

**EVALUATION OF PRICKLY PEAR (*OPUNTIA FICUS-INDICA*) FRUIT ON
GROWTH PERFORMANCE, BLOOD INDICES AND METHANE EMISSIONS BY
YEARLING MALE PEDI GOATS**

by

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DECLARATION

I declare that this mini dissertation hereby submitted to the University of Limpopo for the degree of Master of Science in Agriculture (Animal Production) has not been submitted by me for a degree at this or any other university, this is my own work in design and execution, and that all materials contained herein has been duly acknowledged.

Signature..........

Date...13 December 2023.....

Mr Travor Tshepiso Magonyane

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DEDICATION

This work is dedicated to God Almighty for His guidance and blessings throughout the study period.

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List of abbreviations

AD	Apparent digestibility
ADF	Acid detergent fibre
ADG	Average Daily Gain
ANOVA	analysis of variance
AOAC	Association of Official Analytical Chemists
BA	Basophils
CP	Crude protein
DM	Dry matter
EDTA	Ethylenediaminetetraacetic acid
EE	Ether Extract
EO	Eosinophils
FCR	Feed conversion ratio
GHG	Greenhouse gas
HT	Hydrolysable tannin
LY	Lymphocytes
MO	Monocytes
NDF	Neutral detergent fibre
NE	Neutrophils
OM	Organic matter
P	Probability
PPM-M	Parts per million per metre
r^2	Coefficient of determination
RBC	Red blood cells

Abstract

The study was conducted to determine the effect of prickly pear (*Opuntia ficus-indica*) in diets on growth performance, blood indices, and methane emissions of yearling male Pedi goats. A total number of 24 Pedi goats were randomly assigned to 4 treatments in a completely randomized design, replicated six times with 1 goat per replicate. All goats were of the same age group and were sourced from University of Limpopo Experimental Farm. Prickly pear inclusion levels were at 0, 10, 20 or 30%. The experiment was conducted for 28 days (21-day preliminary and 7-day collection periods). Methane emission by goats was measured daily during the collection period and measurements were done using a hand-held methane detector. Goat blood samples were collected prior the commencement of the experiment and towards the end of the experiment. To assess blood parameters (lymphocytes, monocytes, neutrophils, eosinophils, and basophils), blood samples (5 ml) were collected using hypodermic needles to draw blood from every goat through the jugular vein into marked sterile tubes which contained ethylenediaminetetraacetic acid (EDTA), which served as an anticoagulant. The data collected were subjected to analysis of variance using Statistical Analysis System Software. Prickly pear meal inclusion level on diet had an effect ($P < 0.05$) on DM, OM, Ash, CP, ADF, NDF, and EE intakes of yearling male Pedi goats. Male Pedi goats fed diets having 10 and 20% had higher ($P < 0.05$) DM, OM, Ash, CP, ADF, NDF, and EE intakes than those on a diet having a 0 and 30% Prickly pear meal inclusion levels. Male Pedi goats fed diets having 10 and 30% Prickly pear meal inclusion levels had higher ($P < 0.05$) DM and OM digestibility values than those fed diets having 0 and 20 % Prickly pear inclusion levels. Prickly pear inclusion level in a diet had no significant effect ($P > 0.05$) on the initial live weight, feed conversion ratios and water intake of goats. However, Prickly pear inclusion level in a diet showed a significant effect ($P < 0.05$) on final live weight, average daily gain (ADG) and feed intake of male Pedi goats. Prickly pear inclusion level in a diet had an effect ($p < 0.05$) on methane emissions by Male Pedi goats. Male Pedi goats on a diet having a 0% Prickly pear meal inclusion level had higher ($P < 0.05$) methane emissions than those on a diet composed of 0, 20 and 30% Prickly pear inclusion levels. Blood parameters of male Pedi goats revealed significant differences between the treatments at the beginning of the experiment. At the end of the trial, Prickly pear inclusion in the diet showed significant effect ($p < 0.05$) on eosinophils of male Pedi goats. A positive relationship was observed between Prickly pear meal inclusion level

and monocytes ($r^2=0.340$), eosinophils ($r^2=0.452$) and basophils ($r^2=0.303$) of male Pedi goats. Nutrient intake, digestibility, feed conversion ratio and blood profiles of Pedi goats in the present study were optimized at different inclusion levels of Prickly pear meals. Although, Prickly pear meal reduced methane emission, optimal reduction in methane emission was not determined. Further validation is required to determine Prickly pear inclusion levels for optimal methane production and emission by goats. It was concluded that indigenous Pedi goat optimal productivity responses to Prickly pear meal inclusion were variable, depending on the production parameter in question.

Keywords: Prickly pear, yearling goats, feed intake, digestibility, growth performance, methane and blood indices

CHAPTER ONE
INTRODUCTION

1.1 Background

South Africa has a strong goat (*Capra hircus*) business, with over 6 million goats (DAFF, 2014) which represents around 55% of the entire goat population in southern Africa (FAOSTAT, 2013). Goats are now an important part of the South African livestock industry making up 13% of all livestock in South Africa (FAOSTAT, 2022). Limpopo province has 21% of the total population of goats in South Africa (SEA, 2012). Goat production contributes immensely to the economy and food security of many smallholder farmers, particularly in rural areas (Ng'ambi *et al.*, 2013). Pedi goats have small to medium frames with short horns. Coat colour varies from uniform brown to white with a variety of black and white patterns (Snyman 2014). Goats are economically, nutritionally, and culturally important in South Africa, particularly in rural areas. This is particularly so in communal farming systems (Mataveia *et al.*, 2021). However, livestock contributes 65% of agricultural greenhouse gases, of which enteric fermentation through methane production and emission accounts for 90% (Meissner *et al.*, 2012).

Prickly pear cactus (*Opuntia ficus-indica*) is considered an excellent natural biomass. It is a fast-growing xerophytes draught 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 utilized as a valuable source feed, energy, and water (Andrade-Montemayor *et al.*, 2011). Given its significance, blood is an important medium in assessing the health status of animals. The physiological and pathological conditions of animals can be assessed by haematological and biochemical analyses of the blood (Pessini *et al.*, 2020).

1.2 Problem statement

Indigenous goat breeds known as the Pedi goats are particularly significant nutritionally, commercially, and culturally in South Africa (Matlebyane, 2005). However, during winter and dry seasons, ruminant productivity in rural areas is low when nutritious feeds are unavailable (Brown *et al.*, 2016). Livestock especially ruminants are important contributors to the amount of the GHG emissions from

agriculture into the atmosphere (FAO, 2017). Ruminants produce approximately 30 % of total anthropogenic methane emissions globally (Vargas *et al.*, 2022). In addition, methane (CH₄) produced and emitted by ruminants adversely affects the surroundings, and thus contributes to climate change (Kaufmann *et al.*, 2006; Lassey, 2007; Farnsworth *et al.*, 2019). According to Carulla *et al.* (2005) tannins reduce methane production during microbial fermentation and the formation of ruminal ammonia. Prickly pear is a drought-resistant and sustainable feed source for livestock (Gorostiague *et al.*, 2018). It is, however, recommended that prickly pear be fed to ruminants as a mixed ration with other feedstuffs to account for deficiency of other essential nutrients, which can include crude protein (De Lima *et al.*, 2021). Prickly pear fruits are high in secondary metabolites such as tannins, antioxidants, flavonoids, and polyphenols. There are studies which indicate that some of these secondary metabolites in feeds can reduce methane emissions by goats (Curulla *et al.*, 2005; Garnsworthy *et al.*, 2019). Therefore, it is important to investigate the evaluation of prickly pear fruit meal on growth performance, blood indices, and methane emissions by yearling male Pedi goats.

1.3 Motivation of the study

This study will generate information on the utilization of prickly pear fruit meal in a diet on growth performance, blood profiles, and methane emission by yearling male Pedi goats. Such information may be useful to organisations and governments aiming at reducing methane emissions in ruminant animals. This knowledge will also be beneficial in formulating techniques for reducing goat's methane emission and improving production. Optimization of the productivity of the goats may improve the economic, nutritional, and cultural status of indigenous goat farmers in South Africa.

1.4 Objectives

The objectives of the study were to determine:

- i. the effect of prickly pear fruit meal inclusion level in the diet on live weight, growth rate, digestibility, and diet intake of yearling male Pedi goats.
- ii. the effect of prickly pear fruit meal inclusion level in the diet on blood indices and methane emission of yearling male Pedi goats.

- iii. prickly pear fruit meal inclusion levels for optimal responses in live weight, growth rate, digestibility, diet intake, blood induces and methane emissions of yearling male Pedi goats.

1.5 Hypotheses

- i. The inclusion of prickly pear fruit meal in the diet has no effect on live weight, growth rate, digestibility and diet intake of yearling male Pedi goats.
- ii. The inclusion of prickly pear fruit meal in the diet has no effect on blood indices and methane emissions of yearling male Pedi goats.
- iii. There are no optimal responses in live weight, growth rate, digestibility, diet intake, blood induces and methane emissions of yearly male Pedi goats to prickly pear fruit meal.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

The goats (*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). They 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).

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 (Giuburunca *et al.*, 2014). 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.

2.2 Indigenous Pedi goats of South Africa

Indigenous Pedi goats are important domestic animals in the Limpopo province of South Africa. Indigenous goats of South Africa are of three distinct types, namely, Pedi goats, Nguni goats, and Xhosa lop ear ecotypes (DAFF, 2012). Additionally, the indigenous Pedi goats in Limpopo Province of South Africa constitute a valuable source of genetic material because of their relative adaptation to harsh climatic conditions and their ability to better utilize the limited and poor-quality feed resources (Brown and Ngambi, 2017). The contribution of indigenous goats to the nutritional and economic status of rural dwellers is well recognized (Iniguez, 2011; Ng'ambi *et al.*, 2013). The breed derived its name from the Bapedi people in the north of the country

(Dagris, 2007). 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). Indigenous goats are usually characterised by small body size, slow growth rate, and low milk and carcass yield (Otaru and Iyiola-Tunji, 2015). Coat colour varies from uniform brown to white with a variety of black and white patterns (Snyman, 2014). They are mainly multi-coloured, bearded, horned, with medium to broad lopped ears and they have short hair. Indigenous goats are commonly perceived as less productive than exotic breeds since communal farmers are confronted with challenges at various levels of the goat production value chain such as inaccessibility to input supplies like medicines and feed supplementation to alleviate the effects of diseases and seasonal variations in feed quality and quantity, respectively (Monau *et al.*, 2020).

2.3 Nutritional requirements for Pedi Goats

Nutrient requirements are based on the maintenance of normal body functions over time and they are adjusted with changes in the physiological status of an animal such as animal growth, pregnancy, lactation, and work (Abiola *et al.*, 2022). Dietary energy is often taken as the baseline requirement as it also affects the utilization of other nutrients (Lawrence *et al.*, 2012). Genetic and environmental factors such as nutrition directly affect the growth rate and health status of goats (Simões *et al.*, 2021). Poor nutrition results in low productivity and body weight loss (Sejian *et al.*, 2021). Brown *et al.* (2016), studied haematological parameters of BaPedi goats supplemented with *Vachellia karoo* which revealed no adverse effects in blood parameters, and growth performance was improved. Thus, farmers may use high protein forages as protein supplements for their livestock to enhance productivity (Jayanegara *et al.*, 2019).

There is a need to identify alternate feed resources to boost the feeding values of low-quality roughages. Temperature, humidity, sunshine, and wind velocity may increase or decrease nutrient demands depending on the region (NRC, 2016). Souza *et al.* (2014) discovered that factors such as the body size of the goat, castration status, and the environment may also contribute to a lower energy requirement because the animals do not require more energy to maintain normal body functions. The requirements for feed change based on the animal's preferences both within a meal and over the course of a day. (Provenza *et al.*, 2020). Nutritional requirements of livestock are a guideline to help formulate the ration that will sustain the animals to

attain their genetic potential and develop a supplementary feeding strategy for without compromising some of the essential nutrients needed by the animal.

2.4 Description of Prickly Pear Fruit

Opuntia ficus-indica (Cactaceae family) is a prickly pear species derived from several wild ancestors. It is a tree-like shrub with numerous up-flat branches called cladodes (Mannai *et al.*, 2018a). It is generally a spineless prickly pear, but some cultivars have spines. According to Sipango *et al.* (2022) It is a suitable carbohydrate source and can adapt to various environmental conditions. Prickly pear fruits can present large color differences among cultivars, varying from green to white, yellow to orange, and red to purple. These variations can be attributed to the betalain-type pigments (Cejudo *et al.*, 2014, Cano *et al.*, 2017; Khatabi *et al.*, 2018; Salem *et al.*, 2020). The green cladodes or “nopalitos” (35–45 cm long and 20–30 cm wide) have a spatulate form and are strongly succulent with abundant small spines. The whole fruit of a prickly pear usually weighs from 100 to 200 g and contains a thick peel representing around 28% to 50% of the fruit (Todaro *et al.*, 2020), usually contains a high percentage of sugar, reaching more than 10% of the whole weight (El-Neney *et al.*, 2019).

Prickly pear peels have been found to contain high levels of natural antioxidants (Sallam *et al.*, 2022) and dietary fiber, making them an excellent source of functional ingredients to produce healthy yogurt drinks (El-Hassan *et al.*, 2022) and were considered as a potential source of mucilage with relevant characteristics (Otalora *et al.*, 2022). The red, purple, or yellow flowers (2–3 cm in length) are hermaphrodites, with 4 attached carpels enclosed in a floral cup and an inferior receptacle (ovary). The fruits (figs or prickly pears) are enclosed in a thick skin, covered with small pricklys, and contain up to 270 seeds (Reyes Agüero, 2016). The Prickly pear (*Opuntia ficus-indica*) is presented in Figure 2.01.



Figure 2.01 Prickly pear (*Opuntia ficus-indica*) Source: Kallenborn (2018)

2.5 Prickly pears distribution South Africa

The Prickly pear (*O. ficus-indica*) was introduced to the Eastern Cape in South Africa over 300 years ago. The drought conditions are 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 look for methods 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 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 incredible plant more well-earned attention (Brown, 2016).

As previously stated, Eastern Cape was the first area in South Africa that 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 world-wide 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 2.02.

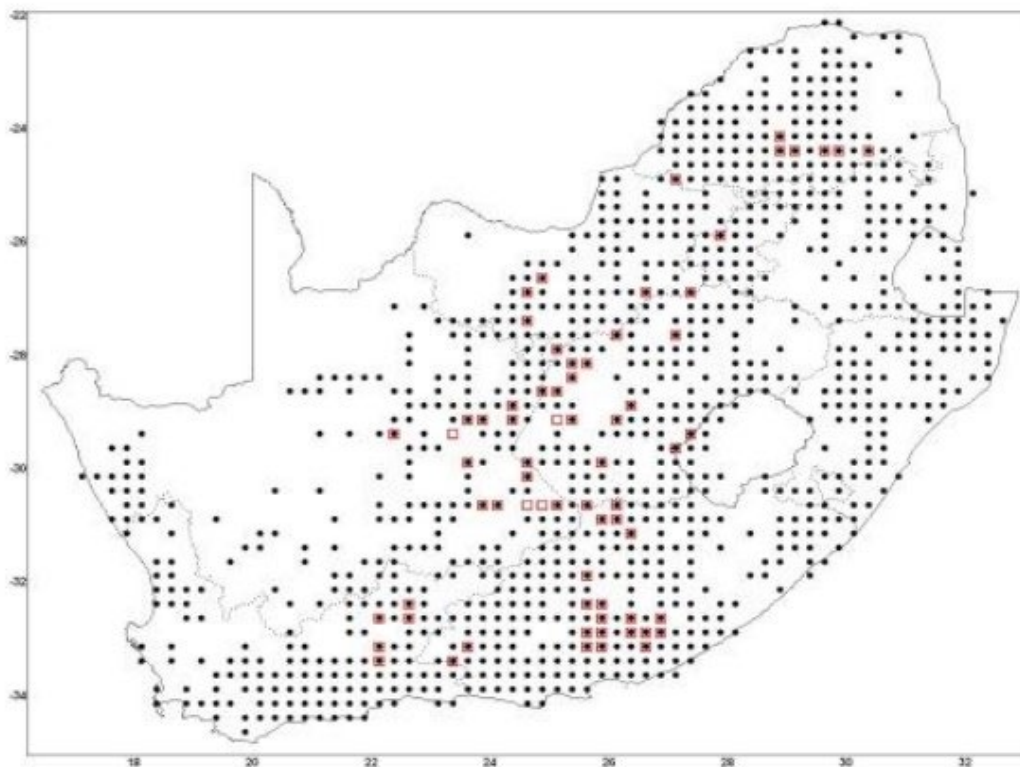


Figure 2.02 The distributions of sweet prickly pear (*Opuntia ficus-indica*) (black dots) and small round-leaved prickly pear (*O. engelmannii*) (red squares). Source: SAPIA, (2019)

2.6 Prickly pear (*Opuntia ficus-indica*) as a livestock feed

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 fibers 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 uses, 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 fleshy leaves and pear fruits are used in multiple productive sectors like industrial. Many productive sectors use cactus pear fruits and their fleshy leaves as industrial basic materials such as food additives, biopolymers, and flocculating agents for water treatment (Albergamo *et al.*, 2022).

In time of crisis, where there is nothing to eat prickly pear cladodes can be fed alone in any form because sheep and cattle can survive on it for a long period. Cutting and carrying prickly pears is practiced during drought periods, but it is not common (Dubeux, 2021). Cactus is also a good supplement to ammonia or urea-treated straw since it provides the soluble carbohydrates necessary for the efficient use of the non-protein nitrogen by microbes in the rumen (Kolawole and Mustapha, 2023). Cactus pear plays a key role as a lifesaving feed both for humans and animals, especially in times of drought. In Africa, the use of cactus for animal feed is currently limited to grazing during the dry season. Although prickly cladodes have significant potential for developing a sustainable animal production system, research about their nutritional value, use as animal feed, and involvement in animal performance is limited. Farmers usually experience diarrhoea in their livestock when fed a high dose of cactus during the dry season (De Wit and Fouché, 2021). This is because Cactus contain a sugar called sorbitol, which can cause digestive issues in goats. In large quantities, sorbitol can lead to diarrhea, bloating, and gas.

2.7 Chemical composition of Prickly pear (*Opuntia ficus-indica*)

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, fiber 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) (Table 2.01). Crude protein in prickly pear 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-Avenidaño *et al.*, 2021; Hernández-Becerra *et al.*, 2022).

Table 2.01: Nutrient composition of *Opuntia ficus indica* (%)

Nutrients	Amount	Reference
Dry matter	6.3 -13.75	Pinos-Rodríguez (2010); Rodrigues <i>et al.</i> (2016)
Crude protein	4.4 – 8.91	Misra <i>et al.</i> (2006)
Ether extract	1046 - 2.3	Toure <i>et al.</i> (2015)
Total carbohydrate	40.13 - 82.9	Rocchetti <i>et al.</i> (2018); Holkovičová <i>et al.</i> (2023)
Non-fibrous carbohydrate	51.4 – 79.2	da Silva <i>et al.</i> (2023)
NDF2	3.51 – 45.00	Rocchetti <i>et al.</i> (2018); Nefzaoui <i>et al.</i> (2001);
ADF2	15.5	Bazie <i>et al.</i> (2019); Rocchetti <i>et al.</i> (2018)
Lignin	1.55 - 3.2	Martínez <i>et al.</i> (2018)
NDF1	18.03 - 26.7	Misra <i>et al.</i> (2006)
ADF1	11.3 – 16.53	Misra <i>et al.</i> (2006)
Ash	0.24— 9.60	Elshehy <i>et al.</i> (2020)
TDN	68.6 - 71.3	Mayer <i>et al.</i> (2019)
Gross energy	13.22	Hernandez-Urbiola <i>et al.</i> (2010)

NDF: Neutral detergent Fibre; ADF: Acid detergent Fibre; DM: dry matter; CP: crude protein; TDN: Total Digestible Nutrients

All units for nutrients are % DM except Gross energy which is MJ/KgDM

2.8 Methane production and emissions by small ruminants

Methane (CH₄) is a potent greenhouse gas (GHG) having a global warming potential 28 times higher than carbon dioxide (CO₂) (Kumari *et al.*, 2016). Methane (CH₄) is a greenhouse gas generated during the feed fermentation processes in the rumen. Methane gas has no colour, no odour, no taste, and is not flammable. According to Dana and Peter (2017), enteric methane is a by-product of ruminant digestion produced by methanogenic microorganisms, Archaea, by the process called fermentation or methanogenesis. Methanogenesis is a process whereby methane is produced by microbes known as methanogens. This process occurs in the rumen during anaerobic conditions and without this process, ruminants such as goats would not be able to consume grass. Ruminant animals are the main methane producer and contribute nearly 95% of total methane emissions from livestock (McAllister *et al.*, 2015). However, the ruminal microbial communities are also responsible for various undesirable processes, for example, the production of methane, excessive degradation of protein, and biohydrogenation of unsaturated fatty acids (Belanche *et al.*, 2021).

A major challenge facing our world today is climate change caused by the emission of greenhouse gases (GHG) of anthropogenic activity (Cardona-Iglesias *et al.*, 2016). Carbon emissions from animal husbandry have been gaining increasing attention due to their high share of global carbon emissions (Shi *et al.*, 2022). Ruminants especially goats produce approximately 115 million tons of methane per year, a gas produced by rumen fermentation, which is carried out by a microbial complex of bacteria, archaea, protozoa, and fungi known as "ruminal microbiota" (Sandoval-Pelcastre *et al.*, 2020). Ruminant livestock contributes the major proportion of the total agricultural emission of methane. The methane produced by ruminants is not only related to environmental problems but is also associated with energy losses (Moumen *et al.*, 2016). Numerous factors influence methane production in livestock. Ramin and Huhtanen (2013) feed intake was found to be the most important factor in total methane production from ruminant animals. The recent focus has centered on the use of plant secondary metabolites to improve ruminal fermentation, ruminant production, and health while minimizing environmental burdens (Singh *et al.*, 2021; Singla *et al.*, 2021).

2.9 Conclusion

Based on the documented information which has been gathered goats undoubtedly need to be the priority focus for livestock industries due to their advantages over other ruminant animals from a climate resilience point of view. For the goats to survive and be productive they must browse or graze on high or adequate quality feed materials. During the dry season at most times, feed materials are scarce and the ones that are available are of low quality to meet the nutrient requirements of the goats. There is a very high potential for the utilization of prickly pear cactus in goat production, in arid and semiarid areas. However, the nutritional value of cactus must be improved to get a better performance of goats and the most efficient utilization of prickly pear. Nutritional interventions and other management strategies are traditional ways by which enteric methane emission is reduced in goats. Prickly pear fruit contains tannins which are considered to have both adverse and beneficial effects depending on their concentration and nature. The inclusion of Prickly pear fruit in the diet may also reduce methane produced by the goats since they contain tannins which tend to bind with nutrients. However, there is paucity of research available on the evaluation of Prickly pear fruit on methane production and emission.

CHAPTER THREE
MATERIALS AND METHODS

3.1 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 undercover. Browsing animals, traditionally, keep a balance between trees and grass.

3.2 Experimental designs, treatments, and procedures

Twenty-four yearling male Pedi goats that had mean live weights of 19± 2kg were used in this research. They were sourced from University of Limpopo Experimental Farm. All goats were of the same age group and before introduction to the dietary treatment goats were fed pellets and grass hay. The goats were randomly allocated to four (4) dietary treatment groups in a complete randomized design having six replications, and 1 animal per replicate. The goats were housed individually in a well-ventilated holding pen size (1 X 3 m²) having one side open to natural light and roofing to protect goats against sun and rain pen space was enough to allow them to move around freely and lie down. Each goat had feeding troughs (60 x 19 x 27cm) 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 3.01). Prickle pear fruit were obtained from Ubali Pomegranate Farm in Pretoria. They were delivered to the University by the courier from the Ubali Farm and stored in the refrigerator for 5 days to avoid them from spoiled. Prickly pear fruit were cut, dried and mixed with pellets, and grass hay to formulate a compound feed. Prickly pear fruit inclusion levels were at 0,10, 20 or 30 % (Table 3.02). The experiment was conducted for a period of 28 days, consisting of a 21-day adaptation period to confinement feeding followed by a collection period of

methane, feed offered, feed leftover, and excreta for 7 days. 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 3.01 Composition of feed materials in the experimental diets

Feed	Diet 1	Diet 2	Diet 3	Diet 4
Prickly pear fruit (%)	0	10	20	30
<i>Cenchrus ciliaris</i>				
hay (buffalo grass) (%)	66	56	46	36
Goats pellets (%)	34	34	34	34
Total (%)	100	100	100	100
Analysed chemical composition (%DM)				
DM	88.0	40.7	39.7	38.2
OM	84.1	37.0	35.4	35.8
ASH	7.47	7.36	7.29	7.17
CP	12.7	12.5	12.3	12.0
ADF	23.9	25.7	26.1	28.3
NDF	29.6	28.1	27.7	26.4
EE	16.2	16.1	16.3	16.6
Energy	1.68	1.73	1.74	1.81
Phenolics	0.0	4.52	8.14	16.2
Tannins	0.0	2.28	4.10	8.21

Table 3.02 Nutrient composition of Prickly pear (*Opuntia ficus-indica*)

Nutritive value	Prickly pear (<i>Opuntia ficus-indica</i>)
Dry Matter (g/kg)	90.40
Organic Matter (g/kg DM)	91.61
Ash (g/kg DM)	10.00
Crude Protein (g/kg DM)	8.50
Neutral detergent fibre (g/kg DM)	24.81
Acid detergent fibre (g/kg DM)	14.40
Ether Extract (g/kg DM)	4.50
Total phenolics (g/kg DM)	4.52
Tannins (g/kg DM)	2.28

Table 3.03. Dietary treatments for the study

Treatment code	Treatment description
PPF ₀	Yearling male Pedi goats fed <i>ad libitum</i> a diet containing no prickly pear fruit meal.
PPF ₁₀	Yearling male Pedi goats fed <i>ad libitum</i> a diet containing 10% prickly pear fruit meal.
PPF ₂₀	Yearling male Pedi goats fed <i>ad libitum</i> a diet containing 20% prickly pear fruit meal.
PPF ₃₀	Yearling male Pedi goats fed <i>ad libitum</i> a diet containing 30% prickly pear fruit meal.

Table 3.04 Nutritional composition of the mineral block offered to the experimental goats.

Nutrients	Quantity	Units
Protein	280	g/kg
Protein from urea	61.5	%
Protein from other NPN	2.85	%
Urea	60	g/kg
NPN	6	g/kg
Crude fibre	120	g/kg
Moisture	120	g/kg
Calcium	10 / 45	g/kg
Phosphorus	6	g/kg
Magnesium	4	g/kg
Sulphur	8	g/kg
Potassium	12	g/kg
Copper	40	mg/kg
Manganese	600	mg/kg
Zinc	600	mg/kg
Cobalt	1	mg/kg
Iodine	8	mg/kg
Iron	500	mg/kg
Selenium	4	mg/kg
Vitamin A	12 000	IE/kg

Source: Molatek Animal feeds (Multi block 28), South Africa

3.3 Data collection

Prickly pear fruits were sourced from a nearby farm, cut and sun dried for 5 days. The dried meals were used in the diets as indicated in Table 3.02 above. At the beginning of the experiment (day 21), goats were weighed using an electronic weighing scale. Thereafter, goats were weighed weekly. Live weight was used to calculate the growth rates of goats (McDonald *et al.*, 2011). Daily feed intakes were recorded throughout the experiment. Goats were provided with the diet every morning at 09:00 am, once every day until the last day of the experiment. According to McDonald *et al.* (2011), calculations for feed conversion ratio were done by dividing the total amount of feed ingested by the live weight increase of the goats. Water intakes were measured by offering goats 2 liters of water *ad libitum*. The amount of water consumed was recorded every morning before fresh water was offered. The evaporative water loss was determined by placing 2 liters of water in empty pens to simulate prevailing conditions. Water intake was adjusted for evaporative loss.

Methane emission by goats was measured daily during the collection period, measurements were done using a hand-held methane detector (Manufacture: RS PRO). The methane detector's laser beam was focused between 1 m from the goat and to goat's nasal region. Each goat had a radius of at least 6 m from any other animal when emission was recorded. The measurement was done two hours after feeding when the animals were ruminating, at 10.00 hrs. 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).

Goat blood samples were collected before the start and at the end of the experimental period. To assess blood parameters (lymphocytes, monocytes, neutrophils, eosinophils, and basophils), blood samples (5 ml) were collected using hypodermic needles to draw blood from every goat through the jugular vein into marked sterile tubes which contained ethylenediaminetetraacetic acid (EDTA), which served as an anticoagulant. The whole blood was used from the EDTA tube as we were interested in plasma samples.

Digestibility measurements were performed in metabolic cages equipped with independent watering and feeding troughs, and excreta collecting trays. Faecal bags

were used during the 7-day collection period (McDonald *et al.*, 2011). Faeces were weighed, dried, and then stored for chemical analysis. Apparent digestibility (AD) of nutrients was determined using the following formula:

$$\text{Apparent Digestibility (\%)} = \frac{\text{intake} - \text{faecal output}}{\text{intake}} \times 100.$$

3.4 Chemical analysis

Dry matter of the feeds, feed refusals, and faeces was determined by drying the samples in the oven for 24 hours at a temperature of 105°C (AOAC, 2012). The procedures for proximate, fibre, and energy analyses were used to determine the samples' neutral detergent fibre, energy content, acid detergent fibre (ADF), and crude protein (CP) contents (AOAC, 2012). The ash contents of feed were done by ashing the samples overnight at 600°C in a muffle furnace. Calcium, phosphorus, potassium, and sodium of the samples were also determined (AOAC, 2012). Using Folin–Ciocalteu methods, the total phenolics were determined and were expressed as tannic acid equivalent (%DM). Using the Butanol–HCl method, the condensed tannins were determined and were expressed as leucocyanidin equivalent (%DM) (AOAC, 2012).

3.5 Statistical analysis

The nutrient and tannin contents of the diets were subjected to analysis of variance (ANOVA) using Statistical Package for the Social Sciences (SPSS, 2020). Data that was collected from the animals was scrutinized by ANOVA using the nutrient and tannin contents and initial weights of the animals, as the covariates to statistically consider differences in baseline values. Where the covariates showed no significant effect, the data were analysed with ANOVA in a completely randomized design with diet as a fixed factor. Additionally, methane and blood data obtained before and during the experiment were compared using ANOVA in a completely randomized design to monitor the changes in methane and blood indices of yearling Pedi goats on prickly pear supplemented diets.

The data was analysed using analysis of variance (ANOVA) using SAS 9.4 (2012). The $Y_{ij} = \mu + T_i + b_1X_1 + e_{ij}$ statistical model was used. Where Y_{ij} represents diet intake, methane emission, blood profiles, digestibility, or productivity; μ = the overall mean; T_i represents dietary treatments ($i = 0, 10, 20, \text{ or } 30\%$); b_1 represents the slope; X_1 represents prickly pear, DM, OM, Ash, CP, NDF, ADF, EE and energy intakes; and e_{ij}

represents random error. For mean separation, the Tukey's honestly significant difference test (HSD) was used when there were significant differences at 5% level of probability ($P < 0.05$).

Regression equations was applied to analyse the relationship and responses of yearling Pedi goats to varying quantities of prickly pear fruit meal in a diet in terms of feed intake, methane emission, growth performance, digestibility, and blood profiles (SPSS, 2020). The following quadratic equation (SPSS, 2020) was used to determine the levels for optimal responses:

$$Y = a + b_1x + b_2x^2 + e$$

Where y = methane emission, blood profile, diet intake, digestibility, or productivity; a = intercept; x = inclusion levels of Prickly pear fruit meal, b_1 and b_2 = coefficients of the quadratic equations, e is the error and $-b_1/2b_2 = x$ value for optimal response.

Where relevant, according to SPSS (2020), the following linear equation was used to model the relationships between inclusion levels of prickly pear and feed intake, methane emission, performance, diet digestibility, or blood profiles of goats:

$$Y = a + bx$$

Where y = methane emission, blood profiles, productivity, diet intake, or digestibility; a = intercept; b = coefficient of the linear equation, and x = inclusion level of prickly pear fruit meal in the diet.

CHAPTER FOUR
RESULTS

4.1 Effect of prickly pear leaf meal inclusion level on diet intake, nutrient intake and digestibility of yearling male Pedi goats

The results of the effect of prickly pear meal inclusion level on diet nutrient intake of yearling male Pedi goats are presented in Table 4.01. Prickly pear meal inclusion level on diet had an effect ($P<0.05$) on DM, OM, Ash, CP, ADF, NDF, and EE intakes of yearling male Pedi goats. Male Pedi goats fed with diets having 10 and 20% had higher ($P<0.05$) DM, OM, Ash, CP, ADF, NDF, and EE intakes than those on a diet having a 0 and 30% prickly pear meal inclusion levels. Similarly, male Pedi goats on diets containing 10 and 20 % prickly pear meal inclusion levels had similar ($P>0.05$) DM, OM, Ash, CP, ADF, NDF, and EE intakes. Male Pedi goats on diets having 30% prickly pear meal inclusion levels had higher ($P<0.05$) diet DM, OM, Ash, CP, ADF, NDF, and EE intakes than those on a diet having a 0% Prickly pear meal inclusion level.

The results of the effect of prickly pear meal inclusion level on nutrient digestibility of yearling male Pedi goats are presented in Table 4.01. Male Pedi goats fed diets having 10 and 30% prickly pear meal inclusion levels had higher ($P<0.05$) DM (90.67% and 90.99%) and OM (90.09% and 90.53%) digestibility values than those fed diets having 0% and 20 % prickly pear inclusion levels. Similarly, male Pedi goats fed diets having 10 and 30 % prickly pear meal inclusion levels had the same ($P>0.05$) DM (90.67% and 90.99%) and OM (90.09% and 90.53%) digestibility values. Moreover, male Pedi goats fed diets having 0, 10, and 30 % prickly pear inclusion levels had similar ($P>0.05$) DM (89.73%, 90.67% and 90.99%) and OM (89.53%, 90.09% and 90.53%) digestibility values. However, male Pedi goats fed diets having 0% prickly pear inclusion levels had higher($P<0.05$) DM (89.73%) and OM (89.53%) digestibility values than those on diets having 20% prickly pear inclusion levels.

Male Pedi goats fed diets having 0% prickly pear meal inclusion level had higher ($P<0.05$) ash (16.78%) digestibility values than those fed diets having 10% (13.68%), 20% (14.85%), and 30% (15.39%) prickly pear meal inclusion levels. Male Pedi goats fed diets having 20 and 30% prickly pear meal inclusion levels had higher ($P<0.05$) ash (14.85% and 15.39%) digestibility values than those fed diets having 10% (13.68%) prickly pear meal inclusion levels. Similarly, goats fed diets containing 20 and 30% prickly pear meal inclusion levels had the same ($P>0.05$) ash (14.85% and 15.39%) digestibility values. Male Pedi goats on diets having 30% prickly pear meal

inclusion level had higher ($P<0.05$) CP digestibility than those fed diets having 0, 10, and 20% prickly pear meal inclusion levels. Similarly, male Pedi goats fed diets having 0, 10, and 30% prickly pear meal inclusion levels had similar ($P>0.05$) CP digestibility. Male Pedi goats fed a diet having 0 and 10% prickly meal inclusion levels had higher ($P<0.05$) CP digestibility values than those on diets having 20% prickly pear inclusion levels. However, male Pedi goats fed diets having 0 and 10% prickly pear meal inclusion levels had the same ($P>0.05$) CP digestibility values. Similarly, male Pedi goats fed diets having 0, 10, and 20% prickly pear meal inclusion levels had similar ($P>0.05$) CP digestibility.

Male Pedi goats fed a diet having 10% prickly pear meal inclusion levels had higher ($P<0.05$) NDF (52.87%) digestibility values than those comprises of 0, 20, and 30% prickly pear meal inclusion levels. However, male Pedi goats fed diets having 30% prickly pear meal inclusion levels had higher ($P<0.05$) NDF (51.17%) digestibility values than those fed diets having 0 and 20% prickly pear meal inclusion levels. Male Pedi goats fed diets having 20% prickly pear meal inclusion levels had higher ($P<0.05$) NDF(50.65%) digestibility values than those fed diets having 0% (48.13%) prickly pear meal inclusion levels.

Male Pedi goats on a diet having 30% prickly pear meal inclusion level had higher ($P<0.05$) ADF (55.82%) digestibility value than those fed diets having 0, 10, and 20% prickly pear meal inclusion levels. However, goats fed diets containing 0% prickly pear meal inclusion levels had higher ($P<0.05$) ADF (55.13%) digestibility than those fed diets having 10 and 20% prickly pear meal inclusion levels. Male Pedi goats fed diets containing 20% prickly pear meal inclusion levels had higher ($P<0.05$) ADF (54.62%) digestibility than those fed diets having 10% prickly pear meal inclusion level.

Male Pedi goats fed a diet having 10% prickly pear meal inclusion level had higher ($P<0.05$) ether extract (EE) (4.89%) digestibility values than those fed diets having 0, 20, and 30% prickly pear meal inclusion levels. Similarly, male Pedi goats fed diets having 0, 10, and 20% prickly pear meal inclusion levels had similar ($P>0.05$) EE (4.66%, 4.89% and 4.37%) digestibility values prickly pear meal inclusion level. Furthermore, male Pedi goats fed diets having 0 and 20% Prickly pear meal inclusion levels had higher ($P<0.05$) EE (4.66% and 4.37%) digestibility values than those on diets having a 30% prickly pear inclusion levels.

Male Pedi goats fed diets having 0 and 20% prickly pear inclusion levels had the same ($P>0.05$) EE digestibility values. Male Pedi goats on a diet having 30 % prickly pear meal inclusion level had higher ($P<0.05$) energy digestibility than those on diets having 0, 10 and 20% prickly pear meal inclusion level. However, male Pedi goats fed diets containing 20 % prickly pear meal inclusion levels had higher ($P<0.05$) energy digestibility than those on diets having 0 and 10% prickly pear meal inclusion levels.

Table 4.01 Effect of prickly pear (*Opuntia ficus-indica*) inclusion level on diet intake, nutrient intake and digestibility yearling male Pedi goats.

Variables	Treatment [#]				P-Value
	PPF ₀	PPF ₁₀	PPF ₂₀	PPF ₃₀	
Diet intake (g/goat/day)					
DM	269.73 ^c ±0.431	278.06 ^a ±0.348	277.32 ^a ±0.225	275.55 ^b ±0.382	<.0001
OM	247.10 ^c ±0.394	254.73 ^a ±0.319	254.05 ^a ±0.203	252.43 ^b ±0.350	<.0001
Ash	28.73 ^c ±0.046	29.61 ^a ±0.037	29.53 ^a ±0.024	29.34 ^b ±0.041	<.0001
CP	22.93 ^c ±0.035	23.64 ^a ±0.028	23.57 ^a ±0.019	23.42 ^b ±0.035	<.0001
ADF	38.84 ^c ±0.061	40.04 ^a ±0.050	39.93 ^a ±0.034	39.68 ^b ±0.055	<.0001
NDF	66.92 ^c ±0.107	68.99 ^a ±0.089	68.80 ^a ±0.055	68.36 ^b ±0.096	<.0001
EE	12.14 ^c ±0.017	12.51 ^a ±0.017	12.48 ^a ±0.010	12.40 ^b ±0.017	<.0001
Energy (MJ/day)	4.77 ^c ±0.018	4.95 ^b ±0.009	4.99 ^{ab} ±0.033	5.02 ^a ±0.005	<.0001
Intake (g/kgW^{0.75})					
DM	40.06 ^d ±0.014	41.95 ^b ±0.017	40.46 ^c ±0.026	45.25 ^a ±0.023	<.0001
OM	36.03 ^c ±0.015	38.04 ^b ±0.017	36.01 ^c ±0.026	41.25 ^a ±0.023	<.0001
Ash	10.78 ^d ±0.015	12.88 ^c ±0.017	14.92 ^b ±0.453	16.30 ^a ±0.023	<.0001

CP	11.01 ^d ±0.015	13.16 ^c ±0.017	16.11 ^b ±0.052	16.74 ^a ±0.023	<.0001
ADF	19.74 ^c ±0.014	23.03 ^b ±0.017	17.85 ^d ±0.026	24.67 ^a ±0.023	<.0001
NDF	27.33 ^c ±0.014	28.80 ^b ±0.017	25.08 ^d ±0.026	30.71 ^a ±0.023	<.0001
EE	9.20 ^a ±0.014	7.14 ^b ±0.017	5.70 ^d ±0.026	6.5 ^c ±0.023	<.0001
Energy (MJ/kg W ^{0.75})	0.74 ^b ±0.017	0.62 ^c ±0.006	0.45 ^d ±0.006	1.27 ^a ±0.039	<.0001
Digestibility					
DM	89.73 ^{ab} ± 0.064	90.67 ^a ± 0.606	87.25 ^b ± 1.083	90.99 ^a ± 0.367	0.0135
OM	89.53 ^{ab} ± 0.038	90.09 ^a ± 0.499	87.00 ^b ± 1.083	90.53 ^a ± 0.367	0.0161
Ash	16.78 ^a ± 0.465	13.68 ^c ± 0.125	14.85 ^b ± 0.015	15.39 ^b ± 0.127	0.0002
CP	87.46 ^{ab} ±0.064	87.69 ^{ab} ±0.606	84.96 ^b ±1.083	88.48 ^a ±0.367	0.0240
NDF	48.13 ^d ± 0.055	52.87 ^a ± 0.078	50.65 ^c ± 0.114	51.17 ^b ± 0.064	<.0001
ADF	55.13 ^b ± 0.035	54.40 ^d ± 0.055	54.62 ^c ± 0.021	55.82 ^a ± 0.035	<.0001
EE	4.66 ^{ab} ± 0.032	4.89 ^a ± 0.026	4.37 ^{ab} ± 0.304	4.22 ^b ± 0.026	0.0596
Energy	2.06 ^d ±0.017	2.33 ^c ± 0.024	2.34 ^b ± 0.023	2.47 ^a ± 0.015	<.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; NDF: Neutral Detergent Fibre; ADF: Acid Detergent Fibre; & EE: Ether extracts

#: Diet codes are explained in Table 3.01, Chapter 3

4.2 Effect of prickly pear leaf meal inclusion level on live weight, feed intake, feed conversion ratio, average daily gains and water intake of yearling male Pedi goats

The results of the effect of prickly pear meal inclusion level on live weights, feed intakes, feed conversion ratios, average daily gains and water intakes of yearling male Pedi goats are presented in Table 4.02. Prickly pear inclusion level in a diet had no effect ($P>0.05$) on the initial live weight, feed conversion ratios and water intake of goats. However, prickly pear inclusion level in a diet had a significant effect ($P<0.05$) on final live weight, average daily gain (ADG) and feed intake of male Pedi goats. Male Pedi goats fed a diet having 20% prickly pear meal inclusion level had higher ($P<0.05$) final weights (23.13kg) than those fed diets having 0% (20.30kg), 10% (22.03kg) and 30% (21.17kg) prickly pear meal inclusion levels. Similarly, goats on diets having 10, 20 and 30% prickly pear meal inclusion levels had similar ($P>0.05$) final live weights. Male Pedi goats fed diets having 10 and 30% prickly pear meal inclusion levels had higher ($P>0.05$) final live weights than those on diets having 0% prickly pear inclusion levels. However, male Pedi goats fed a diet having 10 and 30% prickly pear meal inclusion had the same ($P>0.05$) final live weights (22.03kg and 21.17kg).

Male Pedi goats fed a diet having 30% prickly pear meal inclusion level had higher ($P<0.05$) ADG than those fed diets having 0, 10 and 20% prickly pear meal inclusion levels. Similarly, male Pedi goats fed diets having 10, 20 and 30% prickly pear meal inclusion had similar ($P>0.05$) ADG. Furthermore, goats fed diets having 10 and 20% prickly pear meal inclusion levels had higher ($P<0.05$) ADG than those on diets having 0% prickly pear inclusion levels. However, Male Pedi goats fed a diet having 10 and 20% prickly pear meal inclusion levels had the same ($P>0.05$) ADG values. Similarly, male Pedi goats fed diets having 0, 10 and 2% prickly pear meal inclusion levels had similar ($P>0.05$) ADG values.

Male Pedi goats fed diets having 10 and 20% prickly pear meal inclusion levels had higher ($P<0.05$) feed intakes (278.07g/kg and 275.57g/kg) than those fed diets having 0% (269.73g/kg) and 30% (277.33g/kg) prickly pear meal inclusion levels. Male Pedi goats fed diets having 10 and 20% prickly pear meal inclusion levels had the same ($P>0.05$) feed intake values. However, male Pedi goats fed diets having 30% prickly

pear meal inclusion had higher ($P<0.05$) feed intakes (277.33g/kg) than those fed a diet having 0% (269.73g/kg) prickly pear meal inclusion levels.

Table 4.02 Effect of prickly pear (*opuntia ficus-indica*) inclusion level on live weights, average daily gain and feed conversion ratio, feed intake and water intake of yearling male Pedi goats.

Variables	Treatment [#]				P-Value
	PPF ₀	PPF ₁₀	PPF ₂₀	PPF ₃₀	
Live weight (g/goat/day)					
Initial (kg)	18.67±0.547	20.00±2.260	18.93±1.277	18.93±1.278	0.2921
Final (kg)	20.30 ^b ±0.503	22.03 ^{ab} ±0.924	23.13 ^a ±1.255	21.17 ^{ab} ±0.518	0.1941
ADG (g/goat/day)	58.57 ^b ±6.099	72.77 ^{ab} ±9.922	71.43 ^{ab} ±2.050	79.77 ^a ±3.143	0.1805
Feed Intake	269.73 ^c ±0.433	278.07 ^a ±0.338	275.57 ^a ±0.376	277.33 ^b ±0.240	<.0001
FCR	4.71±0.524	3.99±0.613	3.89±0.110	3.47±0.717	0.2695
Water intake (ml/day)	76.27± 18.087	95.80± 1.443	79.20± 15.158	74.20± 20.158	0.1007

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 3.01, Chapter 3

Dry matter, organic matter, ash, crude protein, acid detergent fibre, neutral detergent fibre, Acid detergent lignin and ether extract intake were optimized at prickly pear meal inclusion levels of (18.5, 18.41, 16.33, 19.50, 22.16, 19.17, 18.29 and 20.5 ($r^2=0.924$, 0.924, 0.924, 0.920, 0.923, 0.923, 0.925, 0.928), respectively (Figures 4.01, 4.02, 4.03, 4.05, 4.06, 4.07 and 4.08, respectively and Table 4.03). Neutral detergent fibre

digestibility was optimized at prickly pear meal inclusion level of 17.50 ($r^2=0.592$), respectively (Figure 4.08, respectively and Table 4.03).

Table 4.03 Prickly pear inclusion levels for optimal diet intake and digestibility in yearling male Pedi goats.

Factor	Formula	X	Y	r^2	P
Intake (g/goat/day)					
DM	$Y = 270.13 + 0.925x \pm 0.025x^2$	18.5	278.69	0.924	0.275
OM	$Y = 247.47 + 0.847x \pm 0.023x^2$	18.41	255.27	0.924	0.275
Ash	$Y = 28.77 + 0.098x \pm 0.003x^2$	16.33	29.57	0.924	0.276
CP	$Y = 22.97 + 0.078x \pm 0.002x^2$	19.50	23.73	0.920	0.282
ADF	$Y = 38.90 + 0.133x \pm 0.003x^2$	22.16	43.32	0.923	0.278
NDF	$Y = 67.021 + 0.230x \pm 0.006x^2$	19.17	69.23	0.923	0.277
EE	$Y = 12.158 + 0.041x \pm 0.001x^2$	20.5	12.58	0.928	0.269
Digestibility					
NDF	$Y = 48.615 + 0.385x + -0.011x^2$	17.50	51.98	0.592	0.639

X: Inclusion level for optimal value

Y: Optimal Y-level

R^2 : Coefficient of determination

P: Probability

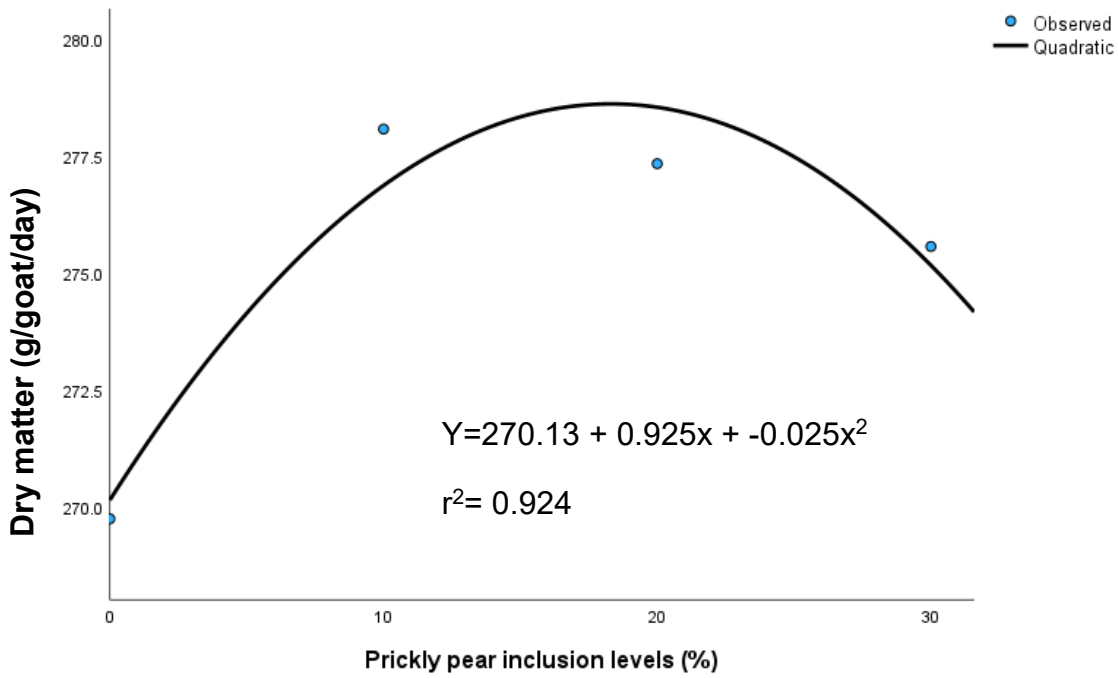


Figure 4.01 The effect of prickly pear inclusion level on dry matter intake of male yearling Pedi goats

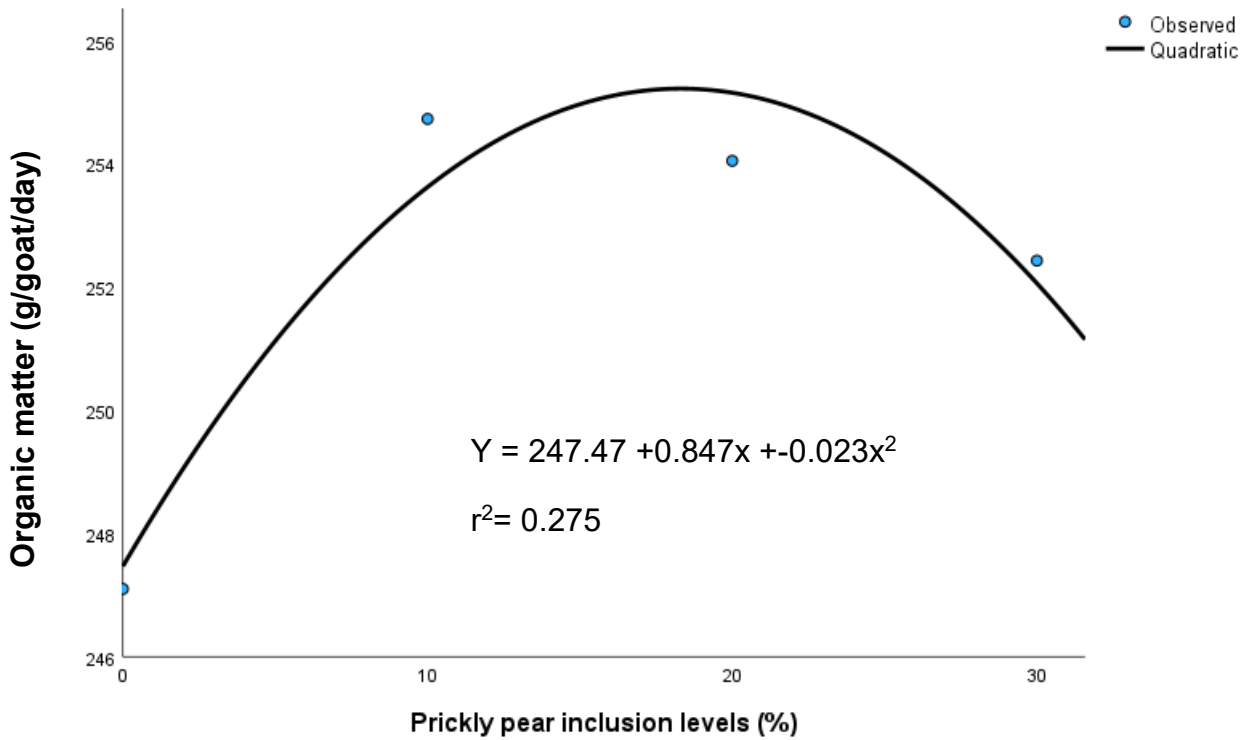


Figure 4.02 The effect of prickly pear inclusion level on organic matter intake of male yearling Pedi goats

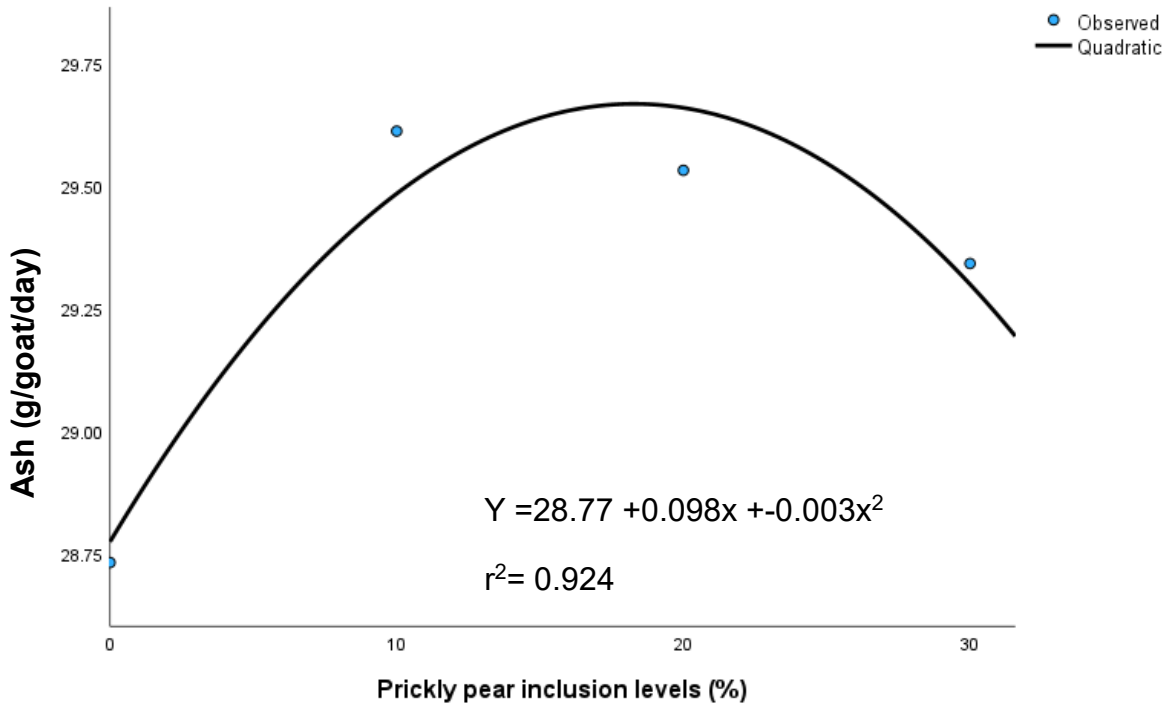


Figure 4.03 The effect of prickly pear inclusion level on ash intake of male yearling Pedi goats.

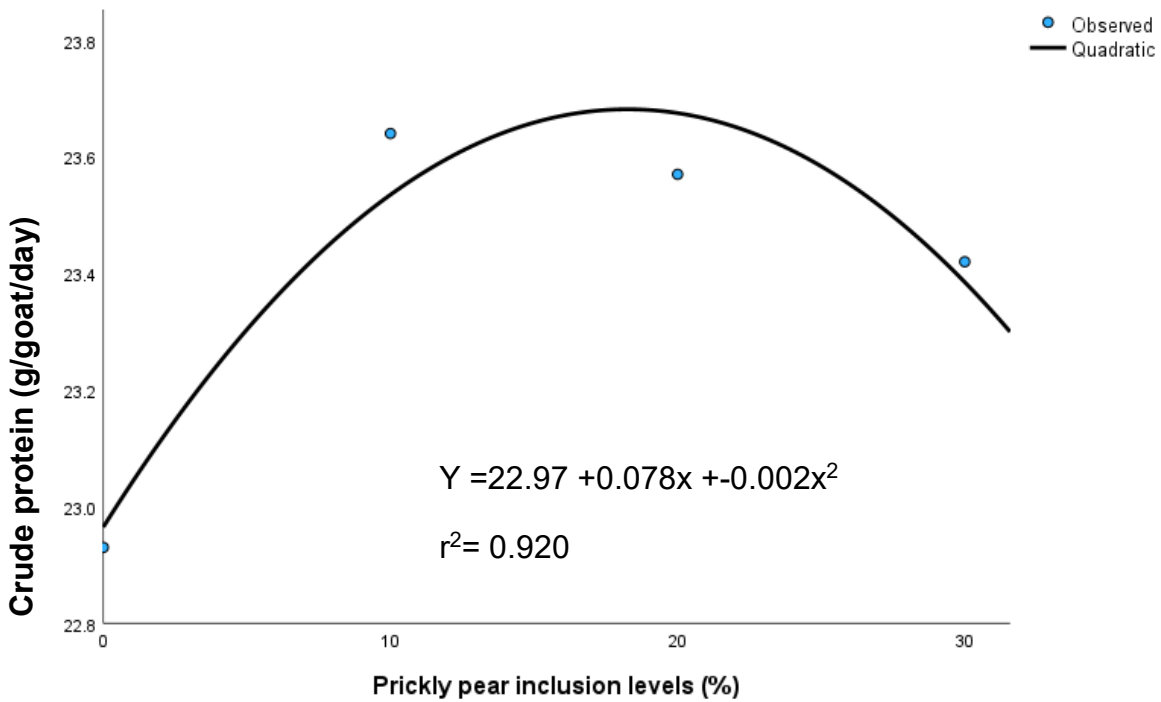


Figure 4.04 The effect of prickly pear inclusion level on crude protein intake of male yearling Pedi goats.

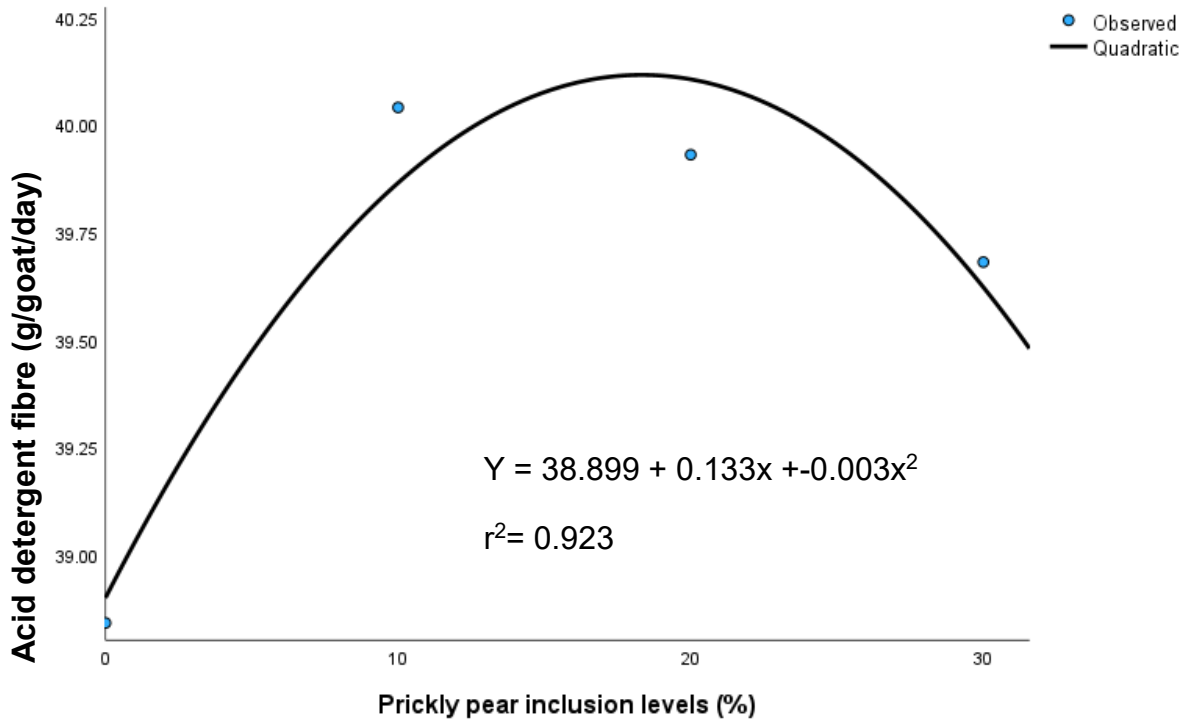


Figure 4.05 The effect of prickly pear inclusion level on acid detergent fibre intake of male yearling Pedi goats.

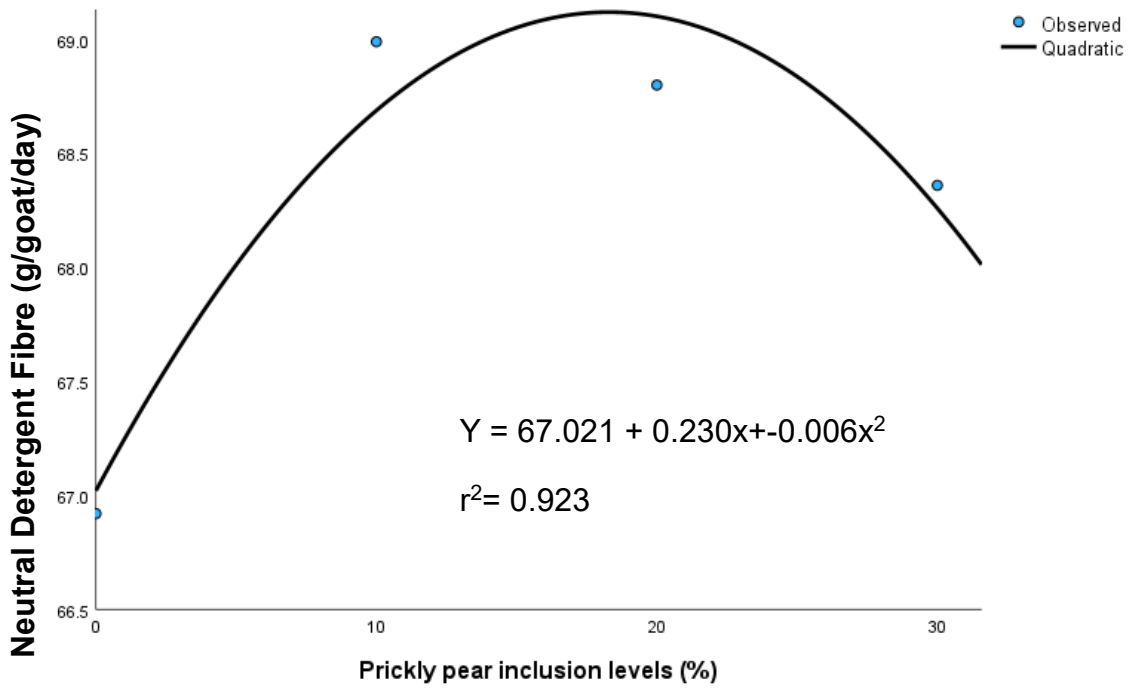


Figure 4.06 The effect of prickly pear inclusion level on neutral detergent fibre intake of male yearling Pedi goats.

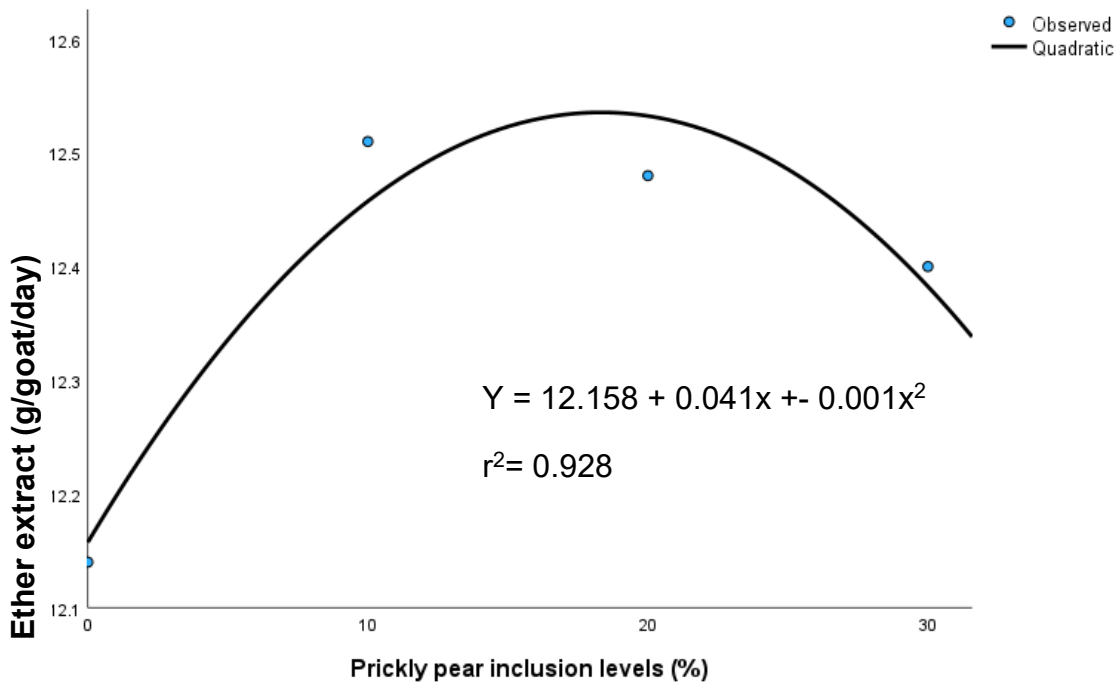


Figure 4.07 The effect of prickly pear inclusion level on ether extract intake of male yearling Pedi goats.

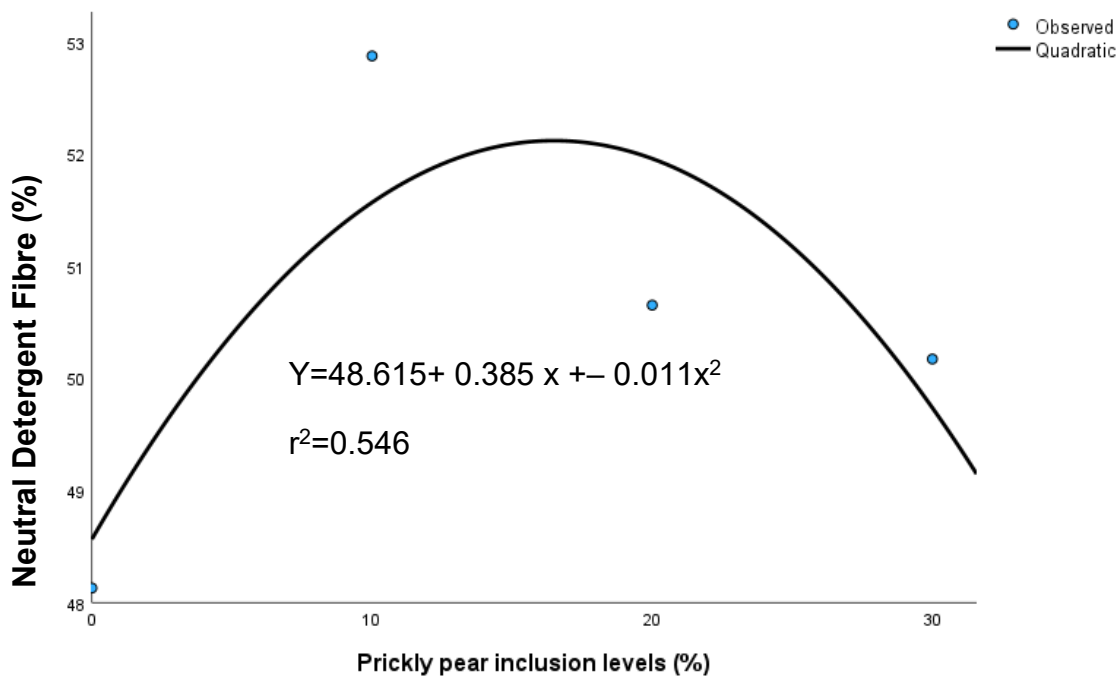


Figure 4.08 The effect of prickly pear inclusion level on NDF digestibility of male yearling Pedi goats

Initial and final weights and feed and water intakes were optimized at Prickly pear meal inclusion of 16.10, 17.07, 21.75 and 13.21 ($r^2= 0.871, 0.933, 0.734$ and 0.608) respectively (Figures 4.09, 4.10, 4.11 and 4.12 respectively and Table 4.04).

Table 4.04 Prickly pear inclusion levels for optimal diet intake, digestibility, initial weight, final weight, feed intake and water intake in yearling male Pedi goats.

Factor	Formula	X	Y	r ²	P
IW (kg)	$Y = 18.5140.284x + -0.008x^2$	16.10	20.81	0.871	0.360
FW (Kg)	$Y = 20.179 + 0.314x \pm 0.009x^2$	17.07	22.92	0.933	0.259
FI (Kg)	$Y = 270.49 + 0.696x + -0.016x^2$	21.75	278.05	0.734	0.516
Water Intake	$Y = 78.657 + 1.612x + -0.061x^2$	13.21	89.31	0.608	0.626

X: Inclusion level for optimal value

Y: Optimal Y-level

r²: Coefficient of determination

P: Probability

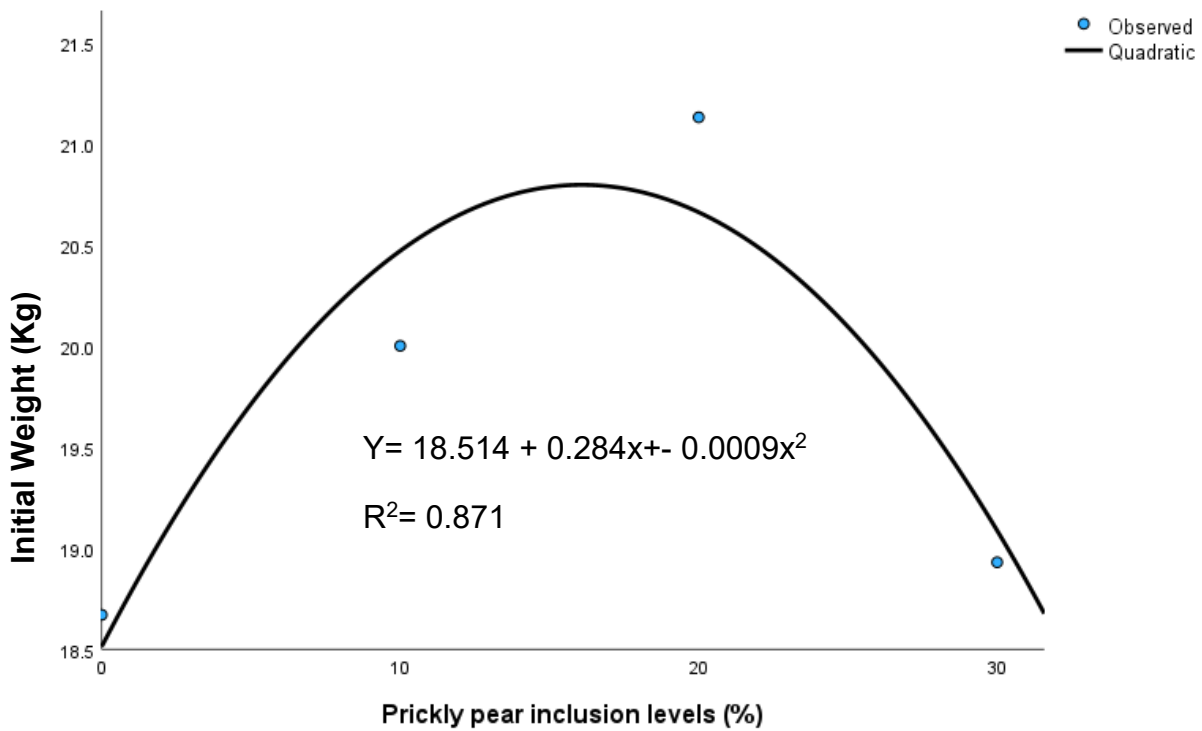


Figure 4.09 The effect of prickly pear inclusion level on initial weight of male yearling Pedi goats

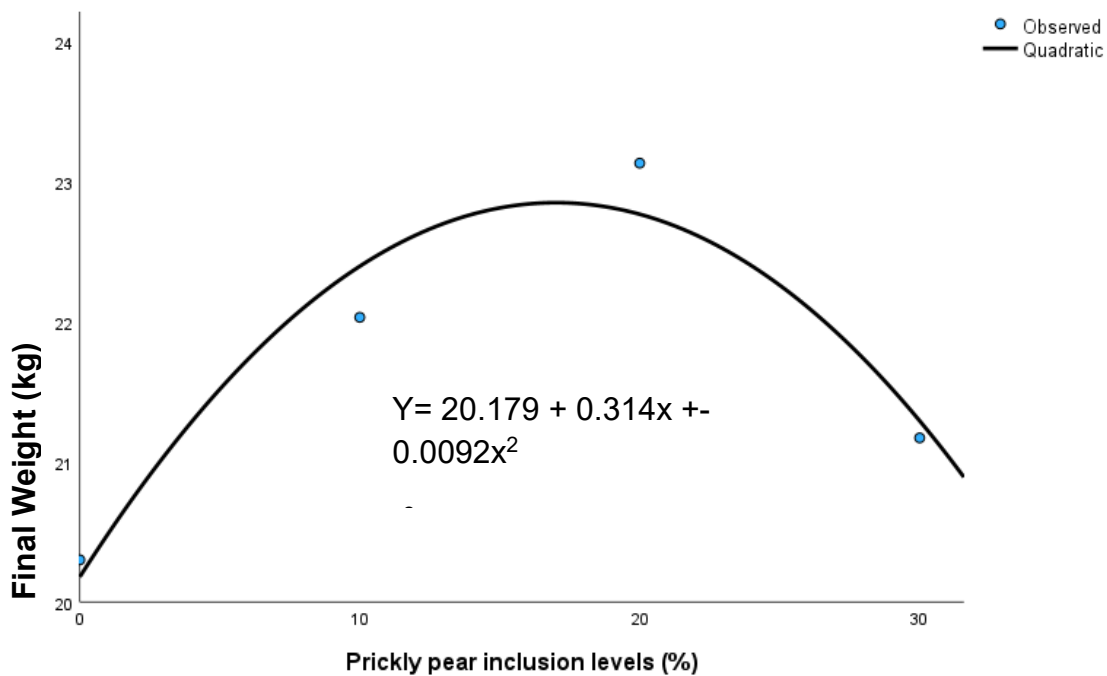


Figure 4.10 The effect of prickly pear inclusion level on final weight of male yearling Pedi goats.

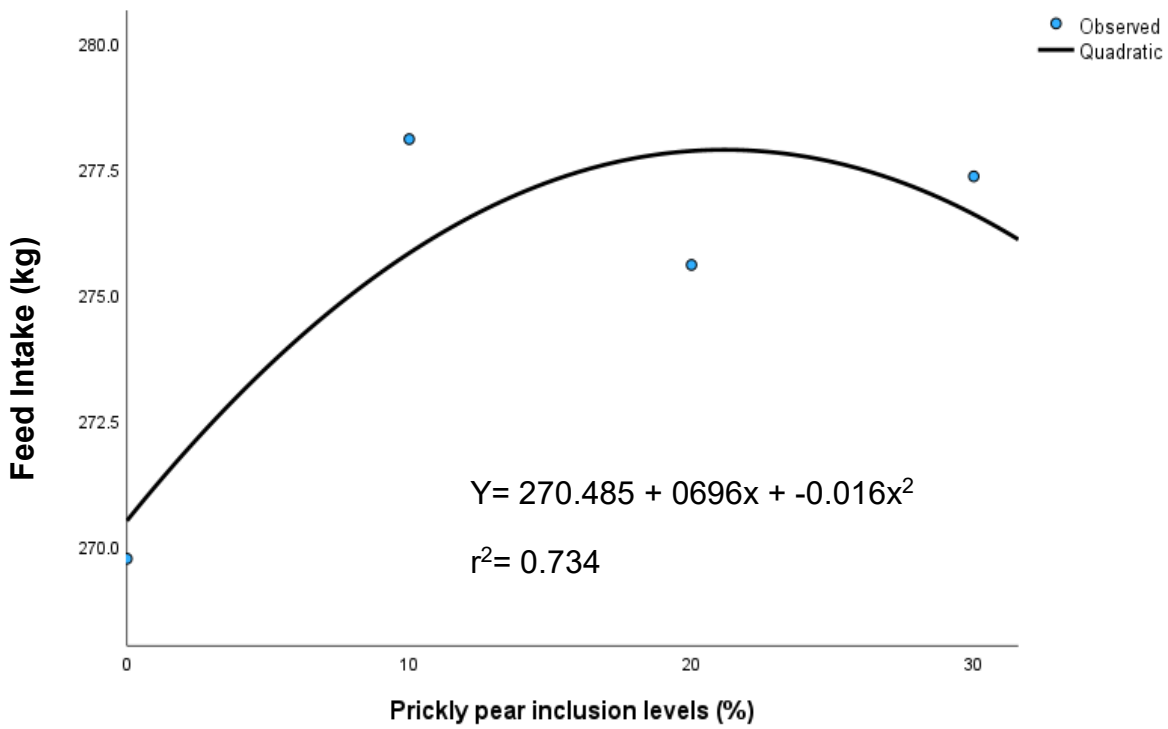


Figure 4.11 The effect of prickly pear inclusion level on feed intake of male yearling Pedi goats

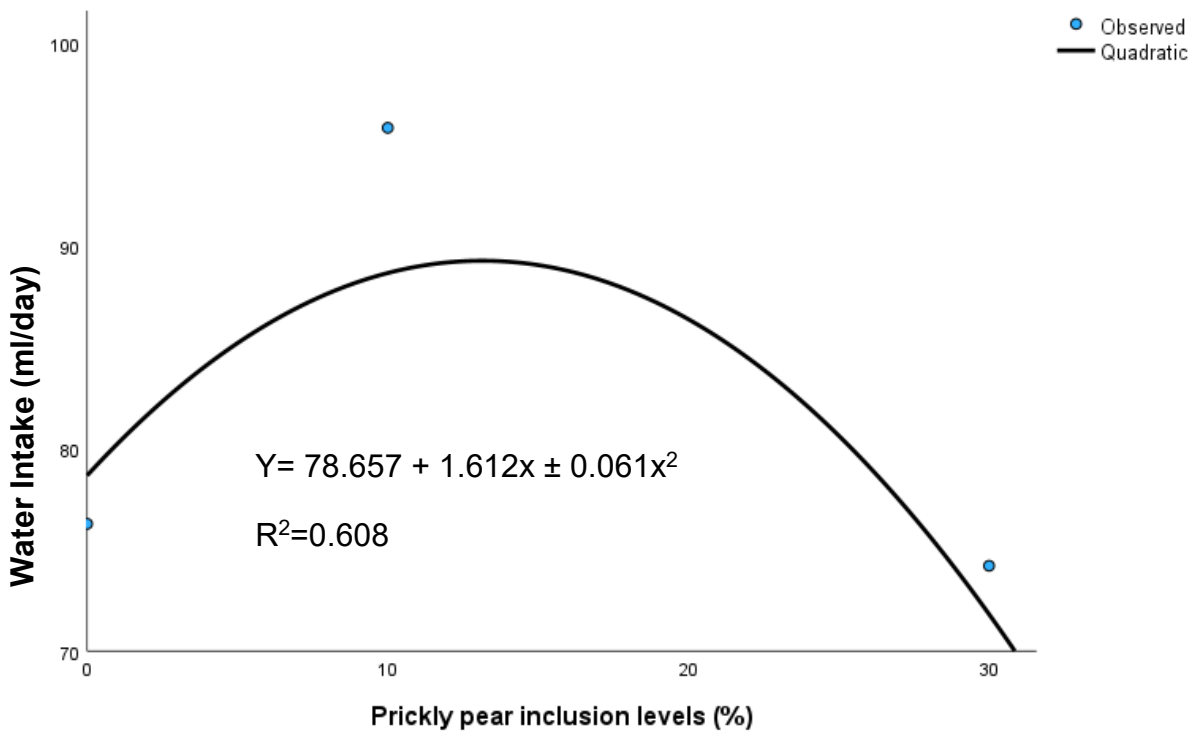


Figure 4.12 The effect of prickly pear inclusion level on water intake of male yearling Pedi goats

A positive relationship was observed between Prickly pear meal inclusion level and Dry matter ($r^2=0.180$), ash ($r^2=0.001$), Crude protein ($r^2=0.001$), acid detergent fibre ($r^2=0.084$) and energy ($r^2=0.968$) digestibilities in male Pedi goats (Figures 4.13, 4.14, 4.15, 4.16 and 4.18, respectively and Table 4.05). Moreover, Positive relationship was observed between Prickly pear meal inclusion level and average daily weight gain ($r^2=0.828$) in male Pedi goats (Figures 4.19 and Table 4.05). A negative relationship was observed between Prickly pear meal inclusion level and ether extract ($r^2=0.631$) digestibility and methane ($r^2=0.889$) in male Pedi goats (Figures 4.17 and 4.20, and Table 4.05 respectively).

Table 4.05 Relationships between prickly pear meal inclusion level and dry matter, Ash, crude protein, acid detergent fibre, ether extract, energy digestibility and average daily gain of male Pedi goats.

Variable	Formula	r^2	Probability
Digestibility (decimal)			
DM	$Y=0.064 + 88.206$	$r^2=0.180$	0.973
Ash	$Y=0.03x + 15.63$	$r^2=0.001$	0.699
CP	$Y=0.003x + 87.10$	$r^2=0.001$	0.972
ADF	$Y=0.053x + 53.95$	$r^2=0.084$	0.531
EE	$Y=-0.018x + 4.811$	$r^2=0.631$	0.205
Energy	$Y=0.0012x + 2.114$	$r^2=0.864$	0.071
Live weight (g/goat/day)			
ADG (g/goat/day)	$Y= 0.623x + 61.296$	$r^2=0.828$	0.090
Methane (ppm-m)	$Y=-0.227x + 18.74$	$r^2=0.880$	0.057

r^2 : Coefficient of determination

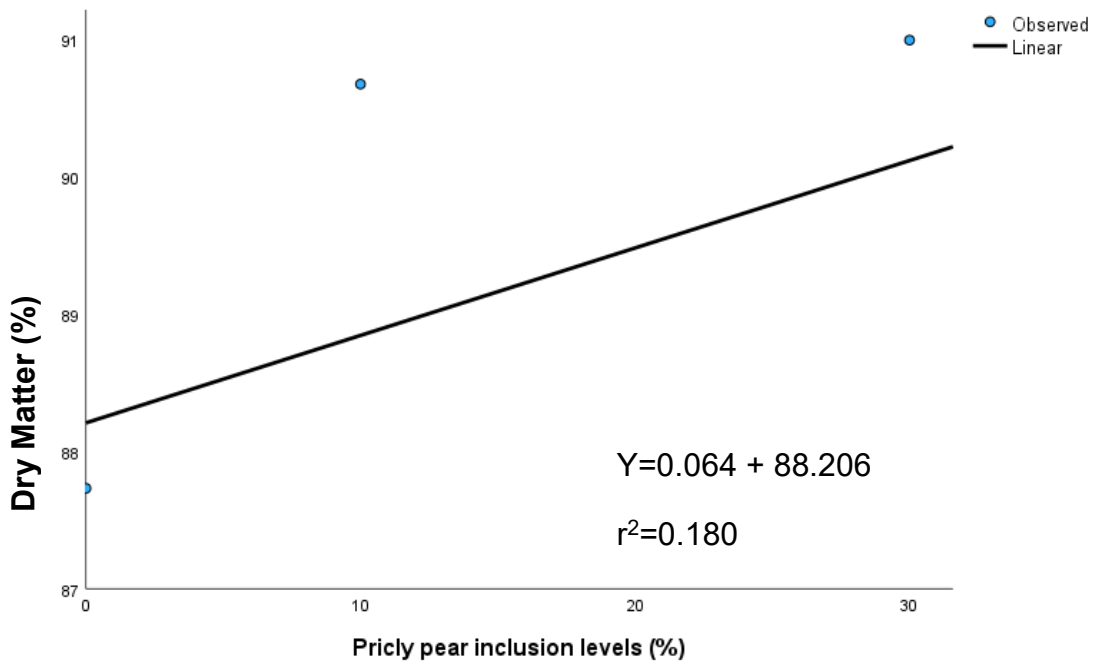


Figure 4.13 The effect of prickly pear inclusion level on DM digestibility of male yearling Pedi goats

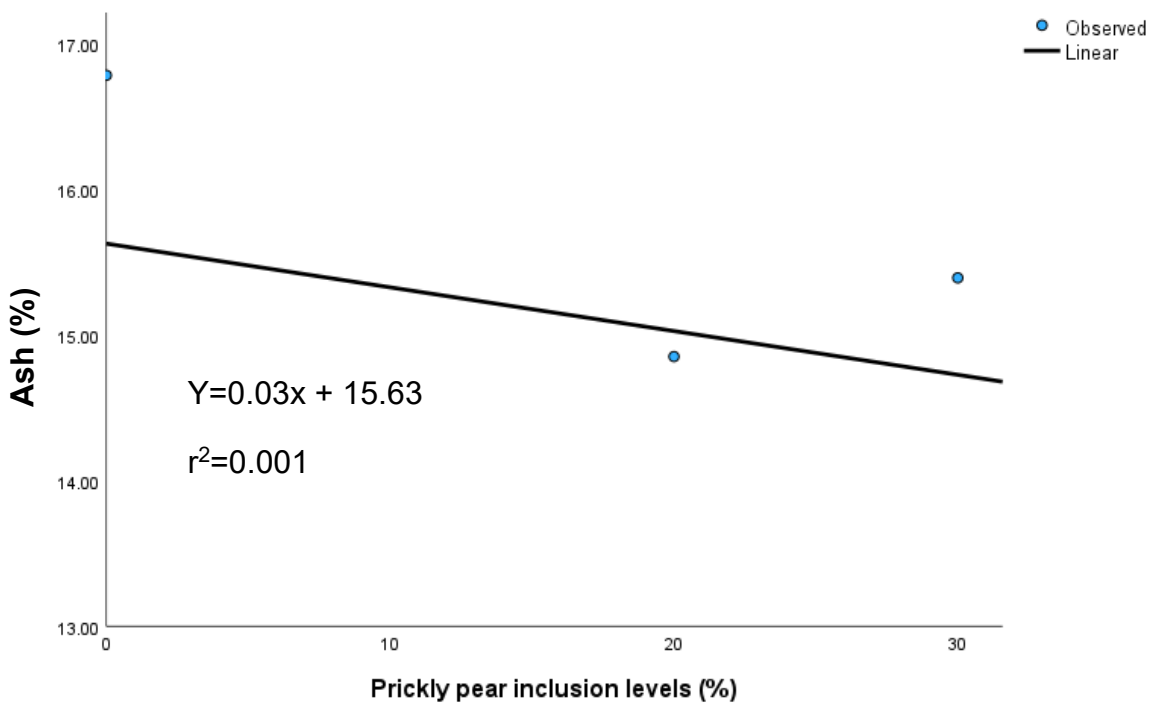


Figure 4.14 The effect of prickly pear inclusion level on Ash digestibility of male yearling Pedi goats

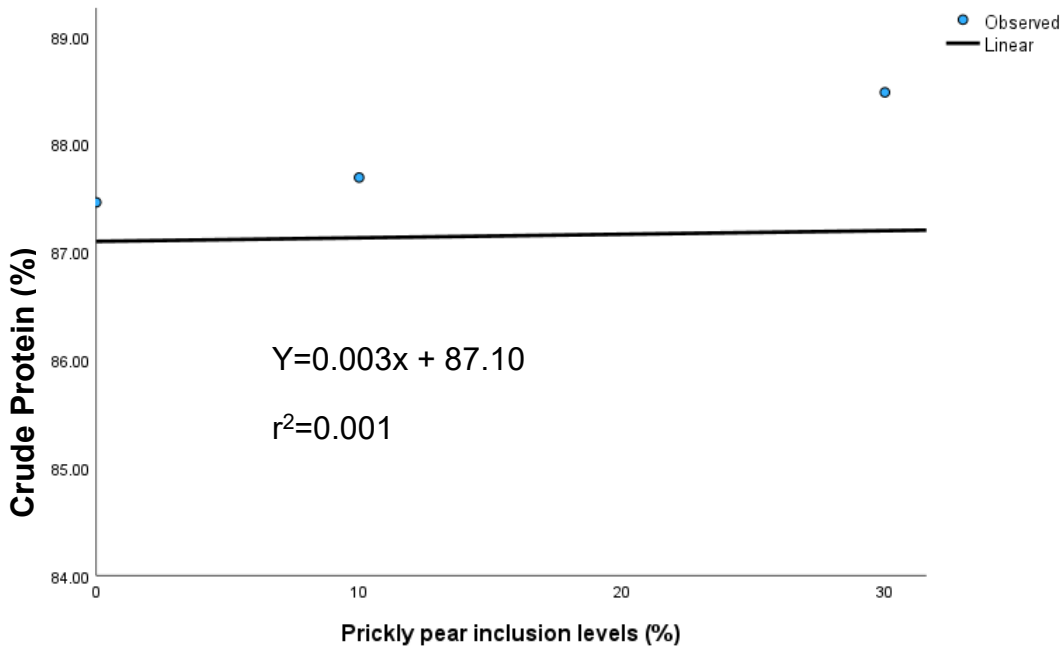


Figure 4.15 The effect of prickly pear inclusion level on CP digestibility of male yearling Pedi goats

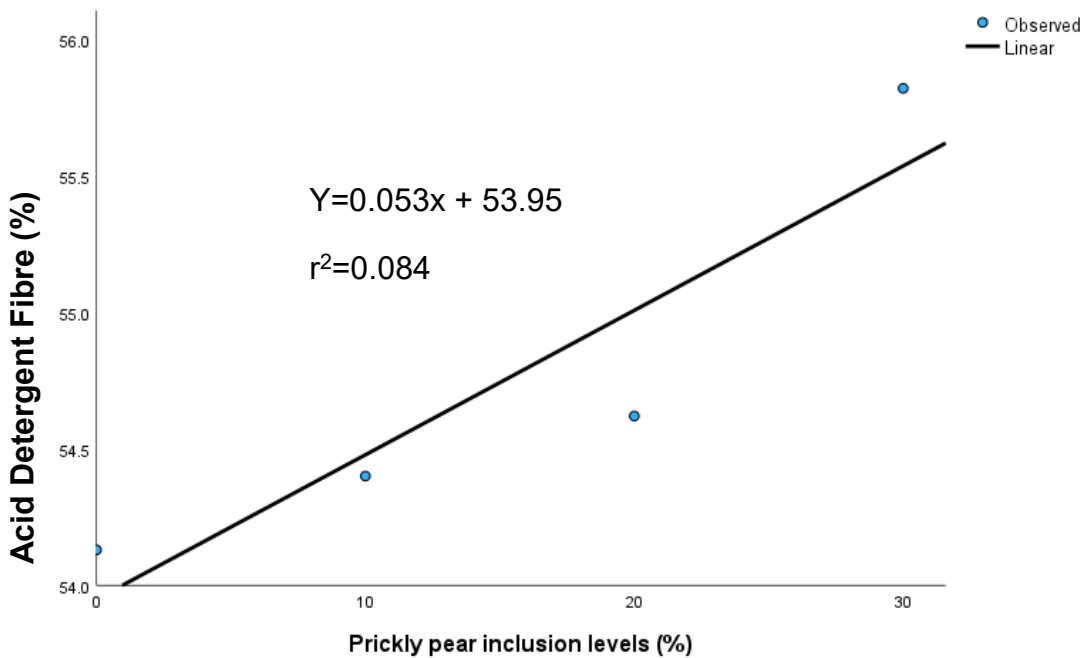


Figure 4.16 The effect of prickly pear inclusion level on ADF digestibility of male yearling Pedi goats

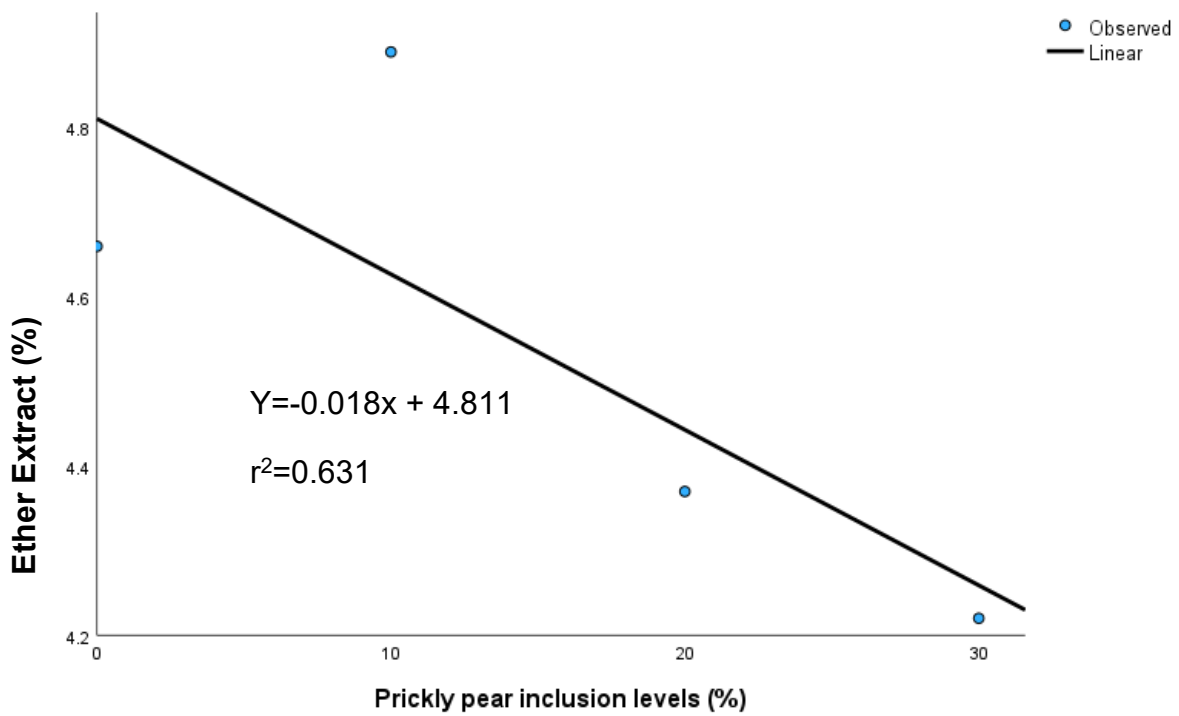


Figure 4.17 The effect of prickly pear inclusion level on EE digestibility of male yearling Pedi goats

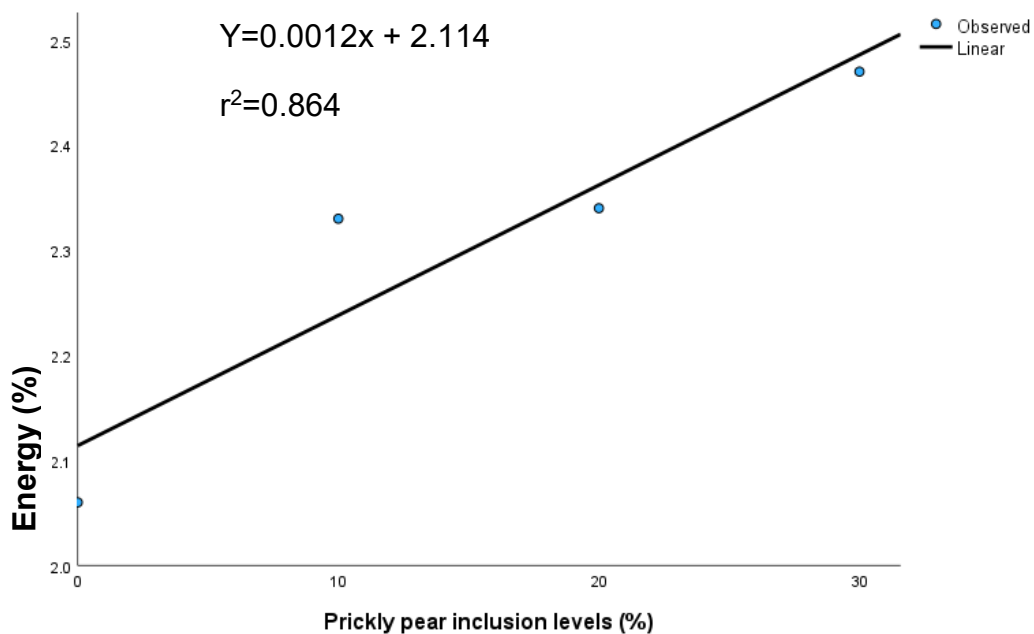


Figure 4.18 The effect of prickly pear inclusion level on energy digestibility of male yearling Pedi goats

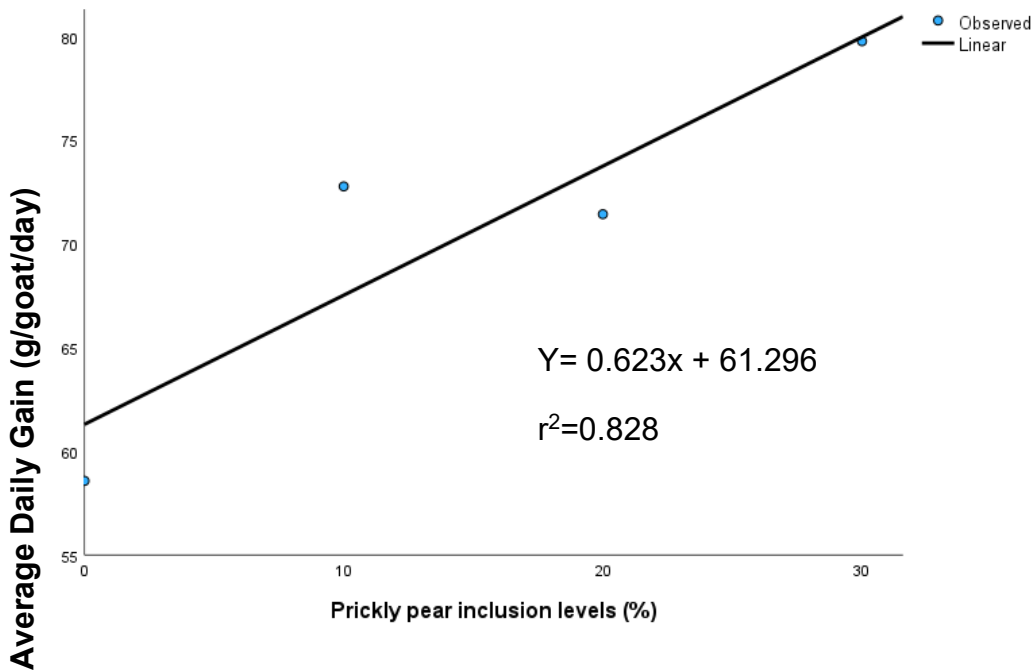


Figure 4.19 The effect of prickly pear inclusion level on average daily gain of male yearling Pedi goats

4.3 The results of the effect of Prickly pear meal inclusion level on methane emission (ppm-m) of yearling male Pedi goats are presented in Table 4.06.

Prickly pear inclusion level in a diet had an effect ($p < 0.05$) on methane emissions by Male Pedi goats. Male Pedi goats on a diet having a 0% Prickly pear meal inclusion level had higher ($P < 0.05$) methane emissions than those on a diet having 10, 20 and 30% Prickly pear inclusion levels. Similarly, male Pedi goats on a diet having 0 and 10% had similar ($p > 0.05$) methane emissions. Male Pedi goats on a diet having a 10% Prickly pear meal inclusion level had higher ($P < 0.05$) methane emissions than those on a diet having 20 and 30% Prickly pear inclusion levels. However, goats on diets containing 10, 20 and 30 % Prickly pear inclusion levels had similar ($P > 0.05$) methane values. Similarly, goats on diets having 20% and 30% Prickly pear inclusion levels had the same ($P > 0.05$) methane values.

Table 4.06 Effect of prickly pear (*Opuntia ficus-indica*) on methane emission of yearling male Pedi goats

	Diets				P-value
	PPF0	PPF10	PPF20	PPF30	
Before					
Methane emission (ppm-m)	21.00 ^a ±0.577	22.67 ^a ±2.404	24.33 ^a ±3.180	20.33 ^a ±0.821	0.5342
After					
Methane Emission (ppm-m)	19.67 ^a ± 1.453	15.00 ^{ab} ± 1.155	14.33 ^b ± 0.882	12.33 ^b ± 0.333	0.0063

a, b: Means in the same row not sharing a common superscript are significantly different (P<0.05)

#: Diet codes are explained in Table 3.01, Chapter 3

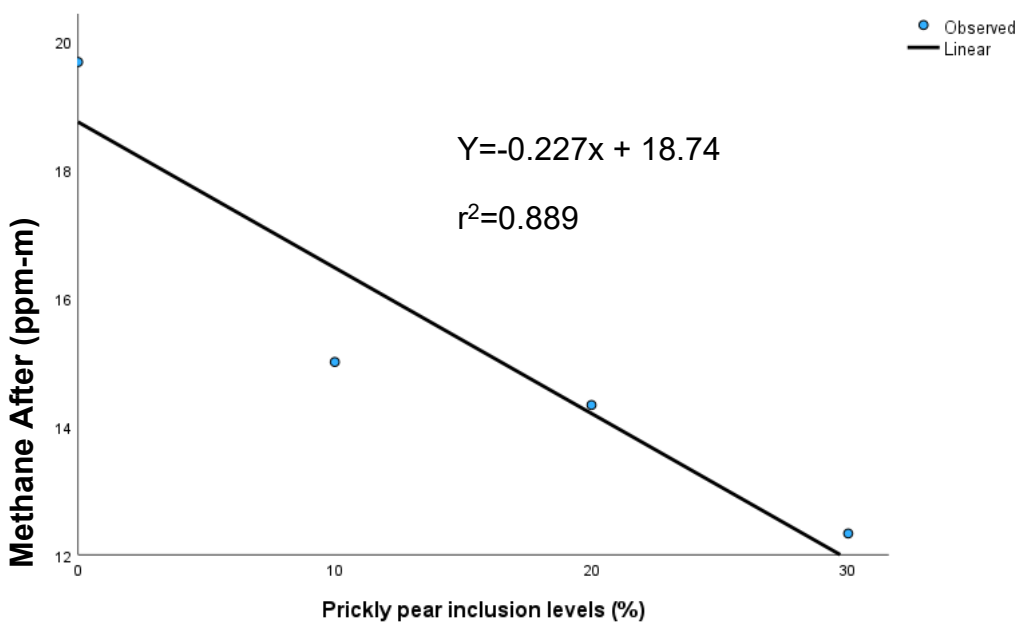


Figure 4.20 The effect of Prickly pear inclusion level on methane (End) of male yearling Pedi goats

4.4 The results of the effect of prickly pear inclusion in the diet on blood parameters of male Pedi goats are presented in Table 4.07.

Blood parameters of male Pedi goats revealed significant differences between the treatments at the beginning of the experiment. These results served as a baseline to monitor the changes in the blood profiles of the goats as affected by the treatments. At the end of the trial, Prickly pear inclusion in the diet had an effect ($p < 0.05$) on eosinophils of male Pedi goats. Prickly pear inclusion in the diet had an effect ($p < 0.05$) on lymphocytes, monocytes, neutrophils and basophils of male Pedi goats. Male Pedi goats fed a diet having 10% prickly pear meal had higher ($p < 0.05$) lymphocytes than those on diets having 0, 20, and 30%. Male Pedi goats fed a diet having 30% prickly pear meal had higher ($p < 0.05$) lymphocytes than those on diets having 0 and 20%. Similarly, male Pedi goats fed diets having 0 and 20% had the same ($p > 0.05$) lymphocytes. Male Pedi goats fed a diet having 30% prickly pear meal had higher ($p < 0.05$) monocytes than those on diets having 0, 10 and 20%. Male Pedi goats fed a diet having 30% prickly pear meal had higher ($p < 0.05$) monocytes than those on diets having 0, 10 and 20% prickly pear inclusion levels. However, Pedi goats fed diets having 10% had higher ($p < 0.05$) monocytes than those on diets having 0 and 30. However, Pedi goats fed diets having 10% had higher ($p < 0.05$) monocytes than those on diets having 0 and 30 prickly pear inclusion levels. Male Pedi goats fed control diets had higher ($p < 0.05$) monocytes than those on diets having 30% prickly pear inclusion levels. Similarly, male Pedi goats fed diets having 0 and 30% prickly pear inclusion had the same ($p > 0.05$) monocytes. Male Pedi goats fed a diet having 20% prickly pear meal had higher ($p < 0.05$) neutrophils than those on diets having 0, 10 and 30% prickly pear inclusion levels. Pedi goats on diets having 0% prickly pear inclusion levels had higher ($p < 0.05$) neutrophils than those on diets having 10 and 30% prickly pear inclusion levels. Male goats on diets having 30% prickly pear inclusion had higher ($p < 0.05$) neutrophils than those on diets having 30% prickly pear inclusion levels. Male Pedi goats fed a diet having 30% prickly pear meal had higher ($p < 0.05$) basophils than those on diets having 0, 10 and 20% prickly pear inclusion levels. However, male goats fed diets having 0 and 30% prickly pear inclusion had similar ($p > 0.05$) basophils levels. Pedi goats fed diets having 0% prickly pear inclusion levels and higher ($p < 0.05$) basophils levels than those on diets having 10 and 20% prickly pear inclusion levels. Similarly, male Pedi goats on diets having 10 and 20% prickly pear had the same ($p > 0.05$) basophils.

Table 4.07 Effect of Prickly pear (*Opuntia ficus-indica*) inclusion level in diet on blood parameters (%) of yearling male Pedi goats.

Parameter	Treatment				Probability
	PPF ₀	PPF ₁₀	PPF ₂₀	PPF ₃₀	
Before					
LY	77.00 ^a ±2.517	71.33 ^d ±5.696	76.67 ^{ab} ±1.856	74.67 ^c ±3.180	0.019
MO	6.00 ^b ±1.528	7.00 ^a ± 2.082	4.67 ^{cd} ±0.882	4.00 ^d ±0.577	0.401
NE	14.00 ^c ±1.732	18.67 ^a ±3.844	16.67 ^b ±0.667	18.33 ^a ±2.963	0.052
EO	2.00 ^a ±0.577	1.67 ^b ± 0.333	1.33 ^b ±0.333	1.33 ^b ±0.333	0.012
BA	1.00 ^{ab} ±0.000	1.33 ^a ±0.333	0.67 ^c ±0.333	1.33 ^a ±0.333	0.033
After					
LY	73.67 ^c ±3.383	79.33 ^a ±2.963	73.67 ^c ±0.333	75.67 ^b ±1.667	0.048
MO	2.67 ^c ±0.333	3.333 ^b ±1.202	2.33 ^{cd} ±1.453	4.33 ^a ±0.667	0.049
NE	21.33 ^b ±1.856	16.33 ^d ±3.180	22.33 ^a ±0.882	17.33 ^c ±1.667	0.038
EO	1.33 ^a ±0.882	1.00 ^a ±0.338	1.67 ^a ±0.333	1.66 ^a ±0.667	0.032
BA	0.33 ^{ab} ±0.333	0.00 ^b ±0.000	0.00 ^b ±0.000	1.00 ^a ±0.000	0.021

a, b, c: Means in the same row not sharing a common superscript are significantly different ($P < 0.05$)

LY: Lymphocytes; MO: Monocytes; NE: Neutrophils; EO: Eosinophils; BA: Basophils

#: Diet codes are explained in Table 3.01, Chapter 3

Lymphocytes were optimized at prickly pear meal inclusion level of 15.44 ($r^2=0.157$), respectively (Figure 4.21).

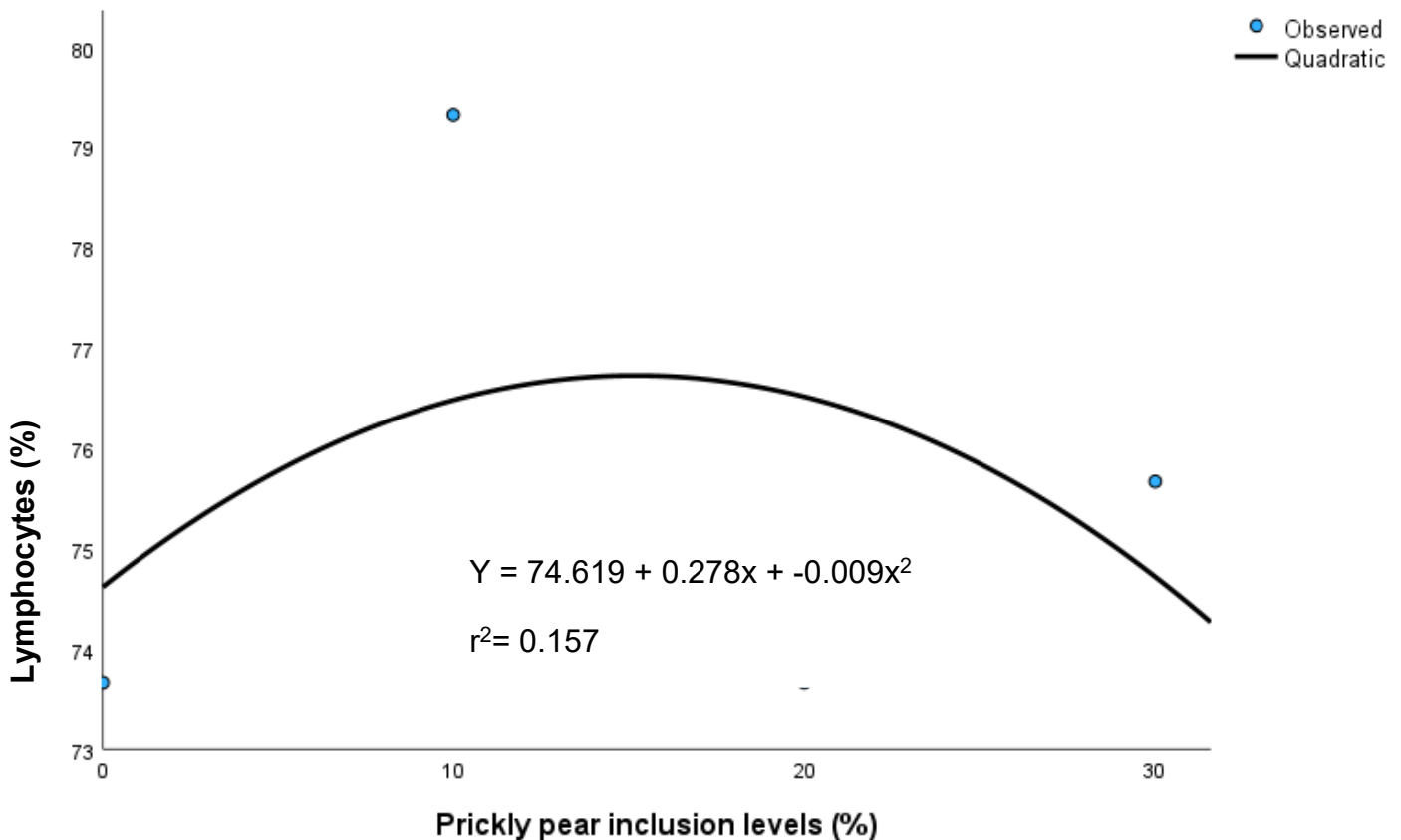


Figure 4.21 The effect of Prickly pear inclusion level on Lymphocytes of male yearling Pedi goats.

Positive relationships were observed between prickly pear meal inclusion level and monocytes ($r^2=0.340$), eosinophils ($r^2=0.452$) and basophils ($r^2=0.303$) of male Pedi goats (Figures 4.22, 4.24 and 4.25, and Table 4.08 respectively). However, a negative relationship was observed between prickly pear meal inclusion level and neutrophils ($r^2=0.069$) and male Pedi goats (Figures 4.23, and Table 4.08 respectively).

Table 4.08 Relationships between prickly pear meal inclusion level and monocytes, eosinophils and basophils of male Pedi goats.

Variable	Formula	r ²	Probability
MO	Y = 0.040x+ 2.568	r ² = 0.340	0.417
NE	Y = -0.06x +20.23	r ² = 0.069	0.737
EO	Y=-0.017x + 1.166	r ² =0.452	0.327
BA	Y=0.020x + 0.03	r ² =0.303	0.450

r²: Coefficient of determination

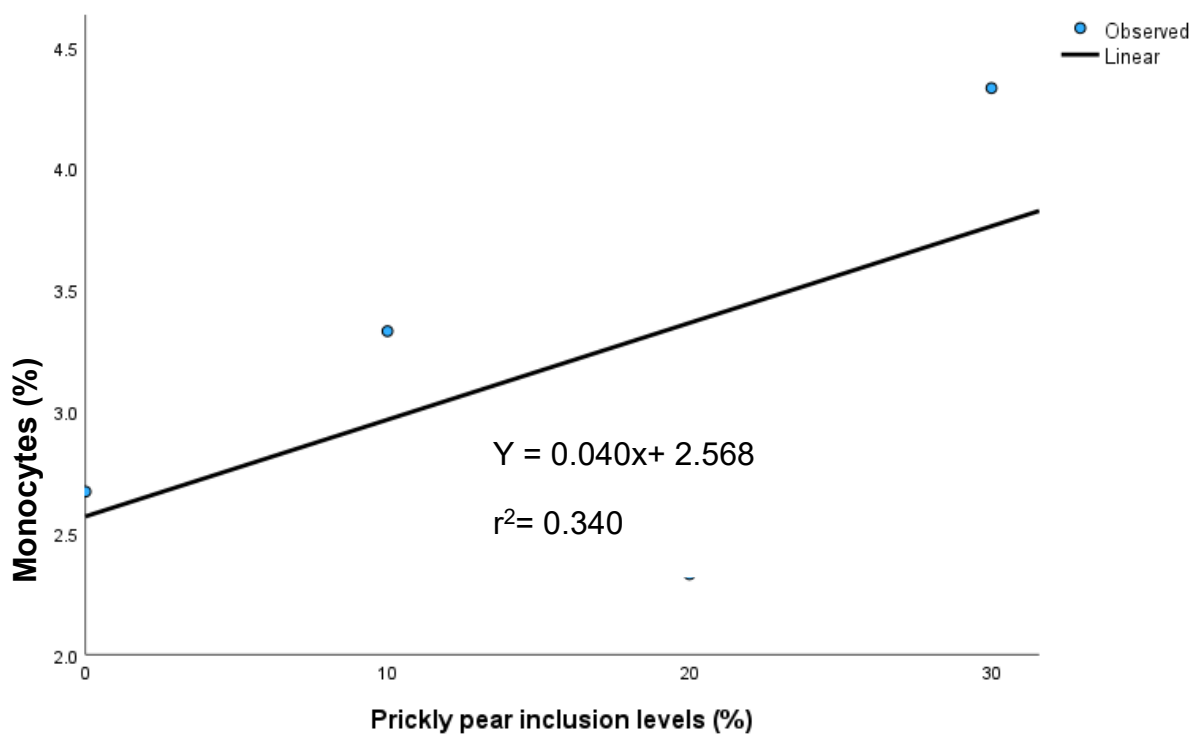


Figure 4.22 The effect of Prickly pear inclusion level on monocytes of male yearling Pedi goats.

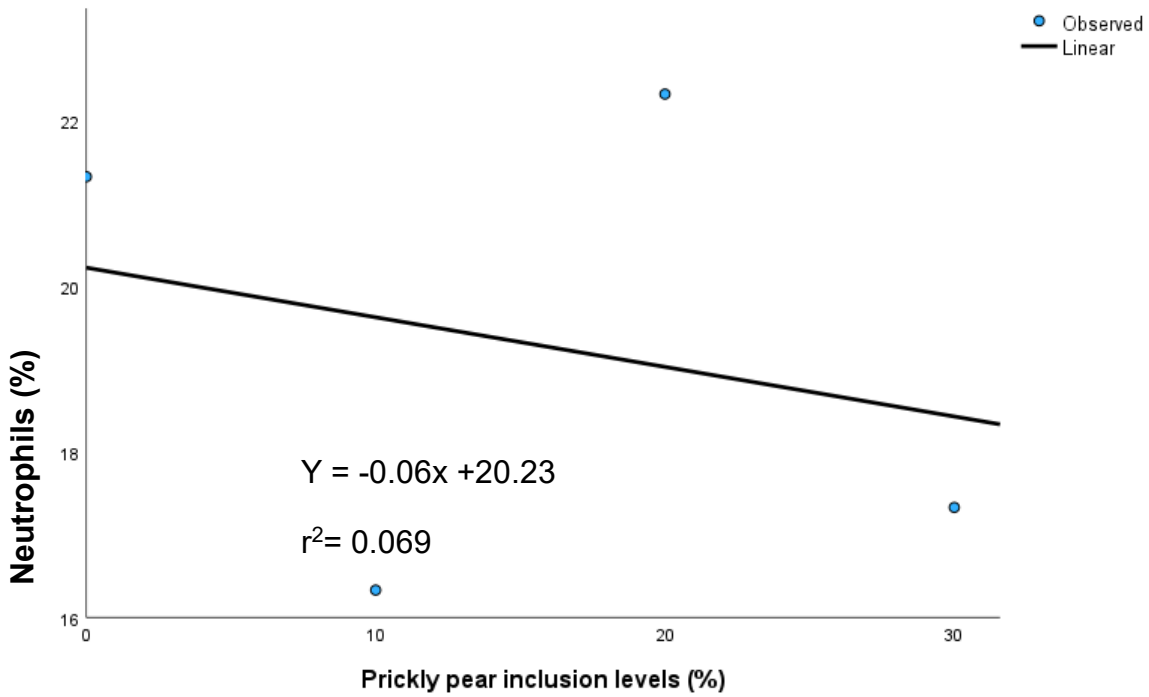


Figure 4.23 The effect of prickly pear inclusion level on neutrophils of male yearling Pedi goats.

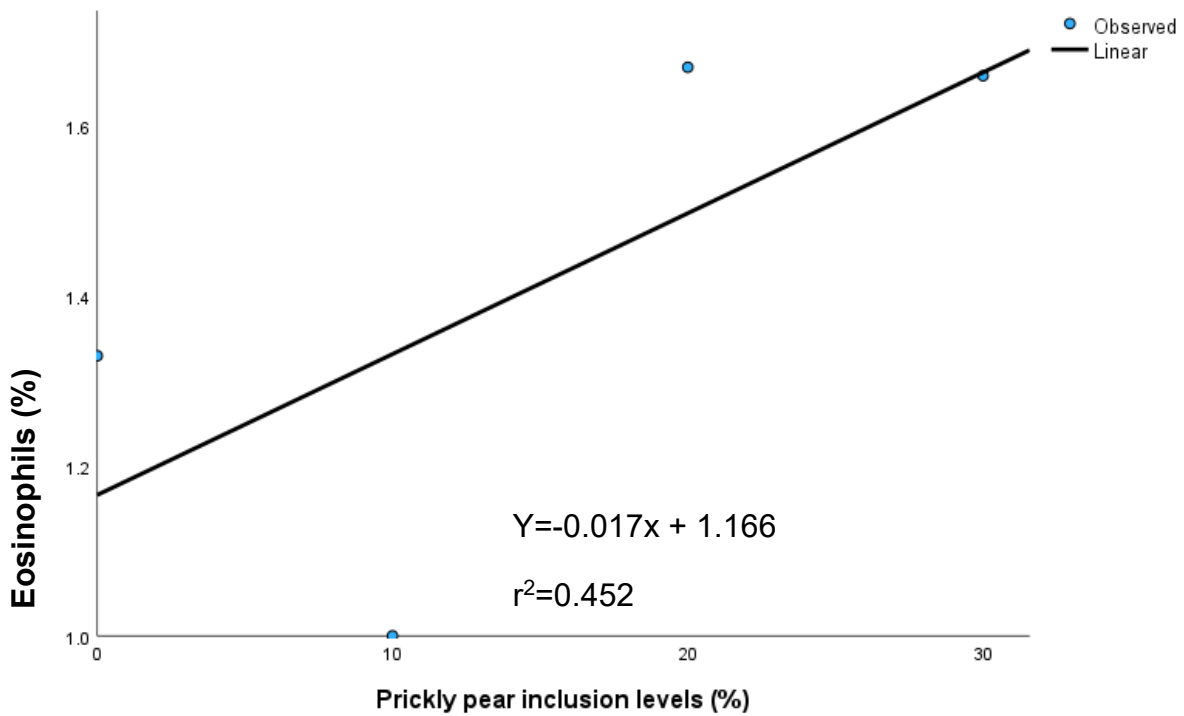


Figure 4.24 The effect of prickly pear inclusion level on eosinophils of male yearling Pedi goats

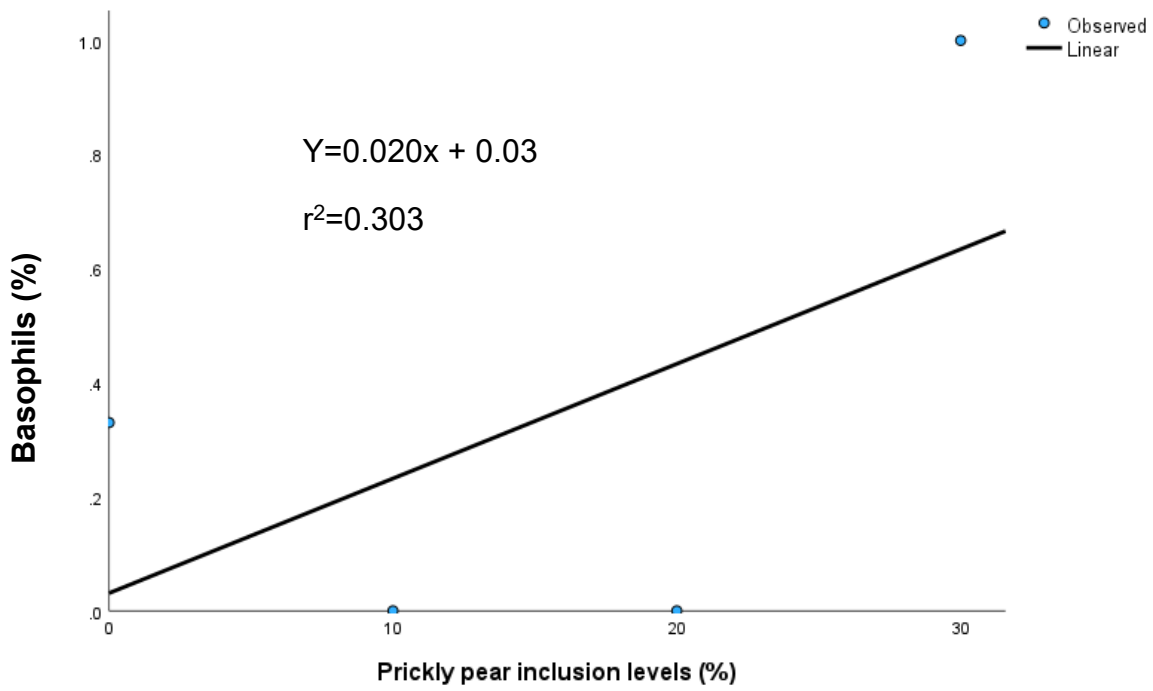


Figure 4.25 The effect of prickly pear inclusion level on basophils of male yearling Pedi goats

CHAPTER FIVE
DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Discussion

The diets used in this study contained similar nutrients except for prickly pear levels which ranged from 10 to 30%. Thus, any difference in response should be due to prickly pear inclusion level. In the current study, prickly pear meal inclusion level in diet had an effect on DM, OM, Ash, CP, ADF, NDF, and EE intakes of yearling male Pedi goats. However, results of the current study are contrary to the results of Inácio *et al.* (2019); Costa *et al.* 2009, reported that cactus *Opuntia*-based diets had no effect on the digestibility of OM, CP and NDF of buck goats. The results of the current study are in agreement with the results of Neto *et al.* (2021) who observed significant differences in dairy goats fed experimental diets having *optunia ficus-indica*. In contrary, Neto *et al.* (2020) observed no significant differences on dry matter (DM), organic matter (OM), neutral detergent fiber (NDF), ether extract (EE) and total carbohydrates (TC) intakes of dairy goats fed diets having *optunia ficus-indica*. Moreover, Vieira *et al.* (2008) observed significant differences in DM intakes of Alpine goats and reported that the DM intakes were maximized at intermediate spineless cactus inclusion levels of 250g/kg while intakes of OM, CP and NDF increased linearly. Whereas Felix *et al.* (2016), observed a reduction in NDF intakes and an increase in the intake of NFC with increasing spineless cactus in the diet fed to confined sheep. According to Góes Neto *et al.* (2021) high concentrations of NDF limit intake due to the physical strain of the rumen reticulum, while the intake of diets with lower NDF levels would be limited in achieving the animal's energy requirement. The results of the current study indicated an increase in NDF intakes with increase in prickly pear inclusion. However, Riaz *et al.* (2014) observed that goats appeared less responsive to increases in dietary fibre fractions (NDF and ADF) than other animal species, and that these feed fractions had a less negative impact on their dry matter intake.

Results of the current study showed that prickly pear meal inclusion level in diet had an effect on DM, OM, Ash, CP, NDF, ADF, EE and energy digestibility of yearling male Pedi goats. The results of the current study are contrary to the results that were observed by Balduino da Silva *et al.* (2021), who observed significant differences only on crude protein and neutral detergent fibre digestibility's between diets of confined Lambs.

Male Pedi goats fed diets having 0% prickly pear meal inclusion level had higher ash digestibility values than those fed diets having 10, 20 and 30% prickly pear meal

inclusion levels. However, the results of the current study agree with the results of Menezes (2008) who observed that apparent ash digestibility on 0% *Opuntia* cladodes inclusion level was significantly lower than diets 24 and 36% on dorper sheep. Male Pedi goats on a diet having 30% prickly pear meal inclusion level had higher CP digestibility than those fed diets having 0, 10 and 20% prickly pear meal inclusion levels. The results of the current study are in line with the results of Menezes (2008) who observed higher CP digestibility of Dorper sheep fed 36% *Opuntia* cladodes than those fed 0 and 24% *Opuntia* cladodes. Protein is the most expensive component of goat rations, and over-feeding of protein normally is wasted as ammonia. Protein degradation in the rumen is necessary to provide the N source needed for microbial growth (Mutsvangwa *et al.*, 2016). Nichols *et al.* (2022) added that the contribution of microbial protein in the rumen plays an important role in sustaining N requirements in ruminants. To reduce avoidable losses of N from ruminant farms, mitigate pressure on the protein ingredient supply, and improve the profitability of goat fattening, it is necessary to feed low-crude-protein (CP) diets to goats (Zhu *et al.*, 2020).

As ruminants, goats require enough dietary fiber to maintain a healthy rumen. In plant species, neutral detergent fiber (NDF) concentrations are often higher than acid detergent fiber (ADF) values (INRA, 2007). The results of the current study showed that prickly pear inclusion in a diet had effect on NDF digestibility of male Pedi goats. However, the results of the current study are contrary to the results of Gebremariam *et al.* (2006), who reported that goats fed prickly pear had higher NDF digestibility values under the controlled diet fed 0% prickly pear than those fed prickly pear in their diet.

The results of the current study showed that prickly pear inclusion in a diet had significant difference on ADF digestibility of male Pedi goats. Male Pedi goats on a diet having 30% prickly pear meal inclusion level had higher ADF digestibility values than those fed diets having 0, 10 and 20% Prickly pear meal inclusion levels. However, the results of the current study agree with the results of Sirohi *et al.* (1997), who reported significant differences on ADF digestibility values of sheep fed *Cenchrus* grass (controlled) and Baru grass with 200g cactus. In contrary, Misra *et al.* (2006) observed that ADF digestibility did not differ significantly among groups. The use of structural carbohydrates in animal nutrition is important for the protection of rumen health and improvement of feed conversion ratio in ruminants. In fact, by encouraging

increased saliva production and providing the right conditions for cellulosic and amylolytic bacteria involved in microbial digestion as well as protozoa and yeast (Tekce *et al.*, 2014). The amount of NDF and ADF in ration or diet is important for some physiologic periods of ruminants in terms of preventing various metabolic diseases such as acidosis, laminitis and rumen parakeratosis (Tekce *et al.*, 2014).

Male Pedi goats fed a diet having 10% prickly pear meal inclusion level had higher ether extract (EE) digestibility values than those fed diets having 0, 20 and 30% prickly pear meal inclusion levels. However, the results of the current study are contrary to results by Balduino da Silva *et al.* (2021) who observed a digestibility of the EE decreased significantly from 0% cactus pear diet to 44% cactus pear diet of sheep. The results of the current study are in line with the results of Costa *et al.* (2012) who observed the coefficient of digestibility of the EE did not increase significantly. The spineless cactus is a rich source of easily digestible carbohydrates and has a high rate of rumen fermentation, which can improve the absorption of nutrients by the animal (Magalhães *et al.*, 2021). Fats plays an important factor in most emulsions and has unique ability to absorb and preserve flavours. A small amount of fat is an essential part of a healthy, balanced diet. Fat is a source of essential fatty acids, which the body cannot make itself (Sanders, 2016). They help the body absorb vitamin A, vitamin D and vitamin E. These vitamins are fat-soluble, which means they can only be absorbed with the help of fats.

Prickly pear inclusion level in a diet had no effect on initial live weight, feed conversion ratios and water intake of goats. However, the results of the current study are contrary to the results of Cardoso *et al.* (2019), who reported that increasing levels of spineless cactus improved the feed conversion ratios of lambs. However, the results of the current study are in line with the results of Tegegne *et al.* (2005), who observed no effect on initial weight and water intake of sheep fed cactus pear. Moreover, the results of the current study are contrary to the results of Góes Neto *et al.* (2021) who observed a significant difference in total water intake of goats fed forage *Optunia*. According to Van Soest (1994), the relation of the water content in tropical forages for intake can be considered a function of the structural volume if the forage contains water in the structure of the cellular wall. Minson (1990) reported that conventionally, water levels exceeding 780 g/kg-1 of fresh forage cause a decrease in voluntary animal intake. In this current study, the high-water levels of prickly pear did not negatively influence the

DMI among the experimental diets. The water intake results in the current study confirm the high concentrations of water in the cellular contents of the prickly pear which is an important characteristic for semi-arid regions, where water availability is a limiting factor for animal production (Costa *et al.*, 2009; Araújo *et al.*, 2010; Salem, 2010).

However, prickly pear inclusion level in a diet had significant effect on final live weight, average daily gains (ADG) and feed intakes of male Pedi goats. The results of the current study are in line with the results of Oliveira *et al.* (2017) and Ribeiro *et al.* (2017) who reported that sheep gained more weight on diets having spineless cactus at 50% level of the roughage fraction of the diet which is higher than levels used in the current study. This might have been due to increase in diet digestibility with an increase in prickly pear inclusion level. Male Pedi goats fed diets having 10 and 30% prickly pear meal inclusion levels had higher final live weights than those on diets having 0% prickly pear inclusion levels. Magistu (2001) and El-Neney *et al.* (2019) made similar observations whereby final body weights of goats when fed diets having 10-30% cactus was higher than those on diets having 0% cactus level.

Male Pedi goats fed a diet comprising 30% prickly pear meal inclusion level had higher ADG than those fed diets having 0, 10 and 20% prickly pear meal inclusion levels. However, the results of the current study are contrary to the results of Arbouche *et al.* (2022), who observed higher ADG with 10% prickly pear inclusion level. Similarly, male Pedi goats fed diets containing 10, 20 and 30% prickly pear meal inclusion had similar ADG. Furthermore, male Pedi goats fed diets having 10 and 20% prickly pear meal inclusion levels had higher ADG than those on diets having 0% prickly pear inclusion levels. However, Male Pedi goats fed a diet having 10 and 20% prickly pear meal inclusion levels had the same ADG values. However, the results of the current study are not in line with the results of Arbouche *et al.* (2022) who observed different ADG between 10 and 20% prickly pear inclusion levels.

Male Pedi goats fed diets having 10 and 20% prickly pear meal inclusion level had higher feed intakes than those fed diets having 0 and 30% prickly pear meal inclusion levels. The results of the current study are in agreement with the results of Menezes (2008) who observed the feed intake by Dorper sheep increased when fed 24% cactus pear. The results of the current study are in disagreement with results of E-Neney *et*

al. (2019) who observed that total feed intake of sheep was higher when fed 0% cactus *opuntia cladodes* than those fed 10, 20 and 30% cactus *opuntia cladodes*. According to Mertens (1992), intake is important for the function of the animal, live weight, production level, variation of live weight, physiological state, and size. Also, feed, nutrient content, energy density, chewing need and filling capacity; and feeding conditions, food availability, space in the feeder, time of access to food, and frequency of feeding.

In the current study, enteric methane emission is expressed as parts per million per metre (ppm-m) as suggested by Chagunda *et al.* (2009). It should be noted that the present study focused on measuring total methane emissions by Pedi goats using a laser methane detector. Prickly pear inclusion level in diets had an effect on methane emissions by Male Pedi goats. Male Pedi goats on a diet having a 0% Prickly pear meal inclusion level had higher methane emissions than those on a diet having 10, 20 and 30% Prickly pear inclusion levels. A negative relationship was observed between Prickly pear meal inclusion level and methane in male Pedi goats. The results of the current study disagree with Elghandour *et al.* (2016), who reported higher methane production with increasing amounts of prickly pear cactus in the experimental diets having 0, 75 and 150g prickly pear cactus. However, the results of the current study are in line with the results that were gathered by Elghandour *et al.* (2016) who observed a decline in methane as the level of prickly pear cactus was increased to 150g prickly pear cactus ration. Contrarily, Arreola *et al.* (2019) observed that methane production in goats fed 50% prickly pear cactus was similar to patterns observed in 25% prickly pear cactus, which suggest that despite increased gas volume, methane and CO₂ production remained unchanged. According to Mathobela *et al.* (2020) and Mavasa *et al.* (2022), small ruminants' CH₄ emissions may be reduced by diets that include forage high in tannins. However, not much has been done on prickly pear meal inclusion levels for optimal CH₄ reduction in goats using a laser methane detector (LMD).

In the current study, blood parameters of male Pedi goats revealed significant differences between the treatments at the beginning of the experiment. These results served as a baseline to monitor the changes in the blood profiles of the goats as affected by the treatments. According to Ajao (2013) and Pessini *et al.* (2020), highlighted that blood is commonly used to detect nutritional problems that an animal

have. The major functions of the white blood cells (WBC) are to fight infections and to produce, transport and distribute antibodies in immune responses (Lawal *et al.*, 2015b). At the end of the trial, prickly pear inclusion in the diet had no effect on eosinophils of male Pedi goats. However, prickly pear inclusion in diet had an effect on lymphocytes, monocytes, neutrophils and basophils of male Pedi goats. Male Pedi goats fed a diet having 10% of prickly pear meal had higher lymphocytes than those on diets having 0, 20, and 30%. Lymphocytes are types of white blood cells which form part of the immune system and reflects the responsiveness of the animal to its internal and external environment, which includes feed and feeding (Saki *et al.*, 2018). Male Pedi goats fed a diet having 30% of prickly pear meal had higher monocytes than those on diets having 0, 10 and 20%. The results of the current study are in contrary to the results of Vieira *et al.* (2022) who observed no significant difference in monocytes of Sheep. Nevertheless, the results of the current study are in line with the results of Ahmed *et al.* (2020) who observed higher monocytes on 20% prickly pear fruit peel-supplemented groups on goats. According to Imaseun (2017), monocytes are the largest member of the white blood cells and can travel to various parts of the body to eliminate harmful matter. This may imply that affected monocytes and white blood cells count, in the current study, were not because of inflammation or diseased goats but was due to the phenolics properties of prickly pear, which are responsible for maintaining total monocytes as to white blood cells count. Pedi goats fed a diet having 20% of prickly pear meal had higher neutrophils than those on diets having 0, 10 and 30% prickly pear inclusion levels. Male Pedi goats fed a diet having 30% of prickly pear meal had higher basophils than those on diets having 0, 10 and 20% prickly pear inclusion levels. The values obtained in this study were an indication that there were no microbial infections or presence of foreign bodies or antigens (Ahamefule *et al.*, 2006) as blood profiles in the current study are, however, across all the various levels in acceptable ranges of blood constituents for normal goats (Nawal *et al.*, 2015).

5.2 Conclusion and recommendation

Prickly pear could be used as an agricultural byproduct with a potential use as a cheap and available feed supplement in the diet of small ruminants like goats reared in arid regions for more sustainable animal production. The high soluble carbohydrate content of prickly pear indicates that it would improve the nutritive value of poor-quality

roughage. Inclusion of prickly pear fruit in the diet improved nutrient digestibility but not intake of indigenous PEDI goats. Diet intakes and neutral detergent fibre digestibilities were optimized at different prickly pear meal inclusion levels respectively, possibly indicating that prickly pear inclusion levels for optimal productivity will depend on the parameter of interest. Prickly pear meal, therefore, has the potential of being utilized as energy feed during the dry season when goats depend on low quality roughages.

The inclusion of prickly pear fruit meal in the diet did significantly affect the live weight, growth rate, digestibility, and feed intake of yearling male PEDI goats, according to the objective and hypothesis of the study. The findings contradict the null hypothesis by showing that the addition of prickly pear fruit meal significantly affected the goats final live weight, average daily growth, and feed intake. Furthermore, the study revealed that a 20% inclusion level of prickly pear meal led to improved performance, hence supporting the alternative theory that prickly pear fruit meal inclusion influences the parameters. Therefore, the study's results confirm the alternative hypothesis and reject the initial null hypothesis. This could mean that prickly pear fruits may have a better impact on PEDI goats' productivity and performance. Overall, it is noticeable that the level of Prickly pear meal inclusion in diet plays a crucial role in determining the nutrient intake and performance of PEDI goats, with 20% being most favourable based on results.

This study covered the current state of knowledge on methane production and emission by goats relevant to productivity of the goats. Prickly pear inclusion levels were found to reduce methane emission by PEDI goats and doesn't support the initial null hypothesis. These results confirmed that prickly pear meal inclusions in the diets provide suitable alternative to mitigate methane emission and possibly production. Reduction in methane emission is associated with reduced green-house gas contribution to global warming and increased efficiency of energy utilization which could be used for body maintenance and productivity. More studies are required to determine prickly pear levels for optimal methane production and emission by goats.

Based on the results, it can be concluded that the inclusion of Prickly pear fruit meal in the diet does not have significant effect on blood parameters (Lymphocytes, Monocytes, Neutrophils, Eosinophils and Basophils). Thus, supporting the initial

hypothesis. It is then suggested that prickly pear meal inclusion levels used will not cause any adverse effects on the blood profiles of the experimental goats.

It is, therefore, concluded that prickly pear can be used as goat feed, which may improve the performance and can be an excellent replacement for a portion of poor fodder. The high moisture content in prickly pear could serve as an important water source for animals during drought periods. Will also be beneficial effects on goat's health which make it a worth and viable feeding strategy. From the economical point of view, especially within a sustainable animal production system, prickly pear could be favourable energy feedstuff. However, it is recommended that more studies be conducted on the subject to ascertain the present findings.

CHAPTER SIX
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APPENDIX



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**ANIMAL RESEARCH ETHICS
COMMITTEE CLEARANCE CERTIFICATE**

MEETING: 05 APRIL 2023
PROJECT NUMBER: AREC/21/2023: PG

PROJECT:

Title: Evaluation of prickly pear (*Opuntia ficus-indica*) fruit on growth performance, blood indices and methane emissions by yearling male Pedi goats.

Researcher: TT Magonyane

Supervisor: Dr TG Manyelo
Co-Supervisor: Prof JW Ng'ambi

School: Agricultural and Environmental Sciences
Degree: Master of Science in Agriculture (Animal Production)

PROF LIC ERASMUS
DEPUTY CHAIRPERSON: ANIMAL RESEARCH ETHICS COMMITTEE

The Animal Research Ethics Committee (AREC) is registered with the National Health Research Ethics Council, Registration Number: **AREC-290914-017**

Note:

- i) Should any departure be contemplated from the research procedure as approved, the researcher(s) must re-submit the protocol to the committee.
- ii) The budget for the research will be considered separately from the protocol.
- iii) PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES.

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