GROWTH PERFORMANCE AND METHANE EMISSION OF LAMBS SUPPLEMENTED WITH HYDROPONIC BARLEY FODDER

by

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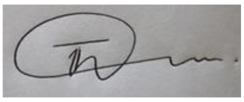
Declaration

I, Thabo Creswell Dhlamini, affirm that this dissertation is an outcome of my investigation under the supervision of Dr T.D.E. Mpanza and Prof K.R. Mbatha and has not been submitted to any other institution. All sources I have used in compiling this work have been duly acknowledged and accredited employing complete references.

Signature:  Date: 12 September 2024

Dedication

This dissertation is primarily dedicated to my mother (Tutu Nomfundo Mbokazi) and aunt (Zanele Annsarah Mavuso), for their deep and infinite mutual, financial, and spiritual support invested in me during the study. Their prayers, efforts and sacrifices are cordially appreciated.

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All thanks are dedicated to the Man above us all, despite all the odds and challenges encountered during the study, He made everything possible for me, and His intervention is always the centre of all possibilities.

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List of abbreviations

ADF	Acid detergent fibre
ADG	Average daily gain
ARC	Agricultural Research Council
BW	Body weight
CH_4	Methane
CO_2	Carbon dioxide
CP	Crude protein
CF	Crude fibre
DM	Dry matter
EE	Ether extract
FCR	Feed conversion ratio
g	Grams
GE	Gross energy
GHG	Greenhouse gases
GLM	General Linear Model
H_2SO_4	Sulphuric acid
Ha	Hectare
Kg	Kilogram
L	Litre
LMD	Laser methane detector
m	Metre
MJ	Mega joules
ml	Millilitre
NDF	Neutral detergent fibre
NFE	Nitrogen free extract
OM	Organic matter
SAS	Statistical Analysis System
TVFA’s	Total volatile fatty acids
UNISA	University of South Africa
VFA’s	Volatile fatty acids

Abstract

The demand for natural resources like water, grazing pastures and land for conventional green fodder production continues to rise, causing the livestock industry to be vulnerable. As a result, it is ideal to find alternative agricultural techniques to produce ample amounts and quality of forage for livestock production. The study aimed to evaluate the effects of supplementing the hydroponic barley fodder sprouts on growth performance, nutrient digestibility, ruminal fermentation and methane emission of Meat-master lambs. In total, 21 male meat-master lambs aged between 3 - 4 months, with an initial body weight of 23.1 ± 1.8 kg were used for this study. Before the experiment, animals were vaccinated for endo, and ecto-parasites and placed for 14 days of quarantine. After that, they were randomly divided into three equal groups; each group had seven lambs. The lambs in the first group (T1) were fed *E. curvula* hay (basal diet), those in the second group (T2) were fed the diet with grass hay plus 25% of hydroponic barley fodder sprouts and those of the third group (T3), were fed the diet that consisted of grass hay plus 50% of hydroponic barley fodder sprouts. Barley grains were washed and soaked for 30 minutes in sodium hypochlorite solution. After that, the seeds were then soaked in tap water overnight. The following morning, the seeds were transferred to the sprouting trays and manually irrigated with tap water three times a day, using a knapsack sprayer until harvested on day eight. All the animals had access to 300 g of concentrate mixture once a day and clean water *ad libitum* throughout the study. They were adapted to experimental diets for seven days. Then, the animals were subjected to a growth study for 61 days; from there, they adapted to faecal bags for five days and another five days for nutrient digestibility. The experimental period was 71 days. On day 52 of the growth study, four animals were randomly selected per treatment for methane detection for nine consecutive days using a laser methane detector (LMD). It was observed that the supplementation of hydroponic barley fodder sprouts had a significant ($p < 0.05$) effect on the growth performance of the animals. The inclusion of sprouted fodder increased feed intake by 42.26 g/day and 114.71 g/day, higher than the animals in T1. Valerate was significantly ($p < 0.05$) increased by the supplementation of sprouted fodder. The supplementation of hydroponic barley fodder sprouts significantly ($p < 0.05$) decreased the production level of NH_3-N and methane emission per the unit of dry matter intake of the animals. The 50% inclusion level of hydroponic barley fodder sprouts can be adopted as supplementary fodder in lamb's diet since it enhanced the growth performance and reduced methane emission. However, further studies are required to evaluate other parameters such as carcass characteristics and validate the adoption of hydroponic barley fodder sprouts as a supplement for optimal animal performance.

Keywords: hydroponic fodder, feed intake, animal performance, rumen fermentation, methane emission, meat-master lambs.

Chapter 1

1. Introduction and background

In recent years, the demand for natural resources like water, grazing pastures and land for conventional green fodder production has continued to rise, causing the livestock industry to be vulnerable (Shah *et al*., 2011). The causes are factors such as high human population growth and the detrimental impacts of climate change (Naqvi *et al*., 2015). Moreover, these factors adversely affect livestock production by causing severe shortages of forages (Rajesh *et al*., 2018). The continuous deficiency in green fodder material threatens food production security and environmental sustainability globally (Falkenmark, 2007).

Therefore, to minimise the vulnerability of livestock production, it is fundamental to intensify research efforts to improve the standards of production, reproduction and profitability of the livestock industry (Safwat *et al*., 2014). This will allow livestock farmers to find alternative agricultural methods of green fodder production with the potential to meet the dietary needs of livestock (Fazaeli *et al.,* 2012). Yet, it will assist them in formulating quality rations for their animals throughout the year (Girma & Gebremariam, 2018). The alternative technique of green fodder production will need to be environmentally friendly, and require minimal space and water with enhanced biomass yields (Kide *et al*., 2015). Since, the impact of climate change continues to have adverse effects on the quality and availability of natural pastures for livestock production (Hoffman & Vogel, 2008; Naqvi *et al*., 2015). This intervention will serve as a significant mitigation strategy to combat the detrimental effects experienced in livestock production.

The livestock industry is of high importance for livelihoods and the eradication of poverty in developing countries (Rajesh *et al*., 2018). Small ruminants play an integral role in food security, community, and economic development, particularly for smallholder farmers (Confort, 2011; Meissner & Shaker, 2013). Small ruminants contribute to job opportunities through their products and by-products (milk, meat, hide, etc.) in the market (Marino *et al*., 2016). The demand for animal meat and by-products is constantly increasing globally (Grunert, 2011). The amount of red meat consumed in 2019-20 was 1 065 000 tonnes (DALRRD, 2021). Consequently, that is due to the increase in global per capita red meat consumption from 23.1 kg to 42.2 kg (Sans & Combris, 2015; Sun *et al*., 2020). However, developing countries are expected to suffer severely to the extent that their arable lands, livestock production and water sources will be incapacitated to meet their daily demands (Gupta *et al*., 2014). Therefore, this has resulted in the urgent need for efficient, reliable and sustainable production of meat and other animal-derived products to meet the increasing market demands (Aziz, 2010). However, the prevalence of climate change and other natural calamities resulted in a shortage of forage supply for livestock (Helal, 2018). These factors inhibit the improvement of livestock production (Shah *et al*., 2008). The effects of climate change, affect agricultural productivity in both direct and indirect ways. The direct impacts involve increased atmospheric temperature, changes in precipitation patterns and unpredictable seasons of the year (Boone *et al*., 2008). The indirect impacts include modifications of ecosystems, deteriorating production yields, the quality of feed crops and increased competition for inadequate natural resources (Naik & Singh, 2013).

Southern Africa is predicted to lose approximately 20% of pasture production potential by the year 2080 due to the adverse effects of climate change (Shah *et al*., 2008; Ramteke *et al*., 2019). This has prompted the urgent need to find reliable alternative agricultural techniques for producing good quality green fodder for livestock production under the extreme climate change impacts (Naik et al., 2015; Al-Saadi & Al-Zubiadi, 2016). Therefore, hydroponics fodder production might be the potential technology able to provide a solution to the challenges of fodder scarcity, because it requires less water as compared to conventional methods (Ata, 2016; Uddin & Dhar, 2018). This can be an efficacious method in providing green fodder to supplement nutrients in poor-quality grass (Naik *et al*., 2015), particularly, during the dry season and in the regions where vegetation is of meagre quality (Abu-Omar *et al*., 2012). The efficiency of the technology makes it one of the most viable and reliable alternatives to growing fodder for livestock (Naik & Singh, 2013).

Chapter 2

2. Literature review

2.1. Introduction

In animal production, feedstuff is one of the aspects that are ultimate and are considered to be the profound input in supplying the dietary requirements of animals irrespective of production stage (Gupta *et al*., 2014). Feeding is considered the most expensive element of livestock production, costing more than 70% of the overall costs (Ramteke *et al*., 2019). Hence, it is necessary to evaluate alternative feed resources with the potential to supply quality forage and reduce the expenses of production regularly (Safwat *et al*., 2014). It is known that the inclusion of good-quality forage is crucial for livestock production (Shah *et al*., 2011). Therefore, high quality forage is essential in livestock diets to maintain or enhance their production (Ata, 2016). So, to improve livestock production to meet the market demands, livestock should be fed good quality forage (Dung *et al*., 2010).

However, the negative climate change impacts have resulted in undesirable attributes that cause imbalances in the availability of forage for livestock production (Tawfeeq *et al*., 2018). Resulting in vulnerability in livestock production associated with the extremity of climate variability extensively experienced worldwide (Farghaly *et al*., 2019). As a result, it is impractical for emerging livestock farmers to meet the dietary demands for livestock production due to exorbitant prices for concentrate diets (Shah *et al*., 2011). The lack of accessibility to high-quality forage for emerging farmers led to a discrepancy between the amount of required forage and what is available, subsequently leading to a decrease in production performance. Hence, the deterioration of rangeland attributed to the extremity of global climate change impact, is the major contributing factor hampering the efficiency of small ruminant production (Naik & Singh, 2014).

2.2. The impact of global climate change on livestock production

The negative impacts of global climate change, make the livestock industry one of the most affected sectors (Rodriguez *et al*., 2004). Climatic conditions include changes in rainfall and environmental temperature resulting in negative natural occurrences such as water scarcity and floods affecting forage yields adversely (Al-Saadi & Al-Zubiadi, 2016). Consequently, forage production and sustainability for livestock are increasingly endangered (Falkenmark, 2007). Natural resources such as grass and water are depleting with negative impacts on livestock's overall performance and welfare. This directly affects the livelihoods of people whose livestock mainly depends on natural forage resources.

2.3. Ruminal microorganisms

The rumen is a complex ecosystem where nutrients are consumed by microorganisms for animals to perform their physiological functions. The ruminal ecosystem consists of a wide range of microorganisms that exhibit symbiotic relationships (Wahrmund *et al*., 2012). The microbes provide the animal with the ability to digest the feed, forage and serve as a source of protein, while the animal provides the microbes with water, warmth and an anaerobic environment. Bacteria, protozoa and fungi form the microbiota (Gonzalez *et al*., 2014). Bacteria play an active role in the digestion of sugars, starch, fibre and protein in rumen (Pitta *et al*., 2010). Protozoa are essential for protein degradation since they engulf large quantities of feed particles and rumen bacteria (Rodriguez *et al*., 2007). Moreover, fungi makes up a small fraction of the rumen population, yet, play a significant role in splitting open plant fibers to make them easily consumed by the bacteria (Maia *et al*., 2010). Ruminants can convert low-quality fibrous materials into products such as milk, meat and fibre for human consumption (Gonzalez *et al*., 2014). Microorganisms produce the enzymes essential for fermentation processes that allow the ruminants to efficiently use the energy contained in forages (Burns, 2008). However, the fermentation process is not entirely efficient because it produces gases such as methane and ammonia that cause detrimental effects on the environment (Kingston-Smith *et al*., 2012).

2.4. Methane emissions by ruminants

Ruminants are distinctively defined as animals with a digestive tract comprising four compartments of the stomach: rumen, reticulum, abomasum and omasum. The rumen is the largest of the four and the original site for enteric methane synthesis produced by archaea bacteria (Martin *et al*., 2009). Furthermore, the environment of the rumen is anaerobic, which facilitates the fermentation of feed by microorganisms that results in the production of volatile fatty acids (VFA's) (acetate, propionate, and butyrate) (Mihaela *et al*., 2014). This serves as the source of energy for ruminants and the synthesis of carbon dioxide (CO_2) and methane (CH_4) that is extracted through eructation (Eugene *et al*., 2008). The CH_4 is formed in the rumen during microbial fermentation of feed, particularly carbohydrates (Sallaku *et al*., 2011). Ruminal methane is a potent greenhouse gas produced by anaerobic fermentation of complex lignocellulosic feeds and non-protein nitrogenous substances by methanogenic archaea, which transform hydrogen and CO_2 to CH_4 (Samal *et al*., 2016). Ruminal methane is capable of (approximately 20 to 25 times more) trapping heat in the atmosphere (Sahebi-Ala, 2021). In addition, it extensively contributes to damaging the ozone layer and causing global warming (Hafla *et al*., 2014). Yet, it is expected to surge even further due to the anticipated increasing demand for animal-derived protein (Arndt *et al.,* 2021). Livestock production, especially ruminants, accounts mainly for anthropogenic CH_4 emissions (Hafla *et al*., 2014). In South Africa, livestock is reported to be responsible for about 41% of the total methane emissions (Blignaut *et al*., 2005).

According to Scholtz *et al*., (2012), ruminants' methane emissions are influenced by various factors, including the level of feed intake, basal diet composition, digestibility and quality of forage. Other than the negative influence it inflicts on the environment, the process of methanogenesis is associated with a loss of about 3 - 14% of gross energy intake and subsequently, leads to the poor use of dietary energy by animals (Immig, 1996; Sallaku *et al*., 2011; Appuhamy *et al*., 2016).

2.5. Management strategies to mitigate methane production in livestock

Despite the social and economic importance of livestock, it remains the primary contributor to greenhouse gases particularly methane, which has adverse impacts on the environment (Arango *et al*., 2020). So, mitigation strategies to abate enteric methane emissions are of prime significance to minimise negative agricultural impacts on global warming and climate change. In this context, it has prompted the importance of giving significant attention to feeding the growing population while minimising the environmental impacts of livestock production (Eisler, 2014). There are a variety of technical options studied as urgent efforts to decrease the production of CH_4 by ruminants in an attempt to combat the prevalence of global warming and climate change (Knapp *et al.*, 2014).

2.5.1. Use of lipids as feed additives

Supplementing traditional diets with lipids is one of the most promising mitigation strategies due to its effectiveness in reducing CH_4 emissions by ruminants, environmental safety, and animal health (Hristov, 2013). According to Eugene *et al*., (2008), a 1% inclusion level of lipids in animals' diet reduces methane production by 2.2% in dairy cows. This is in line with the findings of Beauchemin *et al.*, (2008), who discovered that a 5.6% reduction of methane production is possible in sheep supplemented with coconut oil. Since lipids are not fermented in the rumen, and the digestion of organic matter (OM) is relatively low, there is a potential reduction in CH_4 production (Martin *et al.*, 2009). The addition of dietary fat has been shown to have the potential to decrease methane production by ruminants, Martin *et al*., 2008, reported that the use of linseed oil reduced methane emission by 64% compared to those animals in the control diet. The reduction in the content of methane emissions caused by feeding fat to dairy cows was associated with the reduction in the content of dry matter intake (DMI) (Eugen *et al*., 2008).

2.5.2. Use of ionophore antibiotics

Monensin is rated as the most effective antibiotic in ruminant fermentation (Mihaela *et al*., 2014). It is produced by *Streptomyces cinnamonensis*, known to enhance milk production (Sauer *et al*., 1998). Introducing ionophore antibiotics alters the diversity and quantity of rumen methanogens (Hook *et al*., 2009). This results in the shift of bacterial population from gram-positive to gram-negative and facilitates change in rumen fermentation from acetate to propionate, yet, acetate production is associated with methane production (Patel *et al*., 2011).

2.5.3. **Plant secondary metabolites as feed additives**

Plant secondary metabolites (essential oils, tannins, alkaloids, amines, saponins, flavonoids etc) fall under the group of chemical bioactive compounds in plants that have no role to play in the primary biochemical processes of growth and reproduction and hence play a protective role against invasion by the pathogenic microbes in the host plant (Irchhaiya *et al*., 2015). Livestock production is the main agricultural practice responsible for a considerable part of anthropogenic methane emission, particularly from the enteric fermentation by ruminants (Samal *et al*., 2016). Therefore, using plant extracts, such as saponins and tannins, etc, can effectively reduce rumen methane emission (Leahy *et al*., 2010). Since plant secondary metabolites have an anti-microbial activity that modulates the rumen microbial ecosystem to modify rumen fermentation, thereby reducing methane emission (Samal *et al*., 2016). Concerning the trial conducted by Guo et al. (2008), the inclusion of saponins in the form of additives reduced protozoa number and limited hydrogen availability for methanogenesis. Tannins as feed additives can potentially reduce methane production by 20% (Mohammed *et* *al.*, 2011). In addition, the reduction results from the inhibitory influence on methanogens, protozoa and other hydrogen-producing agents (Patel *et al*., 2011).

2.5.4. Digestibility

Dietary composition significantly influences the amount of methane produced by ruminants (Van Zijderveld *et al*., 2011). Dietary digestibility is positively correlated with the utilisation of feedstuff energy (Alharthi *et al*., 2023). The increased energy intake results in a reduced rate of CH_4 production (Hegarty *et al.,* 2010). Feeds of high quality are usually complimented with high digestibility and energy content, which directly increase animal productivity (Lim *et al*., 2022). Consequently, improving feed utilisation and directly lowering methane production per kg of product (Danielsson, 2016). Hydroponic fodder sprouts exhibit improved nutrient content, low dry matter intake (DMI) and high digestibility, which can play an integral role in reducing enteric methane production due to short rumen retention (Lim *et al*., 2022; Alharthi *et al*., 2023).

2.6. The concept of hydroponic fodder sprout production technology

Hydroponic fodder sprout production is not a new concept, it is dated around the 1600s, and it was used for human consumption (Farghaly *et al*., 2019). Hence, this technique has been developed into the highly sophisticated technology for producing green fodder sprouts for livestock. Thus, hydroponic fodder technology in the livestock sector will build resilience against the adversity triggered by the prevailing scarcity of quality green fodder. Since it is immune to weather variations, requires a small space for production, uses less water for irrigation and uses no soil for germination while providing a constant supply of fodder throughout the year round (Naik and Singh, 2014).

In a hydroponic fodder production system, the quantity of fodder produced within a short period could be ten times more compared to the conventional method based on fresh mass (Mohamed *et al*., 2021). Various types of cereal grains can be used for fresh forage production, including barley, maize, oats, wheat, sorghum and lucerne (alfalfa) (Rodriquez *et al*., 2004; Naik *et al*., 2012). The choice of the preferred seed/s depends on the farm's availability, affordability, geographical location, and agro-climatic condition (Shah *et al.,* 2008). The fodder produced is of good quality, more palatable, digestible, and nutritious, and it can be fed to most herbivorous animals (Getachew *et al*., 2018).

The inclusion of fresh sprout fodder in the livestock's diet can be used to improve production, minimise heat stress and enhance their conceiving and birth rates (Mohsen *et al*., 2015). Therefore, the concept of growing hydroponic fodder may help to minimise the adverse impact of a deficit of green fodder for livestock and improve animal performance (Rodriguez *et al*., 2004). The concept of putting 1 kg of grain seeds into a hydroponic system and producing 4 - 10 kg of fresh green fodder, with a growth height ranging between 15 - 27 cm should be given serious consideration in livestock production (Kruglyakov, 1989; Tawfeeq *et al*., 2018).

2.7. Advantages of hydroponics fodder production technology

Hydroponic fodder production technology is an agricultural method of producing edible and nutritious livestock fodder within a growth chamber or a hi-tech hydroponic structure (Figure 2.1) within 7 to 10 days (Al-Hashmi, 2008). In hydroponic systems, better yields of quality fodder are attained only by using water or nutrient-enriched solution (Kide *et al.,* 2015). The system has better control over global climate change impacts and growing conditions (Al-Karaki & Al-Hashmi, 2012). Adopting hydroponic fodder production technology enables farmers to save money that could be directed to soil preparation, buying and application of fertilizers, removal of weeds, fencing and fuel for harvesting compared to the conventional system (Naik & Singh, 2013). However, the construction of a hi-tech sprouting structure escalates the cost of hydroponic fodder sprouts since the estimated cost of establishing a 4m x 6m x 3m hi-tech structure is more than half a million in South Africa (Rudolph and Machesa, 2023). This indicates that the system would not be affordable for the small-scale farmers. Hydroponic fodder production only requires 1.5 - 2 L of water to produce 1 kg of green fodder compared with the 73 - 160 L of water needed to produce 1 kg of green fodder through the conventional system, which equates to 2 - 3% of water in the traditional model of farming (Naqvi *et al*., 2015; Rajesh *et al*., 2018). In addition, the hydroponic fodder system has a water use efficiency of 80% compared to the conventional method of growing fodder (Rodriguez *et al*., 2004). In this study the cost of production was reduced by modifying the structure where available space was used for sprout production during the trial (See Figure 3.1).

Figure 2.1. Hi-tech greenhouse for the production of hydroponic fodder (Naik and Singh 2014

2.7.1. Usage of pesticides, insecticides, herbicides and reduced carbon footprints

The conventional farming system primarily depends on chemicals like herbicides, fungicides and insecticides to control harmful insects, small animals, weeds and other unwanted organisms for optimum green fodder production (Bakshi *et al*., 2017). Contrarily, the climate-smart agriculture approach is applied in hydroponic technology, which does not use soil, fertilizers and other chemicals (Ata, 2016). Therefore, the fodder produced through the hydroponic system is not exposed to any soil-borne diseases, pests, or fungal infestation which demand the use of pesticides, insecticides and herbicides for control (Bakshi *et al*., 2017). Consequently, the hydroponic fodder production technique is environmentally friendly since it entails zero application of chemicals and machinery. The hydroponic system is more environmentally friendly than traditional fodder production systems (Bakshi *et al*., 2017). Under the traditional forage production system, soil degradation might be caused by land tillering and soil erosion, which have the potential to affect forage production negatively (Naik & Singh, 2014). The hydroponic system helps to reduce the carbon footprints in the atmosphere due to no fuel consumption to transport planting materials (fertilizers, pesticides, herbicides, etc) and no usage of tractors for planting (Bakshi *et al*., 2017).

2.7.2. Constant animal feed supply

The availability of quality green fodder with high digestibility is seasonal, such that the highest quantity and quality are attainable during the rainy season, resulting in grazing animals gaining weight and losing it during the dry season when forage availability and nutrient content depletion (Coleman *et al*., 2018). The constant availability of quality feed supply is essential for the sustainability of livestock production. Therefore, hydroponic fodder is an amicable solution that guarantees farmers year-round production of green fodder (Naik *et al*., 2012; Bekuma, 2019). The nutritional value of the hydroponic fodder is of commendable quality and is suitable to be fed to all categories of livestock (cows, sheep, horses, goats, chickens, pigs, rabbits, etc) (Naik *et al*., 2012; Garuma & Gurmessa, 2021). The year-round production of quality green fodder allows farmers to plan their feed-flow charts precisely, feed their livestock adequately, and sell their animals when the market prices are favourable (Bekuma, 2019).

2.7.1. Efficient use of land

Hydroponic fodder production technology reduces planted land area compared to the conventional method, such that landless farmers can benefit from the system since 600 – 1000 kg of hydroponic fodder can be produced in a 45 – 50 m^2 area. In this system, the area of 50 m^2 is sufficient to produce ± 1000 kg fresh mass of sorghum fodder sprout, while the conventional system requires 1 ha of land to produce the same quantity (Islam *et al*., 2016; Girma & Gebremariam, 2018; Venilla, 2018). In hydroponics technology, crop rotation is not necessary; one crop can be planted throughout the year, excluding improving the soil quality (Bakshi *et al*., 2017).

2.8. The nutritive value of hydroponic fodder sprouts

The sprouted seeds often result in an increased content of protein (Gebremedhin, 2015). According to Lorenz (1980) and Peer & Leeson (1985), the sprouted grains are characterised by an enhanced profile of total crude protein (CP), crude fibre (CF), metabolizable energy (ME), vitamins and minerals, enhanced palatability and digestibility due to the content of starch and dry matter that is decreased. Grains must sprout for their enzymes to function efficiently for nutrients to be hydrolyzed to their basic monomers (carbohydrates are converted to simple sugar, with protein transformed to essential amino acids and fats are altered to essential fatty acids) (Naik & Singh, 2014). The sprouting process increases the availability of calcium, phosphorus and iron as phytase enzymes are readily available in the sprouted grain, which happens to degrade the phytate compounds to form minerals (Dung *et al.,* 2010). In addition, the hydroponic barley sprouts are a rich source of fat-soluble vitamins (vitamin A and vitamin E), water-soluble vitamins (vitamin C), thiamin, riboflavin, niacin, biotin, free folic acid and anti-oxidants (Naik, *et al*., 2015). The sprouting process decreases the level of phytic acid in plant seeds and has effects on mineral absorption which may lead to mineral deficiencies (Farghaly *et al*., 2019). Sprouted fodder serves as a source of essential nutrients than the un-sprouted seed (Kide *et al*., 2015).

Table 2.1. The chemical composition of fodder sprouts from different grains

Sprout	CP %	NDF %	ADF %	GE kcal/Kg	CF %	OM %	EE %	DM %	NFE %	References
Barley	15.23	32.54	15.64	446.75	17.45	96.40	3.95	17.01	60.56	Fargharly *et al*., 2019
Maize	13.75	25.47	10.12	398.89	14.77	85.90	3.55	25.00	60.72	Adebiyi *et al*., 2018
Sorghum	12.31	49.52	19.13	412.62	15.89	80.20	3.23	17.70	63.43	Garuma & Gurmessa, 2021
Oats	23.04	39.50	27.50	436.43	17.32	86.65	4.07	27.00	60.50	Girma & Gebremariam, 2018

CP = crude protein, NDF = neutral detergent fibre, ADF = acid detergent fibre, GE = gross energy, MJ = mega joules, Kg = kilogram CF = crude fibre, OM = organic matter, EE = ether extract, DM = dry matter, NFE = nitrogen free extract.

The soaking and germination processes provide essential moisture necessary to activate the enzyme phytase. That helps to eliminate anti-nutritional factors, such as phytate saponins, enzyme inhibitors, lectins, etc. (Girma & Gebremariam, 2018). Furthermore, germination and sprouting neutralise the inhibitors in cereal grains, which reduces the bioavailability of nutrients (Shipard, 2005).

2.9. Potential effects of hydroponic fodder in livestock production

2.9.1. Milk production and its composition

Accordance to Shit, (2019), feeding of hydroponic maize sprouts on lactating cows improved milk production by 10.3% compared to those fed hay, cereal grains, or silage. In addition, Reddy *et al.,* (1988), Naik & Singh, (2013), observed an increase in milk yield in dairy cows fed maize sprouts. Moreover, the lactating cows fed maize hydroponic sprouts on a fresh mass basis resulted in an improved feed intake and enhanced milk yield by 3.6 kg per day (Shit, 2019). The feeding of hydroponic oats fodder resulted in the improvement in the welfare and milk yield of Comisana sheep (Mincera *et al.,* 2009). The supplementation of hydroponic fodder to the livestock's diet enhanced milk quality by improving the milk fat and protein contents (Agius *et al.,* 2019).

2.9.2. The impact of hydroponic fodder sprouts on animal performance

The benefits of feeding hydroponic sprouts in livestock production include improved weight gain, carcass quality, low feed cost per weight gain and enhanced production potential (Rachel *et al*., 2015).

Table 2.2. Response of different animals on hydroponic fodder sprouts

Fodder sprout offered	Animal used	Animal response	Source
Maize fodder sprouts	Awassi lambs	Improvement in body weight gain.	Naik *et al*., 2015.
Barley fodder sprouts	Beef cattle	An increase in weight gain (±200 g/day).	Muhammad *et al*., 2013.
Maize fodder sprouts	Calves (cross-breed)	An increase in weight gain (±80 g/day).	Rajkumar *et al*., 2018.
Barley fodder sprouts	Awassi lambs	Improved growth performance.	Ata, 2016.
Barley fodder sprouts	Goats	Improved growth performance.	Kide *et al*., 2015.
Maize fodder sprouts	Calves (cross-bred)	Did not change weight gain.	Rani *et al*., 2019.
Barley fodder sprouts	Goats	Improved weight gain and feed conversion efficiency.	Helal, 2015
Barley fodder sprouts	Feedlot steers	Improved growth performance.	Tudor *et al*., 2003
Barley fodder sprouts	Calves	Improved weight gain.	Verma *et al*., 2015
Barley fodder sprouts	Dairy cows	Increased milk yield.	Fazaeli *et al*., 2012

2.9.3. Impact on rumen fermentation activities

The supplementation of hydroponic fodder to ruminants facilitates the increase in total VFA's and propionate since it supplies an adequate amount of vitamins and enzymes (Shipard, 2005). Which in turn, act as bioactive catalysts to promote the metabolism of feed and extract energy essential for growth (Al-Saadi & Al-Zubiadi, 2016). Moreover, the fermentation of nitrogen-free extract (NFE) in the rumen exhibits the production of more propionate, whereas the rumen fermentation of crude fibre (CF) resulted in the production of acetate (Farghaly *et al*., 2019). Feeding hydroponic fodder to sheep decreases the rumen pH level while increasing the concentration of VFA's (Dung *et al*., 2010). In addition, feeding barley sprouts alone to sheep results in reduced dry matter (DM) intake, while improving the digestibility of nutrients and rumen fermentation.

2.10. The feeding value of hydroponic fodder sprouts

The shortage of adequate feed for livestock has been identified as a hindrance in livestock production (Brithal & Jha, 2005). This has necessitated the feeding of hydroponic fodder to livestock, which enhances the digestibility of nutrients and is suitable to be consumed by many categories of animals (Abouelezz *et al*., 2019). This is attributed to the tenderness and palatability of the hydroponic fodder sprouts (Adebiyi *et al*., 2018). The addition of hydroponic green fodder acts as a practical mitigation strategy to address the global issue of green fodder scarcity and nutrient insufficiency in the livestock industry by improving roughage utilisation and digestibility of poor quality. However, the scarcity of data on the nutritive benefits associated with the use of hydroponically sprouted grains in weaned lambs in South Africa led to the creation of this trial. Therefore, this trial aims to evaluate the effects of supplementing hydroponic barley fodder on growth performance and methane emission of lambs fed poor-quality grass hay.

2.11. Challenges in producing hydroponic fodder

Mould infestation is a common challenge associated with hydroponic fodder production (Rajesh *et al*., 2018). This is due to a warm moist environment triggered by irrigating within the planting tray. If consumed in large quantities, mouldy sprouts have proven to cause a serious threat to the well-being of animals and are even capable of causing mortality (Myers, 1974). If the growing plants are not getting sufficient light, poor ventilation and warmth result in a stunted growth rate and that is conducive to mould infestation. Yet, insufficient germination and excessive sprouting can have adverse effects on sprouted grains, which include undesirable bitterness and yielding anti-nutritional factors such as lectins, phytic acid, saponins, and protease inhibitors (Fafiolu *et al*., 2006).

2.12. Problem statement

Livestock production is an important industry that supports food security in many developing countries (Al-Baadani *et al*., 2022). Yet, the productive performance of ruminants is affected by the quality of green fodder in their diets (Ata, 2016). However, due to the effects of climate change and global warming, there is an increasing shortage of feed, both in terms of quality and quantity, which limits the effective productivity of livestock. It has become the greatest challenge among livestock producers to meet the current demands of producing green fodder. On the other hand, ruminant livestock is regarded as the major contributor to GHG emissions, adding greater impact on global warming and climate change, being accountable for approximately 39 - 45% of total agricultural GHG emissions (Herrero *et al*., 2016; Haque, 2018). Ruminants contribute to anthropogenic GHG by as high as 18% (Kreuzer & Soliva, 2008). So, in livestock production, it is important to reduce enteric methane emissions to limit the prevalence of climate change and global warming (Arndt *et al*., 2021). Consequently, emerging farmers are struggling to make viable profits and transition to the main modern agricultural value chains in South Africa (Loeper *et al*., 2016). Exploring alternative technologies for green fodder production and reducing methane emissions is paramount for sustainability in livestock production. Hydroponics is regarded as vital in facing the challenge of green fodder scarcity. Therefore, this study evaluates the effects of supplementing the hydroponic barley fodder sprouts on growth performance, nutrient digestibility, ruminal fermentation and methane emission of meat-master lambs.

2.13. Aim

To determine the effective level of hydroponic barley sprout supplementation to reduce methane emission without compromising the growth performance of lambs.

2.14. Specific objectives

To determine the effects of hydroponic barley sprouts supplement to Meat-master lambs on the following:

I. Growth performance, nitrogen balance and nutrient digestibility of lambs.
II. Ruminal fermentation and methane emission.

Chapter 3

3. Methods and materials

3.1. Ethical clearance and description of the experimental site

The experimental design and all procedures conducted during the experiment were based on animal welfare practices in line with the basis of the approved ethical clearance applications (APAEC/2020/15: ARC and 2021/CAES_AREC/064: UNISA). This study was conducted at the Agricultural Research Council-Animal Production (ARC-AP), in the animal nutrition section, at 25° 53’ 53”S; 28° 11’ 25’E, situated at 1480 m above sea level. It is characterised by an ambient temperature that ranges from hot days in the wet season (17.5 - 32°C) to moderate dry periods with very cold nights (1 - 10°C), with some occasional frost in winter.

3.2. Barley sprout production

The sprouts were produced from barley seeds (*Hordeum vulgare L.*), purchased from Barenbrug SA seeds (Pty) Ltd, with an 80 - 89% germination rate. A steel chamber with dimensions of 2.5 m x 2.5 m and 1 m, length x height x width, respectively was used to produce sprouts. Hence, the steel chamber had a carrying capacity of ±90 perforated sprouting trays. The sprouting trays that were used for sprout production were 100 cm x 40 cm x 5 cm, length x width x length respectively. Before the seeding process, the seeds were washed and then sterilised in sodium hypochlorite solution at a concentration level of 10% for 30 minutes, to prevent fungal infestation (Ajmi *et al*., 2009). After 30 minutes of soaking in solution, the seeds were rinsed with tap water three times. Thereafter, the seeds were soaked overnight in tap water. Then, the following morning, the seeds were transferred to the washed and disinfected sprouting trays. Once planted, the trays were shifted daily to allow the young ones to be above the old ones as a precautionary measure to avoid old sprouts contaminating the young ones in case of mould manifestation. Tap water was used for the irrigation of sprouts, three times a day at 07:30, 12:00 and 16:30, using a 12 L of knapsack sprayer. After a maximum growth period of eight days, sprouts were harvested, hand-shredded, weighed and fed to animals. A 1 kg of dry grains seeded, produced ±5 kg of hydroponic barley fodder sprouts.

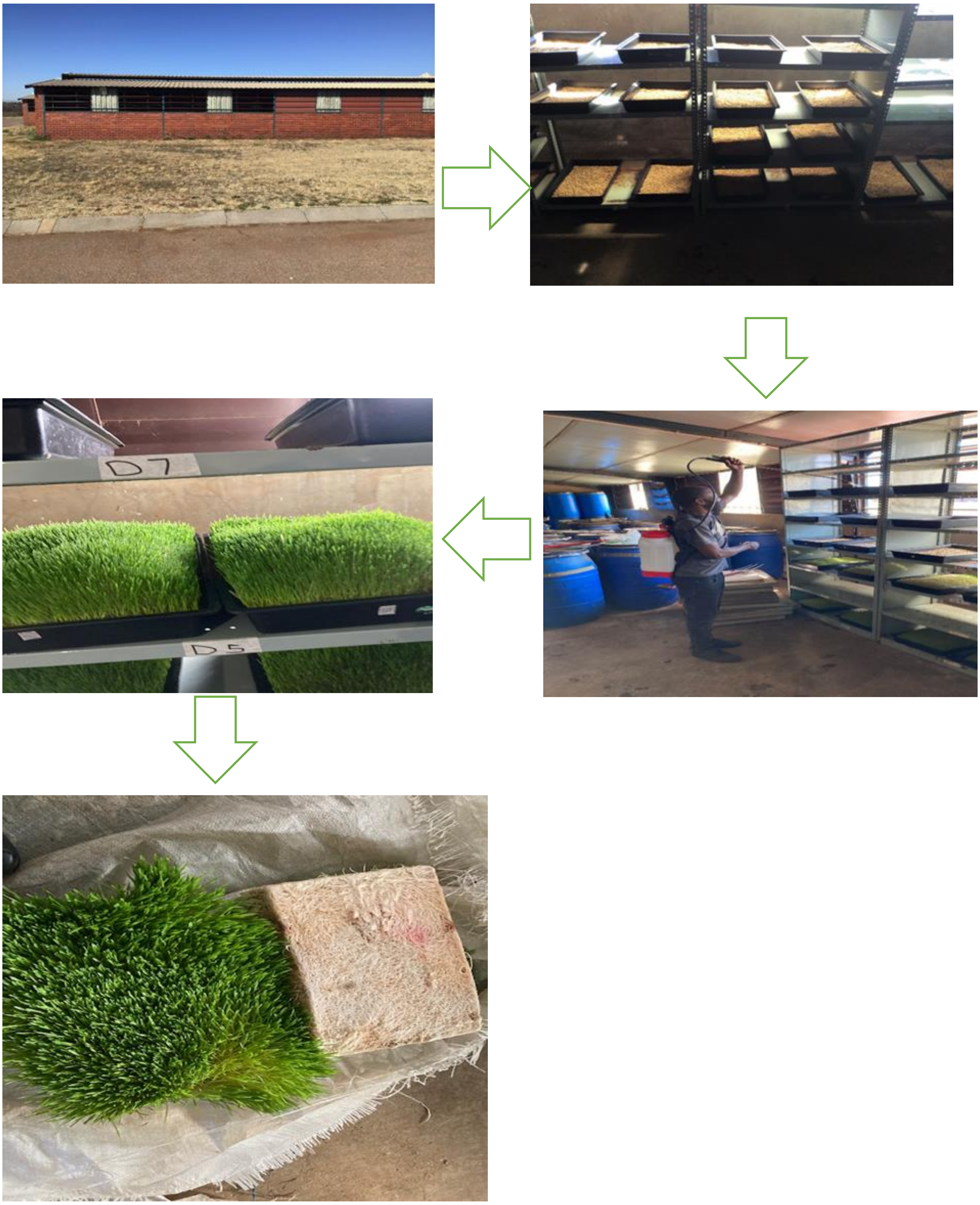

Figure 3.1. Production cycle of hydroponic barley fodder sprout during the study at ARC-AP, Irene.

3.3. Experimental design

A total number of 21 weaned male meat-master lambs, with an initial body weight of 23.1 ± 1.8 kg, aged between 3 - 4 months, were used in this study. Upon arrival at the experimental site, lambs were dewormed, dipped, and vaccinated with Multivax-P and Vecoxan. Experimental animals were grouped in the same camp for a quarantine period of 14 days to ensure that animals were disease-free; during that period, all lambs were fed grass hay and a concentrated diet. After the quarantine period, animals were then subjected to a growth study for 61 days. They were weighed and randomly grouped into three equal groups, with each group having seven animals, and were designated into one of the three dietary treatments.

The dietary treatments used in this experiment were as follows: T1 comprised of grass hay and concentrate (basal diet), T2 comprised of grass hay, concentrate diet and 25% hydroponic fodder sprouts on a dry matter basis while T3 comprised of grass hay, concentrate and 50% hydroponic fodder sprouts on dry matter basis. The 25% and 50% of the hydroponic barley fodder sprouts were calculated from the daily intake of grass hay and concentrate per animal. However, since the fresh hydroponic barley fodder sprouts were used, they were offered separately with grass hay and concentrate diet, owing to their moisture content. On a gradual basis, those animals that consumed hydroponic barley fodder sprouts were adapted to it for seven consecutive days. Following the feeding pattern, those animals in T2 were fed 110 g/head/day of hydroponic barley fodder sprouts until they reached 770 g/head/day on day seven. Similarly, those animals in T3 were fed 220 g/head/day of hydroponic barley fodder sprouts until they reached 1540 g/head/day on day seven. Moreover, the quantity of 770 g and 1540 g of sprouts is what was fed per animal on treatments 2 and 3 from the commencement of the growth study, and it was then adjusted as per the animal's daily feed intake. In addition, all animals received a concentrate supplement of 300 g each per day and had free access to clean water throughout the study period. A concentrate diet was offered once in the morning at about 08:00. The ingredients of the concentrate diet that was fed as a supplement are shown in Table 3.1. Whereas, the varying profiles of chemical composition of the experimental diets are provided in Table 3.2.

Table 3.1. Ingredients of concentrate diet used during the study

Ingredients	Quantity (%)
Hominy chop	50
Wheat bran	30
Soybean cake meal	17
Feed lime	1.5
Salt	0.5
Premix	1
Total	100

Post consuming the concentrate diet, the basal diet was fed to animals. In the case where an animal finishes all feed offered per day, the daily feed offer was increased by 10% from the previous day. The daily feed intake was determined on a subsequent day by weighing the remnants and deducting them from the total amount of feed offered from each animal per metabolic cage. Furthermore, to reduce feed wastage by the animals, diets were offered twice a day at 08:30 in the morning and 15:30 afternoon. After the growth study, animals were subjected to a digestibility study, which took 10 days including five days of adaptation to faecal bags, followed by another five days for data collection.

Table 3.2. Chemical composition of concentrate, grass hay, barley seeds and sprouts (%)

Item	Concentrate	Grass hay	Barley grains	Barley sprouts
DM	89.6	92.8	91.5	24.5
Ash	6.9	3.7	1.5	2.4
CP	15.0	4.8	7.7	10.3
EE	4.3	1.6	2.1	2.4
NDF	26.5	75.9	29.5	32.4
ADF	17.3	70.5	8.5	17.0

DM = dry matter, CP = crude protein, EE= ether extract, NDF = neutral detergent fibre, ADF = acid detergent fibre.

3.4. Growth performance of meat-master lambs

At the beginning of the growth study, all experimental animals were weighed using the small-stock weighing scale (SS4, Tal-tec, South Africa, Model TT40), and their initial body weight was captured. Then, animals were randomly assigned to three treatments, namely (T1, T2 and T3). Each treatment comprised seven animals, which were individually confined in cages. The individual body weight of each was taken and recorded at two-week intervals, this was always done before the morning feed. The feed intake of each animal was calculated as the difference between the feed offered and refusals for 61 days, excluding the initial 14 days of quarantine. The average daily gain (ADG) and feed conversion ratio (FCR) were calculated as follows:

1. $ADG = \frac{\text{Weight gain}}{\text{Number of trial days}}$
2. $FCR = \frac{\text{Feed intake}}{\text{Weight gain}}$

3.5. Enteric methane emissions

On day 52 of the study, four animals were randomly selected per treatment to measure methane production. Enteric methane emission was detected using a hand-held laser methane detector (LMD) (Crowcon Detection Instruments Ltd., Tokyo, Japan), which gave the readings of methane production as ppm-m. The gas column density was measured on the individual animal by directing the auxiliary, targeting the laser beam at the nostrils of the animal at a reasonable distance of 3 m from the animal (Chagunda *et al*., 2009).

This distance was used to avoid any disturbance in animal activities while measuring methane production. All methane measurements were taken four hours post morning feeding and at the same time of the day for nine consecutive days (namely, from day 52 to 60 days of the experiment), starting from 11:00 in the morning to 12:04 in the afternoon. It is recommended to measure methane during the late hours of the day, since, it has proved to be difficult to see the laser beam in direct sunlight, and there must be no or minimal air during the methane production detection process (Chagunda *et al*., 2009). However, in this study, the wind and sunlight presented no difficulties since it was conducted inside a closed structure.

To include the different stages of the respiratory tidal cycle, six measurement readings of methane production of each animal were taken every 60 seconds, four minutes were allocated for each animal and resulting in 24 readings taken per animal per day. The results from this study were reported in grams per day using means of the reworked version of the deterministic model developed by Chagunda *et al*., (2009).

$$Y = d\ (5.76m)$$

Where:

Y = Methane yield g/day

d = 0.31 when a measurement is taken on the animal lying down or 0.38 on a standing animal.

m = Average concentration (ppm) methane measurement from the measurement window.

3.6. Nutrient digestibility and nitrogen balance

At day 66 of the study, the four animals used for the enteric methane emission study that were randomly selected per treatment were harnessed with faecal collection bags, given five days as an adaptation period to metabolic cages and faecal bags. The standard procedures of feeding and animal management applied during the growth study were also applied during the digestibility study. The orts, faeces and urine samples were taken before feeding the animals. The experimental diets, orts and faecal materials were collected for five consecutive days and oven-dried at 60°C for 72 hours. The samples were milled through 1 mm mill screen for nutrient chemical analysis. The nutrient chemicals analysed included crude fibre (CF), crude protein (CP), ether extract (EE), ash and dry matter (DM) using procedures of AOAC (2012). While, acid detergent fibre (ADF) and neutral detergent fibre (NDF) were determined through the procedure of Van Soest *et al*., 1991. Faeces were collected from the faecal bags mounted on the animals and weighed daily. The metabolic cages have designated urine harvesting shelves underneath the cages, then urine was collected and measured daily. Faeces and urine collected from each animal were recorded daily and 10% of the recorded faeces and urine excreta were stored at -20°C. The containers used for urine collection contained 20 mL of 10% HCI, which was used to sustain the pH level of urine below.

3.7. Rumen fermentation

Upon completing the digestibility trial, rumen fluid samples were collected from the four animals per treatment that were used for the digestibility study. The samples of the rumen fluid were collected before the morning feeding by gently inserting the stomach tube into the rumen through the mouth, under the guidance of the registered ARC vet. Then, the rumen samples were strained through four layers of cheesecloth and separated into two portions of 4 and 5 mL of each. The first portion of 4 mL was used to determine the concentration of ammonia nitrogen (NH_3-N) according to the procedure of Conway, (1962). The second portion was used to measure the total volatile fatty acids (TVFA's) following the procedure by Warner, (1964).

3.8. Statistical analysis

Data on growth performance parameters, Ammonia nitrogen (NH_3-N), Volatile fatty acids (VFA's) and nutrient digestibility were analysed using Analysis of Variance (ANOVA) using the General Linear Model (GLM) procedures of SAS version 9.4 M7 (SAS, 2020). Statistical difference was declared at $p \leq 0.05$. Duncan's multiple range test was applied for means separation.

Chapter 4

4. Results

4.1. Growth performance of meat-master lambs

Table 4.1 shows the parameters measured reflecting the growth performance of meat-master lambs from all the experimental diets. The provision of hydroponic barley fodder sprouts significantly ($p < 0.0186$) influenced the final body weight of animals in T2 and T3, since their body weights were respectively 3.31 kg and 4.91 kg heavier than those in T1 (control diet). The supplementation of hydroponic barley fodder sprouts significantly ($p < 0.0001$) influenced the average daily gain (ADG) for animals in T2 and T3 compared to those in T1. A significant difference ($p < 0.0001$) was noted in the feed intake for the animals supplemented with hydroponic barley fodder sprouts T2 and T3 were 42.26 g/day and 226.78 g/day respectively greater than those in T1. A significant variation ($p < 0.0022$) was observed in the feed conversion ratio (FCR) between the animals in different experimental treatments.

Table 4.1. The influence of hydroponic barley fodder sprouts on the growth performance of meat-master lambs

Item	T1	T2	T3	SEM	p-value
Initial body weight (kg)	22.94	22.97	23.34	1.828	0.9015
Final body weight (kg)	28.60^{b}	31.91^{ba}	33.51^{a}	2.961	**0.0186**
Total weight gain (kg)	5.66^{b}	8.94^{a}	10.17^{a}	1.397	**0.0001**
ADG (g/day)	107^{b}	169^{a}	192^{a}	0.026	**0.0001**
Feed intake (g/day)	930.29^{b}	972.55^{b}	1157.07^{a}	0.683	**0.0001**
FCR	3.75^{a}	2.33^{b}	2.26^{b}	0.751	**0.0022**

T1 = treatment 1; T2 = treatment 2; T3 = treatment 3; SEM = standard error of the mean; ADG = average daily gain; FCR = feed conversion ratio; Means within the same line bearing different superscripts differ significantly ($p < 0.05$).

4.2. Nutrient digestibility and nitrogen balance

Table 4.2 represents the results on the influence of hydroponic barley fodder sprouts on nutrient digestibility among the treatments. The supplementation of hydroponic barley fodder sprouts significantly ($p < 0.0024$) affected the CP digestibility.

Table 4.2. The influence of hydroponic barley fodder sprouts on nutrient digestibility of meat-master lambs

Item (%)	T1	T2	T3	SEM	p-value
CP	36.43[b]	44.78[ab]	51.27[a]	10.493	**0.0024**
EE	60.6	71.49	71.62	6.921	0.0823
OM	44.61	51.58	55.21	10.425	0.3723
ADF	46.37	39.29	43.47	12.522	0.7323
NDF	39.46	34.76	34.49	10.515	0.7599

T1 = treatment 1; T2 = treatment 2; T3 = treatment 3; SEM = standard error of the mean; CP = crude protein; EE = ether extract; OM = organic matter; ADF = acid detergent fibre; NDF = neutral detergent fibre; Means within the same line bearing different superscripts differ significantly ($p < 0.05$).

Table 4.3 represents the results on the influence of hydroponic barley fodder sprouts on nitrogen balance among the treatments. From the current research results, a significant ($p < 0.0001$) difference was noted in the content of N-intake in those animals supplemented with hydroponic barley fodder sprouts, yet the rate of increase in the content of N-intake seemed to be interconnected to the content of sprouted fodder supplementation. A significant difference ($p < 0.05$) was noted in the content of N-retained and the percentage of N-retained on animals supplemented with hydroponic barley fodder sprouts.

Table 4.3. The influence of hydroponic barley fodder sprouts on the nitrogen balance of meat-master lambs

Items	T1	T2	T3	SEM	p-value
N-intake (g/day)	14.77^{b}	18.78^{a}	20.98^{a}	0.736	**0.0001**
Faecal-N (g/day)	7.94	8.44	9.09	2.925	0.5477
Urinary-N (g/day)	3.05	4.66	5.27	2.221	0.2623
N-absorbed (g/day)	6.83^{b}	9.59^{a}	11.89^{a}	2.915	**0.0042**
N-retained (g/day)	3.78^{b}	5.68^{a}	6.62^{a}	3.762	**0.0437**
N-retained (%)	25.59^{b}	27.34^{b}	31.55^{a}	3.676	**0.0344**

T1 = treatment 1; T2 = treatment 2; T3 = treatment 3; SEM = standard error of the mean; Means within the same line bearing different superscripts differ significantly ($p < 0.05$).

4.3. Enteric methane emission of meat-master lambs

The results on methane production per day are presented in Figure 4.1. The supplementation of hydroponic barley fodder sprouts significantly ($p > 0.05$) reduced methane production from day 6 to day 8, the rate of methane emission decreased with the content increase in hydroponic barley fodder sprouts supplementation. The effects of supplementing hydroponic barley fodder sprouts on methane emission per dry matter intake (DMI) are presented in Figure 4.2. The inclusion of sprouted barley fodder significantly ($p < 0.05$) reduced the methane emission of the animals per DMI. The methane emission per DMI of T1 on the first day was significantly ($p < 0.05$) higher, while was similar on T2 and T3. From D2-D9 methane emission significantly ($p < 0.05$) differed between T1, T2 and T3.

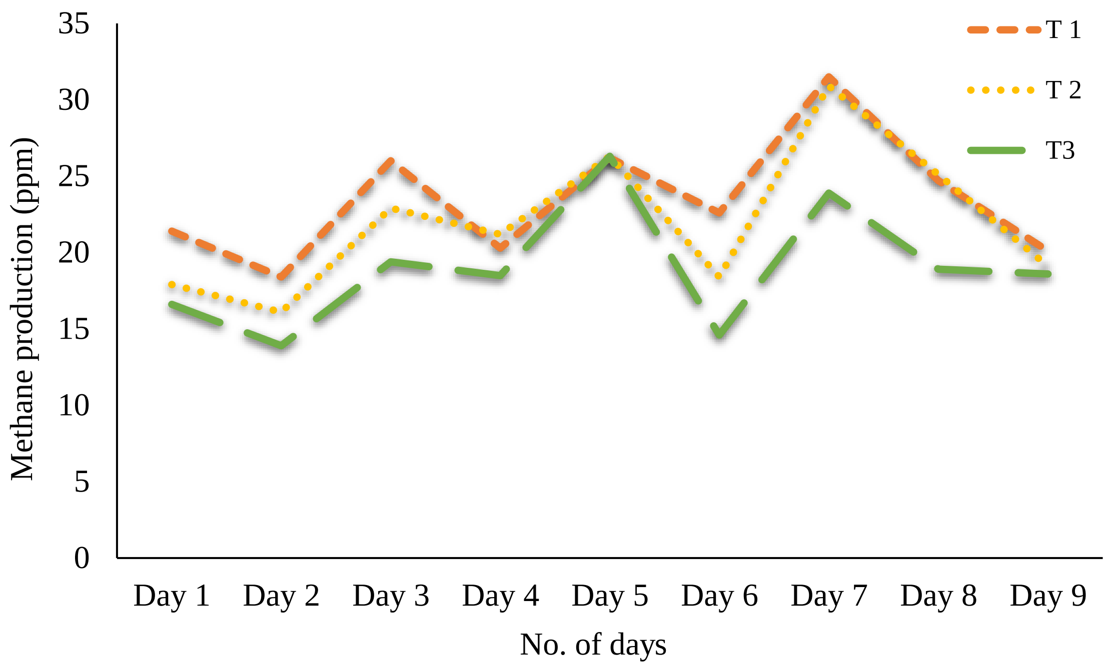

Figure 4.1. The influence of barley fodder sprouts supplementation on daily methane emission of meat-master lambs. T1 = treatment 1; T2 = treatment 2; T3 = treatment 3.

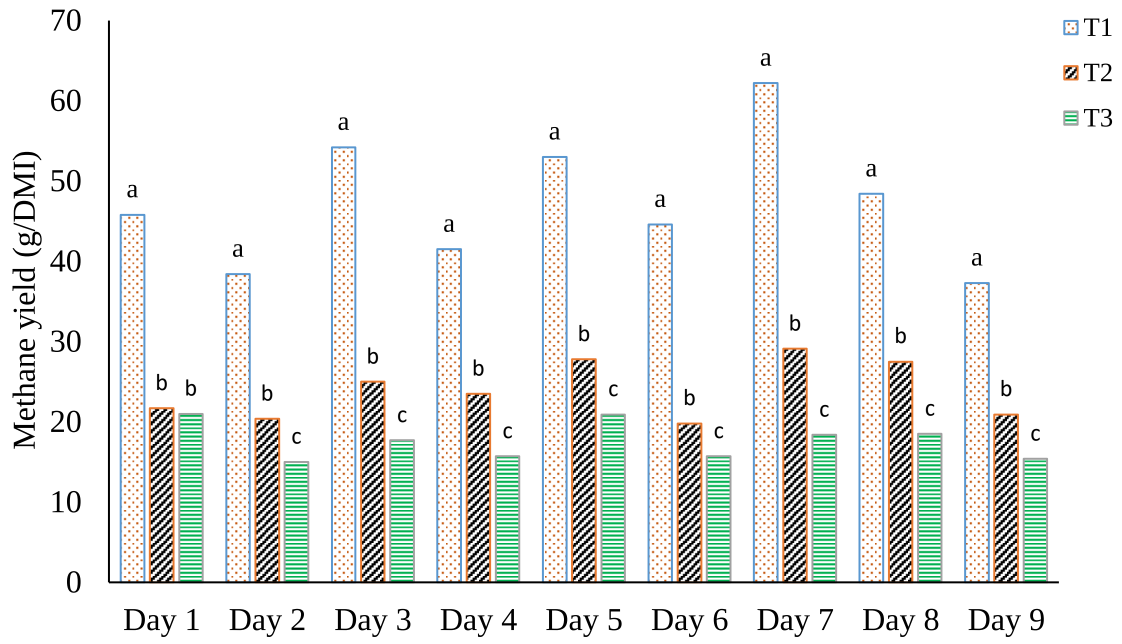

Figure 4.2. The influence of hydroponic barley fodder sprouts on methane emission per dry matter intake of meat-master lambs. T1 = treatment 1; T2 = treatment 2; T3 = treatment 3; Letters "a, b and c" within the daily means are used to indicate the significant difference among the treatments.

4.4. Rumen fermentation of meat-master lambs

The rumen fermentation profiles of meat-master lambs in different experimental diets are presented in Table 4.4. It was noted that the supplementation of hydroponic barley fodder sprouts significantly ($p < 0.0001$) reduced the production rate of ammonia nitrogen (NH_3-N). The concentration of acetate was significantly ($p < 0.0378$) reduced by the supplementation of hydroponic barley fodder sprouts in T3. The supplementation of hydroponic barley fodder sprouts did not significantly ($p > 0.05$) influence the concentration of propionate, butyrate and iso-valerate. The production level of valerate was significantly ($p < 0.0029$) increased in T2 compared to T1 and T3. A significant difference ($p < 0.0426$) was noted in the concentration ratio between acetic and propionic acids because of hydroponic barley fodder sprouts supplementation.

Table 4.4. The influence of hydroponic barley fodder sprouts supplementation on rumen fermentation of meat-master lambs

Items	T1	T2	T3	SEM	*p*-value
NH_3-N (mg/dL)	16.11^{a}	9.41^{b}	7.83^{b}	1.495	**0.0001**
TVFA's (mmol/L)	68.85	68.27	59.79	10.214	0.5344
Rumen VFA's concentrations (mg/100ml)					
Acetate	50.38^{a}	46.03^{a}	40.77^{b}	7.774	**0.0378**
Propionate	11.45	13.66	12.46	2.072	0.4702
Butyrate	4.84	6.01	5.48	1.202	0.5275
Iso-valerate	0.83	0.92	0.58	0.146	0.0685
Valerate	0.51^{b}	0.65^{a}	0.50^{b}	0.035	**0.0029**
A:P ratio	4.2^{a}	3.3^{b}	3.2^{b}	0.234	**0.0033**

T1 = treatment 1; T2 = treatment 2; T3 = treatment 3; SEM = standard error of the mean; Means within the same line bearing different superscripts differ significantly ($p < 0.05$).

Chapter 5

5. Discussion

5.1. Growth performance of meat-master lambs

The results of this research found that the supplementation of hydroponic barley fodder sprouts enhanced the body weight gain of the animals in T2 (grass hay, concentrate diet and 25% hydroponic barley fodder sprouts on dry matter basis) and T3 (grass hay, concentrate diet and 50% hydroponic barley fodder sprouts on dry matter basis). These results were supported by Fayed, (2011), body weight gain was observed in animals supplemented with sprouted fodder than those that were fed only the basal diet. However, contrary results were attained by Saidi & Abo-Omar, (2015), who reported no significant influence on the body weight gain of ewes supplemented with sprouted barley fodder. The improvement in body weight gain reported in this study might be associated with the ability of sprouted fodder to supply the rumen microbes with nutrients sufficient to aid in better utilisation of feed by animals (Alharthi *et al*., 2023).

The average daily gain was improved in lambs with access to hydroponic barley fodder sprouts. This is consistent with the results reported by Verma *et al*., (2015), who observed higher average daily gain in Haryana male calves fed sprouted fodder than those fed the basal diet. In a similar trend, Rajkumar *et al*., (2018) noticed high average daily weight gain in calves that had access to hydroponic fodder sprouts, which may be attributed to the better digestibility and nutrient content of sprouted fodder. It has been evident in the results of this study that the supplementation of hydroponic barley fodder sprouts significantly influenced the feed intake of animals in T3. These findings are in line with the results reported by Helal, (2018), who noticed the higher ($p < 0.05$) feed intake by Barki ewes fed sprouted fodder compared to those fed the control diet. This may be due to the production attributes of sprouts, which include the degradability of complex compounds to their simpler forms and the sprout juice factor, which makes it palatable. Therefore, the animals relish consuming it (Du *et al*., 2020).

The results of this study showed that feeding the hydroponic barley fodder sprouts significantly enhanced the FCR of lambs more than those fed the control diet since it was 2.33 in T2 and 2.26 in T3 compared to 3.75 in T1 (grass hay and concentrate diet). This concords with the findings by Ata, (2016), who reported that the inclusion of hydroponic barley sprouts improved the FCR in Awassi lambs. The animals fed the control diet (T1) utilised the feed consumed less efficiently for body weight gain, whereas those fed the sprouted fodder (T2 and T3), used the consumed feed more efficiently in gaining body weight. However, contrasting results were observed by Fazaeli *et al.*, (2012), who observed non-significant results in FCR of calves fed the sprouted fodder. The improvement in feed conversion efficiency of the animals supplemented with hydroponic barley fodder sprouts observed in this study may be attributed to the high content of CP in sprouted fodder (Fagharly *et al*., 2019).

5.2. Nutrient digestibility and nitrogen balance

For animals to optimally perform their physiological functions, they are primarily dependent on the accessibility of nutrients in the ingested feed by the animal. The findings of this study have shown that the supplementation of hydroponic barley fodder sprouts significantly enhanced the digestibility of CP. These results correlate with Hegab *et al*., (2019) results, where a significant increase in CP digestibility in lambs supplemented with the sprouted fodder was observed. However, it has been evident in the current study that the digestibility of other nutrients was not influenced by the supplementation of hydroponic barley fodder sprouts, which the loss of total dry matter might negate. This aligns with the findings reported by Moghaddam *et al*., (2009) and Fagharly *et al*., (2019).

Moreover, owing to the supplementation of hydroponic barley fodder sprouts the improvement was noted in nutrient digestibility in lambs fed T2 and T3. The enhancement of nutrient digestibility of the animals supplemented with sprouted fodder was noticed by Fayed, (2011). Similar results were also observed by Muhammad *et al*., (2013), who tested the feeding efficiency of hydroponic barley fodder in goats. Salo *et al*., (2019), concluded that the increase in nutrient digestibility in lambs supplemented with hydroponic barley fodder sprouts might be associated with the tenderness of the fodder and the presence of the bioactive catalysts which facilitate the digestion and absorption of nutrients by animals. In addition, Shipard, (2005) reported that, feeding sprouted fodder provided animals with a substantial quantity of nutritional constituents for the functional efficiency of rumen enzymes.

The results of this research illustrated an enhanced rate of N-intake from the animals subjected to hydroponic barley fodder sprout treatments than those fed the control diet. This is in line with the findings by Fayed, (2011), in which female lambs were supplemented with sprouted barley fodder. However, this is dissimilar to the results attained by Fagharly *et al*., (2019), who reported a lower content of N-retention from the animals that were fed the hydroponic barley sprouts compared to those fed the basal diet. An increase in the concentration level of N-retention from animals subjected to diets containing hydroponic barley fodder sprouts may be attributed to the improved rate of N-intake and digestibility (Helal, 2018). An enhanced rate of rumen N is ideal as it plays an imperative role in the efficiency of animal performance and productivity (Fayed, 2011).

5.3. Enteric methane emission of meat-master lambs

Ruminal methane emission has detrimental effects on the environment and profitability of livestock farming enterprises since it is associated with a significant quantity of 2 - 15% of dietary energy that is voided (Kim *et al*., 2012). The enteric methane emission is influenced primarily by factors including feed intake, dietary fibre, digestibility, and feed retention in the rumen (Scholtz *et al*., 2012). Therefore, feeding green fodder, which is highly digestible, like hydroponic barley fodder sprouts, to ruminants may contribute immensely to mitigating ruminant methane output. In this study, the methane emission was reduced by the supplementation of sprouted fodder, this may be due to sprouts providing nutrients that are readily available to ruminal microbes and enzymes that help in fibre digestion. A diet with high digestibility plays an integral role in facilitating the reduction of methane emission per unit of production per animal (Kumar *et al*., 2017). Thus, methane emission is negatively correlated to the increase in sprouts supplementation. The average methane gas emission in T2 and T3 was reduced by 6.3% and 19.2%, respectively compared to the control diet. The CH_4 output in T1 (control diet) was 42.7%. In this study, the basal diet (grass hay) had a high fibre fraction (see Table 3.2). However, barley sprout supplementation provided extra nutrients and enzymes lacking in the fed control diet. Hence CH_4 was high compared to the animals fed barley sprout supplementation (T2 and T3). In a similar trend, Getachew *et al*., (2018) indicated that diets with high fibre content are slowly digestible in the rumen resulting in greater potential for methane emission.

5.4. Rumen fermentation of meat-master lambs

The results show that the supplementation of hydroponic barley fodder sprouts significantly influenced the production level of NH_3-N compared to animals in the control diet. The concentration of NH_3-N decreased when the level of hydroponic barley fodder sprouts increased. These findings concur with the results reported by Raeisi *et al*., (2018) and Fagharly *et al*., (2019). However, contrary results were observed by Helal, (2015), who reported a significant increase in the content of NH_3-N on animals that had access to sprouted fodder. The increase in the content of NH_3-N production indicated the poor use of nitrogen by the animals in the control diet, which might have detrimental effects on the environment through nitrification (McDonald *et al*., 2010). From the results of this study, the inclusion of hydroponic barley fodder sprouts can contribute to the efficient use of nitrogen by animals. However, according to Mpanza *et al*., (2022), supplementation beyond 50% is not recommended owing to the risk of reducing the production level of NH_3-N below the level optimal for ruminal microbial growth.

It has emerged from this study that, there was no significant difference in TVFA's between the animals supplemented with the sprouted fodder compared to those in the control diet. These results concord with the observations made by Hafla *et al*. (2014), but contrary observations were noted by Helal (2018), who reported improved TVFA's in animals supplemented with sprouted barley. The reduced level of TVFA's in animals supplemented with hydroponic barley fodder sprouts might be substantiated by the potential of sprouts to be highly digestible, which then can quickly pass through the rumen, yet attributing to rapid utilisation of VFA's by animals to fulfil their energy demands for physiological functions (Alharthi *et al*., 2023).

From the current results, it was observed that the supplementation of hydroponic barley fodder sprouts significantly reduced the production of acetate. This aligns with the results observed by Hafla *et al*., (2014) on rams fed the hydroponic barley fodder sprouts. The reduction in the acetate concentration might be attributed to the low fibre content in hydroponic barley fodder sprouts (Al-Saadi & Al-Zubiadi, 2016). The propionate concentration was high in animals fed the sprouted fodder compared to those in the control diet, however, it was not statistically significant. This agrees with the results reported by Helal, (2018) on Barki ewes fed the sprouted fodder. The improved content of propionate in animals supplemented with hydroponic barley fodder sprouts may be related to sprouts regarded as a good source of vitamins and enzymes which in turn act as bioactive catalysts essential to stimulate the metabolism of feed and energy release (Shipard, 2005). Furthermore, the content of ratio between the acetic and propionic (A:P) acids was significantly higher in animals fed the control diet than those supplemented with hydroponic barley fodder sprouts. The reduction in the A:P ratio in animals supplemented with hydroponic barley fodder sprouts is an indication that these animals had more energy available to use for maintenance and production (Gupta *et al*., 2014). The available energy was translated to animal performance in terms of weight gain. Hence, animals in T2 and T3 recorded an increased body weight compared to those in T1.

Chapter 6

6. General conclusion and recommendations

6.1. Conclusion

In conclusion, the content of CP which is a limiting factor in ruminants was high in hydroponic barley fodder sprouts. Therefore, the supplementation of hydroponic barley fodder sprouts positively affected the growth performance of the animals in T2 (25% fodder sprout) and T3 (50% fodder sprout). This could also have been influenced by the better-enhanced digestibility of nutrients by animals supplemented with sprouted fodder, which directly resulted in the improved N-retained. In addition, the supplementation of hydroponic barley fodder sprouts resulted in a reduced concentration of acetate, hence, improving propionate production. Consequently, the supplementation of hydroponic barley fodder sprouts exhibited reduced levels of methane production and A:P ratio. The enhanced performance of animals seemed to benefit from the supplementation of hydroponic barley fodder sprouts since more energy was available to animals for maintenance and production.

6.2. Recommendations

The results of this study have shown that the use of hydroponic barley fodder sprouts might improve the growth performance, N-retained while reducing the rate of methane emission of ruminants. Therefore, the use of hydroponic barley fodder sprouts might be recommended to be strategically introduced as a supplementary diet to meet the green fodder demands of small ruminants.

However, given the variations in findings by different researchers about the effectiveness of sprouted fodder in animal performance and the limited information on the application of hydroponic barley fodder sprouts in livestock production in South Africa. Therefore, further studies are recommended to determine other components like carcass quality, reproductive performance, milk quality and yield to draw a conclusive decision on adopting the supplementation of hydroponic barley fodder sprouts for optimal animal performance.

References

Abouelezz, K.F.M., Sayed, M.A.M. and Abdelnabi, M.A., 2019. Evaluation of hydroponic barley sprouts as a feed supplement for laying Japanese quail: Effects on egg production, egg quality, fertility, blood constituents, and internal organs. *Animal Feed Science and Technology. Journal of Egypt Poultry Science.* 37: 834–854.

Abu-Omar, J., Daya, R. and Salama, A., 2012. Effect of different types of Olive Cake on the performance and carcass quality of Awassi lambs. *Animal Feed Science and Technology*. 171: 167-172.

Adebiyi, O., Adeola, A.T., Osinowo, O.A., Brown, D. and Ng'ambi, J.W., 2018. Effects of feeding hydroponics maize fodder on performance and nutrient digestibility of weaned pigs. *Applied Ecology and Environmental Research*. 16: 2415-2422.

Agius, A., Pastorelli, G. and Attard, E., 2019. Cows fed hydroponic fodder and conventional diet: effects on milk quality. *Archive of Animal Breed*. 62: 517–525.

Ajmi, A., Salih, A.A., Kadim, I. and Othma, Y., 2009. Yield and water use efficiency of barley fodder produced under hydroponic system in GCC countries using tertiary treated sewage effluents. *Journal of Phytology*. 1: 342-348.

Al-Baadani, H.H., Alowaimer, A.N., Al-Badwi, M.A., Adbelrahman, M.M., Soufan, W.H. and Alhidary, I.A., 2022. Evaluation of the nutritive value and digestibility of sprouted barley as feed for growing lambs: in vivo and in vitro studies. *Journal of Animal Science*. 12(9): 122-236.

Alharthi, A.S., Al-Baadani, H.H. and Alhidary, L.A., 2023. Effect of feeding different levels of sprouted barley on fermentation characteristics and rumen morphology of growing lambs. *Journal for Veterinary Science*. 10: 15-30.

Al-Hashmi, M.M., 2008. Hydroponic green fodder production in the Arabian Gulf region. MSc Thesis, Faculty of Postgraduate Studies, Arabian Gulf University, Bahram.

AI-Karaki, G.N. and AI-Hashmi, M.M., 2012. Green fodder production and water use efficiency of some forage crops under hydroponic conditions. *International Scholarly Research*. 5: 1-6.

Al-Saadi, M.J. and Al-Zubiadi, I.A.H., 2016. Effects of substitution barley by 10%, 30% of sprouted barley on rumen characters, digestibility and feed efficiency in diet of Awassi male lambs. *International Journal of Science and Research*. 5: 2228-2233.

AOAC, 2012. Official methods of analysis, 19th ed. Association of Official Analytical Chemists, Rockville, MD, USA.

Appuhamy, J.A.D.R.N., France, J. and Kebreab, E., 2016. Models for predicting enteric methane emissions from dairy cows in North America, Europe, and Australia and New Zealand. *Global Change Biology*. 22: 3039-3056.

Arango, J., Ruden, A., Martinez-Baron, D., Loboguerrero, A.M., Berndt, A., Chacon, M., Torres, C.F., Oyhantcabal, W., Gomez, C.A., Ricci, P., Ku-Vera, J. and Burkart, S., 2020. Ambition meets reality: achieving GHG emission reduction targets in the livestock sector of Latin America. *Journal for Sustainable Food System*. 4: 6. https://doi.org/10.3389/fsufs.2020.00065

Arndt, C., Hristov, A.N., Price, W.J., McClelland, S.C., Pelaez, A.M., Cueva, S.F., Oh, J., Bannink, A., Bayat, A.R., Crompton, L.A., Dijkstra, J., Eugene, M.A., Kebreab, E., Kreuzer, M., McGee, M., Martin, C., Newbold, C.J., Reynolds, C.K., Schwarm, A., Shingfield, K.J., Veneman, J.B., Y´ anez-Ruiz, ˜ D.R. and Yu, Z., 2021. Strategies to mitigate enteric methane emissions by ruminants – A way to approach the 2.0°C target. CABI preprint 20210085288, Wallingford, UK. https://doi.org/10.31220/agriRxiv.2021.00040. (Accessed: 21 February 2023).

Ata, M., 2016. Effect of hydroponic barley fodder on Awassi lambs performance. *Journal of Biology, Agriculture and Healthcare*. 6: 2224-3298.

Aziz, M.A., 2010. Present status of the world goat populations and their productivity. *Lohmann Information*. 45:42-52.

Bakshi, M.P.S., Wadhwa, M. and Harinder, P.S.M., 2017. Hydroponic fodder production. *Journal of Animal Nutrition, Veterinary and Animal Science*. 48: 5-6.

Bekuma, A., 2019. Nutritional benefit and economic value of hydroponics fodder production technology in sustainable livestock production against climate change. *Advances in Applied Sciences*. 4: 23-25.

Beauchemin, K.A., Kreuzer, M., O'Mara, F. and McAllister, T.A., 2008. Nutritional management for enteric methane abatement: a review. *Australian Journal of Experimental Agriculture*. 48: 21–27.

Blignaut, J.N., Chitiga-Mabugu, M.R. and Mabugu, R.M., 2005. Constructing a greenhouse gas inventory using energy balances: The case of South Africa 1998. *Journal of Energy South Africa*. 16: 21-32.

Boone, R.B., Conant, R.T., Thornton, P.K. and Herrerd, M., 2008. Climate change impact on selected global rangeland ecosystem services. *Global Change Biology*. 24: 1224-1229.

Brithal, P.S. and Jha, A.K., 2005. Economic losses due to various constraints in dairy production in India. *Indian Journal of Animal Science*. 75: 1470-1475.

Burns, J.C., 2008. Utilisation of pasture and forages by ruminants. *Journal of Animal Science*. 86: 3647-3663.

Chagunda, M.G.G.; Ross, D. and Roberts, D.J., 2009. On the use of laser methane detector in dairy cows. *Computer Electronic of Agriculture*. 68: 157–160.

Coleman, S.W., Chase, C.C., Phillips, W.A. and Riley, D.G., 2018. Feed efficiency of tropically adapted cattle when fed in winter or spring in a temperate location. *Journal of Animal Science*. 96(6): 2438-2452.

Conforti, P., 2011. Looking ahead in world food and agriculture: perspectives to 2050. Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/docrep/014/i2280e/i2280e.pdf (Accessed: 23 April 2023).

Conway, E., 1962. Micro-diffusion analysis and volumetric error, 5th edition, Crosby and Son Ltd, London.

DALRRD (The Department of Agriculture, Land Reform and Rural Development), 2021. A profile of the South African beef market value chain. BEEF MARKET VALUE CHAIN PROFILE (daff.gov.za). Accessed: 25 January 2023.

Danielsson, R., 2016. Methane production in dairy cows. *Animal Nutrition and Management*. 4: 45-52.

Du, S., You, S.H., Bao, J., Gegentu, J.Y.S. and Cai, Y.M., 2020. Evaluation of the growth performance and meta quality of Mongolian lambs fed grass, hay or pellets of inner Mongolian native grass. *Small Ruminant Research*. 181: 34-38.

Dung, D.D., Godwin, I.R. and Nolan, J.V., 2010. Nutrient content and in sacco digestibility of barley grain and sprouted barley. *Journal of Animal and Veterinary Advances*. 9: 2485-2492.

Eisler, M.C., 2014. Steps to sustainable livestock. *Natural Science Journal*. 507: 32–34.

Eugene, M., Massé, D., Chiquette, J. and Benchaar, C., 2008. Meta-analysis on the effects of lipid supplementation on methane production in lactating dairy cows. *Canadian Journal of Animal Science*. 88: 331- 334.

Falkenmark, M., 2007. Shift in thinking to address the 21st century hunger gap moving focus from blue to green water management. *Water Resource Management*. 21: 3-18.

Fafiolu, A.O., Odoguwa, O.O., Ikeobi, C.O.N. and Onwaku, C.F.I., 2006. Utilisation of malted sorghum sprout in the diet of rearing pullets and laying hens. *Archive for Zootechnology*. 55: 361-371.

Farghaly, M.M., Abdullah, A.M.M., Youssef, I.M.I., Abdel-Rahim, I.R. and Abouelezz, K., 2019. Effect of feeding hydroponic barley sprouts to sheep on feed intake, nutrient digestibility, nitrogen retention, rumen fermentation and ruminal enzymes. *Livestock Science*. 228: 31-37.

Fayed, A.M., 2011. Comparative study and feed evaluation of sprouted barley grains on rice straw versus Tamarixmannifera on performance of growing Barki ewes in Sinai. *Journal of American Science*. 7: 954-961.

Fazaeli, H., Golmohammadi, H.A., Tabatabayee, S.N. and Asghari-Tabrizi, M., 2012. Productivity and nutritive value of barley green fodder yield in hydroponic system. *World Applied Sciences Journal*. 16: 531-539.

Garuma, Z. and Gurmessa, K., 2021. Evaluation of hydroponic fodder performance of different varieties of sorghum. *International Journal of Research*. 9: 1-10.

Gebremedhin, W.K., 2015. Nutritional benefit and economic value of feeding hydroponically grown maize and barley fodder for Konkan Kanyal goats. *Journal of Agriculture and Veterinary Sciences*. 8: 24–30.

Getachew, A., Mengistu, U., Getachew, C. and Getnet, A., 2018. Coping strategies to feed shortage, farmers perception and available practices for hydroponic fodder production as feed of dairy cows for selected areas of North-western Ethiopia. *East African Journal of Veterinary and Animal Sciences*. 36: 107-118.

Girma, F. and Gebremariam, B., 2018. Review on hydroponic feed value to livestock production. *Journal of Science and Innovative Research*. 7: 106-109.

Gonzalez, A.R.C., Burrola-Barraza, M.E., Dominguez-Viveros, J. and Chavez-Martinez, A., 2014. Rumen microorganisms and fermentation. *Archivos de Medicina Veterinaria*. 46: 287-293.

Grunert, K., 2011. Sustainability in the food sector: A consumer behavior perspective. *International Journal of Food System Dynamic*. 2: 207-218.

Guo, Y.Q., Liu, J.X., Lu, Y., Zhu, W.Y., Denman, S.E. and MacSweene, C.S., 2008. Effect of tea saponin on methanogenesis, microbial community structure and expression of mcrA gene in cultures of rumen micro-organisms. *Application Microbiology*. 47: 421-426.

Gupta, J.J., Singh, K.M., Bhatt, B.P. and Dey, A., 2014. A diagnostic study on livestock production system in the Eastern Region of India. *Indian Journal of Animal Sciences*. 84: 198-203.

Hafla, A.N., Soder, K.J., Brito, A.F., Rubano, M.D. and Dell, C.J., 2014. Effect of sprouted barley grain supplementation of a herbage-based or haylage-based diet on ruminal fermentation and methane output in continuous culture. *Journal of Dairy Science*. 97: 7856-7869.

Haque, N., 2018. Dietary manipulation as a sustainable way to mitigate methane emissions from ruminants. *Journal of Animal Science and Technology*. 60: 15. http://doi.org/10.1186/s40781-018-0175-7

Hegab, K.K. and Mahmoud, A.E.M., 2019. Effect of sprouted green fodder on lamb's performance. *Egyptian Journal of Nutrition and Feeds*. 22: 265-272.

Helal, H.G., 2015. Sprouted barley grains on olive cake and barley straw mixture as goat diets in Sinai. *Advances in Environmental Biology*. 9: 91-102.

Helal, H.G., 2018. Production and reproduction performance of Barki ewes fed on sprouted barley grains on desert by-products during lactating period. *Research Journal of Animal and Veterinary Sciences*. 10: 37-48.

Hegarty, R.S., Alcock, D., Robinson, D.L., Goopy, J.P. and Vercoe, P.E., 2010. Nutritional and flock management options to reduce methane output and methane per unit product from sheep enterprises. *Animal Production Science*. 50: 1026-1033.

Herrero, M., Henderson, B., Havlik, P., Thornton, P.K., Conant, R.T., Smith, P., Wirsenius, S., Hristov, A.N., Gerber, P., Gill, M., Butterbach-Bahl, K., Valin, H., Garnett, T. and Stehfest, E., 2016. Greenhouse gas mitigation potentials in the livestock sector. *Natural Climate Change*. 6: 452–461.

Hoffman, M.T. and Vogel, C., 2008. Climate change impacts on African rangelands. *Rangelands*. 30: 12-17.

Hook, S.E., Northwood, K.S., Wright, A.D.G. and MacBride, B.W., 2009. Long-term monensin supplementation does not significantly affect the quantity or diversity of methanogens in the rumen of the lactating dairy cows. *Applied and Environmental Microbiology*. 75: 374-380.

Hristov, A.N., 2013. Mitigation of methane and nitrous oxide emissions from animal operations: I. A review of enteric methane mitigation options. *Journal of Animal Science*. 91: 5045–5069.

Immig, I., 1996. The rumen and hindgut as sources of ruminant methanogenesis. *Environmental Monitoring and Assessment*. 42: 57-72.

Irchhaiya, R., Kumar, A., Yadav, A., Gupta, N., Kumar, S., Yadav, V., Prakash, A. and Gurjar, H., 2015. Metabolites in plants and their classification. *World Journal of Pharmacy and Pharmaceutical Sciences*. 4(1): 287-305.

Islam, R., Nabilah, J. and Ali, A., 2016. Effect of seed rate and water level on production and chemical analysis of hydroponic fodder. *European Academic Research*. 4: 6724-6753.

Kide, W., Desai, B. and Kumar, S., 2015. Nutritional improvement and economic value of hydroponically sprouted maize fodder. *Journal of Life Science International Research*. 2: 76-79.

Kingston-Smith, A.H., Marshall, A.H. and Moorby, J.M., 2012. Breeding for genetic improvement of forage plants in relation to increasing animal production with reduced environmental footprints. *Indian Journal of Animal Production*. 1: 1-10.

Kim, E.T., Kim, C.H., Min, K.S. and Lee, S.S. 2012. Effects of plant extract on microbial population, methane emission and ruminal fermentation characteristics in *in vitro*. *Asian-Australian Journal of Science*. 25: 806-811.

Knapp, J.R., Laur, G.L., Vadas, P.A., Weiss, W.P. and Tricarico, J.M., 2014. Enteric methane in dairy cattle production: quantifying the opportunities and impact of reducing emissions. *Journal of Dairy Sciences*. 97: 3231–3261.

Kreuzer, M. and Soliva, C.R., 2008. Nutrition key to methane mitigation in ruminants. *Proceedings of the Society of Nutrition Physiology*. 17: 168-171.

Kruglyakov, Y.A., 1989. Construction of equipment for growing green fodder by a hydroponic technique of SA. *Journal of Agricultural Science*. SA 6: 24-27.

Leahy, S.C., Kelly, W.J., Altermann, E., Ronimus, R.S. and Yeoman, C.J., 2010. The genome sequence of the rumen methanogen *Methanobrevibacter ruminantium* reveals new possibilities for controlling ruminant methane emissions. *Plos One*. *5*(1), e8926. https://doi.org/10.1371/journal.pone.0008926

Lim, W.C., Nadzir, M.H.H.M., Hiew, M.W.H., Mamat, S. and Schaimi, S., 2022. Feed intake, growth performance and digestibility of nutrients of goats fed with outdoor grown hydroponic maize sprouts. *Pertanika Journal of Tropical Agricultural Science*. 45: 321-336.

Loeper, W., Musango, J., Brent, A. and Drimie, S., 2016. Analysing challenges facing smallholder farmers and conservation agriculture in South Africa. *South African Journal of Economic and Management Sciences*. 5: 743-773.

Lorenz, K., 1980. Cereal sprouts, composition, nutritive values, and food applications. *Critical Reviews in Food Science and Nutrition*. 13: 353-385.

Maia, M.R., Chaudhary, L.C., Bestwick, C.S., Richardson, A.J., MacKain, N., Larson, L.R., Graham, I.A. and Wallace, 2010. Toxicity of unsaturated fatty acids to the biohydrogeneting ruminal bacterium. *BMC Microbial*. 10: 52. Doi:10.1186/1471-2180-10-52.

Marino, R., Atzori, A.S., D'Andrea, M., Lovane, G., Trabalza-Marinucci, M. and Rinald, I., 2016. Climate change, production performance, health issues, greenhouse gas emissions and mitigation strategies in sheep and goat farming. *Small Ruminant Research*. 135: 50-59.

Martin, C., Martin, J., Rouel, J.P., Jouany, M. and Doreau, Y., 2008. Methane output and diet digestibility in response to feeding dairy cows crude linseed, extruded linseed or linseed oil. *Journal of Animal Science*. 86: 2642-2650.

Martin, C., Morgavi, D.P. and Doreau, M., 2009. Methane mitigation in ruminants from microbe to the farm scale. *Journal of Animal Sciences*.4: 351-365.

McDonald, P., Edwards, R.A., Greenhaigh, J.F.D., Morgan, C.A., Sinclaire, L.A. and Wilkinson, R.G., 2010. *Animal nutrition*. Longman Scientific and Technical, 7th edition, John Wiley and Sons, Inc, New York, USA.

Meissner, J.A. and Shaker, R.M., 2013. Evaluation of feeding hydroponics barley on digestibility and rumen fermentations in Awassi lambs. *Iraqi Journal of Agricultural Science*. 49: 639-645.

Mihaela, G., Criste, A., Cocan, C., Constantinescu, R., Radacu, C. and Miresan, V., 2014. Methane production in the rumen and its influence on global warming. *Animals*. 7: 64-70.

Mincera, E., Ragni, M., Minuti, F., Rubino, G. and Marisco, G., 2009. Improvement of sheep welfare and milk production fed on diet containing hydroponically germinating seeds. *Italian Journal of Animal Science*. 8: 634-636.

Moghaddam, A.S., Mehdiipour, M. and Dastar, B., 2009. The determining of digestible energy and digestibility coefficients of protein, calcium and phosphorus of malt (germinated barley) in broilers. *International Journal of Poultry Science*. 8: 788-791.

Mohamed, E.M.H., Hassan, A.H. and Abdel-Wareth, A.A.A., 2021. Potential of hydroponic barley in rabbit diet on productive performance, nutrient digestibility, microbilogical and physiological responses. *International Journal of Veterinary Sciences*. 4: 12-23.

Mohammed, R., Zhou, M., Koenig, K.M., Beauchemin, K.A. and Guan, L.L., 2011. Evaluation of rumen methanogen diversity in cattle and fed diets containing dry corn distillers grains and condensed tannins using pcr.dgge and qrt-pcr analyses. *Animal Feed Science and Technology*. 166: 122-131.

Mohsen, M.K., Abdel-Raouf, E.M., Gaafar, H.M.A. and Yousif, A.M., 2015. Nutritional evaluation of sprouted barley grains on agricultural by-products on performance of growing New Zealand white rabbits. *World Rural Observation*. 4: 64-74.

Mpanza, T.D.E., Dhlamini, T.C., Pierneef, R.E. and Mbatha, K.R., 2022. Enteric methane emission, rumen fermentation and microbial profiles of meat-master lambs. *Fermentation*. 8: 434.

Muhammad, S., Afzal, H. and Mudassar, S., 2013. Use of sprouted grains in the diets of poultry and ruminants. *Indian Journal of Research*. 2: 20-27.

Myers, J., 1974. Feeding livestock from the hydroponic garden. MSc Thesis, Arizona State University.

Naik, P.K., Dhuri, R.B., Swain, B.K. and Singh, N.P., 2012. Nutrient changes with the growth of hydroponics fodder maize. *Indian Journal of Animal Nutrition*. 29: 161-163.

Naik, P.K. and Singh, N.P., 2013. Hydroponics fodder production: An alternative technology for sustainable livestock production against impending climate change. *Journal for Sustainable Livestock Production*. 6: 70-75.

Naik, P.K. and Singh, N.P., 2014, Production and feeding hydroponics green fodder. *Indian Farming*. 64: 42-44.

Naik, P.K., Swain, B.K. and Singh, B.K., 2015. Review-Production and utilization of hydroponics fodder. *Indian Journal of Animal Nutrition*. 32: 1-9.

Naqvi, S.M.K., Kumar, D., Kalyan, D. and Sejian, V., 2015. Climate change and water availability for livestock farming. *Indian Journal of Animal Science*. 1: 81-96.

Patel, M., Wredle, E., Borjesson, G., Danielsson, R., Iwaasa, A.D., Sporndly, E. and Bertilsson, J., 2011. Enteric methane emissions from dairy cows fed different proportions of highly digestible grass silage. Journal for *Animal Science*. 61: 128-136.

Peer, D.J. and Leeson, S., 1985. Nutrient content of hydroponically sprouted barley. *Animal Feed Science and Technology*. 13: 191-202.

Pitta, D.W., Pinchak, S.E., Dowd, J., Osterstock, V., Gontcharova, E., Youn, K., Dorton, L., Yoon, B.R., Min, J.D., Fulford, T.A. and Wickersham, D.P., 2010. Rumen bacterial diversity dynamics associated with changing from Bemudagrass hay grazed winter wheat diets. *Microbial Ecology*. 59: 511-522.

Rachel J.E., Gnanaraj, P.T., Muthuramalingam, T., Devi, T., Babu, M. and Sundharesan, A., 2015. Hydroponic green fodder production. Tanuvas Experience. Tamil Nadu Veterinary and Animal Science University, India. 2016023524.Hydroponic.Final.pdf.rkvy.nic.in. Accessed: 25 May 2023.

Raeisi, Z., Tahmasbi, R., Dayani, O., Ayatollahi Mehrgardi, A. and Tavassolian, I., 2018. Digestibility, microbial protein synthesis, rumen and blood parameters in sheep fed diets containing hydroponic barley fodder. *Journal of Livestock Science and Technology*. 6: 9-17.

Rajesh, K., Manishi, M., Monika, K., Sunil, D.C. and Deepika, J., 2018. A review of hydroponics as an alternative to cultivated green fodder. *Journal of Entomology and Zoology Studies*. 6: 791-795.

Rajkumar, G., Diph, M.T., Lalu, K., Shyma, K. and Banakar, P.S., 2018. Evaluation of hydroponics fodder as a partial feed substitute in the ration of crossbred calves. *Indian Journal of Animal Research*. 51: 1809-1813.

Ramteke, R., Doneria, R. and Gendley, M.K., 2019. Hydroponic techniques for fodder production. *Acta Scientific Nutrition Health*. 3: 127-132.

Rani, J.K., Ally, K., Sajith, P. and Anil, K.S., 2019. The effect of feeding hydroponics maize on growth performance and nutrient digestibility in cross-bred calves. *Journal of Entomology and Zoology Studies*. 7(6): 489-492.

Reddy, G.V.N., Reddy, M.R. and Reddy, K.K., 1988. Nutrient utilisation by milch cattle fed rations containing artificially grown fodder. *Indian Journal of Animal Nutrition*. 5: 19-22.

Rodriguez, M.C., Rodriguez, H.E., Ruiz, O., Flores, A., Grado, J.A. and Arzola, C., 2004. Use of green fodder produced in hydroponic system as supplement for lactating cows during the dry season. *Proceedings of the American Society of Animal Science.* 56: 271-274.

Rodriguez, R., Sosa, R. and Rodriguez, Y., 2007. Microbial protein synthesis in rumen and its importance in rumen. *Cuban Journal of Agricultural Scence*. 4(4). 287-293.

Rudolph, M. and Machesa, E., 2023. A review of the agroecological farming system as a viable alternative food production approach in South Africa. *South African Journal of Agricultural Extension*. 51(2): 43-67.

Safwat, M.S., Sarmiento-Franco, L. and Santos-Ricalde, R.H., 2014. Rabbit production using local resources as feedstuffs in the tropics. *Tropical and Subtropical Agroecosystem*. 17: 161–171.

Sahebi-Ala, M., Pirmohammadi, R. and Khalilvandi-Behroozyar, H., 2021. Changes in vitro rumen fermentation, methane emission and microbial populations in response to green tea extract. *Italian Journal of Animal Science*. 20: 1114-1125.

Saidi, M.A. and Abu-Omar, J., 2015. The biological and economical feasibility of feeding barley green fodder to lactating Awassi ewes. *Open Journal of Animal Sciences*. 5: 99-105.

Sallaku, E., Vorpsi, V., Jojic, E., Sallaku, F. and Dodona, E., 2011. Evaluation of methane emissions from animal farms in Shkodra district - Albania. *Research Journal of Agricultural Science*. 43: 484-49.

Salo, S., 2019. Effects of hydroponic fodder feeding on milk yield and composition of dairy cow. *Journal of Natural Sciences Research*. 9, 224-232.

Samal, L., Chaudhary, L.C., Argawal, N. and Kamra, D.N., 2016. Effects of plants containing secondary metabolites as feed additives on rumen metabolites and methanogen diversity of buffaloes. *Journal of Animal Production Science*. 56: 472-481.

Sans, P. and Combris, P., 2015. World meat consumption patterns. An overview of the last fifty years (1961-2011). *Meat Science*. 109: 106-111.

SAS Institute, 2020. SAS User's Guide: Statistics. Version 9.4. M7 SAS Institute, Cary NC, USA.

Sauer, F.D., Fellner, V. and Kinsman, R., 1998. Methane output and lactation response in Holstein cattle with monensin or unsaturated fat added to the diet. *Journal of Animal Science*. 76: 906-914.

Scholtz, M.M., Steyn, Y., Van Merle-Koster, E. and Theron, H.E., 2012. Improved production efficiency in cattle to reduce their carbon footprint for beef production. *South African Journal of Animal Science* 42: 450-453.

Shah, Z., Bai, Y. and Xie, Y., 2008. Using a hybrid fuzzy classifier (HFC) to map typical grassland vegetation. *International Journal of Remote Sensing*. 103: 16-26.

Shah, V.D., Makwana, M. and Sharma, S., 2011. Economics of producing, processing and marketing of fodder crops in Gujarat. India. *Research Study Number*. 4: 144.

Shipard, I., 2005. How can I grow and use sprouts as living food? David Stewart Publishing, Indiana.

Shit, N., 2019. Hydroponic fodder production: an alternative technology for sustainable livestock production in India. *Explore Animal Medical Research*. 9: 108-119.

Sun, Z., Scherer, L., Tukker, A. and Behrens, P., 2020. Linking global crop and livestock consumption to local production hotspots. *Global Food Security*. 25: 100-123.

Tawfeeq, J.A., Hassan, S.A., Kadori, S.H., Shaker, R.M. and Hamza, Z.R., 2018. Evaluation of feeding hydroponics barley on digestibility and rumen fermentation in awassi lambs. *Iraqi Journal of Agricultural Sciences*. 49: 636-645.

Tudor, G., Darcy, T., Smith, P. and Shallcross, F., 2003. The intake and live weight change of draught master steers fed hydroponically grown young sprouted barley. *Department of Agriculture Western Australia*. 333.

Uddin, M.T. and Dhar, A.R., 2018. Socioeconomic analysis of hydroponic fodder production in selected areas of Bangladesh, prospects and challenges. *Journal of Agriculture*. 16: 233-247.

Van Soest, P.J., Robertson, J,B. and Lewis, B., 1991. Methods of dietary fiber, neutral detergent fiber and non-structural polysaccharides in relation to animal nutrition. *Journal of Dairy Science*. 14: 3583-3597.

Van Zijderveld, S.M., Fonken, B., Gerrits, W.J.J., Fokkink, W. and Newbold, R., 2011. Effects of a combination of feed additives on methane production, diet digestibility and animal performance in lactating dairy cows. *Journal of Dairy Science*. 94(3): 1445-1454.

Venilla, C., 2018. Productivity, nutritive value, growth rate, biomass yield and economics of different hydroponic green fodders for livestock. *International Journal of Livestock Research*. 8: 261-270.

Verma, S., Singh, A., Kalra, A. and Saxena, M.M., 2015. Effect of feeding hydroponics barley (*Hordeum vulgare*) fodder on nutrient utilisation, growth, blood metabolites and cost effectiveness in Hariana male calves. *Indian Journal of Animal Nutrition*. 32: 10-14.

Warner, A.C.J., 1964. Production of volatile fatty acids in the rumen methods of measurement. *Nutrition Abstracts and Reviews*. 34: 339-352.