenium (265.81mg/kg), phosphorus (0.88 %), and iodine (3.68 %) compared to commercially available mineral blocks. This is attributed to the mineral premix, Di-calcium phosphate, and salt incorporated into MNLB, which includes essential macro and micro minerals like Ca, P, Na, Fe, Cu, Mn, Zn, I, Se, and Co (Ben Salem, 2007). Supplementation of MNLB could provide animals with their daily mineral requirements, helping to optimize productivity and reproductive efficiency, especially in regions where forage quality is poor and supply is inadequate (Bhanderi et al., 2016).

Table 2 - Mineral analysis and Crude Protein availability of MNLB

Components	Method(s)	MNLB	Commercial mineral block
Manganese, mg/kg	Atomic Absorption Spectrometry	73.51	200
Sodium, mg/kg		5,487.76	3800
Copper, mg/kg		16.35	300
Zinc, mg/kg		43.10	300
Selenium, mg/kg		265.81	10
Calcium, mg/kg		49,968.77	250
Cobalt, mg/kg		1.48	50
magnesium, mg/kg		2,359.43	5000
Phosphorus, %	Colorimetry	0.88	
Iodine, %	Lodometry	3.68	1.5
Crude Protein %		29.83	0

* MNLB: Multi-Nutrient Block

Palatability test and evaluation of the effect of MNLB on growth performance of growing buffaloes

Palatability and acceptance trial

The MNLB formulation used in this study exhibited high palatability and acceptance among buffaloes. All animals readily consumed the blocks, demonstrating frequent licking behavior during the initial week until complete consumption. This positive response suggests that the MNLB's unique composition effectively catered to the buffaloes' nutritional and sensory preferences. The average daily consumption of 192.10 g/head/day over a 30-day period (5, 640 g/animal/day) presented in Table 3 further underscores the MNLB's appeal. This consumption rates indicates that the blocks were palatable to the buffaloes. Several factors likely contributed to the MNLB's palatability and acceptance. The inclusion of molasses, renowned for its sweet taste and pleasant aroma (Upadhyay et al., 2018), likely played a significant role in enhancing the blocks' appeal. Additionally, minerals provided essential nutrients and contributed to the overall nutritional balance of the MNLB. Salt, a common component in mineral blocks, served both as a flavor enhancer and a preservative (Ben Salem et al., 2007; Mohammed et al*.,* 2007). By incorporating salt into the formulation, the MNLB's shelf life was potentially extended, ensuring consistent quality and palatability over time. Urea, another key component, is known for its ability to improve feed digestibility and intake. By providing non-protein nitrogen, urea can supplement protein sources in the diet, potentially enhancing the overall nutritional value of the MNLB (Makkar, 2007).

Table 3. Average MNLB intake and ADG of growing animals fed with MNLB for palatability test.

Parameters	Value
Total consumed (g)	5,640.00
Average daily intake (g)	192.10

* MNLB: Multi-Nutrient Block, ADG: Average Daily Gain

Table 4 - Average dry matter intake (DMI) and crude Protein Intake (CPI) of animals offered with commercial mineral block, Blockmate and control.

Parameters \ Treatment	Control	Commercial mineral block	MNLB	P-Value
DMI Intake, kg				
1st month	10.2 ± 0.02^b	10.3 ± 0.04^b	10.6 ± 0.05^a	<0.001**
2nd month	9.33 ± 0.01^b	9.31 ± 0.01^b	9.58 ± 0.04^a	<0.001**
3rd month	9.12 ± 0.05^c	9.22 ± 0.01^b	9.47 ± 0.03^a	0.001**
Average daily DMI	9.56 ± 0.02^b	9.59 ± 0.01^b	9.88 ± 0.03^a	<0.001**
CPI Intake, kg				
1st month	881 ± 1.23^b	883 ± 2.43^b	906 ± 3.37^a	<0.001**
2nd month	1023 ± 1.29^b	1020 ± 0.65^b	1040 ± 3.33^a	0.003**
3rd month	1046 ± 0.73^b	1049 ± 0.43^b	1071 ±2.46^a	0.002**
Average daily CPI	983 ± 0.63^b	984 ± 0.84^b	1006 ± 2.58^a	<0.001**

* Note: Values are presented as mean ± standard error (Mean ± SE). Different superscript letters (a, b, c) indicate significant differences between treatment means (P < 0.05). Highly significant differences (P < 0.01) are denoted by **, and significant differences by (P < 0.05). MNLB: Multi-Nutrient Lick Block.

Dry matter intake (DMI) and crude protein intake (CPI)

MNLB supplementation significantly influenced both DM intake and CP intake among the groups (Table 4). Statistical analyses revealed significant differences (P<0.05) between treatments for both DMI and CPI over the three-month feeding trial. These findings are similar to those of Bohra et al. (2012) in Rathi cattle, where DMI and CPI in control and supplemented groups were 2.93 and 3.96 kg, and 97 and 274 g per animal per day, respectively. The availability of molasses, urea, and minerals as source of energy, protein, and minerals through urea molasses multi-nutrient block optimizes rumen fermentation and consequently increases utilization of crop residues (Meel et al., 2015).

Animals receiving the MNLB (Treatment 3) consistently consumed significantly higher amounts of both DMI and CPI compared to the other groups (Treatments 1 and 2). This trend persisted throughout the feeding trial, suggesting that the MNLB formulation was more palatable or provided additional nutritional benefits that encouraged increased consumption. In contrast, animals in the control group (Treatment 1) and those offered the commercial mineral block (Treatment 2) exhibited lower DMI and CPI, particularly during the early stages of the trial. These results indicate that the mineral block supplementation, while not as effective as MNLB, did provide some nutritional benefits that may have influenced feed intake to a certain extent. The results of this study suggest that the MNLB formulation developed in this research is more palatable and nutritious than the commercial mineral block. This is likely due to the unique combination of ingredients and nutrients included in the MNLB, which may have enhanced its appeal for the animals. Farmers and animal caretakers should carefully consider these factors when selecting feed blocks to ensure optimal nutrient intake and animal health. By choosing a feed block that is both palatable and provides adequate nutrients, they can improve animal performance, productivity, and overall well-being.

Evaluation of the effect of MNLB on growth performance of growing buffaloes

MNLB supplementation did not result in significant differences in total weight gain or average daily gain (ADG) compared to the other two groups (Table 5). This finding aligns with observations in cattle (Nurwahidah et al., 2016, Windsor et al., 2020), cows (Suharyono, 2014), and Mecheri ram lambs (Muralidharan et al., 2016), which also showed no significant differences in body weight. Although the results in Table 5 for total weight gain and ADG were not statistically significant, animals in T3 showed the highest weight gain and ADG. This is particularly important for fattening animals, as it allows them to reach target weights in a shorter period. According to Mengistul and Hasen (2018), MNLB supplementation has a significant positive effect on rumen microbial growth, feed intake, digestibility, live weight, and growth rate. However, these results contrast with the findings of Hatungimana and Ndolisha (2015), who observed that groups supplemented with blocks containing 7% urea exhibited higher growth performance than the control group. This discrepancy may be attributed to several factors, including differences in the specific mineral block composition, animal breed, environmental conditions, and experimental methodologies (Fesaha and Urge, 2014, Li et al., 2014, Dharan et al., 2015).

For feed conversion efficiency (Table 5), there were no significant differences between the groups. However, numerically, MNLB supplementation reduced the amount of feed required per kg body weight gain by 7-8 %, similar to the findings of Barque et al. (2008) in male buffalo calves, where feed required per kg gain of body weight gain decreased from 2.97 to 2.87. While the MNLB did not significantly impact growth performance in this study, it is important to note that other factors, such as overall feed intake, nutrient digestibility, and health status, may influence the animals' growth rates. Further research is needed to fully comprehend the potential benefits of MNLB supplementation on buffalo growth performance under various conditions.

Table 5 - Growth performance of animals offered with mineral block, MNLB and control (without blocks)

Parameters \ Treatment	Control	Commercial mineral block	MNLB	P-Value
Age (months)	13.8 ± 1.11	13.6 ± 0.91	13.9 ± 0.79	0.969
Initial Weight (kg)	243 ± 5.26	248 ± 4.59	241 ±7.66	0.663
1st monthly Weight (kg)	281 ± 9.04	279 ± 7.12	271 ± 10.23	0.722
2nd monthly Weight (kg)	303 ± 8.36	306 ± 9.28	302 ± 9.91	0.952
Final Weight (kg)	321 ± 9.10	328 ± 8.26	329 ± 9.57	0.811
Total weight gain (kg)	78.3 ± 6.59	79.4 ± 4.30	87.8 ± 6.63	0.487
Average ADG (kg)	0.87 ± 0.07	0.88 ± 0.05	0.98 ± 0.07	0.487
Feed Conversion Efficiency (FCE)	0.71 (71 %)	0.72 (72 %)	0.79 (79 %)	0.735

* Note: Values are presented as mean ± standard error (Mean ± SE); no significant differences (P > 0.05) across treatments for any of the parameters. MNLB- Multi-Nutrient Lick Block

The economic viability of MNLB

Cost to produce MNLB

The MNLB formulation presented in this study demonstrates significant economic advantages over commercially available mineral blocks. Based on prevailing market prices, the cost of producing 100 kilograms of MNLB mixture (20 pieces) was calculated to be 5.67 USD (Table 6), which translates to a suggested retail price of 6.86 USD per block (Table 7). This price is substantially lower than the 14.71 USD (Table 7) cost of commercially available mineral blocks, making the MNLB a highly affordable option for smallholder farmers. The MNLB's affordability is further enhanced by its reliance on locally available resources, which can reduce transportation and handling costs. This aligns with the findings of Muhammed et al. (2016) and Agada et al. (2018), who also emphasized the economic benefits of producing multi-nutrient blocks using locally sourced materials. In addition to its lower cost, the MNLB offers superior nutritional value. As shown in Table 2, the MNLB contains higher levels of Na, Ca, Se, P, and I, compared to commercially available mineral blocks. This enhanced nutritional profile makes the MNLB a more economical and beneficial choice for livestock producers, as it can potentially improve animal health, growth, and reproductive performance. Thus, the MNLB represents a promising and economically viable option for smallholder farmers in the Philippines. Its affordability, coupled with its superior nutritional composition, makes it a valuable tool for improving livestock productivity and profitability.

Table 6 - Cost to produce MNLB based on 2021 price of ingredients.

Supplies and materials / MNLB Technology	Quantity	Unit cost (USD)	Unit	Total cost (USD)
Pail	1.00	4.90	USD/pc	4.90
Shovel	1.00	7.84	USD/pc	7.84
Plastic drum (200 liters capacity) depreciation cost 12 months life span)	1.00	1.96	USD/pc	1.96
Molasses	37.00	0.73	USD/kilo	26.85
Cement	10.00	0.20	USD/kilo	1.96
Rice bran	25.00	0.53	USD/kilo	13.24
Mineral mix	1.00	1.37	USD/kilo	1.37
Salt	1.00	0.20	USD/kilo	0.20
Urea	6.00	0.98	USD/bag	5.88
Ipil-ipil leaves	10.00	0.29	USD/kilo	2.94
Di-calcium phosphate	3.00	1.47	USD/kilo	4.41
Professional services				
Laborer/ helper	2.00	7.84	USD/day	15.69
Other expenses				
Water	1.00	0.33	USD/day	0.33
Fabricated molder	2.00	1.96	USD/pc	3.92
Plastic tray	7.00	1.96	USD/pc	13.73
Drying rack (steel 5 layer)depreciation cost (12 months)	1.00	8.17	USD/month	8.17
Total Expenses	-	-	-	113.40
Cost of producing per block	20.00	-	-	5.67
Gross sales (5 kg/block)	20.00	6.86	-	137.28
Net Income	-	-	-	23.88
ROI	-	-	-	21.06

Cost of ingredients may vary depending on the unit cost of raw materials; USD: United States Dollars

Table 7. Comparison on MNLB over commercially available mineral lick/blocks

Blocks	Wt./block (kg)	Price/block (SRP)	Composition
MNLB	5	6.86 USD	With crude protein
Commercial mineral block	5	14.71 USD	Without crude protein

***Note:** The price of the MNLB was derived from the calculation shown in Table 6. The price of the commercial block reflects the suggested retail price (SRP) at the time of the study; USD- United States Dollars

CONCLUSION AND RECOMMENDATIONS

Based on the findings of this study, the locally produced multi-nutrient block (MNLB) demonstrated superior nutritional value, containing 85.32% dry matter (DM) and 20.50% crude protein (CP), higher than the 17.2 to 17.6% CP in commercial products. Enhanced by ipil-ipil leaves and urea, the MNLB also surpassed commercial mineral blocks in essential minerals, including sodium (5,487.76 ppm) and calcium (49,968.77 ppm). The buffaloes' high acceptance and increased dry matter intake (9.88 kg) and crude protein intake (1,006 g) reflect the MNLB's palatability and effectiveness. Although it did not statistically show impact on growth performance, the MNLB offers substantial cost savings at 6.86 USD per 5 kg block, compared to 14.71 USD for commercial alternatives. This makes the MNLB an affordable, nutrient-rich feed supplement, particularly beneficial for smallholder farmers in resource-limited settings. Given the positive effects of multi-nutrient block on nutrient intake, further research is recommended to assess its impact on different buffalo groups, such as fattening animals, growing bulls, and lactating buffaloes. Additionally, conducting feeding trials in areas prone to dry seasons would help evaluate the MNLB's effectiveness in addressing feed scarcity during these periods.

DECLARATIONS

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Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Acknowledgment

The authors express sincere gratitude to the Philippine Carabao Center National Headquarters and Gene Pool for their generous support and resources that made this research possible. Special thanks are extended to Prof. Tsutomu Fujihara, Dr. Daniel L. Aquino, Dr. Cyril P. Baltazar, and the dedicated teams at the Production System and Nutrition Section and the Gene Pool Farm for their invaluable contributions and assistance throughout the study.

Authors Contribution

The first author, Phoebe Lyndia T. Llantada, contributed to the refinement of the proposal, led the experimental design and execution, conducted data analysis, and played a significant role in manuscript preparation and refinement. The second author, Charity I. Castillo, assisted with the experimental execution, data analysis, manuscript writing and refinement. The third and fourth authors, Mary Rose D. Uy-De Guia and Reynald D. Amido, respectively, contributed to the conceptualization of the research study, submitted the proposal, and drafted the manuscript. The fifth and sixth authors, Vienna Kristel A. Grospe and Psalm Joseph F. Lavarias, respectively, were instrumental in data collection and laboratory analysis. The seventh author, Edwin G. Gonzales, contributed to laboratory analysis. The eighth author, Arnel N. del Barrio, conceptualized the conduct of the study.

Competing interests

The authors declare that they have no competing financial interests, personal relationships or other affiliations that could have appeared to influence the work reported in this paper.

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2024 SCIENCELINE

Online Journal of Animal and Feed Research

Volume 14, Issue 6: 376-382; November 30, 2024

ISSN 2228-7701

DOI: https://dx.doi.org/10.51227/ojafr.2024.43

OCCURRENCE AND LEVELS OF AFLATOXIN CONTAMINATION IN POULTRY FEED INGREDIENTS AND LAYER MASH IN FARMS AND FEED MILLS IN GHANA

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Supporting Information

RESEARCH ARTICLE
PII: S222877012400043-14
Received: September 06, 2024
Revised: November 15, 2024
Accepted: November 17, 2024

ABSTRACT: The study assessed the incidence and contamination levels of total aflatoxins (TAF) and aflatoxin B_1 (AFB_1) in feed ingredients and compound layer mash from six regions in Ghana. Thirty-five facilities comprising commercial poultry farms and feed mills were used in the study. There was 100% incidence of TAF and AFB_1 in the samples of layer mash and feed ingredients (maize, soybean meal and wheat bran). The TAF of layer mash, maize and soybean meal (55.2, 54.0 and 47.6 µgkg^{-1}, respectively) were significantly higher ($P < 0.05$) than TAF of wheat bran (28.6 µgkg^{-1}). Most of the layer mash, soybean meal and wheat bran samples had TAF concentrations exceeding the US Food and Drug Administration (USFDA) maximum limit of 20 µgkg^{-1}. Mean TAF concentrations in layer mash and maize samples were strongly and positively correlated ($r = 0.50$; $P < 0.018$). Layer mash, maize and soybean meal had significantly higher ($P < 0.05$) AFB_1 concentrations (33.0, 35.1, 26.5 µgkg^{-1}, respectively) when compared to wheat bran (13.8 µgkg^{-1}). Most layer mash and maize samples exceeded the European Commission's maximum limits of 20 and 50 µgkg^{-1} respectively for AFB_1. Mean AFB_1 concentrations in layer mash and maize samples were strongly and positively correlated ($r = 0.54$; $P = 0.01$). High aflatoxins contamination of poultry feed is a persistent problem in Ghana. The use of toxin-binders, education of poultry farmers and feed millers on the implication of aflatoxins contamination in poultry feeds and the enforcement of regulation by Ghana's food and drugs authority is recommended.

Keywords: Aflatoxin B_1, Compound feed, Maize, Soybean meal, Total aflatoxin, Wheat bran.

INTRODUCTION

Poultry production plays a major role in poverty reduction and improving food security in developing countries including Ghana. Feed is a major input in livestock production, accounting for approximately 70% of total production costs (Donohue and Cunningham, 2009; Etuah et al., 2021) directly impacting animal health, productivity and public health. Consequently, the need to ensure quality and safety of feeds in animal production cannot be overemphasized.

The feed industry in Ghana has gradually shifted to production of layer feed due largely to bulk importation of chicken meat and the attendant decline in domestic broiler bird production (Ashitey, 2017). As a result, layer feed constitutes approximately 80% of feed manufactured by commercial feed mills and farms (Ashitey, 2017). Poultry feed formulated mostly from feed ingredients including maize, soybean meal, wheat bran, cotton-seed cake, palm kernel cake, copra cake and fish meal (Ashitey, 2017). The above ingredients are however susceptible to contamination by mycotoxin-producing fungi, including *Aspergillus flavus* and *Aspergillus parasiticus* (Nemati et al., 2014) which produce secondary fungal metabolites a major one being aflatoxin. The presence of aflatoxins in feed could reduce nutritive value of feeds and adversely affect animal health and performance as well as compromise the resultant animal products (meat, milk, eggs) and public health (Mokubedi et al., 2019; Ochieng et al., 2021; Thakur et al., 2022). For example, chronic exposure of layer birds to dietary aflatoxins reduced egg production, decreased weight gain and increased liver fat levels (Rosmaninho et al., 2001; Aly Salwa and Anwer, 2009), with attendant economic implications. Aflatoxins contamination of feed can occur at any point along the feed value chain, especially during cultivation and production of feed ingredients as well as production, handling and storage of compound feed (Obonyo and Salano, 2018; Omari et al., 2020). Reducing aflatoxin contamination of feed will help improve human and animal, and productivity.

Some research on aflatoxins contamination of poultry feeds has been carried in Ghana (Kumi et al., 2019; Aboagye-Nuamah et al., 2021), this notwithstanding, information on source tracking of compound poultry feed contamination in Ghana is not readily available. Source tracking of compound feed contamination is particularly imperative on the premise that major feed ingredients (maize, soybean and wheat bran) used in poultry feed compounding in Ghana are susceptible to aflatoxins contamination due to prevailing high temperatures and humidity, poor agricultural, postharvest handling and

Citation: Nkansah B, Adjorlolo L, Appiah-Opong R and Obese F (2024). Occurrence and levels of aflatoxin contamination in poultry feed ingredients and layer mash in farms and feed mills in Ghana. *Online J. Anim. Feed Res*., 14(6): 376-382. DOI: https://dx.doi.org/10.51227/ojafr.2024.43

storage practices (Akowuah et al., 2015; Ashitey, 2017; Nakavuma et al., 2020) during feed production that serve as favorable conditions for aflatoxins contamination. The main objective of this study was therefore to determine incidence and concentrations of total aflatoxins (TAF) and aflatoxin B_1 (AFB_1) in feed ingredients in locally manufactured compounded feed (layer mash) from commercial poultry farms and feed mills in the country.

MATERIALS AND METHODS

Location of study and data collection

Thirty-five facilities comprising commercial poultry farms and feed mills were selected randomly from six regions (Bono, Ashanti, Eastern, Western, Greater Accra and Northern) in Ghana for the study (Figure 1). Ghana is located on longitude 3° 11´W and 1° 11´E and latitude 4° 44´N and 11° 11´N (MOFA, 2011). The country is divided into 16 administrative regions, across five main agroecological zones namely, Rainforest, Deciduous forest, Transitional, Northern Savannah (Guinea and Sudan Savannah) and Coastal Savannah (MOFA, 2011). The climate of Ghana is generally warm and humid with mean annual rainfall of approximately 1187 mm and mean annual temperature ranging between 26.1°C at the coasts to 28.9°C at the extreme north. The Northern region, a relatively dry savannah agroecological zone, has annual rainfall of 1100 mm. The Bono region falls within the moist deciduous ecological zone which has annual rainfall of 1500 mm. The Ashanti and Eastern regions are in the moist semi-deciduous forest agroecological zone and have an annual rainfall of 1500 mm, while the Western Region is located in the rainforest agroecological zone and is the wettest part of Ghana.

The region has annual rainfall of 2200 mm. At each of the facilities, four samples comprising three feed ingredients (maize, soybean meal and wheat bran) and one compound layer mash were collected. In total, eighty-eight samples (n=88) were collected; consisting of feed ingredients (n = 66) and compound layer mash (n = 22). A breakdown of the samples collected per region is shown in Table 1.

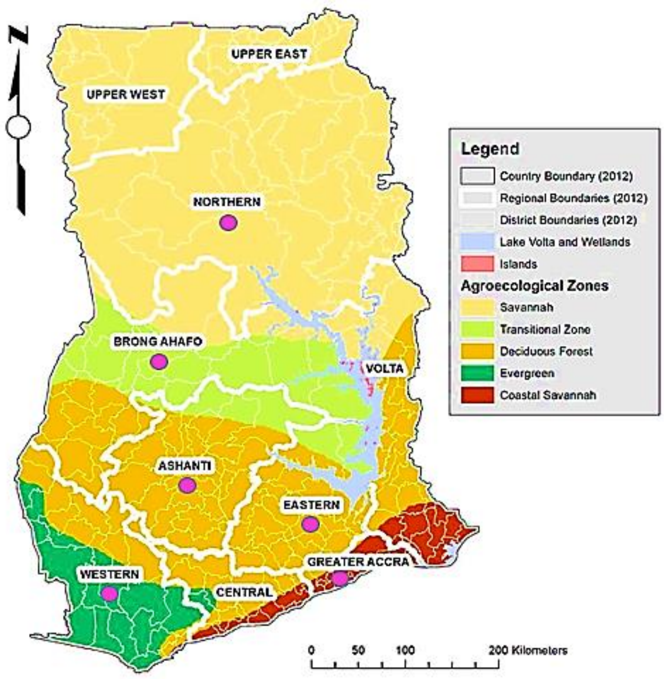

Figure 1 - Regional map of Ghana with agro-ecological zones (Abbam et al., 2018). Sampling points indicated with dots.

Table 1 - Number of feed ingredients and compound feed collected

Region	Maize	Soybean	Wheat bran	Compound feed (layer mash)
Bono	5	5	5	5
Ashanti	4	4	4	4
Eastern	2	2	2	2
Western	2	2	2	2
Greater Accra	7	7	7	7
Northern	2	2	2	2
Total	22	22	22	22

Sample preparation

The samples collected were finely ground in a Retsch® ultra-centrifugal mill (ZM 200) with a sieve size of 0.5 mm. The ground sample was thoroughly mixed and spread out on a flat surface and then 500 g sub-sample was obtained by taking samples from different sections of the spread-out sample. The 500 g sub-sample was mixed thoroughly and then 10g was taken from it for analysis.

Aflatoxin extraction

Aflatoxins extraction was performed according to the kit manufacturer's procedure of the R-Biopharm® laboratories (R-Biopharm, 2008). All feed samples and reagents were brought to room temperature (25°C) and the extraction carried out at room temperature. Aflatoxins were extracted from the analytical sample by mixing the 10 g analytical sample with 50 ml methanol (70%). The mixture was shaken manually for 15 minutes at room temperature and filtered through a Whatmann No. 1 filter paper. The filtrate was kept in covered bottles and refrigerated (5°C) prior to analysis.

Determination of aflatoxin concentrations

The TAF and AFB_1 concentrations in feed ingredients (maize, soybean meal and wheat bran), and the compound layer mash were analysed by direct competitive Enzyme-Linked Immunosorbent Assay (ELISA) using the Ridascreen® total aflatoxin and the Ridascreen® aflatoxin B130/15 procedures respectively by R-Biopharm® laboratories. Analysis was performed according to the manufacturer's procedure (R-Biopharm, 2008).

Statistical analysis

Means and standard deviations of results obtained were computed and subjected to Analysis of Variance using SPSS version 26 (2019). Test of significance between mean concentrations of TAF and AFB_1 was determined using Least Significant Difference (LSD) at 5% level of probability. The Pearson's correlation coefficient was computed between concentrations of TAF and feed ingredients, and also between AFB_1 and feed ingredients.

RESULTS AND DISCUSSION

Incidence and mean concentrations of aflatoxins in layer mash and feed ingredients

There was 100% incidence of TAF and AFB_1 in the samples of layer mash, maize, soybean meal and wheat bran. The mean concentrations of TAF in layer mash and the feed ingredients (maize, soybean meal and wheat bran) are indicated in Table 2. Layer mash, maize and soybean meal had higher ($P < 0.05$) TAF concentrations than wheat bran. Most of the layer mash, soybean meal and wheat bran samples had TAF concentrations exceeding the US Food and Drug Administration (USFDA) or the Ghana Standards Authority (GSA) maximum limit of 20 μgkg^{-1}. This is likely due to non-adherence to Good Manufacturing Practices (GMPs) and poor storage practices at majority of the farms sampled. Mean TAF concentrations in layer mash and maize samples were positively correlated ($r = 0.50$; $P < 0.018$). The observed total aflatoxins concentration of layer mash 55.2 μgkg^{-1} (Table 2) was similar to concentrations of 57.2 μgkg^{-1} reported by Aboagye-Nuamah et al. (2021) for TAF in compounded poultry feed sampled from three regions in Ghana (Bono, Ashanti and Eastern), but higher than the mean of 2.85 μgkg^{-1} and upper limit of 22 μgkg^{-1} reported by Kumi et al. (2019), who also observed 100% incidence of TAF in compounded poultry feed from the Greater Accra, Bono, Ashanti and Western regions of Ghana. Furthermore, Nsiah et al. (2023) investigating the incidences of aflatoxin contaminations in ingredients, feed and products of poultry from the Greater Accra and Eastern regions of Ghana recorded 100% incidence of TAF in poultry feed and maize. High aflatoxins contamination of poultry feed is therefore a persistent problem in Ghana. Similar high incidence of TAF have also been reported in broiler and layer mash from South Africa (92%; Mokubedi et al., 2019), Cameroon (83%; Kana et al., 2013) and Kenya (93%; Kemboi et al., 2020).

Table 2 - Concentration of total aflatoxins (TAF) in layer mash and feed ingredients (Mean ± SE)

Feed/ Ingredient	Mean concentration (μgkg^{-1})	Range (μgkg^{-1})	Percentage of samples exceeding USFDA maximum limit (%)
Layer Mash	55.2 ± 6.08^{a}	23.2 – 114	100
Maize	54.0 ± 7.29^{a}	17.0 – 125	13.6
Soybean	47.6 ± 1.43^{a}	38.0 – 61.0	100
Wheat bran	28.6 ± 2.83^{b}	15.2 – 79.5	72.7
P-value	P < 0.001	-	-

Means within a column with different superscripts (a, b) are significantly (P<0.05) different; SE= Standard Error; USFDA= United States Food and Drugs Authority. USFDA maximum limit for total aflatoxins in layer mash, soybean meal and wheat bran is 20 μgkg^{-1} and for maize is 100 μgkg^{-1}

The concentrations of AFB_1 in layer mash, maize, soybean meal and wheat bran are shown in Table 3. Layer mash, maize and soybean meal had higher ($P < 0.05$) AFB_1 concentrations than wheat bran. Most layer mash and maize samples exceeded the European Commission (EC) maximum limits of 20 μgkg^{-1} and 50 μgkg^{-1} respectively for AFB_1. The mean AFB_1 concentrations in layer mash and maize samples were strongly and positively correlated, ($r = 0.54$; $P = 0.01$). Ezekiel et al. (2012) reported higher AFB_1 levels of up to 1067 μgkg^{-1} in layer and broiler mash in Nigeria. The reported concentrations were over tenfold the upper limit observed for AFB_1 in the current study (74 μgkg^{-1}, Table 3). Kirinyet et al.

(2023) have also reported of high AFBI in broiler feed samples from selected farms in Nairobi City County in Kenya. High AFB_1 contamination of feed is of particular concern as it is the most potent genotoxic and carcinogenic strain of the aflatoxins (Patel et al., 2015), because of its highly reactive metabolite, AFB_1-8, 9-epoxide.

Table 3 - Concentrations of aflatoxin B_1 (AFB_1) in layer mash and feed ingredients (Mean ± SE)

Feed/ Ingredient	Mean concentration (μgkg^{-1})	Range (μgkg^{-1})	Percentage of samples exceeding EC maximum limit (%)
Layer mash	33.0 ± 4.58^a	8.50 – 74.0	63.6
Maize	35.1 ± 6.68^a	5.00 – 104	54.6
Soybean	26.5 ± 0.91^a	19.5 – 35.0	0.00
Wheat bran	13.8 ± 2.39^b	5.25 – 60.0	4.55
P-value	0.003	-	-

Means within a column with different superscripts (a, b) are significantly (P<0.05) different; SE= Standard Error; EC= European Commission. The EC maximum limit for AFB_1 aflatoxins in layer mash and maize is 20 μgkg^{-1}, and for soybean meal and wheat bran is, 50 μgkg^{-1}.

The much lower TAF and AFB_1 concentrations in wheat bran compared to maize, soybean meal and layer mash (Tables 2 and 3) may be attributed to the fact that all wheat on the Ghanaian market is imported from temperate countries where conditions are unfavorable for aflatoxins contamination coupled with its proper drying postharvest prior to storage and export. Also, the cleaning and sorting procedures carried out during industrial processing of wheat into flour and bran in Ghana may have contributed to reducing aflatoxins contamination. The high TAF and AFB_1 concentrations in layer mash in this current study corroborates reports of high prevalence and contamination of feeds in Ghana and other tropical countries in Africa owing to conducive climatic conditions (warm and humid) which encourage fungal growth and aflatoxins production in feed ingredients (Hell et al., 2000; Ochieng et al. 2021).

Amongst the feed ingredients, high TAF and AFB_1 were recorded in maize, 54.0 μgkg^{-1} (Table 2) and 35.1 μgkg^{-1} (Table 3) respectively. Similar reports of higher aflatoxins concentrations have been reported for maize from Ghana. For example Kortei et al. (2021) found 80% incidence of TAF and AFB_1 in maize samples from various markets in Ghana, at levels ranging from 0.78 μgkg^{-1} to 445 μgkg^{-1} and 0.78 μgkg^{-1} to 339 μgkg^{-1} respectively. Also, Dadzie et al. (2019) found TAF and AFB_1 concentrations of up to 945 μgkg^{-1} and 821 respectively in maize. Furthermore, in a recent study, Nsiah et al. (2023) reported 100% incidence in samples from the Greater Accra and Eastern Regions of Ghana with TAF and AFB_1 ranging from 2.53 to 54.26, and 1.62 to 45.70 μgkg^{-1} respectively. Considering the high aflatoxins contamination of maize and the common practice of channeling bad grains to animal feed, poultry in Ghana may be continually exposed to high concentrations of dietary aflatoxins. Mwalwayo and Thole (2016) and Worku et al. (2019) also reported 100% incidence of TAF in maize from Ethiopia and Malawi respectively. Ayalew (2010) also found 88% incidence of total aflatoxins in maize samples in Uganda similar to the high incidence of total aflatoxins observed in this study.

Concentrations of TAF (28.6 μgkg^{-1}; Table 2) and AFB_1 (13.8 μgkg^{-1}; Table 3) in wheat bran were relatively low. Similarly, Rodrigues et al. (2011) determined concentrations of mycotoxins in maize, wheat bran and soybean meal from seven African countries (including Ghana, Nigeria, and Kenya) and reported lower total aflatoxins contamination in wheat bran (1 μgkg^{-1}) and soybean meal (4 μgkg^{-1}) compared to maize (28 μgkg^{-1}). High aflatoxins concentrations were also found in soybean meal in the current study. Poor storage conditions at majority of the facilities may have led to such high contamination levels.

The high concentrations of aflatoxins observed in the maize ingredient in the current study might be due to infestation of fungi before and at harvest due to poor agricultural and cultural practices (Williams et al., 2004; Chandra and Bishnoi, 2015). Maize cultivation in Ghana and majority of African countries, for instance is predominantly carried out by smallholder resource-poor farmers who often use poor harvesting, drying and storage methods (Kortei et al., 2021). This creates avenues for fungal contamination and aflatoxins production prior to processing into feed. High total TAF and AFB_1 concentrations observed in the layer mash may reflect the high aflatoxins concentrations in maize samples used in formulating this compound feed. This is suggested by the significant positive correlation between the two variables. Similarly, Streit et al. (2013) reported that high aflatoxins concentration in maize used in feed preparation, directly influenced concentration of aflatoxins in the compounded feed. This may be due to the high proportion of maize in compound feed, i.e. approximately 60% of entire formulation (IFPRI, 2017), as well as high susceptibility of maize grains to mycotoxigenic fungal contamination and aflatoxins production (Streit et al., 2013). In the current study however, aflatoxins contamination levels in soybean meal were also found to significantly influence the contamination levels in layer mash.

Concentration of total aflatoxin (TAF) and aflatoxin B_l (AFB_1) in layer mash and feed ingredients from commercial poultry farms and feed mills

Although the mean TAF, and AFBI concentrations from the commercial poultry farms were higher than those from the commercial feed mills, they were however not significantly (P>0.05) different (Table 4). Generally, aflatoxins contamination was higher in feed ingredients from commercial poultry farms than the commercial feed mills (Table 5). This may be due to non-adherence to good farm management practices (eg. poor facility design, ingredients quality assurance, equipment cleaning, pest management) as well as the poor storage conditions at majority of the farms observed during the study. Similar high concentrations of aflatoxins were reported in layer mashes from smallholder farms (98.4 μgkg^{-1}) than samples from commercial feed mills (40.4 μgkg^{-1}) in Uganda (Nakavuma et al., 2020).

Table 4 - Concentrations of total aflatoxins and AFB_1 in layer mash from commercial poultry farms and feed mills (Mean ± SE)

Facility	Total aflatoxins Conc. (μgkg^{-1})	AFB_1 Conc. (μgkg^{-1})
CFMs	42.6 ± 6.62	24.4 ± 5.73
CPFs	64.0 ± 8.58	39.0 ± 6.29
P-value	< 0.084	< 0.119

Means within a column with same superscripts are not significantly (P>0.05) different; SE= Standard Error; CPFs = commercial poultry farms; CFMs = commercial feed mills

Table 5 - Concentration of total aflatoxins and aflatoxin B_1 in feed ingredients across commercial poultry farms and feed mills (Mean ± SE)

Type of facility	Total Aflatoxins (μgkg^{-1})			AFB_1 (μgkg^{-1})		
	Maize	Soybean	Wheat bran	Maize	Soybean	Wheat bran
CFMs	38.2 ± 10.90	45.6 ± 2.55	21.6 ± 2.59	22.5 ± 9.68	23.9 ± 0.96^b	9.50 ± 1.61
CPFs	64.9 ± 8.85	49.0 ± 1.62	33.4 ± 3.98	43.8 ± 8.56	28.3 ± 1.16^a	16.7 ± 3.74
P-value	< 0.071	< 0.239	< 0.380	< 0.118	< 0.014	< 0.142

Means in the same column with different superscripts (a, b) are significantly different (P < 0.05). SE= Standard Error; AFB_1= Aflatoxin B_1. CFMs – Commercial feed mills, CPFs – Commercial poultry farms.

CONCLUSION AND RECOMMENDATIONS

All samples (100%) of layer mash, maize, soybean meal and wheat bran were contaminated with total aflatoxins (TAF) and aflatoxin B_1 (AFB_1). Higher concentrations of TAF and AFB_1 were found in layer mash, maize and soybean meal than in wheat bran. Most of the samples of layer mash had TAF concentrations above the Ghana Standards Authority (GSA) and US Food and Drug Administration (USFDA) maximum limit, while AFB1 concentrations were above the EC maximum limit.

Feed millers and poultry farmers should be educated on the implications of aflatoxins contamination in poultry feeds and its impact on animal health, production and public health. The need to include toxin binders in compound poultry feed is being recommended. In addition to continuous surveillance and monitoring of aflatoxin levels in feed and feed ingredients, the Food and Drug Administration (FDA) in Ghana should intensify regulation of commercial feed mills and on-farm feed mills in the country to ensure strict compliance to Good Manufacturing Practices (GMPs) to ensure safety of locally manufactured poultry feed.

DECLARATIONS

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Authors' contribution

Bella Nkansah participated in the proposal design, performed the laboratory analysis and statistical analysis and prepared the manuscript in writing. Leonard Adjorlolo, Regina Appiah-Oppong and Frederick Obese all participated in the reviewing and editing the proposal and write-up. All authors read and approved the final manuscript before submitting for publication.

Ethical consideration

The authors complied with the ARRIVE guidelines and the Interdisciplinary Principles and Guidelines for the Use of Animals in Research, Testing, and Education by the New York Academy of Sciences, Ad Hoc Animal Research Committee.

Acknowledgements

The authors are grateful to the Food and Drugs Authority-Ghana is acknowledged for providing sponsorship for this research work. Mr. Ebenezer Ofori-Atta of the Clinical Pathology Department of Noguchi Memorial Institute for Medical Research is acknowledged for assisting in the laboratory work and Dr. Raphael Ayizanga of the Department of Animal Science, university of Ghana is appreciated for assisting me with the statistical analysis.

Consent to publish

All the authors agree to publish this manuscript in this journal.

Competing interests

The authors have no competing interests.

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2024 SCIENCELINE

Online Journal of Animal and Feed Research

Volume 14, Issue 6: 383-389; November 30, 2024

ISSN 2228-7701

DOI: https://dx.doi.org/10.51227/ojafr.2024.44

THE EFFECT OF NEUROTROPIC SUPPLEMENTS ON LACTOGENESIS IN FEMALE PIGS AND THE DEVELOPMENT OF THEIR OFFSPRING

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Supporting Information

RESEARCH ARTICLE
PII: S222877012400044-14
Received: July 14, 2024
Revised: November 12, 2024
Accepted: November 13, 2024

ABSTRACT: The aim of study was to evaluate the influence of biologically active additives on the hormonal status of lactating sows and the absolute growth of suckling piglets. Glutam 1M, nanoaquachelates of germanium (NPs-Ge) and Quatronan-Se (Cu-NPs, Se-NPs, Cr-NPs, Ge-NPs, Mn-NPs) have been administered orally (lat. per os) for animals in different percentage doses and schemes. Five animals groups have been formed by the method of analogues: control (20 ml physiological solution) and four experimental (group M: 18 mg/kg Glutam 1M; group G18: 5 µg/kg Ge-NP + 18 mg/kg Glutam 1M; group G9: 5 µg/kg Ge-NP + 9 mg/kg Glutam 1M; and group Q: Quatronan-Se (0.02 ml/kg) administered for 14 days). Results showed positive effects of the use of supplements on prolactin secretion. Administration of 5 mg/kg live weight NPs-Ge for sows G18 and G9 for 4 days before the farrowing increased the level of prolactin in the blood serum. On farrowing day, the hormone level in these groups was 14.6 ng/ml (G18) and 13.42 ng/ml (G9), while in K and M groups it was 12.02 and 9.94 ng/ml, respectively. On the day of weaning, the highest prolactin content has been observed in the G18 group as 14.9 ng/ml. Also, suckling piglets from this group have had the highest growth during the studied period. During the entire suckling period, the growth of piglets in the G18 group was 3.65 kg and was higher compared to the K (2.94 kg), M (3.58 kg), G9 (3.31 kg) and Q (3.44 kg) groups. It's suggested that the scheme introduction of Germanium (5 mg/kg) additives, 4 days before and 10 days after farrowing + Glutam 1M (18 mg/kg) 3 days after farrowing is the most effective (group G18) in means of growth performance.

Keywords: Biologically active drugs, Glutam 1M, Prolactin, Hormone, Sows.

INTRODUCTION

The hormonal profile of sows is one of the markers that indicate the general condition of the female body and its reproductive capacity (Soede et al., 2011). As one of the main signs of the reproductive capacity of sows, milk production largely determines the growth, development, and safety of piglets (Quesnel, 2011). The amount of milk produced primarily depends on the structure and size of the sow's mammary gland (Zhang et al., 2018). An intense increase in the size of the lacteous gland occurs in the final stages of pregnancy and during lactation (Grahofer and Plush, 2023).

The process of milk formation in the secretory cells of the mammary gland of pigs (lactogenesis), like other animal species, is controlled by hormones. Endocrine regulation of lactation involves adrenocorticotropic, somatotropic, thyroid-stimulating hormones, insulin, prolactin and oxytocin. Prolactin is the most important one (Kemp et al., 1978; Lacasse et al., 2011). Prolactin is involved in the biosynthesis of α-lactoalbumin, lactose, casein and directly affects the epithelial cells of the lacteous gland (Kemp et al., 1978; Iakubchak et al., 2010). According to Trokoz et al., (2014), Loisel et al. (2015) prolactin stimulates the growth of the lacteous gland and milk synthesis. It is also known that prolactin in milk enables the maturation of the neuroendocrine and immune systems of the newborn (Vlasenko, 2013).

It was found that during gestation, the prolactin content reaches a peak value at the time of farrowing (Garcia-Ispierto et al., 2009). After farrowing, prolactin secretion is supported by sucking and udder massage (Pilipchuk and Sheremeta a, 2016). It was also investigated and found that the level of prolactin in the blood of sows on the day after farrowing increases to 86.42-96.72 ng/ml against its concentration of 48.44-52.20 ng/ml on the 113th day of gestation (Saletskaya, 2008). Pilipchuk and Sheremeta (2016a) found that Glutam 1M affects the hypothalamic-pituitary system, which confirms the effect of this drug on increasing the content of prolactin in the serum of sows on the 4th day of the weaning period.

Therefore, further study of the effect of biologically active, environmentally friendly supplements on the hormonal status of sows' blood remains a timely area of research. The aim of the study was to investigate the effects of Germanium

Citation: Khomenko M, Seba M, Ruban S, Holovetskyi I, Kurbatova I, Bogdanova N, Trokhymenko V, and Kepkalo I (2024). The effect of neurotropic supplements on lactogenesis in female pigs and the development of their offspring. *Online J. Anim. Feed Res.*, 14(6): 383-389. DOI: https://dx.doi.org/10.51227/ojafr.2024.44

nanoaquachelate (Ge-NPs) Glutam 1M and Quatronan-Se [Cu (NPs), Se (NPs), Cr (NPs), Ge (NPs), Mn (NPs)] supplements and effective schemes of their administration on the body of lactating sows and the growth of suckling piglets.

MATERIALS AND METHODS

Experimental design

The experimental study was conducted in the experimental farm (Stepne Farm), which is located in the Poltava region (Ukraine) on sows of the large white breed, which were selected by the method of groups of analogues based on live weight, age, origin and farrowing, From the selected animals, 5 groups were formed - control K and four experimental group M, G18, G9, Q. There were 5 sows in each group. The experimental animals were inseminated with the sperm of a single sire boar. Therefore, the influence of parents on the results was levelled out.In previous studies, the doses of administration for each of the additives were determined separately. The most effective doses of Glutam 1M were 18 mg/kg and 9 mg/kg, and Germania - 5 mg/kg. Quatronan-Se was used in pigs for the first time, so the recommended dose of 0.02 mg/kg was used, which was used for cattle. This experiment investigates the most effective supplementation scheme.

Supplements (Table 1) to avoid stress in sows were administered orally according to the study scheme:

- Group K (control): physiological solution (20 ml) 4 days before farrowing and 10 days after;
- Group M: Glutam 1M (18 mg/kg of live weight) 3 days after farrowing;
- Group G18: Germanium nanoaquachelate (5 μg/kg) 4 days before and 10 days after farrowing + Glutam 1M (18 mg/kg) 3 days after farrowing.
- Group G9: Germanium nanoaquachelate (5 μg/kg) 4 days before and 10 days after farrowing + Glutam 1M (9 mg/kg) 3 days after farrowing.
- Group Q: Quatronan-Se (0.02 ml/kg) was administered 14 days, 4 days before and 10 days after farrowing. The composition of the supplements includes nanoparticles of trace elements Cu, Se, Cr, Ge, Mn in the form of carboxylates.

5 days before the expected date of farrowing, the sows have been transferred to a farrowing room.

Table 1 - The composition of supplements.

Supplements					
Germanium nanoaquachelate		**Glutam 1M**		**Quatronan-Se**	
Component	%	Component	%	Component	%
Germanium nanoaquachelate ($Ge_{\eta}^{2n-}(H_2O)_n$)	100	Monosodium glutamate ($C_5H_8NNaO_4$)	16	Cu (NPs)	19
		Sodium carbonate ($NaHCO_3$)	9	Se (NPs)	5
		Distilled water	75	Ge (NPs)	23
				Cr (NPs)	5.5
				Mn (NPs)	27.5 %
				Distilled water	20 %

NPs: nanoparticles.

Feeding

The sows were fed with complete ration compound feed, which was produced at the compound feed factory according to a special recipe. Pig rations were balanced in exchangeable energy, digestible protein, essential amino acids, minerals and vitamins. Before farrowing, the dry feed in the diet of sows was 3.3 kg per day, after farrowing – 6.3 kg per day (Barley: 25%, wheat: 28.5%; corn: 15%, sunflower meal: 4%, soybean meal: 15%, wheat bran: 5%, sunflower oil: 2.5%, premix - 5%).

Serum hormones concentrations

Blood collection from sows was performed on the day of farrowing, the 4th day of the suckling period, and the on day of weaning (Table 2). Blood was taken from the ear vein in the morning before feeding in dry sterile vacuum tubes with a capacity of 4 ml. The samples were settling at room temperature for 2-3 hours before clotting reaction to obtain blood serum. The resulting serum was centrifuged for 20 minutes at 1500 rpm, and then pipetted into microtubes (1.5 ml). Selected samples were frozen in liquid nitrogen for further analysis to determine the level of hormones in the sow's body. The content of prolactin, progesterone, testosterone and oestradiol in sows' blood was determined. The study was performed in the certified and accredited laboratory on the immunoassay analyser Immunochem-2100 using special reagents (LLC “Hema”).

Table 2 - The scheme of blood sampling in experimental sows

Group	Blood collection days	Indicator
Group K (Control)	On the farrowing day	Prolactin hormone
	On the 4th day after farrowing	
	On the 28th day after farrowing (weaning)	Prolactin, progesterone, testosterone estradiol hormones
Group M	On the farrowing day	Prolactin hormone
	On the 4th day after farrowing	
	On the 28th day after farrowing (weaning)	Prolactin, progesterone, testosterone estradiol hormones
Group G18	On the farrowing day	Prolactin hormone
	On the 4th day after farrowing	
	On the 28th day after farrowing (weaning)	Prolactin, progesterone, testosterone estradiol hormones
Group G9	On the farrowing day	Prolactin hormone
	On the 4th day after farrowing	
	On the 28th day after farrowing (weaning)	Prolactin, progesterone, testosterone estradiol hormones
Group Q	On the farrowing day	Prolactin hormone
	On the 4th day after farrowing	
	On the 28th day after farrowing (weaning)	Prolactin, progesterone, testosterone estradiol hormones

Statistical analysis

Statistical processing of the obtained results was performed using the programmable module "Data Analysis" in Microsoft Excel. The arithmetic mean (M) and its error (m) were determined. The level of statistical significance (P) was determined using the Student's t-test table. The results are considered statistically significant at $P<0.05$, $P<0.01$.

RESULTS AND DISCUSSION

Lactogenesis is initiated before farrowing by the peak of prolactin, which is induced by a decrease in the concentration of progesterone in sows' organisms. In addition, prolactin stimulates the growth of mammary glands and milk synthesis (Pilipchuk and Sheremeta, 2016a; Loisel et al., 2017).

In the serum of sows of the G18 and G9 groups after the farrowing there was a tendency to increase in the concentration of prolactin compared with the control and the M groups. The content of prolactin in the blood serum in groups G18 (14.6 ng/ml) and G9 (13.42 ng/ml), was higher compared with the K group (12.02 ng/ml) and the M group (9.94 ng/ml) (Table 3). The content of prolactin in the M group after the farrowing was lower by 2.08 ng/ml compared with the K group. A low level of prolactin in this group after the farrowing is not associated with the use of supplements because animals did not receive them before farrowing. Therefore, the indicators of the M group can be equated to the control data. The results of studies of the Q group (11.34 ng/ml) show that the concentration of prolactin in this group was higher compared to the M group, and lower, compared to the K (control).

Thus, it can be assumed that the introduction of Germanium and Quatronan-Se supplements in 4 days before the farrowing stimulates the synthesis of prolactin. A further experimental study showed a slight decrease in the content of prolactin in the serum of sows on the 4th day of the weaning period in the K (control), G18 and Q groups; and an increase in this indicator for animals of the M and G9 groups compared with data after the farrowing. Such changes can be explained by the fact that before the farrowing the secretion of this hormone increases significantly in response to estrogen, and after the farrowing its content is maintained during lactation by neuro-reflex way (Farmer, 2022).

Based on the report of Pilipchuk and Sheremet (2016 b), one can suppose that the additive Glutam 1M affects the hypothalamic-pituitary system, which confirms the effect of this supplements on increasing the content of prolactin in the serum of sows on the 4th day of the suckling period. In the M (10.8 ng/ml) and G9 (14.58 ng/ml) groups, the hormone concentration increased compared to the K (10.54 ng/ml) and compared to its content after the farrowing (M - 9.94 ng/ml; G9 -13.42 ng/ml). It was also found that this indicator in the G18 group -11.76 ng/ml was higher compared to the K, M and Q (10.54 ng/ml, 10.8 ng/ml, 7.76 ng/ml) groups (Table 3). Data on the concentration of prolactin in the blood of experimental sows on the day of weaning show that this indicator was the highest in the G18 group and was 14.9 ng/ml. While in the K- 12.8 ng/ml, M - 10.6 ng/ml, G9 -10.6 ng/ml and Q - 10.78 groups.

Taking into account the results of the effect of supplements on the induction of prolactin, and hence on milk secretion, we decided to investigate the growth of piglets obtained from sows of each group.

The analysis of research results regarding the growth (from 1 to 11 days) shows (Table 4) that during the 11 days of the suckling period it was significantly higher in piglets of groups M (1.72 kg), G18 (1.69 kg), G9 (1.69 kg) and Q (1.67 kg) compared to the control group (1.27 kg). It should be noted that in the M group during this period the growth in live weight of piglets was higher than for piglets of the G18, G9 and Q groups, but was within error. At the same time, between the 11th and 21st day of the suckling period, the growth for animals of the K group (1.53 kg) was lower compared to the M group (1.86 kg, P<0.05), G18 (1.96 kg), G9 (1.61 kg) and Q (1.75 kg). The growth dynamics of the animal of the G18 group was superior to the other experimental groups the growth of piglets of this group was 1.96 kg, and was higher than in the M, G9 and Q groups. Over the entire suckling period the growth of piglets of groups M, G18, G9 and Q was 3.58 kg, 3.65 kg, 3.31 kg and 3.44 kg, respectively, and was higher than that of K by 0.64 kg (P<0.001), 0.71 kg (P<0.001), 0.37 kg (P<0.05) and 0.5 kg (P<0.01), the difference was statistically significant. It should be noted that the growth of suckling piglets for the entire study period was the highest in the G18 group (3.65 kg).

From the results you can see that all the studied supplements have a positive effect on the growth rate of piglets. From the analysis of growth, which is shown in Table 3, and the content of prolactin in the blood of experimental sows (Table 2), it can be argued that the scheme of administration of Glutam 1M at a dose of 18 mg/kg, combined with germanium nanoaquachelate of after the farrowing is the most effective. As the concentration of prolactin was the highest in this group, this indicates that these supplements have a higher stimulating effect on the pituitary gland and, as a result, on milk secretion. The effectiveness of the application of this scheme is evidenced by the results of the growth in live weight of piglets, in the second experimental group they were the highest for the entire post-weaning period. Our results are confirmed by the results of Rezaei et al. (2022), who found that feeding a dietary supplement containing monosodium glutamate increases milk consumption by piglets by 14% and, accordingly, increases growth by 23-44%.

Also, to analyse the effect of the studied additives on the reproductive capacity of sows, the concentration of progesterone, testosterone and estradiol in the blood of sows on the day of piglet weaning (28 days after farrowing) was determined (Table 5). Testosterone levels in all study groups ranged from 1.11 to 1.77 ng/ml and corresponded to all physiological norms.

Table 3 - The content of prolactin in the blood of sows on different days of the suckling period, ng/ml (n=5)

Group \ Indicators M±m	After the farrowing	4-th day	Weaning
Group K (control)	12.02±0.97	10.54±2.09	12.8±0.98
Group M	9.94±1.45	10.8±1.79	10.6±1.77
Group G18	14.6±1.18[a]	11.76±2.31	14.9±0.12[a]
Group G9	13.42±1.63	14.58±2.19[b]	10.6±1.2[b]
Group Q	11.34±2.00	7.76±1.22[c]	10.78±2.18

[a]P<0.0 - compared with the M group; [b]P<0.01: compared with the G18 group; [c]P<0.05: compared with G9 group; M: arithmetic mean; m: standard error of means

Table 4 - Growth at different intervals of the sucking period, kg

Group \ Indicators M±m	For 11 day	Within 11 and 21 days	Whole suckling period
Group K (control)	1.27±0.097	1.53±0.122	2.94±0.140
Group M	1.72±0.064[b]	1.86±0.091[a]	3.58±0.114[b]
Group G18	1.69±0.091[a]	1.96±0.073[b]	3.65±0.131[b]
Group G9	1.69±0.091[a]	1.61±0.083[a]	3.31±0.107[a]
Group Q	1.67±0.057[b]	1.75±0.073[a]	3.44±0.103[b]

[a]P<0.05: compared with the K; [b]P<0.01: compared with the M group; M: arithmetic mean; m: standard error of means

Table 5 - Concentration of hormones in the blood of sows on the day of weaning and their subsequent reproductive capacity (n=5)

Groups \ Indicators M±m	Progesterone n/ml	Testosterone ng/ml	Estradiol pg/ml	First estrus after weaning (days)
Group K (control)	18.66±1.76	1.23±0.27	39.8±4.83	6.7±0.84
Group M	23.46±2.16	1.11±0.04	50.6±7.08	3.8±0.84
Group G18	21.48±1.97	1.74±0.26[a]	50.0±5.7	4.0±1.22
Group G9	23.34±4.87	1.56±0.16[a]	49.6±5.09	3.6±0.89
Group Q	21.56±4.16	1.77±0.10[b]	50.6±6.61	4.2±1.30

[a]P<0.05: compared with the K; [b]P<0.01: compared with the M group; M: arithmetic mean; m: standard error of means

It is known that the content and the ratio of sex hormones in the blood of females vary depending on their physiological condition. The concentration of progesterone and oestradiol in the serum characterizes the stage of the reproductive cycle of animals. The highest level of progesterone is observed during the corpus luteum phase and pregnancy, and the lowest level during the beginning of the follicular phase (Seba and Khomenko, 2017). In our studies, it was found that the lowest level of progesterone was in the K group as 18.66 ng/ml, and the highest in the M group – 23.46 ng/ml, the difference was 20.6%. In the G18, G9 and Q groups, the hormone concentration was at the level of 21.48, 23.34 and 21.56 ng/ml, which is by 13.1, 20.0 and 13.4% higher compared to control animals. Based on the fact that supplements have been used in the M, G18, G9, Q groups, and the level of progesterone the was higher compared to animals in the K group, it can be assumed that the studied supplements affect the synthesis of progesterone.

Analysis of the content of oestradiol in the serum of sows shows that the lowest level of this indicator, as well as progesterone, was in the K group, and was 39.8 pg/ml, while in the M, G18, G9, Q groups it was higher by 21.3; 20.4, 19.8 and 21.3%. The difference between the experimental groups was within 2%. It should be noted that the animals in the control group came into heat 6.7 days after weaning, while in the experimental groups it was 2.9 (M), 2.7 (G18), 3.1 (G9) and 2.5 (Q) days earlier.

The supplement Glutam 1M was created on the basis of glutamine amino acid, which belongs to the 116 neurotransmitter amino acids that stimulate the transmission of excitation in the synapses of the central nervous system (Mosharova et al., 2004). Studies by several scientists testify to the influence of glutamate on the endocrine cells of the adenohypophysis, thus it can induce the release of prolactin (Frederick et al., 2006). During usage of the supplement Glutam 1M, an increase in the prolactin level was observed in sows, and an increase in growth in piglets of these groups. Based on this, it can be assumed that the supplement, which includes monosodium glutamate, stimulates the pituitary gland to release an additional amount of prolactin into the blood, and due to prolactin, the secretion of milk increases and its consumption by piglets increases, which contributes to the increase in growth of in these groups compared to group K.

The results of the studies of the Q group show that the microelements included in the supplement do not affect the prolactin level; however, in this group the growth was 14.5% and 3.8% higher compared to groups K and M. Such indicators show a positive effect of microelement not only on the body of the sow, but also through milk on the body of suckling piglets. According to the research data of some authors, it is known that the administration of selenium in the form of chelated form to farrowing and suckling sows contributes to the increase of multiple fertility, litter weight on the day of farrowing, milk yield, and also increases the average growth and survival of suckling piglets (Usenko et al., 2019). In addition, the researchers found that adding Cu at a dose of 60 to 250 mg to sows before farrowing reduced piglet mortality and increased piglet weight due to increased milk production in the sow. According to their data, the higher average daily growth may be associated with the participation of copper in the regulation of mRNA expression of neuropeptide Y, which stimulates feed consumption by animals.

Pilipchuk and Sheremeta et al. (2016 a, b) established that the Glutam 1M supplement /component affects the hypothalamic-pituitary system in sows. In addition, glutamate affects the hypothalamus and, due to an increase in glutamatergic transmission through KiSS-1 peptide to GnRH neurons, stimulates the increase of antral follicles (Bezverkha et Al., 2019; Meza-Herrera et. al, 2020; Santos Soares et. al, 2023). The results of research showed that feeding Glutam 1M to sows of a large white breed causes a tendency to increase the concentration of progesterone and oestradiol in the blood, which contributes to the improvement of their reproductive capacity, namely: fertilization, multiple fertility, high fertility and preservation of piglets in the embryonic period increase (Pilipchuk and Sheremeta, 2016 a; Bezverkha et Al., 2019). According to the results of research, the oestradiol level was higher by 21.3% and 21.3%, progesterone by 20.6% and 20%, in the groups usage Glutam 1M at a dose of 18 mg per kg. In the Q group (Table 5), there is also an increase in these indicators compared to the control, which is probably related to the fact that trace elements such as copper, manganese, selenium, chromium included in the Quatronan-Se are directly related to the action of enzymes, hormones (Scott, 2005; Nicola et al., 2013). They are the part of vitamins, take an active part in the metabolism of nucleic acids, protein synthesis, tissue differentiation and growth, and reproductive capacity (Hayirli, 2005), Manganese takes a direct part in the synthesis of cholesterol, which in turn affects the formation of sex hormones, including progesterone and estrogen (Jan et al., 2022). Cr plays an important role in the production of insulin, which affects the synthesis of progesterone, LH (luteinizing hormone) and stimulates the growth of follicles and ovulation (Kafilzadeh et al., 2012; Jan et al., 2022).

The analysis of the subsequent reproductive function shows that the animals of the experimental groups came into heat on average 3-4 days after weaning, while the sows of the control group came into heat on the 6-7th day (Table 5). It is known from the scientific literature that at the end of the follicular phase, under the influence of luteinizing hormone, progesterone is secreted by the ovaries. Ovulation occurs against the background of a high level of oestradiol and the release of progesterone (Rosca et al., 2017; Langendijk, 2021). These data confirm the results of present research, from which we can conclude that the studied supplements and their administration schemes have a positive effect on the further reproductive capacity of sows.

CONCLUSION

It was found that feeding sows (before and after farrowing) with nanoaquachelate germanium, Glutam 1M and Quatronan-Se supplements have a positive effect on the synthesis of prolactin in sows and the growth of suckling piglets. The use of the above supplements helps increase the sows' reproductive capacity.

- The highest level of prolactin in the blood was observed in the sows of G18 group as 14.6 ng/ml after farrowing and 14.9 ng/ml – on the day of weaning piglets, respectively 21.5 and 16.4% more compared to control animals.
- During the entire pre-weaning period, the piglets of group G18 had a growth in live weight of 24.1; 1.9; 9.3, and 5.7% higher than the analogues of the K, M, G9 (P<0.05), and Q groups.
- Sows of the M, G18, G9, Q groups went back into heat on average 3-4 days after weaning piglets, and animals of the K group, 6-7 days.

It can be suggested that the proposed regimen for sows administrating with Glutam 1M at a dose of 18 mg/kg, with nanoaquachelate germanium at a dose of 5 mg/kg (study group G18) is the most effective.

DECLARATIONS

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Ethical regulation

When conducting the study, the rules of handling animals were followed in accordance with the European Convention "On the Protection of Vertebrates. Animals Used for Research and Other Scientific Purposes" (1986). The protocol for taking blood from sows was agreed with the Bioethical Commission of the National University of Life and Environmental Sciences of Ukraine (No. 002/2023).

Data availability

The datasets used during the current study available from the corresponding author on reasonable request.

Authors' contribution

Inna Kurbatova, Ihor Holovetskyi, and Inna Kepkalo helped in the planning and design of the study. Maryna Khomenko, Seba Mykola, Ruban Serhiy, Bogdanova Nataliya participated in the conducted research and processing of the received data. Mykola Seba and Maryna Khomenko revised the manuscript critically. All authors have read and approved the published version of the manuscript.

Acknowledgements

The authors would like to thank the owner, employees of the commercial farm SERF «Stepne» where the experimental study was conducted.

Competing interests

The authors have not declared any conflict of interests.

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2024 SCIENCELINE

Online Journal of Animal and Feed Research

Volume 14, Issue 6: 390-401; November 30, 2024 ISSN 2228-7701

DOI: https://dx.doi.org/10.51227/ojafr.2024.45

EVALUATION OF THE STINGING NETTLE (*Urtica simensis*) AS NON-CONVENTIONAL ANIMAL FEEDSTUFF IN SELECTED HIGHLAND AREAS OF SOUTH WOLLO OF ETHIOPIA

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Supporting Information

RESEARCH ARTICLE
PII: S222877012400045-14
Received: August 08, 2024
Revised: November 18, 2024
Accepted: November 19, 2024

ABSTRACT: This study assessed the use of stinging nettle as animal feed and evaluated its biomass yield and nutritional quality in Dessie Zuria and Legambo districts, Ethiopia. Data were collected from 384 randomly selected respondents and growing niches across 8 *kebeles*. Findings indicated a demand for 1935 tons of dry matter (DM), while available feed resources contributed only 915.41 tons of DM, highlighting a significant feed shortage. Stinging nettle, which remains vegetative in both wet and dry seasons, was identified as a potential supplementary feed. Over 77.86% of respondents reported that ruminants consume the leaves and stems, while 13.02% noted that chickens rarely use the leaves, and equines never consume any part of the plant. Cattle preferred stinging nettle in both seasons, but small ruminants showed preference only during the dry season, and chickens showed the least preference in the wet season. Most households (83.6-89.3%) treated the plant by wilting it for 2-6 hours, while others (4.40-10.16%) dry it, and the rest (4.69-9.89%) mix it with other feeds to minimize its stinging nature. Common growing niches for stinging nettle include backyards, pastureland, and roadsides, with the first producing a higher biomass yield of 22.29 tons/ha ($P<0.02$) than the roadsides (14.89 tons/ha), and the pastureland yielded intermediate biomass (19.21 tons/ha). Stinging nettle from pastureland niche had higher crude protein (CP, 25.26%) and *in vitro* dry matter digestibility (60.90%, $P<0.001$). The ash (7.90%), neutral detergent fiber (NDF, 39.74%), and acid detergent fiber (24.16%) contents were lower for samples taken from the pastureland niche. In conclusion, stinging nettle is suitable for supplementation due to its favorable nutritional qualities. Further studies, such as animal feeding trials and investigations into anti-nutritional factors, are needed for more detailed information on the use of the stinging nettle plant as an animal feedstuff.

Keywords: Agro-ecology, Biomass yield, Growing niche, Nutritional quality, Stinging nettle, Wilting.

INTRODUCTION

The livestock sector in Ethiopia is vital for providing food, income, services, and foreign exchange (Osei et al., 2018). The productivity of livestock depends on animals' nutrition, health status, and genetic potential (Getahun, 2012). Among these key factors, nutrition is the most critical factor, representing a significant cost in livestock production. Unfortunately, Ethiopia's livestock productivity remains low, lagging behind the growth of the human population, which leads to a decline in per capita consumption of animal products (Tegegne and Feye, 2020). This productivity challenge primarily stems from several factors, with feed scarcity both in quality and quantity being the principal problem (Alemayehu et al., 2016).

Livestock feed resources in Ethiopia mainly originate from natural pastures and crop residues. However, the natural pastures are shrinking due to the expansion of crop production to support the rapidly growing human population and urbanization (Kassahun et al., 2016). Besides, crop residues, which are obtained post-harvest, tend to be more fibrous and less digestible. Consequently, both crop residues and natural pastures typically fail to meet the nutritional needs of livestock, resulting in low productivity (Dereje et al., 2015; Getnet et al., 2016). Furthermore, smallholder farmers rarely utilize grains, essential ingredients in concentrated livestock feeds, due to their high cost and limited availability, as there is direct competition for grains with food for human consumption. Therefore, enhancing feed availability and quality is critical for boosting livestock productivity in the country (Tegene et al., 2009; Ayele et al., 2021).

Although efforts have been made to introduce improved species of grasses, legumes, and fodder trees across various regions in Ethiopia, the adoption of these forages within the mixed crop livestock farming systems faces numerous challenges (Diribi, 2022). To improve the productivity and reproductive capacity of animals under smallholder conditions, ensuring the availability and quality of feedstuffs is imperative. One potential option to these challenges, particularly in the dry season, could be the use of indigenous drought-resistant and non-conventional feed resources (Chharang, 2022). Assessing alternative feeds from locally available sources could help meet nutritional

Citation: Abera F, Seid A and Kehaliew A (2024). Evaluation of the stinging nettle (*Urtica simensis*) as non-conventional animal feedstuff in selected highland areas of South Wollo of Ethiopia. *Online J. Anim. Feed Res.*, 14(6): 390-401. DOI: https://dx.doi.org/10.51227/ojafr.2024.45

needs, reduce competition for human food, lower feed costs, and contribute to self-sufficiency (Belay and Janssens, 2021).

Among the locally available feed resources, stinging nettle (*Urtica simensis*), which is endemic to Ethiopia, can be one of the potential feed resources for livestock (Dagem et al., 2016). Stinging nettle, known locally as '*samma*' in Amharic, is a perennial plant recognized for its unpleasant stinging hairs on the stems and leaf surfaces. It is an erect and non-branched plant that grows wild in the highland regions of Ethiopia, such as north and south Gondar, north and south Wollo, north Shewa, and Wag Hamra (Dagem et al., 2016). Stinging nettle is nutritionally robust and has a higher nutritional value (Bhusal et al., 2022). The leaves are rich in protein and vitamins (Joshi et al., 2014), with an average crude protein (CP) content of about 22% (Teixeira et al., 2023). The leaves contain crude protein, ash, crude fiber, and carbohydrate contents of 33.77%, 16.21%, 9.08%, and 37.39%, respectively (Kregiel et al., 2018). Despite its high nutritional potential, stinging nettle is underutilized as animal feed (Dereje et al., 2015). Earlier studies indicate that the nutritional value of stinging nettle as animal feed is influenced by anti-nutritional factors, harvesting stage, and nitrogen fertilization (Radman et al., 2016). Additionally, Jimoh et al. (2010) reported that the leaves contain alkaloids, phytates, and saponins, which may affect livestock health.

Currently, there is limited information on the use of stinging nettle as animal feed, and its biomass yield and the nutritional quality, especially in the highland areas of South Wollo, where it is used as animal feed in districts like Dessie Zuria and Legambo. Therefore, this study was carried out in the highland areas of Dessie Zuria and Legambo districts to assess the extent of use of stinging nettle as animal feed and evaluate its biomass yield and nutritional quality.

MATERIALS AND METHODS

Description of the study area

The study was carried out in the highland areas of Dessie Zuria and Legambo districts, located in South Wollo, Ethiopia. Dessie Zuria is located between 10°50′00″ and 11°30′00″ N latitude and 39°20′00″ and 40°00′00″ E longitude, covering a total area of 937.32 km^2. On the other hand, Legambo district lies between 10°40′00″ and 11°20′00″ N latitude, and 38°40′00″ and 40°00′00″ E longitude with an area of 1017 km^2 (Figure 1).

Dessie Zuria district has a diverse landscape, including valleys, gorges, and mountainous areas, and it is classified into three agro-ecological zones: sub afro-alpine (*wurch*), highland (*dega*), and midland (*woina dega*), comprising 25, 30, and 45% of the district's total area, respectively. The altitude ranges from 1800 to 3700 meters above sea level (masl). Likewise, Legambo district has a comparable landscape and is similarly categorized into three agro-ecological zones: 2.2% *wurch*, 48.4% *dega*, and 49.4% *woina dega*. The altitude of Legambo district ranges from 2100 to 4050 masl. According to 17 years of climatic data (2002 to 2018) collected from the Kombolcha Meteorological Agency, Dessie Zuria district had mean annual minimum and maximum temperatures of 4.25 and 14.75°C, respectively. Over a span of 20 years (1999-2018), the mean annual rainfall was recorded at 1354.3 mm. Based on 10 years of data (2009 to 2018) obtained from the same meteorological agency, Legambo district's mean annual minimum and maximum temperatures were 4.8 and 18.3°C, respectively. Additionally, the mean annual rainfall obtained over 20 years (1998-2017) was 1180.3 mm. Both districts have a mixed crop-livestock production system. The common livestock species include cattle, sheep, goats, equines, poultry, and honeybee colonies. The primary feed resources for livestock consist of natural pastures and crop residues, with the latter primarily derived from barley (*Hordeum vulgare*) and wheat (*Triticum aestivum*) straws, and maize (*Zea mays*) stover.

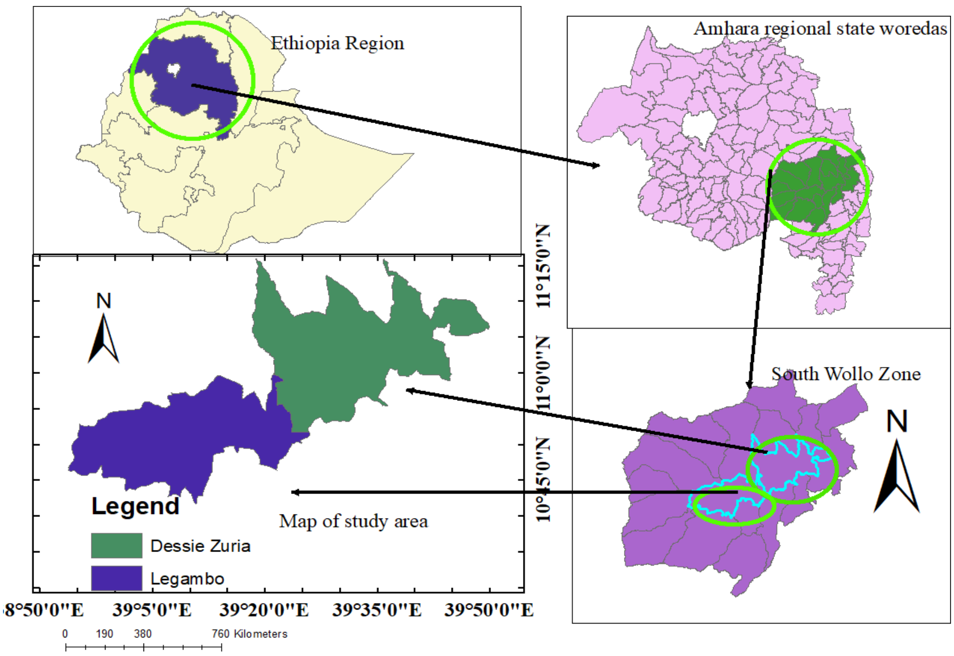

Figure 1 - Map of Dessie Zuria and Legambo districts, South Wollo, Ethiopia

Sample size determination, sampling design, and method of data collection for the survey study

A rapid rural appraisal (RRA) was conducted to identify *kebeles* (smallest administrative units within a district) which were highly dominated by stinging nettle plants. Since it was difficult to find previous exploratory studies regarding stinging nettle use as animal feed and its nutritional quality in South Wollo, a 50% expected use of this plant as animal feed was considered. Using 5% desired absolute precision and a 95% confidence interval (CI), the sample size was determined using the formula for sample size determination in random sampling for a large population (Thrusfield, 2007): $n = [(Z\alpha/2)^2P(1-P)]/d^2 = [(1.96)^2(0.5)(1-0.5)]/(0.05)^2 = 384$ where, n = required sample size; $Z\alpha/2$ = reliability coefficient or confidence interval (CI) = 1.96 for the 95%; P = expected use of stinging nettle as animal feed; and d = desired absolute precision. Accordingly, 384 respondents were selected for the study.

In the two districts, eight rural *kebeles* were purposefully selected based on their potential for stinging nettle and accessibility. In each district, two *kebeles* were selected from the highland (*dega*) agro-ecology and another two from the sub afro-alpine (*wurch*) agro-ecology. A total of 48 respondents were randomly selected from each *kebele*. Data were collected from respondent household heads using a pre-tested semi-structured questionnaire. Eight enumerators, one for each *kebele*, were chosen from development agents and received training before and during the questionnaire pre-testing. The survey was conducted using a single-visit multiple-subject survey method of ILCA (1990).

The questionnaire generated information on the mode of utilization of stinging nettle, including the parts of the plant consumed by livestock, preference levels, seasonal availability, and preparation practices for fresh herbage prior feeding to livestock. Additionally, one focus group discussion (FGD) was conducted in each district with 8-12 participants, including elders, livestock keepers, and agricultural experts. Key informants, who were knowledgeable about stinging nettle and for data related to land and livestock holdings of the study districts and major livestock feed resources, were also consulted to provide supplementary information.

The feed supply was estimated using key data from respondents, particularly the total dry matter yield. The nutrient contributions from each feed type were assessed based on the total dry matter (DM) output and nutrient content of each feed type (Kumara et al., 2022). Practical carrying capacity (PCC) was used to calculate the total demand for forage, indicating the actual number of livestock carried by a certain area within a certain period and reflecting the current carrying capacity. Demand for feed was calculated by standardizing the number of each animal species into Tropical Livestock Units (TLU; Rothman-Ostrow et al. 2020) using the conversion factors of 0.7 for cattle, 0.1 for small ruminants, 0.01 for chicken, 0.8 for horses, 0.7 for mules, and 0.5 for donkeys (ILCA, 1990; Jahnke, 1982). Furthermore, the theoretical carrying capacity (TCC) was used to estimate feed supply by including all available feed resources. The TCC represents the maximum number of livestock an area can support in a certain period to meet the requirements for livestock production (growth, reproduction, etc.) under the premise of moderate grazing and sustainable grassland production (Xu, 2014). Hay, crop residues, and natural grasses, comprising over 90% of livestock feed resources in Ethiopia, were used for the estimation of the quantity of feed supplied in the study area.

Sampling stinging nettle and preparation of samples

Stinging nettle herbage sampling was conducted after completing the household survey. Stinging nettle plants that grew naturally were collected in the highland (*dega*) and sub afro-alpine (*wurch*) agro-ecological zones of both districts. Based on the information generated during the survey part of the study, the stinging nettle plants were sampled at a maturity stage preferred by livestock species, as reported by respondents. Three niches (backyard, pastureland, and roadside), on which stinging nettle grows with high production potential, were considered for sampling in each of the 8 *kebeles*. A niche refers to the specific environmental conditions under which stinging nettle species thrive (Neto and Albuquerque, 2018). It includes sets of biotic and abiotic factors of the environment that define the limits within which a species can survive (Fodor, 2011). In each selected niche, 3 quadrats, each measuring 1 m^2 (1 m × 1 m) were demarcated at random (Tarawali et al., 1995). The entire stinging nettle within each quadrat was harvested at a stubble height of 20 cm from the ground using a sickle.

The harvested stinging nettle herbage biomass from a specific niche was thoroughly mixed to make a composite sample, from which a 1 kg sub-sample was taken. A total of 72 samples (8 *kebeles* × 3 niches/*kebele* × 3 samples/niche) were collected. The samples were partially dried under shade to prevent spoilage and nutrient loss until transported to the feed analysis laboratory of Holeta Agricultural Research Center.

Analysis of the chemical composition of stinging nettle

The proximate chemical compositions of stinging nettle were analyzed following standard methods (AOAC, 1999). Moisture content was determined by drying samples in an oven at 102°C for 16 h (AOAC method 950.46). The dried samples were incinerated in a muffle furnace at 550°C for 5-6 h to determine the ash content. The N content was determined by the Kjeldahl method (AOAC method 981.10; AOAC, 1999) using a mixture of copper sulfate and potassium sulfate in a 2:1 ratio as a catalyst. The crude protein (CP) content was calculated by multiplying the N concentration by 6.25. Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin

(ADL) were determined by the method of Van Soest et al. (1991); whereas, *in vitro* dry matter digestibility (IVDMD) was determined following the methods of Tilley and Terry (1963).

Statistical analysis

Data were analyzed using SAS software, version 9.1 (SAS Institute Inc., Cary, NC, USA) (SAS, 2004). Descriptive statistics, including frequency, means, percentages, range, and standard deviation, were employed for the survey data. Nominal frequency data for specific variables were compared using the one-way Chi-Square test. Laboratory analysis data were subjected to analysis using the General Linear Model (GLM) procedure of SAS. The least squares means were generated using the LSMEANS option and separated by PROC GLM with the PDIFF option for treatments with significant effects at $P<0.05$ using Tukey's multiple comparison procedure. The following model was used to analyze the effect of all possible factors on the quantitative data:

$$Y_{ijkl} = \mu + D_i + A_j + N_k + (DA)_{ij} + (DN)_{ik} + (AN)_{jk} + (DAN)_{ijk} + e_{ijkl},$$

where, Y_{ijk} = response or dependent variable (biomass yield and chemical composition of stinging nettle) across districts, agro-ecologies, and niches,

μ = overall mean; D_i = the effect of district (i = Dessie Zuria and Legambo); A_j = the effect of agro-ecology or altitude (j = sub afro-alpine and highland); N_k = the effect of niche type (k = backyard, pastureland, and roadside); $(DA)_{ij}$ = the interaction between the ith district and the jth agro-ecology; $(DN)_{ik}$ = the interaction between the ith district and the kth growing niche; $(AN)_{jk}$ = the interaction between the jth agro-ecology and the kth growing niche; $(DAN)_{ijk}$ = the second-order interaction; and e_{ijkl} = the random error.

RESULTS

Feed supply and demand in the study area

Table 1 illustrates the estimated feed produced for the maintenance requirement of the livestock population in the study districts. The total annual utilizable dry matter (DM) produced from major livestock feed resources was 915.41 tons, markedly insufficient compared to the 1935 tons of DM required for the 712 tropical livestock units (TLUs) present (Table 2). This negative feed balance signifies a substantial feed gap in the study area.

Table 1 - Estimated amount of feed produced for maintenance requirement of the livestock population in the study districts.

District	Feed resource	Area covered (ha)	Estimated feed productivity (tons/ha)	Total DM feed produced (ton)
Dessie Zuria	Barley straw	144	1.8	259.20
	Natural pasture	41.37	2.0	82.74
	Fallow land	38.25	1.8	68.85
	Improved forage	1.31	8.0	10.48
Legambo	Barley straw	147.00	1.8	264.60
	Natural pasture	52.50	2.0	105.00
	Fallow land	27.25	1.8	49.05
	Improved forage	9.49	8.0	75.49
Total				915.41

DM = dry matter; ha = hectare

Table 2 - Estimated amount of feed demanded for maintenance requirement of the livestock population in the study districts

Species	Dessie Zuria			Legambo		
	Number	TLU	Annual DM demand (ton)	Number	TLU	Annual DM demand (ton)
Cattle	511	358	817	540	378	862
Sheep	1179	118	269	1622	162	370
Goat	163	16	37	263	26	59
Horses	109	87	199	147	118	269
Donkeys	190	95	217	223	112	256
Mules	48	33	75	67	46	105
Chicken	532	5	11	593	6	14
Total	-	712	1625	-	848	1935

Conversion factors used to change animal numbers to tropical livestock unit (TLU): cattle = 0.7, sheep and goat = 0.1, horses = 0.8, donkeys = 0.5, mules = 0.7, and chicken = 0.01 (ILCA, 1990; Jahnke, 1982).

Table 3 - Respondents' observation on the consumption of the different parts of stinging nettle by livestock species in Dessie Zuria and Legambo districts, South Wollo, Ethiopia

Species	Part of stinging nettle consumed	Dessie Zuria		Legambo		Overall	
		N=192	%	N=192	%	N=384	%
Cattle	Leaf	0	0.00	1	0.52	1	0.26
	Leaf and stem	176	91.67	189	98.44	365	95.05
	None	16	8.33	2	1.04	18	4.69
Sheep	Leaf	3	1.56	0	0.00	3	0.78
	Leaf and stem	173	90.11	190	98.96	363	94.53
	None	16	8.33	2	1.04	18	4.69
Goat	Leaf	35	18.23	21	10.94	56	14.59
	Leaf and stem	136	70.83	163	84.89	299	77.86
	None	21	10.94	8	4.17	29	7.55
Chicken	Leaf	14	7.29	36	18.75	50	13.02
	Leaf and stem	0	0.00	0	0.00	0	0.00
	None	178	92.71	156	81.25	334	86.98
Horse	Leaf	0	0.00	0	0.00	0	0.00
	Leaf and stem	0	0.00	0	0.00	0	0.00
	None	192	100.00	192	100.00	384	100.00
Donkey	Leaf	0	0.00	0	0.00	0	0.00
	Leaf and stem	0	0.00	0	0.00	0	0.00
	None	192	100.00	192	100.00	384	100.00
Mule	Leaf	0	0.00	0	0.00	0	0.00
	Leaf and stem	0	0.00	0	0.00	0	0.00
	None	192	100.00	192	100.00	384	100.00

None refers to respondents who noted that any part of the stinging nettle was not consumed by animals

Table 4 - Extent of preference for stinging nettle plant by livestock species as perceived by respondents in Dessie Zuria and Legambo districts, South Wollo, Ethiopia

Species	Preference	Dessie Zuria		Legambo		Overall	
		N=192	%	N=192	%	N=384	%
Cattle	Low	18	9.38	14	7.29	32	8.33
	Moderate	23	11.98	29	15.10	52	13.54
	High	151	78.64	149	77.60	300	78.13
Sheep	Low	21	10.94	36	18.75	57	14.84
	Moderate	148	77.08	118	61.46	266	69.27
	High	23	11.98	38	19.79	61	15.89
Goat	Low	35	18.23	59	30.73	94	24.48
	Moderate	142	73.96	103	53.65	245	63.80
	High	15	7.81	30	15.62	45	11.72
Chicken	Low	192	100.00	186	96.88	378	98.44
	Moderate	0	0.00	1	0.52	1	0.26
	High	0	0.00	5	2.60	5	1.30

Mode of utilization of stinging nettle

Parts of stinging nettle consumed by different livestock species and their level of preference

Tables 3 and 4 summarize the parts of stinging nettle consumed by different livestock species and their preference levels. The survey revealed that around 77.86-95.05% of respondents observed ruminants (cattle, sheep, and goats) consuming all parts of the stinging nettle plant (leaves and stems). In contrast, only 13.02% of respondents noted that chickens rarely consume the leaves, while equines (horses, donkeys, and mules) do not consume any part of the plant. The majority of respondents (78.13%) stated that cattle highly prefer stinging nettle, with moderate preference noted for sheep (69.27%) and goats (63.80%). Chickens particularly exhibited the least preference (98.44%).

Season of feeding

Table 5 presents the seasonal feeding patterns of livestock species concerning stinging nettle plant. Slightly more than half of the respondents (52.3%) indicated that cattle consume the plant during both dry and wet seasons.

Small ruminants are reported to favor the plant predominantly in the dry season, as indicated by nearly 75-76% of the respondents. Chickens under free-range conditions rarely eat the plant during the wet season. Although preferences vary over seasons, the stinging nettle remains vegetative throughout both periods, as confirmed by 169 (88.02%) and 159 (82.81%) respondents in Dessie Zuria and Legambo districts, respectively (Figure 2).

Form of feeding of stinging nettle plant to animals

Due to its stingy nature, stinging nettle is often unsuitable for animal consumption unless treated. Over 83% of respondents stated wilting as a common treatment method to reduce the stinginess of the plant before feeding to ruminants. Additionally, less frequently used methods included drying and mixing the stinging nettle with other palatable feeds (Table 6).

Growing niches and wilting time of stinging nettle

A significant proportion (58.3%, P<0.003) of respondents indicated a need for 2 to 6 hours of wilting before feeding stinging nettle to animals. The most common growing niche for the plant was the backyard, followed by roadside, pastureland, farmland, and areas around water bodies (Table 7).

Biomass yield and chemical composition of stinging nettle

There was no significant difference in dry matter yield (DMY) of stinging nettle based on variations in district and agro-ecology. However, a significant difference (P<0.02) was noted in DMY among the growing niches. The backyard growing niche produced higher DMY than the roadside niche, and that of the pastureland was in-between (Table 8). The effects of district, agro-ecology, and growing niche on the chemical composition and *in vitro* dry matter digestibility (IVDMD) of stinging nettle are presented in Table 9. Values of all parameters did not vary significantly (P>0.05) between the two districts. Agro-ecology had a significant effect on dry matter (DM; P<0.01), neutral detergent fiber (NDF; P<0.003), and acid detergent fiber (ADF; P<0.03) contents, with higher values recorded in the sub afro-alpine than in the highland agro-ecology. Stinging nettle collected from different niches showed significant variations in all the chemical composition and IVDMD parameters except for the acid detergent lignin (ADL) content. The crude protein (CP) (P<0.001), organic matter (OM), and IVDMD (P<0.0001) contents of stinging nettle collected from the pastureland niche were higher than those obtained from the other niches. Conversely, lower contents of ash, NDF (P<0.0001), and ADF (P<0.004) were recorded for samples collected from the pastureland niche compared to the other niches. There was some inconsistency due to the significant interaction effect between the factors. Although the NDF value was higher in the roadside niche than in the backyard niche, the backyard niche from Dessie Zuria and the roadside niche from Legambo had comparable but higher NDF values compared to the NDF value at Legambo in the backyard niche. On the other hand, the pastureland niche in Dessie Zuria and the backyard niche in Legambo had higher IVDMD values than the values recorded in a similar niche of the other district. The overall average contents of the chemical composition and IVDMD of stinging nettle were 23.60% for CP, 43.43% for NDF, 25.45% for ADF, 3.82% for ADL, 10.25% for ash, and 56.07% for IVDMD.

Table 5 - The season when stinging nettle is mainly consumed by domestic animals in Dessie Zuria and Legambo districts, South Wollo, Ethiopia

Species	Season	Dessie Zuria		Legambo		Overall	
		N=192	%	N=192	%	N=384	%
Cattle	Wet	3	1.6	0	0.0	3	0.8
	Dry	66	34.4	96	50.0	162	42.2
	Both	107	55.7	94	49.0	201	52.3
	None	16	8.3	2	1.0	18	4.7
Sheep	Wet	4	2.1	0	0.0	4	1.0
	Dry	153	79.7	139	72.4	292	76.0
	Both	19	9.9	51	26.6	70	18.2
	None	16	8.3	2	1.0	18	4.7
Goat	Wet	4	2.1	0	0.0	4	1.0
	Dry	153	79.7	135	70.3	288	75.0
	Both	14	7.3	49	25.5	63	16.4
	None	21	10.9	8	4.2	29	7.6
Chicken	Wet	12	6.3	19	9.9	31	8.1
	Dry	1	0.5	3	1.6	4	1.0
	Both	1	0.5	14	7.3	15	4.0
	None	178	92.7	156	82.3	334	87.0

None refers to respondents who noted that the animals did not consume the stinging nettle at both seasons

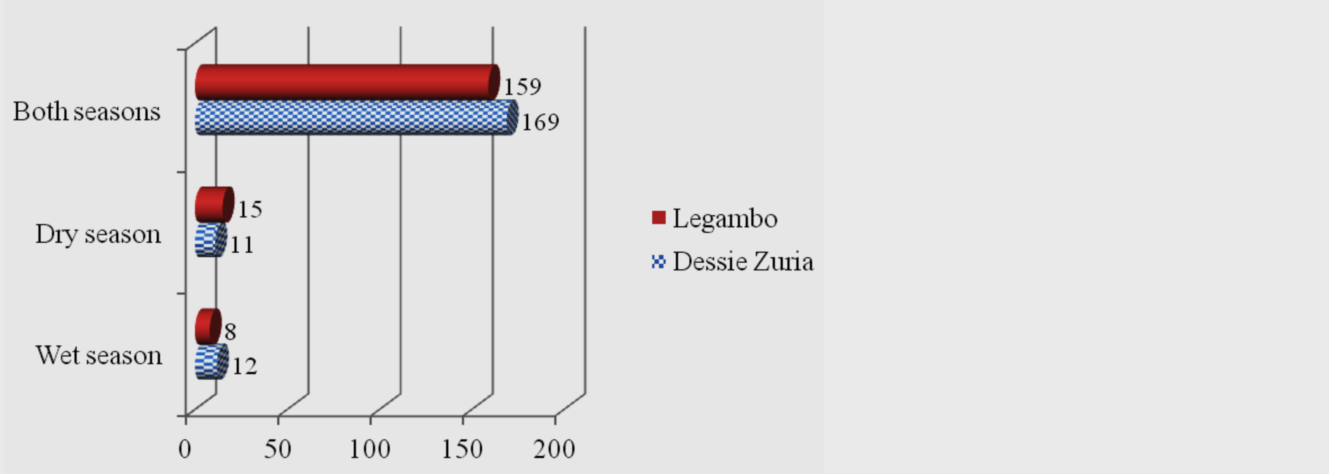

Figure 2 - Vegetativeness of stinging nettle over seasons

Table 6 - Practices or forms of feeding of stinging nettle to livestock species in Dessie Zuria and Legambo districts, South Wollo, Ethiopia

Species	Form of feeding	Dessie Zuria		Legambo		Overall	
		N=192	%	N=192	%	N=384	%
Cattle	Wilting	163	84.90	180	93.75	343	89.3
	Drying	7	3.60	10	5.21	17	4.4
	Mix with other feeds	22	11.5	2	1.04	24	6.3
Sheep	Wilting	166	86.46	161	83.86	327	85.15
	Drying	10	5.21	29	15.10	39	10.16
	Mix with other feeds	16	8.33	2	1.04	18	4.69
Goat	Wilting	165	85.94	156	81.25	321	83.60
	Drying	5	2.60	20	10.42	25	6.51
	Mix with other feeds	22	11.46	16	8.33	38	9.89

Table 7 - Growing niches and wilting time of stinging nettle in Dessie Zuria and Legambo districts, South Wollo, Ethiopia

Variables	Dessie Zuria		Legambo		Overall		P-value
	N=192	%	N=192	%	N=384	%	
Time of wilting							
2-6 h	117	60.9	107	55.7	224	58.3	0.003
7-11 h	51	26.6	48	25.0	99	25.8	
12 h	24	12.5	37	19.2	61	15.9	
Growing niche							
Backyard	76	39.6	76	39.6	152	39.6	
Roadside	48	25.0	49	25.5	97	25.3	0.038
Farmland	20	10.4	30	15.6	50	13.0	
Pastureland	42	21.9	31	16.1	73	19.0	
Side of a water body	6	3.1	6	3.1	12	3.1	

Table 8 - Values (Mean±SEM) of the dry matter yield of stinging nettle plant (ton/ha) at varying niches and agro-ecologies in Dessie Zuria and Legambo districts, South Wollo, Ethiopia

Niche	Dessie Zuria		Legambo		Overall mean	P-value
	SA	HL	SA	HL		
Backyard	21.83±3.28	19.51±3.28	26.75±3.28	21.11±3.28	$22.29±1.64^{a}$	
Pastureland	17.02±3.28	17.54±3.28	20.34±3.28	21.92±3.28	$19.21±1.64^{ab}$	0.02
Roadside	13.50±3.28	16.50±3.28	12.40±3.28	17.16±3.28	$14.89±1.64^{b}$	
Overall mean	17.45±1.89	17.85±1.89	19.83±1.89	20.06±1.89	18.80	
P-value			0.87			

SA = sub afro-alpine, HL= highland, SEM = standard error of the mean

Table 9 - Chemical composition and *in vitro* organic matter digestibility (%) of stinging nettle at varying agro-ecologies and niches in Dessie Zuria and Legambo districts, South Wollo, Ethiopia

Source of variation / Chemical composition	DM	Ash	OM	CP	NDF	ADF	ADL	IVDMD
District (A)								
Dessie Zuria	86.27	10.67	89.33	23.47	44.45	25.69	3.94	55.71
Legambo	87.06	9.82	90.18	23.73	42.42	25.22	3.70	56.44
P-value	NS	NS	NS	NS	0.002	NS	NS	NS
Agro-ecology (B)								
Highland	85.97[b]	9.78	89.56	23.48	42.47[b]	24.89[b]	3.41	56.02
Sub afro-alpine	87.36[a]	10.71	89.96	23.72	44.39[a]	26.01[a]	4.24	56.13
P-value	0.01	NS	NS	NS	0.003	0.03	NS	NS
Niche (C)								
Backyard	87.73[a]	11.25[a]	88.75[b]	22.83[b]	44.44[b]	25.89[a]	3.97	53.88[b]
Pastureland	85.88[b]	7.90[b]	92.10[a]	25.26[a]	39.74[c]	24.16[b]	3.29	60.90[a]
Roadside	86.49[ab]	11.59[a]	88.41[b]	22.71[b]	46.13[a]	26.30[a]	4.20	53.44[b]
P-value	0.02	0.0001	0.0001	0.001	0.0001	0.004	NS	0.0001
Interactions								
A × B	NS	NS	NS	NS	NS	NS	NS	NS
A × C	NS	NS	NS	NS	0.013	NS	NS	0.005
B × C	NS	NS	NS	NS	NS	NS	NS	0.006
A × B × C	0.01	0.01	NS	NS	NS	NS	NS	0.012
Overall mean	86.67	10.25	89.75	23.60	43.43	25.45	3.82	56.07

[a,b,c] Values in a column, within each source of variation, followed by a common superscript letter are not significantly different at $p<0.05$; DM = dry matter, OM = organic matter, CP = crude protein, NDF = neutral detergent fiber, ADF = acid detergent fiber, ADL = acid detergent lignin, IVDMD = *in vitro* dry matter digestibility, NS = not significant.

DISCUSSION

Feed supply and demand in the study area

The forage gap analysis has indicated a wide disparity between the amounts of forage supplied and demanded in the study area. The rapid increase in human population has led to a reduction in grazing lands. Specifically, lands allocated for fallowing and improved forage production have been converted to cropland to sustain families' food security. Consequently, the amount of feed produced for livestock has diminished, resulting in a negative feed balance. Similar negative feed balances were reported by Adinew et al. (2020) in the Misha district of the Hadiya zone, Ethiopia. The current investigation has revealed feed shortages as a critical issue affecting both study districts. Despite the feed scarcity, there is a great opportunity to raise output levels by addressing the issue of nutritional imbalance and enhancing livestock performance (Jabesa et al., 2021).

The local feed resources are under increasing pressure to meet the growing demands of the livestock population, aiming to improve productivity (Habib et al., 2016). Through focus group discussions and key informant interviews, it was revealed that local inhabitants utilize stinging nettle as an alternative feed resource for livestock due to the scarcity of conventional feed resources. However, it's important to note that biodiversity of plant species, including herbaceous and browse forages, tends to decline with altitude increase, while the prevalence of stinging nettle rises (Swierszcz et al., 2024). These conditions may have further contributed to the use of stinging nettle as a non-conventional animal feed in the highland areas of the study districts to address the imbalance between the demand and supply of feed.

The lack of adequate feed, both in quantity and quality, improper utilization of crop residues, inconsistent supply of agro-industrial by-products, poor quality of commercial concentrates, and high cost of all the feed resources significantly contribute to feed shortages across Ethiopia (Melkamu and Wazir, 2022). This feed gap, defined by the discrepancy between available feed resources (expressed as dry matter (DM), metabolizable energy (ME), and CP) and the requirements of all animal species, indicates a 9% deficiency in DM and 45% and 42% deficiencies in ME and CP, respectively, reflecting the lack of quality feed in Ethiopia. Although the yearly feed availability equals the amount produced in that year, and imported and stocked feeds from previous years, the current study only accounted for the feed produced in the year under study to estimate the amount of feed supplied, as feed importation and stocking for future years were not common in the study area.

Mode of utilization of stinging nettle

Parts of stinging nettle consumed by livestock species and level of preference

This study highlighted the vital role of stinging nettle as a wild, non-conventional herbaceous feed source for ruminant domestic animals (cattle, sheep, and goats) and, to a lesser extent, for chickens (non-ruminants), with no contribution to equines (horses, donkeys, and mules). The feeding of stinging nettle by various livestock species may depend on their adaptive feeding behavior and the availability of alternative feed options (Ginane et al., 2015). Ruminants exhibit specific feeding behaviors that differ from non-ruminants, characterized by various morphological adaptations for consuming and digesting the chemical compounds of the plant cell wall (Nielsen et al., 2016).

Season of feeding

Due to seasonality in forage production, where feed is more abundant during the main rainy season and scarce during the dry season, there is no consistent supply of feed in Ethiopia. This inconsistency requires urgent attention to alternative methods of feed production, conservation, and utilization to sustain feed availability throughout the year. Consistent with the current study, reports indicate that farmers use various locally available non-conventional feed sources during times of feed scarcity as a coping mechanism to sustain livestock production (Juana et al., 2013). Unlike naturally growing grasses, stinging nettle remains vegetative in both the dry and wet seasons, similar to the forage trees and shrubs, and can be supplemented at any time of the year when feed scarcity occurs.

Form of feeding of stinging nettle plant to animals

Focus group participants indicated that stinging nettle, growing in pure stands in specific niches like backyards or roadsides, is harvested and allowed to wilt before being fed to livestock. In contrast, the plants growing in a mixture with other herbaceous forages on pasturelands are either grazed directly in the field or harvested and supplied to animals after drying for hay along with the other herbaceous forages. This illustrates the experiences of local farmers in managing feed resources effectively amidst challenges of availability. The plant loses its stinging nature following drying and becomes a valuable animal feed (Dereje et al., 2016).

Growing niches, biomass yield, and chemical composition of stinging nettle

Stinging nettle plants grow in various niches, each with distinct fresh or dry matter biomass yield potentials. The variation may primarily be associated with differences in soil fertility and harvesting frequency. The yield was higher in the backyard niche than on roadsides, likely due to the more fertile soil enriched by animals' organic manure and waste from homesteads. Stinging nettle plants thrive better in nitrogen-rich soils (Dereje et al., 2016; Kregiel et al., 2018).

The survey revealed that stinging nettle plants in pasturelands grow together with herbaceous grasses or legumes, which results in more frequent grazing. This frequent grazing or defoliation of the plants enables more tiny tillers of lower fibrous content to develop, leading to lower values of NDF and ADF, but higher contents of OM, CP, and IVDMD (McDonald et al., 2010). Grasses, legumes, and grass-legume mixtures with over 19% CP are rated as prime quality, while those below 8% are considered inferior (Kazemi et al., 2012). In the current study, the average CP content of stinging nettle was 23.60%, with all samples exceeding 22.71%, indicating a high quality consistent with the findings of Kassahun et al. (2016). The ADL values were comparable to those reported by Dereje et al. (2016), although some studies noted slightly higher CP values of 25.7% and 25.5% (Dereje et al., 2015; Dereje et al., 2016). Differences in CP values among studies may arise from variations in plant maturity and morphology, soil fertility, agro-ecology, and rainfall patterns (Dereje et al., 2016).

Overall, the average chemical composition and IVDMD values of stinging nettle in this study were 23.60% CP, 43.43% NDF, 25.45% ADF, 3.82% ADL, 10.25% ash, and 56.07% IVDMD. In contrast, Belete et al. (2012) reported a lower CP content of 14.40%, and higher values for some of the other parameters: 35.3% ADF, 13.5% ADL, and 13.2% ash in indigenous browse trees. According to NRC (2007), a CP content of above 20% is suitable for use as a protein supplement in low-quality roughages. The variability in IVDMD values across different growing niches can be linked to differing soil fertility levels. The lower IVDMD values for stinging nettle from backyard and roadside niches likely correlate with higher NDF and ADF values and lower CP contents. Conversely, the higher IVDMD for the stinging nettle collected from the pastureland niche can be attributed to elevated CP levels and reduced NDF and ADF values.

CONCLUSION

Based on the findings from the present study, there is severe feed scarcity in the highland areas of Dessie Zuria and Legambo districts. This situation has led livestock owners to utilize the non-conventional stinging nettle as an alternative animal feed. The leaves and stems of this herbaceous plant are used by ruminant animals, while only the leaves are rarely used by chickens. However, equines do not feed this plant. Livestock owners usually prepare the plant by wilting it for 2-6 hours before feeding it to animals, while a few of them adopt drying or mixing the stinging nettle with other herbaceous forages. Common growing niches for stinging nettle include the backyard, pastureland, and roadside areas, producing promising biomass yields ranging between 12.40 and 26.75 tons/ha. The plant is also a good source of crude protein (CP). The pastureland niche provides the plant with better CP and *in vitro* dry matter digestibility (IVDMD), and lower levels of fiber. With its superior biomass yield, high CP content, and IVDMD, stinging nettle is suitable for supplementation in animal feeding, mainly for ruminants during the dry season when feed supply is scarce. Further studies, such as animal feeding trials and investigations into anti-nutritional factors, are needed for more detailed information on the use of stinging nettle plant.

DECLARATIONS

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Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Acknowledgments

We are thankful to Wollo University for financially supporting this research. We also thank experts and development agents in Dessie Zuria and Legambo districts for their assistance during data collection, and to respondents who provided valuable survey data. We extend our gratitude to Holeta Agricultural Research Center for the chemical composition analysis of the feed samples.

Authors' contribution

Fatuma Abera involved in the inception of the study, data collection, data analysis and drafting of the manuscript. Dr. Ali Seid participated in the design, data analysis, and write-up of the manuscript. Dr. Aemiro Kehaliew conducted chemical composition analysis of forage samples and design of the study.

Competing interests

All authors declare that they have no conflicts of interest regarding this research work.

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2024 SCIENCELINE

Online Journal of Animal and Feed Research

Volume 14, Issue 6: 402-409; November 30, 2024

ISSN 2228-7701

DOI: https://dx.doi.org/10.51227/ojafr.2024.46

GROWTH PERFORMANCE, HAEMATOLOGICAL AND SERUM BIOCHEMICAL INDICES OF WEANER PIGS FED *Carica papaya* SEED AND LEAF MEAL AS DIETARY SUPPLEMENT

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Supporting Information

RESEARCH ARTICLE
PII: S222877012400046-14
Received: December 16, 2023
Revised: November 20, 2024
Accepted: November 21, 2024

ABSTRACT: A 28-day feeding trial was carried out to evaluate the performance characteristics and hemato-biochemical parameters of weaner pigs fed graded levels of *Carica papaya* seed and leaf meal supplementation. A total of 36 cross-bred (Large white x Landrace) strains of weaner pigs of average initial weight of 8.86±0.10 kg were used for the study. Four treatment diets designated T_1, T_2, T_3 and T_4 replicated 3 times in a completely randomized design (CRD) were formulated to include the *Carica papaya* leaf and seed meal at 0, 1, 2 and 3% levels, respectively. Data were collected on daily feed intake (DFI), daily weight gain (DWG), feed conversion ratio (FCR), cost benefit analysis, hematological indices and serum biochemistry. The body weight gain of the weaner pigs was highest in T_4 (3%) *Carica papaya* seed and leaf meal mix (CSLM) supplementation with the value of 353 g while the least value of 228 g was recorded by T_2 which significantly differed (P<0.05) from the control group. Hemato-biochemical parameters showed significant differences (P<0.05) between treatments, indicating positive influence of CSLM on the investigated parameters. The blood urea nitrogen and creatinine, alkaline phosphatase, alanine aminotransferase and aspartate aminotransferase concentration increased as the dietary levels of CLSM increased in the diets. Based on the above findings, it is recommended that CLSM can be included at a level of 3% for optimum performance, hemato-biochemical stability and profit maximization.

Keywords: *Carica papaya*, Dietary supplementation, Haematology, Serum biochemistry, Weaner pigs, biochemistry, supplement

INTRODUCTION

The increasing demand for animal protein coupled with more stringent economic conditions in Nigeria have encouraged greater interest in fast growing animals like pigs with short generation interval. Janson (2018) stated that with rising demands for animal protein production and continuous challenges in availability and composition of feed raw materials, the need for advancements in sustainable animal production rapidly increases. Moreover, with no end in sight to the war in Ukraine and tight global stocks, uncertainty continues to hang over conventional feed raw materials like wheat, soybean, millet and oilseed cakes etc. (AMIS, 2023).

Pig production despite the social and religious barriers attached to it is gradually gaining ground in Nigeria though dominated by small scale pig farmers. According to the Federal Ministry of Agriculture and Rural Development (FMARD), the Nigerian pig population stand at 8.0 million (FAOSTAT, 2019) as against the population figure of 3.6 million reported by National Agricultural sample survey (National Bureau of Statistics, 2016). This represents only 1.05% of the world pig population. Consumption of pork in Nigeria is on upward spiral trend despite the Muslims and Pentecostals religious views of the meat and intensifying pig productivity will certainly bridge the animal protein deficit gap and boost economic prosperity in sub-Saharan African countries (Nkwocha et al., 2021).

Sastry and Thomas (2015) reported that there is a wide range of feedstuff on which pigs can live on. Therefore, alternative feed sources need to be investigated such as *Carica papaya* leaf along with usual feed material as *Carica papaya* leaf and seeds have been used as animal feed in many places.

Carica papaya is a multipurpose plant with useful characteristics. Scientific studies revealed the existence of considerable levels of glycosides, flavonoids, alkaloids, saponins, phenolic compounds, amino acids, lipids, carbohydrates, enzymes, vitamins, and minerals in papaya leaves (Alara et al., 2022; Ugo et al., 2019). *Carica papaya* leaves and seeds are used as livestock feed and its twigs are reported to be very palatable to ruminants and have appreciable crude protein

Citation: Nkwocha G, Ekenyem B, Anukam K, Adeolu A, Nwose R, Ahaotu E, Anosike F and Callistus M (2024). Growth performance, haematological and serum biochemical indices of weaner pigs fed *Carica papaya* seed and leaf meal as dietary supplement. *Online J. Anim. Feed Res.*, 14(6): 402-409. DOI: https://dx.doi.org/10.51227/ojafr.2024.46

levels ranging from 21-25.1% (Rahmasari et al., 2021). *Carica papaya* is the power house of papain, cystatin, chymopapain A and B, tocopherol, glucosinolates, vitamin C and papaya peptidase A (Oloruntola et al., 2018; Palanisamy and Basalingappa, 2020). According to Maisarah et al. (2014), proximate analysis of dried pawpaw seeds contains 97.27% dry matter, 30.08% crude protein, 34.80% crude fat, 1.67% crude fiber, 7.11% ash and 23.67% nitrogen free extract.

The leaves of *Carica papaya* are an excellent source of the sulphur containing amino acids, methionine and cysteine, which are often limiting in most feedstuff used for feeding animals (Abdel-Halim et al., 2020). Onyimonyi and Ernest (2009) showed that dietary inclusion of 2% *Carica papaya* leaf meal in finisher diets improved carcass and organoleptic traits of swine meat and moreover, the phenolic compounds in leaf meals inhibits lipogenesis in animals. In a similar experiment on *Carica papaya* seed meal reported by Saputri et al. (2017), adding water extract of papaya seeds as much as 300 mg/kg/day was able to reduce cholesterol by 13.39% and SGPT level 31.4% in hypercholesterolemic white male rats. Calvache et al. (2016) treated papaya peel residues with ethanol and drying them in a microwave oven to generate dietary fibre concentrates (DFCs) in order to demonstrate its antioxidant activity. Carotenoids, phenolics, ascorbic acid, proteocatechuic acid, manghaslin, quercetin 3-0-rutinosides, caffeoyl hexoside, ferulic acid, lutein, zeaxanthin, and beta-carotene were detected in the chromatographic analysis of the samples. Sharma et al. (2022) investigated the antioxidant bioactives, biological activities, innovative products and safety aspects of *Carica papaya* leave extracts and demonstrated successful medical evidence for the use of papaya leaf extracts in the health care system as a supplemental herbal medication in a variety of clinical settings.

In line with enough medical and nutritional evidence of the value of papaya leaves and seed meals, it is therefore ideal to evaluate the nutritive value of *Carica papaya* leaf and seed meal so as to determine the optimal dietary inclusion level for optimum productivity of weaner pigs.

MATERIALS AND METHODS

Experimental site

This study was carried out at the Teaching and Research farm of the Imo state Polytechnic Umuagwo- Ohaji, Imo State. The site has geographical coordinates of latitudes 5^0 17^1 and 5^0 19^1 N and longitudes 07^o 54^1 and 06^0 56^1 E of the equator with temperature ranging from (26.5–32 °C) and humidity of (70–85%). The mean annual rainfall ranges between (2000–2500 mm). The soil is sandy loamy and slightly acidic (NIMET, 2015).

Experimental animals and design

36 cross-bred (Large White x Landrace) strains of weaner pigs with average initial weight of 8.86$\pm$0.10 kg were used for the study. Pigs were acclimatized in the study area by feeding control diet for one week during which time routine management practices notably deworming was carried out to keep endoparasites under check and oxytetracycline were also given to the pigs as prophylactics against bacterial infections. The pigs were divided into 4 groups of 9 weaner pigs each in a completely randomized design (CRD) and fed one of the experimental diets for 28 days. Each treatment was replicated three times (3 weaner pigs per replicate). Feed and clean water were provided *ad libitum*. Feed intake was recorded daily by computing the difference between the feed offered and the feed left over throughout the duration of the experiment.

Housing and management

The pigs were housed in pens with total area measuring 22.4 m² i.e. (7.0 x 3.2) m divided into 16 compartments, each measuring 1.4 x 1.0 m. The piggery house is constructed with concrete floor with dwarf wall in which the open part was covered with wire mesh. The roof was covered with corrugated iron sheets with overhang to prevent the splashing of water into the pens. The pens were washed and disinfected with germicide "Izal" one week before the commencement of the experiment.

Ethical regulation of experiment

This study was approved by the Animal Production and Health Departmental Board of the Imo State Polytechnic, Umuagwo-Ohaji, Owerri, Imo State, Nigeria. The Authors voluntarily participated and there was no deception, no risk of harm, accuracy of reporting were ensured and they complied with the ARRIVE guidelines.

Preparation of *Carica papaya* seeds and leaf meal

Fresh Carica papaya seeds and leaves used for this experiment were plucked at the forestry unit of Imo State Polytechnic, Umuagwo, Imo state. The leaves were chopped, spread on a clean tarpaulin under the shade to air-dry for about 10 days and then milled to *Carica papaya* leaf meal (CLM). Seeds were collected from ripped pawpaw fruits and were spread lightly on tarpaulin to air-dry for 10 days and then ground to form *Carica papaya* seed meal (CSM). The CLM and CSM were thoroughly mixed together in a ratio of 2:2 to form *Carica papaya* leaf and seed meal composite mix (CSLM) and subjected to proximate analysis in accordance with standard methods of AOAC (2016). The C*arica papaya* seed and leaf meal mix were therefore included at the levels of 0% (T_1), 1% (T_2), 2% (T_3) and 3% (T_4) accordingly. Other conventional feed ingredients such as Maize, rice meal, fish meal, groundnut cake (GNC), wheat offal, bone meal, palm kernel cake (PKC) and salt were procured from certified raw material sales outlets at Owerri, Imo State and injected into the feed in line with their inclusion rate (Table 1).

Phytochemical analysis

The CSLM was analyzed in the Laboratory and the percentage proportions of the respective toxicants notably; Tannins, Flavonoids, alkaloids, saponins, cardiac glycosides, phytate, oxalate, phenols, steroids, terpenoids etc. were evaluated using elaborate laboratory procedures as described by Roghini and Vijayalakshmi (2018) (Table 2).

Table 1 - Ingredient composition of the experimental treatment diets fed to weaner pigs.

Ingredients / Dietary levels of CSLM	T_1 (0%)	T_2 (1%)	T_3 (2%)	T_4 (3%)
Maize meal	34.00	33.00	33.00	33.00
Rice meal	25.75	25.75	24.75	24.75
CSLM	0	1	2	3
GNC	18	18	18	18
Wheat offal	8.00	8.00	8.00	7.00
Fish meal	3	3	3	3
P.K.C	8	8	8	8
Bone meal	3	3	3	3
Salt (Nacl)	0.25	0.25	0.25	0.25
Total	100	100	100	100
Calculated analysis				
Energy (kilocal/kg)	2810.65	2810.65	2810.65	2810
Crude Protein (CP)	19.045	19.045	19.03	19.03

CSLM= Carica papaya seed and leaf meal; GNC= Groundnut cake; P.K.C= Palm kernel cake

Table 2 - Proximate composition of *Carica papaya* seed and leaf meal composite mix.

Parameter	Composition (%)
Dry matter	93.70
Crude protein	17.00
Ash	7.14
Ether extract	12.42
Crude fibre	18.49
Nitrogen free extract	24.28
ME (Kcal/kg)	2496.96

ME = Metabolizable energy calculated; ME (Kcal/kg) = 37x %CP + 81 X %EE + 35.5 X %NFE (Pauzenga, 1985).

Haematological and serum biochemical studies

At the end of the 28 day feeding trials, three pigs were randomly selected from each treatment i.e. a pig per replicate, starved of feed overnight but was given access to water. Blood samples were collected (10 ml per pig) through the vein at the ham section with a 10 ml sterile syringe after local disinfection with methylated spirit. Five (5) ml of blood samples were collected into Bijou bottles containing ethylene diamine tetra acetic acid (EDTA) as the anti-coagulant and shaked vigorously to avoid coagulation. The remaining 5 ml of blood samples for serum biochemical indices were dispensed into labeled bottle (without EDTA) and the blood sera were separated by centrifuging for 10 minutes at 2000 revolutions per minute (rpm) at 4°C after which the sera was decanted into a well labeled bottle for further analysis. Blood samples for haematology were taken to the laboratory and analyzed for the following parameters namely haemoglobin (Hb), packed cell volume (PCV), white blood cell (WBC), red blood cell (RBC), mean cell volume (MCV), mean cell haemoglobin (MCH), mean cell haemoglobin concentration (MCHC) and blood clotting Time (BCT) according to Merck Veterinary Manuals, (Aiello et al., 2016).

Serum biochemical indices variables taken were blood urea, serum creatinine, blood glucose, cholesterol, serum total protein, albumin, globulin, alkaline phosphatase, alanine aminotransferase (ALT) and aspartate aminotransferase (AST) and were determined according to Latimer (2003).

Statistical analysis

All data collected were subjected to analysis of variance (ANOVA) using Statistical Package for Service Solution (SPSS) version 20. The treatment means were separated by Fisher's Least Significant Difference (LSD) Test (Williams and Abdi, 2010).

RESULTS AND DISCUSSION

Tables 2 and 3 showed the proximate and phytochemical composition of *Carica papaya* seed and leaf meal mix. The nutritive assessment of CSLM showed that the mix contained 17.00% crude protein while other compositional values of 7.14, 12.42, 18.49 and 24.28% were recorded for ash, ether extract, crude fibre and nitrogen free extract respectively (Table 2). The combination of *Carica papaya* seed and leaf meal as a dietary supplement positively enhanced the crude protein content of the test ingredient. The oily nature of pawpaw seed reflected in the value obtained for ether extract of the CSLM and this agreed with the reports of Rahmasari et al. (2021) that the seed is high in lipids. The crude fibre level of CSLM is relatively high probably due to the presence of non-starchy polysaccharides existing in the leaves (Bidhendi and Geitmann, 2016; Rahmasari et al., 2021). The presence of high level of ash content indicates that the total inorganic mineral in CSLM is high (Maisarah et al., 2014).

The test additive (CSLM) significantly (P<0.05) affected the average daily feed intake, weight gain, feed conversion ratio and cost per kg live weight of weaner pigs (Table 4). T_4 recorded the highest feed intake (635 g) followed by T_I (600 g) >T_2 (540 g) >T_3 (522 g) in that order. Moreover, there was a proportional increase in average daily weight gain (ADWG) as CSLM increased in the ration. The T_4 promoted the highest weight gain while the least was recorded by weaner pigs in group 2 (T_2). Weight gain is a function of feed utilization for the formation of adipose tissues. T_2 promoted the least weight gain of 228 g but a positive trend of weight gain was observed in T_3 and T_4 with higher inclusion levels of CSLM. The higher weight gain of T_3 (260 g) and T_4 (353 gm) may be attributed to the action of papain, a natural enzyme occurring on the leaves of *Carica papaya* plant which helps in the digestion of proteins in the digestive tract and synthesis of vitamins C and E (Singh et al., 2011; FAO, 2014; Oloruntola et al., 2018; Rahmasari et al., 2021; Sharma et al., 2022). According to Barroso et al (2016), the major active ingredient recorded in pawpaw seed such as carpine, chymopapin, and papain are enzymes capable of enhancing appetite and metabolism and this appears to be responsible for increased daily feed intake while benzyl isothiocyanate has active anthelminthic activity.

Feed conversion ratio (FCR) increased (P<0.05) as dietary CSLM increased in the ration. The best FCR was recorded by T_4 which was consistently different (P<0.05) from other treatment means. Conversely, the control diet (T_1) was significantly costlier than CSLM based diets. Nevertheless, efficiency in relationship to cost reduction is influenced by other variable notably growth rate and feed conversion ratio which as a matter of fact T_4 < T_3 were the cheapest (Table 5).

Although studies on the utilization of *Carica papaya* seed and leaf meal is limited in swine, it was shown that papaya seed meal was able to improve the production performances of poultry, including increasing growth rate, egg production, and feed efficiency of poultry. In broiler chickens, Muazu and Aliyu-Paiko (2020) showed that incorporation of 1% papaya seed powder in rations increased the final body weight and feed intake. In line with this, Rachmatika and Prijono (2015) reported that incorporation of 1.2% papaya seed in diets increased body weight gain, reduced feed intake, and improved feed efficiency of *Raja* ducks. Likewise, Soedji et al. (2017) documented that inclusion of 0.5, 1.0, and 2% papaya seed in the rations increased daily weight gain of pullet when compared with the control.

Table 3 - Quantitative and qualitative values of phytochemical analysis of *Carica papaya* seed and leaf meal composite mix (CSLM).

Parameter	Qualitative Score	Quantitative
Tannins	+	20.14%
Saponins	+	42.70 µg/ml
Alkaloids	+	63.05 µg/ml
Flavanoids	+	1375.40 µg/ml
Phytate	+	7.95%
Oxalate	+	2.8 x 10^4 mg/100 g
Phenols	-	0
Cardiac Glycosides	++	181.34%
Steroids	++	54.17 mg/100 g
Terpenoids	++	118.85 mg/100g

Table 4 - Performance characteristics of weaner pigs on graded levels of *Carica papaya* seed and leaf meal supplementation

Parameters / Dietary levels of CSLM	T_1 (0%)	T_2 (1%)	T_3 (2%)	T_4 (3%)	SEM
Initial body weight (kg)	8.90 ^{a}	8.96 ^{a}	8.73 ^{b}	8.83 ^{a}	0.06
Final body weight (kg)	17.70 ^{a}	15.33 ^{bc}	16.00 ^{b}	18.70 ^{a}	0.89
Body weight change (kg)	8.80 ^{a}	6.37 ^{b}	7.27 ^{b}	9.87 ^{a}	0.90
Daily feed intake (gm)	600 ^{a}	540 ^{b}	522 ^{b}	635 ^{a}	30.32
Daily body weight gain (gm)	314 ^{a}	228 ^{b}	260 ^{b}	353 ^{a}	32.15
Feed conversion ratio	1.91 ^{bc}	2.37 ^{a}	2.01 ^{b}	1.86 ^{c}	0.14
Cost/kg live weight ($)	0.16	0.10	0.09	0.09	8.19

T_1: diet without CLSM (control), T_2: diet containing 1% CLSM, T_3: diet containing 2% CLSM and T_4: diet containing 3% CLSM. ^{abc} Means along the rows having different superscript of letter differed significantly at P<0.05 level LSD.

Haematological values such as HB, WBC, RBC, MCV, MCH, MCHC and BCT obtained for pigs fed control diet (T_1) were superior when compared with groups fed CSLM based diets. This definite trend of reduction in the haematological parameters though in line with the recommended values reported by Latimer (2003) for normal haematological reference range for pigs did not negatively affect the performance parameters (Table 5). PCV ranged from 37.80-46.00% while haemoglobin, white blood cells and red blood cells ranged from 12.60-15.30 g/dl, 3.10-5.10x10^3 µl and 4.50-7.40x10^6 µl respectively.

The serum biochemistry of weaner pigs fed graded levels of *Carica papaya* seed and leaf meal mix revealed that urea, creatinine, ALP, ALT, AST concentrations significantly (P<0.05) increased as dietary levels of CSLM increased in the diets. However, the values for creatinine (1.50-2.10 mg/dl); urea (18-23 mg/dl); alkaline phosphatase (41-65.00 µl); alanine aminotransferase (8.60-14 µl) and aspartate aminotransferase (8-11 µl) recorded in this study falls within the normal range of (0.8-2.30 mg/dl creatinine), (8.20-24.6 mg/dl urea), (41.0-176.10 µl alkaline phosphatase), (21.7-46.50 µl ALT) and (15.3-55.3 µl AST) recommended by Merk Veterinary Manual, (2016). Nevertheless, other biochemical parameters like Glucose, cholesterol, total protein, Albumin and globulin decreased substantially (P<0.05) in CSLM based diets (Table 6). This reduction is in agreement with the report of Juárez-Rojop et al. (2012) that aqueous extract of *Carica papaya* (0.75 g and 1.5 g/100 ml) significantly decreased blood glucose levels, cholesterol, triacylglycerol and amino-transferase blood levels. The decreasing trend in blood glucose level of CLSM based diets revealed that *Carica papaya* leaf and seed possesses hypoglycemic and antidiabetic effects and could be used to stabilize blood glucose level in animals justifying the reasons for its use in traditional Ayurveda medicines for diabetes in India.

However, the combination of *Carica papaya* leaves and seed meal elevated the blood serum enzymes as observed in Alanine aminotransferase, alkaline phosphatase and Aspartate transferase. It appears from the result that the albumin values of weaner pigs on the control diet were slightly above the range of 22.60-40 g/l (Merk Veterinary Manual, 2016) recommended for healthy tone of pigs while the AST values of (8-11. µl) obtained from the result was comparatively low from the recommended reference range of (15.30-55.30 µl) (Merk Veterinary Manual, 2016).

Table 5 - Haematological parameters of weaner pigs on graded levels of *Carica papaya* seed and leaf meal mix

Parameters / Dietary levels of CSLM	T_1 (0%)	T_2 (1%)	T_3 (2%)	T_4 (3%)	SEM
Haemoglobin (HB) g/dl	15.30 ^{a}	14.50 ^{a}	14.00 ^{a}	12.60 ^{b}	0.80
Packed cell volume (PCV) (%)	46.00 ^{a}	43.00 ^{a}	42.00 ^{a}	37.80 ^{b}	2.73
White blood count (WBC) x 10^3	5.10 ^{a}	4.80 ^{a}	4.00 ^{a}	3.10 ^{b}	0.67
Red blood count (RBC) x10^6 µl	7.40 ^{a}	6.60 ^{a}	6.00 ^{a}	4.50 ^{b}	0.77
Mean cell volume (MCV) fl	80.00 ^{a}	78.20 ^{a}	75.00 ^{a}	72.40 ^{d}	2.53
Mean cell Hemoglobin (MCH) pg	15.10 ^{a}	14.50 ^{a}	14.00 ^{a}	13.00 ^{b}	0.70
MCHC (pg)	26.20 ^{a}	25.40 ^{a}	25.00 ^{a}	23.30 ^{b}	0.97
Blood clothing time (BCT)	33.00 ^{b}	34.50 ^{b}	36.30 ^{a}	40.00 ^{a}	2.33

T_1: diet without CLSM (control), T_2: diet containing 1% CLSM, T_3: diet containing 2% CLSM and T_4: diet containing 3% CLSM. ^{Abcd} Mean along the rows having different superscript of letters differed significantly at P < 0.05 level (LSD); MCHC = Mean cell haemoglobin concentration

Table 6 - Serum biochemistry of weaner pigs fed graded levels of *Carica papaya* seed and leaf meal mix.

Parameters / Dietary levels of CSLM	T_1 (0%)	T_2 (1%)	T_3 (2%)	T_4 (3%)	SEM
Urea (mg/dl)	18.00 [b]	19.50 [ab]	20.40 [a]	23.00 [a]	1.67
Creatinine (mg/dl)	1.50 [b]	1.60 [b]	1.70 [b]	2.10 [a]	0.20
Glucose (mg/dl)	79.00 [a]	77.00 [a]	76.20 [a]	72.00 [b]	2.33
Cholesterol (mg/dl)	115.40	110.60	110.00	108.00	2.47
Total protein (g/l)	80.00	78.00	76.4.60	73.00	2.33
Albumin (g/l)	42.10 [a]	41.20 [a]	41.00[a]	39.00 [b]	1.70
Globulin (g/l)	37.80 [a]	37.80 [a]	35.60 [b]	34.00 [b]	1.07
Enzymes					
ALP (μ/l)	41.00 [bc]	48.00 [b]	48.00 [b]	65.00 [a]	5.67
ALT (μ/l)	8.60 [b]	12.50 [a]	13.30 [a]	14.00 [a]	1.80
AST (μ/l)	8.00 [b]	8.80 [b]	9.50 [ab]	11.00 [a]	1.00

T_1: diet without CLSM (control), T_2: diet containing 1% CLSM, T_3: diet containing 2% CLSM and T_4: diet containing 3% CLSM. [Abcd] Mean along the rows having different superscript of letters differed significantly at $P < 0.05$ level (LSD); ALP = alkaline phosphatase; ALT = Alanine Aminotransferase; AST = Aspartate aminotransferase.

CONCLUSION

The result of the study indicated that *Carica papaya* seed and leaf meal mix at inclusion level dietary level of 3% fully support productive performance of weaner pigs, in terms of improved nutrient utilization and gut health of weaner pigs. Moreover, the positive response of the hematological and serum biochemical parameters shows that its inclusion in pig ration poses no danger to their physiological wellbeing hence a good supplement for pigs.

For future studies, the authors recommend an in-depth study on the mineral constituents of *Carica papaya* leaf and seed meal and an examination of the carcass characteristics of weaner pig placed on this supplement.

DECLARATIONS

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Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Authors' contribution

G. Nkwocha = Conceptualization, Statistical design, data analysis, section writing and proof-read.
B. Ekenyem and Kevin Anukam = Data analysis, results editing, proof-reading and grammar checking.
A. Adeolu & R. Nwose = Results and Discussion, Conclusion/Recommendation section writing, reference sorting and editing.
F. Anosike & M. Callistus = Materials & Methods, reference sorting, data processing, data sorting and coding.

Acknowledgements

The authors acknowledged the role played by Prof. I.I. Osakwe, Department of Agriculture, Alex Ekwueme Federal University Ndufu-Alike Ikwo, Abakaliki, Ebonyi State, Nigeria in overall proofreading and strengthening the models used.

Competing interests

The authors declare no competing interests in this research and publication.

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2024 SCIENCELINE

Online Journal of Animal and Feed Research

Volume 14, Issue 6: 410-423; November 30, 2024 ISSN 2228-7701

DOI: https://dx.doi.org/10.51227/ojafr.2024.47

EVALUATION OF NUTRITIONAL COMPOSITION OF MAJOR AVAILABLE FEED RESOURCES FOR BACKYARD SHEEP FATTENING IN SOUTHERN ETHIOPIA

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Supporting Information

RESEARCH ARTICLE
PII: S222877012400047-14
Received: August 25, 2024
Revised: November 24, 2024
Accepted: November 25, 2024

ABSTRACT: The study was conducted in the Bule district of Gedeo zone in southern Ethiopia to assess the available feed resources for sheep fattening and their chemical composition in backyard sheep fattening operations. A reconnaissance study identified the main sources of feed, followed by a multi-stage sampling procedure to select kebeles and households involved in sheep fattening. Six kebeles were specifically selected based on sheep population, experienced fatteners and accessibility. A total of 126 households were randomly selected for the study. The main food sources included natural pasture, stubble pasture, forage, bamboo leaves, enset (*Ensete ventricosum*), crop residues, desho grass (*Pennisetum pedicellatum*), tree alfalfa, kitchen residues and mill products. Feed samples were taken for laboratory analysis, and the average values for dry matter (88.3%), ash (10.71%), organic matter (77.25%), crude protein (11.21%), neutral detergent fibers (60.2%), and acidic detergent fibers yielded (39.42%) and acidic detergent lignin (10.22%). Tree alfalfa (26.06%), mill products (16.11%), green fodder (13.88%), and bamboo leaf (12.45%) had the highest crude protein content. Bamboo leaves (21.15%), forage (15.17%), and stubble pasture (12.36%) provided suitable ash levels for mineral intake. However, concerns arise regarding fiber content in crop residues, grazing practices, and bamboo leaf quality, affecting feed intake, digestibility, and absorption. Promising feeds such as alfalfa, mill products, and forage boost high protein content, but better fiber management is essential for feeds with excessive fiber. Tailored feeding strategies, enhanced feed conversion, and thorough training for sheep fatteners are pivotal to address these challenges.

Keywords: Bamboo leaf, Desho grass, *Ensete ventricosum*, Fattening, Feed Resource, Sheep.

INTRODUCTION

Sheep fattening is widely practiced across the country of Ethiopia, through the scale and resources used vary significantly. It is particularly suited for smallholder farms, requiring minimal capital, have shorter production cycles, and have better environmental adaptation ability than large ruminants (Sejian et al., 2021). However, the status of sheep productivity is generally hampered by numerous factors, such as insufficient energy at breeding when in poor body condition, early embryonic death, predators, and feed shortage (Bachano and Etefa, 2022) Among the problems feed shortages with quantity and quality and the escalation of feed prices, which hampering sheep production and productivity in the country (Ayele et al., 2021).

In many regions, sheep graze on permanent grazing areas, fallow land, and post-harvest cropland, relying primarily on natural pasture and crop residues, which fail to meet their nutritional needs (Belay and Negesse, 2019). The practice of sheep fatting in various parts of the country is predominantly limited to two fattening cycles (Belachew, 2019). As a result, producers are not getting the expected benefit from it (Shimelis, 2018). It is required to assess an optional way of solving the problem in line with analyzing available feed sources. Hence, different previous studies have been done on sheep-fattening areas to overcome such challenges. However, aside from listing many kinds of feed available in that vicinity, the majority of them have no documentation about feed nutrient composition related to sheep fattening at farmer levels (Gufa et al., 2017) except for the research done by Jarso et al. (2023) which focused on only natural pasture and barely crop residues. Bule district is among the possible locations with a favorable environment for sheep production in the Gedeo Zone of Ethiopia, is known for its favorable environment for sheep production and a long-standing tradition of backyard fattening (Tezera and Engidashet, 2022). It also has a large sheep population and active livestock marketing. Despite these advantages, modern sheep fattening practices are lacking, and no comprehensive study has been conducted on the area's feed resources and their nutritional composition, except for commercial feeds. This study aims to assess the available feed resources and evaluate their nutritional chemical composition for sheep fattening in the area.

Citation: Galchu TU and Wondater WB (2024). Evaluation of nutritional composition of major available feed resources for backyard sheep fattening in southern Ethiopia. *Online J. Anim. Feed Res*., 14(6): 410-423. DOI: https://dx.doi.org/10.51227/ojafr.2024.47

MATERIALS AND METHODS

Description of study area

The study was carried out in chosen kebeles of Bule District which is located in the Gedeo zone in Southern Ethiopia. The district lies between latitudes 6°04'16" and 6°23'50" N, and longitudes 38°18'00" and 38°30'00" E, approximately 386 km from Addis Ababa, 117 km from Hawassa, and 27 km from Dilla, the zone's capital. Bule District is bordered by Oromiya Region to the south, east, and west, and Sidama Zone to the north. Covering 27,300 hectares, it ranges from 2,001 to 3,000 meters above sea level. The district includes 15 rural and 3 peri-urban kebeles, with a total area of 11,546.2 hectares and a population of about 95,436. About 70% of the district is highland agro-ecology, while 30% is mid-altitude. The average annual rainfall is 1,600 mm, with temperatures ranging from 12.6°C to 20°C. Farming in the area follows a mixed crop-livestock system, with land primarily used for annual crops and perennial plants (CSA, 2021).

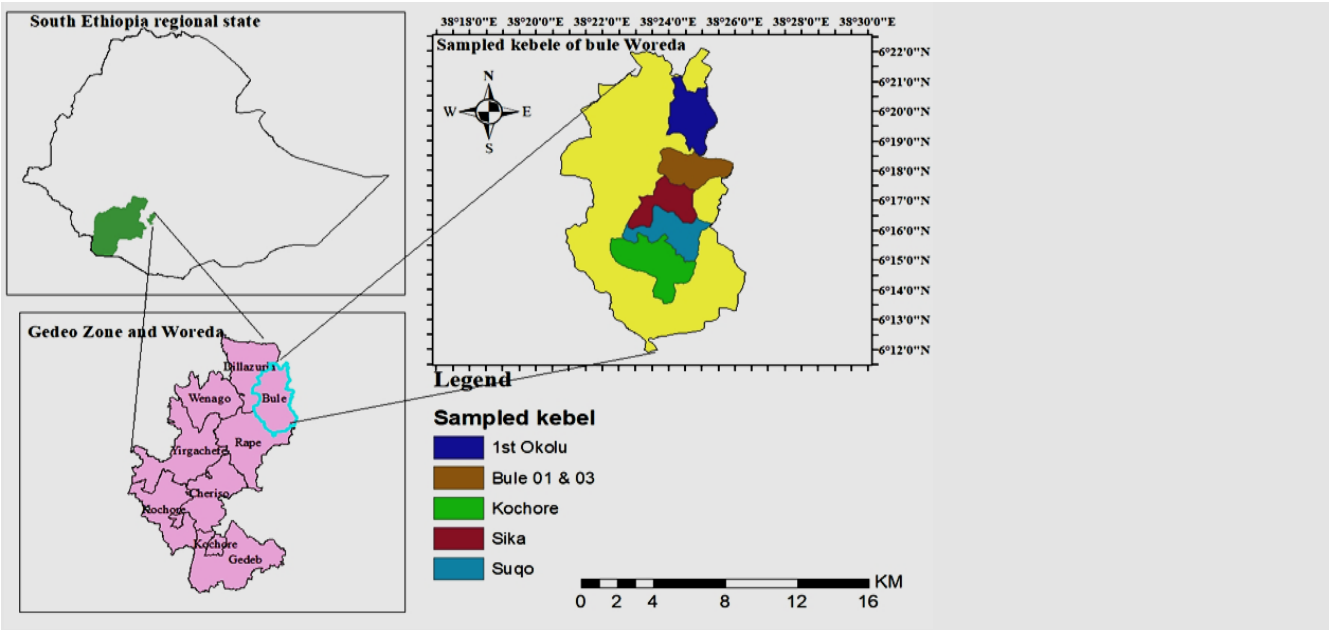

Figure 1 - Location of study area.

Sampling method

Before selecting a representative sample, a reconnaissance survey and consultations were conducted with district agricultural experts. Based on this information, six Kebeles were purposively chosen for their sheep resources, farmers' experience in sheep fattening, and accessibility. From each selected kebele, households engaged in sheep fattening were randomly chosen based on their number of fattening sheep, experience, and willingness to participate. According to the district's livestock resources department, 328 households in the study area were involved in sheep fattening.

Sample size determination

The sampling frame consists of farmers who raise sheep for fattening and are willing to participate in the study. According to the district agricultural office's livestock data, the total number of sheep fattening households in the study kebeles is 126. To meet the study's requirement for a representative sample within the constraints of time and budget, all 126 households across the six sampled kebeles were selected using systematic random sampling for interviews and data collection. The sample size for each kebele was determined using Yamane (1973) formula with a 0.07 standard error and 95% confidence level, resulting in 21 households per kebele.

$$n = \frac{N}{1+N(e2)}$$

Where: n= sample size required; N = number of people in the population; e = allowable error (%)

Therefore, the total of 126 households (38.4% of 328) were randomly selected from the six Kebeles, with 21 households from each kebele. A semi-structured questionnaire was used for interviews. Additionally, an introductory meeting was held at the village level in each kebele to brief farmers on the study's objectives.

Collection of feed sample

Ten feed samples were collected from 60 randomly selected fatteners (10 from each kebele). The fresh samples were spread on plastic sheets and air-dried in the shade for 3-5 days before being placed in an oven. After drying, the samples were mixed thoroughly, sub-sampled to 500g for each feed type, packed in airtight polythene bags, labeled, and transported to the lab for analysis. A 500g portion from each sample was weighed using a sensitive balance and taken to the Dilla University animal nutrition laboratory, where it was dried at 65°C for 72 hours, ground through a 1 mm sieve in a Willey mill, equilibrated at room temperature for 24 hours, and stored in airtight containers for chemical analysis (AOAC, 1995).

Laboratory analysis

Feed samples collected from the study area were processed and analyzed for chemical composition at Dilla and Hawass University's Animal Nutrition Laboratory. To ensure consistent weight, samples were dried for 72 hours at 65°C in a forced-air oven. Each dried sample was then ground and sieved through a 1 mm mesh. The ground samples were stored in airtight plastic bags for analysis. Chemical composition was determined following AOAC (1995) procedures, with analyses for dry matter (DM), organic matter (OM), crude protein (CP), acid detergent fiber (ADF), acid detergent lignin (ADL), and ash content. Neutral detergent fiber (NDF) was measured according to Van Soest (1982). Crude protein content was calculated using the Kjeldahl method, with the nitrogen concentration multiplied by 6.25

Statistical data analysis

Data were checked, corrected, and coded using SPSS version 20 for analysis. Descriptive statistics, including mean, percentage, and standard deviation, were used to present the findings. ANOVA, performed with SAS, tested differences in the chemical composition of major feedstuffs, with mean separation via the Tukey test at P<0.05.

RESULTS AND DISCUSSION

Status of backyard sheep fattening

As described in Tables 1 and 2, sheep fattening was the common practice in the study area, with 94.4% of households engaging in tethering and free-grazing systems. Traditional fattening systems prevailed, that the mean sheep fattened per household (1.97±0.08) for 2–6 months and 1.59±0.059 sheep fattened per year. Rams were the most commonly fattened (72.2%), followed by both rams and ewes (17.5%), and only 10.3% of households fattened ewes. In contrast, Mohammed (2020) found that 55.7% of farmers in Fogera District did not engage in sheep fattening. However, the current study aligns with Assefa and Ayza (2020), who reported an average fattening period of 3–4 months in southern Ethiopia. The mean sheep fattened per household (1.97±0.08) in this study was lower than Shewangzaw et al. (2018), who found 2.86 sheep fattened per period in Amhara. This discrepancy may be due to differences in resources (e.g., feed, land) and inputs available for fattening.

Available feed resources for fatteners and utilization

The major feed resources for fattening sheep in the study area, ranked in order of availability, are listed in Table 2. These include natural pasture (1st), green fodders (3rd), kitchen leftovers (5th), enset (6th), crop residues (4th), cultivated forage (7th), stubble grazing (8th), salt (5th), bole (9th), mill products (11th), and bamboo leaves (9th). This ranking aligns with Belay and Negesse (2019), who identified similar primary feed sources such as crop residues, natural pasture, stubble grazing, agro-industrial by-products, and improved forages in the Chalia districts of the West Shoa Zone.

Natural pasture, enset, and green fodder (fresh grass and bamboo leaf) were identified as the top three feed sources in the study area for fattening sheep. This reflects that natural pasture was the primary source, followed by green fodder and enset. Similar findings were reported by Mekuria et al. (2018) in the Amahara region, where natural pasture was also the predominant feed source for fattening small ruminants. Crop residues were ranked fourth, while home leftovers with salt and stubble grazing followed closely with index values (Table 3). Crop residues and stubble grazing were mainly available during dry seasons after crop harvest. Additionally, cultivated forage, bole and bamboo leaf alone, salt with bole, and mil1 products were identified as other important feed sources, with rank indexes of 0.059, 0.021, 0.0056, and 0.006, respectively.

On the other hand, fatteners and group discussants responded that the availability of such feed resources was limited by the seasons. Accordingly, natural pasture, forage (other than fresh grass) and enset were available over the years, but crop residues and forage resources were available for stubble grazing during the harvest season. In addition, the information received from the fattener and panelist shows that the use of available feed resources is also seasonally limited. Mainly crop residues and stubble pastures served as fodder along with other and supplementary fodder during the rainy season deficiency (Table 6). This suggested that if sufficient and protein-rich supplementary feed was not provided to fattening sheep during periods of rain deficiency, this could be influenced by nutritional deficiencies and a long period of time to reach the optimal marketing weight due to low CP % and poor quality could be forage species in the study area. Consistent with the current study, it was indicated that stubble pasture is available immediately after harvest in Tigray (Gizaw et al., 2017). It was also noted that the proportion of crop residues during the dry season is high and can be up to 80% (Schillinger and Wuest, 2021). Likewise, crop residues play a particularly important role during the dry season when there is a critical feed shortage (Duguma and Janssens, 2021). Also, Belay and Negesse (2019) reported a similar result, where crop residues and crop stubble grazing are important sources of forage during the dry season.

This study also determined the utilization status of these feed resources in the feed lots of the study area (Table 3). Accordingly, the combination of different available feed sources was a common usage trend throughout the study area. The combination of available feed resources most commonly used by fatteners in the study area were natural pasture, green fodder, crop residues, and stubble pasture (19.8%), followed by natural pasture, crop residues, green fodder, and enset (18.3%), natural pasture, crop residues and enset (16.7%), forage (fresh grass and bamboo leaves) and crop residues with stubble pasture (12.7%) and natural pasture, enset and cultivated fodder (desho and alfalfa) (11.9%). At certain fattening farms (4.8%), only natural pasture, crop residues and cultivated fodder (desho and alfalfa) were available as feed for fattening sheep in the region (Table 4). This shows that the availability of feed resources varied from farmer to farmer depending on the type of use and most feeders in the study area had a combination of natural pasture, forage, crop residues and stubble pasture (19.8%). The main reason why fatteners rely on such combined feed resources may be that the region has conditions for high crop production and mixed agriculture. In addition, it was pointed out that the most commonly used feed source combinations in the study area had low quality in terms of NDF, ADF, ADL and CP%, with the exception of forage. Similarly, Feyisa et al. (2022) stated that fodder is considered low grade if the crude protein content is less than 8 %, acid detergent fiber is more than 45 %, and neutral detergent fiber content is more than 65%.

Table 1 - Overall backyard sheep fattening status in the area

Variables		Kebeles						Total N=126	P-value
		Bule 01	Bule 03	Sika	Suqo	Kochore	1g na okolu		
FS	M ±SE	5.62±0.71	5.10±0.46[b]	5.43±0.50	5.14±0.46[c]	7.14±0.43[a]	7.43±0.62[a]	5.98±0.23	0.004
	Minimum	0	3	2	2	4	3	0	
	Maximum	14	10	12	10	10	13	14	
Age	Me ±SE	36.24±2.8[b]	37.33±1.6	45.90±3.3	40.05±1.6	42.00±1.8	46.76±2.6[a]	41.38±1.0	0.007
	Mi	19	24	26	25	28	29	19	
	Ma	72	46	83	56	56	81	83	
TLHg (ha)	M ±SE	0.70±0.07	0.69±0.06	0.67±0.05	0.851±0.09	0.76±0.10	0.90±0.06	0.76±0.04	0.094
	Mi	0.23	0.25	0.25	0.25	0.25	0.35	0.023	
	Ma	1.65	1	1.03	1.70	1.25	1.67	1.70	
MS (%)	Married	14.3	16.7	14.3	15.9	15.9	15.9	92.9	0.6
	Single	0.8	0	1.6	0	0	0	2.4	
	Widowed	1.8	0	0.8	0.8	0.8	0.8	4.8	

		Participation status in sheep fattening			
		Frequency	%	X^2	P-value
Do you participate in sheep fattening?	Yes	119	94.4	18.05	0.001
	No	7	5.6	1	

Preferred type of sheep for fattening activities

	Type	Frequency	%
Type of sheep used for fattening	Ram	91	72.2
	Ewe	13	10.3
	Both	22	17.5
	Total	126	100.0

FS= family size; TLHg= total land holding per hectar; MS= marital status; SEM =standard error of means

Table 2 - Provided feed and feeding/fattening system in study area

Description	Sheep fattening/Feeding system	Free grazing with cut and carry system	Tethering with stall feeding system	semi-grazing with stall feeding system	Total	X^2	p-value
Mostly provide feed for sheep during stall-feeding	Bamboo leaf and home leftover	2.4(1.0)	20.6(3.8)	6.3(0.9)	29.4(5.3)	7.78	0.4
	Green fresh grass	4.8(1.3)	23.8(4.3)	6.3(0.9)	34.9(6.2)		
	Cultivated forage	4.0(1.3)	10.3(2.4)	2.4(0.3)	16.7(3.3)		
	Enset (*Ensete ventricosum*)	0	10.3(3.6)	3.2(0.4)	13.5(4.0)		
	Crop residues with Bole	0	3.2(0.2)	2.4(0.2)	5.6(1.4)		
Total		11.1(5.0)	68.3(11.2)	20.6(4.8)	100.0(17.2)		

The parenthesis value in the table is SEM (standard error of means)

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Table 3 - Ranking of available feed resources in study area

No	Available feed resources categories	Frequency of rank given by respondents											
		1st	2nd	3rd	4th	5th	6th	7th	8th	Sum	Weight	Index	Rank
1	Natural pasture	42	39	15	4	5	3	1	0	109	750	0.18	1
2	Crop residues	0	10	25	28	23	13	7	2	108	507	0.12	4
3	Cultivated forage	11	7	7	8	4	3			40	244	0.06	7
4	Stubble grazing	14	13	16	7	0	1			51	337	0.08	8
5	Green fodder (fresh grass and bambo leaf)	39	27	17	5	1	1			90	635	0.15	3
6	kitchen left over	0	10	14	23	21	9	5	1	83	391	0.09	5
7	Enset	20	18	28	25	12	4	1	1	109	642	0.16	2
8	Salt and *bole*				3	2				5	23	0.01	11
9	Salt			2	10	41	43	21	4	121	401	0.09	5
10	*Bole*			1	2	4	5	7	1	20	62	0.02	9
11	Mill product			1	2	2	1			6	27	0.01	11
12	Bamboo leaf alone		2	1	9	2	1	1		16	78	0.02	9

Index = [(8 × number of responses for 1st rank + 7 × number of responses for 2nd rank + 6 × number of responses for 3rd rank + 5 × number of responses for 4th rank +4 × number of responses for 5th rank+3 × number of responses for 6th rank+2 × number of responses for 7th rank+1 × number of responses for 8th rank)] divided by (8 × total responses for 1st rank + 7 × total responses for 2nd rank + 6 × total responses for 3rd rank + 5× total responses for 4th rank + 4×total responses for 5th rank+3 × total responses for 6th rank+2 × total responses for 7th rank+1 × total.

Table 4 - Available feed resources utilized by sheep breeders

No	Fatteners used available feed resources	F	%
1	Natural pasture(grazing), crop residues and enset	21	16.7
2	Natural pasture(grazing), crop residues, green fodder and enset	23	18.3
3	Natural pasture and green fodders (fresh grass and bamboo leaf)	12	9.5
4	Natural pasture, green fodder, crop residues and Stubble grazing	25	19.8
5	Natural pasture, crop residues and cultivated forage (desho and treelucern)	6	4.8
6	Green fodders (fresh grass and bamboo leaf) and crop residual with stubble grazing	16	12.7
7	Natural pasture, enset and cultivated forage (desho and treelucern)	15	11.9
8	Natural pasture, green fodder, enset, crop residues and Stubble grazing	8	6.3
	Total	126	100.0

F= frequency

Major supplementary feed resources for fattening sheep's

Providing supplementary feed for their fattening sheep was a common practice in the fattening farms in the study area. All fatteners in the study area used locally available feed sources as a supplement to sheep fattening and thus achieved the required body weight change and minimized fattening time, which these trends were common practice in most countries as a common fattening method (Mengistu et al., 2020; Wamatu et al., 2021; Alimi et al., 2024).

As shown in Figure 1, Salt, kitchen leftover (sorting out grains from cereals, coffee residues (*ashara*), and enset (18.3%) were mostly used as supplementary feed combinations, followed by the uniform provision of Salt, bole, and home leftover (15.1%), and Enset with salt (11.1%). obtained from cereal crops was mostly available at harvest time and used mainly after mixing with coffee residues and salt or mineral soil (named local *bole*). According to report of Nurlign (2020) most households provided their fattening sheep with leftover feed and screening. The current result was also consistent with Bekele et al. (2019), as about 100% of the respondents in the highlands have the experience of feeding mineral soil/salt to their sheep in the Arba Minch *Zuria* District. There was leftover for the fatting sheep (6.3%) other additional feed sources and feeding practices among the fattener's response in the study area. According to the fattener's response and field observation data, feeding green fodder such as locally available fresh grass and bamboo leaves has practiced when after the animals have passed some limited grazing conditions. Accordingly, freshly cut and carried locally available fresh grass and bamboo leaves are used when after air drying to enhance their palatability by animals. Moreover, respondents informed us that green fodders were preferred and that they commonly provided feed to animals with salt or kitchen leftovers rather than cultivated forage in the area. In support of the current finding, previous various researchers also reported similar findings. According to Schillinger and Wuest (2021) native grasses are better if timely cut and proper handling and storage measures are applied. Many farmers currently practice an intermediate system, where sheep have limited grazing but are also fed additional 'cut-and-carried' fodder (Duguma and Janssens, 2021). Coffee residues are used as supplementary feed in Daramillo Woreda of Gamo Gofa Zone (Gufa et al., 2017). In the Arba Minch Zuria District of Gamo Zone, common supplements offered to sheep are Green fodders, Food leftovers, and Bole provided in the afternoon when the animals return home (Guyo, 2016).

On the other hand, about 0.8% of fatteners used both enset and mill products with salt for their fattened sheep as a supplementary feed for their fattening sheep, and 4.8% of them utilized salt alone. The variation was due to the difference in the availability access of feed types among households in the study area. Respondents responded that the combined utilization of all available feeds was carried out based on their availability in the study area. However, provision of crop residues for fattening animals can be taken placed with combined supplementary feeds such as kitchen leftovers including screening from cereals and coffee residues/*ashara*; and salt and enset when after animals brought from stubble semi-grazing area. This indicated that fatteners have knowledge or information about crop residues that do have not enough nutrition if provided alone to fattening sheep. A similar finding was reported by different previous researchers. According to Byaruhanga et al. (2015), crop residues do not fulfill the nutritional requirements of animals, particularly in the dry season due to poor management and poor quality. Thus, the provision of supplementary feeds to increase the productivity of livestock is essential (Belay and Negesse, 2019).

Seasonal Feed shortage for sheep fattening

The main seasons for feed shortage and reasons in the study area are summarized in Table 5. The majority of respondents (44.2%) identified the dry seasons as the most critical period for facing feed shortages, compared to the short rain season (38.3%) and long rain seasons (11.7%) alone. These findings are consistent with earlier reports (Mengistu et al., 2017) which highlighted seasonal variations, particularly dry seasons, as contributing to feed shortages in Ethiopia. The primary reasons identified for feed shortage across the study area were unproductive land (soil acidity) (35%), followed by land scarcity (30%), and both lack of improved forage and land (26.7%). This underscores that factors contributing to feed shortages are closely linked to seasonal variations and highlight limited access to feed as a common issue in the study area.

Fattening animals were most unproductive during the short rainy season (dry season) (Table 5), primarily due to land constraints ($P<0.05$). Field observations and discussions indicated that frequent tethering with other livestock contributed significantly to feed shortages in the study area. Consequently, cultivated crops, including forage, took longer to grow and were less productive. Consistent with these findings, Samuel (2016) noted that feed accessibility in the lowlands of the Amhara Region was predominantly hindered by low land productivity. Addressing this issue requires enhancing farmers' skills to implement soil fertility rehabilitation strategies such as rotational grazing, resting land through crop rotation, and planting improved forage materials. Additionally, utilizing local waste materials for composting could further benefit the study area. Teague and Barnes (2017) suggested that collective management of grazing lands can enhance resource utilization effectively.

Likewise, fatteners faced higher land shortages ($P<0.05$) in both dry and rainy seasons due to their cultivated lands being occupied by seasonal crops after harvest. According to respondents, 46.6% of existing lands were occupied by seasonal crops, while land fragmentation (34.2% per household member) and unproductive grazing land (19.2%) were major factors limiting productive land availability in the study area (Table 4). This indicates that land occupied by seasonal crops is a primary cause of land shortage, leading to limited availability of feed resources. Therefore, promoting and adopting feed conservation practices is essential to mitigate feed shortages resulting from land competition, through increased awareness among farmers in the study area.

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Land fragmentation due to household expansion was the second most significant factor limiting land availability, leading to feed shortages in the study area. Wassie (2020) similarly noted that land scarcity is likely to worsen with the ongoing population growth in Alaba Woreda. Hence, the study's findings underscore the constraints in implementing alternative forage development strategies that could efficiently utilize the available land for fattening sheep in the study area.

Furthermore, respondents cited a higher prevalence ($P<0.05$) of improved forage shortage during both seasons compared to the dry and rainy seasons alone (Table 5). Inadequate availability of improved forage also hinders sheep fattening practices, affecting adherence to recommended criteria such as fattening duration, feeding systems, and overall management across the study area. A majority (68.3%) of sheep fatteners in all study kebeles do not cultivate forage in their home yards. Only 31.8% of households grow cultivated forage, predominantly desho grass (30%) and tree lucerne (25%), which are most common in the area. The current proportion of forage-cultivating farmers in the study area is lower than reported figures from Damote Gale District (Shimelis, 2018), where 99% and 82.5% of farmers in intervention and non-intervention sites, respectively, practiced forage cultivation. However, Assefa and Ayza (2020) reported a lower percentage of sheep fatteners using improved forage in Duna Woreda. Major reasons cited for the shortage of improved forage include land scarcity (52.38%), lack of attention (30.95%), soil acidity/unproductivity (14.29%), and lack of awareness (2.38%) (Figure 2). This suggests that limited land access may contribute to the higher prevalence of improved forage shortage among households in the study area. Similar constraints of land scarcity and lack of awareness were noted in Damote Gale District (Shimelis, 2018).

Seasonal feed shortage and feed management

As shown in Figure 3, fatteners in the study area were examined for various options. Accordingly, about 48.33% of sheep farmers have tied their animals in enset farms to graze available green fresh feed material such as grass, enset leaves and herbs; and then provided kitchen scraps, while households representing 39.17% and another 12.50% of households could have the option of doing nothing but feeding available feed sources and selling fattening sheep, respectively, until these seasonal conditions cut off are. This indicated that almost half of the beneficial opportunities implied by fattening to also use these food materials left over from the kitchen as a supplement to solve such problems in the study areas. Guyo (2016) noted that using homemade concentrates could also help overcome periods of feed shortage. In addition, the current study results also suggest that the presence of fatteners who do not take measurable measures, as such a condition, also represent factors for the lengthening of the fattening period per cycle and the presence of constraints on available feed management in the region. Tegegne and Feye (2020) pointed out that feed management systems such as storing and purchasing sufficient feed during times of abundance from feeders have been cited as strategies to overcome seasonal feed shortages in Ethiopia.

Feed shortage consequences and measurements

The different available feed resources in Ethiopia have different palatability and nutritional status. In addition, however, availability in sufficient quantity and quality is questionable in all parts of the country, resulting in farmers facing varying feed restrictions (Shapiro et al., 2015). As a result, these farmers adopted different mechanisms to deal with such problems in the country. In this study, similar conditions were also found in the sheep fattening households in the study area. Accordingly, the lack of feed had serious consequences in the study area. According to surveyed households, weight loss of fattening sheep (47.6%), shortened fattening cycle per year (42.9%) and increased mortality of fattening sheep due to vulnerability to harsh conditions (9.5%) were the major consequences of feed shortages in sheep fatteners (Table 7). Under such conditions, farmers in the study area proposed various measurable measures, such as purchasing fodder or renting pasture land (42.9%), using available crop residues (9.5%), and excluding pasture land from stocks (47 .6%). Guyo (2016) reported a similar finding and found that in Bonke Woreda in Gamo-Gofa Zone, most highland households (62.5%) use agricultural residues, while about 37.5% of mid-altitude producers rely on purchased feed to overcome problems associated with feed shortages. However, this finding is greater than the current study result of crop residue users and feed purchasing households in the region.

The purchase of various feedstuffs such as enset and its residues as well as crop residues and the rental of pasture land for all stocks and especially for fattening animals from the neighboring general were measures taken before and during the above-mentioned consequences in the region. This demonstrated that certain farmers are knowledgeable and competent in predicting threats related to feed shortages and protecting them by applying necessary measurements in the study area. Furthermore, it was predicted that such events also represent an opportunity for the expansion of improved forage production. In conclusion, the fatteners explained that after the development of another way of fattening sheep, the available family land was protected from encroachment on the stock for a certain period of time until pasture grass developed to take measures to some extent and deal with the consequences of the feed shortage. About 47.6% of surveyed households followed such measurements to prevent weight loss and mortality of their fattening animals and to lengthen the fattening cycle per year (Table 6).

Table 5 - Reasons for shortage of land in study area.

Description		Reasons for seasonal shortage of feedstuffs				Total	X²	P-value
		Unprod. L.	Shor. L	Shor. I. F.	Shor. L. & I.F.			
Reasons for shortage of land (%)	Existed lands are occupied by seasonal crop	0	21.9	1.4	23.3	46.6	12.38	0.017
	Grazing land become unproductive due the tethering other livestock	2.7	4.1	1.4	11.0	19.2		
	Fragmentation of land	0	23.3	1.4	9.6	34.2		
Total		2.7	49.3	4.1	43.8	100		

Unprod. L=Unproductivity of land due to soil acidity; Shor. L= shortage of land; Shor. I. F= shortage of improved forage; Shor. L. & I.F.= shortage of land and improved forage.

Table 6 - Reasons and seasons of feed shortage occurred at study area

Description		Seasons of feed shortage occurred			Total	X²	P-value
		Short rainy season (dry season) %	Long rainy season %	Both seasons %			
Reasons for seasonal shortage of feedstuffs	Unproductivity of land (soil acidity)	24.2	5.8	5.0	35.0	37.03	0.0001
	Shortage of land	5.8	2.5	21.7	30.0		
	Shortage of improved forage	1.7	0.8	5.8	8.3		
	Shortage of land and improved forage	6.7	8.3	11.7	26.7		
Total		38.3	17.5	44.2	100.0		

Table 7 - Consequences, techniques and measurement taken to alleviate feed shortage problems

Variables		Frequency	%
Consequences of the feed shortage	Weight loss of fattening sheep	60	47.6
	Reduced fattening cycle/ year	54	42.9
	Increased mortality of fattening sheep due to harsh condition	12	9.5
Fatteners applied techniques to improve intake and nutrient status of available feed	Chopping	42	33.3
	Mix with Bole	30	23.8
	Salting	54	42.9
Measurement taken to alleviate feed shortage related problems	Purchase forage (rent grazing land)	54	42.9
	Use crop residues	12	9.5
	Excluded areas from stock	60	47.6

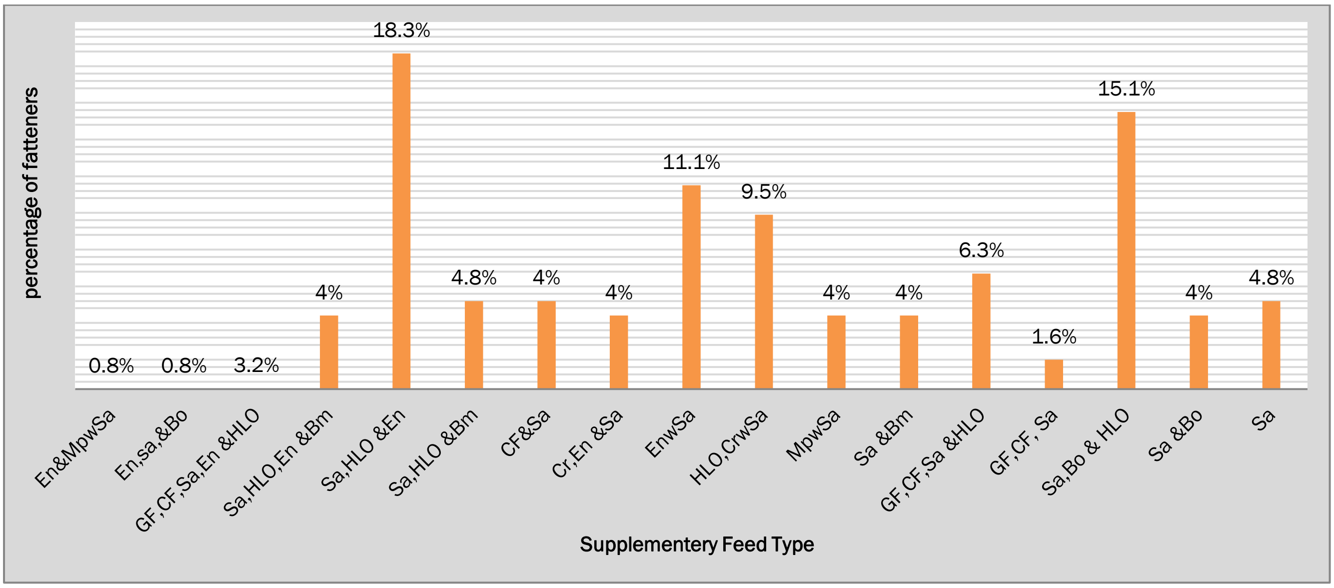

Figure 1 - Status of utilization and type of available supplementary feed. En=enset; MpwSa=mill product with salt; Sa=salt; Bo=bole; GF=green fodder; CF=cultivated forage; HLO= homeleftover;Bm=bamboo leaf; EnwSa=enset with salt; CrwSa= crop residues with salt.

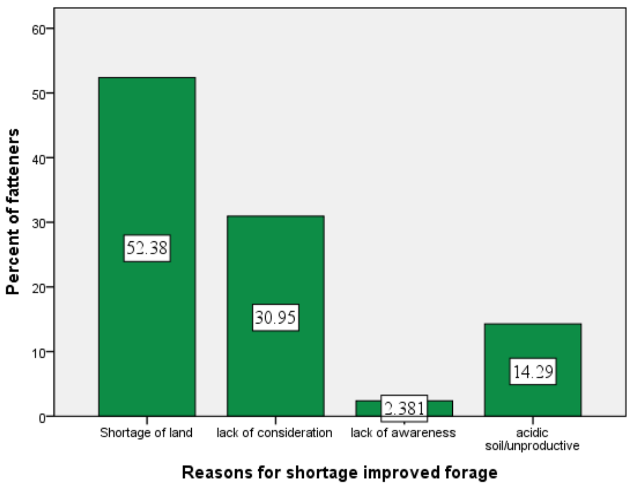

Figure 2 - Reasons for shortage of improved forage across study kebeles.

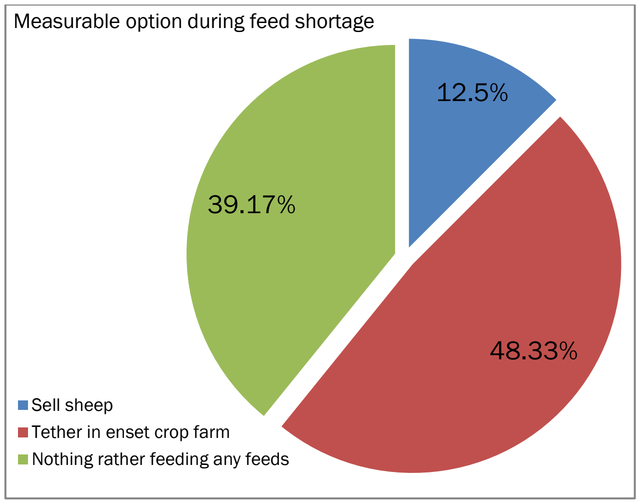

Figure 3 - Practiced option to overcoming seasonal feed shortage in study area.

Table 8 - Chemical composition of available feed types in study area.

No.	Feed Types	DM%	Ash%	OM%	NDF%	ADF%	ADL%	CP%
1	Natural pasture grass	90.82^{bac}	9.39^{cd}	81.43^{ba}	64.42^{b}	40.85^{dc}	7.91^{c}	7.4^{d}
2	Crop residue	92.87^{a}	8.36^{cd}	84.54^{a}	73.33^{a}	57.050^{a}	12.06^{b}	3.15^{e}
3	Stubble grazing	92.02^{ba}	12.36^{cb}	79.66^{ba}	57.21^{c}	46^{bc}	8.30^{c}	2.9^{e}
4	Green fodders (fresh grass)	85.98^{ef}	15.17^{b}	70.80^{dc}	52.78^{d}	29.71^{e}	4.78^{d}	13.08^{c}
5	*Desho* grass	89.37^{bdc}	13.64^{b}	75.73^{bc}	71.05^{a}	42.86^{c}	6.04^{dc}	7.43^{d}
6	Tree lucerne	85.72^{ef}	5.68^{ed}	80.04^{ba}	51.47^{d}	31.49^{de}	11.33^{b}	26.06^{a}
7	Bamboo leaf	85.76^{ef}	21.15^{a}	64.61^{d}	71.96a	54.6^{ba}	12.95^{b}	12.45^{c}
8	*Enset*	88.47^{edc}	8.61^{cd}	79.86^{ba}	62.28^{b}	36.81^{dce}	7.81^{c}	11.52^{c}
9	Mill products	84.5^{f}	3.69^{e}	80.81^{ba}	48.26^{d}	16.86^{f}	4.82^{d}	16.11^{b}
10	Home left overs	87.58^{ed}	9.10^{cd}	74.98^{bc}	49.27^{d}	38.61^{dce}	26.19^{a}	11.98^{c}
Overall mean		88.31	10.71	77.25	60.20	39.48	10.22	11.21
P-value		0.0004	0.0001	0.0012	0.0001	0.0001	0.0001	0.0001

Chemical composition of available feedstuffs

The chemical compositions of the available forage species in the study area are shown in Table 8. The main feed resources studied include natural pasture grass, stubble pastures, crop residues, forage (fresh grass), desho grass, tree alfalfa, bamboo leaves and enset, mill products and household residues such as coffee residues and crop sieves. The current study examined the nutritional properties of ten different feed samples used by sheep farmers in the study area

There is a significant variation (P<0.05) in the chemical composition of major feed resources within the different species (Table 8). The DM content of mill products and crop residues ranged from 84.5 to 92.87%, while the OM content varied between 64.61% bamboo leaves and 84.54% crop residues. The ash content varied from 3.69% mill product to 21.15% bamboo leaf. Crude protein (CP) content ranged from 2.9% for stubble pasture to 26.06% for tree alfalfa. Fiber content was also significantly different between species (P<0.05). The NDF content ranged from 48.26% for mill products to 73.33% for crop residues. The ADF content ranged from 16.86% to 57.05% for mill products and crop residues, respectively.

Furthermore, ADL content varied from 4.82% for mill products to 26.19% for leftover houses across the study area. This study result revealed that there are significant differences in the chemical composition of available feeds, which may be due to the variation of forage plant species, cultivar, maturity level, soil type and fertility status, plant environment temperature and general management status of such feed resources. The current study results confirmed the idea expressed by previous researchers that the stage of forage crop maturity, the plant species; Plant variety, plant fraction, crop management and environmental factors such as soil type and fertility as well as temperature during plant growth are factors that influence feed quality (Tikabo and Belay, 2021; Feyissa et al., 2022).

The DM content (90.82%) of natural pasture obtained in the current study is higher than that of Tamene et al. (2022), who reported that 89.64% of the DM from natural pasture grass from low agroecological areas The focus was on the Haru district. The current DM content of crop residues (92.87%) is comparable to the results of previous studies, which reported

DM content of crop residues between 89.86 and 93.6%. This variation may be due to differences in source (plant species), soil fertility status, and general handling of crop residues and their source from cultivation to harvest or storage. In support of this finding, Tamene et al. (2022) listed management practices, soil fertility, crop species and diversity as factors that vary the DM content of crop residues from area to area. The DM content of the milled product (84.5%) in the current study is lower than the report of Fekadu et al. (2020) who reported the DM content of the milled product of 91.36% in Homa district of West Wollega.

Furthermore, the current DM value of forage (fresh grass) was over 30.49% as reported by Tikabo and Belay (2021) from central Tigray in northern Ethiopia. Finally, the overall average of all available DM contents in the feed in the study area resulted in a value of over 85%, which represents an advanced value for the extraction of essential nutrients for fattening sheep. In line with this, Fekadu et al. (2020) stated that feed dry matter content is important as it contains the essential nutrients in a particular feed ingredient or feed.

This result showed that tree alfalfa (CP=26.06%) has higher and more beneficial protein value, followed by mill products, green fodder and bamboo leaves. Therefore, tree alfalfa could be categorized as high-quality feed, while mill products, green fodder and bamboo leaves could be classified as mediocre and all remaining forages could be divided into intermediates based on the classification with low quality of their protein content (Lonsdale, 1989), the feeds with CP values of less than 12%, between 12 and 20%, and more than 20% are categorized into low, medium, and high protein sources, in that order.

The current CP content of tree alfalfa is comparable to the results of study conducted by Gebrehiwot et al. (2017) which reported a CP content of tree alfalfa of 27.8%, but higher than the report of Meron (2016) stated that the CP value of tree alfalfa is 8.9 -20.9% or 16.6%. The higher CP content of tree alfalfa species in the current study area could make them a potential source of strategic supplements to poor quality forages such as crop residues, natural pastures, stubble pastures and desho grass. The present results on crude protein content of bamboo leaves were not as high as the results published by Desalegne et al. (2019), which indicated that the crude protein content of bamboo leaves introduced in Ethiopia ranged from 15.17% to 37.92%. However, the current CP content of bamboo was found to be higher than the minimum threshing value of 8% CP required for optimal rumen function and feed intake in ruminants (McDonald et al., 2002) and therefore can be used as a commodity Source of protein to supplement low-quality staple foods. As shown in Figure 1, the fatteners in the study area additionally fed their sheep bamboo leaves, which was an indicator that they provided them with a good source of protein. This is consistent with the findings of Desalegne et al. (2019), who found that bamboo leaves reduced the protein requirements of small ruminants (sheep and goats) by 14%.

In the current study, the Enset CP content (11.52%) was found to be lower than the values of 14.9% and 16.5% reported by Geremew et al. (2017). However, the current CP value is above the threshold and is intended to promote microbial development in the rumen and thus improve fermentation. This variation could be due to differences in soil fertility and type, species diversity, seasons and agroecology. The current CP content of Desho grass is lower than the value of the previous result of 10% CP reported by Bezabih et al. (2023), while it is higher than that of Genet et al. (2017) reported value of 3.97% Somewhat similar to the CP value of 6.93% reported by Asmare et al. (2017) for planted desho grass in another region of Ethiopia. The growing conditions of the feed, the variety and quality of the raw materials, and the processing methods used during the extraction, drying, milling, and storage processes could all be factors that contribute to the differences between the current result and previous research. Similar arguments were made by Hailecherkos et al. (2021), who pointed to differences in drying, extraction, milling and storage processes, as well as maturation stages and variability

Lastly, the study area's feeds from stubble grazing and crop residues have excessively low crude protein (CP <7%), which limits the amount of dry matter that sheep can consume overall and makes farmers less profitable by extending the fattening cycle and decreasing the number of sheep. It suggests that to produce sheep fattening in the studied locations suitably, protein source feed must be supplemented, and the nutritional content of this type of feed must be enhanced through physical, biological, and chemical processes.

The current OM content of crop residues (84.54%) is lower than the results (Degefa and Tamirat, 2022) recorded for barley crop residues (88.82%) and wheat crop residues (91.48%). Likewise, higher organic matter (OM) content values were reported from previous findings for desho grass (86.3%) and tree alfalfa species (95.6%) by Shewaye et al. (2021). The differences in OM value between such feeds could be related to the proportion of ash content in the dry matter of these feeds. Accordingly, (Al-Arif et al., 2017) stated that organic matter consisted of all nutrients except ash.

This study result revealed that bamboo leaves provide a larger amount of intermediate storage ash and advanced sources for meeting the mineral requirements of fattening sheep in the study area compared to other types of feedstuffs. A supported finding was reported by José et al. (2019), who described that the ash content in a particular animal feed is considered a good criterion for the total mineral content of the plant material and when its value is above 10%, it becomes acceptable. The ash content of the mill products used in this study was above 4.45% as reported by Degefa and Tamirat (2022) but below 18.78% as reported by Debeko et al. (2023) from Sidama highland in Ethiopia. This could be due to the amount of sampled and composite crop species in the mill products. Furthermore, the ash content of crop residues in the present study (8.36%) was higher than the ash content (4.7%) of barley crop residues in the three agroecologies in East Gojjam zone as reported in Desta (2023). This discrepancy could be due to the different seasons of the forage samples collected as well as the contamination level of this forage type with the soil and dry matter content. This is consistent with other researchers' findings that the ash content of a particular forage in a particular region can be influenced by seasonal variations as well as soil and other habitat factors that need to be studied by forage crops (Kafeel et al., 2013).

In the current study, the ADF content *of desho* grass (42.86%) and tree lucerne (31.49%) was lower than 48.4% and 35.4%, respectively, whereas the ADF content of mill product (28.5%) was higher than 14.4 % reported by Al-Arif et al. (2017). Furthermore, the ADF of natural pasture (40.85%) and crop residues (57.05%) of the current finding are higher than the results of Aruwayo (2018) who reported 36.35% of ADF to natural pasture and 51.71% ADF to crop residue, respectively. On the contrary, however, the current result of ADF was lower than the values reported by Desta (2023) for barley crop residues at 63.0 % and by Tamene et al. (2022) ranging 47.47%–50.51% for natural pastures. This may be associated with variations in sources, variety, soil types, and climate and crop management between previous studies conducted and in the current study area. Similarly, Tamene et al. (2022) explained that species, soil, temperature, amount, and intensity of rainfall could make the variation between ADF values of different feed types from place to place. On other hand, a previous work scientific findings indicated that a feed type with acid detergent fiber is more than 45 % be considered a low-grade feed source (Feyisa et al., 2022). Based on this conclusion, mill products (16.86%), green fodders (29.71%), tree lucerne (31.49%), enset (36.81%), home leftovers (38.61%), and natural pasture (40.85%) presented less than 45 % of ADF content and were considered a good fodder.

This study result revealed that bamboo leaves provide a larger amount of intermediate storage ash and advanced sources for meeting the mineral requirements of fattening sheep in the study area compared to other types of feedstuffs. A supported finding was reported by José et al. (2019), who described that the ash content in a particular animal feed is considered a good criterion for the total mineral content of the plant material and when its value is above 10%, it becomes acceptable. The ash content of the mill products used in this study was above 4.45% as reported by Degefa and Tamirat (2022). This could be due to the amount of sampled and composite crop species in the mill products. Furthermore, the ash content of crop residues in the present study (8.36%) was higher than the ash content (4.7%) of barley crop residues in the three agroecologies in East Gojjam zone as reported in (Desta, 2023). This discrepancy could be due to the different seasons of the forage samples collected as well as the contamination level of this forage type with the soil and dry matter content. This is consistent with other researchers' findings that the ash content of a particular forage in a particular region can be influenced by seasonal variations as well as soil and other habitat factors that need to be studied by forage crops (Kafeel et al., 2013)

The ADL concentration of sampled feeds varies depending on the type and species of feed available in the study area. According to the results of the present study in Table 8, the lignin content of forage (fresh grass), mill products and desho grass were comparable and below the critical lignin value (7%) (Degefa and Tamirat, 2022). The result showed that these animal feed species have good fiber digestibility and intake by sheep due to their low ADL value and are classified as medium quality feedstuffs among the available feedstuffs in the study area. This result is consistent with the finding of (Degefa and Tamirat, 2022), who found that feeds with a lignin content above the maximum lignin content (7%) had limited intake and were classified in a low-quality group, while feeds with a with a lower lignin content and good intake were considered to be medium quality feed sources.

The current ADL study result of various grass feeds such as natural pasture grass (7.91%), forage (4.78%) and desho grass (6.04%) was below 14.4% and 6.7% (Mohammed, 2020; Shewaye, 2021) each for different grass species. This suggested that the fiber of this forage species of the current study area is more digestible than that of the grass species reported in previous work because ADL is less bound to their fiber. This was supported by Aruwayo (2018), who found that the digestibility of plant cell wall material is mainly influenced by lignin, which is the non-carbohydrate of the cell wall of feed and has been shown to limit fiber digestion. More lignin generally results in higher levels of ADF and NDF and lower animal performance, intake and digestibility. Therefore, fatteners in the current study area have the opportunity to improve their fattening activities by improving this grass species with nutritional supplements while offering it to animals.

CONCLUSION AND RECOMMENDATION

The aim of this study was to examine the nutritional quality of available feed at the level of backyard sheep farms in Bule district. The result obtained through the collection and analysis of data based on the objectives showed that a combination of locally available feed sources was a commonly practiced feed conversion method for sheep fattening, with a large number of households using natural pasture, forage, crop residues, etc. and stubble grazing in such a system in the study area. In addition, fatteners are engaged in the use of high fiber and low crude protein (CP) feed sources, with the exception of forages. In addition, it was pointed out that fattening sheep fed on such a combination suffer from the influence of nutrient deficiencies due to the low digestibility and absorption properties of such feed sources. Regarding forage quality, this study concluded that the CP content of crop residues, stubble pastures, relatively dry grass and natural pasture was below the minimum threshing value (8%) required for maintenance, optimal rumen function and forage intake. Likewise, the structural components (NDF, ADF and ADL) of stubble willows and bamboo leaves were optimal and could be classified as mediocre. On the other hand, green fodder, alfalfa, mill products and household residues were identified as quality feed in terms of their structural components (NDF, ADF and ADL) and their crude protein. In addition, the study results revealed that bamboo leaves, green fodder and desho grass have beneficial ash levels. Therefore, the study could conclude that unless feed quality is improved through quality-improving mechanisms such as crushing, mixing with salt, treating with urea and combining with high-quality sources, those sources whose CP content is below 8% should be fed and which have a high structure ingredient had a greater impact on the productivity of fattening sheep in the study area. However, they suffered more from access to important nutrients when only single food sources were available to them, rather than combinations of different sources.

Therefore, based on these study results, the following recommendations are made to improve fattening activities: Feed sources vary in quality within similar parameters. To maximize feed intake, it is important to design through improving feed conservation and treating way and, choose appropriate sources based on quality and provide them to sheep in the study area.

• To improve the productivity of fattening sheep in the study area, a combination of forage, alfalfa, mill products and household residues is beneficial and recommended for their diet.

• It is recommended to train the fatteners in the area of use of improved feed development of feed on available piece of land to address the seasonal fodder shortage and the associated consequences

DECLARATIONS

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Ethical consideration

Present study is based on *in vitro* evaluations and it’s according to nutritional laboratory guidelines for each essay, and there is no any *in vivo* experiment in present research work.

Data availability

The data that support the study findings are available from the corresponding author upon request.

Author contribution

T. Udesa: designed the study, performed the experiment and collect the data, and discussed the results to the final manuscript;

W. Bekele: Proposal design, supervision; validation; visualization; writing-review and editing;

Consent to publish: Both researchers have consented to the submission of the research article to the journal.

Acknowledgements

I would like to thank Woreda Agricultural Office, Livestock and Fisher Development Department staffs, farmers, agricultural development agents for their assistance in in all their support including feed chemical composition analysis of this research. I would also like to show my gratitude to all laboratory staff of Hawasa and Dilla university nutrition laboratory.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing interests

The authors declare no competing interests in this research and publication.

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