WATER SHORTAGE EFFECTS AND UTILISATION OF PRICKLY PEAR FRUIT ON GROWTH PERFORMANCE, BLOOD INDICES, MEAT QUALITY, AND METHANE EMISSIONS BY PEDI GOATS

Report to the

Water Research Commission

by

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WRC report no. 3256/1/26
ISBN 978-0-6392-0772-8

June 2026

This is the final report of WRC project no. WRC C2023/2024-01433.

EXECUTIVE SUMMARY

Background

A drop in goat productivity during winter and dry seasons in rural areas due to the unavailability of nutritious feeds is a challenge to farmers. Another challenge is that ruminants produce and emit methane. Ensiled prickly pear fruits are high in secondary metabolites. Secondary metabolites in feeds can reduce methane emissions by small ruminants. Therefore, this study aimed to investigate the effect of ensiled prickly pear (*Opuntia ficus-indica*) in diets on growth performance, blood profiles, methane emissions, and meat quality of indigenous male Pedi goats.

Aims

The project’s main aims were threefold:

i. To investigate goat farmers' perceptions of drought impact and local adaptation measures and methane emission mitigation strategies.
ii. To determine the chemical characteristics of the prickly pear fruits as potential feed for goats.
iii. To evaluate the effect of ensiled prickly pear inclusion in diets on growth performance, blood indices, meat quality, and methane emission by yearling male Pedi goats.

Methodology

Chapter 1 focuses on the study of literature regarding the current strategies proposed to reduce methane emissions from livestock. A comprehensive search was conducted to identify eligible studies using a five-stage process. In the first stage, a search to obtain all relevant studies that were published before May 2023 was performed using databases such as the Web of Science, Science Direct, Google Scholar, and the Wiley Online Database. For Chapter 2, A total of 72 goat farmers were interviewed using a well-structured questionnaire. Statistical Package for Social Sciences (IBM SPSS, 2022) version 28.0 software was used for data analysis. Descriptive statistics such as frequencies and percentages were used to achieve the objective. For Chapter 3, the Official Methods of Analysis (AOAC) was used for nutrient composition analysis, whereas Quadrupole Time-of-Flight Mass Spectrometry (QTOF-MS) was used for the

phenolic compounds. For Chapters 4 and 5, 24 indigenous male Pedi goats were randomly allocated to 4 dietary treatment groups in a completely randomised block design, replicated 3 times with 2 goats per replicate. Goats were raised for a period of 75 days (15 days for adaptation, 60 days for the feed trial, followed by 7 days of digestibility trial). Prickly pear inclusion levels were at 0,10, 20 or 30%. The data collected were subjected to analysis of variance using Statistical Analysis System Software (SPSS).

Results and discussion

The first chapter highlights that many feeding strategies are only now being introduced in ruminant farming to reduce CH_4 production. Unfortunately, the world generally continues to observe a global increase in CH_4 emissions. Moreover, rumen microbes' manipulation and genetic selection are also being used as mitigation strategies. However, according to the data presented in the chapter, more intense research is needed to reduce ruminant CH_4 emissions. These studies must take into account both the economic capabilities of developing countries, such as South Africa, and the animal husbandry methods used. Whereas Chapter 2 assessed goat farmers' perceptions of drought impact and adaptation measures. The chapter highlights that the farmers are knowledgeable about drought, but they are unaware of its effects on goats and coping mechanisms during drought. In addition, farmers were unaware of the use of prickly pear as a potential livestock feed during drought seasons. Drought-tolerant forages such as prickly pear have been traditionally used for livestock feeding in South African semi-arid regions and have been studied in many countries to mitigate feed and water shortages in drought-prone dry areas. This type of forage is adapted to semi-arid conditions and can yield large amounts of fresh water per cultivated surface because of its high moisture and mucilage-rich composition. In addition, the majority of farmers reported no implications as a result of the drought to goats, while a few farmers reported some consequences. The majority of farmers stated that they were unaware of methane, while only a small percentage reported that they were aware of it. The chapter served as a foundation for future in-depth research into the feasibility of farmers adopting more reliable and sustainable coping strategies for drought.

Chapter 3 investigated the nutrient composition and phenolic compounds of prickly pear (*Opuntia ficus-indica*) fruit as a potential feed for indigenous goats. The chapter highlighted that the proximate composition of the prickly pear was 90.40% DM, 9.60% moisture, 8.50% protein, 4.50% fat, 14.40% ADF, 24.81% NDF, 10.00% ash, and 6.60 (MJ/kg DM) GE contents. From the reported nutrients, only fat and ash meet goat requirements. However, other nutrients such as crude protein, ADF, and NDF were below the required amounts for goats. In this chapter, it is highlighted that the protein content of prickly pear was lower than the required quantities by goats. Thus, due to lower protein levels, when feeding goats with prickly pear, protein supplementation may be required. Apart from primary nutrients, a total of 12 compounds were detected and identified. Phenolic compounds in prickly pear were identified with a clear indication of the abundance of Fukiic acid Psidic acid, (2R,3S)-Piscidic acid, (1S,6R)-2-succinyl-6-hydroxycyclohexa-2,4-diene-1-carboxylic acid, Teucardoside, Veranisatin C, MINEs-504496, Manghaslin, Rutin, Keioside, (+)-7-epi-Syringaresinol 4'-glucoside, and Alpha-dimorphecolic acid. The phenolic compounds identified include phenolic acids and flavonoids. The chapter highlighted that prickly pear fruits are rich sources of valuable nutrients and diverse phenolic compounds. In addition, prickly pear can be used in goats' diets as it is a good source of minerals and some nutrients. However, when incorporating prickly pear in goats’ diets, they need to be supplemented with other nutrients like crude protein, as prickly pear has low content. Lastly, the chapter highlighted that secondary metabolites, specifically flavonoids, were shown to be abundant in prickly pear, which highlights its potential for enhancing immunity and gut functions in animals. Chapter 4 reports on the effect of ensiled prickly pear (*Opuntia ficus-indica*) in diets on growth performance and methane emissions of yearling male Pedi goats. This chapter demonstrated that ensiled prickly pear inclusion levels significantly influence growth performance in indigenous male Pedi goats. Moreover, a 30% inclusion level yielded the highest final live weight and average daily gains, while the lowest values were observed at 0% inclusion. These findings highlight the positive impact of ensiled cactus on goats' performance. The feed intake and feed conversion ratio were not significantly affected by ensiled prickly pear inclusion. Water intake, however, showed a significant negative relationship with ensiled prickly pear inclusion, supporting the notion that cactus serves as an alternative water source in arid and semi-arid regions. This suggests that ensiled prickly pear can be particularly beneficial in water-scarce environments.

Lastly, the chapter highlighted that methane emissions were significantly reduced with increasing levels of prickly pear inclusion, with the lowest emissions observed at 30% inclusion. These findings indicate that ensiled prickly pear could serve as a sustainable dietary strategy for mitigating methane emissions in goats, potentially contributing to environmental conservation efforts.

Chapter 5 investigated the effect of prickly pear (*Opuntia ficus-indica*) levels in the diet on blood metabolites and meat quality of Pedi goats. Based on the results of this chapter, the inclusion of prickly pear in the diet has no significant effect on the blood haematological parameters of goats. Thus, supporting the initial hypothesis. Therefore, it is suggested that prickly pear can be utilised without causing any adverse effects on the blood profiles of goats. In addition, the results of this chapter demonstrate that prickly pear inclusion levels significantly influence meat quality in male Pedi goats. A 30% inclusion level yielded the highest final slaughter weight and hot and cold carcass weights, while the lowest values were observed at 0% inclusion for slaughter weight and 10% for hot and cold weights. These findings highlight the positive effect of fermented prickly pear on goats' performance. The dressing percentage, final pH, cooking loss, shear force, and meat colour were not significantly affected by prickly pear inclusion. However, sensory attributes (juiciness, flavour, and overall acceptability) showed a significant positive relationship with prickly pear inclusion. When coming to fatty acids, C10, C12:0, C14:0, C16:0, C20:1, and C18:2n6c fatty acids were optimized at 11.250, 6.417, 11.315, 9.059, 12.250, and 8.865% prickly pear inclusion levels.

Conclusion

The conclusion of the project is based on the social, environmental impact, Governance/Policy, and economic aspects as follows:

1. Social impact

The social impact of using prickly pear feeding in goats manifests itself in the form of reduced goat losses and increased production, which will positively influence the provision of socio-cultural goods and services to farmers. Meat from indigenous goat breeds provides socially and psychologically rooted benefits for the consumers.

2. Environmental impact

The utilisation of prickly pear with secondary metabolites is an important issue for cleaner production, as secondary metabolites are associated with methane (CH_4) reduction. Methane is classified as a greenhouse gas produced and emitted by ruminants, adversely affecting the surrounding environment and thus contributing to climate change.

3. Governance/Policy

Understanding goat farmers’ perceptions of drought impact, local adaptation measures, and administrative methane reduction strategies helps mitigate the impact of methane emissions and water shortage on goat production. That could help formulate developmental and institutional policies and interventions at local, provincial, and national levels that reduce risks associated with recurrent droughts and methane emissions.

4. Economic impact

The use of drought-tolerant forages such as prickly pear will assist the goat farmers in drought-stricken areas to sustainably and efficiently increase goat productivity. This has a positive influence on current and future food, nutrition, and income security at the household, provincial, and national scales. An increase in animal production reduces unemployment, erosion of the tax base, and animal products, and also increases animal products exports and foreign currency inflows.

Therefore, it can be concluded that prickly pear can be included in diets to improve the meat quality of goats. This means the ensiled prickly pear inclusion level requirements for indigenous goats will depend on the particular production variable of interest. This has implications for rations for indigenous goats. Thus, there is a need for more studies on the subject to ascertain the present findings.

Recommendations

It is recommended that the following be done; screening of non-conventional animal feeds, especially tree leaves and extracts for anti-protozoal activity, standardization of the defaunation method for its implication at the farmer's level, new species/ strains of microorganisms should be screened to use as probiotics, and the mechanism of action of probiotics should be studied thoroughly, since farmers are unaware of drought solutions and potential feed for their goats. Lastly, the government should intervene

by providing farmers with drought management training workshops. It is also recommended that more studies be conducted on the subject to ascertain the present findings.

ACKNOWLEDGEMENTS

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CONTENTS

Table of Contents

LIST OF TABLES

LIST OF FIGURES

ACRONYMS & ABBREVIATIONS

a*	Redness
ADF	Acid detergent fibre
ADG	Average daily gains
ANOVA	Analysis of Variance
ARC	Agricultural Research Council
b*	Yellowness
BE	Betanin equivalent
°C	Degrees Celsius
$C_4H_6O_5$	Malic acid
CAM	Crassulacean acid metabolism
CO_2	Carbon dioxide
CL	Cooking Loss
CP	Crude Protein
d.f	Degrees of Freedom
DM	Dry Matter
EDTA	Ethylenediaminetetraacetic acid
EE	Ether Extract
FAO	Food and Agriculture Organisation
FCR	Feed Conversion Ratio
g	Gram
GAE	Gallic acid equivalent
H_2O	Water
ha	Hectare
HSD	Honestly Significant Difference
kg	Kilograms
L*	Lightness
LTL	Longissimus Thoracis at Lumborum
MCHC	Mean corpuscular haemoglobin concentration
MCV	Mean cell volume
NDF	Neutral detergent fibre

NRC	National Research Council
O_2	Oxygen
OM	Organic matter
p	Probability
PPF	Prickly Pear Fruit
QE	Quercetin equivalent.
r	Coefficient of determination
RBCC	Red blood cell count
RCDW	Red cell distribution width
SANS	South African National Standards
SAS	Statistical analysis system
SF	Shear Force
WBSF	Warner Bratzler Shear Force
WCC	White cell count
WRC	Water Research Commission
X	Inclusion level for optimal value
Y	Optimal Y-level

CHAPTER 1: REVIEW OF STRATEGIES FOR REDUCING METHANE EMISSIONS BY PEDI GOATS

Abstract

Methane (CH_4) emission from livestock is a huge global concern because it is a powerful greenhouse gas and also causes a 6–10% waste of energy in the feed that can be used for productive purposes. Around 15% of all anthropogenic greenhouse gas emissions are generated by livestock. Therefore, reducing methane emissions from ruminant livestock is an important goal for reducing the environmental impact of agriculture. There is a variety of strategies that can be used to reduce methane emissions, including dietary modifications, genetic selection, microbiome manipulation, and feed additives, such as plant secondary metabolites (tannins, saponins, flavonoids, and essential oils), methane inhibitors, and algae. Their impacts on the rumen microbial population are frequently indirect as opposed to direct. Plants may produce a wide range of secondary metabolites in high or low concentrations, which may affect how they interact with rumen microbes. Therefore, main and important objective of this comprehensive review is to critically discuss the current strategies proposed to reduce methane emissions from livestock.

1.1 Introduction

Small ruminant production is vital for socio-economic development on each continent. In addition to producing 25.6 million tons of milk and 1.5 million tons of meat, according to the FAO's 2016 report, this industry also supplies products to niche markets and helps preserve ecosystems, landscapes, and biodiversity (Marino *et al.*, 2016). Climate change, which is brought on by rising levels of greenhouse gases such as methane (CH_4) and other gases in the atmosphere, will have an impact on agricultural production systems in the future (causing drought, floods, etc). CH_4 emissions to the atmosphere are significantly increased by ruminant production systems (Beauchemin *et al.,* 2020). In particular, the "ruminal microbiota," a microbial complex of bacteria, archaea, protozoa, and fungi, produces over 115 million tons of CH_4 each year in ruminants (Sandoval-Pelcastre *et al.,* 2020), especially in large-scale agricultural systems, ruminant production accounts for over 80% of anthropogenic CH_4 emissions

(Gill *et al*., 2010). Since sheep and goats make up roughly 56% of all ruminants worldwide, the small ruminant production sector is under scrutiny for reducing methane emissions (FAO, 2016).

Methane emissions from livestock, especially when forage-based diets are supplied, account for an energy loss from livestock on the order of 6–10% of the gross energy intake of small ruminants, apart from their contribution to global warming (Cottle *et al*., 2011). The potential for this powerful greenhouse gas to cause global warming is 28 times greater than that of carbon dioxide (CO_2), and significant scientific efforts are being made to try to reduce it (IPCC, 2013). The defensive function of plant secondary metabolites against plant predators has long been recognised as being important. The synthesis of these metabolites is controlled by external, seasonal, or environmental factors. Secondary metabolites have long been regarded as poisonous to animals and as anti-nutritional elements (Gilani *et al*., 2012). However, due to their advantageous effect on the reduction of methane synthesis, those metabolites have recently received much interest in animal nutrition. Tannins (Bhatta *et al.,* 2023; Naumann *et al.,* 2017), saponins (Olagaray and Bradford, 2019; Torres *et al*., 2023), essential oils (Lei *et al.,* 2019; Cieslak *et al.,* 2013), and flavonoids (Ban *et al.,* 2022; Olagaray and Bradford, 2019) have all been reported to have the potential to reduce enteric CH_4 in small ruminants evaluated. Their impacts on the rumen microbial population are frequently indirect as opposed to direct. Plants may produce a wide range of secondary metabolites in high or low concentrations, which may affect how they interact with rumen microbes.

1.2 Methodology

A comprehensive search was conducted to identify eligible studies using a five-stage process. In the first stage, a search to obtain all relevant studies that were published before May 2023 was performed using databases such as the Web of Science, ScienceDirect, Google Scholar, and the Wiley Online Database. The search strategy involved a combination of the following keywords: tannins, flavonoids, saponins, essential oils, and methane. The search was not restricted by language, date, or study type. During the second stage, the search was narrowed down by adding the words “goats and sheep”. Furthermore, the search was narrowed down to the time scale of 2010 to 2023 (the period was chosen to capture as wide a range of articles as possible). In the third stage, the exclusion criteria included articles where the abstract could not be found and written in a language that could not be understood by the authors (i.e., German, Dutch, Spanish, or Italian). A final total of 69 remaining full-text studies on plant secondary metabolites were consequently assessed for eligibility. The fourth stage involved the reading of article titles and abstracts through screening of the retrieved articles. Thereafter, the full-length individual manuscripts were screened, and papers not satisfying the inclusion criteria were excluded. In the fifth stage, the remaining additional literature was included through the examination of the reference lists in the literature extracted, academic resources (master's and doctoral dissertations), PLoS ONE, and the Directory of Open Access Journals.

1.3 Methane production

It is challenging to comprehend all the mechanisms underlying the functioning, complexity, and interactions of the rumen microbiome because it has not been thoroughly studied (Kamra and Singh, 2019). Protozoal, bacterial, and fungal communities in the rumen ferment proteins, carbohydrates, and starches through enzymatic mechanisms. Volatile fatty acids, CO_2, and metabolic H_2 are formed during the fermentation process and utilized by methanogenic archaea for the synthesis of CH_4 (Cammack *et al.,* 2018). Starch, cellulose, hemicellulose, pectin, and soluble sugars are utilized by protozoa to produce volatile fatty acids and metabolic H_2, which is then utilized by the attached archaea to produce CH_4 (Van Soest, 2018); as a result, there is a relationship between archaea and protozoa in the rumen (Patra *et al.,*2017; Malik *et al*., 2017). In a series of biochemical reactions connected to Adenosine triphosphate (ATP) synthesis, rumen methanogens use the H_2 produced by the fermentation of carbohydrates to reduce CO_2 to CH_4, where CO_2 is used as a carbon source and H_2 is the primary electron donor. 4 moles of H_2 are utilised in this process to create 1 mole of CH_4 (Czerkawski, 2013). The chemical reaction for methane synthesis is $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$.

1.3.1 Mitigation Strategies

1.3.1.1 Mitigation through Feed Additives

1.3.1.1.1 Tannins

Tannins are the most abundant polyphenolic secondary metabolites, accounting for 5 to 10% of dry vascular plant materials (Barbehenn and Constabel, 2011), primarily found in the bark, stems, seeds, roots, buds, and leaves (Barbehenn and Constabel, 2011; Giovando *et al.*, 2019; Tomak and Gonultas, 2018). Tannin-rich terrestrial plants are abundant in ruminant grazing areas. Tannins are widely found in numerous leguminous and non-leguminous leaves of trees or shrubs (e.g., *Acacia angustissima, Argania spinosa, and Ceratonia siliqua*) that are fed to small ruminants in tropical regions. Tannins can either directly or indirectly inhibit methane synthesis in the rumen by suppressing methanogens or the protozoal population. There are various possibilities that could explain how tannins reduce enteric CH_4 levels (Naumann *et al.,* 2017). According to Bhatta *et al*. (2014), tannins can directly reduce methanogenesis by impacting rumen archaea rather than by defaunation (removal of protozoa). Protozoa can offer H_2 as a source of electrons to methanogens in a synergistic manner; hence tannins with antiprotozoal effects would be expected to reduce CH_4 production by methanogens linked to protozoa. Another concept suggests that condensed tannins themselves operate as hydrogen sinks, reducing their availability for carbon dioxide reduction to methane, meaning that 1.2 mol methane is reduced per mol of catechin (i.e., 6 H_2 atoms per molecule of catechin) (Naumann *et al.,* 2017). Bhatta *et al.* (2013) showed that tannins from *Mimosa spp*. at low concentrations (28 g/kg DM) can decrease CH_4 emissions in goats without influencing the digestibility of dietary components. However, at greater tannin concentrations (5.6 g/kg DM), CH_4 reduction was also attributed to decreased organic matter fermentation. These findings suggested that tannins have the potential to reduce CH_4 emissions from small ruminants and to develop viable methods for utilising tree leaves containing a significant amount of tannins. Delgado *et al*. (2013) reported that the inclusion of 27% of *Leucaena leucocephala* in a *Pennisetum purpureum* basal diet reduced methane production by 15.6% without affecting the apparent digestibility of nutrients in sheep. It has been proposed that high molecular weight condensed tannins fractions of *Leucaena leucocephala* have higher protein-binding affinities than low molecular weight fractions, and thus the effect may be associated with the ability to bind to cell membranes, preventing nutrient transport into the cell and inhibiting microbial growth (Saminathan *et al.,* 2014). Rita *et al.* (2013) investigated methane reduction in *in vitro* and *in vivo* experiments using tannin-rich plants (*Gliricidia sepium, Leucaena leucocephala*, and *Manihot esculenta*). In an *in vitro* experiment, tannin-rich plants given at 39, 75, and 92g (CT/kg DM, respectively) lowered CH_4 production due to the high number of condensed tannins, which inhibited archaeal growth (Rira *et al*., 2015). However, the tannin-rich extracts did not influence the methanogen population in an *in vivo* experiment (Rita *et al*., 2015).

1.3.1.1.2 Saponins

Saponins are a type of plant secondary metabolite that has a high level of complexity in both structure and biological activity (Jayanegara *et al*., 2014). Saponins are found in many tropical trees and bushes, and small ruminants enthusiastically ingest their leaf or pods while browsing. It is widely assumed that their primary biological effect is on cell membranes. Their anti-protozoal activity is exerted by interactions with cholesterol in the cell membrane, which causes disruption, disintegration, lysis, and, eventually, cell death. According to Ramos-Morales *et al.* (2014), the effect of saponins on protozoa is only temporary since bacteria can break down saponins into sapogenins, which cannot affect protozoa. Torres *et al*. (2023) reported that adding saponins and nitrates to diets reduced methane production, but more research is needed to validate these findings and better understand the mechanisms that interact with sheep responses to saponin and nitrate supplementation. Shilwant *et al.* (2023) suggested that a composite plant extract from *Dolichos biflorus* (horse gram), root of *Asparagus racemosus* (shatavari), bark of *Amoora rohituka* (rohitaka), and peel of *Punica granatum* (pomegranate) rich in both phenolics and saponins can increase ruminal fermentation, milk production, and nutritional utilisation in lactating goats with improved health while reducing methane emissions. In a series of *in vitro* investigations, the addition of papaya leaf (a saponin-rich source), methanolic extract of *papaya* leaf, and other solvent extracts of *papaya* leaf reduced CH_4 synthesis by 37, 34, and 30%, respectively, when compared to the control group (Jafari et al., 2016 a, b, and c). The intraruminal administration of polymeric media-coated gynosaponin (8 g/kg) reduced methane production in Xinjiang goats, according to Li *et al.* (2022). Li *et al*. (2022) also stated that polymeric media-coated gynosaponin (8 g/kg) may predominantly inhibit methanogens and bacteria, resulting in lower acetate concentrations and the acetate to propionate ratio, which may result from hydrogen accumulation. According to Guo *et al.* (2008), using tea saponin to reduce methanogenesis resulted in decreased activity of the mcrA gene (an indication of the methanogenic activity of the methanogen population) without affecting overall methanogen numbers. Tea saponins at 3 g/day in sheep diets, on the other hand, had no effect on methanogen populations (Mao *et al.,* 2010; Zhou *et al.,* 2011). Furthermore, in addition to inhibiting CH_4 synthesis, saponins may provide nutritional benefits by increasing microbial protein synthesis due to protozoa suppression and by increasing the fibre-degrading bacteria and fungi in the rumen, which is useful for utilisation in low-quality-based diets (Rira *et al.,* 2015).

1.3.1.1.3 Flavonoids

Flavonoids are naturally occurring polyphenolic phytochemicals present in plants that are responsible for a wide range of biological functions (Samanta *et al*., 2011). They are linked to a group of secondary metabolites in plants that have a polyphenolic structure (Feng *et al.,* 2017). Flavonoids are categorized into eight main flavonoid categories based on their molecular structure: flavanol, flavandiol, flavanone, dihydroflavonol, flavone, flavonol, isoflavone, and anthocyanidin (Halbwirth, 2010).
Flavonoids have been proposed for inclusion in ruminant feeds to enhance productivity by increasing propionate production relative to acetate (Olagaray and Bradford, 2019). In vitro, the flavonoids naringin and quercetin inhibited methane synthesis, ciliate protozoa, and hydrogenotrophic methanogens, according to Oskoueian *et al.* (2013). According to Santas *et al.* (2010), quercetin and kaempferol have the ability to suppress Gram positive bacteria such as *Bacillus cereus, Staphylococcus aureus, Microcroccus luteus,* and *Listeria monocytogenes.* An in vitro review investigated at the potential of eight flavonoids to reduce CH_4 emissions (epicatechin, luteolin-7-glucoside, quercetin, isoquercetin, catechin, gallocatechin, epigallocatechin, and epigallocatechin gallate) and found that uteolin-7-glucoside (50 mg/g DM) has promising potential to reduce CH_4 and ammonia formation during ruminal fermentation (Sinz *et al.,* 2018).

Mulberry leaf biomass effectively decreased daily CH_4 emission in ewes in a study by Ma *et al.* (2017) by reducing the population of protozoa and methanogens. This increase in cellulolytic bacteria population was linked with a decrease in protozoal population. Mulberry leaf biomass (150 mg/kg diet) improved *in vitro* dry matter digestibility, and increased total gas production and volatile fatty acids, while reducing CH_4 production in sheep ruminal fluid (AL-Bayati and Hassan, 2018). Feeding mangosteen peel powder (rich in condensed tannins, flavonoids, and cinnamic acid) to meat goats reduced methane emissions (Ban *et al.,* 2022). The fermentation of enzymatically structural carbohydrates, starch, and proteins in the rumen for the production of metabolic H_2, CO_2, and volatile fatty acids is a complex process, and the fermentation end-products are used by rumen methanogens for CH_4 synthesis during methanogenesis (Ku-Vera *et al.,* 2020). More volatile fatty acids produced during fermentation, in particular, yield more CH_4. Mangosteen peel powder, on the other hand, had a negative impact on methanogenesis by blocking H_2-releasing processes or removing H_2 during carbohydrate fermentation (Ban et al., 2020).

1.3.1.1.4 Essential oils

Essential oils are aromatic chemicals that are mostly volatile and can be found in food, medicinal, and herbal plants. They are created in distinctive cells in various sections of plants, including roots, seeds, fruit, leaves, flowers, bark, petals, and stems (Ugbogu et al., 2019). The essential oil composition is distinct and unique to the plant species and is responsible for the aroma (Cieslak et al., 2013). Essential oils can either directly restrict the growth and activity of methanogenic microorganisms or indirectly reduce the number of protozoa associated with methanogens (Cieslak et al., 2013).

Due to its richness in phenolic components, *Salvia officinalis* essential oil is distinguished by its antioxidant and antibacterial properties. In an in vitro experiment utilizing goat rumen fluid, Saber et al. (2022) found that the addition of *Salvia officinalis* essential oil to oat hay reduced methane (CH_4) production in a dose-dependent manner starting at the dose of 20 g/ml. By reducing rumen protozoa in goats, Abubakr et al. (2013) observed that adding decanter cake and palm kernel cake at up to 80% inclusion reduces methanogenesis in an experiment involving Boer X Catcang crossbred goats. Essential oil-cobalt complexes that directly inhibited methanogenic archaea decreased the amount of methane produced (Lei et al., 2019). In sheep feedstuffs, Naseri et al. (2022) showed that the addition of essential oils from Pistacia atlantica gum can replace antibiotics and reduce the relative population of methanogens in the rumen. In a study by Soltan et al. (2018) sheep fed a basal diet containing 200 and 400 mg/kg of a microencapsulated blend of essential oils showed a decrease in methane emissions. One key strategy for reducing methane emissions is to minimize the quantity of H_2 producers such as protozoa in the rumen (Morgavi et al., 2010). *Angelica (Heracleum persicum Desf. ex-Fischer)* and *Eucalyptus (Eucalyptus globulus Labill)* essential oils decreased the protozoa population in sheep, which led to a decline in methane production (Nooriyan and Rouzbehan, 2017).

1.3.1.1.5 Prickly pear as a forage

Opuntia ficus-indica has been used as a source of forage in dry seasons due to its good palatability, high humidity, water content, and in vitro digestibility (Albuquerque et al., 2023). This is because of the shortage of feed and water for the livestock sector in semi-arid and arid areas. Fresh cladodes, fruits, and flowers are traditionally used for different purposes. Cladodes are rich in fibres such as pectin, lignin, cellulose, and hemicellulose and can be used as animal feed, fodder, or for human consumption (Rocchetti et al., 2018). In the semi-arid region, several food sources can be used as ruminant feed. However, the nutritional value and quality of these sources are determined by a complex interaction between ingested nutrients and microbial action in the digestive tract, which involves digestion, transport, metabolite use, and animal physiological status (Nunes et al., 2015; Celi et al., 2017). Prickly pear (*Opuntia ficus-indica*) possesses important characteristics for animal feed in drought-prone regions. This includes high dry matter yields, drought tolerance, good nutritive value, and palatability for animals (Arba, 2020). Cactus pear leaves and fruits are used in multiple productive sectors, such as the industrial sector. Many productive sectors use cactus pear fruits and their fleshy leaves as industrial basic materials, food additives, biopolymers, and flocculating agents for water treatment (Albergamo et al., 2022).

Recently, secondary metabolites have become one of the subjects of research aimed at reducing CH_4 emissions from ruminants. In general, prickly pear contains polysaccharides, peptides, lipids, phlorotannins, saponins, and alkaloids that are known to reduce CH_4 production by suppressing archaea and protozoa. However, the mode of action responsible for the mitigation effect centres around the content of volatile halogenated compounds (bromoform CHBr3). Dictyota (brown) and Asparagopsis (red) had the greatest potential for decreasing CH_4 production among many widely studied species. The best-studied species exhibiting CH_4 emission properties are Asparagopsis taxiformis and A. armata. In vivo studies reported dose (from 3.0 to 51.0 mg/kg of DMI) and diet-dependent (high-concentrate vs. high-forage) decreases from 9 to 98% of CH_4 production by algae preparation (Króliczewska *et al*., 2023).

1.3.1.2 Mitigation through forage feeding

The Prickly pear (*Opuntia. ficus-indica*) was introduced to the Eastern Cape in South Africa over 300 years ago. The drought conditions because of climate change, as well as the plant's numerous uses in South Africa, boosted the interest of farmers to grow the cactus pears (Brown, 2016). In South Africa, Cactus pears are found throughout the country but are primarily used for feed and fruit production in arid to semi-arid regions, especially in the Karoo, Highveld, and Eastern Cape. Its use for feed production has increased over the past decade as farmers search for ways to buffer themselves against the impact of climate change and droughts. The demand for agricultural products is expected to increase by 50% in 2030 to prevent hunger, as the global population is expected to increase (Wheeler and Von Braun, 2013). It is not only being used as drought-tolerant livestock feed, but there are producing orchards that yield food for humans, fruit, vegetables, oil, and animal feed. It is therefore crucial to give this miracle plant more well-earned attention (Brown, 2016).

As mentioned, the Cape was the first area in South Africa where the cactus plant (spiny *Opuntia ficus-indica* species) inhabited. The infestation with prickly pear was aided by their spines that were too long, making it impossible for the livestock to graze on it. In 1914, 22 spineless *O. ficus-indica* and *O. robusta* cultivars were imported by the Grootfontein Research Institute (Middelburg, Eastern Cape) from the Burbank Nursery in the United States of America (AgriOrbit, 2019). These spineless cactus pear plants were then established by Karoo farmers as livestock feed to mitigate the drought that was then present. Today, this unique collection in South Africa is one of a few collections worldwide where these cultivars can be found. The Prickly pear fruit's potential was evaluated intensively for fruit production by the Department of Agriculture during the 1990s in the Limpopo and Gauteng provinces, and this period can be regarded as the second heyday of crop history in South Africa.

Today, more than 900 local farms devote a total of about 4,500 ha to cactus pear production, including 1,500 ha for fruit harvesting and 3,000 ha for fodder production

(Seligson, 2023). *Opuntia ficus-indica* is subject to regulation under the National Environmental Management: Biodiversity Act of 2004, specifically the Alien and Invasive Species (AIS) regulation, as amended by Act No. 10 of 2004 (DEA 2014, Moshobane *et al.*, 2019). It holds the classification of a Category 1b species. The regulation explicitly states that "Spineless cactus pear cultivars and selections are not listed." Despite this, certain farms across the country engage in the cultivation and retail of these cultivars as fruits. Additionally, it is noteworthy that the inclusion of sweet prickly pear fruit for human consumption is not encompassed within the stipulated listing. The distribution of *Opuntia ficus indica* in South Africa is presented in Figure 1.01.

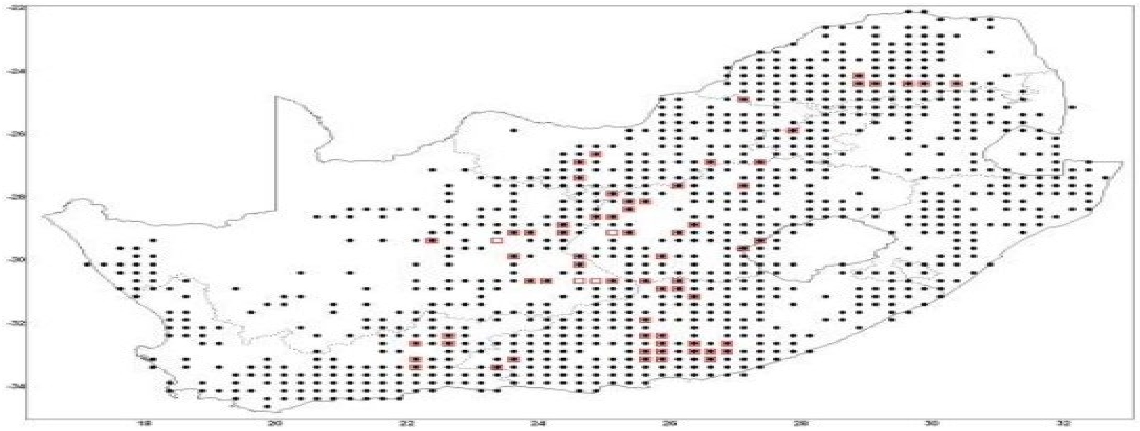

Figure 1.01: The distributions of prickly pear (Opuntia ficus-indica) (black dots) and small round-leaved prickly pear (O. engelmannii) (red squares). Source: SAPIA, (2019)

1.3.1.3. Mitigation through rumen microbes' manipulation

Rumen is a natural fermentative anaerobic system that should be manipulated essentially by altering the composition of rumen microflora. There is ample scope to manipulate the microbes in the rumen by feeding local plants or tree leaves or agro-industrial by-products to defaunate the animals for improving their productivity. The introduction of naturally occurring microorganisms from the digestive system of one species to another species for efficient degradation of plant toxins as well as for efficient utilisation of nutrients will be one of the major thrust areas in the near future for rumen manipulation. Genetic manipulation of rumen microorganisms for efficient ruminal fermentative digestion has enormous biotechnological potential. However, in tropical countries, more emphasis is given to manipulating the rumen to increase cellulolytic activity for efficient utilisation of low-grade roughage.

Probiotics are microbiological feed additives based on selected bacterial or yeast cultures. According to Tavendale et al. (2005), probiotics affect rumen fermentation and improve animal health by modulating the gastrointestinal microflora. The colonisation of the rumen ecosystem with probiotics supports rumen fermentation and increases feed efficiency, which may reduce CH_4 emissions (Islam and Lee, 2019). A well-established relationship exists between increased propionate production and reduced CH_4 emissions (Haque, 2018; Janssen, 2010). Microbial additives direct the fermentation pathway toward hydrogen-based propionate production. Thus, the concentration of a key precursor in CH_4 production decreases (Króliczewska et al., 2023).

1.3.1.4 Reducing Methane Emissions through Genetic Selection

Several studies over the last decade have shown that the heritability of CH_4 characteristics in dairy cattle was moderate, ranging from 0.11 to 0.33; however, the heritability of CH_4 yield in sheep was higher (0.24–0.55) (Pickering et al., 2012; Pinares-Patiño et al., 2013; Pszczola et al., 2017; Rowe et al., 2019; Sypniewski et al., 2021). Genetic selection is a very attractive solution because changes are cumulative and permanent; however, it requires multidisciplinary investigation and a large number of animals with CH_4 records, but only a few countries actively record CH_4 animal emissions. Moreover, animal selection is a very long-term process, and selecting animals with low CH_4 emissions looks rather like an excellent future strategy. Here are some examples of multidisciplinary and international CH_4 mitigation projects in animals: RuminOmics is a multidisciplinary research project funded by the European Union that aims to develop innovative solutions for reducing CH_4 emissions from ruminants. The project brings together experts from various fields, such as genomics, microbiology, nutrition, and environmental science, to study the interactions between rumen microbiota and the host animal; The Animal Selection, Genetics, and Genomics Network (ASGGN) is a collaborative research initiative that formalised protocols for the collection and storage of data (including direct and indirect phenotypes, DNA, and rumen samples (if available) from all animals measured; The Global Research Alliance is an international partnership that aims to coordinate and fund research on greenhouse gas mitigation in agriculture, including livestock. The alliance involves more than 60 member countries, including many of the world's major livestock-producing nations, and focuses on a range of research areas, including livestock genomics, nutrition, and manure management.

Bringing together the information from various studies and countries could help create a future and accurate genomic reference database and develop precise genetic parameters for CH_4 traits.

When making a genetic selection, productivity is one of the important factors to be considered. There are numerous examples from across the industry of how rising animal performance has, over time, decreased the intensity of CH_4 emissions. However, as animal productivity increases, CH_4 intensity decreases curvilinearly. Thus, increasing the productivity of lower-producing animals has a relatively significant impact, whereas increasing the productivity of high-producing animals has a relatively small impact (Beauchemin et al., 2020). Manzanilla-Pech et al. (2021), based on their analyses, find that CH_4 concentration is genetically more closely related to CH_4 production than any of the other CH_4 variables investigated. They conclude that, when compared to CH_4 production (MeP; g/d), CH_4 yield (MeY; g/kg DMI), and CH_4 intensity (MeI; g/kg energy-corrected milk), residual CH_4 has the greatest potential for inclusion in the breeding goal because it allows for selecting low-methane-emitting animals without compromising other economically important traits. Furthermore, possible relationships between enteric CH_4 emissions and feed efficiency must be considered.

The selection of low-emitting animals may reduce the efficiency of feed digestion, particularly NDF, an essential ruminant characteristic in human food production. Many interacting biological and physiological factors, such as digestion rate, passage rate, rumen microbiome, and rumen fermentation, can all have an impact on feed efficiency and CH_4 emission.

In a 10-year investigation, Rowe et al. (2013; 2019) demonstrated that CH_4 yield is heritable and, consequently, is under host control. Genetic selection has resulted in physiological changes affecting the rumen, feeding behaviour, rumen outputs, and body composition (Bian et al., 2014; Rowe et al., 2013). These changes appear to be economically beneficial, as ewes with low CH_4 yield wean heavier, leaner lambs that produce more wool. Selected ewes have a 12% difference in CH_4 emission yield between high and low emitters (Rowe et al., 2013). Moreover, the heritability and repeatability of $CH_4/(CH_4 + CO_2)$ for the CH_4 yield traits were higher than CH_4/DMI, indicating that gas traits are a reliable and accurate substitute for DMI at a constant level of feed intake (Hickey et al., 2022). On the other hand, preliminary studies show that genetic variation in CH_4 emissions is present in Angus cattle; however, they did not identify antagonistic phenotypic or genetic relationships between CH_4 and body composition traits.

One of the most difficult challenges in selecting animals with low CH_4 production is measuring CH_4 in a large group of animals. Even commercial farms have difficulty performing these measurements (De Hass et al., 2021). A genetic selection program necessitates thousands of measurements, which should be taken on a weekly basis. Selection is also difficult because grazing systems differ depending on climate, plant species, soil types, and livestock, and include season-long continuous grazing, rest-rotation grazing, deferred rotational grazing, and intensively managed grazing. It appears that animal selection is required to develop biomarkers that can reliably estimate CH_4 production on all types of farms (Manzanilla-Pech et al., 2021). Bringing together the data from various studies and countries could help create a future and accurate genomic reference database and develop precise genetic parameters for CH_4 traits. Unfortunately, we should start reducing CH_4 and other GHGs from livestock right now, not in an additional 10 years. If the country governments decide to implement animal breeding strategies to reduce enteric CH_4 production and achieve the expected breeding impact, there must be predictability. The only way to accomplish this is to have a sufficient number of animals genotyped and phenotyped, and this data should be made public (De Hass et al., 2021).

1.4 Conclusion and Recommendations

1.4.1 Conclusion

According to information from the published literature used in this comprehensive review, many feeding strategies are only now being introduced in ruminant farming to reduce CH_4 production. Unfortunately, we generally continue to observe a global increase in CH_4 emissions. Moreover, rumen microbial manipulation and genetic selection are also being used as mitigation strategies. However, according to the data presented in the current review, more intense research is needed to reduce ruminant

CH_4 emissions. These studies must take into account both the economic capabilities of developing countries such as South Africa and the animal husbandry methods used.

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CHAPTER 2: GOATS FARMERS' PERCEPTIONS ON DROUGHT

Abstract

The study was conducted to investigate goat farmers' perception of drought impact and local adaptation measures in three villages called Ga-Dikgale, Chuene and Maja located in Polokwane Municipality, Capricorn District in Limpopo province of South Africa. Twenty-four farmers from each village, with at least 10 indigenous Pedi goats, were randomly selected in the study. Therefore, 72 goat farmers were interviewed using a well-structured questionnaire. Statistical Package for Social Sciences (SPSS) version 28.0 software was used for data analysis. Descriptive statistics such as frequencies and percentages were used to achieve the Objective. In all three villages, the majority of goat keepers were males (81.9%) compared to females (18.1%). Education data showed that 11.1%, 20.8%, 54.2%, 11.1%, 2.8%, and 0% of respondents had no education and had completed their primary, secondary, college diploma, bachelor's or higher education, and postgraduate degrees. Most farmers (51%) kept mixed goat breeds, with Pedi goats accounting for 38%. The fewest farmers (11%) kept Boer goats. About 14% of farmers reported they tether their goats in the dry season, whereas about 86% of farmers reported that they don’t practice tethering or feeding. The majority of farmers (58%) reported that they use fodder and trees as a feed resource for their goats, followed by approximately 32% of farmers who rely on grass, and the fewest farmers (10%) use supplements as a feed resource for goats. The majority of farmers (76.4%) use traditional trees as feed supplements for goats, followed by farmers who use commercial feed (11.1%). Approximately 12.5% of farmers do not supplement their goats. Most farmers stated their goats have no implications due to nutrition. Similarly, the majority of farmers reported no implications as a result of the drought to goats, while a few farmers reported some consequences. The majority of farmers stated that they were unaware of methane, while only a small percentage reported that they were aware of it. In conclusion, the farmers are knowledgeable about drought, but they are unaware of its effects on goats and coping mechanisms during drought. In addition, farmers were unaware of the use of Prickly pear as a potential livestock feed during a drought.

Keywords: Drought, indigenous goats, villages, goat farmers, methane emission, Prickly pear

2.1 Introduction

South Africa is facing one of the worst droughts to hit the southern African region in recent years. The drought is threatening animal production, mainly because of its impact on fodder and water availability. The frequency and intensity of drought in South Africa are expected to continue increasing in the coming years because of the changing climate. As a result, the country will increasingly face growing pressure on the sustainable use of its freshwater resources, especially in arid and semi-arid regions of the country. Drought-tolerant forages such as Prickly pear have been traditionally used for livestock feeding in South African semi-arid regions and have been studied in many countries to mitigate feed and water shortages in drought-prone dry areas (Wanderley et al., 2002; Melo et al., 2003; Ben Salem et al., 2004; Misra et al., 2006; Tegegne et al., 2007), where it represents the main forage source during the dry season. This type of forage is adapted to semi-arid conditions and can yield large amounts of fresh water per cultivated surface because of its high moisture and mucilage-rich composition. Prickly pear has low levels of dry matter (DM) (10–14%), crude protein (4–6%), and neutral detergent fibre (26.8%) (Abidi et al., 2009; Tosto et al., 2015). On the other hand, it is an excellent energy source, rich in non-fibrous carbohydrates (61.7%), and presents a high dry matter digestibility coefficient (Cordova-Torres et al., 2022). Besides, cactus pear contains significant levels of calcium, potassium, and magnesium, and secondary metabolites such as tannins, antioxidants, flavonoids, and polyphenols (Santos et al., 1997). Thus, prickly pear constitutes a potential water and food source for animals during the dry season (Tegegne et al., 2007), and may reduce the negative effects of drought on animal performance. The high water level in prickly pear represents an important alternative to supplying water requirements of animals in arid and semi-arid regions, where water may be a limiting factor for animal production. Prickly pear, like other fibre sources, increases DM levels in the diet and keeps normal conditions in the rumen, thus preventing such undesired effects as bloat (Mattos et al., 2000). Thus, the use of drought-tolerant forages such as prickly pear could be the way forward for managing growing trends of water scarcity for livestock in South Africa, and also as a strategy to mitigate against methane emission. Such a strategy may mitigate against poverty and vulnerability to water scarcity for smallholder goat farmers and build the capability to manage current and future water scarcity-induced shocks at household and national levels.

2.2 Materials and Methods

2.2.1 Study site

The study was conducted in three villages called Ga-Dikgale, Chuene and Maja located in Polokwane Municipality, Capricorn District in Limpopo province of South Africa. The villages are about 45 km away from Polokwane and 31 kilometres from the University of Limpopo.

2.2.2 Research design

The study was conducted following a cross-sectional study design, which is a type of observational study design involving a once-off data collection and analysis in a population at a given point in time. Questionnaires were administered once to each farmer of the Pedi indigenous goat.

2.2.3 Sample size

The study focused on the three villages: Ga-Dikgale, Chuene, and Maja tribal authorities. The sample size of the villages was calculated using the Yamane formula (Yamane, 1967). Therefore, the study used a sample size of 3 villages.

2.2.4 Sampling Procedure

A purposive sampling procedure was used for sampling in the study. The purposive sampling procedure is a procedure that allows judgement to be employed to select situations that allow study objectives to be tackled (Saunders et al., 2009). Polokwane Local Municipality was purposively selected based on the information from the Department of Agriculture, Land Reform, and Rural Development in Limpopo indicating that the municipality has a high population of Pedi indigenous goats. Dikgale, Chuene, and Maja tribal authorities were purposively selected due to the availability of Pedi indigenous goat farmers working with the extension officers. From the three selected villages, a minimum of 72 indigenous goat farmers (Louanrath and Sutanepong, 2019) were used in the study. Twenty-four farmers from each village, with at least 10 goats, were randomly selected in the study. Therefore, 72 Pedi indigenous goat farmers were interviewed.

2.2.5 Data collection

Data on farmers' socio-economic characteristics, goat flock size, composition, performance, feeding and watering management, reasons for keeping goats, farmers' perceptions of the impact of drought on goat production, local and administrative adaptation, and mitigation strategies adopted were collected through face-to-face interviews using a well-structured questionnaire. The questionnaires were translated into a local language (Pedi) understood by the farmers.

2.2.6 Data analysis

Statistical Package for Social Sciences (IBM SPSS, 2022) version 28.0 software was used for data analysis. Descriptive statistics such as frequencies and percentages were used to achieve the objective.

2.3. Results and Discussion

2.3.1 Demographic characteristics of respondents

A total of 72 households were interviewed from three villages (Ga-Dikgale, Chuene, and Maja), with 81.9% males and 18.1% females. However, this was really expected because, traditionally, when coming to South African customary patterns, men are considered the head of the household and likely to have the final say in issues related to the keeping of livestock. The results of the current study are in line with the results of Onzima et al. (2018) and Sheriff et al. (2020), who reported that the majority of goat keepers are male farmers (84.8% and 67.5%) compared to females. The majority of respondents had an average farming experience of more than ten years, ranging from eleven to fifteen. Education data showed that 11.1%, 20.8%, 54.2%, 11.1%, 2.8%, and 0% of respondents had no education and had completed their primary, secondary, college diploma, bachelor's or higher education, and postgraduate degrees, respectively which means that goat’s farming was mostly practiced by people who can read and write the results of the current study are comparable with the results of Tyasi et al. (2022) who reported that most goat keepers around Lepelle-Nkumpi Local Municipality in Limpopo province. Table 2.01 shows detailed figures.

Table 2.01. *Demographic characteristics*

Demographics	**Variables**	**Frequencies**	**Percentage**
Villages			
	Dikgale	19	26.4
	Chuene	20	27.8
	Ga-Maja	33	45.8
Gender			
	Male	59	81.9
	Female	13	18.1
Age			
	24 yrs.	2	2.8
	25-34 yrs.	2	2.8
	35-44 yrs.	11	15.3
	45-54 yrs.	31	43.1
	55yrs and over	26	36.2
Farm Experience			
	Less than 2 yrs.	6	8.6
	3-5 yrs.	19	26.4
	6-10 yrs.	22	30.6
	11-15 yrs.	25	34.8
Education			
	Never attended school	8	11.1

Primary school	15	20.8
Secondary school	39	54.2
College Diploma	8	11.1
University Degree	2	2.8
Post-graduate	0	0

2.3.2 Goat Breeds

In this study, goat farmers were defined as those who owned at least ten goats. Table 2.02 presents the breeds kept by goat farmers. Most farmers (51%) kept mixed goat breeds, with Pedi goats accounting for 38%. The fewest farmers (11%) kept Boer goats. The preference for the type of goats kept normally is focused on the ability of the goat to survive the environmental conditions that exist in the particular area. In the current study, the farmers also preferred local mixed breeds (Pedi indigenous breeds), simply because they required less input cost in terms of medical supplies and feeds. Results of the current study are in agreement with the results of Mataveia et al. (2018); the authors observed that smallholder goat farmers preferred to farm with local breeds. Goat's coat colour, body conformation, and size are also some of the traits other farmers prefer when farming with local goats (Nigussie et al., 2013). However, results obtained by Onzima et al. (2018) stated that farmers in their study area preferred adaptation traits over production traits.

Table 2.02. Goat breeds

Breed	Frequency	Percentage
Boer goat	8	11.1
Pedi goat	27	37.5
Mixed goat	37	51.4

2.3.3 Reason for keeping goats

Figure 2.01 shows respondents' perceptions of reasons for keeping goats. The most perceived reason for keeping goats was for income generation, followed by traditional use. Whereas consumption was perceived as the least important reason for keeping goats. Goats are the preferred livestock species in dry areas due to their ability to convert poor quality pasture into good quality protein for human consumption (Mataveia et al., 2021). Thus, the results of the current study are in agreement with the results of Mataveia et al. (2018); Onzima et al. (2018); Sheriff et al. (2020); Nguluma et al. (2020); Masawana et al. (2022) observed that most farmers keep goats for consumption, as investments (generate income), traditional ceremonies, and status symbols. According to Mataveia et al. (2021) improvement in goat production and commercialisation has a positive impact on the whole value chain, including processors and marketers.

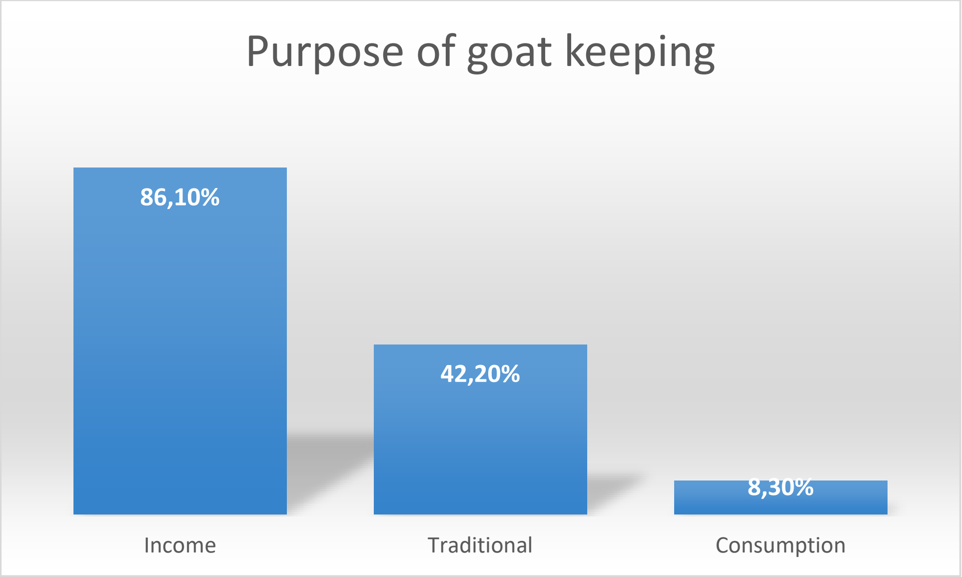

Figure 2.01. *Purpose of goat-keeping*

2.3.4 Feeding practices

During the dry season, desertification worsens, resulting in a decline in rangeland resources that are frequently insufficient to meet livestock demand, as well as a decrease in total feed resources (Salem and Smith, 2008). As a result, goats are experiencing serious nutrient deficiencies. These animals frequently feed on low-quality crop residues and costly feed supplements. This was also supported by Shoo et al. (2015) who reported that there is a declining grazing land and limited feed resources in the dry season. Due to declined access for animals to nutritious pastures, thereby forcing farmers to supplement or completely stall-feed their goats. In the current study, during dry seasons, most farmers reported that they allow their goats to free-roam for feed, while few farmers reported that they don't allow their goats to roam at all. Few farmers reported they stall-feed their goats during dry seasons, while the vast majority do not. About 14% of farmers reported they tether their goats in a dry season, whereas about 86% of farmers reported that they don't practice tethering (Figure 2). This supports the report by Koura et al. (2021) who stated that free-roaming was the main practice during dry seasons in both zones. However, they contradict those of Nalabuma et al. (2014), who found that the most common management system for goats in the dry season was tethering during the day and returning in the evening to stall-feed with crop residues, due to the unavailability of nutritious feed for goats.

During the wet season, the majority of farmers allow their goats to roam freely for feed, while the least reported not allowing their goats to roam. The majority of farmers do not practice stall feeding or tethering of their goats (Figure 3.02). This could be explained by the fact that the wet season provides the best forage nutrition and availability, with higher crude protein concentrations and more herbaceous plants available (Cooke et al., 2023), and hence farmers depend on grazing to feed their goats.

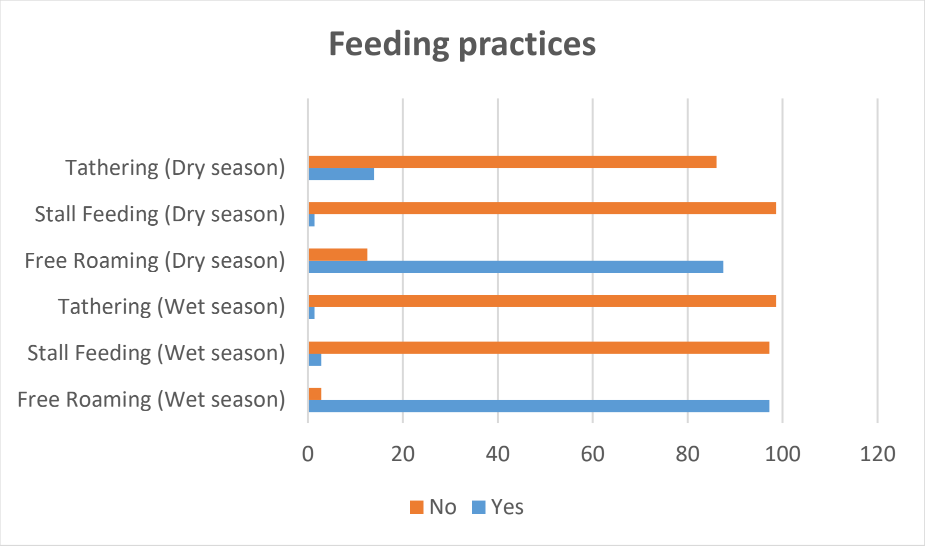

Figure 2.02. *Feeding practices*

2.3.5 Feed resources

Figure 2.03 shows feed resources used for goats. The majority of farmers (58%) reported that they use fodder and trees as a feed resource for their goats, followed by approximately 32% of farmers who rely on grass, and the fewest farmers (10%) use supplements as a feed resource for goats. This could be because the browse fodders are useful sources of cheap feed for ruminant animals, especially during dry seasons when herbaceous pasture grasses and legumes senesce. This was also supported by Olsfdeham and Okunade (2018), who reported that smallholder ruminant farmers in developing countries cannot afford concentrates and thus depend almost entirely on browse fodders for feeding their stock. The findings of the current study are consistent with the findings by Kujoana et al. (2023), who reported that goats in Vhembe district in Limpopo rely on fodder trees. However, they contradict the findings of Sha (2023), which stated that the preferred feeds for the goats were Napier grasses and various crop residues provided in combinations depending on availability. This variation may be due to the different geographic areas of the studies.

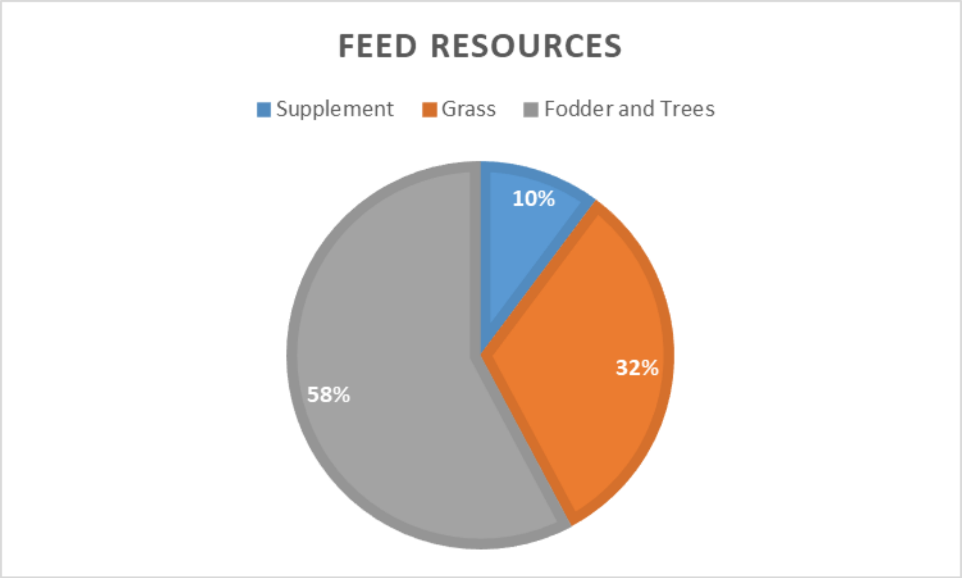

Figure 2.03 *Feed resources for goats*

2.3.6 Feed Supplementation

The results of goat supplementation are presented in Table 2.03. The majority of farmers (76.4%) use traditional trees as feed supplements for goats, followed by farmers who use commercial feed (11.1%). Approximately 12.5% of farmers do not supplement their goats. This is because including tree fodder in the animal ration leads to improved performance. Rahman et al. (2015) indicated that using shrubs and tree leaves as supplements yielded positive results in goat performance.

Table 2.03. *Feed supplementatio*

Supplements	Frequency	Percentage
Don’t supplement	9	12.5
Purchased feed	8	11.1
Traditional tress	55	76.4

2.3.7 Prickly pear as goat feed

Several studies have investigated the effect of prickly pear as forage on livestock performance (Tarefe, 2016; Morshedy et al., 2020). Prickly pear is reported to optimally substitute pasture to a level of 60%, and additionally contributes to sustaining the water requirement of the animals (Pastorelli et al., 2022). Figure 4 presents the consumption of Prickly pear as feed by goats. Most farmers (93.1%) reported that their goats do not consume Prickly pear, whereas about 4.2% reported that their goats do. This could be because farmers had no idea that prickly pear could be used as livestock fodder. These findings contradict the report by Lauhainchi et al. (2018), who reported that farmers in Pakistan had a higher proportion of farmers who were actual adopters compared with non-adopters of cactus, and similar results were found in India. The reasons for goats being attracted to prickly pear are presented in Figure 5. The majority of farmers don’t use prickly pear as feed. About 1.4% of farmers reported that their goats are drawn to prickly pear due to its palatability, followed by 1.4% of farmers who reported that goats are attracted because of the colour of the prickly pear tree.

The response of goats to prickly pear is shown in Table 4. About 1. 4% of farmers reported that goats fed with prickly pear increased their weight gain. This is supported by many authors (Araújo et al., 2022; Albuquerque et al., 2020; Morshendy et al., 2020) who found that livestock fed cactus pear improved their body weight. On the other hand, 1.4% of farmers reported that goats fed prickly pear are not prone to diseases.

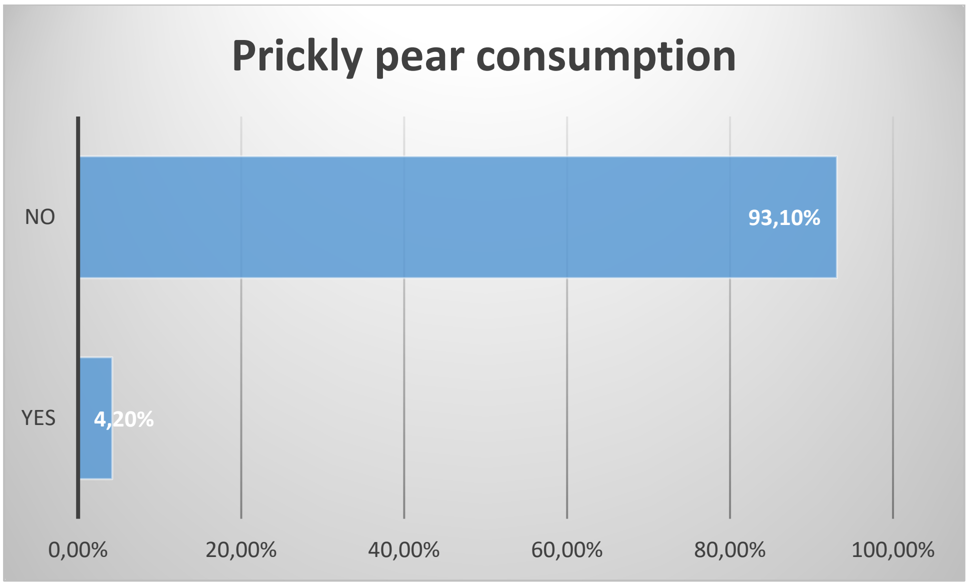

Figure 2.04. *Prickly pear consumption by goats*

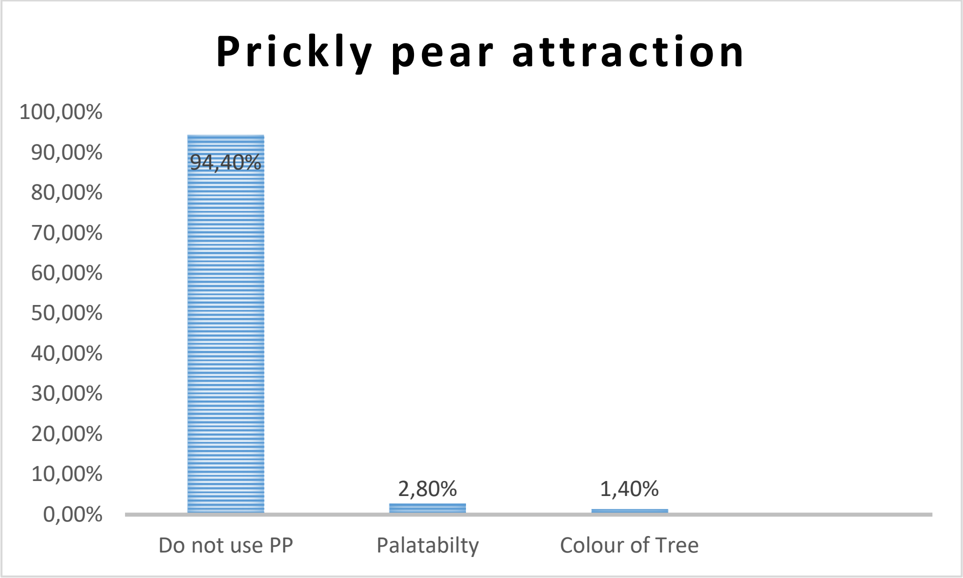

Figure 2.05. *Reasons for goats to be attracted to Prickly pear*

Table 2.04. *Response of goats fed with Prickly pear*

Variables	Frequency	Percentage
Do not use Prickly pear	70	97.2
Increase weight gain	1	1.4
Not prone to diseases	1	1.4

2.3.8 Drought

Table 2.05 shows farmers' knowledge of drought and methane. All of the farmers reported that they have knowledge about drought. Farmers defined drought as a period of low or shortage of rain, resulting in low forage availability for livestock. Our findings are consistent with the findings of Muyambo et al. (2017), who reported that the majority of farmers were aware of drought. Table 6 shows the drought-related and nutrition-related implications for goats. Most farmers stated that nutrition was not a factor affecting their goats. Similarly, the majority of farmers reported no implications as a result of the drought to goats, while a few farmers reported some consequences. Our findings differ from those of Alabadi et al. (2022), who found that drought has numerous negative effects and consequences in rural communities, including reduced water supply, lower income, less vegetation and pastures, and migration. All farmers reported that they do not have knowledge about drought coping strategies. Our findings are consistent with the study of Kesharz and Karami (2014), who found that farmers are less likely to take any measures regarding drought.

2.3.9 Methane

Emissions of greenhouse gases from various sources have led to climate change and increased global surface temperatures (Calabrò, 2009). Methane is the second most significant contributor to global warming, after carbon dioxide (Yusuf, 2012). Table 5 shows the results of knowledge of methane emissions. The majority of farmers stated that they were unaware of methane, while only a small percentage reported that they were aware of it. This could be because the farmers interviewed are not well-educated and trained on climate change. Our study differs from the report by Jankle et al. (2020), which indicated that the majority of farmers perceive methane emissions as an important issue, but only a few farmers stated that they estimate GHG emissions from their animals.

Table 2.05. *Knowledge of drought and methane*

Knowledge	**Yes**		**No**	
	Frequency	**Percentage**	**Frequency**	**Percentage**
Drought	72	100	0	0
Methane	1	1.4	71	98.6

Table 2.06. *Implications due to nutrition and drought*

Implication	**Yes**		**No**	
	Frequency	**Percentage**	**Frequency**	**Percentage**
Nutrition implication	8	11.1	64	88.9

Drought implication	8	11.1	64	88.9

2.4. Conclusions and recommendations

2.4.1 Conclusions

The study assessed goat farmers' perceptions of drought impact and adaptation measures. The study's findings lead to the following conclusions: the farmers are knowledgeable about drought, but they are unaware of its effects on goats and coping mechanisms during drought. In addition, farmers were unaware of the use of prickly pear as a potential livestock feed during drought.

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CHAPTER 3: NUTRIENT COMPOSITION AND SECONDARY METABOLITES OF PRICKLY PEAR FRUITS

Abstract

This study aimed to investigate the nutrient composition and phenolic compounds of Prickly pear cactus (*Opuntia ficus-indica*). AOAC method was used for nutrient composition, whereas QTOF-MS was used for the phenolic compounds. The proximate composition of the prickly pear was 90.40% DM, 9.60% moisture, 8.50% protein, 4.50% fat, 14.40% ADF, 24.81% NDF, 10.00% ash, and 6.60 (MJ/kg DM) GE contents. The Prickly pear had more mineral content. A total of 12 compounds were detected and were tentatively identified. Phenolic compounds in Prickly pear were identified with a clear indication of the abundance of Fukiic acid, Psidic acid, (2R,3S)-Piscidic acid, (1S,6R)-2-succinyl-6-hydroxycyclohexa-2,4-diene-1-carboxylic acid, Teucardoside, Veranisatin C, MINEs-504496, Manghaslin, Rutin, Keioside, (+)-7-epi-Syringaresinol 4'-glucoside, and Alpha-dimorphecolic acid. The phenolic compounds identified include phenolic acids and flavonoids. These results confirmed that Prickly pear fruits are rich sources of valuable nutrients and diverse phenolic compounds.

Keywords: Prickly pear, secondary metabolites, minerals, flavonoids

3.1 Introduction

Prickly pear cactus (*Opuntia ficus-indica*) is considered an excellent natural biomass. It is a fast-growing xerophytes drought-resistant plant and well adapted to an arid and hot environment (Sahoo *et al*., 2017). The prickly pear cactus is a plant that has developed characteristics of adaptation to low water availability and extreme temperature changes, as is present in these areas. This plant grows in arid and semiarid regions at high temperatures and low water availability (Kluge and Ting, 2013). In arid areas of northern Mexico, the prickly pear cactus is used for animal feed as a source of fodder, energy, and water (Andrade-Montemayor *et al*., 2011).

Prickly pear is high in soluble carbohydrates, calcium, and vitamin A, and has a high dry matter yield potential, but is low in Crude Protein, fibre and sodium (Dubeux *et al*., 2015). Spineless cactus plants have high water content and energy. Water content is 90%, and water-soluble carbohydrates range from 45 to 55%. The fruit is constituted mainly by its juicy pulp (28-58% of fruit mass), seeds (2-10%), which have a high content of oil, and a thick peel (37-67%) (Barba *et al*., 2017). Crude protein in prickly pear normally varies depending on the species, the fertilization of the soil, and the cultivation practices. In addition, Giraldo-Silva *et al*. (2023) reported comparatively high amounts of aspartic and glutamic acids, estimated at 200mg/kg juice in *Opuntia ficus-indica*.

Studies reveal that when sheep consume roughly 300g of DM of cactus, their water intake is negligible. According to Elshehy *et al*. (2020), cactus varieties have ash contents ranging from 10.4 to 13.3%. This is less than the figures of 27.4 and 30%, respectively, that were reported by Howari *et al*. (2022). According to Diaz *et al*. (2017), De Santiago *et al*. (2018), and Rocchetti *et al*. (2018), water is the primary component of *Opuntia ficus-indica* cladodes (80-95%), followed by carbohydrates (3-7 %), fibre (1-3 %), and proteins (0.5-1 %) (Diaz *et al*., 2017). *Opuntia ficus-indica* has been evaluated by various authors, and the values are always variable (Astello-García *et al*., 2015; Díaz *et al*., 2017; Dubeux *et al*., 2021; Perucini-Avendaño *et al*., 2021; Hernández-Becerra *et al*., 2022). Moreover, the fruits contain phenolic alkaloids (betalains) such as betacyanin and betaxanthin, and glycosylated flavonoids that exhibit several pharmacological activities. The red and yellow-coloured betalains, which are water-soluble pigments, are used as natural food colorants (Stintzing *et al*., 2005; Ahmed *et al*., 2005). In terms of antioxidant potential, cactus fruits are twice as potent as pears, apples, tomatoes, bananas, white grapes, and almost equipotent to red grapes and grapefruit (Seham *et al*., 2020). Hence, the present study investigated the nutrient composition and phenolic compounds of Prickly pear cactus (*Opuntia ficus-indica*).

3.2. Materials and Methods

3.2.1 Nutrient composition

Prickly pear fruits were obtained from Ubali Pomegranate Farm in Pretoria, South Africa. Samples of Prickly pear was finely ground into flour and prepared in duplicate, which were then analysed for DM, crude protein (CP), ash, crude fat, NDF, and acid detergent fibre (ADF). of DM was determined after drying at 105°C, and ash after combustion at 550°C (AOAC, 2012). Crude fat was extracted for 6 h with petroleum ether, whereas the Kjeldahl method was used to determine nitrogen (N) (AOAC, 2012). CP was calculated as N × 6.25. NDF and ADF were determined according to the methods of Van Soest *et al*. (1991) using an ANKOM 220 Fibre Analyzer (ANKOM Technology Corporation, NY, USA). Mineral contents were analysed using the standard method of AOAC (2000); the wet digestion method was used; 0.5 grams of flour was taken and digested with 5 ml conc. nitric acid (HNO_3) and 1 ml conc. perchloric acid ($HClO_4$); then, the digested sample was filtered and made up to 100 ml in a standard flask. Phosphorus was determined by the UV-visible spectrophotometric method, while Calcium, Magnesium, Copper, Iron, Manganese, Zinc, Sodium and Potassium were determined by Atomic Absorption using the method of Varian SpektrAA.

3.2.2. Phenolic compounds extraction

The extracts were prepared by using 2g dry Prickly pear material + 15 ml 50% methanol/1% formic acid in water with ultrasonication for 1 hour and standing overnight, followed by centrifugation and transfer of the supernatant to a glass vial prepared in duplicate, ready for the LC-MS analysis.

3.2.3. UPLC-UV analysis

A Waters Synapt G2 Quadrupole time-of-flight (QTOF) mass spectrometer (MS) connected to a Waters Acquity ultra-performance liquid chromatograph (UPLC) (Waters, Milford, MA, USA) with a photodiode array (PDA) detector was used for high-resolution UPLC-UV/MS analysis. Electrospray ionization was used in negative mode with a cone voltage of 15 V, desolvation temperature of 275 °C, desolvation gas at 650 L/h, and the rest of the MS settings optimised for best resolution and sensitivity. Data were acquired by scanning from m/z 150 to 1500 m/z in resolution mode as well as in MSE mode. In MSE mode, two channels of MS data were acquired, one at a low collision energy (4 V) and the second using a collision energy ramp (20−60 V) to obtain fragmentation data as well. Leucine enkaphalin was used as lock mass (reference mass) for accurate mass determination and the instrument was calibrated with sodium formate. Separation was achieved on a Waters HSS T3, 2.1 × 100 mm, 1.7 μm column. An injection volume of 2 μL was used and the mobile phase consisted of 0.1% formic acid (solvent A) and acetonitrile containing 0.1% formic acid as solvent B. The gradient started at 100% solvent A for 1 min and changed to 28% B over 22 min in a linear way. It then went to 40% B over 50 s and a wash step of 1.5 min at 100% B, followed by re-equilibration to initial conditions for 4 min. The flow rate was 0.3 mL/min and the column temperature was maintained at 55 °C. Compounds were quantified in a relative manner against a calibration curve established by injecting a range of catechin standards from 0.5 to 100 mg/L catechin.

3.2.4 Chemicals

The following chemicals were used: formic acid was purchased from Merck Pty Ltd. (Darmstadt, Germany), acetonitrile 200, and methanol 215 were purchased from Romil Ltd. (Waterbeach, Cambridge, UK); catechin was from Sigma-Aldrich (St. Louis, MO, USA), and Millipore water purification.

3.3. Results and Discussion

3.3.1 Nutrient composition

3.3.1.1 Nutrient Composition of Prickly Pear vs goat requirement

The proximate chemical composition of a prickly pear, i.e., DM, moisture, protein, fat, fibre (ADF and NDF), ash, and GE are presented in Table 3.01. The proximate composition of the prickly pear was 90.40% DM, 9.60% moisture, 8.50% protein, 4.50% fat, 14.40% ADF, 24.81% NDF, 10.00% ash, and 6.60 (MJ/kg DM) GE contents. Prickly pear meets goat requirements in fat and ash. However, other nutrients such as crude protein, ADF, and NDF were below the required amounts for goats. In the current study, the protein content of prickly pear was lower than the required quantities by goats. Findings are similar to the results reported by Hamard et al. (2024) and AbdelFatt et al. (2020), who found protein content of 7.9% and 10.7% in prickly pear, respectively. Due to lower protein levels, when feeding goats with prickly pear, protein supplementation may be required.

Prickly pears provide a fat content that is within the range of what goats require; they satisfy the goats' fat requirements. However, the findings of Heba *et al*. (2020) and Rocchetti *et al*. (2018), who reported lower fat levels of 0.11% and 0.12%, respectively, do not align with our results. This difference might result from the fact that we conducted our nutrient study on fruit dry matter, whereas other studies used prickly pear cladodes extract.

Table 3.01. Nutrient composition of Prickly pear vs goat requirement

Nutritive value	Content	Goat Requirement	References
Dry Matter (%)	90.40	-	-
Moisture (%)	9.60	-	-
Crude Protein (%)	8.50	12-17	Hamard et al. (2024)
Acid detergent fibre (%)	14.40	18-20	Lu et al. (2005)
Neutral detergent fibre (%)	24.81	40	Lu et al. (2005)
Ether Extract (%)	4.50	2-5	Heba *et al*. (2020)
Ash (%)	10.00	18-21	Rocchetti *et al*. (2018)
Gross energy (MJ/kg DM)	6.60	13-18.6	Rocchetti *et al*. (2018)

3.3.1.2. Mineral composition of Prickly pear vs goat requirement

The mineral composition of prickly pears is presented in Table 3.02 in comparison to the minerals that goats need. The macro mineral composition of the prickly pear was Ca 1.67, P 0.14, Mg 0.73, K 2.71, and Na 0.03. Prickly pear provides all the macronutrients that goats need, except for Na. The micromineral composition of the Prickly pear was Fe 797, Mn 74, Cu 5, Zn 34. Also, the microminerals present in the Prickly pear meet the required amount for goats except for Zn. Our findings indicate that the prickly pears have high quantities of minerals due to their high ash content. The ash content provided by Prickly pear is higher than the ash content needed by goats in a diet. These results contrast with those of AbdelFatt *et al*. (2020), who reported an ash content of 3.3%. This distinction results from the fact that, while we concentrated on the entire fruit, AbdelFatt *et al*. (2020) concentrated on prickly pear seeds. Both ADF and NDF provided by Prickly pear are much less than the amounts needed by goats.

The present findings are consistent with the report of Hamad *et al*. (2024) that prickly pear is rich in K, Ca, P, and Mg minerals. The current results indicate that prickly pear is rich in both macro and microminerals required by goats, although it does not meet Na and Zn quantities required by goats. These results suggest prickly pear is a good source of minerals needed by goats.

Table 3.02. Mineral composition of Prickly pear and goat mineral requirement

Minerals	**Content**	**Goat Requirement**	**References**
Ca (%)	1.67	0.3-0.8	Hamad et al. (2024)
P (%)	0.14	0.25-0.4	and
Mg (%)	0.73	0.18-0.4	AbdelFatt *et al*. (2020)
K (%)	2.41	0.8-2.0	
Na (%)	0.03	0.2	
Fe (%)	797	50-1000	
Mn (ppm)	34	0.1-3	
Cu (ppm)	5	10-80	
Zn (ppm)	34	40-500	
K/Ca+Mg (%)	0.43	-	

Values are the means of duplicates of analysed Prickly pear

3.3.2 Secondary metabolites of prickly pear

The characterisation of the phenolic profiles of different plants has been widely determined using LC-MS (Li *et al*., 2015). The phenolic compounds identified in Prickly pear fruits using LC-MS methods are presented in Table 3.03, and chromatograms are presented in Figure 3.01. In the present study, about 12 compounds were detected and are shown in Table 3.01. Compound 1 was identified as Fukiic acid based on precursor ion [M − H]− at m/z 271,04614 with retention time 2.92. Whereas Psidic acid on precursor ion [M − H]− at m/z 255,05132 with retention time 3,181, (2R,3S)-Piscidic acid on precursor ion [M − H]− at m/z 255,05135 with retention time 3,455, (1S,6R)-2-succinyl-6-hydroxycyclohexa-2,4-diene-1-carboxylic acid on precursor ion [M − H]− at m/z 239,05656 with retention time 3,815, Teucardoside on precursor ion [M − H]− at m/z 489,16214 with retention time 4,16, Veranisatin C precursor ion [M − H]− at m/z 371,09921 with retention time 4,435, MINEs-504496 precursor ion [M − H]− at m/z 787,26953 with retention time 4,456, Manghaslin precursor ion [M − H]− at m/z 755,20599 with retention time 4,576, Rutin precursor ion [M − H]− at m/z with 609,14655 retention time 4,766, Keioside precursor ion [M − H]− at m/z with 623,16296 retention time 4,984, (+)-7-epi-Syringaresinol 4'-glucoside precursor ion [M − H]− at m/z with 579,20898 retention time 5,195, Alpha-dimorphecolic acid precursor ion [M − H]− at m/z with 295,22766 retention time 9,669. The major phytochemical compounds from plants with antioxidant capabilities are known as phenolics and flavonoids. It is interesting to note that most of the phenolic compounds found in the Prickly pear studied have clustered on a stacked bar chart, Principal Component Analysis (PCA) scatter plot, and Hierarchical clustering. However, no comparable findings could be found in the literature. Due to frequent droughts, plants have to develop several defence mechanisms to deal with or resist this stress (Kgabi *et al*., 2016). One of these methods is the production of phenolic compounds (Salehi-Lisar and Bakhshayeshan-Agdam, 2016). Several native species of severe habitats manufacture phenolic compounds (or polyphenols) as one of their defence mechanisms against the oxidative damage caused by dehydration (Sharma, 2019). Phenolic compounds in Prickly pear are displayed with clear indication of the abundance of Fukiic acid Psidic acid, (2R,3S)-Piscidic acid, (1S,6R)-2-succinyl-6-hydroxycyclohexa-2,4-diene-1-carboxylic acid, Teucardoside, Veranisatin C, MINEs-504496, Manghaslin, Rutin, Keioside, (+)-7-epi-Syringaresinol 4'-glucoside, and Alpha-dimorphecolic acid. Rutin can be found in many different food and medicinal plants. Phenolic compounds can be found as crystalline powder or as light yellow or light green needles (Yang *et al*., 2008). Pharmacological studies have demonstrated that phenolic compounds have anti-oxidation (Dobson *et al*., 2000), anti-inflammation (Yoo *et al*., 2014), anticarcinogenic (Alonso-Castro *et al*., 2013), and immune-stimulating (Awad *et al*., 2019; Casa *et al*., 2000) properties. Furthermore, may have antiulcer and mucosal protective properties (Olaleye and Akinmoladun, 2013). According to studies by Gautam *et al*. (2016) and Yang *et al*. (2008), they also have a high level of reactive oxygen species scavenging potency. Research has shown that flavonoids may reduce oxidative stress and protect the body's tissues and organs from free radical damage, including the brain, testis, liver, kidney, pancreatic islets, and other organs (Hosseinzadeh and Nassiri-Asl 2014). This improves the body's antioxidant capacity and strengthening the immune system (Russo *et al*., 2000; Caglayanetal, 2019).

In a study by Chen *et al*. (2022), dietary supplementation of rutin improved the growth performance (especially for the starter period), jejunal morphology, and enhanced the intestinal barrier function of broilers. The beneficial effects of flavonoids in animals may be related to enhanced immunity and the improved antioxidant capacity of the intestine (Chen *et al*., 2022). Ma *et al*. (2024) found that rutin improved the intestinal barrier function of weaned pigs, which may be linked to a decrease in intestinal inflammation. It also improved the microbial composition of the cecum and its antioxidant capacity. Furthermore, Ma *et al*. (2024) found that phenolic compounds enhanced antioxidant capacity related to the activation of the signalling pathway, as well as an improvement in the microbial composition and mitochondrial activity of the cecum.

Table 3.03. *Phenolic compounds identified in different Prickly pear fruits using LC-MS analysis*

No	Retention Time	Mse Fragments	Identification	Formula	Ontology
1	2,92	271,04614	Fukiic acid	$C_{11}H_{12}O_8$	Phenylpropanoic acids
2	3,181	255,05132	Psidic acid	$C_{11}H_{12}O_7$	Pyranones and derivatives
3	3,455	255,05135	(2R,3S)-Piscidic acid	$C_{11}H_{12}O_7$	Phenylpropanoic acids
4	3,815	239,05656	(1S,6R)-2-succinyl-6-hydroxycyclohexa-2,4-diene-1-carboxylic acid	$C_{11}H_{12}O_6$	Gamma-keto acids and derivatives
5	4,16	489,16214	Teucardoside	$C_{21}H_{30}O_{13}$	Iridoid O-glycosides
6	4,435	371,09921	Veranisatin C	$C_{16}H_{20}O_{10}$	Terpene lactones
7	4,456	787,26953	MINEs-504496	$C_{35}H_{48}O_{20}$	Saccharolipids

8	4,576	755,20599	Manghaslin	$C_{33}H_{40}O_{20}$	Flavonoid-3-O-glycosides
9	4,766	609,14655	Rutin	$C_{27}H_{30}O_{16}$	Flavonoid-3-O-glycosides
10	4,984	623,16296	Keioside	$C_{28}H_{32}O_{16}$	Flavonoid-3-O-glycosides
11	5,195	579,20898	(+)-7-epi-Syringaresinol 4'-glucoside	$C_{28}H_{36}O_{13}$	Lignan glycosides
12	9,669	295,22766	Alpha-dimorphecolic acid	$C_{18}H_{32}O_{3}$	Lineolic acids and derivatives

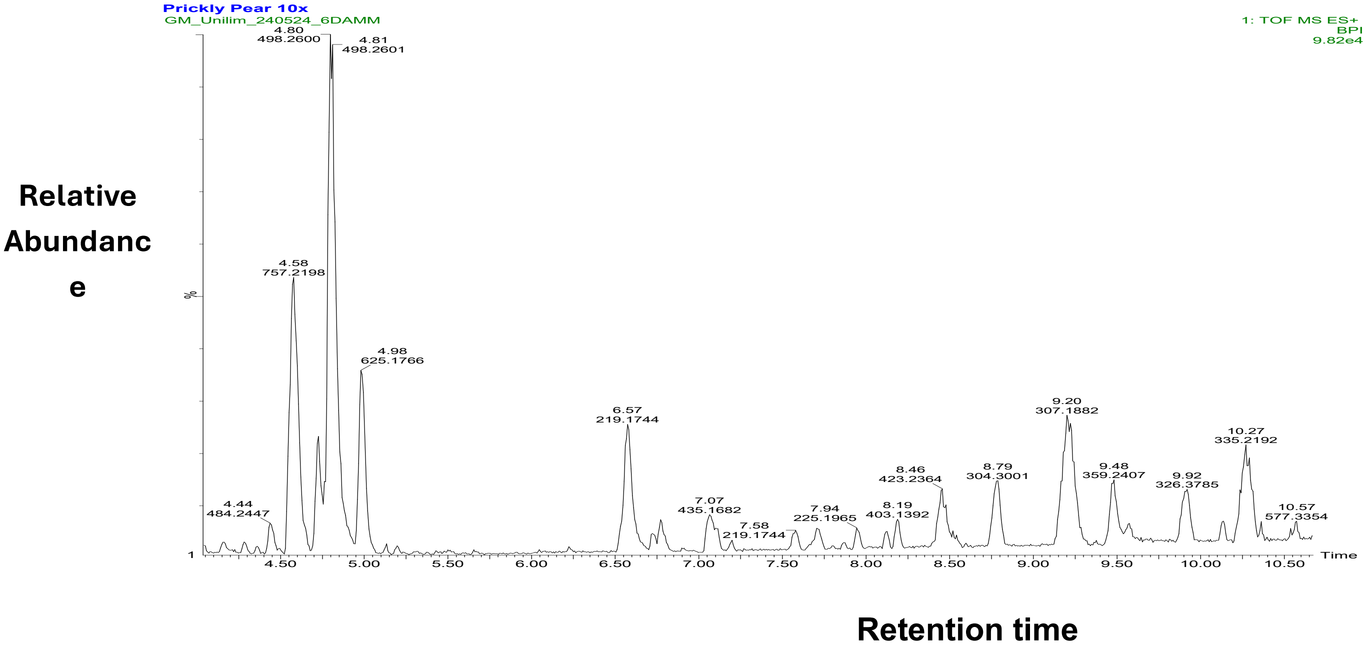

Figure 3.01. *Chromatograms of Prickly pear species*

Table 3.04. *Quantified individual phenolic compounds in plants (mg/kg)*

Compound	Ontology	Quantity (mg/kg)
Fukiic acid	Phenylpropanoic acids	304.4
Psidic acid	Pyranones and derivatives	9018.9
(2R,3S)-Piscidic acid	Phenylpropanoic acids	477.7

(1S,6R)-2-succinyl-6-hydroxycyclohexa-2,4-diene-1-carboxylic acid	Gamma-keto acids and derivatives	5682.7
Teucardoside	Iridoid O-glycosides	190.7
Veranisatin C	Terpene lactones	292.7
MINEs-504496	Saccharolipids	40.8
Manghaslin	Flavonoid-3-O-glycosides	1105.6
Rutin	Flavonoid-3-O-glycosides	421.8
Keioside	Flavonoid-3-O-glycosides	618.1
(+)-7-epi-Syringaresinol 4'-glucoside	Lignan glycosides	100.2
Alpha-dimorphecolic acid	Lineolic acids and derivatives	2.6

Phenolic compounds in prickly pear are displayed in the stacked bar chart, Principal Component Analysis (PCA) scatter plot, and Hierarchical clustering (Figure 3.02, 03 & 04). All compounds were displayed with a clear indication of the abundance of Fukiic acid, Psidic acid, (2R,3S)-Piscidic acid, (1S,6R)-2-succinyl-6-hydroxycyclohexa-2,4-diene-1-carboxylic acid, Teucardoside, Veranisatin C, MINEs-504496, Manghaslin, Rutin, Keioside, (+)-7-epi-Syringaresinol 4'-glucoside, Alpha-dimorphecolic acid.

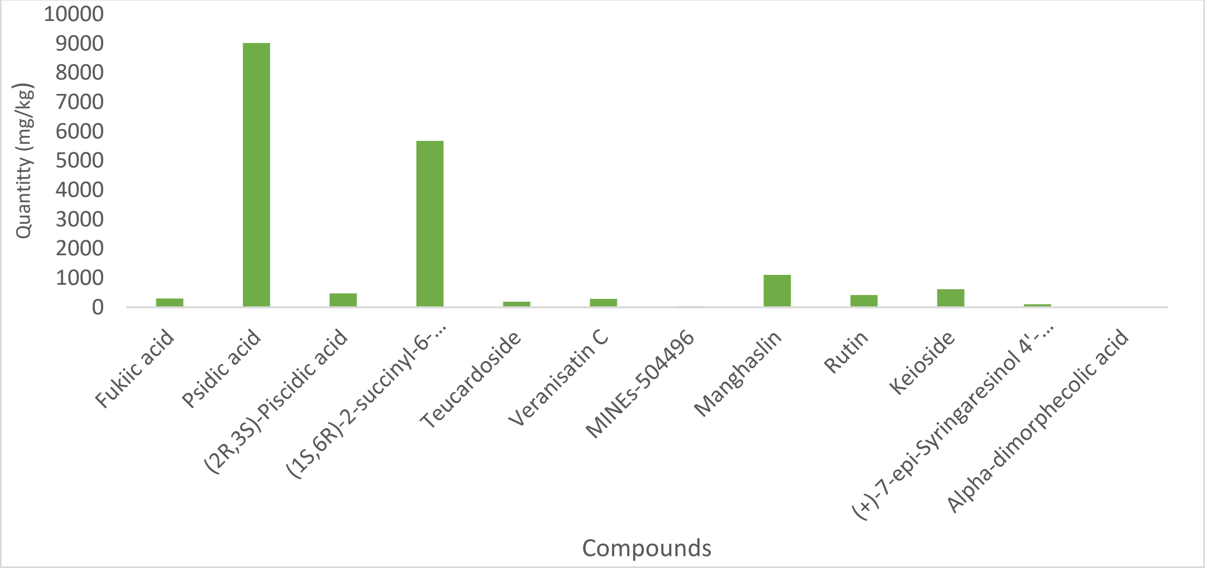

Figure 3.02. *Stacked bar graph of phenolic compounds*

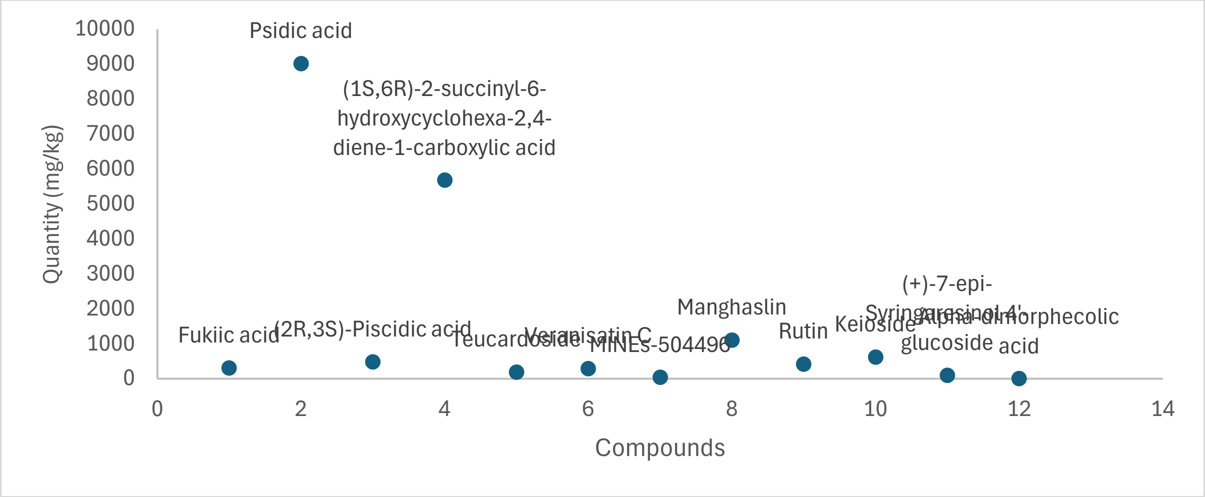

Figure 3.03. *Principal component analysis (PCA) scatter plot*

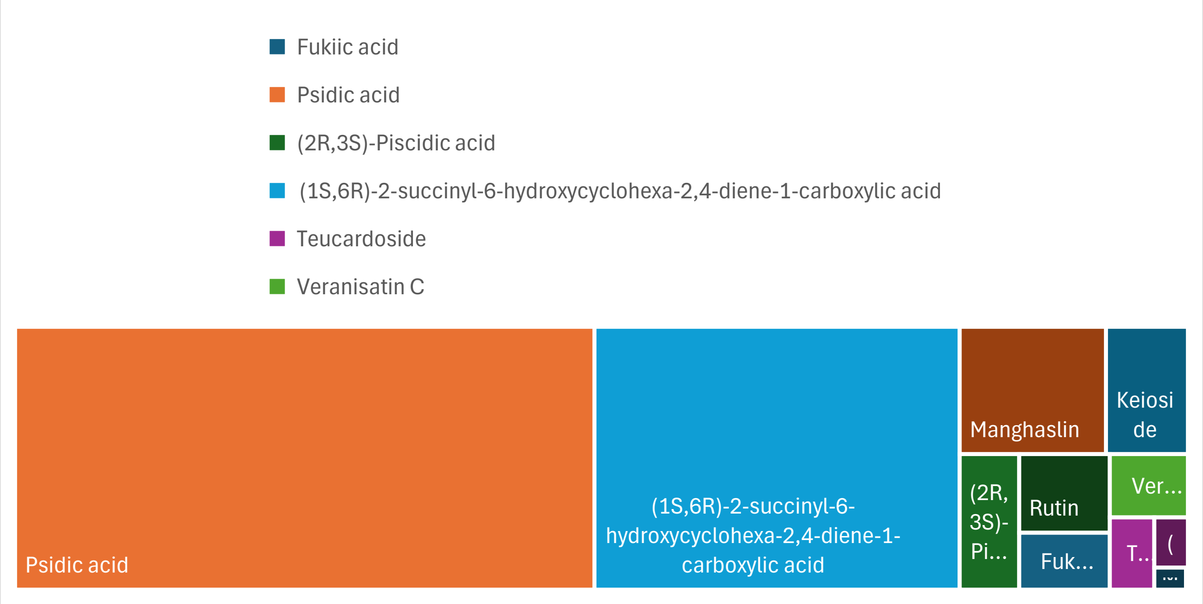

Figure 3.04. *Hierarchical clustering*

3.4. Conclusions

In conclusion, Prickly pear can be used in goats' diets as it is a good source of minerals and some nutrients, and diverse phenolic compounds. In addition, prickly pear can be used in goats' diets as it is a good source of minerals and some nutrients.

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CHAPTER 4: UTILISATION OF PRICKLY PEAR ON GROWTH PERFORMANCE AND METHANE EMISSION BY GOATS

Abstract

The study was conducted to determine the effect of ensiled prickly pear (*Opuntia ficus-indica*) in diets on growth performance and methane emissions of yearling male Pedi goats. A total number of 24 Pedi goats were randomly assigned to 4 treatments in a completely randomised block design with three replications, and 2 goats per replicate, thus six goats per treatment. Prickly pear inclusion levels were at 0,10, 20 or 30%. The data collected were subjected to analysis of variance using Statistical Package for the Social Sciences (SPSS). Ensiled prickly pear inclusion level in a diet had no effect ($P>0.05$) on the initial live weight and feed intake of indigenous male Pedi goats. However, ensiled prickly pear inclusion in a diet had a significant effect ($P<0.05$) on final weight, average daily gains, feed conversion ratio, and water intake of indigenous male Pedi goats. Prickly pear inclusion significantly ($p<0.05$) influenced methane emissions, with goats on a 0% inclusion diet emitting the highest methane levels compared to those on 10%, 20%, and 30% inclusion levels. Before the dietary intervention, methane emissions were similar across all treatments ($p=0.5342$). However, following the inclusion of prickly pear meal, a significant decline ($p=0.0063$) in methane emissions was observed, with the lowest emissions recorded at 30% inclusion (12.33 ppm-m), and the highest at 0% (19.67 ppm-m). A negative correlation was observed between prickly pear meal inclusion and methane emissions. In conclusion, ensiled prickly pear meal presents a promising feed alternative for enhancing weight gain and reducing methane emissions in small ruminants.

Keywords: Growth performance, indigenous goats, goat farmers, methane emission, Prickly pear

4.1 Introduction

The goat (*Capra hircus*) represents one of the most important livestock species found in many parts of the world. Goats are browsers and selective feeders; thus, bush enhancement in free-grazing areas must be controlled (Tilahun et al., 2019). Goats are highly fertile species that can reach maturity at an early stage with low input requirements (Marius et al., 2021). Goats are generally reared on pasture. Hence, pasture and grazing management can affect forage nutritive value and total intake by the animals (Meister et al., 2021). They played a central role in the Neolithic agricultural revolution. There has recently been an increase in the marketing of goat-derived products (Washaya et al., 2018; Mazhangara et al., 2019). South African indigenous goat breeds are particularly significant nutritionally, commercially, and culturally in South Africa (Matlebyane, 2005; Ng'ambi et al., 2010). However, during winter and dry seasons, ruminant productivity in rural areas is low when nutritious feeds are not available (Brown et al., 2016). However, animals can also obtain water through feed, especially feed with a high-water content, such as drought-tolerant plants like prickly pear (*Opuntia ficus-indica*) (Cordova-Torres et al., 2022). Tropical climates, such as those in South Africa, present characteristic arid and semi-arid regions with low precipitation that reduces forage production and water availability. Therefore, animal performance is usually limited by forage availability and especially by the scarce water resources. Local forage resources have been largely studied and, in most cases, are known to provide adequate moisture content and nutrient levels for small ruminants like goats (Misra et al., 2006).

In South Africa, 50% of the indigenous goat population is kept under small-scale conditions (Ng'ambi et al., 2013). In the Eastern Cape province of South Africa, goats are among the major socio-economically critical livestock species (Mataveia et al., 2021). The productivity of goats is limited by high methane production from the rumen, poor quality, and limited quantity of pastures (Middelaar et al., 2013). However, they produce a lot of methane gas, which contributes to the loss of dietary gross energy and global warming. Forage quality affects methane production significantly. If the feed quality is poor, the production of methane gas increases (Saha et al., 2014). Naumann et al. (2017) indicated that feeding tannins and other approaches could reduce enteric methane emissions. Thus, low feed quality and inadequate amounts of pasture result in reduced goat productivity. Therefore, the objective of the study was to determine the effect of prickly pear fruit meal inclusion level on growth performance and methane emission by yearling indigenous male Pedi goats.

4.2 Materials and Methods

4.2.1 Study site

The study was carried out at the University of Limpopo experimental farm (latitude 23°49’ S and longitude 29°41’ E), South Africa. It has a mean yearly rainfall of 495 ± 11 mm. Summer temperatures in the study area vary between 20 and 36 °C, whereas winter temperatures range between 5 and 25 °C. The vegetation structure around the study area is a Savannah type (bushveld) that is characterized by trees, shrubs, and grass under cover. Browsing animals, traditionally, keep a balance between trees and grass.

4.2.2 Experimental designs, treatments, and procedures

The study was conducted to determine the effect of prickly pear (*Opuntia ficus-indica*) in diets on the growth performance of yearling male Pedi goats. A total number of 24 indigenous male Pedi goats were randomly allocated to 4 dietary treatment groups in a completely randomized block design, replicated 3 times with 2 goats per replicate. The goats were housed individually in a well-ventilated holding pen (1 X 3 m^2), having one side open to natural light and roofing to protect them against sun and rain. The pen space was enough to allow them to move around freely and lie down. Each goat had feeding troughs provided, and each animal was exposed to the experimental diets. The position of the troughs was randomized each day to avoid “habit reflex”.

A cafeteria feeding approach described by Larbi et al. (1993) was used, thus permitting free access to the diet of their choice. A compound feed was mixed to have goats’ pellets, grass hay, and prickly pear fruit (Table 4.01 & 4.02). Prickly pear fruit was obtained from Ubali Pomegranate Farm in Pretoria. Prickly pear fruit inclusion levels were at 0,10, 20, and 30% (Table 4. 03). The experiment was conducted for 75 days (15 days for adaptation, 60 days for the feed trial, followed by 7 days of digestibility trial). The study applied the “three R principle”, which are replacement, reduction, and refinement, to ensure minimal exposure to any discomfort to goats (Balls et al., 1995; Russell and Burch, 1959). Thus, goats were well taken care of and monitored for any changes, and they were always provided with fresh feeds and water.

Table 4.01. *Nutrient composition of prickly pear (Opuntia ficus-indica)*

Nutritive value	Ensiled prickly pear (*Opuntia ficus-indica*)
Dry Matter (%)	90.40
Organic Matter (%)	91.61
Ash (%)	10.00
Crude Protein (%)	8.50
Acid detergent fibre (%)	14.40
Neutral detergent fibre (%)	24.81
Ether Extract (%)	4.50
Metabolisable energy (MJ/kg DM)	6.60

Table 4.02. *Nutritional composition of goats' pellets (%DM)*

Nutrients	Composition
Dry Matter (%)	91.70
Organic Matter (%)	91.54
Ash (%)	14.29
Crude Protein (%)	13.00
Acid detergent fibre (%)	32.24
Neutral detergent fibre (%)	51.56
Ether Extract (%)	5.01
Metabolisable Energy (MJ/kg DM)	12.00

Table 4.03. *Nutritional composition of buffalo hay grass (Cenchrus ciliaris) (%DM)*

Nutrients	Buffalo grass (*Cenchrus ciliaris*)
Dry matter (%)	93.76
Organic matter	93.4
Ash (%)	6.87
Crude protein (%)	6.75
Acid detergent fibre (%)	42.25
Neutral detergent fibre (%)	67.78
Ether extract (%)	1.75
Metabolisable energy (MJ/kg DM)	8.00

Table 4.04: *Dietary treatments for the study*

Treatment code	Treatment description
PPF_0	Yearling male Pedi goats fed *ad libitum* diet containing no ensiled prickly pear fruit
PPF_{10}	Yearling male Pedi goats fed *ad libitum* diet with 10% ensiled prickly pear fruit
PPF_{20}	Yearling male Pedi goats fed ad libitum diet with 20% ensiled prickly pear fruit
PPF_{30}	Yearling male Pedi goats fed *ad libitum* diet with 30% ensiled prickly pear fruit

Table 4.05: *Composition of feed materials in the experimental diets*

Feed	PPF$_0$	PPF$_{10}$	PPF$_{20}$	PPF$_{30}$
Ensiled Prickly pear fruit (%)	0	10	20	30
Cenchrus ciliaris Hay (buffalo grass) (%)	66	56	46	36
Goats pellets (%)	34	34	34	34
Total (%)	100	100	100	100
Analysed chemical composition (%DM)				
OM	92.77	92.59	92.41	92.23
ASH	9.39	9.71	10.02	10.33
CP	8.88	9.05	9.23	9.40
ADF	38.85	36.06	33.28	30.49
NDF	62.27	57.97	53.67	49.37
EE	2.86	3.13	3.41	3.68
ME (MJ/Kg DM)	9.36	9.22	9.08	8.94

4.2.3. Data collection

4.2.3.1 Preparation of silage

Prickly pear fruits were sourced from Ubali Pomegranate Farm in Pretoria. Prickly pears were processed to a particle size of 3 cm and ensiled in 200 L polyethylene drums. To stimulate fermentation, plastic tapes and lids were used to close polyethylene drums. After being prepared for a minimum of 60 days, it is then that the silage was used for the experiment. Silage samples were collected at the time of supplying the diets and every 15 days pH analysis was done.

4.2.3.2. Growth performance

At the commencement of the study, goats were weighed individually using an electronic weighing scale to measure changes in body weight in response to the experimental treatments. Thereafter, goats were weighed weekly, with final body weight measurements taken on the last day of the study. Live weight was used to calculate the growth rates of goats.

The average daily gain (ADG) was calculated by dividing the total weight gain by the number of days in the trial.

$$ADG = \frac{\text{Final body weight} - \text{initial body weight}}{\text{number of days}}$$

The daily amount of feed provided and the morning feed refusal were measured using an electronic weighing balance and recorded to compute the daily feed intake. Goats were provided with the diet every morning at 08:30 am, once every day until the last day of the study.

The average daily feed intake (ADFI) was then calculated by averaging the total feed consumed.

$$\text{ADFI} = \frac{\text{Feed offered} - \text{feed left overs}}{\text{number of days}}$$

Feed conversion ratio was calculated as the summation of the amount of feed ingested divided by the average daily gain of the goats:

$$\text{Feed Conversion Ratio} = \frac{Daily\ feed\ intake}{Average\ daily\ gains}$$

4.2.3.2. Methane emissions measurement

Methane emission by goats was measured daily during the collection period, measurements were done using a hand-held methane detector (Manufacture: RS PRO). The measurements for each goat were taken within 60 seconds daily and repeated for five consecutive days. The amount of methane generated was measured in parts per million meters and presented in ppm-m (Chagunda *et al*., 2009).

4.4 Data analysis

The growth performance and methane emission data were subjected to a one-way analysis of variance (ANOVA) using the Statistical Package for the Social Sciences (SPSS, 2020). The statistical significance of the difference between the means was compared by Duncan's new multiple range test. The p-value was considered significantly different at a 95% interval ($P < 0.05$).

The model $Y_{ij} = \mu + T_i + e_{ij}$ applied

Where:

Yij = response variables for performance;

μ = Overall population mean;

Ti = fixed effect of prickly pear inclusion levels;

eij = the residual (error)

4.5 Results and discussion

4.5.1 Growth Performance

Live weight, feed intake, average daily gains, feed intake, feed conversion ratio and water intake

Results on the effect of ensiled prickly pear inclusion in the diet on live weight, feed intake, average daily gains, feed intake, feed conversion ratio and water intake of Pedi indigenous goats are presented in Table 4.01 and Figures 4.01, 02, 03 and 04, respectively. Ensiled prickly pear inclusion level in the diet had no effect ($P>0.05$) on the initial live weight and feed intake of indigenous male Pedi goats. However, ensiled prickly pear inclusion in the diet had a significant effect ($P<0.05$) on final weight, average daily gains, feed conversion ratio and water intake of indigenous male Pedi goats. Male on-descript indigenous goats fed 30% ensiled prickly pear meal inclusion level had higher ($P<0.05$) final weights than those fed 0, 10 and 20% ensiled prickly pear inclusion levels. Similarly, goats fed 10 and 20% ensiled prickly pear inclusion levels had higher ($P<0.05$) final live weights than those fed 0% ensiled prickly pear inclusion level. However, indigenous male Pedi goats fed 10 and 20% ensiled prickly pear inclusion levels had similar ($P>0.05$) final live weights. The results of this study are contrary to

Salem et al. (2019), who reported that cactus had no effect on live weight in goats during the breeding season. Similarly, Zouaghi et al. (2009) reported that in growing goat kids, after 12 weeks of experimentation period, live weight was similar for all groups that were subjected or not to the incorporation of cactus on their diets. However, the results of this study are in agreement with the results of Flores-

Hernandez et al. (2019) who reported that fermented cactus had an effect on final live weights. Fermented cactus pear significantly improved the final live weights of Dorper lambs (Flores-Hernandez et al., 2019).

Indigenous male Pedi goats fed a 30% ensiled prickly pear meal inclusion level had higher ($P<0.05$) average daily gains than those fed 0, 10, and 20% ensiled prickly pear inclusion levels. Similarly, goats fed 10 and 20% ensiled prickly pear inclusion levels had higher ($P<0.05$) average daily gains than those fed 0% ensiled prickly pear inclusion level. However, indigenous male Pedi goats fed 10 and 20% ensiled prickly pear inclusion levels had similar ($P>0.05$) average daily gains. The results are in agreement with the study of Araújo et al. (2022), who reported that cactus meal had a significant effect on average daily gains. Araújo et al. (2022) reported that 33% cactus meal had improved daily average gains of crossbred Boer goat kids. However, the results of our study are contrary to the results of Albuquerque. et al (2020), who reported that goats fed cactus pear silage had no significant effect on average daily gains of goats. Furthermore, Albuquerque et al. (2020) reported that the goats had similar average daily gains of 76g/day, which is lower than the expected 100g/day according to the recommendations of the NRC. Similarly, in the sheep breed, there was no significant effect on average daily gains in Tigray highland sheep fed cactus meal (Gebretsadik et al., 2024). Gebretsadik et al. (2024) further stated that the average daily gain (58.10 - 67.20 g/day) was comparable with the previous reports by Tikabo et al. (2006) and Amare et al. (2009) for the same sheep breed.

The results of the current study indicated that ensiled prickly pear inclusion levels had no effect ($P>0.05$) on the feed intake of indigenous male Pedi goats. The results of this study are in agreement with the results of Shiningavamwe (2009), who reported that opuntia-based diets had no effect on feed intake in Dorper lambs. However, in contrary to the results of our study, Atti et al. (2009) observed that cactus had a significant effect on feed intake in goat kids. According to Atti et al. (2009), spineless cactus improved the feeding intake of male goat kids.

Male indigenous goats fed 0 and 20% ensiled prickly pear meal inclusion levels had a higher ($P<0.05$) feed conversion ratio than those fed 10 and 30% ensiled prickly pear inclusion levels. Similarly, goats fed 10% ensiled prickly pear inclusion levels had a higher ($P<0.05$) feed conversion ratio than those fed 30% ensiled prickly pear inclusion level. However, indigenous male Pedi goats fed 0 and 20% ensiled prickly pear inclusion levels had similar ($P>0.05$) feed conversion ratios. The results of this study are in agreement with the results of Taddesse et al. (2014), who reported that supplementation of cactus significantly improved the feed conversion ratio of Somali goats. Similarly, in sheep breeds, Cardoso et al. (2019) reported that increasing levels of spineless cactus improved the feed conversion ratios of lambs.

Male indigenous goats fed 0% ensiled prickly pear meal inclusion level had higher ($P<0.05$) water intake than those fed 10, 20 and 30% ensiled prickly pear inclusion levels. Similarly, goats fed 10% ensiled prickly pear inclusion levels had higher ($P<0.05$) water intake than those fed 20 and 30% ensiled prickly pear inclusion levels. Similarly, indigenous male Pedi goats fed 20% ensiled prickly pear inclusion levels had higher ($P<0.05$) water intake than those fed 30% ensiled prickly pear inclusion level. The results of this study are in agreement with the results of Costa et al. (2019), who reported that cactus supplementation had a significant effect on water intake in goats. A negative relationship was observed between cactus inclusion levels and water intake in a diet of dairy goats (Costa et al., 2019). Similarly, in sheep breeds, Shruthilaya et al. (2022) reported a negative relationship between cactus inclusion levels and water intake in Nellore lambs. The water intake results in the current study suggest that there is the are high concentrations of water in the cellular contents of the prickly pear; therefore, cactus pear may be an important source of water for animals in seasons of water scarcity (Neto et al., 2016 and Araújo, 2015). According to Albuquerque et al. (2020), cactus pear silage inclusion at up to 42% for goats is recommended during periods of water shortage in semi-arid and arid regions because it improves the eating and ruminating efficiency rates and body water retention and reduces drinking water ingestion without affecting the performance or health of the animal.

Table 4.06: *Effect of ensiled prickly pear inclusion in the diet on live weight, feed intake, average daily gains, feed intake, feed conversion ratio and water intake of Pedi indigenous goats*

Variables	Treatment#					
	PPF_0	PPF_{10}	PPF_{20}	PPF_{30}	SEM	P-value
Initial weight (kg)	13.47^a	13.77^a	14.33^a	14.71^a	0.462	0.1007
Final weight (kg)	15.57^b	16.40^{ab}	16.47^{ab}	17.67^a	0.452	0.0114
ADG (g/day)	60.29^b	75.24^{ab}	61.14^{ab}	84.48^a	3.786	0.0005
Feed Intake (g/day)	336.67^a	370.00^a	340.00^a	383.33^a	19.582	0.1147
FCR	5.59^a	4.97^{ab}	5.57^a	4.55^b	0.301	0.0232
Water intake (L/day)	2.74^a	2.47^{ab}	2.15^b	1.32^c	0.087	<0.0001

a, b, c : Means with different superscripts in the same row indicate significant differences between treatments ($P<0.05$)

FCR: Feed Conversion Ratio; ADG: Average Daily Gain

#: Diet codes are explained in Table 4.04, Chapter 4

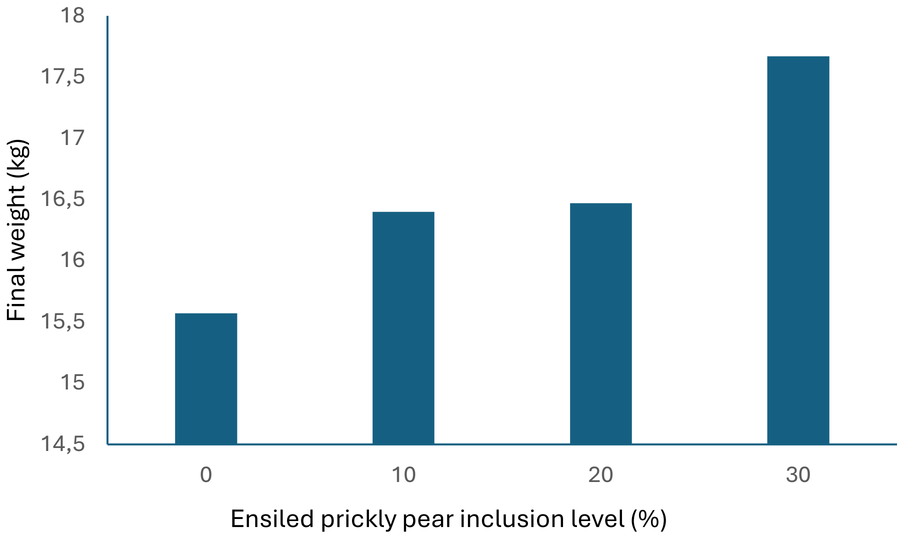

Figure 4.01: *The relationship between ensiled prickly pear inclusion level in the diet and final weight of indigenous male Pedi goats.*

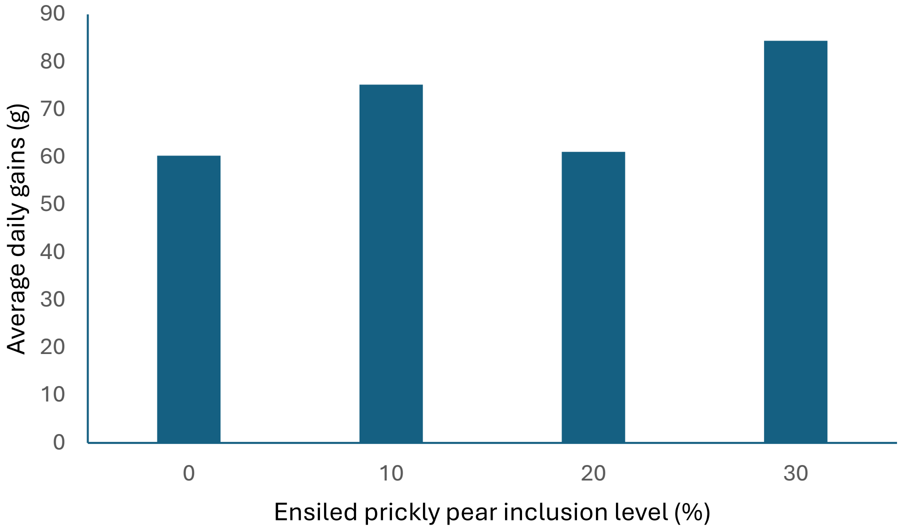

Figure 4.02: *The relationship between ensiled prickly pear inclusion level in the diet and average daily gains of indigenous male Pedi goats.*

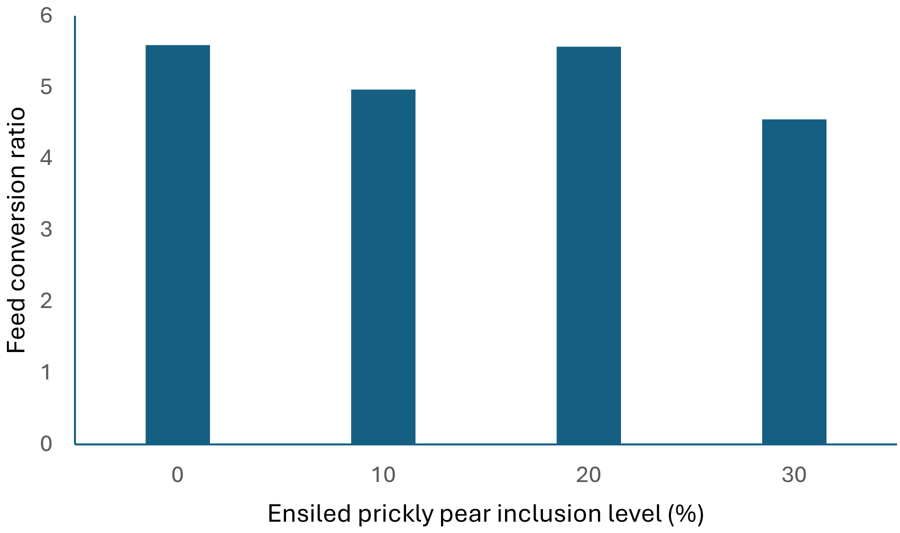

Figure 4.03: *The relationship between ensiled prickly pear inclusion level in the diet and feed conversion ratio of indigenous male Pedi goats*.

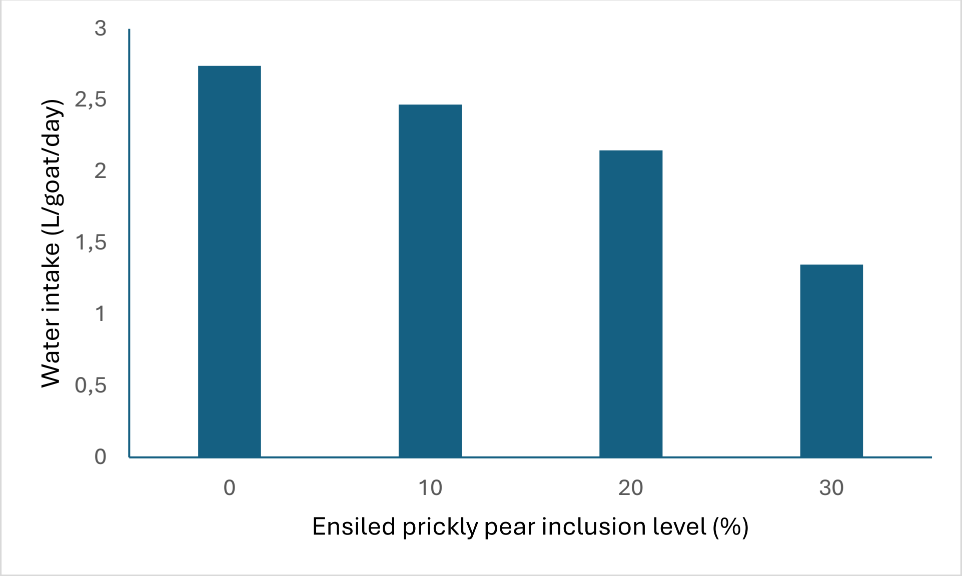

Figure 4.04: *The relationship between ensiled prickly pear inclusion level in the diet and water intake of indigenous male Pedi goats.*

4.5.2 Digestibility

Results on the effect of ensiled prickly pear inclusion in the diet on intake, nutrient intake and digestibility of Pedi indigenous goats are presented in Table 4.02 and Figures 4.05-4.17, respectively. Ensiled prickly pear inclusion level in the diet had an effect ($P<0.05$) on the dry matter, organic matter, ash, crude protein, acid detergent fibre, neutral detergent fibre, ether extract, and energy intake of indigenous male Pedi goats. Vieira *et al.* (2008) observed significant differences in dry matter intakes of Alpine goats and reported that the dry matter intakes were maximized at intermediate spineless cactus inclusion levels of 250g/kg while intakes of organic matter, crude protein, and neutral detergent fibre increased linearly. In sheep, Nobre *et al.* (2023) reported significant differences in dry matter, organic matter, crude protein, and ether extract in lambs fed cactus pear silage. Costa *et al.* (2012) reported increased dry matter and nutrient intakes with increasing levels of cactus pear in the diet of Santa Inés lambs. Similarly, Cardoso *et al*. (2019) found enhanced intakes of dry matter and nutrients (organic matter, crude protein, and ether extract) with increasing inclusion levels of spineless cactus in the diet of lambs. A significant effect was also observed on the intakes of dry matter and nutrients (organic matter, crude protein and neutral detergent fibre) in sugar cane-based Santa Inés lambs in which wheat bran was replaced by different levels of spineless cactus (0, 25, 50, 75, and 100%) (Lins *et al*., 2016). Dry matter intake is an important factor in the performance of animals, being considered the determining point of the supply of nutrients necessary to meet the requirements of maintenance and weight gain of the animals (McGrath *et al*., 2018). Goats' body weight, the type and quality of the feed, the amount provided, the breed, and the feed's palatability are some of the variables that might affect how much feed they consume (Berhe *et al*., 2024). Han *et al.* (2019) emphasized that palatability plays a significant role in determining feed consumption in livestock. The dietary neutral detergent fibre content, which is known for its slow degradation and low rate of passage through the rumen, is considered to be limiting (Berhe *et al*., 2024). Small ruminants' intake and digestion of roughages are greatly influenced by the fibre content, particularly the neutral detergent fibre (Mertens, 2002; Harper and Mcneill, 2015). The neutral detergent fibre intake of goats in this present study increased linearly with increasing ensiled prickly pear from 10% to 30% inclusion levels in the experimental diet, which is similar to the finding of Costa *et al*. (2012).

The results of the current study indicated that ensiled prickly pear had no effect (P>0.05) on dry matter, organic matter, crude protein, and ether extract digestibility of male t indigenous goats. The results of our study are contrary to those of Costa *et al*. (2022), who reported that the coefficients of digestibility of the DM, OM, and CP increased linearly with increasing levels of cactus pear in the diet of Santa Inês lambs. However, the results of our study are in agreement with Gebretsadik *et al*. (2024), who observed that cactus pear meal had no effect on dry matter, organic matter, and ether extract digestibility of sheep. The dry matter digestibility of the present study is in accordance with the findings of Einkamerer *et al*. (2009) and Sahoo *et al*. (2016) for sheep fed diets containing cactus. Similar to the findings of the current study, Thakuria (2021) reported that edible spineless cactus did not affect the ether extract digestibility of male goat kids. The results of our study are in agreement with Manhume *et al.* (2021), who observed that spineless cactus did not affect crude protein digestibility of male goats.

The results of the current study indicated that ensiled prickly pear had an effect (P<0.05) on ash digestibility of male indigenous goats. At 30% ensiled prickly pear inclusion level, the highest ash digestibility was observed and at 0% ensiled prickly pear inclusion level, the lowest ash digestibility was observed. The results of this study are in agreement with Rakotoarivonona *et al.* (2022), who observed that crushed red cactus had an effect on ash digestibility of goats.

The results of the current study indicated that ensiled prickly pear had an effect (P<0.05) on neutral detergent fibre digestibility of male indigenous goats. The results of this study are in agreement with Araujo *et al*. (2022), who observed that cactus pear silage had an effect on neutral detergent fibre digestibility in lambs. However, the results of our study are contrary to those of Costa *et al.* (2012), who observed that cactus pear had no effect on neutral detergent fibre digestibility of Santa Inés lambs. Similarly, Maciel *et al*. (2019) observed that spineless cactus had no effect on neutral detergent fibre digestibility of sheep.

The results of the current study indicated that ensiled prickly pear had an effect (P<0.05) on acid detergent fibre digestibility of male indigenous goats. The results of this study are in agreement with Shruthilaya *et al.* (2022), who observed that cactus had an effect on acid detergent fibre digestibility of Nellore lambs. However, the results of our study are contrary to the results of Thakuria *et al*. (2021), who reported that edible spineless cactus had no effect on the dry matter of male goat kids. Gebremariam *et al.* (2006) observed that the digestibility coefficients for acid detergent fibre, crude protein, and neutral detergent fibre decreased as the quantity of cactus increased in the diet. In a similar way, the digestibility coefficients of acid detergent fibre, crude protein, and neutral detergent fibre in this present study decreased as the level of cactus cladodes increased from 10% to 30%.

Table 4.07: *Effect of ensiled prickly pear inclusion in the diet on dry matter, ash, crude protein, ether extracts, gross energy, neutral detergent fibre, acid detergent fibre digestibility of Pedi indigenous goats.*

	Treatment#					
Variables	PPF_{0}	PPF_{10}	PPF_{20}	PPF_{30}	SEM	P-value
			Diet intake (g/goat/day)			
DM	336.67^{a}	370.00^{a}	340.00^{a}	383.33^{a}	19.582	0.1147
OM	303.00^{a}	334.38^{b}	307.48^{cc}	345.00^{a}	2.636	<.0001
Ash	28.16^{a}	29.02^{a}	28.94^{a}	28.76^{a}	0.474	0.3234
CP	22.47^{a}	23.17^{a}	23.10^{a}	22.96^{a}	0.378	0.3176
ADF	38.07^{a}	39.24^{a}	39.14^{a}	38.89^{a}	0.641	0.3172
NDF	65.59^{a}	67.62^{a}	67.43^{a}	67.00^{a}	1.104	0.3165
EE	11.90^{a}	12.26^{a}	12.23^{a}	12.15^{a}	0.200	0.3230
Energy (MJ/day)	4.68^{a}	4.85^{a}	4.89^{a}	4.92^{a}	0.080	0.0588
			Intake (g/kgW$^{0.75}$)			
DM	39.26^{b}	41.12^{bb}	39.66^{bb}	44.35^{a}	0.679	0.0003
OM	35.31^{cc}	37.28^{b}	35.29^{c}	40.43^{a}	0.613	<.0001
Ash	10.57^{a}	12.62^{b}	14.62^{c}	15.98^{d}	0.224	<.0001
CP	10.79^{c}	12.90^{b}	15.79^{a}	16.41^{aa}	0.233	<.0001

ADF	19.35^{c}	17.50^{d}	22.57^{b}	24.18^{a}	0.347	<.0001
NDF	26.79^{b}	24.58^{c}	28.23^{bb}	30.10^{a}	0.454	<.0001
EE	9.02^{a}	7.00^{b}	5.59^{d}	6.37^{c}	0.117	<.0001
Energy (MJ/kg W$^{0.75}$)	0.73^{b}	0.61^{c}	0.44^{d}	1.25^{a}	0.013	<.0001
Digestibility						
DM	87.95^{a}	88.87^{a}	85.52^{a}	89.18^{a}	1.450	0.1227
OM	87.75^{a}	88.30^{a}	85.27^{a}	88.73^{a}	1.444	0.1542
Ash	13.41^{c}	14.55^{b}	15.08^{bb}	16.45^{a}	0.246	<0.0001
CP	85.72^{a}	85.95^{a}	83.27^{a}	86.72^{a}	1.409	0.1606
ADF	47.17^{b}	49.64^{ab}	50.15^{a}	51.82^{a}	0.889	0.0033
NDF	54.03^{b}	53.32^{c}	53.53^{cc}	54.71^{a}	0.820	<.0001
EE	4.57^{a}	4.79^{a}	4.28^{a}	4.14^{a}	0.073	0.4543
Energy (MJ/kg W$^{0.75}$)	2.02^{c}	2.28^{b}	2.29^{bb}	2.42^{a}	0.037	<.0001

a, b, c : Means with different superscripts in the same row indicate significant differences between treatments ($P<0.05$)

DM: Dry matter, OM: Organic matter, CP: Crude protein, ADF: Acid detergent fibre, NDF: Neutral detergent, EE: Ether extract

#: Diet codes are explained in Table 4.04, Chapter 4

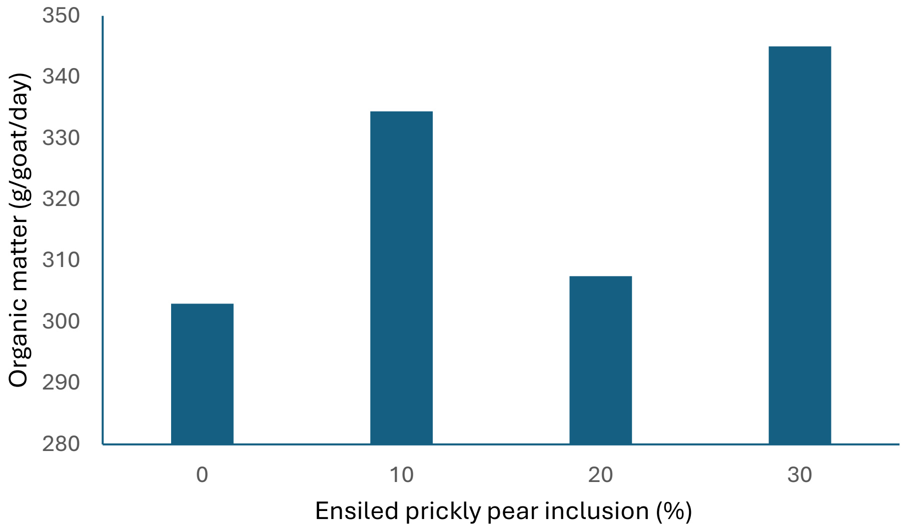

Figure 4.05: *The relationship between ensiled prickly pear inclusion levels in the diet and organic matter intake of indigenous male Pedi goats.*

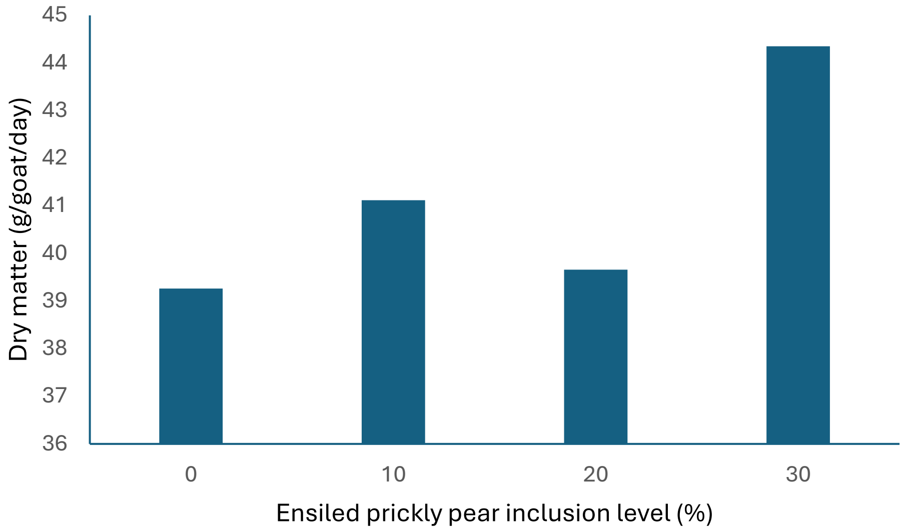

Figure 4.06: *The relationship between ensiled prickly pear inclusion levels in the diet and dry matter intake of indigenous male Pedi goats.*

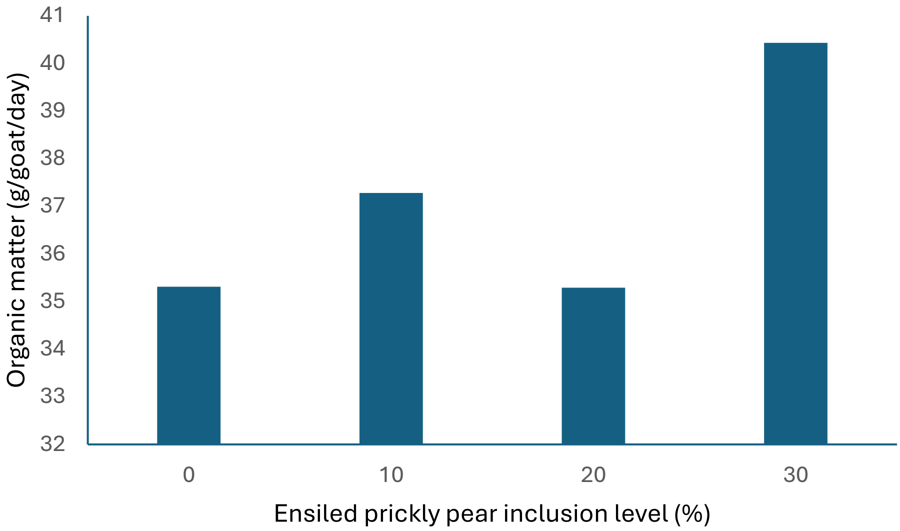

Figure 4.07: *The relationship between ensiled prickly pear inclusion levels in the diet and organic matter intake of indigenous male Pedi goats.*

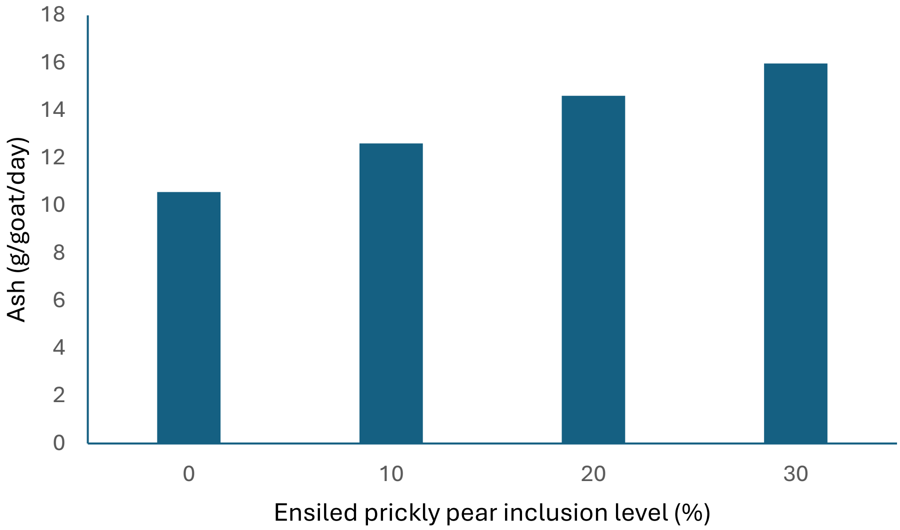

Figure 4.08: *The relationship between ensiled prickly pear inclusion levels in the diet and ash intake of indigenous male Pedi goats.*

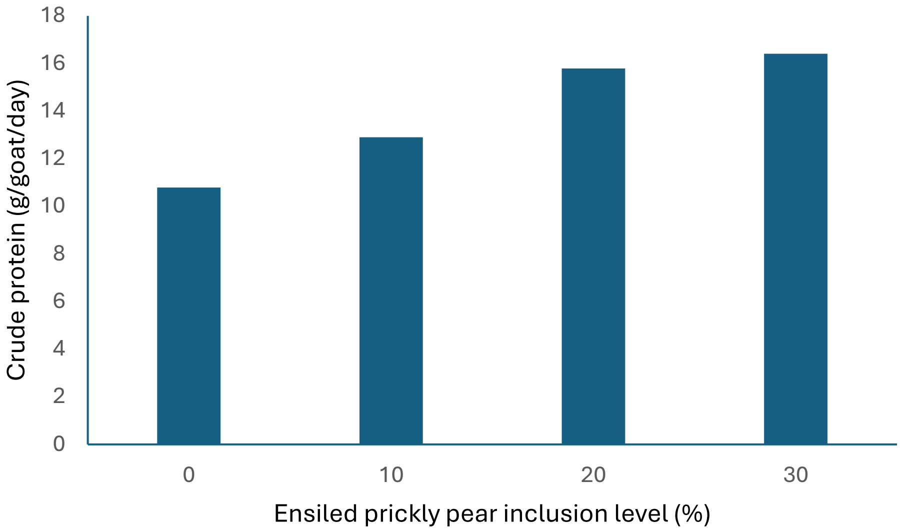

Figure 4.09: *The relationship between ensiled prickly pear inclusion levels in the diet and crude protein intake of indigenous male Pedi goats.*

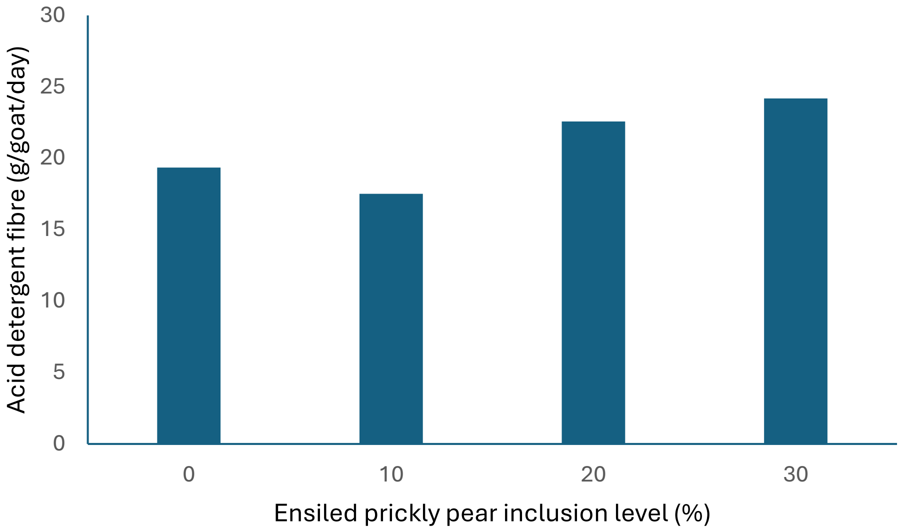

Figure 4.10: *The relationship between ensiled prickly pear inclusion levels in the diet and acid detergent fibre intake of indigenous male Pedi goats.*

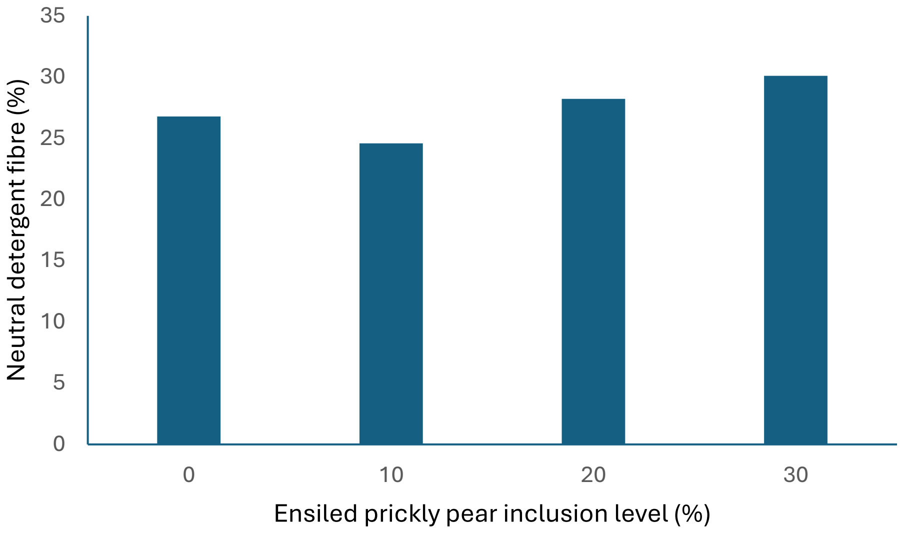

Figure 4.11: *The relationship between ensiled prickly pear inclusion levels in the diet and neutral detergent fibre intake of indigenous male Pedi goats.*

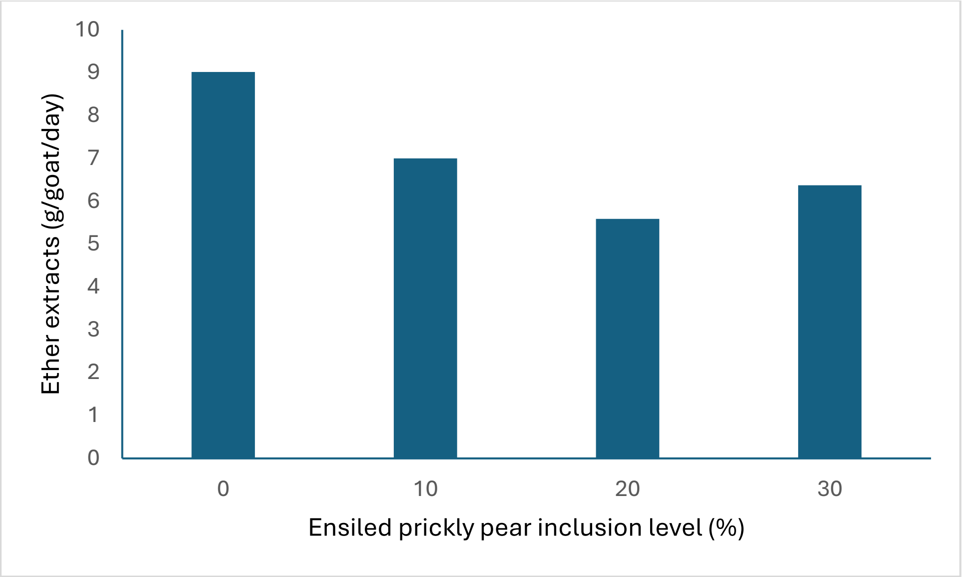

Figure 4.12: *The relationship between ensiled prickly pear inclusion levels in the diet and ether extract intake of indigenous male Pedi goats.*

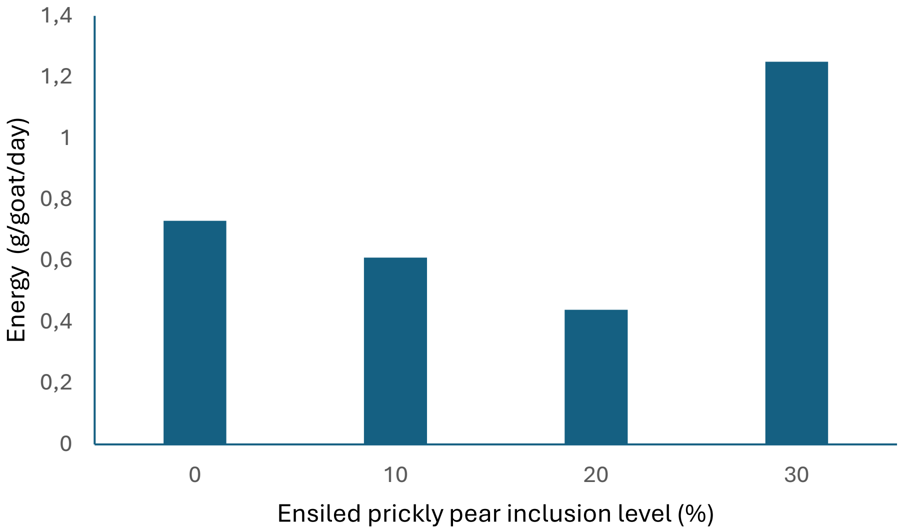

Figure 4.13: *The relationship between ensiled prickly pear inclusion levels in the diet and energy intake of indigenous male Pedi goats.*

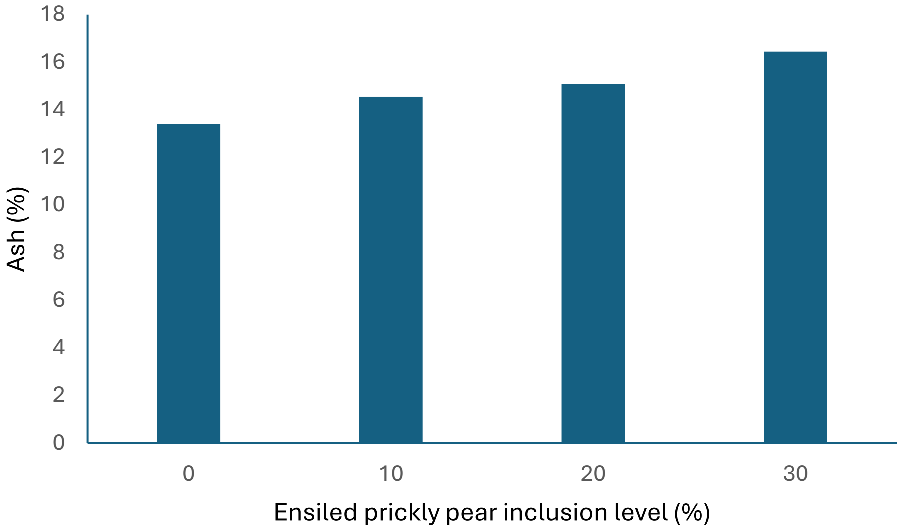

Figure 4.14: *The relationship between ensiled prickly pear inclusion levels in the diet and ash digestibility of indigenous male Pedi goats.*

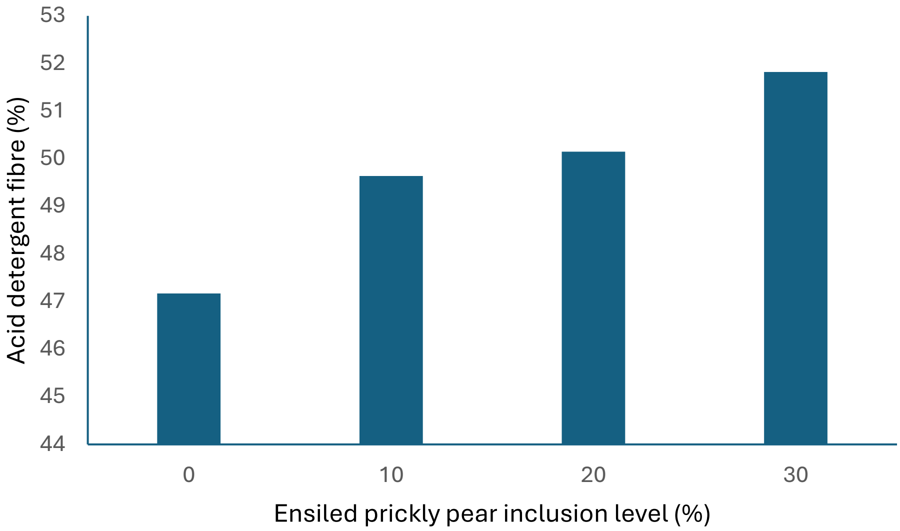

Figure 4.15: *The relationship between ensiled prickly pear inclusion levels in the diet and acid detergent fibre digestibility of indigenous male Pedi goats.*

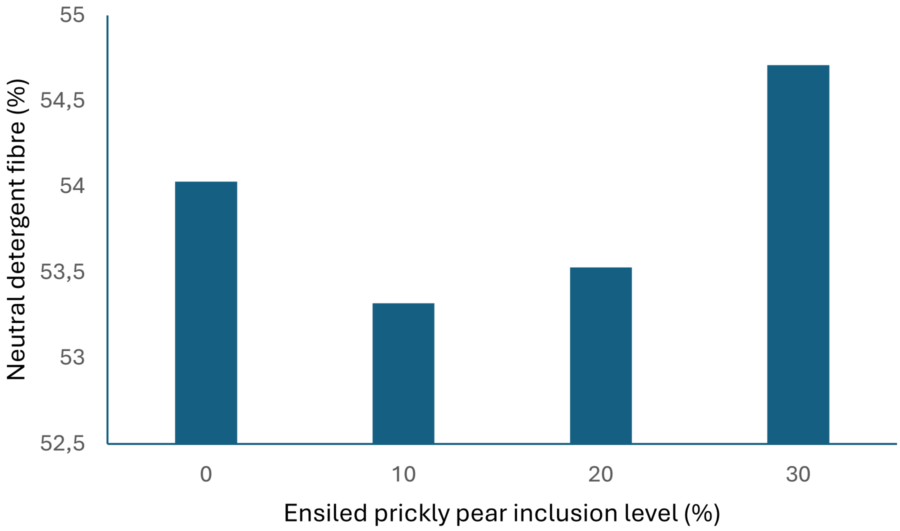

Figure 4.16: *The relationship between ensiled prickly pear inclusion levels in the diet and neutral detergent fibre digestibility of indigenous male Pedi goats.*

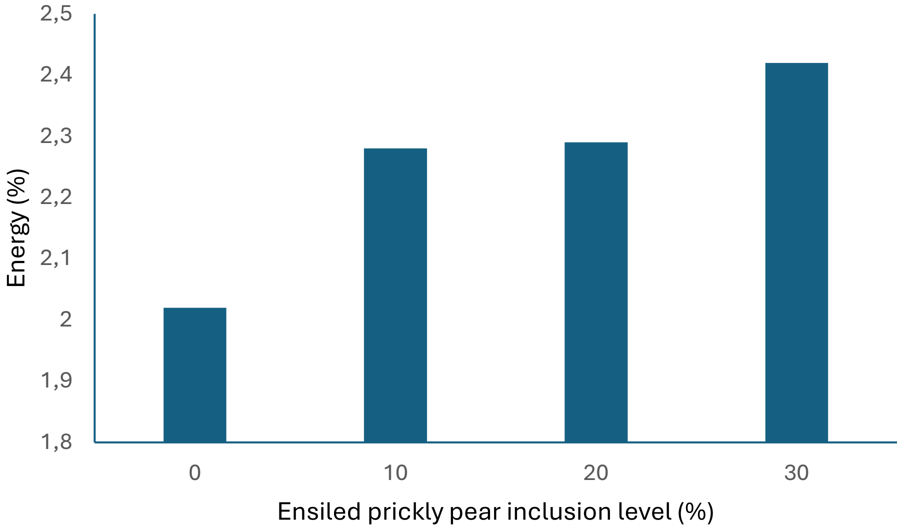

Figure 4.17: *The relationship between ensiled prickly pear inclusion levels in the diet and energy digestibility of indigenous male Pedi goats.*

4.7 Conclusion

In conclusion, these findings highlight the potential of ensiled prickly pear as a valuable feed resource for improving goat productivity while addressing environmental and water scarcity challenges. The inclusion of ensiled prickly pear in the goat's diet improved growth performance, water intake, and methane emission without negative impact on the goats.

The results of this study demonstrate that ensiled prickly pear inclusion levels significantly influence growth performance in indigenous male Pedi goats. A 30% inclusion level yielded the highest final live weight and average daily gains, while the lowest values were observed at 0% inclusion. These findings highlight the positive impact of fermented cactus on goat performance. The feed intake and feed conversion ratio were not significantly affected by ensiled prickly pear inclusion. Water intake, however, showed a significant negative relationship with ensiled prickly pear inclusion, supporting the notion that cactus serves as an alternative water source in arid and semi-arid regions. This suggests that ensiled prickly pear can be particularly beneficial in water-scarce environments.

Lastly, methane emissions were significantly reduced with increasing levels of prickly pear inclusion, with the lowest emissions observed at 30% inclusion. These findings indicate that ensiled prickly pear could serve as a sustainable dietary strategy for mitigating methane emissions in goats, potentially contributing to environmental conservation efforts.

4.8 References

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CHAPTER 5: UTILISATION OF PRICKLY PEAR ON BLOOD METABOLITES, AND MEAT QUALITY OF PEDI GOATS

Abstract

The study was conducted to determine the effect of prickly pear (*Opuntia ficus-indica*) levels in the diet on blood metabolites and meat quality of Pedi goats. A total number of 24 Pedi goats were randomly assigned to 4 treatments in a completely randomized block design, with three replications and 2 goats per replicate, thus six goats per treatment. Prickly pear inclusion levels were at 0,10, 20, or 30%. Goats were raised for a period of 75 days (15 days for adaptation, 60 days for the feed trial, including 7 days of digestibility trial). The data collected were subjected to analysis of variance using Statistical Package for the Social Sciences (SPSS). Prickly pear inclusion levels in a diet had no effect (P>0.05) on blood profiles of male Pedi goats. However, prickly pear inclusion levels in diet had a significant effect (P<0.05) on slaughter weight, hot carcass weight, cold carcass weight, initial pH (45 minutes post slaughter) and drip loss of male Pedi goats. Male Pedi goats fed prickly pear at an inclusion level of 30% had higher (P<0.05) hot carcass weight than those fed 0, 10 and 20% prickly pear inclusion levels. Prickly pear inclusion levels in a/the diet had no effect (P>0.05) on dressing percentage, final pH (24 hours post-slaughter), cooking loss and shear force of male Pedi goats. Similarly, prickly pear inclusion levels had no effect (P>0.05) on yellowness, redness and lightness of male Pedi goats. Prickly pear inclusion levels in the diet had no effect (P>0.05) on tenderness of male Pedi goats. However, prickly pear inclusion in the diet had a significant effect (P<0.05) on the total content of saturated fatty acids, monounsaturated fatty acids, and polyunsaturated fatty acids in the meat of male Pedi goats. Similarly, prickly pear inclusion levels in the diet had an effect (P<0.05) on juiciness, flavour, and overall acceptability of male Pedi goats. Male Pedi goats fed prickly pear at an inclusion level of 30% had higher (P<0.05) juiciness than those fed 0, 10, and 20% prickly pear inclusion levels. Therefore, it can be concluded that ensiled prickly pear can be included in diets to improve the meat quality of goats. An inclusion level of 30% prickly pear is recommended for improving meat quality without adversely affecting blood metabolites in male Pedi goats.

Keywords: goat productivity, blood profile, water scarcity, fatty acids, meat quality, indigenous goats

5.1 Introduction

Semi-arid and arid regions around the world are normally home to large numbers of flocks of small ruminants subjected to water shortages, which are increasingly intensified by the effects of climate change (de Lima Cruz *et al*., 2023). Nonetheless, small ruminants' productivity is normally affected by physiological and behavioral changes in response to hot environments and water scarcity (Joy *et al*., 2020). Agricultural production in southern Africa is quite likely to be reduced due to the climate change scenario (Scholes and Engelbrecht, 2021). This is due to the fact that the southern Africa region is already above the optimal temperature for most livestock and crop or forage production (Scholes and Engelbrecht, 2021), and climate change effects, such as changes in rainfall patterns, are aggravating the challenge of water shortage in the region. Thus, alternatives that alleviate the challenges of water scarcity in regions with low and irregular rainfall should be studied, in addition to the difficulty of accessing water sources. In South Africa, 50% of the indigenous goat population is kept under small-scale conditions (Ng'ambi *et al*., 2013). In most parts of rural areas of Limpopo & Eastern Cape provinces of South Africa, goats are among the major socio-economically critical livestock species (Mataveia *et al*., 2021). Several studies have shown that moderate water restriction does not result in considerable changes in the productivity, blood profiles and carcass and meat patterns of small ruminants (Campos *et al*., 2017; dos Santos *et al*., 2019). Blood parameters are critical indicators of an animal's health, immune function, and metabolic response to dietary changes. Blood biochemical parameters are essential in revealing an animal's health status and pathophysiological state (Piotrowska *et al*., 2011; Minias, 2015). Analysis of blood can be used to determine the nutritional, physiological, and pathological status of an animal (Dos Santos Schmit *et al*., 2009; Odunitan-Wayas *et al*., 2018).

The availability of water through feeds can be used to mitigate the effects of water scarcity. Another way is through the adoption of moist feeds in the diet of ruminants; amongst them is the prickly pear (*Opuntia ficus-indica*), which is a drought-tolerant crop with low maintenance requirements. Several researchers have found that diets based on prickly pear have the potential to cover the water needs of small ruminants such as goats, particularly during the dry season (Matias *et al*., 2020; do Souza *et al*., 2020; Sipango *et al*., 2022; Majdoub *et al*., 2010). Prickly pear cactus can be used as forage for goats, and in some cases can provide more than 35% of the daily crude protein requirements for goats (Shaw, 2017). The importance of prickly pear as a feed for ruminants has been noted globally, especially in semi-arid areas where rainfall is erratic (Rodrigues *et al*., 2016; Abay, 2018). The use of indigenous Pedi goats is justified by their prevalence in Limpopo and their adaptability to local climatic and nutritional conditions. They are genetically adapted to harsh environments and are commonly kept by rural farmers, making them ideal subjects for evaluating alternative feeding strategies. However, the information on the effect of prickly pear fruit meal inclusion level on blood metabolites and meat quality of yearling indigenous goats is limited and inconclusive. Therefore, the objective of the study was to investigate the effect of prickly pear fruit meal inclusion level on blood metabolites and meat quality of yearling male Pedi goats.

5.2 Materials and Methods

5.2.1 Study site

Refer to Section 4.2.1.

5.2.2 Experimental procedures, dietary treatments and design

Refer to Section 4.2.2

5.2.3 Data collection

5.2.3.1 Blood haematology

A total of five mls of blood was collected from the jugular vein of 2 goats per replicate (thus 6 goats per treatment) to assess haematological parameters. Blood samples (5 mls) were drawn using hypodermic needles (21-gauge) and then immediately transferred into marked sterile tubes, which contained ethylenediaminetetraacetic acid (EDTA), which served as an anticoagulant.

Permitted to coagulate at ambient temperature, serum analysis blood samples were collected in anticoagulant tubes, and then centrifuged for 10 minutes at 1500 x g. The total blood cell count was determined in an improved Neubauer hemocytometer (Merck Sigma-Aldrich).

5.2.3.2 Meat part weights and meat pH

At the end of the experiment, goats were transported in a well-ventilated truck to “Vencor holdings” commercial abattoir 45 km from the experimental site. The truck had a floor space of 0.4 m² per goat, a non-slip floor with proper drainage, and was protected from the sun and rain (Livestock Welfare Coordinating Committee, 2018). Three goats from each treatment were randomly selected. The goats were given a rest period of 24 hours before being slaughtered (Chambers *et al.*, 2001). This was to prevent the results of the study being affected by the animals not having enough rest period before being slaughtered. Goats were electrically stunned (200V applied for 4 seconds) and slaughtered by exsanguination after 16 h off feed, with access to water only. After slaughtering, the carcasses were classified based on the South African Meat Industry Company (2006) by assessing age, fatness, and conformation. The carcasses were immediately weighed to obtain hot carcass weights. The dressing percentage was calculated using this formula:

$$Dressing\ (\%) = \frac{Hot\ carcass\ weight}{live\ weight} \times 100$$

The carcasses were chilled at 7 to 0 degrees Celsius for 24 h and weighed again to determine the cold carcass weight. The whole left longissimus thoracis et lumborum (LTL) muscle of each goat was excised for meat quality analyses.

The pH (Crison PH25 pH meter, Lasec, South Africa) values were measured on the longissimus thoracis et lumborum (LTL) muscle between the 12th and 13th ribs, 45 min, and 24 h post-slaughter.

5.2.3.3 Meat colour and drip loss

Colour measurements were performed directly on the meat surface after bleeding for 6 minutes. Lightness (L*), redness (a*) and yellowness (b*) parameters were recorded using the Hunter Lab test three times at different locations.

The drip loss sample was divided into two equal portions, weighed, and suspended in an inflated plastic bag. Drip loss was estimated as a percentage ratio of weight loss to initial weight after meat samples were stored for 24 h at 4°C in a refrigerator (Honikel, 1998).

5.2.3.4 Cooking loss

For cooking loss determination, meat samples were weighed, held in plastic bags and then immersed in a water bath at 80°C for 60 min to have a meat internal temperature of 75 °C. The bags were cooled at 4°C and blotted dry with paper towels, without any added pressure, and re-weighed. The cooking loss was calculated as the percentage of the difference in weight before and after cooking (Honikel, 1998). The cooking loss percentage was calculated as follows:

$Cooking\ Loss\ (\%) = \frac{W0-W1}{W0} \times 100$, where W_0 and W_1 were the weights before and after cooking, respectively.

5.2.3.5 Meat shear force

The cooked samples were used to determine meat shear force. A minimum of six cylinders from each meat sample were removed in the direction of the muscular fibres using a sharp, stainless steel 1.27 cm diameter borer. Then analysed for shear force using a V-shaped, 1-mm thick Warner Bratzler cutting blade attached to an Instron 3344 (Universal) equipped.

5.2.3.6 Fatty acid analyses

For fatty acid analyses, intramuscular lipids were extracted from LTL samples using a mixture of chloroform: methanol (2:1, v/v) according to Folch *et al.* (1957). Aliquots of muscle lipids (10 mg) were methylated separately using acid (5% methanolic HCl) and base (0.5 N sodium methoxide) reagents (Kramer *et al.,* 2008). An internal standard, 1 ml of 1 mg c10-17:1 methyl ester/ml toluene (standard no. U-42M from Nu-Check Prep Inc., Elysian, MN, USA), was added before the addition of methylating reagents. Fatty acid methyl esters (FAME) were analysed using the gas chromatography (GC) and silver-ion high-performance liquid chromatography methods outlined by Cruz-Hernandez *et al.* (2004), except t-18:1 isomers that were analysed using two complementary GC temperature programs as described by Kramer *et al.* (2008). The FAME was quantified using chromatographic peak area and internal standard-based calculations. Individual fatty acids were reported as a percentage of the total fatty acids identified.

5.2.3.7 Sensory attributes

Sensory evaluation was done according to Meilgaard *et al.* (1999). A sensory profile in which seven trained judges were asked to indicate the perceived intensity of flavour, juiciness and firmness characteristics was carried out on left LTL muscle. Flavour intensity was evaluated on a scale of 0 to 5, while texture characteristics (tenderness and juiciness) were evaluated on a scale of 0 to 5 (Table 5.01). At each of the seven sessions, each judge was given a sample from both the short loin and the leg for the evaluation of flavour, while juiciness and firmness were assessed from a sample from the rack only. All the judges were trained on making inferences and recording the scores for each sample. All participants received instructions on drawing conclusions and recording the results for each sample. There was a 5-minute waiting period between each meat sample tasting. To reduce the crossover effects, the judges rinsed their mouths out with water after each sample before tasting the next one (Xazela *et al.,* 2011).

Table 5.01: *Evaluation scores to be used by sensory panel*

	Meat			
Score	Tenderness	Juiciness	Flavour	Overall acceptability
1	Too tough	Much too dry	Very bad flavour	Strong dislike
2	Tough	Dry	Poor flavour	Dislike
3	Neither too tough nor tender	Neither too dry nor juicy	Neither bad nor good flavour	Neither dislike nor like
4	Tender	Juicy	Good flavour	Like
5	Too tender	Too juicy	Very good flavour	Strongly like

Source: Palvelkovà *et al.* (2013)

5.2.4 Data Analysis

Data was analysed using analysis of variance (ANOVA) to determine the effect of dietary prickly pear inclusions on Pedi goats. The data collected were subjected to analysis of variance using the Statistical Package for the Social Sciences (SPSS). Means were considered different when P<0.05, the treatment means were separated using Tukey's (HSD) test at P<0.05. The fit was performed by using nonlinear regression by means of PROC NLIN. The statistical model was:

$Y_{ij} = \mu + T_I + \beta_j + e_{ij}$ where:

Yij = response variables (blood haematology or meat quality)

μ = overall population mean

T_i = fixed effect of prickly pear inclusion levels (0, 10, 20, 30%)

e_{ij} = the residual (error).

5.3. Results and Discussion

5.3.1 Blood hematology

Results on the effect of ensiled prickly pear inclusion in the diet on blood profiles of indigenous male Pedi goats are presented in Table 5.02. Ensiled prickly pear inclusion in the diet had no effect (P>0.05) on blood profiles of indigenous male Pedi goats. The results of the current study indicated that prickly pear did not affect the blood haematology of male Pedi goats. The results of our study are in agreement with the results of Albuquerque et al. (2020), who observed that cactus pear silage had no significant effect on blood metabolites of crossbred goats subjected to an intermittent water supply. Similarly, in sheep, Morshedy et al. (2020) reported that prickly pear cactus peel supplementation did not affect blood haematological parameters in lambs.

Table 5.02: *Effect of ensiled prickly pear inclusion levels in the diet on blood profiles of indigenous male Pedi goats.*

	Treatment#					
Variables	PPF_0	PPF_{10}	PPF_{20}	PPF_{30}	SEM	P-value
RBCC (x10^12/L)	15.78^a	13.68^a	14.42^a	14.73^a	7.044	0.9922
Haemoglobin (g/dL)	10.55^a	13.37^a	11.90^a	11.43^a	2.959	0.8124
Haematocrit (%)	38.67^a	33.37^a	38.92^a	38.15^a	9.098	0.9160
MCV	17.87^a	28.30^a	31.28^a	30.93^a	6.886	0.2373

(fL)						
RCDW (%)	40.37^{a}	37.95^{a}	41.47^{a}	38.65^{a}	1.648	0.1980
MCHC (g/dL)	33.73^{a}	31.90^{a}	31.08^{a}	32.63^{a}	6.544	0.2987
WCC (x10^9/L)	11.25^{a}	11.32^{a}	11.42^{a}	11.73^{a}	6.580	0.7490
PC (x10^9/L)	717.33^{a}	594.00^{a}	745.67^{a}	640.33^{a}	127.141	0.6080

a, b, c : Means with different superscripts in the same row indicate significant differences between treatments ($P<0.05$)

RBCC: Red blood cell count; MCV: Mean cell volume; RCDW: Red cell distribution width; MCHC: Mean corpuscular haemoglobin concentration; WCC: White cell count

#: Diet codes are explained in Table 4.04, Chapter 4

5.3 Meat quality

5.3.1 Carcass weights, dressing percentage, pH, drip loss, cooking and shear force.

Results on the effect of ensiled prickly pear inclusion in the diet on slaughter weight, hot carcass weight, cold carcass weight, dressing percentage, initial pH (45 minutes post slaughter), final pH (24 hours post slaughter), drip loss, cooking loss and shear force of indigenous male Pedi goats are presented in Table 5.03 and Figures 5.01,02,03,04 and 05, respectively. Ensiled prickly pear inclusion in the diet had no effect ($P>0.05$) on dressing percentage, final pH (24 hours post slaughter), cooking loss, and shear force of indigenous male Pedi goats. However, ensiled prickly pear inclusion in the diet had a significant effect ($P<0.05$) on slaughter weight, hot carcass weight, cold carcass weight, pH (45 minutes post slaughter) and drip loss of indigenous male Pedi goats. At 30% prickly inclusion level, the highest slaughter weight was observed and at 0% prickly inclusion level, the lowest slaughter weight was observed. The results of our study are in contrary with de Lima Cruz *et al*. (2023), who observed that cactus pear silage had no effect on the slaughter weight of crossbred goats. Similarly, in sheep, Oliveira *et al*. (2021) observed that cactus pear had no effect on the slaughter weight of Santa Inês lambs. Since forage cactus supplies energy readily available in the rumen, favouring the synthesis of microbial protein and the production of volatile fatty acids, it also promotes higher feed use by the animal and hence more growth and muscle development, which is reflected in more carcass elongation and muscle deposition (do Nascimento Souza *et al.,* 2020). This explains the higher weight at slaughter for animals receiving prickly pear silage levels in the present study.

The results of the current study indicated that prickly pear had an effect (P<0.05) on hot carcass weight of male Pedi goats. At 30% prickly pear inclusion level, the highest hot carcass weight was observed, and at 10% prickly pear inclusion level, the lowest hot carcass weight was observed. The results of our study are in agreement with de Lima Cruz *et al*. (2023), who observed that cactus pear silage had no effect on the hot carcass weight of crossbred goats. The results of our study are in contrary with Alves *et al.* (2023), who observed that cactus pear had no effect on hot carcass weight in lambs. Similarly, Ali *et al*. (2023) reported that crushed cactus had no effect on hot carcass weight in Awassi sheep.

The results of the current study indicated that prickly pear had an effect (P<0.05) on the cold carcass weight of male Pedi goats. At the 30% prickly pear inclusion level, the highest cold carcass weight was observed, and at the 10% prickly pear inclusion level, the lowest cold carcass weight was observed. The results of our study are in contrast with de Lima Cruz *et al*. (2023), who reported that there was no significant effect on cold carcass weight of crossbred goats supplemented with cactus pear silage. Similarly, Mahouachi *et al*. (2012) observed that spineless cactus did not affect the cold carcass weight of goat kids. In sheep, Balduíno da Silva *et al*. (2021) also observed that cactus pear as roughage had no effect on cold carcass weight of lambs. However, the results of our study are in agreement with Oliveira *et al*. (2019), who observed that cactus had an effect on cold carcass weight of goats. Similarly, Berhe *et al.* (2024) observed that cactus had an effect on cold carcass weight of yearling central highland goats.

The results of the current study indicated that prickly pear had no effect (P>0.05) on the dressing percentage of male Pedi goats. The results of our study are in agreement with Atti *et al*. (2009), who observed that the incorporation of cactus in the diet of goat kids had no effect on dressing percentage. However, the results of our study are in contrary to those of Berhe *et al.* (2024), who observed that cactus had an effect on the dressing percentage of yearling central highland goats. Similarly, Oliveira *et al*. (2019) observed that cactus had an effect on dressing percentage in goats. In sheep, Degu *et al*. (2009) observed that cactus had an effect on the dressing percentage of Tigray Highland sheep.

The results of the current study indicated that prickly pear had an effect ($P<0.05$) on the initial pH of male Pedi goats. At 30% prickly inclusion level, the highest slaughter weight was observed and at 0% prickly inclusion level, the lowest slaughter weight was observed. The results of our study are in contrary with de Lima Cruz *et al*. (2023) who observed that cactus pear silage had no effect on the initial pH of crossbred goats. Similarly, El Otman *et al*. (2020) observed that cactus had no effect on the initial pH of male goat kids. The value of initial pH has to be lower than 6.4, and that of final pH between 5.4 – 5.7 to be commercialized (Hamdi *et al.* 2016, Maltin *et al.* 2003). The initial pH right after slaughter should be close to neutrality, as well as in the live animal, indicating that the animal did not suffer from stress during the pre-slaughter period (de Lima Cruz *et al*., 2013). This explains the results obtained in the present study.

The results of the current study indicated that prickly pear had no effect ($P>0.05$) on the final pH of male Pedi goats. The results of our study are in agreement with Pinheiro *et al.* (2023), who observed that cactus pear silage had no effect on the initial pH of crossbred goats. Similarly, Oliveira *et al*. (2022) observed that spineless cactus had no effect on the initial pH of grazing goats. Oliveira *et al*. (2019) also observed that cactus meal had no effect on the final pH of goats. In sheep, do Nascimento Júnior *et al*. (2022) also observed that cactus pear had no effect on the final pH of Santa Inês male lambs. Similarly, Oliveira *et al.* (2021) also observed that cactus pear had no effect on final of male crossbred *Santa Inês* lambs. The absence of variation in final pH among treatments in the results of our study can be explained by the fact that prickly pear supplementation did not affect glycogen reserves in the muscle. Thus, its conversion to lactate and hydrogen ions (H$^{+)}$ was similar among the treatments. This content, in turn, also depends on the pre-slaughtering state of animals. Stressed animals partially or completely use their muscle glycogen reserves (de Felício, 1997). In the present study, the animals were not subjected to any pre-slaughter stress, resulting in average final pH values of 5.64 for diets with prickly pear and average final pH values which are within the limits (5.4–5.7) reported by Sebsibe (2008) for good-quality meat.

The results of the current study indicated that prickly pear had an effect (P<0.05) on drip loss of male Pedi goats. At 0% prickly pear inclusion level, the highest drip loss was observed and 30% prickly pear inclusion level the lowest drip loss was observed. According to the best of our knowledge, no research has been conducted on the effect of prickly pear on drip loss of Pedi goats.

The results of the current study indicated that prickly pear had no effect (P>0.05) on the cooking loss of male Pedi goats. The results of our study are in agreement with Oliveira *et al*. (2022), who observed that spineless cactus had no effect on the cooking loss of grazing goats. Similarly, Pinheiro *et al*. (2023) observed that spineless cactus had no effect on cooking loss of male goat kids. Oliveira *et al*. (2019) also observed that cactus meal had no effect on cooking loss of goats. de Lima Cruz *et al.* (2023) observed that cactus silage had no effect on cooking loss of crossbred goats. In sheep, Alves *et al.* (2023) observed that spineless cactus had no effect on cooking loss of crossbred lambs. Similarly, Ali *et al*. (2023) observed that crushed cactus had no effect on cooking loss of Awassi sheep. do Nascimento Júnior *et al.* (2022) also observed that cactus pear had no effect on cooking loss of Santa Inês male lambs. The instrumental parameter of cooking weight loss was not affected by the diet which occurred due to the pH values being normal in slaughter (Meléndez-Martínez *et al*., 2022)

The results of the current study indicated that prickly pear had no effect (P>0.05) on shear force of male Pedi goats. The results of our study are in contrary with Pinheiro *et al.* (2023) who observed that spineless cactus had an effect on shear force of male goat kids. However, the results of our study are in agreement with Oliveira *et al.* (2022) who observed that spineless cactus had no effect on shear force of grazing goats. Similarly, Oliveira *et al*. (2019) also observed that cactus meal had no effect on shear force of goats. de Lima Cruz *et al.* (2023) observed that cactus silage had no effect on shear of crossbred goats. In sheep, do Nascimento Souza *et al.* (2020) also observed that cactus silage had no effect on shear force of crossbred lambs. do Nascimento Souza *et al*. (2020) further stated that shear force of the meat did not present a significant difference between the treatments, probably due to this parameter being unrelated to the diet and more directly related to the age, breed and sex of the animal, as the animals were of the same sex, of similar race and age, no differences were observed. This explains the results of our study as the animals were of the same sex, breed and of similar age.

Table 5.03: Effect of ensiled prickly pear inclusion in the diet on slaughter weight, hot carcass weight, cold carcass weight, dressing percentage, initial pH, final pH, drip loss, cooking loss and shear force of indigenous male Pedi goats.

	Treatment#					
Variables	PPF_0	PPF_{10}	PPF_{20}	PPF_{30}	SEM	P-value
Slaughter weight (kg)	15.57^b	16.40^{ab}	16.47^{ab}	17.67^a	0.452	0.0114
Hot carcass weight (kg)	6.93^{ab}	5.93^b	7.33^{ab}	8.50^a	0.588	0.0162
Cold carcass weight (kg)	6.77^{ab}	5.83^b	7.20^{ab}	8.39^a	0.588	0.0145
Dressing percentage (%)	44.47^a	36.25^a	44.61^a	48.09^a	3.760	0.0682
Initial pH	6.22^d	6.31^c	6.35^b	6.39^a	0.016	<0.0001
Final pH	5.63^a	5.62^a	5.66^a	5.63^a	0.152	0.9830
Drip Loss (%)	8.10^a	7.15^b	7.42^b	6.02^c	0.102	<0.0001
Cooking Loss (%)	30.51^a	29.24^a	28.99^a	30.67^a	0.355	0.2608
Shear force (N)	41.63^a	41.24^a	41.86^a	40.62^a	1.305	0.8698

a, b, c : Means with different superscripts in the same row indicate significant differences between treatments (P<0.05)

#: Diet codes are explained in Table 4.04, Chapter 4

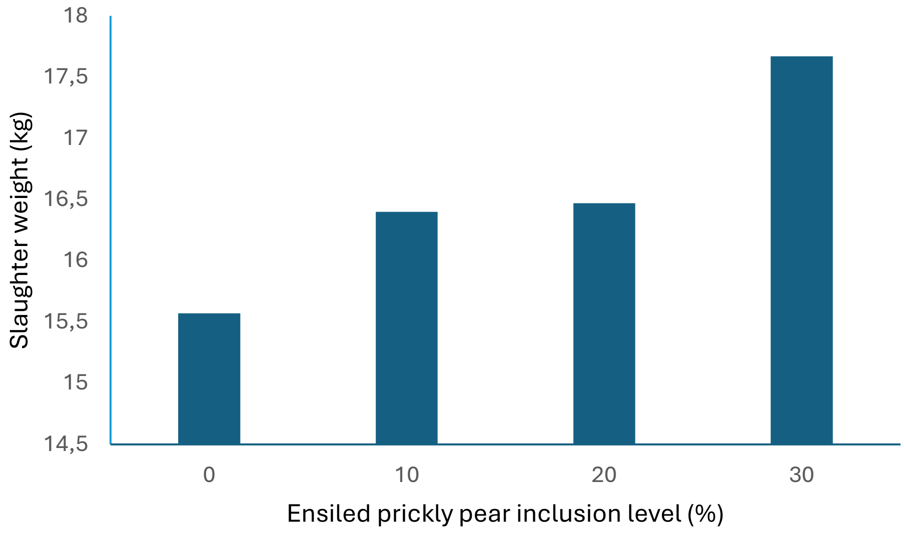

Figure 5.01: *The relationship between ensiled prickly pear inclusion levels in the diet and slaughter weight of indigenous male Pedi goats.*

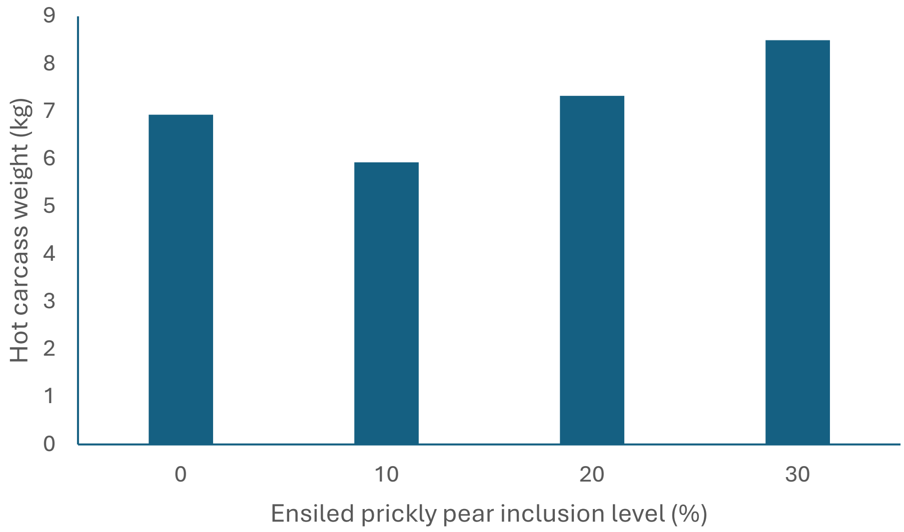

Figure 5.02: *The relationship between ensiled prickly pear inclusion levels in the diet and hot carcass weight of indigenous male Pedi goats.*

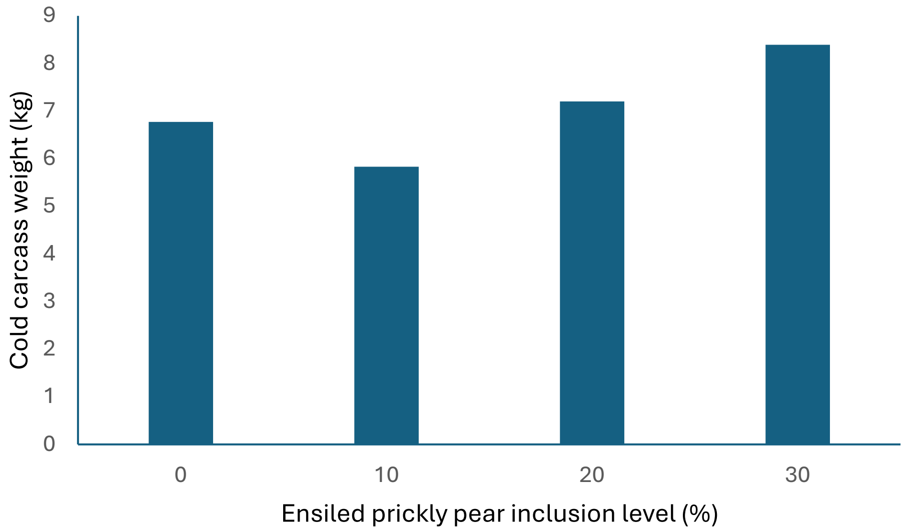

Figure 5.03: *The relationship between ensiled prickly pear inclusion levels in the diet and cold carcass weight of indigenous male Pedi goats.*

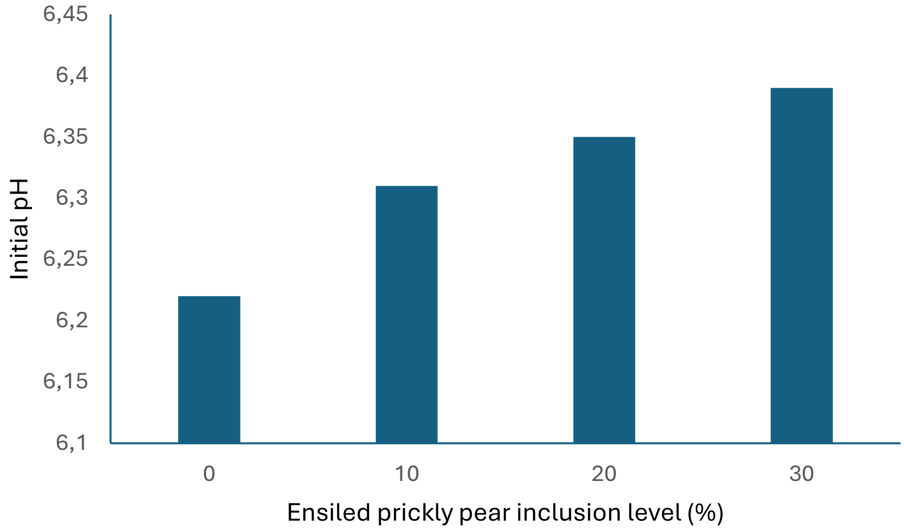

Figure 5.04: *The relationship between ensiled prickly pear inclusion levels in the diet and initial pH of indigenous male Pedi goats.*

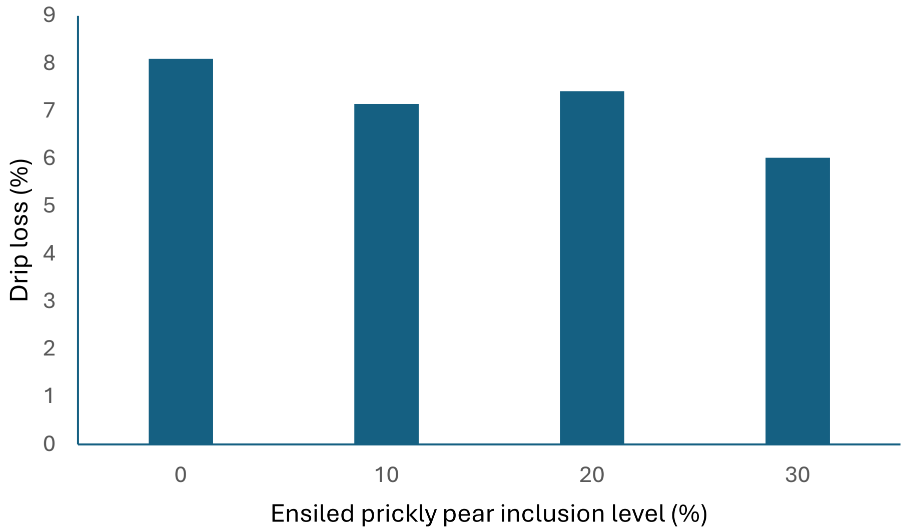

Figure 5.05: *The relationship between ensiled prickly pear inclusion levels in the diet and drip loss of indigenous male Pedi goats.*

5.3.2 Meat colour

Results on the effect of ensiled prickly pear inclusion levels in the diet on lightness, redness and yellowness of indigenous male Pedi goats are presented in Table 5.04. Ensiled prickly pear inclusion levels had no effect (P>0.05) on yellowness, redness and lightness of indigenous male Pedi goats. The results of the current study indicated that prickly pear had no effect (P>0.05) on lightness of male Pedi goats. However, the results of our study are contrary to Oliveira *et al.* (2022), who observed that spineless cactus had no effect on lightness of grazing goats. Similarly, Pinheiro *et al*. (2023) who observed that forage cactus had no effect on lightness of goat kids. In sheep, the results of our study are contrary to those of Alves *et al.* (2023) observed that spineless cactus had an effect on lightness of crossbred lambs. Similarly, do Nascimento Souza (2020) observed that cactus silage had an effect on lightness of crossbred lambs. However, Oliveira *et al.* (2021) also observed that cactus pear had no effect on lightness of male crossbred *Santa Inês* lambs. The results of our study are in line with Dawson *et al.* (2002), who recommended that the minimum critical value for meat luminosity (L*) is 34. Lower values of L are related to elevated final pH, which results in the high concentration of metmyoglobin, making the meat darker, which causes rejection by consumers for associating dark meat with old meat (de Lima Cruz., 2023).

The results of the current study indicated that prickly pear had no effect (P>0.05) on redness of male Pedi goats. The results of our study are in agreement Oliveira *et al.* (2019), who observed that cactus meal had no effect on redness of goats. Similarly, El Otmani *et al.* (2020) also observed that cactus cladodes had no effect on redness of male goat kids. de Lima Cruz *et al.* (2023) observed that cactus silage had no effect on redness of crossbred goats. In sheep, do Nascimento Souza *et al.* (2020) observed that cactus silage had an effect on lightness of crossbred lambs. However, Alves *et al.* (2023) observed that spineless cactus had no effect on yellowness of crossbred lambs. Although in our research prickly pear supplementation did not have a significant effect on the redness and other colour parameters, we can indicate that the meat obtained in this research would be well accepted by consumers, because Hopkins (1996) suggests that consumers will consider meat colour acceptable when the L* value is equal to or exceeds 34, and a* value below 19 or equal to or exceeds 9.5 according to Khliji *et al.*(2010). In the present study, all values for L* remained above this threshold and the values of a* remained within these values, which suggests that meats from all diets and water supply levels had an acceptable colour for consumers.

The results of the current study indicated that prickly pear had no effect (P>0.05) on yellowness of male Pedi goats. The results of our study are in agreement with Oliveira *et al.* (2022), who observed that spineless cactus had no effect on yellowness of grazing goats. Similarly, Pinheiro *et al.* (2023) observed that forage cactus had no effect on yellowness of goat kids. De Lima Cruz *et al.* (2023) also observed that cactus silage had no effect on yellowness of crossbred goats. In sheep, the results of our study are contrary to those of Alves *et al.* (2023), who observed that spineless cactus had an effect on yellowness of crossbred lambs. Similarly, do Nascimento Souza (2020) observed that cactus silage had an effect on lightness of crossbred lambs. However, Oliveira *et al.* (2021) also observed that cactus pear had no effect on yellowness of male crossbred Santa Inês lambs. The b* index in meat may be related to the concentration of fat and/or the presence of carotenoids in the diet, which can be affected by forage preservation processes, such as silage and hay, which significantly reduce carotenoid levels by up to 80% (Lawrie, 2014).

Table 5.04: *Effect of ensiled prickly pear inclusion levels in the diet and lightness, redness and yellowness of indigenous male Pedi goats.*

Variables	Treatment#					
	PPF_0	PPF_{10}	PPF_{20}	PPF_{30}	SEM	P-value
Lightness (L*)	39.17^a	40.31^a	40.43^a	39.65^a	1.706	0.8664
Redness (a*)	12.20^a	13.73^a	12.03^a	12.57^a	1.094	0.4483
Yellowness (b*)	8.26^a	7.92^a	8.71^a	8.97^a	0.335	0.0556

a, b, c : Means with different superscripts in the same row indicate significant differences between treatments (P<0.05)

#: Diet codes are explained in Table 4.04, Chapter 4

5.3.3 Fatty acid analysis

Results on the effect of ensiled prickly pear inclusion in the diet on fatty acid analysis of indigenous male Pedi goats are presented in Table 5.05 and Figures 5.06-5.28, respectively. Ensiled prickly pear inclusion in the diet had no effect (P>0.05) on C11:0, C20:0, C18:3n3, C20:3n6, and C20:4 of indigenous male Pedi goats. However, ensiled prickly pear inclusion in the diet had a significant effect (P<0.05) on C6, C8, C10, C12:0, C13:0, C14:0, C15:0, C16:0, C17:0, C18, C14:1, C16:1, C17:1, C18:1n9c, C18:1n9t, C20:1, C18:2n6c, C18:2n6t, C20:2, and C20:5n3 fatty acids concentration of indigenous male Pedi goats. Similarly, ensiled prickly pear inclusion in the diet had a significant effect on the total content of saturated fatty acids, monounsaturated fatty acids, and polyunsaturated fatty acids in the meat of indigenous male Pedi goats. The fatty acids profile of meat influences meat quality flavour, consumer acceptance, hardness, and palatability), shelf life and human health (Kotsampasi et al., 2017; Webb et al., 2005). The results of the current study indicated that prickly pear had an effect (P<0.05) on the total saturated fatty acids concentration of male Pedi goats. A negative relationship was observed between prickly pear inclusion levels and the total saturated fatty acid concentration in the meat of Pedi goats. At 0% prickly pear inclusion level the highest total saturated fatty acid concentration was observed and at the 30% prickly pear inclusion level the total saturated fatty acid concentration was observed. According to de Lima Cruz et al. (2023) high concentration of saturated fatty acids present in meat is not desirable, as there is evidence that saturated fatty acids, mainly C16:0, as well as myristic (C14:0) and lauric (C12:0) increase the blood cholesterol and low-density lipoproteins (LDL) concentration, due to interferences with hepatic LDL receptors (Woollett et al., 1992). According to Porto Filho et al. (2024), the inclusion of spineless cactus can improve the nutritional quality of the meat due to its fatty acid profile, since the more expressive saturated fatty acids present in the meat have less hypercholesterolemic action, while the higher mono- and polyunsaturated fatty acids promote the reduction of unwanted cholesterol.

In this study, C14:0, C16:0, and C18:0 were the most abundant ones in the lipid profiles in relation to the total saturated fatty acids. Similar findings were observed in other studies previously (do Nascimento Souza et al., 2020 and Atti et al., 2009). In relation to total fatty acid concentration in meat, values obtained on other goat's breeds (Banskalieva et al 2000; and Atti et al 2006) were similar to this present study, showing the prevalence of palmitic (C16:0) and stearic (C18:0) fatty acids. This can be explained by the inclusion of a source of higher carbohydrate concentration (pectin) such as cactus silage promotes greater energy intake and the animal stores this excess energy as fatty acids up to 16 carbons, fatty acids in meat above 18 carbons are usually derived from the diet (Deng et al., 2018 and Silva et al., 2016).

In the current study, C16:0, C18:0, and C18:1 accounted for 82.63% of the total fatty acids, with C16:0 being the saturated fatty acid that contributed most to the profile, followed by C18:1n9 cis, which accounted for 81.2% of the monounsaturated fatty acid and 30.4% of the fatty acid profile of the meat. The results of our study are similar to Porto Filho et al. (2024) who reported that C16:0, C18:0, and C18:1 accounted for 79.7% of the total fatty acids, with C16:0 being the SFA that contributed most to the profile, followed by C18:1n9 cis, which accounted for 86.09% of the monounsaturated fatty acid and 28.5% of the fatty acid profile of the meat. The predominance of these acids has been reported in previous studies (Abidi et al., 2009; Atti et al., 2006; Costa et al., 2017; Madruga et al., 2008).

According to Lopes et al. (2012), the meat of ruminant animals has a higher amount of saturated fatty acids and lower concentrations of monounsaturated and polyunsaturated fatty acids. This is due to the process of biohydrogenation, which involves the addition of a hydrogen ion to a double bond, resulting in the conversion of unsaturated fatty acids into their corresponding saturated fatty acids. However, the biohydrogenation process is not 100% complete for all polyunsaturates, some of which reach the duodenum and are absorbed (Holanda et al., 2012). This explains the prevalence of saturated fatty acids in comparison to monounsaturated and polyunsaturated fatty acids total concentration observed in the present study.

Table 5.05: *Effect of ensiled prickly pear inclusion in the diet on fatty acid analysis of Pedi indigenous goats*

Variables	Treatment#					
	PPF_{0}	PPF_{10}	PPF_{20}	PPF_{30}	SEM	P-value
Saturated						
C6	5.50^{a}	5.85^{a}	4.57^{b}	4.42^{b}	0.209	0.0003
C8	5.59^{aa}	5.04^{a}	5.31^{aa}	3.44^{b}	0.201	<.0001
C10	3.07^{bc}	3.77^{a}	3.39^{ab}	2.68^{c}	0.133	0.0002
C11:0	1.90^{a}	2.07^{a}	1.84^{a}	2.04^{a}	0.080	0.0594
C12:0	8.96^{aa}	8.91^{aa}	8.31^{a}	5.94^{b}	0.332	<.0001
C13:0	2.14^{a}	2.07^{ab}	1.86^{bc}	1.72^{c}	0.080	0.0028
C14:0	32.49^{b}	46.97^{a}	35.12^{aa}	16.13	1.409	<.0001

C15:0	12.78^{aa}	12.60^{a}	9.31^{bb}	8.31^{b}	0.447	<.0001
C16:0	277.85^{aa}	294.53^{aa}	273.83^{a}	226.30^{b}	11.009	0.0015
C17:0	23.27^{a}	19.68^{b}	16.72^{c}	11.39^{d}	0.748	<.0001
C18	235.65^{a}	207.40^{bb}	207.30^{bb}	196.70^{b}	8.676	0.0107
C20:0	2.00^{a}	1.90^{a}	2.07^{a}	1.93^{a}	0.081	0.2320
Total Saturated	611.21^{a}	610.80^{a}	522.09^{b}	528.53^{b}	23.290	0.0060
Monounsaturated						
C14:1	5.63^{aa}	5.51^{a}	2.68^{b}	1.97^{c}	0.175	<.0001
C16:1	26.59^{a}	27.00^{a}	16.04^{bb}	13.98^{b}	0.888	<.0001
C17:1	20.66^{a}	16.50^{b}	10.19^{c}	5.26^{d}	0.589	<.0001
C18:1n9c	417.92^{a}	359.43^{b}	276.03^{c}	186.19^{d}	13.161	<.0001
C18:1n9t	45.38^{a}	34.72^{b}	27.88^{c}	17.13^{d}	1.346	<.0001
C20:1	2.58^{aa}	2.24^{b}	2.59^{aa}	2.30^{ab}	0.100	0.0136
Total Monosaturated	518.77^{a}	445.39^{b}	335.41^{c}	226.84^{d}	16.241	<.0001
Polyunsaturated						

C18:2n6c	41.51^{ab}	46.64^{a}	38.94^{bc}	33.81^{c}	1.655	0.0004
C18:2n6t	3.76^{a}	2.95^{bb}	2.87^{b}	2.36^{c}	0.124	<.0001
C18:3n3	6.80^{a}	6.19^{a}	6.00^{a}	6.39^{a}	0.260	0.0696
C20:2	2.69^{a}	2.36^{bb}	2.46^{ab}	2.17^{b}	0.099	0.0051
C20:3n6	1.82^{a}	1.86^{a}	1.65^{a}	1.78^{a}	0.073	0.0883
C20:4	11.89^{a}	12.37^{a}	12.24^{a}	12.28^{a}	0.499	0.7855
C20:5n3	1.92^{bb}	1.64^{c}	1.78^{bc}	2.29^{a}	0.079	0.0002
Total Polyunsaturated	70.40^{a}	74.01^{a}	65.94^{ab}	61.09^{b}	2.781	0.0083

a, b, c : Means with different superscripts in the same row indicate significant differences between treatments ($P<0.05$)

#: Diet codes are explained in Table 4.04, Chapter 4

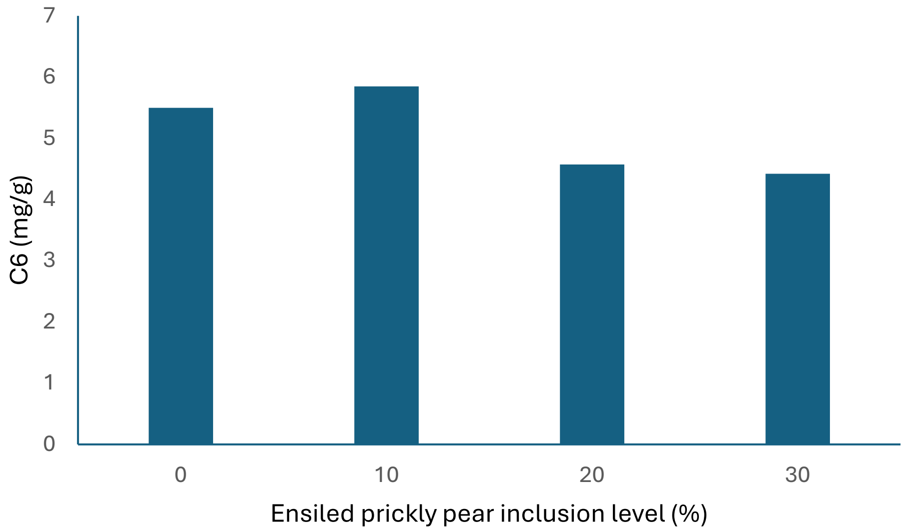

Figure 5.06: *The relationship between ensiled prickly pear inclusion levels in the diet and C6 concentration of indigenous male Pedi goats.*

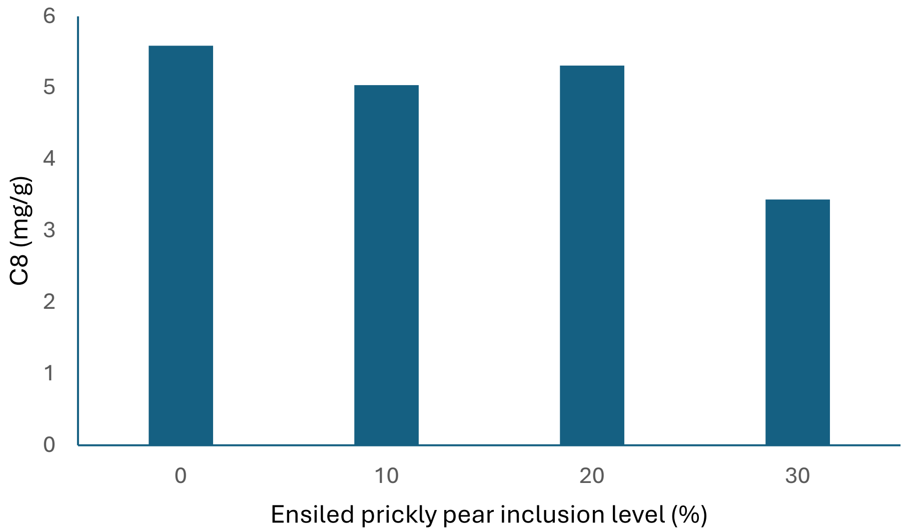

Figure 5.07: *The relationship between ensiled prickly pear inclusion levels in the diet and C8 concentration of indigenous male Pedi goats.*

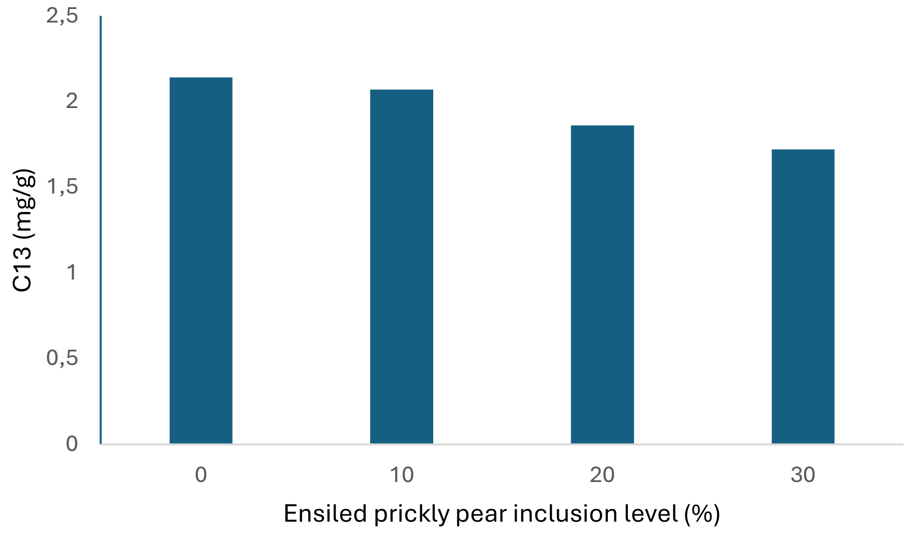

Figure 5.08: *The relationship between ensiled prickly pear inclusion levels in the diet and C13:0 concentration of indigenous male Pedi goats.*

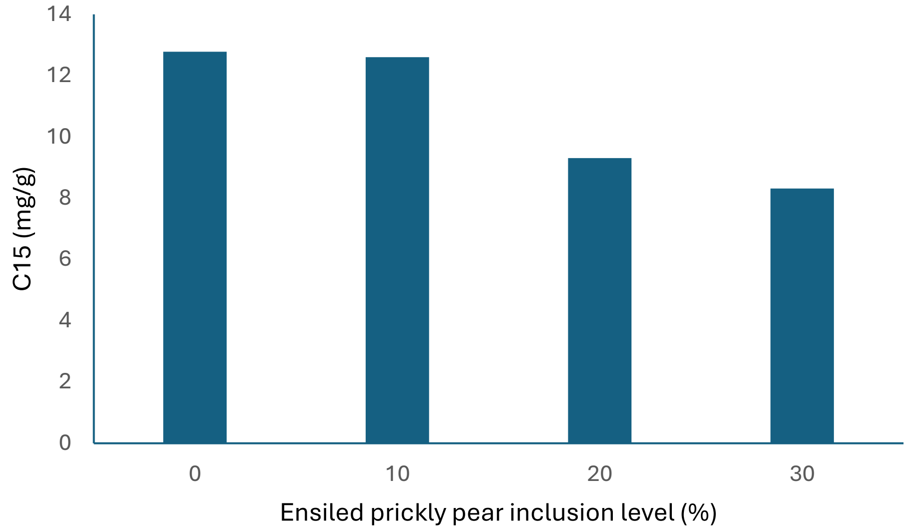

Figure 5.09: *The relationship between ensiled prickly pear inclusion levels in the diet and C15:0 concentration of indigenous male Pedi goats.*

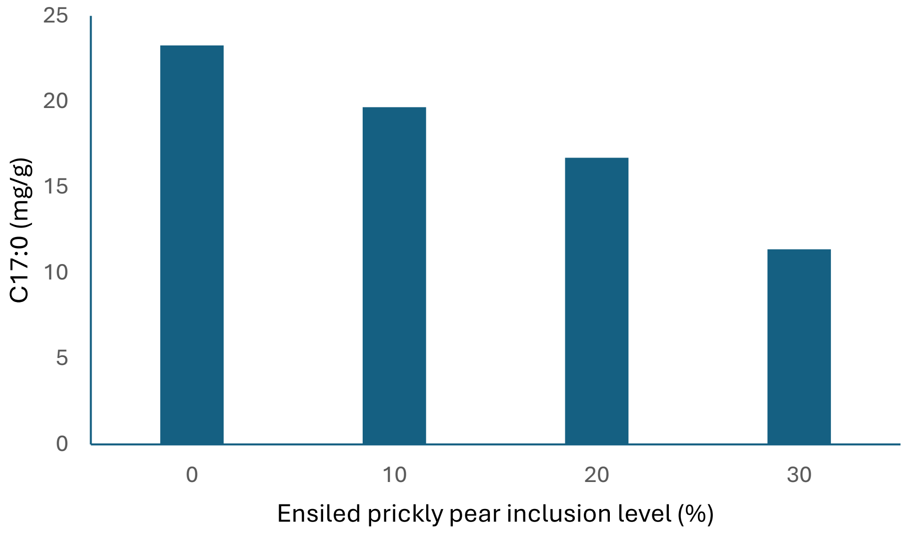

Figure 5.10: *The relationship between ensiled prickly pear inclusion levels in the diet and C17:0 concentration of indigenous male Pedi goats.*

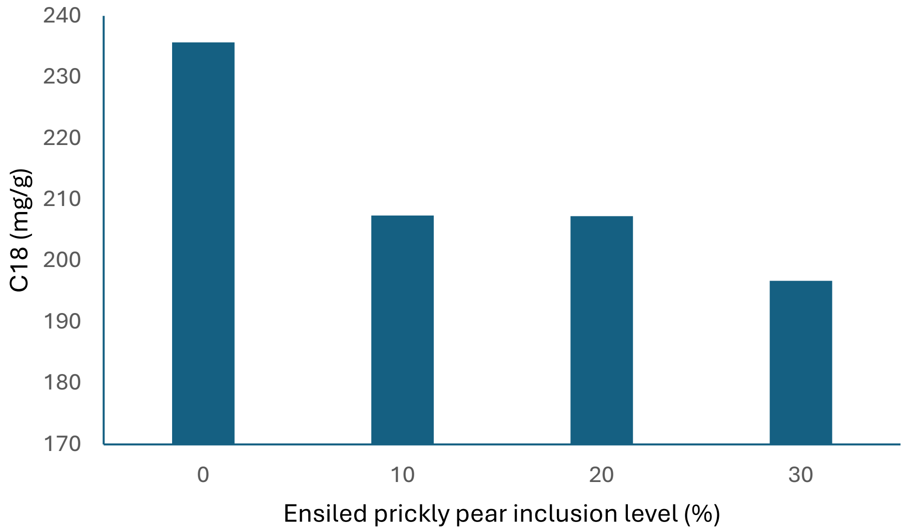

Figure 5.11: *The relationship between ensiled prickly pear inclusion levels in the diet and C18 concentration of indigenous male Pedi goats.*

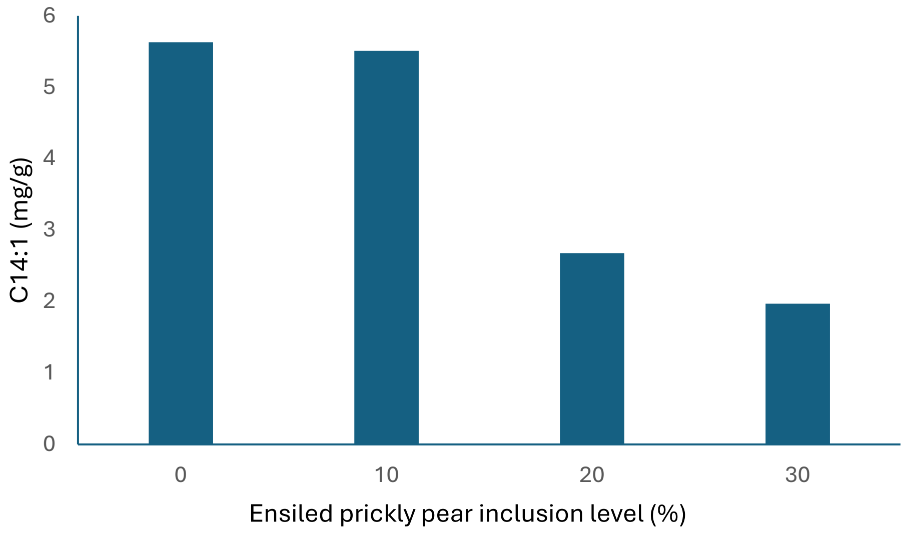

Figure 5.12: *The relationship between ensiled prickly pear inclusion levels in the diet and C14:1 concentration of indigenous male Pedi goats.*

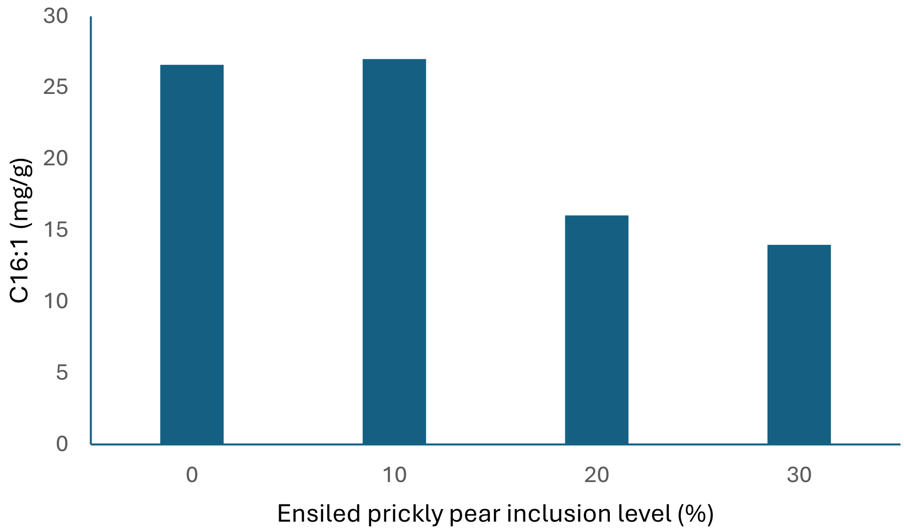

Figure 5.13: *The relationship between ensiled prickly pear inclusion levels in the diet and C16:1 concentration of indigenous male Pedi goats.*

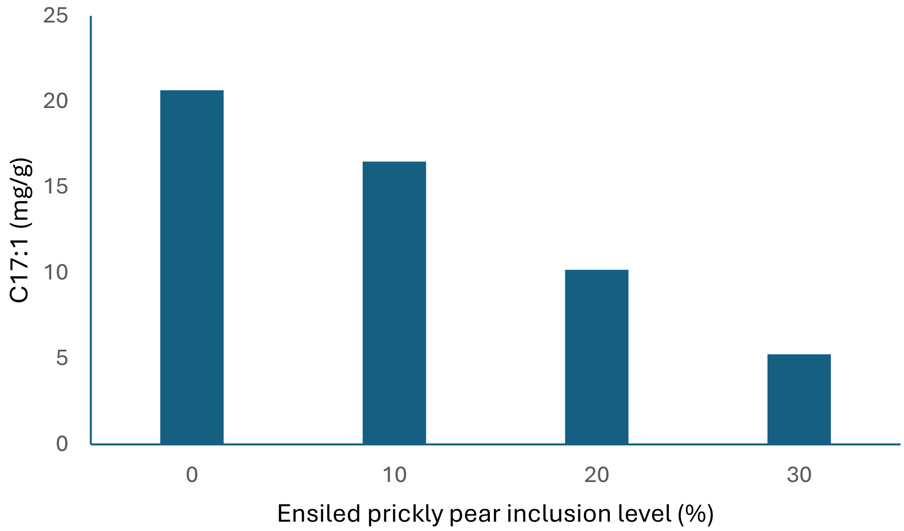

Figure 5.14: *The relationship between ensiled prickly pear inclusion levels in the diet and C17:1 concentration of indigenous male Pedi goats.*

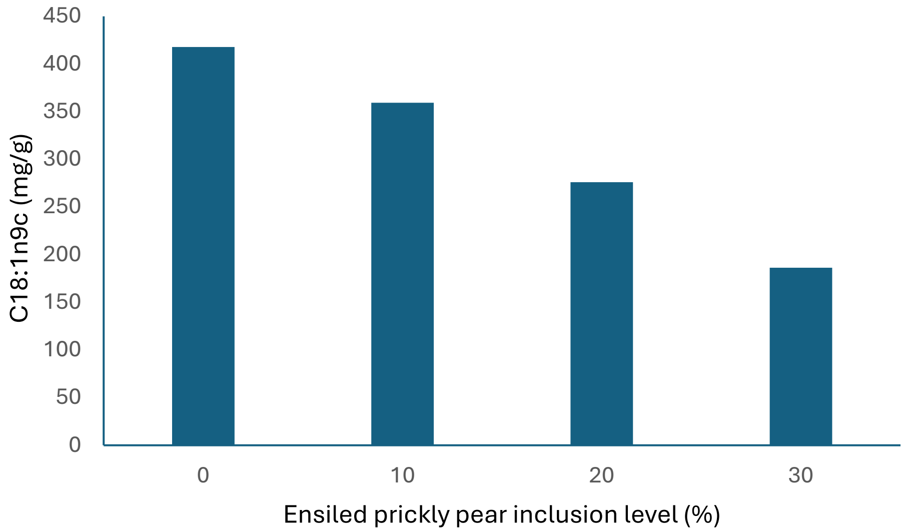

Figure 5.15: *The relationship between ensiled prickly pear inclusion levels in the diet and C18:1n9c concentration of indigenous male Pedi goats.*

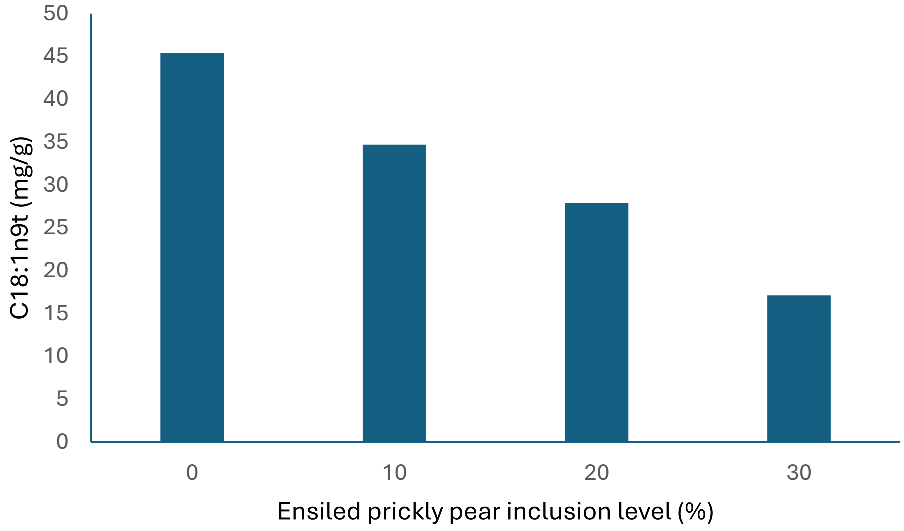

Figure 5.16: *The relationship between ensiled prickly pear inclusion levels in the diet and C18:1n9t concentration of indigenous male Pedi goats.*

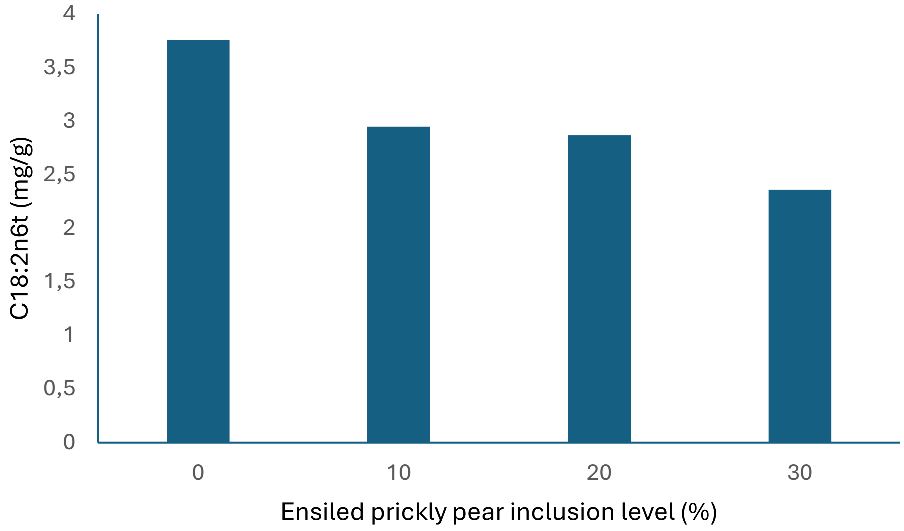

Figure 5.17: *The relationship between ensiled prickly pear inclusion levels in the diet and C18:2n6t concentration of indigenous male Pedi goats.*

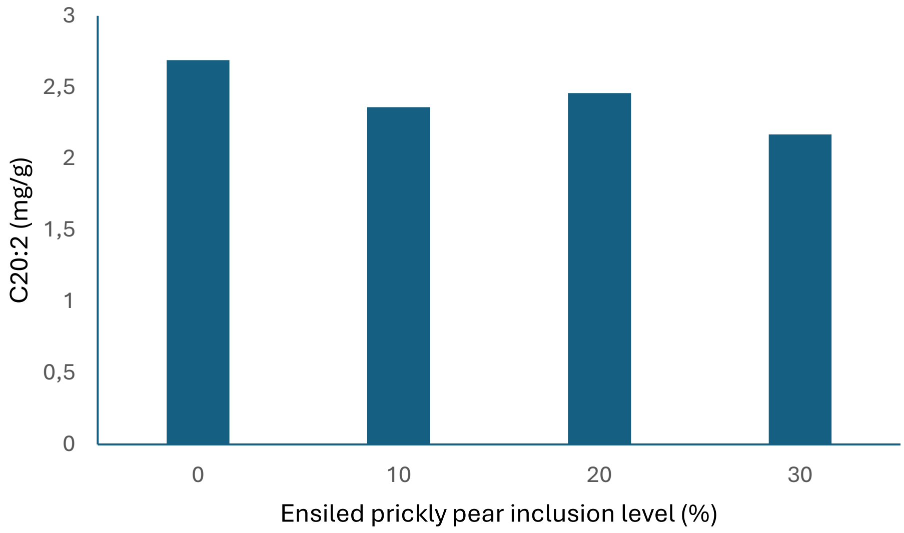

Figure 5.18: *The relationship between ensiled prickly pear inclusion levels in the diet and C20:2 concentration of indigenous male Pedi goats.*

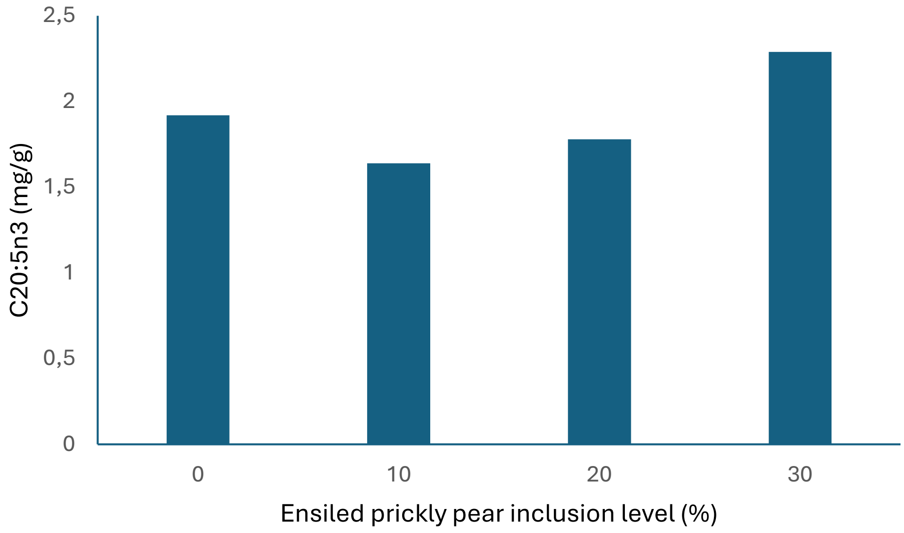

Figure 5.19: *The relationship between ensiled prickly pear inclusion levels in the diet and C20:5n3 concentration of indigenous male Pedi goats.*

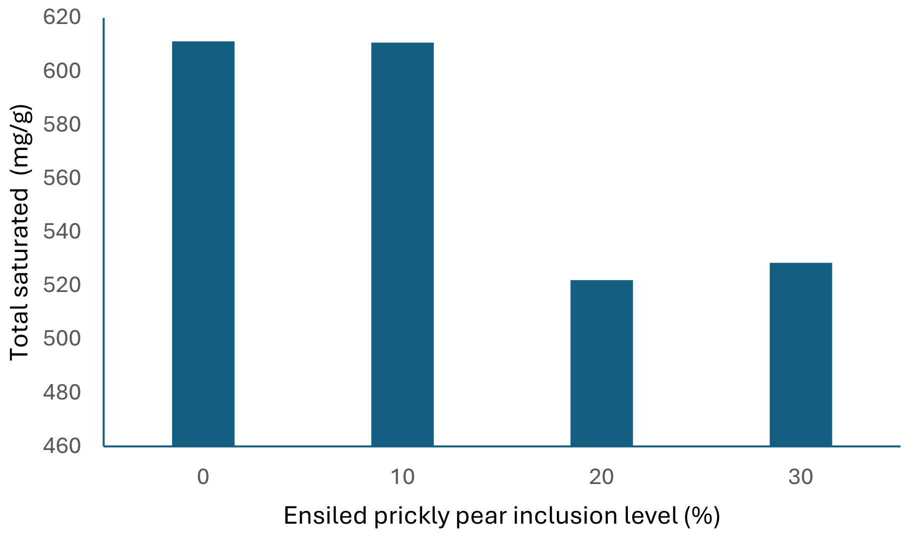

Figure 5.20: *The relationship between ensiled prickly pear inclusion levels in the diet and total saturated fatty acids concentration of indigenous male Pedi goats.*

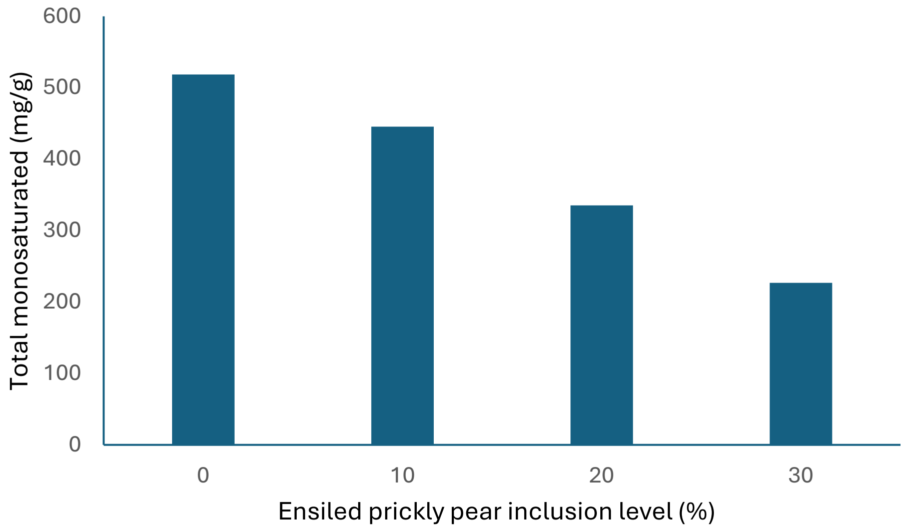

Figure 5.21: *The relationship between ensiled prickly pear inclusion levels in the diet and total monounsaturated fatty acids concentration of indigenous male Pedi goats.*

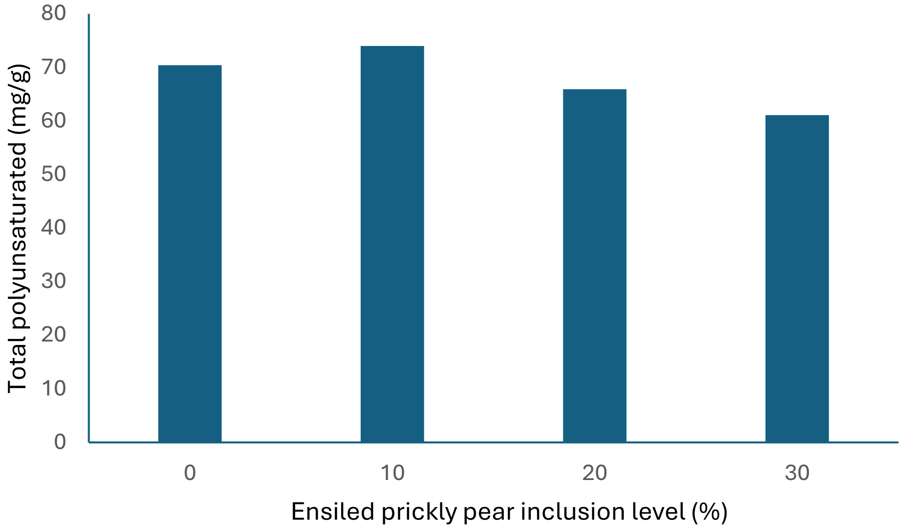

__Figure 5.22:__ The relationship between ensiled prickly pear inclusion levels in the diet and total polyunsaturated fatty acids concentration of indigenous male Pedi goats.

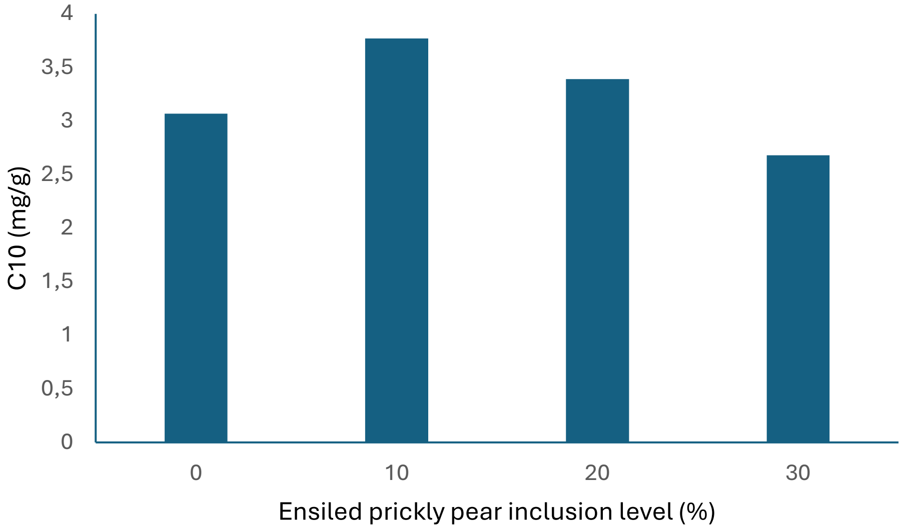

__Figure 5.23:__ Effect of ensiled prickly pear inclusion levels in the diet on C10 concentration of indigenous male Pedi goats.

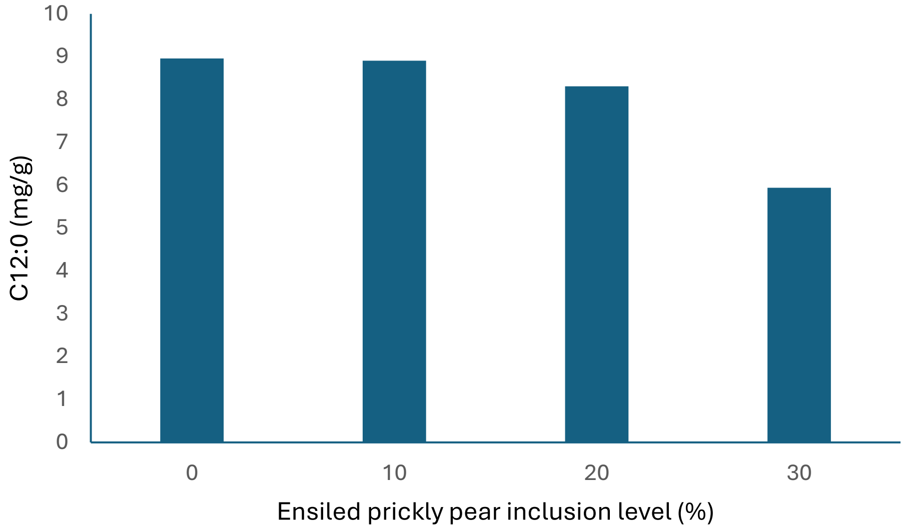

Figure 5.24: *Effect of ensiled prickly pear inclusion levels in the diet on C12:0 concentration of indigenous male Pedi goats.*

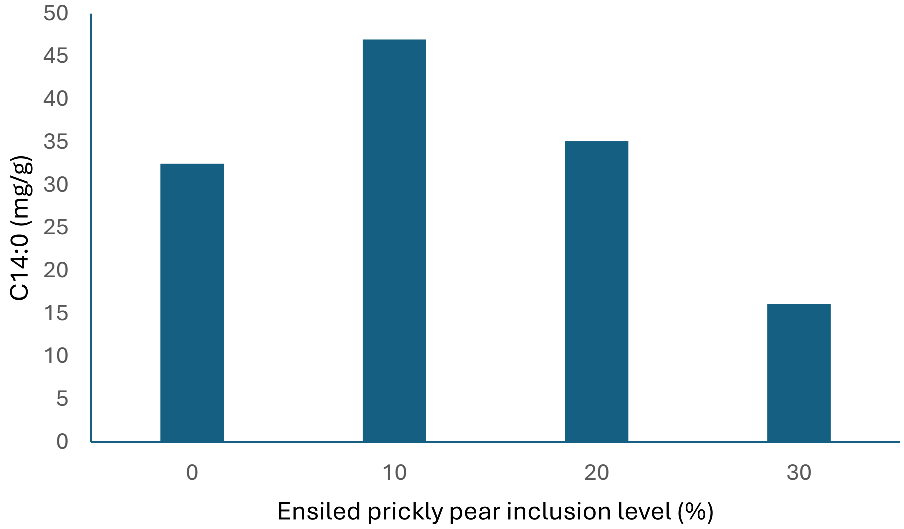

Figure 5.25: *Effect of ensiled prickly pear inclusion levels in the diet on C14:0 concentration of indigenous male Pedi goats.*

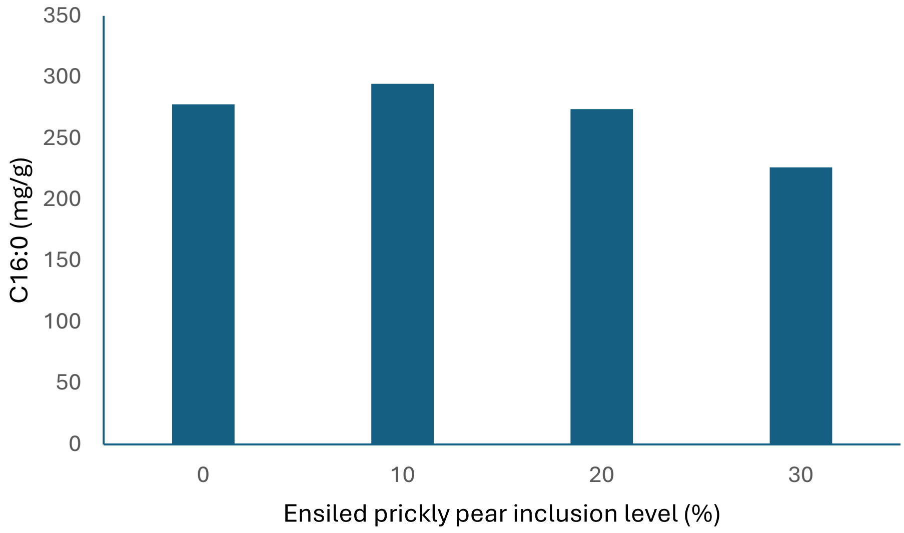

Figure 5.26: *Effect of ensiled prickly pear inclusion levels in the diet on C16:0 concentration of indigenous male Pedi goats.*

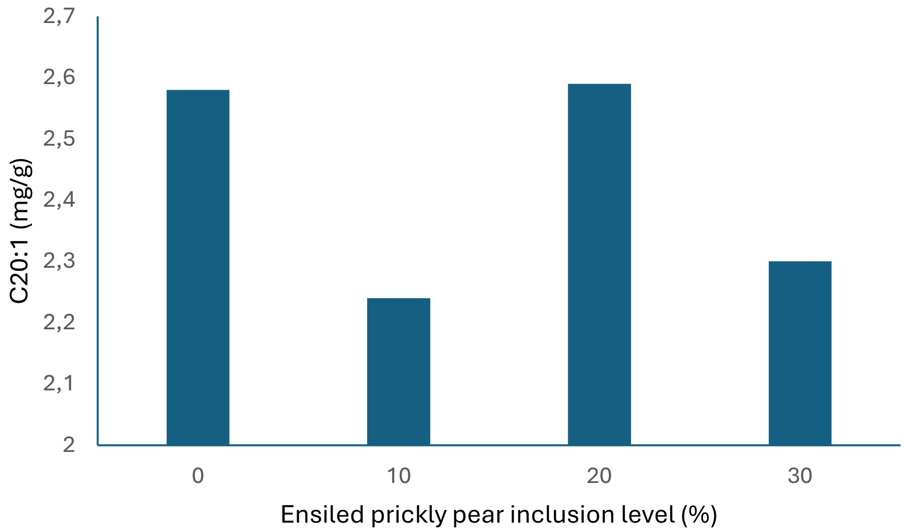

Figure 5.27: *Effect of ensiled prickly pear inclusion levels in the diet on C20:1 concentration of indigenous male Pedi goats.*

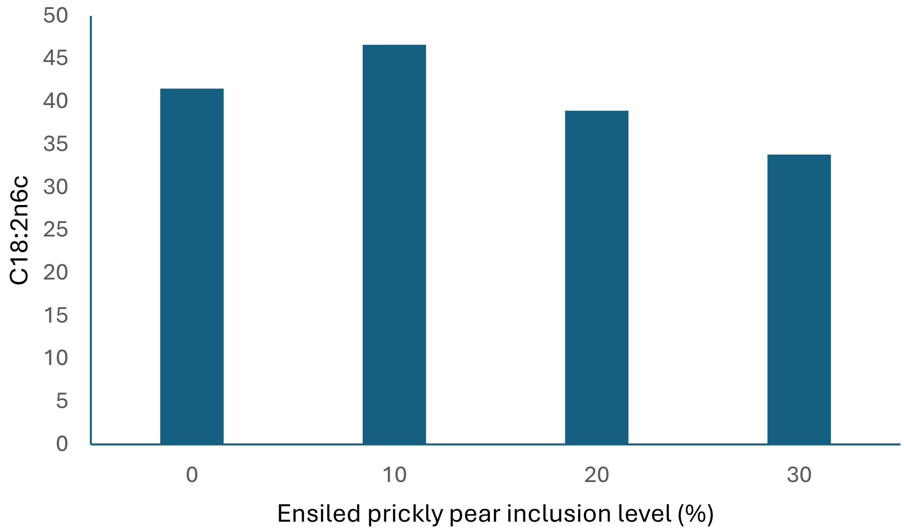

Figure 5.28: *Effect of ensiled prickly pear inclusion levels in the diet on C18:2n6c concentration of indigenous male Pedi goats.*

5.3.4 Sensory attributes

Results on the effect of ensiled prickly pear inclusion levels in the diet on tenderness, juiciness, flavour, and overall acceptability of indigenous male Pedi goats are presented in Table 5.06 and Figures 5.29, 2.30 & 2.31, respectively. Ensiled prickly pear inclusion levels in the diet had no effect (P>0.05) on the tenderness of indigenous male Pedi goats. Ensiled prickly pear inclusion levels in the diet had an effect (P<0.05) on juiciness, flavour, and overall acceptability of indigenous male Pedi goats. The results of the current study indicated that prickly pear had no effect (P>0.05) on the tenderness of male Pedi goats. The results of our study are in agreement with Oliveira et al. (2019), who observed that cactus meal had no effect on the tenderness of goats. Similarly, Porto Filho et al. (2020) observed that spineless cactus had no effect on the tenderness of Santa Inês sheep. The cooking loss (CL) and shear force (SF) were within the values recommended (20–35% CL, and SF up to 44.13 Newton (N) for goat meat) to classify the meat as soft and tender (Webb et al., 2005).

The results of the current study indicated that prickly pear had an effect (P<0.05) on juiciness, flavour, and overall acceptability of male Pedi goats. At 30% prickly pear inclusion level, the highest juiciness, flavour, and overall acceptability were observed and 0% prickly pear inclusion level, the lowest juiciness, flavour, and overall acceptability were observed. The results of our study are in agreement with Pinheiro et al. (2023), who observed that forage cactus had an effect on juiciness, flavour and overall acceptability and, flavour of goat kids. The influence of diets rich in polyunsaturated fatty acids on the volatile compounds of beef and sheep shows greater lipid oxidation in meat (Elmore et al., 2000). In the present study, the meat of the animals that received the control diet had a higher content of polyunsaturated fatty acids, which may have provided greater lipid oxidation in the meat, resulting in greater rancidity and lower overall acceptance. Lipids, especially unsaturated fatty acids, are prone to oxidation and can act as pro-oxidants, resulting in the development of off-flavors (Bartosz, 2013). This better explains the results of the present study, as the sensory attributes that presented the highest scores were the meat of goats that received cactus in the diet. The lowest total polyunsaturated fatty acids concentration is at 30% prickly pear inclusion level, whereas the highest scores of sensory attributes are at 30% prickly pear inclusion level.

Table 5.06: *Effect of ensiled prickly pear inclusion levels in the diet on tenderness, juiciness, flavour and overall acceptability of indigenous male Pedi goats.*

Variables	Treatment#					
	PPF_0	PPF_{10}	PPF_{20}	PPF_{30}	SEM	P-value
Tenderness	2.67^a	2.00^a	3.33^a	4.00^a	0.471	0.0770
Juiciness	1.67^b	2.00^b	2.67^{ab}	4.33^a	0.667	0.0026
Flavour	2.67^b	2.33^b	3.33^{ab}	4.67^a	0.707	0.0050
Overall Acceptability	2.67^b	2.33^b	3.33^{ab}	4.33^a	0.471	0.0126

a, b, c : Means with different superscripts in the same row indicate significant differences between treatments (P<0.05)

#: Diet codes are explained in Table 4.04, Chapter 4

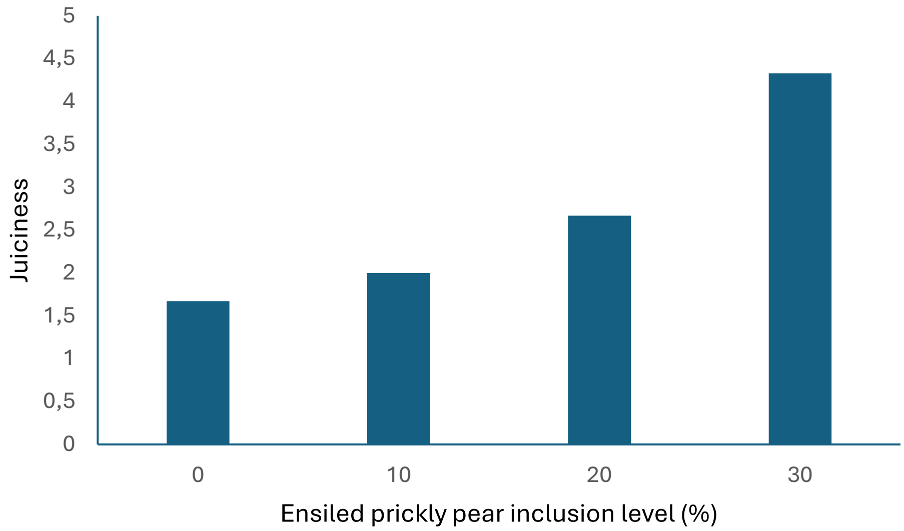

__Figure 5.29:__ The relationship between ensiled prickly pear inclusion levels in the diet and meat juiciness of indigenous male Pedi goats.

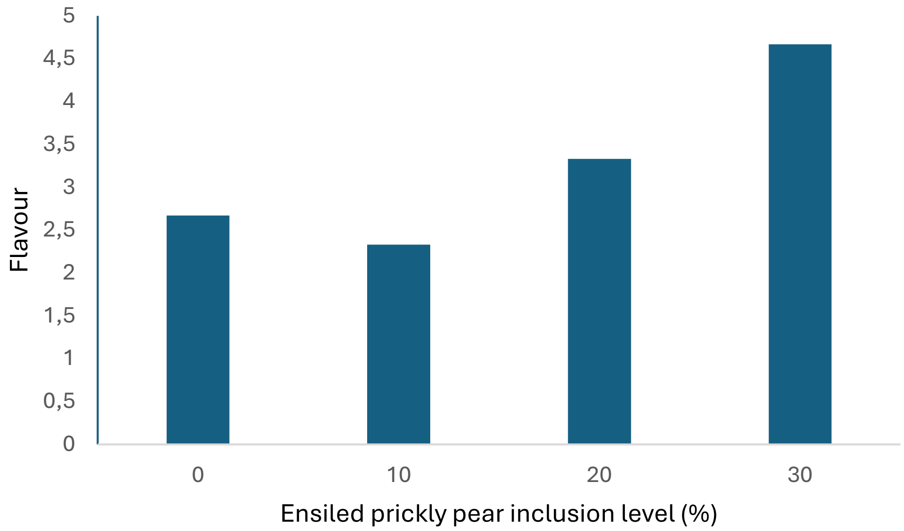

__Figure 5.30:__ The relationship between ensiled prickly pear inclusion levels in the diet and flavour of indigenous male Pedi goats.

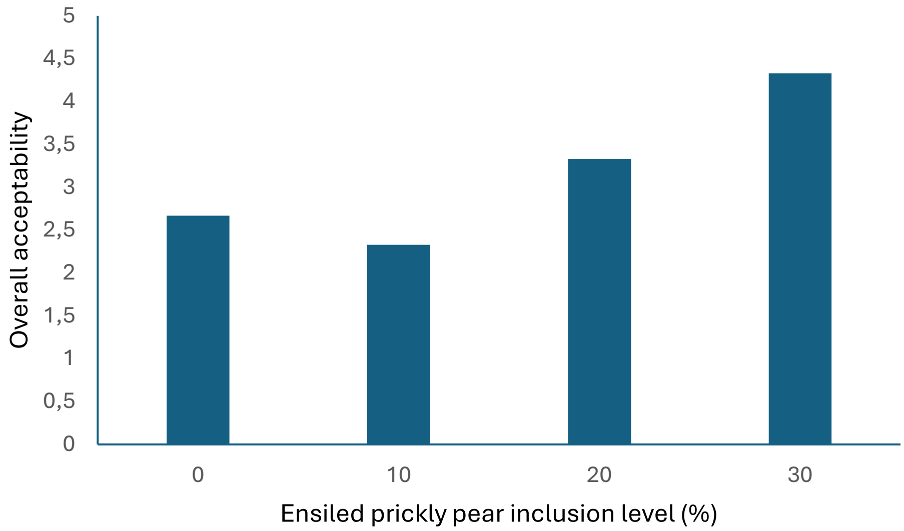

Figure 5.31: *The relationship between ensiled prickly pear inclusion levels in the diet and overall acceptability of indigenous male Pedi goats.*

5.5 Conclusion

Based on the results of our study, it can be concluded that the inclusion of prickly pear in the diet has no significant effect on the blood haematological parameters of goats. Thus, supporting the initial hypothesis. Therefore, it is suggested that prickly pear can be utilized without causing any adverse effects on the blood profiles of goats.

The results of this study demonstrate that prickly pear inclusion levels significantly influence meat quality in male Pedi goats. A 30% inclusion level yielded the highest final slaughter weight, hot and cold carcass weights, while the lowest values were observed at 0% inclusion for slaughter weight and 10% for hot and cold weights. These findings highlight the positive effect of fermented prickly pear on goats' performance. The dressing percentage, final pH, cooking loss, shear force, and meat colour were not significantly affected by prickly pear inclusion. However, sensory attributes (juiciness, flavour and overall acceptability) showed a significant positive relationship with prickly pear inclusion.

C10, C12:0, C14:0, C16:0, C20:1 and C18:2n6c fatty acids were optimized at 11.250, 6.417, 11.315, 9.059, 12.250 and 8.865% prickly pear inclusion levels.

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6. CHAPTER 6 CONCLUSIONS & RECOMMENDATIONS

6.1 Conclusions

Based on the results of our study, it can be concluded that the inclusion of ensiled prickly pear in the diet does not have a significant effect on blood haematological parameters of goats. Therefore, it is suggested that ensiled prickly pear can be utilized without causing any adverse effects on the blood profiles of goats. The results of this study demonstrate that ensiled prickly pear inclusion levels significantly influence meat quality in male non-descript indigenous goats. A 30% inclusion level yielded the highest final slaughter weight and hot and cold carcass weights, while the lowest values were observed at 0% inclusion for slaughter weight and 10% for hot and cold weights. These findings highlight the positive impact of fermented cactus on goats' performance. The dressing percentage, final pH, cooking loss, shear force and meat colour were not significantly affected by ensiled prickly pear inclusion. However, sensory attributes (juiciness, flavour and overall acceptability) showed a significant positive relationship with ensiled prickly pear inclusion. Therefore, it can be concluded that ensiled prickly can be included in diets to improve the meat quality of goats.

6.2 Recommendations

It is recommended that the following should be done: screening of non-conventional animal feeds, especially tree leaves and extracts, for anti-protozoal activity; standardization of defaunation methods for its implication at the farmer's level; new species/ strains of microorganisms should be screened to use as probiotics, and the mechanism of action of probiotics should be studied thoroughly. Since farmers are unaware of drought solutions and potential feed for their goats, it is recommended that the government should intervene by providing farmers with drought and management training workshops. The current study served as a foundation for future in-depth research into the feasibility of farmers adopting more reliable and sustainable coping strategies for drought.

It is recommended that when incorporating prickly pear in goats' diets, they need to be supplemented with other nutrients like crude protein, as prickly pear has low content.

Optimal Inclusion Level: A 30% ensiled prickly pear inclusion level is recommended for maximizing weight gain and average daily gains in indigenous male Pedi goats.

Water Scarcity Management: Ensiled prickly pear can be integrated into goat diets in arid regions to reduce drinking water dependency. Methane Reduction Strategy: Inclusion levels of 20–30% ensiled prickly pear should be considered for reducing methane emissions in goats, contributing to more environmentally sustainable livestock farming. Further Research: Additional studies using advanced methane measurement techniques, such as the laser methane detector (LMD), are needed to refine recommendations on the most effective inclusion levels for greenhouse gas mitigation. It is also recommended that more studies be conducted on the subject to ascertain the present findings. Therefore, it can be concluded that prickly pear can be included in diets to improve the meat quality of goats. This means the ensiled prickly pear inclusion level requirements for indigenous goats will depend on the particular production variable of interest. This has implications for rations for indigenous goats. Thus, there is a need for more studies on the subject to ascertain the present findings.

7. APPENDIX

7.1 Project Achievements

Capacity Building

1. Phasha T: Bachelor of Agricultural Management Honours – student graduated 2023. Title: Goats farmers' perceptions of drought impact and local adaptation measures and methane emission mitigation strategies.

Contribution: The student assisted greatly in data collection during the project survey.

2. Kgaphola BT: Bachelor of Agricultural Management Honours – student graduated 2024. Title: Effect of ensiled prickly pear supplementation levels in the diet on the growth performance and methane emission of Pedi indigenous goats.

Contribution: The student assisted greatly in data collection during the project survey.

3. Matabane DM: Master of Agricultural Management – student awaiting 2026 Autumn graduation. Title: Effects of ensiled prickly pear (*Opuntia ficus-indica*) in the diet on growth performance, blood hematology, and meat quality of indigenous goats.

Contribution: The student assisted greatly in data collection during the project experiments, also assisted with data analysis and write-ups.

4. Lekgoathi PP: Bachelor of Agricultural Management Honours – student awaiting 2026 Autumn graduations. Title: Effect of ensiled prickly pear (*opuntia ficus-indica*) fruit on meat sensory attributes of yearling male Pedi goats: Awaiting 2026 Autumn graduations.

Contribution: The student assisted greatly in data collection during the project experiments.

5. Masemola MO: Bachelor of Agricultural Management Honours – student awaiting 2026 Autumn graduations. Title: Effect of ensiled prickly pear (*opuntia ficus-indica*) fruit on meat shear force and water holding capacity of yearling male Pedi goats.

Contribution: The student assisted greatly in data collection during the project experiments.

7.2 Knowledge Dissemination

Workshops

1st Farmer's Day Workshop –09 May 2024, Ga-Molepo, Makatjane village

2nd Farmers Day Workshop- 23 October 2025, Ga-Mogano Moshate Hall

Conferences/Symposium attendance

1. A poster presented at the Animal Feed Manufacturers Association (AFMA) CSIR, Pretoria, South Africa, 31 October 2024.

Title: Nutrient composition and secondary metabolites of prickly pear fruits as potential feeds for goats.

2. A paper presented at the Faculty of Science and Agriculture Research Day, The Ranch Hotel, Polokwane, 17-20 September 2024.

Title: Goat farmers' perception of drought and local adaptation measures in Polokwane municipality, Capricorn district, in Limpopo, a South African province.

3. A paper presented at the 12th International Conference on Agriculture. Bangkok, Thailand, 22-23rd September 2025

Title: Effect of ensiled prickly pear in the diet on growth performance and meat quality of indigenous Pedi goats.

4. A paper presented at the International Conference on Climate Resilience, Smart and Sustainable Futures (ICCRSF), Venue: Emperors Palace, Johannesburg, 25-29th August 2025.

Title: Effect of ensiled prickly pear on growth performance and methane emission by indigenous goats.

Publications

1. Matabane, DM., Ng'ambi, J.W., Mabelebele, M., Gunya, B. and Manyelo, T.G. (2024). The Role of Secondary Metabolites on Methane Reduction in Small Ruminants. In Book: Latest Scientific Findings in Ruminant Nutrition - Research

for Practical Implementation. Intech Open, ISBN978-0-85014-283-9. DOI: 10.5772/intechopen.1005461.

2. Tlou Grace Manyelo, Jones Wilfred Ng'ambi, and Busisiwe Gunya. Nutrient composition and secondary metabolites of prickly pear fruits as potential feeds for goats. Journal of Food Composition and Analysis (Under review).
3. Tlou Grace Manyelo, Jones Wilfred Ng'ambi, and Busisiwe Gunya. Goat farmers' perception of drought and local adaptation measures in Polokwane municipality, Capricorn district, in Limpopo, a South African province. Heliyon (Under review).

Innovation

1. Management strategies to reduce methane emissions and improve goats' productivity.
2. Ensiled prickle pear inclusion levels for optimum productivity and methane reduction.

Collaboration

1. University of South Africa

7.3 Consent form

University of Limpopo

School of Agriculture and Environmental sciences

Department of Agricultural Economics and Animal Production

Private Bag X1106, Sovenga, 0727, South Africa

Cell: 066 441 4281, Email: grace.manyelo@ul.ac.za

INFORMED CONSENT FORM FOR PARTICIPATING IN A RESEARCH STUDY

Before, as well as to clarify you where you might need clarity. You are cordially asked to sign the form after you have decided to take part in this project.

I, …………………………………. agree to participate in research titled “INVESTIGATION OF GOATS FARMERS' PERCEPTIONS OF DROUGHT IMPACT AND LOCAL ADAPTATION MEASURES AND METHANE EMISSION MITIGATION STRATEGIES taking part in this research, the researcher will talk to you, and will give you this consent form to read OBJECTIVES AND PRACTICES AT………… VILLAGE, LIMPOPO PROVINCE, SOUTH AFRICA” in the Department of Agricultural Economics and Animal Production University of Limpopo.

Furthermore, I understand that:

1. My participation in this research is voluntary, and I will not gain monetary/ financial compensation for my participation. I may withdraw my participation in a case of discomfort, and my withdrawal will not affect my relationship with the researcher.
2. I have the right to not answer certain questions if I am uncomfortable. I understand that this participation is entirely voluntarily. I can withdraw my consent at any time with no penalty.
3. My response to the questions will be recorded at my permission. However, where I am not comfortable about recording my response, the researcher will have to write down my responses by him/herself.
4. Confidentiality and anonymity of records identifying you as a participant will be maintained by me and my learning institution, if necessary.
5. If you have any questions or concerns about participating in the interview or about contributing to this study, you may contact me or my supervisor on the numbers listed above.

____________________	____________________	______________
Participant (Full name)	Signature	Date

I, Tlou Grace Manyelo have clarified the scope of the research to the participant and explained his/ her rights concerning his/ her participation in the study. She/ He agrees to participate in this study.

Kind regards,

_______________________ _________________ ________________

Researcher Signature Date

Department of Agricultural Economics and Animal Production,

University of Limpopo,

Private Bag X1106, Sovenga 0727,

South Africa

7.4 Questionnaire:

QUESTIONNAIRE FOR COMMUNAL GOAT FARMERS

All the information provided here will be treated as strictly exclusive. Data gathered by this questionnaire will be used only for the purpose of this intended evaluation and nothing else. Personal and socio-economic information of respondents will be kept confidential and no mention of names shall be made in the final report that shall be compiled. For purposes of report, it is hereby required that consent is given through *signing the declaration below by the respondent before the beginning of the application.*

1. SECTION A: *Demographic Information*

Names:						
Contact Number:						
Village name:						
Please mark the appropriate answer with an X in the box of the table provided						
What is your gender	*Male:*	*Female:*				
Indicate your age group	*24 years and younger*	*25 to 34 years*	*35 to 44 years*	*45 to 54 years*	*55 years and over*	
Indicate your Position	*Goat farmer (Owner):*	*Goat herder:*	*Other (Specify):*			
Indicate your farming experience	*Less than 2 years*	*3 to 5 years*	*6 to 10 years*	*11 to 15 years*	*16 years and over*	
Indicate your educational background	*Never attended*	*Primary school*	*High School*	*College Diploma*	*University Degree*	*Post-Graduate qualification*

2. SECTION B: *Herd size, feeding and management*

2.1 How many goats are under your care (including kids)?

Males		*Females*		*Kids*		*Total*	

2.2 Which goat breeds are you farming with?

2.3 What is the purpose of farming with goats?

Income		*Traditional/Prestige*		*Consumption*	

Others (please specify):

2.4 Which goat feeding practices are used in the farm?

2.4.1 Rearing mode in dry season

Free roaming	Yes:			No:		
Why?						

Stall feeding	Yes:			No:		
Why?						

Tethering	Yes:			No:		
Why?						

2.4.2 Rearing mode in wet season

Free roaming	Yes:			No:		
Why?						

Stall feeding	Yes:			No:		
Why?						

Tethering	Yes:			No:		
Why?						

Others (please specify):

2.5 What is/ are the feed resources used?

	Yes:	No:	Examples
Fodder and trees			
Grass			
Supplement			

2.6 Do your goats like consuming the prickle pear?

Yes		*No*	

2.7 If yes, what do you think attracts them to the prickle pear?

Palatability		*Colour of tree*		*Odour of tree*	

2.8 Are your goats responding well when fed with prickle pear?

Increased weight gain	
High feed intake	
Not prone to diseases	
Other	

Others (please specify):

2.9 Which supplement do you use?

Purchased feed:		*Traditional trees*		*Others (mention)*	

2.10 How do you manage your goats daily? Please explain.

2.11 Have your goats had implication due to nutrition in the past? If yes, please elaborate.

2.12 Have your goats had implication due to drought in the past? If yes, please elaborate.

3. SECTION C: ***Drought local adaptation measures and methane mitigation strategies***

3.1 Do you have any knowledge on the drought? If yes, do you have any drought local adaptation strategies used on your farm? If no, provide reasons.

3.2 If you answered yes on 3.5, what are the drought local adaptation measures used on your farm?

3.3. Do you have any knowledge on the methane emission? If yes, do you have any methane mitigation strategies used on your farm? If no, provide reasons.

3.4 If you answered yes on 3.5, what are the methane mitigation strategies used on your farm?

************************ ***End of Survey*** *********************