CULTIVATION AND USE OF MORINGA AS A NUTRITIONAL AND MEDICINAL SUPPLEMENT FOR GOATS IN CENTRAL NAMIBIA

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2. Comparative proximate and mineral compositions of *Moringa oleifera* and *Moringa ovalifolia* grown in Central Namibia**,** *Sustainable Agriculture Research*, Vol. 6 (4), August 2017, pp. 31-44.

3. Comparative study of *M. oleifera* and *M. ovalifolia* survival rates in Central Namibia, *HSOA Journal of Plant Science: Current Research*, United States of America, Vol.1 (1), October 2017, pp. 2-8.

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Conference Proceedings

1. Anti-parasitic effect of *Moringa oleifera* leaf supplement in Boer goats, Proceedings of the 2nd International Conference of the African Association for the Study of

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Presentations at Conferences

1. Cultivation of *Moringa oleifera* and *Moringa ovalifolia* in Namibia, presented at University of Namibia Research Day 2014 Conference, Neudamm Campus, 26th September, 2014.

2. Anti-parasitic effect of *Moringa oleifera* leaf supplement in Boer goats, presented at University of Namibia Research Day 2016 Conference, University of Namibia School of Medicine, 22nd October, 2016.

3. The effect of *Moringa oleifera* supplemented diet on growth rates of pre-weaning Boer goat kids, presented at 4th Science Conference, University of Namibia and National Commission on Research Science and Technology (NCRST), University of Namibia, Windhoek, 16th -17th November, 2016.

4. Cultivation of moringa in Central Namibia: Research collaboration with UNAM library, presented at Systematic Review Workshop, University of Namibia, Windhoek, 13th–16th June, 2017.

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7. Field Growth Performance of *Moringa oleifera* and *Moringa ovalifolia* in Semi-arid Environment: A Comparative Study of Central Namibia, paper presented at the 5nd Annual Science Research Conference, 15th–16th November, 2017 at the University of Namibia, Windhoek.

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List of Abbreviations/Acronyms

AES ……..	Atomic Emission Spectroscopy
AgriLASA ……	Agri-Laboratory Association of Southern Africa
ANOVA ……	Analysis of Variance
AOAC ……...	Association of Official Agricultural Chemists
BGBSN …….	Boer Goat Breeders' Society of Namibia
CHN ……..…	Carbon Hydrogen Nitrogen
CRD ……..	Completely Randomized Design
DE …….....	Digestible Energy
DM ……..…..	Dry Matter
DW ……..…..	Dry Weight
EDTA ……...	Ethylenediaminetetraacetic acid
EoE…….……...	Extent of endurance
FAO …….….	Food and Agriculture Organization
GIP ……..…..	Gastrointestinal Parasites
GLM …….….	General Linear Model/Generalised Linear Model
GSB……...	Life stages by
IFAD …….	International Fund for Agricultural Development
ICP ……...	Inductively Coupled Plasma
IU …….…….	International Unit
LSD …….….	Least Significant Difference
ME …….…...	Metabolisable Energy
m/v…….	Mass Per Volume

n.d. ……..……...	No Date
NDF ……..….	Neutral Detergent Fibre
NDFIP ……..	Neutral Detergent Fiber Insoluble Protein
NEU ……..…	Neudamm
Spp. …..…….....	Species
SPSS …….	Statistical Package for Social Sciences
TDN ……..	Total Digestible Nutrients
WFP ……..…	World Food Program

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Dedication

This dissertation is dedicated to my mother, Fenio Korsor who stood firm for my education under unbearable and unbelievable circumstances. She deserves all the praises and honours for this achievement that had rocky journey, but was strengthened by her real and true support. My late father (R.I.P), Mr. Korsor Karma also deserves an honour for exposing me to early education, where the interest was catapulted.

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Declaration

I, Morlu Korsor, hereby declare that this study is my own work and is a true reflection of my research, and that this work, or any part thereof has not been submitted for a degree at any other institution.

Morlu Korsor		March 6, 2018
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Name of Student	Signature	Date

Chapter 1

Introduction

1.1 Summary of Chapters

This dissertation is organized into seven chapters. Chapter 1 is an introduction to the study, which includes the orientation of the study, the problem statement, objectives, hypotheses, the significance and the limitations of the study. Chapter 2 deals with the nursery establishment of *Moringa oleifera* (*M. oleifera*) and *Moringa ovalifolia* (*M. ovalifolia*), and compares the performance of their seeds and seedlings in terms of emergence and establishment. This chapter serves as a preliminary chapter to chapter 3, which elucidates on the life stages by (LSB) heights and leaf-dry-matter yields of *M. oleifera* and *M. ovalifolia* on the field for two summer seasons (2014/2015 and 2015/2016) as well as their extent of endurance (EoE) after three winter seasons. Chapter 4 explains the determination of the proximate and mineral compositions of *M. oleifera* and *M. ovalifolia* grown in Namibia. Chapter 5 assesses the efficacy of *M. oleifera* in treating gastrointestinal parasites in Boer goats, in comparison with the drug ecomectin® (ECO Animal Health Southern Africa (Pty) Ltd. in Faerie Glen) with a composition of ivermectin 0.08% m/v). Chapter 6 on the other hand, evaluates the indirect effects of feeding *M. oleifera* supplements on growth rates in pre-weaning kids. Finally, chapter 7 closes with the conclusions and recommendations of this study.

1.2 Orientation of the Study

Goats (*Capra aegarus hircus*) are small ruminants found in almost all parts of the world reared by both rural subsistence and commercial farmers as a sustainable source of

household income and protein-food supply. About 480 million goats exist across the world, about 75% of which are found in developing countries (Boer Goat Breeder's Society of Namibia, 2008). Goats can be classified in a number of ways, but the simplest classification is by animal products. The three major classifications are (1) dairy, (2) fibre and (3) meat. The two other major classifications include pets or companions and goatskin breeds. Furthermore, some breeds are dual-purpose from which two products can be obtained, such as meat and milk (Flanders & Gillespie, 2015).

Much of southern and western Namibia is used for small-stock farming in which goats predominate in many communal farming districts. Among the 2.5 million goats in Namibia, about 40% are Boer goats and 60% belong to indigenous breeds, and, over 65% of all goats are found in communal areas (Mendelsohn, 2006; Kruger & Lammerts-Imbuwa, 2008). Although goats are predominantly browsers that do not seem to compete with cattle and sheep when roaming freely in the natural veld (Rothauge & Engelbrecht, 2000), it is critical to feed and supplement their rations, especially during lactation, for improved production. Lactating Boer goats need 400 g of lucerne, 150 g maize and 150 g broiler litter per day, or 100 g of brewer grains supplement daily during winter (Smith, 2006). In Namibia, goats are mostly reared for meat, when the owner is too poor to own cattle. Goats, which are more popular than sheep, are milked for domestic purposes, slaughtered for household consumption and sold in times of cash needs (Schneider, 1994).

Namibia is one of the most arid countries in sub-Saharan Africa, with low rainfall and a high occurrence of drought as a natural phenomenon (Kruger & Lammerts-Imbuwa,

2008). These conditions reduce the potential of grazing lands. Hence, the inclusion of fodder and medicinal trees in the rangeland will improve productivity. Locally available and easily accessible ethno-veterinary medicinal plants provide a cheaper treatment, compared to use of western drugs (Galav *et al.,* 2010), which serve as remedies for goats and other livestock treatment in Namibia. The incorporation of tree and shrub species in animal production systems can be a viable alternative for improving the utilization of land and at the same time improving the diet of ruminants (Sanchez *et al.*, 2006).

The *M. oleifera* tree is native to India but has been planted around the world and is naturalized in many countries. It has a high growth rate and capacity to produce large quantities of fresh biomass (Sanchez *et al.,* 2006*;* Prince, 2007*).* The plant is commonly known as horse-radish or drumstick tree in English and belongs to the family Moringaceae. It is used as an ethno-medicinal plant and livestock feed in many tropical and subtropical countries. It is a rapidly growing deciduous tree that takes 4-5 months to mature and be ready for use, even in poor soils (Prince, 2007; Radovich, 2007; Alhakman, Kumar, & Khan, 2013). The plant is considered a miracle tree because, it contains a high proportion of nutrients such as protein, minerals, vitamins, carbohydrates, and fats (Moringa Mission Trust, 2005) that are essential for improving performance of both animals and humans (Prince, 2007).

Moringa ovalifolia, which also belongs to the Moringaceae family, is a native tree of Namibia and Angola. It grows in the wild in both countries. As with *M. oleifera,* the fruits, leaves and roots of *M. ovalifolia* are edible (Curtis & Mannheimer, 2005). The two *Moringa* species (*M. oleifera* and *M. ovalifolia*) are important because they can

grow and endure under harsh environmental conditions like those of Namibia and have the propensity to improve rangeland productivity and subsequent livestock production (Fuglie, 2001; Olson, 2007; Adegun & Ayodele, 2015).

Improving goat, as well as other livestock production would increase household income and animal food supply. This would minimize the malnutrition problem among Namibian inhabitants, where one million people (33.9% of population) have been identified as undernourished (FAO, WFP, & IFAD, 2012). Being a semi-arid country, livestock production is regarded as the primary farming activity in Namibia over crop production. Schneider (1994) affirmed that more than 90% of the 690,000 km^2 of land for agriculture use in Namibia is utilized for extensive livestock farming: cattle ranging 48%, mixed cattle/small-stock ranging 14.50% and small-stock ranging 37.50%. Even though commercial farmers provide nutritional supplements and medications to their animals, subsistence rural communal farmers cannot afford to do so, and/or many of them are even not aware of this practice. The unawareness and unavailability of nutritional supplements and medications for their animals leads to poor productivity of rural subsistence farmers' livestock (Namibia Broadcasting Corporation TV, 2017). Moringa is not only a source of feed, but also has medicinal properties (Fuglie, 2001; Moyo, Masika, Hugo, & Muchenje, 2010); however, it is still unexploited due to unawareness and unavailability to livestock farmers.

1.3 Problem Statement

The main problems faced by many livestock farmers in Namibia are related to the purchasing of feed, nutritional supplements, and medication to maintain their animals' health and enhance productivity, especially during winter when herbage is in short supply in the natural veld. Research shows that poor growth rates, lower weaning weights, and 90% of deaths of young animals are due to inadequate feed, nutritional supplements and poor healthcare for lactating animals and their offspring, especially in communal areas (Mendelsohn, 2006; De Lange, 2008). Kuvare *et al.* (2008) concurred that both communal and, chiefly, commercial livestock farmers of Namibia use commercial supplementary feeds for livestock. The second problem facing goat production is the infestation of animals by parasites, especially internal parasites that result from their grazing behaviour and susceptibility. Stehman and Smith (2004), reported that goats are very sensitive to the effects of internal parasitism (such as anaemia and low blood protein), which can cause decreased fertility, abortion, unthriftiness, increased susceptibility to disease, and death.

Kuvare *et al.* (2008) pointed out that as a coping strategy, animal disease management is done through indigenous and scientific techniques among farmers in Namibia. Fuglie (2001) revealed that *M. oleifera* leaves are known to have anthelmintic properties when they are used as animal feed or supplement. Moreover, there is limited forage in the veld during winter with poor nutrient content. This requires the production of fodder crops such as moringa trees for feed supplementation of animals for proper productivity as described by the Pace Project (n.d.). Therefore, this study investigated the adaptability of *M. oleifera*, along with *M. ovalifolia* (native to Namibia and Angola), grown under the

central Namibian climatic conditions from nursery and field establishments; their proximate and mineral compositions; the indirect effect of *M. oleifera* leaves as a nutritional supplement on Boer goat kids' growth parameters; and, the effect of *M. oleifera* leaves on gastrointestinal parasites as an anthelmintic ethno-medicinal plant.

1.4 Objectives of the Study

1.4.1 General Objective

The general objective of this study was to determine how to improve goat production at Neudamm Experimental Farm, and Namibia at large, through the production and use of two moringa tree species as a nutritional and medicinal supplement by livestock farmers.

1.4.2 *Specific objectives*

The specific objectives of the study were:

1. To compare seedling emergence, establishment and extent of endurance of *M. oleifera* and *M. ovalifolia*;
2. To measure the establishment, life stages by heights in terms of growth and yield of *M. oleifera* and *M. ovalifolia* and their extent of endurance after winter season;
3. To determine the proximate and mineral compositions of *M. oleifera* and *M. ovalifolia*;
4. To assess the efficacy of *M. oleifera* in treating gastrointestinal parasites of goats;
5. To evaluate the indirect effects of feeding *M. oleifera* supplements on the growth rates of pre-weaning kids.

1.5 Hypotheses of the Study

H_{01}: *M. oleifera* and *M. ovalifolia* do not significantly differ in seedling emergence and life stages by heights and extent of endurance;

H_{02}: *M. oleifera* and *M. ovalifolia* do not significantly differ in life stages by heights, leaf dry matter yields and extent of endurance after the winter season;

H_{03}: *M. oleifera* and *M. ovalifolia* do not significantly differ in proximate and mineral compositions;

H_{04}: *M. oleifera* does not have anthelmintic properties.

$H_{05:}$ Feeding *M. oleifera* as a supplement to lactating goats does not directly affect the growth rate parameters of their pre-weaning kids.

Although the objectives and hypotheses are given, for the purpose of associating them to their respective chapters of discussion, a tabular summary is incumbent. Therefore, Table 1.1 presents the specific objectives and hypotheses of the study in accordance to their associated stand-alone chapters.

Table 1.1 Specific objectives, hypotheses and their associated chapters

No	Objective	Hypothesis	Stand-alone chapter
1.	To compare seedling emergence, establishment and EoE of *M. oleifera* and *M. ovalifolia*	H_{01}: *M. oleifera* and *M. ovalifolia* do not significantly differ in seedling emergence and LSB heights and EoE	Chapter 2: Comparative Performance of *M. oleifera* and *M. ovalifolia* Seeds and Seedlings Establishment in Central Namibia
2.	To measure the establishment, LSB height and yield of *M. oleifera* and *M. ovalifolia* and their EoE after winter season	H_{02}: *M. oleifera* and *M. ovalifolia* do not significantly differ in LSB height, leaf dry matter yields and EoE after the winter season	Chapter 3: Field Establishment, EoE and Yield of *M. oleifera* and *M. ovalifolia* in a Semi-arid Environment: The Case of Central Namibia Rangeland
3.	To determine the proximate and mineral compositions of *M. oleifera* and *M. ovalifolia*	H_{03}: *M. oleifera* and *M. ovalifolia* do not significantly differ in proximate and mineral compositions	Chapter 4: Comparative Proximate and Mineral Compositions of *M. oleifera* and *M. ovalifolia* Grown in Central Namibia
4.	To assess the efficacy of *M. oleifera* in treating gastrointestinal parasites of goats	H_{04}: *M. oleifera* does not have anthelmintic properties.	Chapter 5: Assessment of the Anthelmintic Effect of *M. oleifera* Leaf-supplemented Diet on Gastrointestinal Parasites in Boer Goats
5.	To evaluate the indirect effects of feeding *M. oleifera* supplements on the growth rates of pre-weaning kids.	$H_{05:}$ Feeding *M. oleifera* as a supplement to lactating goats does not directly affect the growth rate parameters of their pre-weaning kids.	Chapter 6: Indirect Effect of a *M. oleifera* Leaf-Supplemented Diet on Growth Rates of Pre-Weaning Boer Goat Kids

1.6 Significance of the Study

Moringa oleifera has great potential as a sustainable means of improving livestock productivity and reducing internal parasite infestation of goats, because of its health improving properties. It has the potential of increasing households' animal-protein food supply as well as household income when goats are healthy. Moreover, since veterinary services are expensive and limited in rural Namibia, the use of *M. oleifera* for both nutritional and ethno-medicinal purposes in small ruminants would serve as an indigenous sustainable way for not only improving animal productivity, but also for socio-economic development of rural communities. Cultivation or growing of both *M. oleifera* and *M. ovalifolia* would provide ensiled fodder and supplement for livestock especially during winter when grasses and browse are limited. Ecologically, since moringa are fast-growing trees, their roots enhance the soil and prevent soil erosion while the falling leaves decompose and add fertility to the soil in the form of green manure as discussed by (Prince, 2007).

1.7 Limitations of the Study

Due to limited research fund, the costs of proximate and mineral analyses of moringa leaves as well as that of coprological analysis were limiting factors for this study. The sourcing of *M. oleifera* was another challenge due to long winter seasons that affect its leaf production; however, it was sourced from Kaisosi in Rundu where winter is less intense, while some leaves were sourced from the Neudamm Campus moringa orchard.

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Chapter 2

Comparative Performance of *Moringa oleifera* and *Moringa ovalifolia* Seeds and Seedlings Establishment in Central Namibia

2.1 Abstract

Trees and shrubs can serve as fodder to supplement shortages of feed for livestock, particularly in arid and semiarid environments where palatable grasses or browse plants could be limited due to low rainfall pattern and constant droughts. However, in Namibia moringa tree species (spp.) have the potential to curb shortage of feeds for livestock. A completely randomized design (CRD) was used in this study to compare the performance of *M. ovalifolia* and *M. oleifera* with respect to seedling emergence and seedling establishment. Seeds of the two *Moringa* species were sown in a nursery in 253 polythene bags (149 for *M. oleifera* and 104 for *M. ovalifolia*) at two centimetre uniform sowing depths. Seedling emergence were recorded and the life stages by (LSB) heights of seedlings were measured from the ground surface to the tip of the plant leaves, using a 30-centimeter ruler with the ruler placed vertically along-side the plant. The parameters measured were seedling emergence difference and seedling LSB height. *Moringa ovalifolia* had a higher seedling emergence of 99.03% (206 out of 208 seeds) compared to *M. oleifera* that had 15.06% (75 out of 298 seeds). Also, *M. ovalifolia* emerged faster (started emergence on the 7th day and completed on the 18th day) than *M. oleifera* (started on the 11th day and completed on the 28th day). Conversely, *M. oleifera* had faster seedling establishment, with an overall average height of 18.77 cm compared to *M. ovalifolia* which had slower LSB height over time with 13.25cm average height. An independent sample t-test results revealed that *M. oleifera* and *M. ovalifolia* mean of

seedling emergence and emergence days were significantly different ($P < 0.05$), which indicated that the two *Moringa* species had differences in emerged seedlings and number of days. Furthermore, LSB heights per week of the two *Moringa* species were significantly different ($p < 0.05$). Therefore, from the results, the null hypothesis (H_{01}) that *Moringa* species were not different in emergence and LSB heights was rejected.

Keywords: Emergence, LSB height, *Moringa oleifera*, *Moringa ovalifolia*, nursery

2.2 Introduction

The incorporation of tree and shrub species in livestock production systems is a viable alternative that could improve the utilization of land resources and the quality of feeds for livestock species particularly for ruminants (Sanchez *et al*., 2006). Further, fodder trees and shrubs are quite essential in livestock farming, particularly in semi-arid environments where palatable grasses or browsers are scarce predominantly during times of drought (Franzel *et al*., 2014). However, the moringa tree species show the potential to prevent the shortage of feed for livestock.

Moringa oleifera is a native tree to India but has been planted worldwide. It is naturalized in many countries with a high LSB height and capacity to produce large quantities of biomass even in poor soils (Alhakman *et al*., 2013). The leaves have high nutritional and medicinal benefits and are readily eaten by cattle, sheep, goats, pigs and rabbits. The leaves contain a high proportion of nutrients such as protein, minerals, vitamins, carbohydrates, and fats (Olson, 2001; Fuglie, 2001; Moringa Mission Trust, 2005) that are essential for improving the performance of both animals and humans (Prince, 2007; Thurber & Fahey, 2009; Philips, 2014). Furthermore, *Moringa ovalifolia*,

which also belongs to the Moringaceae family and is described as a bottle tree because of the shape off its trunk, is native to Namibia and Angola. This species is generally uncommon but widespread in western Namibia, as far south as 26^{o} S; in scattered localities in the Karstveld; occasionally in the south; and common in the central areas. It grows in the wild in both countries (Curtis & Mannheimer, 2005; Van Wyk, Van Wyk, & Van Wyk, 2011; Makita, Chimuka, Steenkamp, Cukrowska, & Madala, 2016).

Moringa ovalifolia is a small deciduous tree with a distinctive, squat, swollen stem and branches and is also commonly known as "ghost tree" or "phantom tree". The roots, bark and wood are eaten by goats; the leaves are also browsed by giraffe (Olson, 2001; Curtis & Mannheimer, 2005; Van Wyk *et al*., 2011). However, *M. ovalifolia* and *M. oleifera* are yet to be cultivated, and the agronomical information for their cultivation is not available in Namibia. This information is vital in order to enable farmers to understand the appropriate methods required for the cultivation of different species of moringa as fodder for livestock, particularly during droughts when feedstuffs are most scarce. Starting with a trial for germination and establishment, could pave a way for the cultivation of *Moringa* species for livestock consumption in the country.

Therefore, to fill these gaps, a comparative study was conducted to assess the performance of *M. ovalifolia* and *M. oleifera* for seed germination and seedling establishment. It was hypothesized that the performance of *M. ovalifolia* and *M. oleifera* in seed germination and seedling establishment do not differ significantly and can adapt similarly to diverse environmental conditions.

With seed propagation, tree and shrub cultivation begins with the sowing of seeds and raising of seedlings either in the nursery or in the fields. For faster germination, a forced scarification has to be done on seeds to weaken the seed coats for moisture penetration under favourable oxygen and temperature conditions. This was done using several methods, including soaking the seeds in water (Haferkamp, Kissock, & Webster, 1984; Evans & Blazich, 1999). A germination research study conducted by Saeed and Thanos (2006) revealed that seed germination were faster when scarification was done before sowing. Using this method, the final germination was achieved within two weeks. Plants that have not been domesticated like *M. ovalifolia* need germination and/or seedling emergence experimentations to establish the level of scarification, germination, emergence and the LSB height.

Moringa oleifera is a new and exotic species in Namibia, while *M. ovalifolia* only grows in the wild. To the best of our knowledge, there is no known study comparing the propagation of these two species in Namibia. Therefore, the objective of this study was firstly to document the agronomy of *M. ovalifolia* and *M. oleifera* propagated by seeds in the nursery and to compare their seedling emergence and LSB heights of both species under the Namibian conditions. Second, the study aimed to compare their EoE and adaptability differences at nursery level, since *M. ovalifolia* was only known to grow in the wild, while *M. oleifera* was just being introduced into Namibia. Finally, this research was undertaken to establish the seedling emergence differences of *M. ovalifolia* in comparison to *M. oleifera* using the same scarification (seed coat treatment) to reduce or eliminate germination inhibitors as suggested by Haferkamp, Kissock & Webster (1984).

2.3 Materials and Methods

2.3.1 Study Area

This study was conducted from November 2013 to January 2014 at the Neudamm Campus of the University of Namibia, about 30 km east of Windhoek with an area of 10, 187 hectares of land on the agronomy site of the campus. Neudamm Campus is located at 22° 30′ 07″ S and at 17° 22′ 14″ E**,** and at an altitude of 1762 meters above sea level. Neudamm Experimental Farm's temperature ranges between a minimum of -7°C and a maximum of 44°C (University of Namibia, 2011) and received an annual average rainfall of 498 mm in the 2013/2014 summer season (P. Beukes, 2017).

The vegetation of Neudamm Experimental Farm is classified as highland savannah (semi-arid savannah) and is characterized by grasses, shrubs and trees that are well spread over the farm. An annual grass like *Melinis repens* and perennial grasses like *Schmidtia pappophoporoides, Anthephora pubescens* and *Brachiaria nigropedata* are well represented on the farm. Different types of trees like *Acacia brownii, Acacia erioloba, Acacia mellifera* as well as shrubs like *Grevia flava* are found on this farm. The estimated carrying capacity is about 12 hectares per large stock unit or 45 kg per hectare biomass (Kahumba, 2010; Kapu, 2012; A. Beukes, 2017).

2.3.2 Experimental Design

A completely randomized design (CRD) was used for the experiment in which seed of the two species were used for sowing in their shells. The seeds of the two species of moringa seeds were sown in two plots of 104 polythene bags of *M. ovalifolia* and 149

polythene bags of *M. oleifera* in rows of 10. The unequal number of polythene bags and seeds sown was due to the available number of seeds of each *Moringa* species. From each moringa type emerged seedling counts were made and height measurements were randomly taken from 20 seedlings at weekly intervals, as described by Manh, Dung and Ngoi (2005). Mean were used to determine any differences in seedling emergence and the seedling LSB heights of both *M. oleifera* and *M. ovalifolia*. An independent sample t-test was used to analyse the data, and parameters such as standard error of means, standard deviation, means, minimum, maximum, and number of cases were calculated in the current study. The independent sample t-test was used to determine if there was a significant difference in seedling emergence and the LSB height of the two *Moringa* species. The null hypothesis (H_{01}) that there were no significant differences in the seedling emergence and LSB height in *M. oleifera* and *M. ovalifolia* were tested.

2.3.3 Preparation of Moringa Nursery and Management of Seedlings

In this study, both *M. oleifera and M. ovalifolia* were propagated by seeds in the nursery as recommended by Prevost and Le Glorus (1997). The pit soil, river sand, and cow manure at a ratio of 6:2:3 were thoroughly mixed and filled in one-litre polythene bags as suggested by Fuglie and Sreeja (2001). Thereafter, the polythene bags were placed in a wire mesh enclosure to protect them from animals. The filled polythene bags were watered 24 hours before the seeds were sown. *Moringa oleifera* and *M. ovalifolia* seeds were soaked in hot water that was cooled for 5 minutes after boiling at 100^{o}C, and overnight as a treatment of the seedcoats before being sown the following day as described by Haferkamp *et al*. (1984) and Pace Project (n.d.). Two seeds of each *Moringa* species were sown in each polythene bag, as suggested by Sanchez *et al*.

(2006). Seeds are usually planted in nurseries, either bare-rooted or in polythene pots. Although bare-rooted seedlings cost less to produce than potted seedlings, Franzel *et al.* (2014) argued that they are more susceptible to drought after transplanting. Polythene bags are therefore very important in nursery-making in order to avoid future losses; that is why they were used in the current study. The seedlings were watered twice a week.

After seedling emergence, the seedlings were thinned to reduce the number of seedlings to one in each polythene bag. The process of thinning was done after watering the seedlings for easy uprooting and transplanting of thinned seedlings in other polythene bags with the same soil content mixture. The transplanted seedlings were placed in the shade for a week to avoid sun stress after transplanting.

2.3.4 Procedures for Data Collection

The seedling emergence of both *Moringa* species was thoroughly monitored and recorded on daily and weekly in the nursery. *Moringa ovalifolia* seedling emergence started on the seventh day with two shoots. However, growth measurement only started on the eleventh day when the shoots had completely surfaced with at least two leaves. On the other hand, seedling emergence of *M. oleifera* started on the twelfth day and was also only measured after it had fully surfaced with two leaves. The EoE of thinned seedlings was monitored and recorded to determine their adaptability. This was done by monitoring them on a daily basis to see if there was any mortality until they had properly recovered and were well established. In this study, heights of *M. ovalifolia* and *M. oleifera* seedlings were measured to determine their LSB heights at nursery level. The heights of seedlings were measured using the method suggested by Heady (1957): from

the ground surface to the tip of the plant leaves, using a 30-centimeter ruler with the ruler placed vertically along-side the plant. The heights of 20 seedlings were measured for each *Moringa* species on a weekly basis, as suggested by Manh *et al*. (2005). Average heights were determined during each set of measurement.

2.3.4 Data Analysis

Independent sample t-tests were used for data analysis using Statistical Package for Social Sciences (SPSS® version 23) and determined differences between *M. oleifera* and *M. ovalifolia* seedling emergence and height increments. All statistical analyses were only considered significantly different at the alpha levels of $p \leq 0.05$, and all p-values above these alpha levels were considered non-significant. Microsoft Office Excel® 2010 was used to derive averages of emerged seedlings and height increments that were used for all data analyses as well as the figure.

2.4 Results and Discussion

The results of the present study indicated that both *M. ovalifolia* seeds and M. *oleifera* seeds started to emerge in the second week; however, *M. ovalifolia* seeds started to emerge earlier — on day 7, while *M. oleifera* seeds only started to emerge from day 11 after sowing. The results agree with those reported by Fuglie & Sreeja (2001) who found that *M. oleifera* starts to germinate and emerge within 5-12 days. They are also in agreement with the findings of a study conducted in Malawi and a review which reported that viable *M. oleifera* seeds germinate within two weeks (Nalivate *et al*., 2011; Leone *et al*., 2015). The early seedling emergence of *M. ovalifolia* observed in the present study could probably be attributed to the quality of its seeds. Further, the results

showed that on the 11th day, the percentage of emerged seedlings of *M. ovalifolia* in polythene bags was higher (72%) than that of *M. oleifera* (only 3.8%). The results revealed that *M. ovalifolia* ended seedling emergence earlier—in the 3rd week (day 18), with a higher overall emergence rate (99.03%), whereas *M. oleifera* ended relatively late—in the 4th week (day 28) with a lower overall seedling emergence rate of 25.17%. These results are in disagreement with those reported by KOMEHO Namibia (2015) that obtained a 98% seedling emergence rate for *M. oleifera* seeds. This discrepancy probably could be attributed to differences in harvesting time of the seeds (possibly immature seeds) and/or poor storage conditions (Fuglie & Sreeja, 2001). Another reason for the discrepancy might be attributed to the long-time storage of the seeds. In fact, Leone *et al*. (2015) discussed that *M. oleifera* seed viability decreases if they remain at ambient temperature and high relative humidity, their germination rate dropping to 7.50% after three months. On the other hand, out of the 97 *M. ovalifolia* thinned seedlings, only 18 (18.55%) died while out of 8 *M. oleifera* thinned seedlings, 2 (25%) died.

2.4.1 Seedling Emergence and Establishment

The seeds of both *Moringa* species were soaked in hot water overnight and sown the following day. According to the Pace Project (n.d.), the following method would get the seeds to germinate quickly. That is, boil some water, cool it for 5 minutes and then soak the seeds overnight, using at least three times more water than seeds to cover the seeds completely. Scarification, which is considered to be safer under semi-arid conditions as is the case of Namibia, also speeds up the seed germination and seedling emergence processes. Tables 2.1 and 2.2 show the results of *M. ovalifolia* and *M. oleifera*

cumulative seedling emergence per polythene bag over a period of time. Accordingly, *M. ovalifolia* started emerging on the 7th day, with two shoots (0.96%) while for *M. oleifera* seedling emergence started on the 11th day with 4 shoots (1.34%). Furthermore, *M. ovalifolia* emerged more rapidly within 18 days (3 weeks) of sowing with a 99.03% seedling emergence rate (208 seeds sown in 104 polythene bags). All the 104 (100%) polythene bags had emerged seedlings. Conversely, *M. oleifera* emerged slowly within 28 days (4 weeks) with a 15.06% seedling emergence rate (75 out of 298 seeds). Seventy-four out of 149 (49.66%) polythene bags had emerged seedlings.

A germination test conducted by Haferkamp *et al*. (1984) showed that final germination was more than 75%, although the speed of germination was slower. Germination was considered completed when there were no additional seeds germinated, as described by Saeed & Thanos (2006). Besides the viability of the seeds, *M. ovalifolia* seeds are smaller with softer seed coats when compared to *M. oleifera* seeds. This also may have contributed to the faster and more rapid seed germination and seedling emergence rate of *M. ovalifolia*.

Table 2.1: Daily and cumulative seedling emergence of *M. ovalifolia*

Emergence after sowing (days)	Emerged seedlings (cumulative)	Difference in seedlings' emergence	Emergence rate (%)	Number of polythene bags	Percent of polythene bags
7	2	2	0.96	2	0.96
9	50	48	24.04	30	28.84
11	113	63	54.34	75	72.11
13	136	23	65.38	100	96.15
16	203	67	97.59	104	100.00
18	206	3	99.03	104	100.00

Table 2.2: Daily and cumulative seedling emergence of *M. oleifera*

Emergence after sowing (days)	Emerged seedlings (cumulative)	Difference in seedlings' emergence	Emergence rate (%)	Number of polythene bags	Percent of Polythene bags
7	0	0	0.00	0	0.00
9	0	0	0.00	0	0.00
11	4	4	1.34	4	2.68
13	20	16	6.71	19	12.75
16	32	12	10.74	29	19.46
18	53	21	17.79	47	31.54
25	55	2	18.46	50	33.56
28	75	20	25.17	74	49.66

Table 2.3 presents the descriptive statistics for seedling emergence. From the means of the two species, *M. ovalifolia* had a higher number of seedlings that emerged (118.33), whereas the number of *M. oleifera* seedlings that emerged was relatively lower (29.88) but could still be placed in the maximum column. In addition, the mean statistical analysis result of the cumulative number of seeds that emerged and emergence days can be found in Table 2.4.

Table 2.3: *Moringa* species seedling emergence over time (days)

Moringa seeds	N	Mean	Standard Deviation	Standard Error Mean	Minimum	Maximum
M. ovalifolia	6	118.33	81.73	33.37	2.00	67.00
M. oleifera	8	29.88	28.68	10.14	0.00	21.00

Note: mean of emerged seedlings

Table 2.4: Emergence of *Moringa* species over time (days)

Emerged seedlings						
Time (Days)	Mean Emergence	*Moringa* spp.	Standard Deviation	Standard Error of Mean	Minimum	Maximum
7	1.00	2	1.41	1.00	0.00	2.00
9	25.00	2	35.36	25.00	0.00	50.00
11	58.50	2	77.07	54.50	4.00	113.00
13	78.00	2	82.02	58.00	20.00	136.00
16	117.50	2	120.92	85.50	32.00	203.00
18	129.50	2	108.19	76.50	53.00	206.00
25	55.00	1	0.00	0.00	55.00	55.00
28	75.00	1	0.00	0.00	75.00	75.00

Note: Mean emerged seedlings

An independent sample t-test (Table 2.5) was used to compare the means of *M. ovalifolia* and *M. oleifera*'s emerged seedlings. The result of the analysis revealed that there was a mean difference of 88.46 emerged seedlings, which led to a significant difference ($P < 0.05$) in emerged seedlings between the two *Moringa* species. The results of the statistical analysis thus support the information on seedling emergence presented in Table 2.3 in which *M. ovalifolia* had a mean of 118.33 emerged seedlings while *M. oleifera* had 29.88 emerged seedlings. Tables 2.1 and 2.2 also occurred with the difference between the two *Moringa* species emerged seedlings. The difference in seed germination and seedling emergence between the two *Moringa* species may rather be attributed to the thinness of their seedcoats than to the number of days. *M. ovalifolia* seedcoats are thinner and softer than *M. oleifera* seed coats. They may therefore germinate and emerge faster due to their permeability and gaseous exchange ability. This was demonstrated by Saeed and Thanos (2006), who observed that thin and soft seed coats are readily permeable to water and gaseous exchange in the first few days of imbibition when seeds are in "activation" stages, with an increased requirement for oxygen, which speeds up germination. Hence, the null hypothesis that there is no significant difference between *Moringa* species seedling emergence is rejected.

Table 2.5: Independent sample test of *Moringa* species emerged seedlings

Moringa species	Mean Difference	Pooled Standard Error Difference	t	df	Sig. (2-tailed)
Emerged seedlings	88.46	30.85	2.87	12	0.014*

Note: Mean difference in emerged seedlings; * = significant at 0.05 alpha levels

2.4.2 Seedling Extent of Endurance and Mortality

These results show that emergence is higher around days 16 and 18 (week 3) with means of 117.5 and 129.5 respectively. Seedling mortality of *M. oleifera* and *M. ovalifolia* in the current study due to cold (frost), pests, thinning effect and waterlog are presented in Tables 2.6, 2.7 and 2.8, respectively. During the period under study, 38 (18.44%) seedlings died out of 206 of *M. ovalifolia* seedlings which had emerged and 5 (6.66%) out of 75 *M. oleifera* seedlings, which brings the total mortality cases to 43 out of 281 total seedlings (15.30%). Overall, *M. ovalifolia* had 81.56% of EoE while *M. oleifera*'s EoE was 93.33%, which gives a total cumulative EoE of 84.70%. This indicates that *M. oleifera* had greater EoE and adaptability compared to *M. ovalifolia*. Since seedling mortality was due to cold, waterlog, thinning effect and pests, the EoE's difference of the two species may be attributed to the difference between the diameters of their shoots, as observed. Indeed, *M. oleifera* shoots had larger diameters and circumferences than *M. ovalifolia,* giving them an EoE and adaptability edge in this harsh environment that gets either too cold or too hot at any given time. Hassan and Ibrahim (2013) stated that *M. oleifera* tree is tolerant to light frosts, but as a perennial crop, cannot survive under freezing conditions. Bey (2010) supported that *M. oleifera* is found in many tropical and sub-tropical regions, and can be grown in even the harshest and driest of soils, where barely anything else will grow. It was emphasized that one of the nicknames of *M.*

oleifera is "never-die" due to its incredible ability to survive harsh weather including droughts, which is typical of Namibian climatic conditions. Statistically, an independent t-test of *Moringa* species seedling mortality (Table 2.7) results showed no significant difference (P > 0.05) between *M. ovalifolia* and *M. oleifera*, which is buttressed in Table 2.8 that presents the descriptive statistics where there was mean mortality for *M. ovalifolia* 7.8, while that of *M. oleifera* was 1.00.

Table 2.6: Cumulative mortality of moringa seedlings

Moringa species	Mortality after emergence	Mortality due to cold (frost)	Mortality due to pests	Mortality after thinning	Mortality due to waterlog (rain)	Total mortality	Mortality (%)
M. ovalifolia	5	4	2	18	9	38	18.45
M. oleifera	1	2	0	2	0	5	6.67
Total	6	6	2	20	9	43	15.30

Table 2.7: Independent t-test for *Moringa* species seedling mortality differences

	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
Mortality	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Standard Error Difference	Lower	Upper
Equal variances assumed	5.48	0.047*	2.41	8	0.042	6.80	2.82	0.30	13.30
Equal variances not assumed			2.41	4.21	0.070ns	6.80	2.82	-0.87	14.48

Note: Mean difference of dead seedlings; ns = non-significant; * = significant at 0.05 alpha level

Table 2.8: Descriptive statistics of *Moringa* species seedling mortality differences

	Moringa species	N	Mean	Standard Deviation	Standard Error Mean
Mortality	*M. ovalifolia*	5	7.80	6.22	2.78
	M. oleifera	5	1.00	1.00	0.45

Note: Mean of dead seedlings

2.4.3 Growth Performance of *M. ovalifolia* and *M. oleifera* Seedlings

The results on growth progression of *M. ovalifolia* and *M. oleifera* seedlings are shown in Figures 2.1 to 2.4. The results of the present study show that after emergence, *M. oleifera* grew faster than *M. ovalifolia* seedlings. The results also show that the height of *M. oleifera* seedlings continued to increase at a similar level for the entire study period. On the other hand, the height changes of *M. ovalifolia* were faster in the first three weeks after emergence but became slow and steady thereafter for the entire study period. These results suggest that growth progression of *M. oleifera* seedlings could probably be attributed to water use efficiency requiring little water to endure in the nursery. In addition, *M. oleifera* are slender trees whose stems and roots contain tissues that store less water than other *Moringa* species. Also, if propagated from the seeds, it also develops tubers on a small scale, in comparison to *M. ovalifolia*, that store energy for use during adverse conditions (an endurance mechanism). This might be the reason why most of the times the stems of *M. oleifera* die during harsh conditions and sprout soon after conditions improve (Hassan & Ibrahim, 2013).

Figure 2.1: Emergence of *M. ovalifolia* (day 12)

Figure 2.2: Emergence of *M. oleifera* (day 12)

Figure 2.3: Performance of *M. ovalifolia* seedlings at day 25

Figure 2.4: Performance of *M. oleifera* seedlings at day 25

The descriptive statistics of *M. oleifera* and *M. ovalifolia* weekly LSB heights showing mean, standard deviation and standard error of mean are presented in Table 2.9. The result showed a continuous weekly growth in heights for both *Moringa* species, except for week two when *M. oleifera* seedlings had not emerged properly for measurement of heights. This resulted in the zero heights of *M. oleifera* for week two. However, *M. oleifera* grew faster than *M. ovalifolia* in LSB heights even though the later emerged earlier.

Table 2.9: Descriptive statistics of *Moringa* species weekly LBS heights

Weeks	*Moringa* species	N	Mean	Standard Deviation	Standard Error Mean
	M. ovalifolia	20	2.48	0.44	0.10
2	*M. oleifera*	20	0.00	0.00	0.00
	M. ovalifolia	20	4.38	0.46	0.10
3	*M. oleifera*	20	4.00	0.00	0.00
	M. ovalifolia	20	7.43	1.13	0.25
4	*M. oleifera*	20	8.20	1.67	0.37
	M. ovalifolia	20	8.83	1.57	0.35
5	*M. oleifera*	20	10.33	1.10	0.25
	M. ovalifolia	20	9.28	1.09	0.25
6	*M. oleifera*	20	12.00	0.76	0.17
	M. ovalifolia	20	9.35	1.09	0.24
7	*M. oleifera*	20	16.13	1.22	0.27

Note: Mean of seedling heights

Table 2.10 presents an independent sample test of the two *Moringa* species weekly LSB heights. The result of the analysis showed highly significant differences ($P < 0.05$) between *M. oleifera* and *M. ovalifolia* weekly growth in LSB heights, except for week 4 that had no difference. This means that the two species grew at different levels over time as seen in Table 2.9. *Moringa oleifera* grew faster and increased more in weekly LSB heights than *M. ovalifolia*, even though it emerged later. Thus, the null hypothesis that there was no significant difference between *M. oleifera* and *M. ovalifolia* in weekly LSB

heights was rejected. Literature concurs with the faster growth of *M. oleifera*, suggesting that it is based on one of its active substances known as *Zeatin*, a plant hormone from the cytokines group that supports faster plant growth. This may account for the faster growth of *M. oleifera* in comparison to its counterpart *M. ovalifolia* (Bey, 2010; Leone *et al*., 2015).

Table 2.10: Independent sample test of *Moringa* species weekly LSB heights

Weeks	Mean Difference	Pooled Standard Error Difference	t	df	Sig. (2-tailed)
2	-2.48	0.10	-24.96	38	0.000***
3	-0.38	0.10	-3.68	38	0.001***
4	0.78	0.45	1.72	38	0.094ns
5	1.50	0.43	3.50	38	0.001***
6	2.73	0.30	9.15	38	0.000***
7	6.78	0.37	18.50	38	0.000***

Note: Mean difference in seedling heights; ns = non-significant at 0.05; *** = extremely significant to ≤ 0.001 alpha levels

Figure 2.5 shows the average heights of *M. oleifera* and *M. ovalifolia* over time in weeks. It was noticed that *M. ovalifolia* grew faster at first and slowed down later. Besides emergence that was slower, *M. oleifera* grew at the same level throughout the research period. This contributed to *M. oleifera*'s increase in elongation compared to *M. ovalifolia*. The result shows that the highest LSB heights attainment was observed in *M. ovalifolia* seedlings from 2 week till week 5. This could be due to the development of its sprout. Height increase is most active during the first months of the cycle under favourable environmental conditions as suggested by Prevost and Le Glorus (1997). The LSB height observed in *M. ovalifolia* seedlings between week five and week seven

after emergence in the present study could probably be due to roots development into tubers to serve as a support for its further elongation.

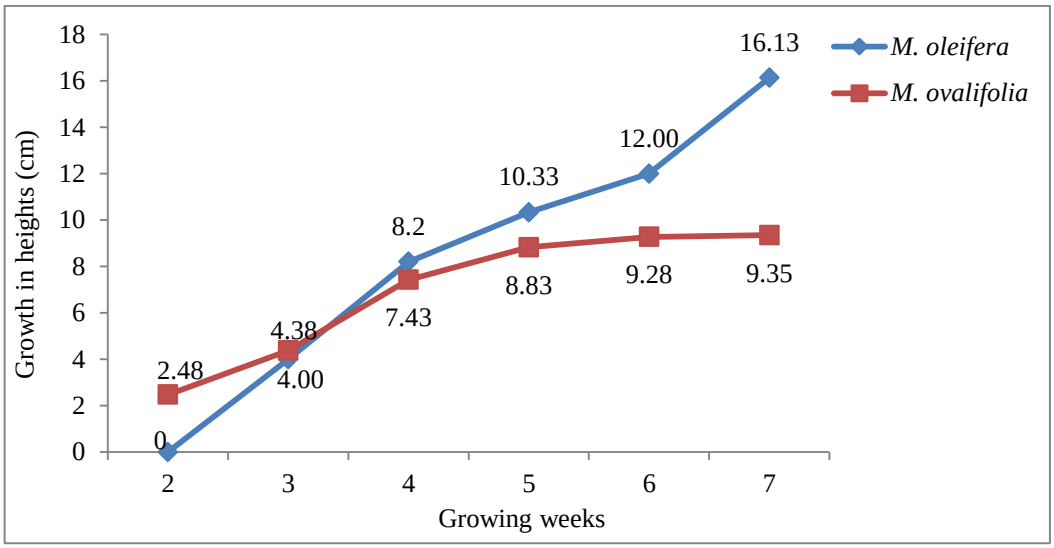

Figure 2.5: Average weekly growth in heights of the two *Moringa* species

As a semi-arid climatic plant, *M. ovalifolia* develops tubers as early as possible for energy storage (Figure 2.6). Energy is being accumulated into the developed tuberous roots as an endurance mechanism against harsh environmental limiting factors such as winter or drought that affect light, temperature, atmosphere, water as well as nutrients which are contributing factors to plant productivity (Haferkamp, 1988). Besides the absorption of water and nutrients needed by the roots, they produce growth substances that are used for the normal functioning of the plant. In addition, they serve as storage of food materials as in the case of root crops such as cassava and carrot (AVRDC, 1990). This is also the case with *M. oleifera* roots on a lesser scale in comparison to *M. ovalifolia* roots, because *M. oleifera* contains stems within their roots while *M. ovalifolia* roots are complete tubers (no stems). Further, *M. ovalifolia* belongs to bottle trees which

are filled with pulpy water-storing tissues (Olson, 2001) which helps them to endure in dry environments.

Figure 2.6: Special "tuberous" roots of *M. ovalifolia* at 4 months

2.5 Conclusion

In conclusion, this study was able to reveal that *M. oleifera* seeds had a lower emergence than *M. ovalifolia* seeds, which might be attributed to differences in harvesting time and post-harvest storage. However, *M. oleifera* seedlings had higher LSB heights than *M. ovalifolia* that had lower LSB height extension over time. The thinned and transplanted seedlings of *M. oleifera* had higher EoE of 93.33% and lower mortality of 6.67% compared to *M. ovalifolia* that had 81.56% and 18.44% for EoE and mortality, respectively. Based on its fast growth, *M. oleifera* cultivation can be encouraged in Namibia, which is predominantly semi-arid. In addition, *M. oleifera* being a "never-die" tree has the ability to withstand the drought and water shortages that are frequent in Namibia. Due to its fast LSB height increase, *M. oleifera* has a high leaf-dry matter

production ability which can be used as animal feed or supplement. Similarly, *M. ovalifolia* cultivation should be encouraged since it is indigenous to Namibia, grows in the wild and has the ability to endure on its own with little care. Ecologically, due to its adaptability to this region, it will have an edge of endurance over *M. oleifera*, which is exotic to Namibia. Although it grows more slowly and produces little leaf-dry matter at first, once established, it can grow into a bigger tree with more leaf-dry matter. This can even be enhanced by domestication of this species since it is an endangered species. However, the major challenge to the cultivation of *M. oleifera* in Namibia is its susceptibility frost. Nevertheless, the cultivation of both *Moringa* species is important for the dry environmental conditions of Namibian.

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Chapter 3

Field Establishment, Extent of Endurance and Yield of *Moringa oleifera* and *Moringa ovalifolia* in a Semi-arid Environment: The Case of Central Namibia Rangeland

3.1 Abstract

The objectives of this chapter were to study the life stages by (LSB) height, leaf-dry-matter yields and extent of endurance (EoE) of *Moringa oleifera* and *Moringa ovalifolia* grown in central Namibia rangeland. Since this central part of Namibia is semi-arid, the growing of drought-resistant fodder trees to aid in the provision of animal fodder or supplement is essential and of paramount importance to livestock farmers. It is upon this background that both *Moringa* species were grown to evaluate their LSB heights and EoE as well as their leaf-dry-matter yields. If these fodder plants are proven to withstand the harsh environmental conditions; namely, cold winter and constant drought, they may be used to boost the animal production sector of Namibia. The results of statistical analyses revealed that *M. oleifera* and *M. ovalifolia* LSB heights, EoE and leaf-dry-matter yields were significantly different ($P < 0.05$) even though they are from the same family and were grown under the same conditions. Thus, *M. oleifera* grew faster (224.90 cm and 281.45 cm) in LSB heights and yielded more leaf-dry matter (482.93 kg/ha/season and 297.60 kg/ha/season) in the two summer seasons (2014/2015 and 2015/2016). On the other hand, *M. ovalifolia* had LSB heights of 78.80 cm and 113.20 cm and yields of 94.67 kg/ha/season and 76.81 kg/ha/season, respectively for the indicated seasons, although *M. ovalifolia* is an indigenous tree of Namibia. For the EoE, *M. ovalifolia* had a higher EoE of 81.25% after winter in the first season (2014/2015)

than *M. oleifera* that had 70.83%; however, *M. oleifera* (97.50%) surpassed *M. ovalifolia* (82.69%) in the second season (2015/2016) due to its faster root-system establishment. Hence, *M. oleifera* would serve as a better alternative for improving rangeland productivity under these adverse climatic and environmental conditions, since it can produce enough leaf-dry matter and has a higher EoE after winter than *M. ovalifolia*. Therefore, the hypothesis (H_{02}) that *M. oleifera* and *M. ovalifolia* do not vary in LSB heights and leaf-dry-matter yields and EoE after winter in central Namibia is rejected because they differ in all parameters.

Keywords: Extent of endurance, life stages by height, leaf-dry-matter yield, *Moringa oleifera*, *Moringa ovalifolia*

3.2 Introduction

There are 13 known species of moringa trees belonging to the Moringaceae family. These species are divided into three groups based on the shapes of their trunks: slender trees, bottle trees and tuberous shrubs. The slender trees are: *Moringa oleifera* of India, *Moringa concanensis* of India, Pakistan and Bangladesh, and *Moringa peregrina* of Arabia, the Red Sea area, Egypt, Sinai, Israel and Sudan. The bottle trees include: *Moringa ovalifolia* of Namibia and Angola, *Moringa drouhardii* and *Moringa hildebrandtii* of Madagascar; and *Moringa stenopetala* of Ethiopia and Kenya. The tuberous shrubs and trees of northeast Africa comprise the last group: *Moringa Arborea* of Kenya; *M. rivae* of Kenya and Ethiopia; *Moringa borziana* of Kenya and Somalia, *Moringa pygmaea* of Somalia; *Moringa longituba* of Kenya, Ethiopia and Somalia; and *Moringa ruspoliana* of Kenya, Ethiopia and Somalia (Fuglie, 2001; Olson, 2001; Prince, 2007). Although there are many *Moringa* species, *M. oleifera* is the plant most adapted

worldwide, compared to the other species; it is also the most widely known and studied species (Prince, 2007; Leone *et al*., 2015). Many research studies have been done on its uses and numerous beneficial properties in the plant kingdom (Edward, Chamshama, Ngaga, & Mndolwa, 2014; Fuglie, 2001).

Moringa oleifera is a fast-growing and drought-resistant tree that is native to the southern foothills of the Himalayas in northern India (Fuglie, 2001; Radovich, 2007). It is commonly known as horse-radish or drumstick tree in English (Moringa Mission Trust, 2005). It grows rapidly even in poor soils, and arid-lands (Alhakman *et al*., 2013; Morton, 1991). Although native to India, it has been planted around the world and is naturalized in many countries (Sanchez *et al*., 2006; Sanchez-Machado, Núñez-Gastélum, Reyes-Moreno, Ramírez-Wong, & López-Cervantes, 2010). For instance, it is commonly cultivated throughout Senegal as a living fence around compounds in villages (Ojukwu, 2012). Other examples of moringa growing in African countries showed that the seeds germinate within 5 to 12 days and are transplanted at the height of 60 to 90 cm. *Moringa oleifera* can tolerate up to 6 months of dry season reasonably well; however, prolonged stress from lack of water can lead to loss of leaves (Fuglie, 2001; Sanchez *et al*., 2006). It grows rapidly and has the capacity to produce large quantities of fresh biomass (Sanchez *et al*., 2006). A research study done at the International Trypanotolerance Centre in Banjul (The Gambia) showed that *M. oleifera* could yield biomass in excess of 15 tonnes dry matter/hectare (DM/ha) in a 60-day growing cycle (Akinbamijo *et al*., n.d.).

On the other hand, *M. ovalifolia*, which is described as a bottle tree because of the shape of its trunk, is native to Namibia and Angola. This species is uncommonly found in the central areas of Namibia, and is widespread in western region as far south as 26^{o} S. However, it is generally uncommon in many other areas of Namibia. *Moringa ovalifolia* can be found in scattered localities in the Karstveld and occasionally in the south. It grows in the wild in both Namibia and Angola. It is a deciduous tree with a distinctive, squat, swollen stem and branches and is commonly known as "ghost tree or phantom tree". The roots, bark and wood are eaten by goats and the leaves are also browsed by giraffe (Curtis & Mannheimer, 2005; Olson, 2001; Van Wyk *et al*., 2011). Under cultivation, *M. ovalifolia* grows fast in height in the first three weeks of development at nursery level, after which growth becomes slower for root development (Korsor *et al*., 2016).

The problem is that Namibia is both an arid and a semi-arid country with low rainfall and persistent drought occurrences that adversely affect rangeland productivity and livestock production. (Agra Professional Services, 2013; Van Schalkwyk, 2014) described Namibia as a country with the driest climate in sub-Saharan Africa. Sijssens (2014) concluded that the production of additional fodder from dry-land, cultivated grass pastures and plantations of drought-tolerant fodder shrubs should become a priority in Namibia; hence, emphasizing that livestock production should no longer be dependent solely on highly sensitive native rangeland but should also include other sources of fodder. Therefore, *M. oleifera*, which is known to be a fast-growing and drought-tolerant fodder and medicinal tree, could serve the purpose of Namibia's rangeland improvement through its incorporation into rangelands along with *M. ovalifolia*, which is to some

extent slower growing in LSB height and less productive at first, but has proved to be a highly drought-tolerant tree.

3.3 Materials and Methods

3.3.1 Study Area

A moringa orchard of 0.21 hectares (0.11 hectares for *M. oleifera* and 0.10 hectares for *M. ovalifolia*) was established in 2014 at the Neudamm Experimental Farm of the University of Namibia, about 30 km east of Windhoek, with an area of 10, 177 hectares. It was carried out over two summer-growing seasons of 2014/2015 and 2015/2016 for LSB height and leaf-dry-matter yield, and three winter seasons of 2014, 2015 and 2016 for EoE, starting from February 2014 and ending in January 2017. Neudamm Campus is located at 22° 30′ 07″ S and 17° 22′ 14 E**,** and at an altitude of 1762 meters above sea level. The farm's temperature ranges between a minimum of -7°C and a maximum of 44°C (University of Namibia, 2011), and received annual average rainfall of 229 mm, 247.8 mm and 368 mm in 2014/2015, 2015/2016 and 2016/2017 summer seasons, respectively (P. Beukes, 2017).

The vegetation of Neudamm Farm is classified as highland savannah (semi-arid savannah) and characterized by grasses, shrubs and trees that are well spread over the farm. An annual grass like *Melinis repens* and perennial grasses like *Schmidtia pappophoporoides*, *Anthephora pubescens* and *Brachiaria nigropedata* are well represented on the farm. Different types of trees like *Acacia brownii*, *Acacia erioloba*, *Acacia mellifera* as well as shrubs like *Grevia flava*, are found on Neudamm

Experimental Farm. The estimated carrying capacity is about 12 hectares per large stock unit or 45 kg per hectare biomass (Kahumba, 2010; Kapu, 2012; A. Beukes, 2017).

3.3.2 Experimental Design

A completely randomized design (CRD) was used for this study for both *M. oleifera* and *M. ovalifolia*. In February 2014, 120 *M. oleifera* and 64 *M. ovalifolia* two-months old seedlings were transplanted on the field at spacing distances of 2.5 m x 2.5 m and 3 m x 3 m for *M. oleifera,* as suggested by Fuglie and Sreeja (2001) and Radovich (2007), and distances of 3 m x 3 m, 3.5 m x 3.5 m, 4 m x 4 m and 4.5 m x 4.5 m for *M. ovalifolia* between rows and plants, respectively. The four spacing distances for *M. ovalifolia* were meant to determine the appropriate spacing distances since there is no knowledge of its domestication. For *M. oleifera,* the field was divided into two plots with four microplots within each plot. Fifteen seedlings were transplanted into each microplot, which amounted to 120 trees. *Moringa ovalifolia,* on the other hand, had four spacing distances with four microplots which had 16 plants each, amounting to 64 seedlings. *Moringa oleifera* had more seedlings transplanted than *M. ovalifolia* due to the limited number of available *M. ovalifolia* seedlings at the time of planting although the study intended to have equal of trees planted for both *Moringa* species.

3.3.3 Field Preparation and Transplanting of Seedlings

The field was an old cereal production site that had no trees or stumps to uproot. Clearing of grass and ploughing were done concurrently on the field using a tractor, which incorporated the grass into the soil. Since it was a rainy season, the field was left for the grass to rot within a month before transplanting as suggested by Onwueme and

Sinha (1991). After a month, holes of 50 cm diameter were dug to a depth of 50 cm for the purpose of loosening the soil and retaining moisture in root zones, as well as enabling the roots of seedlings to develop rapidly. The holes were left open to receive rain, after which seedlings were transplanted the following day in the morning and at sunset to avoid sun stress. Five kilograms (kg) of cow manure was thoroughly mixed with topsoil for use during the transplanting of the seedlings in the field (Fuglie and Sreeja, 2001). The seedlings were about 60 days old with average LSB heights of 19 cm for *M. oleifera* and 13 cm for *M. ovalifolia* at transplanting time. Transplanting was completed within two weeks.

Watering was done once a week during the first growing season (2014/2015) summer, and once fortnightly during the second growing season (2015/2016) summer. Watering was done weekly for the first growing season because the trees were younger, with shallow root systems and needed water at shorter intervals compared to the second growing season, when the trees were bigger with established tap roots, thus, needed less water to survive. During winter, watering was done biweekly for both the first and second seasons (2014 winter and 2015 winter) to avoid freezing of the trees and subsequent mortality. Fuglie and Sreeja (2001) stated that *M. oleifera* trees do not need much watering, except in very dry conditions when it must be done regularly for the first two months and afterwards only when the trees are obviously suffering.

Superphosphate fertilizer with a P content of 83 g/kg (Wonder superphosphate granular, AGRO-SERVE (Pty) Ltd., Bryanston, South Africa) and nitrogen fertilizer with an N content of 280 g/kg (Limestone Ammonium Nitrate - LAN), from WONDER

HORTICULTURAL PRODUCTS (Pty) Ltd., Silverton, South Africa were applied at the rate of 0 g, 100 g, 200 g and 300 g a month after transplanting to boost the root system development as well as the leaves (Radovich, 2007), since winter was about to begin in two months. Both *Moringa* species were cultivated in the same field of 0.21 hectares but the field was divided into two parts in which the *M. oleifera* site had dimensions of 73 m x 15 m = 1,096m^2 (0.11 ha), while the *M. ovalifolia* area was 60.4 m x 15 m = 906m^2 (0.10 ha) in size.

3.3.4 Soil Composition of the Experimental Field

The results of soil analysis for the determination of the amount of nutrients and their properties are found in Table 3.1. The analysis was done at the Ministry of Agriculture, Water and Forestry soil laboratory in Windhoek. These results include the soil pH, electrical conductivity or soluble salts (EC), organic matter (OM), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na) and soil texture. The 30-60 cm soil depth range had higher nutrient contents than the 0-30 cm soil depth range, except for OM and P levels, which were higher, with values of 0.87% and 24.60 ppm, respectively. Johnston and Steen (2013) stated that adequate and readily available reserves of P must be available in the soil; however, most un-manured soils contain too little of this plant micronutrient readily available to meet the large demand of crops, particularly during certain growth periods such as root development of seedlings and flowering of plants. Therefore, fertilizers containing P must be added to the soil to boost plant growth, development and yield. The soil analysis results show that the soil was slightly basic with pH values of 7.22 and 7.67 for 0-30 cm and 30-60 cm depths, respectively. Fuglie and Sreeja (2001) emphasized that moringa tolerates a wide range of

soil conditions, but prefers a neutral to slightly acidic pH of 6.3-7.0. The particle size analysis revealed that the soil is sandy (84.2% at 0-30 cm depth and 82.1% at 30-60 cm depth), with low silt and clay (< 10% each).

Table 3.1: Soil nutrient properties and characteristics

		Sample No.	
Type of Analysis	Units	0-30 cm depth	30-60 cm depth
pH		7.22	7.67
Electrical Conductivity or Soluble Salts (EC)	mS/cm	80	87
Organic Matter (OM)	%	0.87	0.65
Phosphorus (P)	ppm	24.60	12.30
Potassium (K)	ppm	295	384
Calcium (Ca)	ppm	572	586
Magnesium (Mg)	ppm	95	107
Sodium (Na)	ppm	5	8
Texture	----	Loamy sand	Loamy sand
Sand	%	84.2	82.1
Silt	%	8.2	9.7
Clay	%	7.6	8.1

3.3.5 Weeds and their Control

As with all cultivated plants, weeds were a major challenge to the moringa orchard. Weeding was done manually by hoeing, hand pulling, and brushing of the field at regular weeding intervals, as suggested by Ojiako *et al*. (2012). In this study, weeds were only a problem during the summer season (October to May) when rain was falling and temperatures were optimum for plant growth; no weeding was done in winter. Ojiako *et al*. (2012) noted that weeding has to be done at intervals to prevent weeds from competing with the crops for nutrients. During the winter season, many plants, including grasses, become dormant, thus minimizing their growth and development. Both *M. oleifera* and *M. ovalifolia* grew well in a weeded/cleaned environment.

Moringa oleifera is very sensitive to weeds in that weeds foster pests such as insects (crickets, bugs and caterpillars) which in turn feed on moringa leaves and shoots causing it to lose leaves and growth vigour. Field observation showed that in un-weeded conditions, *M. ovalifolia* maintained proper growth and development despite the weeds and insects, while *M. oleifera* was negatively affected by the insect infestations. Ojiako *et al*. (2012) also argues that pest attacks are reduced through weeding because weeds may serve as hosts to insect pests.

3.3.6 Pests of *M. oleifera* and *M. ovalifolia*

Although at different extent, *M. oleifera* and *M. ovalifolia* are vulnerable to pests such as crickets, locusts, bugs and caterpillars that tend to feed on the leaves and shoots. Pest attacks cause the plants to lose their leaves and growth vigour. Sometimes the trees even die. Also, wild animals such as rodents feed on the roots of both species of moringa trees, killing them.

Moringa, like other plants, have natural enemies that obstruct their growth and survival. They are normally attacked in the early life stages of their growth, from seedlings to three months of age. One order of insects that affects moringa is *Hemiptera*, which consists of bugs. They are of the phylum *Arthropoda*, class *Insecta* and sub-class *Pterygota* (winged insects). Many hemipterans pierce plant tissues to feed on the sap, while others use the same organ to suck the juices of other animals. Because of their sucking habit, they are potential pests, especially when they are vectors for viruses, bacteria and fungi that cause diseases in crop and garden plants (Callaghan & Fellowes, 2017; Picker, Griffiths, & Weaving, 2004). They colonize the plants and feed on the sap

of the young plants, which weaken the trees and consequently cause them to die off. The sap is responsible for transporting plant nutrients to all parts of the tree. When tree sap is drained off by insects, the flow of nutrients becomes limited, leading to the drying out of leaves and the eventual death of the trees. Figure 3.1 shows some of the bugs found on moringa trees during this study.

Figure 3.1: Hemiptera (bugs) on tree leaves

The infestation by insects was mostly noticed from October 2014 to January 2015 due to the attractive sprouting of young shoots after winter. Also, during this time, young plants growing from directly-sown seeds in the field are targeted by those insects which may kill the plants if left unnoticed within two-to-five days.

The second order of insects that affected moringa plants was Orthoptera (family of Tettigoniidae and subfamily of Hetrodinae), especially the *Acanthoplus discoidalis* (*A. discoidalis*) species commonly known as armoured bush crickets or armoured ground crickets and the common milkweed locusts (*Phymateus moribillosus*) (Figure 3.2 A and B and C). This species is more abundant in arid and semi-arid zones, and it is native to parts of Namibia, Botswana, Zimbabwe and South Africa (Mosupi, 2003; *Picker et al.*,

2004; Wikipedia, 2017). A few of *A. discoidalis* were noticed on the field around late January 2017 but they had less effect by then. On the other hand, *P moribillosus* were seen on trees throughout the period under study (2014 to 2017), but their damage to plants was unnoticeable, in comparison to other insects.

It was observed that *A. discoidalis* fed on the leaves and buds of *M. oleifera* trees, causing 95 to 100 percent loss of leaves (Figure 3.3) from around February to May; however, they had little or no impact on *M. ovalifolia* trees (Figure 3.4). Mosupi (2003) confirmed that nymphs and young adults of *A. discoidalis* feed mainly on the vegetative parts of grasses and broadleaf plants as well as crop fields flowering panicles and developing grain until April and early May. The locusts had less impact on both species of moringa leaves. In the current study, young moringa trees in the field were affected by bugs while older trees were affected by *A. discoidalis.*

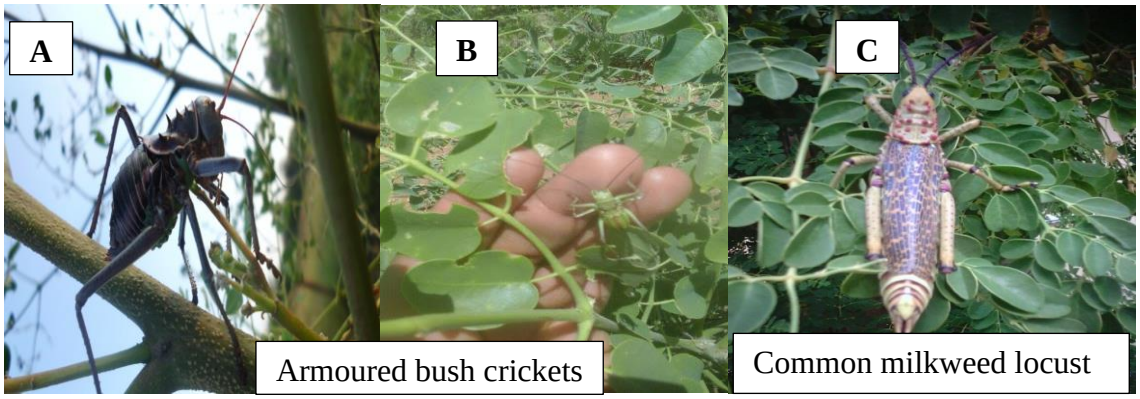

Figure 3.2: *A. discoidalis* (A and B) and *P. moribillosus* (C) feeding on buds and leaves of *Moringa* species

Figure 3.3: Effect of *A. discoidalis* and caterpillar feeding on *M. oleifera* trees

Figure 3.4: *M. ovalifolia* trees showing little or no pest damage

Beside insects, other pests such as wild animals, especially rodents were also major challenge. While the insects feed on the leaves, these animals uprooted the trees and fed on the roots; thus, killing the trees completely (Figure 3.5). The only control used for this was fencing off the entire field perimeter with wire mesh and attaching barbed wire at the ground-level of the fence to prevent the animals' access into the orchard.

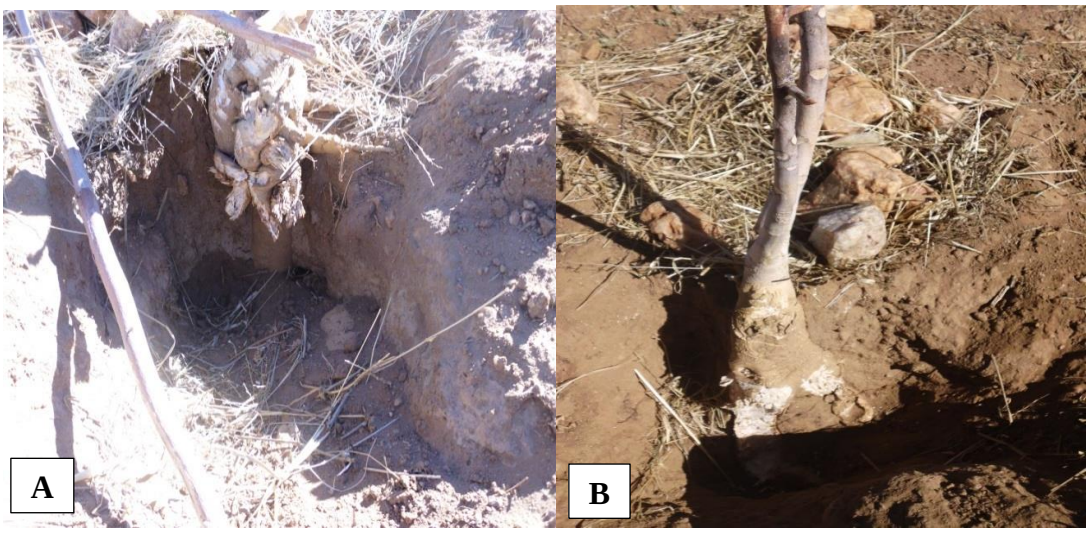

Figure 3.5: *M. oleifera* (A) and *M. ovalifolia* (B) roots dug and eaten by animals

Insects caused more damage on *M. oleifera* compared to *M. ovalifolia*. This may be caused by *M. ovalifolia*'s adaptability to its environment as an indigenous tree of Namibia, giving it an edge over *M. oleifera*. Hand-picking of insects was used as a natural control method, which worked well when the plants where younger but as they got older, it became difficult and resulted in *M. oleifera* being damaged by the insects.

3.3.7 Data Collection Procedures

Data collected included tree heights, dry-matter yields of leaves harvested during summer seasons and trees' counts for the EoE after winter. Heights were measured for a random sample of 20 *M. oleifera* and 20 *M. ovalifolia* trees at 30-day intervals in 2014/2015 and 60-day intervals in 2015/2016 to determine the LSB heights during the growing seasons in summer, at which time the leaves were harvested to evaluate the leaf-dry-matter yields concurrently. Harvested leaves were thinly spread on plastic sheets in the farmhouse for shade drying for 2-3 weeks without turning. Harvesting was

done in summer because 99% of rainfall occurs in the summer months in Namibia (Pallett, 1994), which is considered as the growing season for plants in Namibia. After summer, winter sets in and causes all the moringa trees to go into dormancy. After winter, all trees were counted to determine their EoE and sprouting differences for both species of moringa.

3.3.8 Data Analysis

Statistical Package for Social Sciences (SPSS® version 23) and Microsoft Excel® (version 13) were used to do all the analyses. A generalized linear model (GLM) and independent sample t-tests were used to analyse LSB heights and leaf-dry-matter yields of *M. oleifera* and *M. ovalifolia*, in which heights of trees and weights of leaf-dry matter were used as dependent variables, while months and years were used as independent variables. It is worth noting that all statistical analyses were only considered significantly different at the alpha levels of $p \leq 0.05$, and all p-values above these alpha levels were considered non-significant. A column chart in Excel was used to compare the two *Moringa* species' EoE.

3.4 Results and Discussion

The results presented and discussed here include *M. oleifera* and *M. ovalifolia* growth as measured by LSB heights and harvested leaf-dry-matter yields for two summer seasons of 2014/2015 and 2015/2016 as well as the EoE of trees for three winter seasons (2014, 2015, 2016). Despite the scarcity of water, both species are drought-resistant trees and do quite well when fully established, as described by Morton (1991). However, tolerance to cold and freezing winter weather had not yet been established in Namibia.

3.4.1 *M. oleifera* and *M. ovalifolia* Height Increase (cm) for 2014/15 and 2015/16 Summer Seasons

Figure 3.6 shows the average LSB heights of trees for each summer growing season. In the orchard, *M. oleifera* had greater maximum LSB height (224.90 cm) than *M. ovalifolia* (77.03 cm) in the month of April, whereas the lowest LSB heights were 36.75 cm and 5.40 cm, respectively, in November 2014/2015. The lowest LSB heights were observed in November because the plants sprouted late, after the 2014 winter dormancy. In 2015/2016, *M. oleifera* had an average best LSB height of 281.45 cm in March, compared to that of *M. ovalifolia* (113.20 cm) in April; while the minimum heights of 70.05 cm and 22.00 cm for the two species, respectively, were observed in October. *Moringa oleifera* had an overall average best and greatest LSB heights of 130.50 cm and 194.06 cm, while *M. ovalifolia* measured 40.77 cm and 66.74 cm in the 2014/2015 and 2015/2016 growing seasons, respectively. *Moringa oleifera* is an extremely fast-growing tree and can reach a height of 400 cm in a year, and, eventually, 600 to 1500 cm (Prince, 2007; Radovich, 2007). However, the results of this study for both species had lower heights due to the shorter growing summer seasons (September to April) as discussed by Pallett (1994). The highest LSB heights in 2015/2016 can be attributed to the already established root systems of the trees in comparison to the 2014/2015 season when the trees were younger with shallow root system establishments.

Central Namibia being an arid and semi-arid region, plants grow more rapidly during summer seasons (October to April), after which winter (May to September) sets in and negatively affects the plants' growth. This could explain the minimum heights observed in October (a transition month) 2015 for both species. According to Billings (1987), all

environments and all stressors do not have the same effects on plant growth and reproduction. Likewise, all kinds of plants do not adapt equally to environmental changes, nor do they have the same level of coping with stress factors.

Seasonally, Figure 3.6 shows that both *M. oleifera* and *M. ovalifolia* grew taller in terms of LSB height in the second summer-growing season (2015/2016) compared to the first summer-growing season (2014/2015). This means that between the two growing-summer seasons, the lowest heights were observed in the first season (2014/2015), while the highest heights were in the second season (2015/2016). Within species, LSB heights were lower in each species in the first growing season than in the second season. In the 2015/2016 growing season, *M. oleifera* had the highest average LSB heights (cm) of 281.45 cm against 224.90 cm in the 2014/2015 growing season. *Moringa ovalifolia* likewise elongated faster in 2015/2016, with a maximum of 113.20 cm in the month of April, while 2014/2015 had a maximum of 77.025 cm in the same month. Just as in the highest, the lowest LSB heights (cm) for *M. oleifera* were observed during the 2014/2015 growing season as 36.75 cm recorded in November 2014 while for the 2015/2016 season, a minimum height of 70.05 cm was recorded in October 2015. Similarly, the lowest LSB heights (cm) of *M. ovalifolia* were 5.40 cm in November 2014 and 22 cm in October 2015, which clearly indicates that the more the trees mature, the faster they sprout and elongate after the winter season.

These differences in LSB heights between the two summer-growing seasons can be attributed to two factors; namely, the ages of the trees and the cutting and/or harvesting interval. That is, in the first growing season (2014/2015), trees were younger/smaller and

measured at 30-day intervals after which they were harvested and cut back for regrowth. This may have affected the elongation of the young trees. In the second growing season (2015/2016), trees were older/bigger and measured and harvested and/or cut at 60-day intervals for regrowth. This may have contributed to the highest LSB heights for 2015/2016. Besides the differences between the 30-day and 60-day harvesting and cutting intervals, the differences in LSB heights between the two growing seasons can also be attributed to the root systems becoming better established; that is, roots of young trees are shallow in the soil compared to roots of older trees that are deeply rooted, which enables them to elongate faster, thus promoting more vegetative growth. Fuglie (2001) reported that in the first year, *M. oleifera* will grow up to 500 cm in LSB height and if left alone, it subsequently reaches 1200 cm in height, with a trunk of 30 cm circumference over the years.

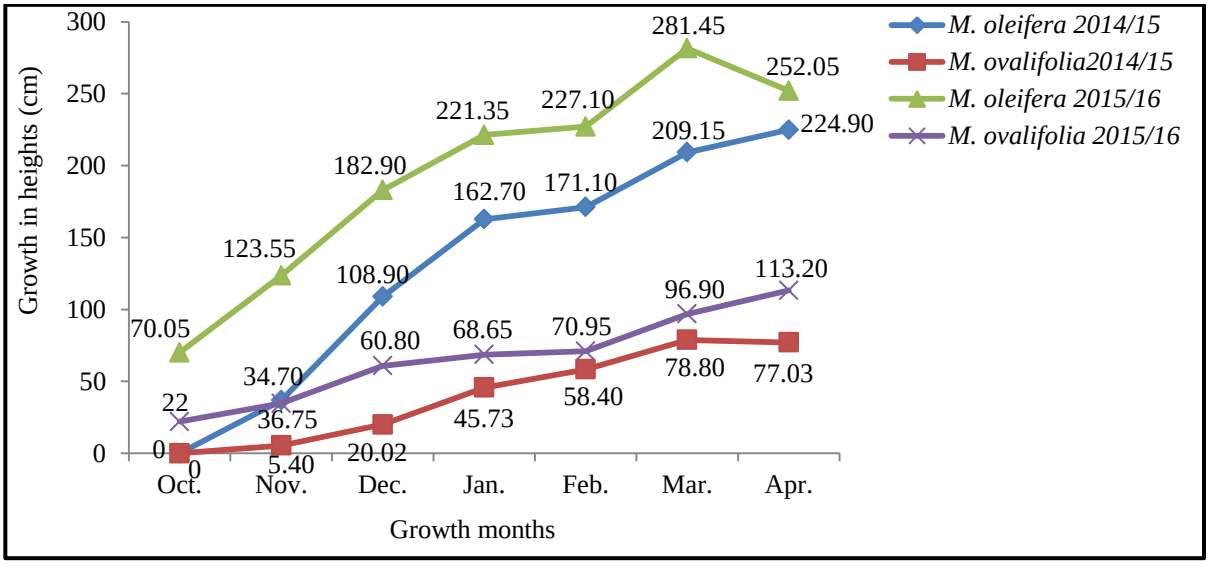

Figure 3.6: Monthly average increase in LSB heights of *Moringa* species in 2014/15 and 2015/16

The results of a general linear model (GLM) analysis of variance test of *Moringa* species' monthly LSB height with an $F_{(1,\ 38)}$-value of 548.60 for the 2014/2015 and 2015/2016 summer-growing seasons showed a highly significant difference ($P < 0.001$) in mean monthly increase in heights between *M. oleifera* and *M. ovalifolia* for the two seasons. Table 3.2 presents the results of the Pairwise Multiple Comparisons test of *Moringa* species monthly increase in heights (cm) for the 2014/2015 and 2015/2016 summer growing seasons. The analysis reveals that both *M. oleifera* and *M. ovalifolia* had a highly significant difference ($P < 0.001$) in mean monthly LSB height increments over the two seasons. This implies that the two species had different LSB heights in the two seasons. Hence, the hypothesis (H_{02}) that *M. oleifera* and *M. ovalifolia* do not vary in LSB heights is rejected because they differ in heights significantly.

Table 3.2: Pairwise comparisons of *Moringa* species monthly height increments (cm) for 2014/15 and 2015/16 seasons

(I) *Moringa* spp.	(J) *Moringa* spp.	Mean Difference (I-J)	Standard Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
M. oleifera	*M. ovalifolia*	116.88	4.99	0.000***	106.77	126.98
M. ovalifolia	*M. oleifera*	-116.88	4.99	0.000***	-126.98	-106.77

Based on estimated marginal means

***. The mean difference is highly significant at the 0.001 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

The GLM analysis used to test monthly differences of *Moringa* species and their LSB heights for 2014/2015 and 2015/2016 summer seasons is shown in Tables 3.3. The test results showed that mean monthly LSB height increments (cm) contrasts were significantly different ($P < 0.05$) within most of the months, that is, from November 2014 to April 2016. This was with the exception of January versus February 2015,

March versus April 2015, January versus February 2016 and March versus April 2016, that were not significantly different ($P > 0.05$) in LSB heights. For the contrasts in LSB heights of the *Moringa* species, there was a mean significant difference in height ($P < 0.05$) within 2014; *M. ovalifolia*'s LSB heights in 2014 had no significant differences ($P > 0.05$) within November versus December 2014, December 2014 versus January 2015, April versus October 2015, October versus November 2015, November versus December 2015 and March versus April 2016 LSB height increments, respectively. On the other hand, there were no significant differences ($P > 0.05$) within January versus February 2015, December 2015 versus January 2016, January versus February 2016 and February versus March 2016 in LSB height increments and *Moringa* species, respectively, as presented in the discussion of Table 3.4.

Table 3.3: Monthly differences in LSB heights (cm) of *Moringa* species in 2014/2015 and 2015/2016

Source	Heights (cm)	Type III Sum of Squares	df	Mean Square	F	P-values
Heights (cm)	Nov.'14 vs. Dec.'14	75281.65	1	75281.65	147.53	0.000***
	Dec. '14 vs. Jan. '15	63218.40	1	63218.40	46.23	0.000***
	Jan. '15 vs. Feb. '15	4441.56	1	4441.56	1.98	0.167ns
	Feb. '15 vs. Mar. '15	34164.03	1	34164.03	9.83	0.003***
	Mar. '15 vs. Apr. '15	1953.01	1	1953.01	1.17	0.286ns
	Apr. '15 vs. Oct. '15	440475.16	1	440475.16	185.28	0.000***
	Oct. '15 vs. Nov. '15	43824.40	1	43824.40	23.34	0.000***
	Nov. '15 vs. Dec. '15	73017.03	1	73017.03	48.48	0.000***
	Dec. '15 vs. Jan. '16	21436.90	1	21436.90	4.91	0.033*
	Jan. '16 vs. Feb. '16	648.03	1	648.03	0.21	0.647ns
	Feb. '16 vs. Mar. '16	64480.90	1	64480.90	21.94	0.000***
	Mar. '16 vs. Apr. '16	1716.10	1	1716.10	0.29	0.594ns
	Nov.'14 vs. Dec.'14	33102.76	1	33102.76	64.87	0.000***
Heights*_Moringa_ species	Dec. '14 vs. Jan. '15	7890.48	1	7890.48	5.77	0.021*
	Jan. '15 vs. Feb. '15	182.76	1	182.76	0.08	0.777ns
	Feb. '15 vs. Mar. '15	3115.23	1	3115.23	0.90	0.350ns
	Mar. '15 vs. Apr. '15	3071.26	1	3071.26	1.84	0.183ns
	Apr. '15 vs. Oct. '15	99650.31	1	99650.31	41.92	0.000***
	Oct. '15 vs. Nov. '15	16646.40	1	16646.40	8.87	0.005**
	Nov. '15 vs. Dec. '15	11055.63	1	11055.63	7.34	0.010**
	Dec. '15 vs. Jan. '16	9363.60	1	9363.60	2.15	0.151ns
	Jan. '16 vs. Feb. '16	119.03	1	119.03	0.04	0.844ns
	Feb. '16 vs. Mar. '16	8065.60	1	8065.60	2.74	0.106ns
	Mar. '16 vs. Apr. '16	20884.90	1	20884.90	3.51	0.069ns
Error (Heights)	Nov.'14 vs. Dec.'14	19390.14	38	510.27		
	Dec. '14 vs. Jan. '15	51964.12	38	1367.48		
	Jan. '15 vs. Feb. '15	85114.94	38	2239.87		
	Feb. '15 vs. Mar. '15	132057.75	38	3475.20		
	Mar. '15 vs. Apr. '15	63418.99	38	1668.92		
	Apr. '15 vs. Oct. '15	90341.79	38	2377.42		
	Oct. '15 vs. Nov. '15	71342.70	38	1877.44		
	Nov. '15 vs. Dec. '15	57229.35	38	1506.04		
	Dec. '15 vs. Jan. '16	165807.50	38	4363.36		
	Jan. '16 vs. Feb. '16	115325.95	38	3034.89		
	Feb. '16 vs. Mar. '16	111685.50	38	2939.09		
	Mar. '16 vs. Apr. '16	226145.00	38	5951.18		

Note: ns = non-significant at 0.05; * = significant at 0.05; ** = highly significant at 0.01;
*** = Extremely significant to ≤ 0.001 alpha levels

Tables 3.4 indicates the GLM descriptive statistics results for two *Moringa* species' mean monthly LSB height increments (cm) for the 2014/2015 and 2015/2016 summer seasons. The descriptive statistics showed that the lowest means were observed in November 2014 for both *M. oleifera* (36.75 cm) and *M. ovalifolia* (5.40 cm), while the highest heights were obtained in March 2016, with *M. oleifera* measuring 281.45 cm and April 2016 for *M. ovalifolia*, with a height of 113.20 cm as captured in Figure 3.6. Based on the field observations, *M. oleifera* grew faster on average than *M. ovalifolia*, and this was statistically significant. The slower LSB height of *M. ovalifolia* might be attributed to the first focus on underground growth of the roots into tubers to preserve energy for rough conditions (winter/drought) as described by Korsor *et al*. (2016).

Table 3.4: Descriptive statistics for *Moringa* species monthly LSB height increments (cm) for 2014/15 and 2015/16

Moringa Species heights (cm)		N	Mean	Standard Deviation	Standard Error of Mean
November 2014	*M. oleifera*	20	36.75	23.34	5.22
	M. ovalifolia	20	5.40	4.96	1.11
	Total	40	21.08	23.01	3.64
December 2014	*M. oleifera*	20	108.90	26.78	5.98
	M. ovalifolia	20	20.02	8.67	1.94
	Total	40	64.46	49.11	7.77
January 2015	*M. oleifera*	20	162.70	33.37	7.46
	M. ovalifolia	20	45.73	15.56	3.48
	Total	40	104.21	64.57	10.21
February 2015	*M. oleifera*	20	171.10	49.62	11.10
	M. ovalifolia	20	58.40	20.14	4.50
	Total	40	114.75	68.22	10.79
March 2015	*M. oleifera*	20	209.15	50.00	11.18
	M. ovalifolia	20	78.80	27.58	6.17
	Total	40	143.98	77.11	12.19
April 2015	*M. oleifera*	20	224.90	51.96	11.62
	M. ovalifolia	20	77.03	25.82	5.77
	Total	40	150.96	85.13	13.46
October 2015	*M. oleifera*	20	70.05	30.88	6.92
	M. ovalifolia	20	22.00	12.23	2.74
	Total	40	46.03	33.61	5.31
November 2015	*M. oleifera*	20	123.55	43.10	9.64
	M. ovalifolia	20	34.70	12.93	2.89
	Total	40	79.13	54.87	8.68
December 2015	*M. oleifera*	20	182.90	58.73	13.13
	M. ovalifolia	20	60.80	25.56	5.72
	Total	40	121.85	76.30	12.06
January 2016	*M. oleifera*	20	221.35	71.35	15.95
	M. ovalifolia	20	68.65	30.69	6.86
	Total	40	145.00	94.43	14.93
February 2016	*M. oleifera*	20	227.10	39.70	8.88
	M. ovalifolia	20	70.95	25.58	5.72
	Total	40	149.03	85.67	13.55
March 2016	*M. oleifera*	20	281.45	83.51	18.68
	M. ovalifolia	20	96.90	31.51	7.05
	Total	40	189.18	112.31	17.76
April 2016	*M. oleifera*	20	252.05	77.81	17.40
	M. ovalifolia	20	113.20	41.35	9.25
	Total	40	182.62	93.41	14.77

Mean: LSB heights

3.4.2 Comparison of *M. oleifera* and *M. ovalifolia* Sprouting and Extent of Endurance

All environments are stressful to plants in one way or another. The significance of stress to plant extent of endurance (EoE) depends on how long an environment has existed and, therefore, on how long plant taxa have to evolve adaptations to the environmental stressor (Billings, 1987). moringa trees are widely adapted to the tropics and subtropics (Radovich, 2007; Nouman *et al*., 2013; Leone *et al*., 2015). The climate plays an important role in the growth, development and endurance of plants. It governs the plants' area of distribution and sets limits for their EoE. This is seen on a large scale in the global distribution of the various types of vegetation according to zonal climate and soil type, and on a smaller scale, in the distribution of plant species and communities according to local conditions (Larcher, 1995). Since Namibia is a semi-arid and drought-prone country (Pallett, 1994), drought-resistant plants like *M. oleifera*, which Morton (1991) described as a boon to arid lands, can grow and survive in such environments. *Moringa oleifera* is a fast-growing drought-resistant tree that is native to the southern foothills of Himalayas in northern India (Fuglie, 2001). *Moringa ovalifolia*, a tree native to Namibia and Angola, is physiologically well adapted to its native semi-arid and drought-prone environment, as can be seen in its roots systems as discussed by Korsor *et al*. (2016) and Ministry of Agriculture, Water and Forestry (n.d.). Figure 3.7 shows a global humidity index map in which Namibia is shown as a semi-arid and arid country.

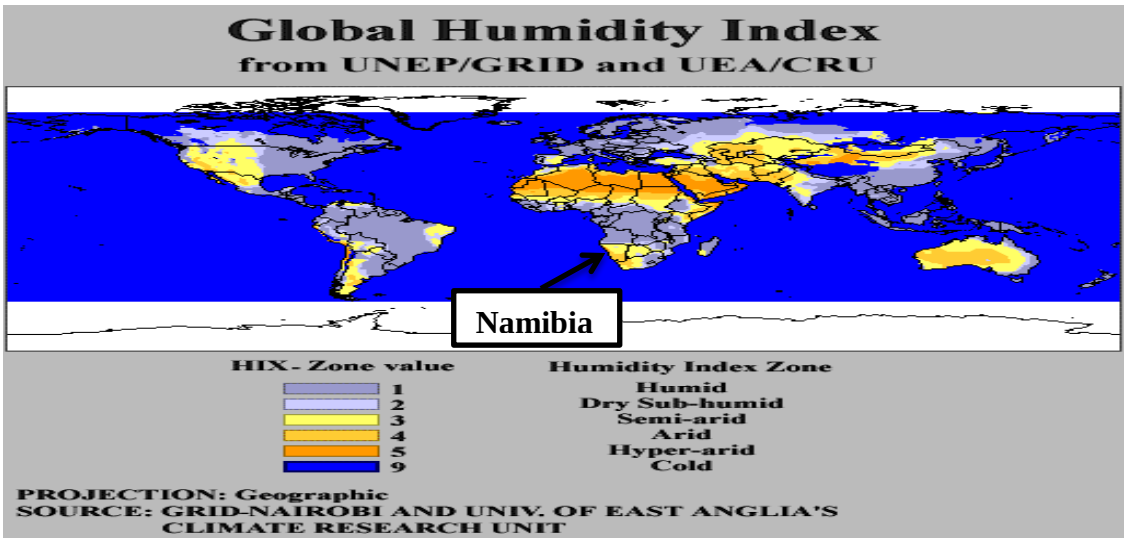

Figure 3.7: World Humidity Index Zone showing the study area (Source: United Nations Environment Program), Retrieved on November 10, 2016 from https://www.google.com.na/search?q=global+humidity+index+map&safe=active&source=lnms&sa=X&sqi=2&pjf=1&ved=0ahUKEwiQpPC5k9PSAhUpIMAKHWGZAh0Q_AUIDCgA&biw=1920&bih=901&dpr=1

Figure 3.8 shows the effect of winter on *M. oleifera* at the beginning and the end of 2015 winter, while Figure 3.9 displays *M. ovalifolia* at the beginning and the end of the same 2015 winter season. These pictures are a clear indication of how much damage winter frosts can cause to the trees every season. Obviously, such damage, depending on the severity can lead to the death of many trees after winter.

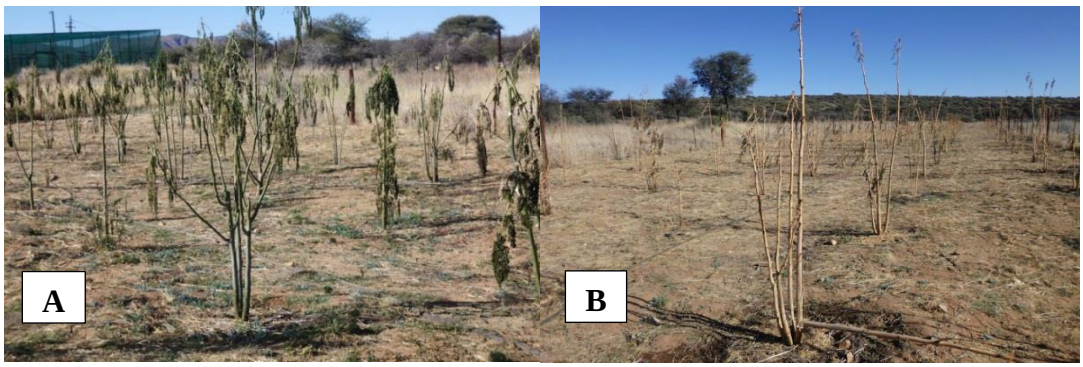

Figure 3.8: *M. oleifera* at the beginning (A) and at the end (B) of winter 2015

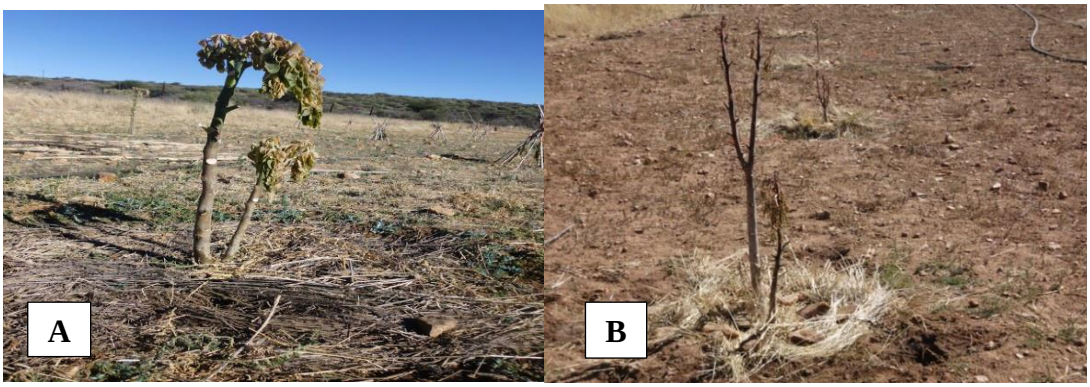

Figure 3.9: *M. ovalifolia* at the beginning (A) and at the end (B) of winter 2015

Figure 3.10 presents the EoE of *M. oleifera* and *M. ovalifolia* trees after the 2014 winter season. Although all 120 *M. oleifera* and 64 *M. ovalifolia* seedlings were transplanted from the nursery to the field in early 2014 (late January to February), they were all affected by winter (May to September) frost. Afterwards, summer sets in from October to April (Pallett, 1994) and temperatures rise to the level that could support both *Moringa* species' growth and development, as discussed by Metcalfe and Elkins (1980) and Larcher (1995). Sprouting was thoroughly observed in October 2014 in which *M. oleifera* had 66 sprouted trees (55%) compared to *M. ovalifolia* with 10 sprouted trees (15.63%). The sprouting process continued up to January 2015 with the highest count of 85 for *M. oleifera* (70.83%) and 45 for *M. ovalifolia* trees (70.31%) respectively. As newly planted trees, many of their roots were not fully established and therefore the trees succumbed to the winter frost to which they are susceptible. Metcalfe and Elkins (1980) agreed that plants are dependent on the root systems, for water and nutrients, as well as for anchorage in the soil for their very life.

Moringa oleifera had higher EoE in the four months (55% in October, 57.5% in November, 63.33% in December and 70.83% in January), and *M. ovalifolia* had lower EoE of 10 (15.63%) in October, 29 (45.31%) in November, 50 (78.13%) in December and 52 (81.25%) in January. Comparatively, *M. oleifera* had an average EoE of 61.67% and a mortality of 38.34%, while *M. ovalifolia* had an average EoE of 55.08% and a mortality of 44.92%. McDowell *et al*. (2008) agreed that longer winter minimum temperatures can lead to trees mortality, and Parker (1969) concurred that freezing temperatures can retard plant growth. This clearly indicates that *M. oleifera* had a higher EoE than *M. ovalifolia* during 2014/2015 summer season, which supports Morton (1991) and Fuglie (2001)'s statement that *M. oleifera* is a drought-resistant plant and thus a boon in arid lands. At the end of the 2014 winter season, 46 out of 120 *M. oleifera* trees had died, but they were all replaced through direct sowing of seeds. Twelve out of 64 *M. ovalifolia* trees died but were not replaced due to a lack of seeds. Thus, a total of 52 *M. ovalifolia* trees survived and could be found on the field. It was observed that winter in 2014 started with a sudden drop in temperature, affecting almost all the trees, which may have contributed to the high mortality of trees. Metcalfe and Elkins (1980) agreed that a rapid drop in temperature frequently kills plants.

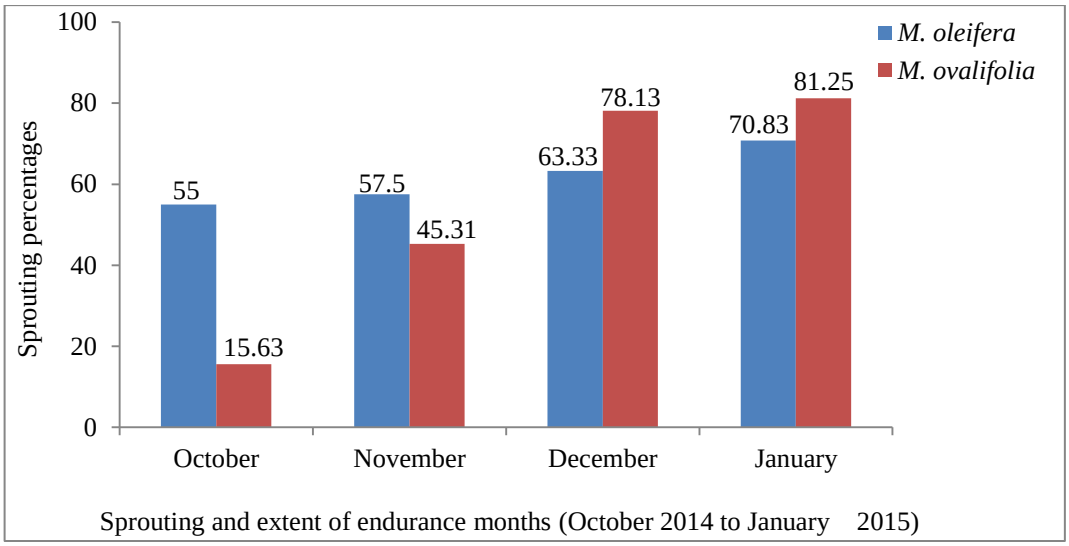

Figure 3.10: Moringa trees' sprouting and EoE differences after 2014 winter season

The descriptive statistics for *M. oleifera* and *M. ovalifolia* EoE after the 2014 winter season are found in Table 3.5. *M. oleifera* had a mean of 61.67 with a maximum of 70.83% EoE, while *M. ovalifolia* had a mean of 55.08 with a maximum of 81.25% EoE. A study conducted by Korsor *et al*. (2016) with *M. oleifera* and *M. ovalifolia* seedlings had the EoE of 81.56% for *M. ovalifolia* and 93.33% for *M. oleifera*, which is consistent with the present study's *M. ovalifolia* EoE, but higher than the EoE for *M. oleifera* in this study.

Table 3.5: Descriptive statistics of *Moringa* species EoE differences after 2014 winter season

Moringa spp.	N	Mean	Standard Deviation	Standard Error Mean
M. ovalifolia	4	55.08	30.92	15.46
M. oleifera	4	61.67	7.04	3.52

Note: Mean of sprouted and/or endured trees

An independent sample test was conducted to determine the statistical difference between the EoE of *M. oleifera* and *M. ovalifolia* after the 2014 winter season (Table 3.6). The sprouted trees were used as dependent variables while the two *Moringa* species were used as independent variables for the analysis. The analysis shows that *M. oleifera* had a higher mean difference of 6.59 sprouted trees (see Table 3.5), which was not statistically significantly different (P > 0.05) from *M. ovalifolia*'s sprouted trees after 2014 winter season. This is an indication that both *Moringa* species had similar endurance as seen in Figure 3.10. Table 3.7 shows the distribution of independent sample mean of the two *Moringa* species. Diagrammically, the distribution of the independent sample mean are presented in Figure 3.11.

Table 3.6: Independent sample t-test of *Moringa* species EoE after 2014 winter season

Moringa spp.	Mean Difference	Pooled Standard Error Difference	t	df	Sig.(2-tailed)
Sprouted trees	6.59	15.86	0.42	6	0.692n.s

Mean difference in extent of endurance rate; note: n.s = non-significant at 0.05 alpha level

Table 3.7: Distribution of independent sample mean of *Moringa* species

	Posterior			95% Credible Interval	
Moringa spp.	Mode	Mean	Variance	Lower Bound	Upper Bound
Sprouted/endured trees	6.59	6.59	0.75	4.89	8.28

Note: Mean difference of sprouted and/or endured trees

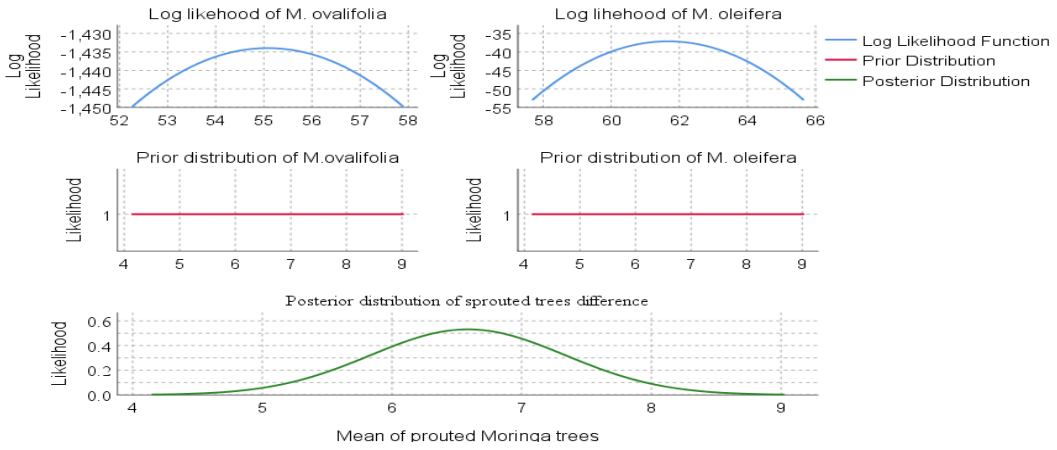

Figure 3.11: Mean distribution of *Moringa* species EoE differences after 2014 winter season

The EoE of *M. oleifera* and *M. ovalifolia* trees after the 2015 winter season is presented in Figure 3.12. *Moringa oleifera* had 117 out of 120 trees that sprouted, which corresponds to a 97.50% EoE with 2.50% total mortality at the end of October 2015. The situation remained unchanged until the end of January 2016 when it was noticed that three trees, which did not sprout had died of winter frost, and they were replaced immediately. A research study with *M. oleifera* in Ihumwa and Ruvu, Tanzania assessing 30-month old trees showed extent of endurance rates of 98.67% and 92% respectively (Edward *et al*., 2014). The present study concurs with their research findings, even though the period of this research in Namibia was under complete drought with winter spell conditions. *Moringa ovalifolia* trees had a gradual sprouting and EoE of 30 (57.69%), 36 (69.23%), 40 (76.92%) and 43 (82.69%) out of 52 trees in four months (October 2015 to January 2016 respectively), with an average mortality of 28.37%. The extent of endurance rates of the two *Moringa* species after the 2015 winter season were carefully monitored from October 2015 to January 2016, and it was noticed that sprouting was faster compared to 2014/2015 when the trees were younger and had

only started sprouting in November. Larcher (1995) pointed out that perennial plants in the first year form a rosette and underground storage organs to ensure a rapid start for development in the second year. It was observed that *M. ovalifolia* trees can take longer (6 to 10 months) in consequential dormancy than *M. oleifera* (4 to 6 months) and still sprout. This extent of endurance ability might be attributed to *M. ovalifolia*'s tuberous-root system that stores food for its future uses during stress. Billings (1987) reported that most perennial plants, both dicotyledonous and monocotyledonous, have large underground root and rhizome systems in which carbohydrates and other compounds are stored. Besides the issue of root development, winter in 2015 set in slowly and affected the trees gradually, which may have contributed to the low mortality rates compared to 2014. Metcalfe and Elkins (1980) noted that plant roots often also perform an important function in storing food for future use. They also emphasized that a gradual drop in temperature kills fewer plants.

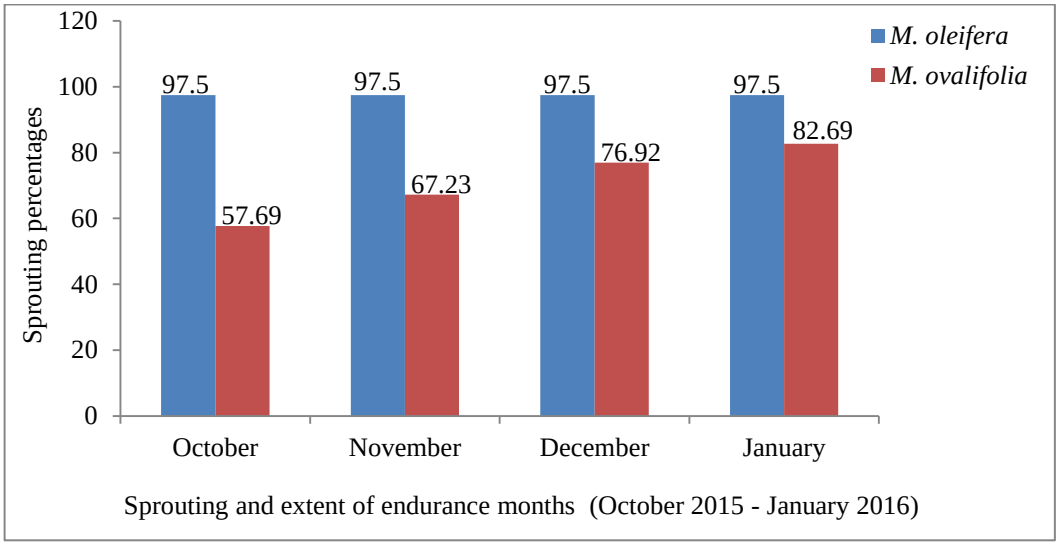

Figure 3.12: Moringa trees' sprouting and EoE differences after 2015 winter season

The descriptive statistics of the two *Moringa* species' EoE after the 2015 winter season are found in Table 3.8. The statistics for EoE show the means of 97.50 and 71.63 endured trees for *M. oleifera* and *M. ovalifolia*, respectively. *Moringa oleifera* sprouted in one month in 2015, causing it to have zero standard deviation and standard error of the mean, while *M. ovalifolia* had a gradual sprouting with 10.81 standard deviation and 5.40 standard error of the mean.

Table 3.8: Descriptive statistics of *Moringa* species EoE differences after 2015 winter season

Moringa spp.	N	Mean	Standard Deviation	Standard Error Mean
M. ovalifolia	4	71.63	10.81	5.40
M. oleifera	4	97.50	0.00	0.00

Note: Mean of sprouted trees

Table 3.9 presents an independent sample test of two *Moringa* species' EoE after the 2015 winter season. The test result reveals that *M. oleifera* had a mean difference of 25.87 endured trees (see Table 3.8), resulting into a significant difference ($P < 0.01$) from *M. ovalifolia* in EoE. Although planted in the same orchard and environmental conditions, each *Moringa* species endured the 2015 winter season at different level (see Figure 3.12). Table 3.10 indicates the distribution of the independent sample mean of sprouted *Moringa* species, which are diagrammatically represented in Figure 3.12.

Table 3.9: Independent sample t-test of *Moringa* species EoE after 2015 winter season

Moringa spp.	Mean Difference	Pooled Standard Error Difference	t	df	Sig. (2-tailed)
Sprouted trees	25.87	5.40	4.79	6	0.003**

Mean of difference in extent endurance rate; note: ** = extremely significant to ≤ 0.001 alpha level

Table 3.10: Distribution of independent sample mean of *Moringa* species

	Posterior			95% Credible Interval	
Moringa spp.	Mode	Mean	Variance	Lower Bound	Upper Bound
Sprouted trees	25.87	25.87	0.75	24.17	27.56

Note: Mean of sprouted trees

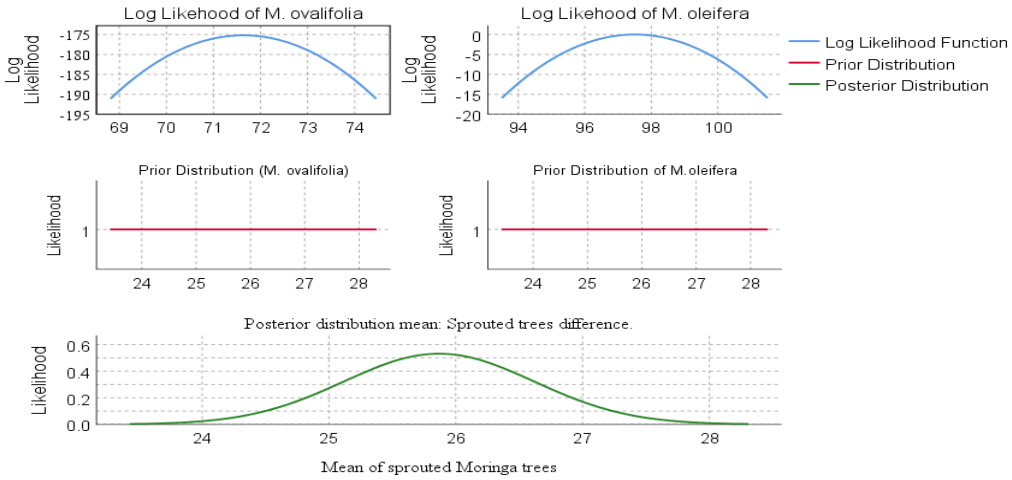

Figure 3.13: Mean distribution of *Moringa* species EoE differences after 2015 winter season

The sprouting and EoE of *M. oleifera* and *M. ovalifolia* trees after the 2016 winter season are found in Figure 3.14. This winter season came in the middle of a severe drought that started in 2015 and continued through 2016, which created a scarcity of water and affected annual and some perennial plant feed sources for wild and domestic animals' grazing and browsing. *Moringa ovalifolia* roots, being more succulent (no stems) than *M. oleifera*, were subject to wild animals, mainly rodents, uprooting them as a source of food and water (23 trees were uprooted in total). Haferkamp (1988) emphasized that water is required by all living organisms. In this case, only 20 trees were left on the field out of the 43 trees that endured the 2015 winter season.

The result in Figure 3.14 shows earlier sprouting and EoE of *M. oleifera* and *M. ovalifolia* species starting in September with 93.33% and 42.11%, October 99.17% and 89.47%, and November 99.17% and 100%, respectively. These earlier sprouting and higher EoE of both *Moringa* species after the 2016 winter season are an indication that older trees have higher endurance capacity and faster sprouting rates compared to younger trees. As observed on the field, older trees (three years old) sprouted within three to five days whenever temperatures improved even in the middle of the winter season, and died off when temperatures worsened. It implies that optimum temperatures are of cardinal importance to plants' growth and EoE, as well as moisture, as stated by Haferkamp (1988).

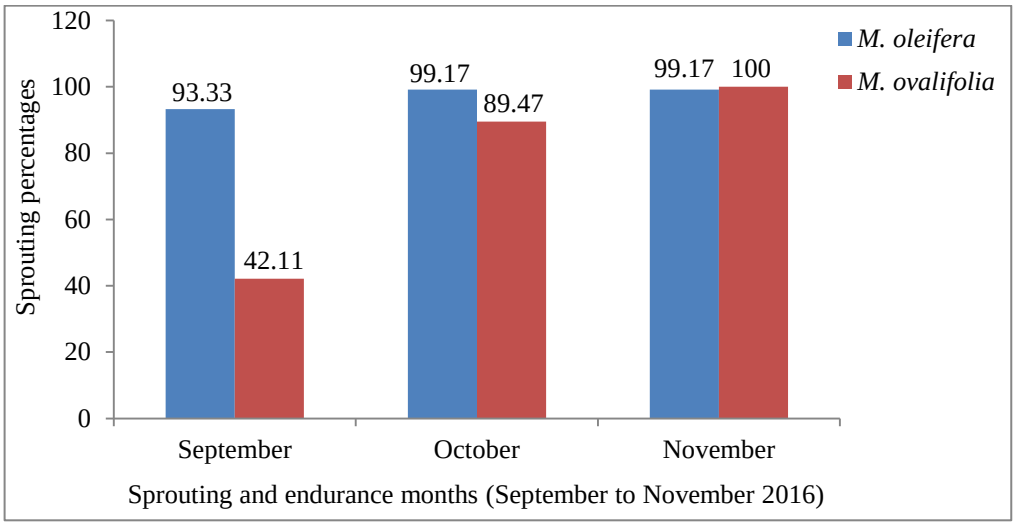

Figure 3.14: Moringa trees' species sprouting and EoE differences after 2016 winter season

Table 3.11 presents descriptive statistics of the two *Moringa* species' EoE after the 2016 winter season. The two *Moringa* species had equal EoE after the 2016 winter season when *M. ovalifolia* had a mean of 57.90 sprouted trees with a maximum of 99.19 % tree

endurance, while *M. oleifera* had a mean of 72.92 sprouted trees with a maximum of 100% tree endurance.

Table 3.11: Descriptive statistics of *Moringa* species EoE differences after 2016 winter season

Moringa spp.	N	Mean	Standard Deviation	Standard Error Mean	Minimum	Maximum
M. ovalifolia	4	57.90	46.08	23.04	0.00	99.17
M. oleifera	4	72.92	48.69	24.34	0.00	100

Note: Mean of sprouted trees

An independent sample t-test of *Moringa* species EoE after 2016 winter season is seen in Table 3.12. During the analysis, the endured (sprouted) trees were used as dependent variables, while the two *Moringa* species were used as independent variables. The test result shows a mean difference of 15.02 sprouted trees that led to no statistical significant difference ($P > 0.05$) between *M. oleifera* and *M. ovalifolia* EoE after the 2016 winter season (see Table 3.11). This may be attributed to the ages of the trees (see Figure 3.14) in comparison to the first and second winter (2014 and 2015) seasons when the trees were younger, with less roots system establishment, as discussed by Foth (1990) and Larcher (1995). Table 3.13 shows the distribution of the independent sample mean of *Moringa* species' sprouted trees in 2016. Figure 3.15 reveals the diagrammatically distribution of the independent sample mean of the endured trees.

Table 3.12: Independent sample t-test of *Moringa* species EoE after 2016 winter season

Moringa spp.	Mean Difference	Pooled Standard Error Difference	t	df	Sig. (2-tailed)
Sprouted trees	15.02	33.52	0.45	6	0.670ns

Mean difference in extent of endurance rate; note: n.s = non-significant at 0.05 alpha level

Table 3.13: Distribution of independent sample mean of *Moringa* species in 2016

	Posterior			95% Credible Interval	
Moringa spp.	Mode	Mean	Variance	Lower Bound	Upper Bound
Sprouted trees	15.02	15.02	0.75	13.32	16.72

Note: Mean of sprouted trees

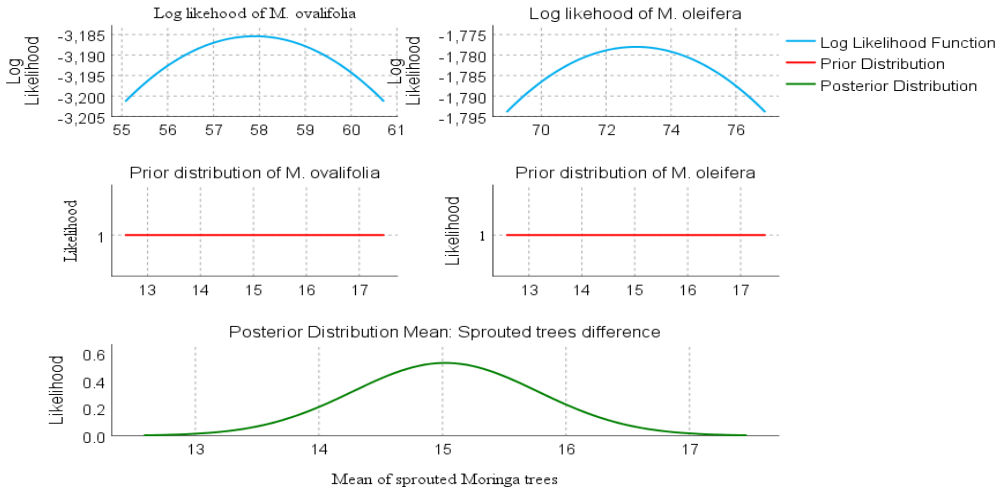

Figure 3.15: Mean distribution of *Moringa* species EoE differences after 2016 winter season

Figure 3.16 presents sprouting of *M. oleifera* (A) and *M. ovalifolia* (B) in the middle of the 2016 winter season, while Figure 2.17 shows well-established roots of *M. oleifera* (A) and *M. ovalifolia* (B) after the 2016 winter. As the trees grew older and bigger with firm root-system establishment in 2016, they were less affected by winter and whenever temperatures improved, they sprouted immediately even in the middle of winter, which reduced the mortality rates.

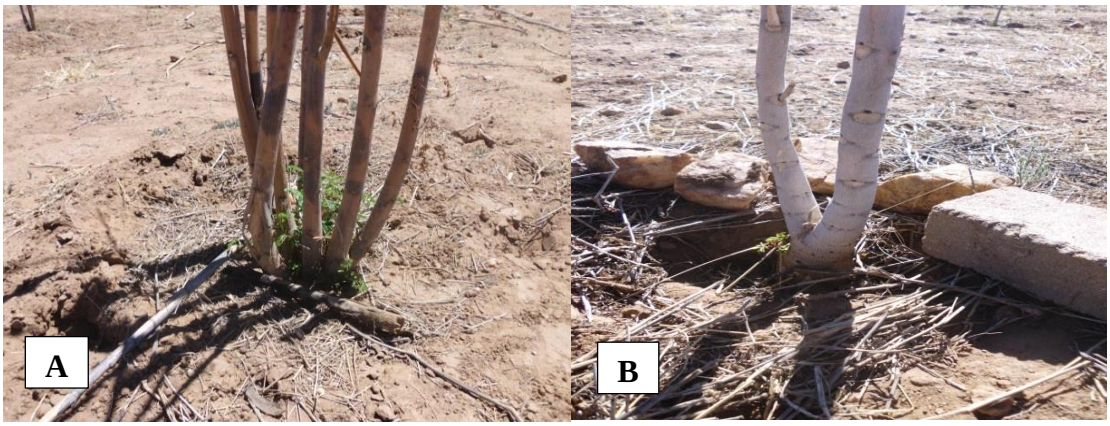

Figure 3.16: Sprouting of *M. oleifera* (A) and *M. ovalifolia* (B) in the middle of 2016 winter

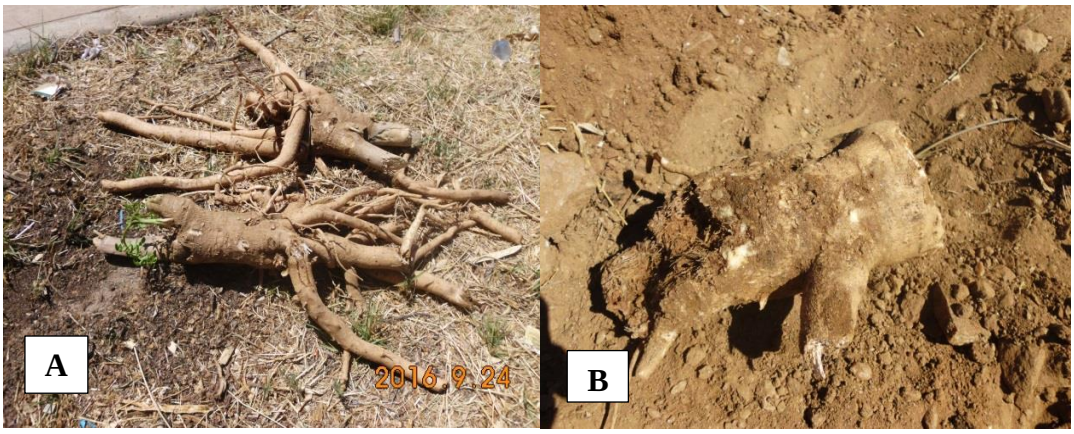

Figure 3.17: Well-established roots of *M. oleifera* (A) and *M. ovalifolia* (B) after 2016 winter

The sprouting ability of *M. oleifera* and *M. ovalifolia* showed no significant differences ($P > 0.05$) after the 2014 and 2016 winter seasons, but there was a significant difference after 2015 winter season, which is an indication that both species of moringa have the ability to endure in the harsh environmental conditions of central Namibia. For this reason, the hypothesis (H_{02}) that *M. oleifera* and *M. ovalifolia* do not differ in the EoE differences after winter seasons partially failed to be rejected because only in 2015 the two species were significantly different, but they do not differ significantly in 2014 and

2016. In the two seasons (2014 and 2016) where there was no significance between the two species of moringa in endurance might be due to the abrupt setting of winter compared to 2015 when winter set in gradually.

3.4.3 Comparison of *M. oleifera* and *M. ovalifolia* Leaf-Dry-Matter Yield

Almost all parts of moringa tree are used for food, oil, fiber, and/or medicine. The leaves are readily eaten by cattle, sheep, goats, pigs, chickens and rabbits and can also be used as food for fish (Radovich, 2007; Van Wyk *et al*., 2011) as well as humans. This creates a huge demand for leaves biomass production to meet the demand for human food and medicine as well as for animal fodder and ethno-veterinary medicine, as pointed out by Adegun and Ayodele (2015). In this research, a moringa plantation was established, in which two-months-old seedlings of *M. oleifera* and *M. ovalifolia* were transplanted into a field of 0.21 hectares. The field was divided into two parts, one for *M. oleifera* (0.11 ha) and the other for *M. ovalifolia* (0.10 ha). The field layout and experimental design are discussed in section 3.2.2. At transplanting, the soil was mixed with 5 kg cow manure and used to fill planting pits, as suggested by Fuglie and Sreeja (2001). One month after transplanting, phosphorus and nitrogen fertilizer treatments were applied as in the following sequence: treatment1 (control – 0 g), treatment2 (100 g), treatment3 (200 g) and treatment4 (300 g), respectively. Fuglie and Sreeja (2001) and Radovich (2007) recommended both fertilizer and irrigation for maximum productivity. Lea-dry-matter yield in this study was assessed on the four fertilizer treatment levels (1= 0 g, 2 = 100 g, 3 = 200 g and 4 = 300g) that were applied on the two *Moringa* species trees. The yields obtained from the two summer growing and harvesting seasons of 2014/2015 and 2015/2016 were all presented on a kilogram (kg) per hectare (ha) basis.

Figure 3.18 presents *Moringa* species average leaf-dry-matter yields in kg/ha for 2014/2015 and 2015/2016 summer harvesting seasons according to the four fertilizer treatment levels. For *M. oleifera*'s leaf-dry-matter yield in kg/ha, the control treatment1 (0 g) had the highest yield of 379.36 kg/ha, followed by treatment2 (100 g) with 315.13 kg/ha, treatment3 (200 g) with 246.43 kg/ha while treatment4 (300 g) had the lowest yield of 207.73 kg/ha for the 2015/2016 summer growing and harvesting season. The control treatment yielding more leaf-dry matter is an indication that *M. oleifera* can grow and yield more leaves with little or no fertilizers. Fuglie and Sreeja (2001) confirmed that *M. oleifera* trees will generally grow well without adding much fertilizer. For the 2014/2015 summer harvesting season, treatment2 (100 g) had the highest yield of 289.55 kg/ha, followed by treatment1 (0 g) with 241.53 kg/ha, treatment4 (300 g) with 191.85 kg/ha and the lowest was treatment3 (200 g) with 110.98 kg/ha. These leaf-dry-matter yields per hectare obtained for *M. oleifera*'s leaf-dry-matter yields in the present research are much lower compared to those in tropical countries like the Gambia where 15 tonnes/ha dry matter were obtained (Akinbamijo *et al*., n.d.). This can be attributed to the short growing season in the semi-arid climate of Namibia (October to April summer season) as discussed by Pallett (1994), coupled with the fact that the trees were very young and not fully established for proper comparison with well-established plantations.

On the other hand, the leaf-dry-matter yield in kg/ha for *M. ovalifolia* during the two summer growing and harvesting seasons of 2014/2015 and 2015/2016 are also presented in Figure 3.18. *Moringa ovalifolia*, like *M. oleifera* had four fertilizer treatment levels

presented as follow: treatment1, the control (0 g), treatment2 (100 g), treatment3 (200 g) and treatment4 (300 g), respectively. The result showed that treatment4 (300 g) yielded the highest leaf-dry matter of 94.67 kg/ha. The second highest was treatment2 (100 g) that yielded 74.69 kg/ha, and successively followed by treatment1 (0 g) that yielded 31.25 kg/ha and treatment3 (200 g) that yielded the lowest of 27.68 kg/ha in 2014/2015. For 2015/2016 growing season, treatment1 (0 g) had the highest yield of 76.81 kg/ha, followed by treatment2 (100 g) that yielded 60.63 kg/ha, treatment4 (300 g) that yielded 58.82 kg/ha while treatment3 (200 g) yielded the lowest of 41.97 kg/ha. Unlike 2014/2015 season, *M. ovalifolia*'s yields also declined as the fertilizer treatment levels increased in 2015/2016 as was the case with *M. oleifera*, an evidence that both *Moringa* species do not need much fertilizer to increase leaf-dry matter production.

Concerning the requirement for fertilizers, *M. oleifera* and *M. ovalifolia* can yield well even without phosphorus and nitrogen fertilizers since the control treatment yielded more leaf-dry matter compared to treatments where fertilizers were applied. Fuglie and Sreeja (2001) and Radovich (2007) stated that moringa trees will generally grow well without adding much fertilizer; however, they recommended that compost can be used during planting. Taking into consideration the 2.5 m x 2.5 m spacing, a hectare would contain 4,000 *M. oleifera* trees while 3 m x 3 m spacing would allow 3333 trees; thus, yielding more leaf-dry matter per summer season. *Moringa ovalifolia* on the other hand had four treatment levels with four different plant spacings but same plant densities. As a baseline study for *M. ovalifolia*, the different spacings were meant to determine the appropriate spacing for domestication purposes. The spacings were 4.5 m x 4.5 m, 4 m x 4 m, 3.5 m x 3.5 m and 3 m x 3 m to which phosphorus and nitrogen fertilizer treatments

were applied consecutively: control treatment (0 g), treatment2 (100 g), treatment3 (200 g) and treatment4 (300 g), respectively. At all fertilizer treatment levels and both 2014/2015 and 2015/2016 summer growing and harvesting seasons, *M. oleifera* yielded more leaf-dry-matter in kg/ha than *M. ovalifolia*, which can be attributed to its fast growth as described by many literature (Sanchez *et al*., 2006; Prince, 2007; Radovich, 2007; Isah, Bello, & Zarumaye, 2014).

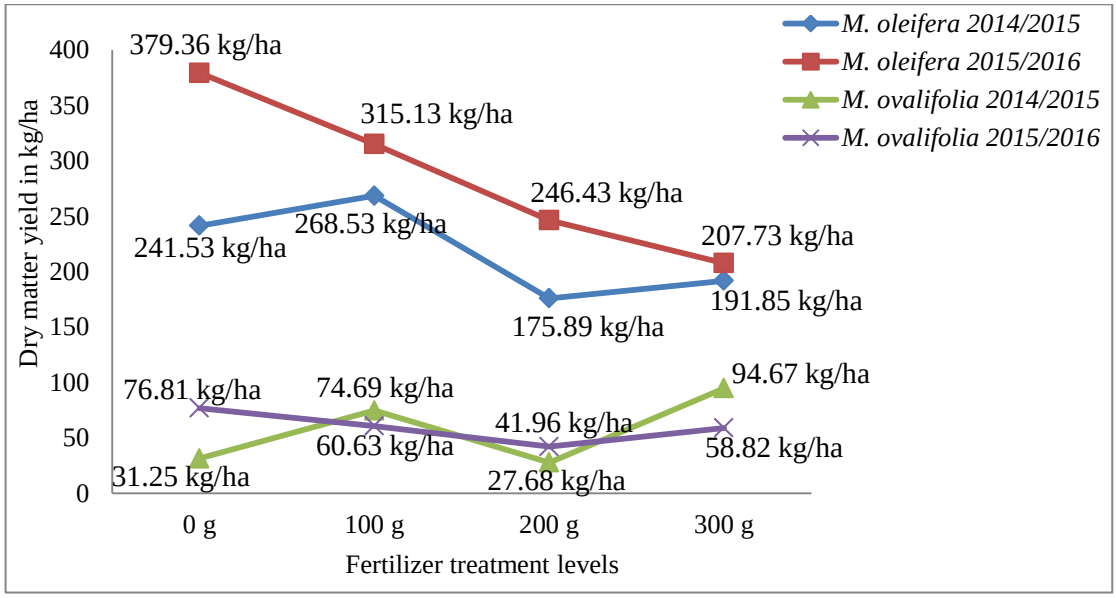

Figure 3.18: *Moringa* species seasonal leaf-dry-matter yields in kg/ha per treatment levels

An independent sample t-test was conducted to compare the two *Moringa* species and their harvesting seasons (Table 3.14), which showed that *M. oleifera*'s leaf-dry-matter yields had extremely significant differences ($P < 0.001$) from *M. ovalifolia*'s yields with mean differences of 162.38 kg/ha in 2014/2015 and 227.61 kg/ha in 2015/2016. These large statistical mean differences in leaf-dry-matter yields between the two species for both seasons supports the results in Figure 3.18 in which *M. oleifera* had higher average

leaf-dry-matter yields in kg/ha than *M. ovalifolia* at all treatment levels. This can be attributed to *M. oleifera* fast growth and development as pointed out by many authors (Sanchez *et al*., 2006; Prince, 2007; Radovich, 2007; Isah, Bello, & Zarumaye, 2014). Hence, the hypothesis (H_{02}) that *M. oleifera* and *M. ovalifolia* do not significantly differ in leaf-dry-matter yields is rejected because the two species of moringa significantly differ yields at all treatment levels and seasons.

Table 3.14: Independent sample t-test of *Moringa* species and seasonal leaf-ry-matter yield in kg/ha

Summer seasons	Mean Difference	Pooled Standard Error Difference	t	df	Sig. (2-tailed)
2014/2015	162.38	27.10	5.99	6	0.001***
2015/2016	227.61	38.58	5.90	6	0.001***

Mean difference in leaf-dry-matter yield; note: *** = extremely significant to ≤ 0.001 alpha level

Table 3.15 presents the descriptive statistics of *Moringa* species as well as 2014/2015 and 2015/2016 summer seasons' leaf-dry-matter yields in kg/ha. Comparing the means on the seasonal basis, *M. oleifera* produced 287.16 kg/ha and 219.45 kg/ha for 2015/2016 and 2014/2015 summer harvesting seasons, respectively, while *M. ovalifolia* had lower means of 59.55 kg/ha and 57.07 kg/ha. The distribution of the independent sample mean of *Moringa* species' leaf-dry-matter yields based on 2014/2015 and 2015/2016 summer-harvesting seasons are presented in Table 3.16, which are diagrammatically shown in Figures 3.19 and 3.20, respectively.

Table 3.15: Descriptive statistics of *Moringa* species seasonal leaf-dry-matter yields kg/ha

Summer seasons	*Moringa* spp.	N	Mean	Standard Deviation	Standard Error Mean
2014/2015	*M. ovalifolia*	4	57.07	32.94	16.47
	M. oleifera	4	219.45	43.04	21.52
2015/2016	*M. ovalifolia*	4	59.55	14.25	7.12
	M. oleifera	4	287.16	75.83	37.92

Note: Mean difference in leaf-dry-matter yield

Table 3.16: Distribution of independent sample mean of *Moringa* species leaf-dry-matter yields based on seasons

Summer seasons	Mode	Posterior Mean	Variance	95% Credible Interval Lower Bound	Upper Bound
2014/2015	162.38	162.38	0.75	160.68	164.08
2015/2016	227.61	227.61	0.75	225.91	229.31

Note: Mean difference in leaf-dry-matter yield

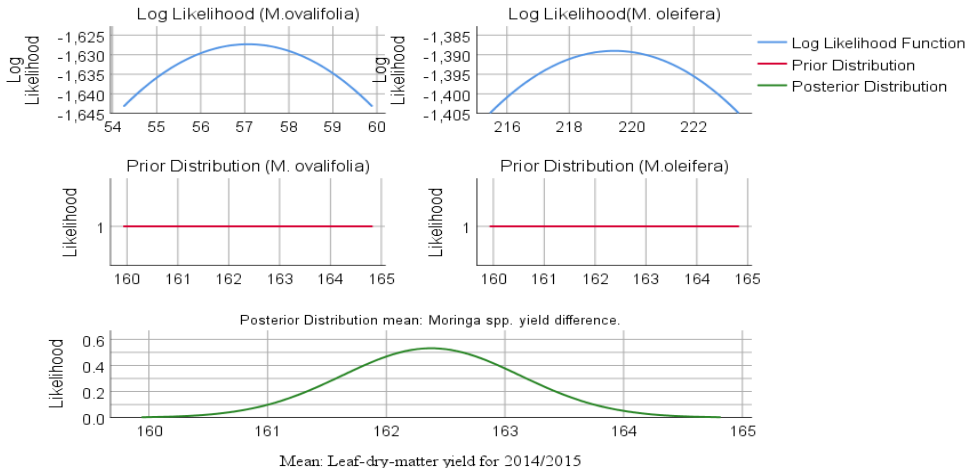

Figure 3.19: Mean distribution of *Moringa* species leaf-dry-matter yield in kg/ha for 2014/2015

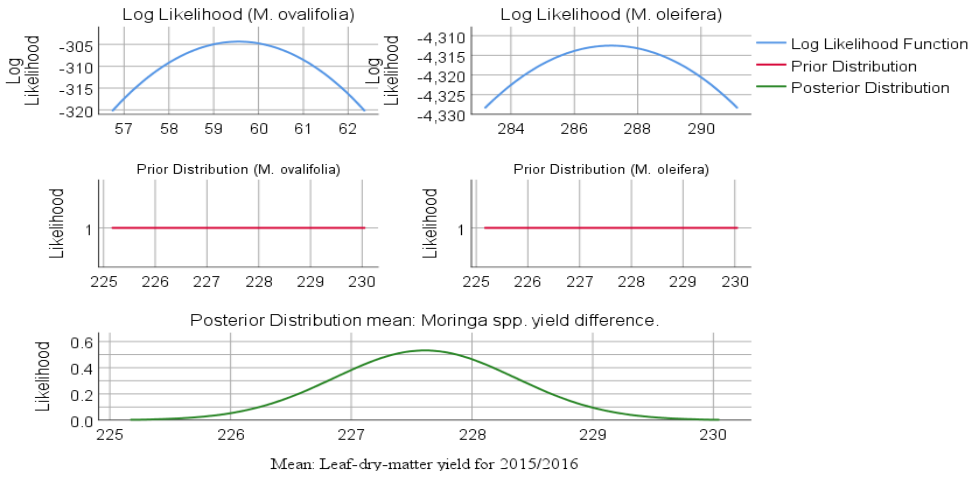

Figure 3.20: Mean distribution of *Moringa* species leaf-dry-matter yield in kg/ha for 2015/2016

In a nutshell, *M. oleifera* yielded more leaf-dry matter than *M. ovalifolia* during the period under investigation. Thus, the hypothesis (H_{02}) that *M. oleifera* and *M. ovalifolia* do not differ in leaf-dry-matter yields was rejected because they differed significantly in leaf-dry-matter production in both seasons (2014/2015 and 2015/2016) and at all treatment levels. The yield differences of the two *Moringa* species can be attributed to *M. oleifera's* fast growth that leads to large leaf-biomass production (Sanchez *et al*., 2006; Prince, 2007; Radovich, 2007).

3.5 Conclusion

Moringa oleifera and *M. ovalifolia* have the ability to grow, endure and yield enough leaf-dry matter under harsh conditions. *Moringa oleifera* reaches maximum heights within four to five months while *M. ovalifolia* takes longer to develop into a fully grown tree. Both species need little water (water once a week in the first year and once every two weeks in the second year) to grow and endure, which makes them suitable for arid

and semi-arid climates like Namibia. Although many trees in this central part of Namibia, including moringa, are affected by winter frost annually, both species are able to endure, sprout, and produce abundant leaf-dry matter quickly after winter seasons.

Moringa oleifera had an EoE of 97.50% against 71.63% for *M. ovalifolia* in the 2015/2016 summer season. During summer season, species of moringa both can yield a considerable amount of leaf-dry matter that may be used as a feed supplement. *Moringa oleifera* had maximum yields of 379.36 kg/ha and 268.53 kg/ha for 2015/2016 and 2014/2016, while *M. ovalifolia*'s maximum yields were 94.67 kg/ha and 76.81 for 2014/2014 and 2015/2016 seasons. Therefore, *M. oleifera* (especially) and *M. ovalifolia* are possible alternative trees species that can be planted to improve rangeland productivity in terms of fodder especially when allowed to grow into full capacity.

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Chapter 4

Comparative Proximate and Mineral Compositions of *Moringa oleifera* and *Moringa ovalifolia* Grown in Central Namibia

4.1 Abstract

The objective of this study was to compare the proximate and mineral compositions of *Moringa oleifera* and *Moringa ovalifolia* grown together at Neudamm Experimental Farm of the University of Namibia in central Namibia. *Moringa oleifera* (*M. oleifera*), which is well known for its rich nutritional value was compared to the nutritional value of *Moringa ovalifolia* (*M. ovalifolia*), a native plant of Namibia and Angola, which is less studied. Because Namibia is arid and semi-arid climates, many plants in the rangelands are low in nutrients essential for livestock nutrition. This creates the necessity for planting fodder trees like moringa that withstand the harsh climatic conditions and retain their nutritional quality for sustainment of livestock production through supplementation. Leaves of both *Moringa* species were harvested together with twigs and twiglets, along with *M. oleifera* flowers, and samples were taken to the Ministry of Agriculture's Nutrition Laboratory for proximate and mineral analyses. Statistically, *M. oleifera* nutrient values were significantly different ($P < 0.05$) in moisture, ash, crude protein (CP) and crude fibre (CF) from those of *M. ovalifolia*, but there were no significant differences ($P > 0.05$) in fat, acid detergent fibre (ADF) and neutral detergent fibre (NDF). Additionally, *M. oleifera* was significantly different ($P < 0.05$) from *M. ovalifolia* in potassium (K), magnesium (Mg), copper (Cu) and zinc (Zn), but there were no significant differences in calcium (Ca), sodium (Na), phosphorus (P), iron (Fe) and manganese (Mn) values. The almost equal nutrient values of the two

Moringa species, suggests that *M. ovalifolia* could serve as an alternative supplement for livestock since there is known human and livestock competition for *M. oleifera,* and *M. ovalifolia* being native and well adapted to the Namibian environmental conditions. Hence, the hypothesis (H_{03}) that *M. oleifera* and *M. ovalifolia* do not significantly differ in proximate and mineral compositions was partially rejected because the two *Moringa* species significantly differ in Ca, Mg and Zn but do not differ in K, Na, P, Cu, Fe and Mn nutrient values.

Keywords: *Moringa oleifera*, *Moringa ovalifolia*, proximate composition, mineral composition

4.2 Introduction

The diversification and production of quality feeds and fodders that are of high metabolisability and that possess a good balance of macro- and micro-nutrients which cost-effectively support animal production are important for achieving economically sustainable animal production systems. For this diversification of feed and fodder production, *M. oleifera* tree foliage is one of the best options to replace concentrates in the diet of farm animals (Huque & Sarker, 2014), as its leaves are used as a high protein forage (Radovich, 2007). In the tropics, it is used as forage for livestock, and in many countries as a vegetable that has the potential to improve nutrition, boost food security, foster rural development and support sustainable land care (Foidl, Makkar, & Becker, 2001; Joshua & Vasu, 2013). *Moringa oleifer*a's nutritional properties have the potential to alleviate malnutrition and starvation (Bey, 2010) in both humans and livestock populations. Although scarce, *M. ovalifolia* is a drought-resistant and fodder tree eaten by both humans and animals (Van Wyk *et al*., 2011).

Moringa oleifera leaves are highly nutritious, and are also a source of beta-carotene, vitamin C, protein, iron and potassium (Makkar & Becker, 2007). Phytochemical analyses of *M. oleifera* have shown that its leaves are particularly rich in potassium, calcium, phosphorous, iron, and vitamins A and D, as well as in essential amino acids (Mbikay, 2012). Research shows that every 100 grams of *M. oleifera* contains protein, vitamins, minerals, carbohydrates, fats, and so on in the following amounts: 6.70 g of protein in leaves, 2.50 g of protein in pods, 27.10 g of protein in leaf powder, 259 mg of mineral potassium (K) in leaf power, 259 mg K in pods, 1,324 mg of K in leaf powder, and 6.8 mg of vitamin A in leaves, 0.11 mg in pods and 16.3 mg in leaf powder (Prince, 2007). In another study, the chemical composition (of dry leaves) ranged from 19.34% to 22.42% for protein, 1.28% to 4.96% for lipids, 7.62% to 14.60% for ash, and 30.97% to 46.78% for dietary fibre. The leaves and flowers are a protein source with an adequate profile of amino acids and ash, while the immature pods show a high content of dietary fibre and low lipid content (Sánchez-Machado *et al*., 2009).

Moringa oleifera leaves have a high potential as a protein source supplement for ruminants and their feeding value is similar to that of the widely used soybean meal and rapeseed meal (Soliva *et al*., 2005). Its protein (25-35% in leaves) is of high quality having significant quantities of all the essential amino acids, which is very unusual in plant foods (Radovich, 2007). The crude protein content of extracted and unextracted *M. oleifera* leaves was 43.50 and 25.10%, respectively, suggesting that both the extracted and unextracted leaves are good sources of protein for livestock (Foidl *et al*, 2011). *Moringa oleifera* has high energy values and can be a significant source of high crude

protein supplement for small ruminants and non–ruminants (Bridgemohan, Bridgemohan, & Mohamed, 2014). It has proven to be a valuable supplement for animals in other countries (Mendieta *et al*., 2007), and is readily eaten by animals as fodder (Foidl *et al*., 2011). On the other hand, *M. ovalifolia* tree roots, bark and wood are eaten by goats, while trees are also browsed by giraffe (Curtis & Mannheimer, 2005; Van Wyk *et al*., 2011).

Moringa oleifera has long been considered a panacea for improving the nutrition of poor communities in the tropics and subtropics (Radovich, 2007). Moringa has traditionally been used both as a food for human consumption and as feed or fodder for animals. However, whether used as human food or feed for livestock, the benefits of moringa have become increasingly obvious and this demands concerted national action (Ojukwu, 2012). It is upon this background that this study was aimed at comparing the proximate and mineral compositions of *M. oleifera*, which has been widely researched, with that of *M. ovalifolia* which has been scantily researched and less reported in the literature.

4.3 Materials and Methods

4.3.1 Sample Collection

Thirty-day-old leaves of *M. oleifera* and *M. ovalifolia* were randomly collected with all their twigs in March 2016 from the moringa orchard established in 2014 at the agronomic section at the Neudamm Experimental Farm of the University of Namibia, about 30 km east of Windhoek. *Moringa oleifera* is an extremely fast-growing tree and grows and matures faster than *M. ovalifolia* (Prince, 2007), and it flowers within 4-5

months after planting (Radovich, 2007). At harvesting, *M. oleifera* had flowers, which were also harvested from the grown trees. *Moringa ovalifolia* had not yet produced flowers within that time frame. Leaves were randomly harvested from each block for both *Moringa* species, while flowers were harvested from blocks where inorganic fertilizers were applied and where only manure (organic fertilizer) was applied, in order to compare their effects on the chemical and nutritional composition of the plants. Data were collected during summer seasons when both species of moringa trees had leaves and *M. oleifera* had flowers because of its early maturation and flowering. In Namibia, summer extends from September to April of the following year, when more than 99% of annual rainfall occurs (Pallett, 1994) and temperatures are optimal for plant growth. Harvested leaf and flower samples were conveyed to the nutrition laboratory of the Ministry of Agriculture, Water and Forestry in Windhoek for analysis.

4.3.2 Sample Preparation

Moringa leaves and flowers were shade-dried for two weeks, as described by Madukwe, Ezeugwu and Eme (2013), and taken to the nutrition laboratory of the Ministry of Agriculture, Water and Forestry in Windhoek, where subsequent preparation and analysis were done. *Moringa oleifera* leaves and flowers and *M. ovalifolia* leaf samples were ground to pass through a sieve with circular openings of 1mm diameter, and stored in clean plastic bottles, labelled [Agri-Laboratory Association of Southern Africa (AgriLASA, 1993)]; [Association of the Official Agricultural Chemists (AOAC, 1996)] and subsequently used for all analyses.

4.3.3 Nutritional Analysis Procedures

Moringa oleifera and *M. ovalifolia* leaf and flower samples were analysed for nutritional composition such as dry matter (DM), ash, fat, crude fibre (CF), crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF), carbohydrate, total digestible nutrients (TDN), digestible energy (DE), metabolisable energy (ME), calcium (Ca), phosphorus (P), sodium (Na), potassium (K), magnesium (Mg), manganese (Mn), iron (Fe), zinc (Zn), copper (Cu) and water soluble tannins, using the procedures of AgriLASA (1993) and AOAC (1996).

Protein content was determined through a combustion method in a CHN628 machine. Approximately 0.1 g of a sample was weighed into a foil cup and placed in a CHN628 Leco Machine. Samples were burned at 950^{o}C in the presence of oxygen, and then the released gases were separated by helium. The released nitrogen was measured in a thermal conductivity cell and the reading was sent automatically to the screen. Percent protein was calculated by multiplying the reported nitrogen by 6.25. Ethylenediaminetetraacetic acid (EDTA) was used for quality control during analysis (AgriLASA, 1993; AOAC, 1996).

Crude fibre was determined using Weende method (AgriLASA, 1993), in which a FIWE Raw Fibre Extractor was used. A ground sample of approximately 1g was weighed in glass crucibles and inserted into the extractor to which 150 mL of diluted and preheated sulfuric acid (H_2SO_4) was added, followed by 4 drops of antifoam agent (n-octanol) and boiled for 30 minutes. Afterwards, filtering of the remaining reagent was done and washed 3 times with de-ionized hot water. Thereafter, 150 mL of sodium hydroxide was

added followed by 4 drops of n-octanol and the mixture was boiled for another 30 minutes. Then, the reagent was filtered out and washed 3 times with de-ionized hot water. The remaining residues were dried at 105^{o}C for five hours in a conventional oven, cooled in a desiccator and weighed to obtain the crude fibre content. The percentage of crude fibre was calculated using the following formula:

$$F1 - F2 \div F0 \times 100 \quad (1)$$

where F0 = weight of sample, F1 = crude fibre plus ash content and F2 = sample plus crucible. This same formula was used for crude fibre, acid detergent fibre and neutral detergent fibre calculations. Ash content was determined by placing dried residues from crude fibre in a muffle furnace at a temperature of 550^{o}C for 5 hours, cooled it in a desiccator and weighed to obtain the ash content (AgriLASA, 1993; AOAC, 1996).

Acid detergent fibres (ADF) were determined using the Weende method in which a FIWE Raw Fibre Extractor (VELP Science, Italy) was used. A ground sample of approximately 1 g was weighed in a glass crucible and inserted into the extractor, to which 100 mL of cetyltrimethylammonium bromide technical grade ($C_{19}H_{42}BrN$) and sulfuric acid (H_2SO_4) with 4 drops of n-octanol were added, and then left to boil for one hour. Afterwards, filtering of the remaining reagent was done and it was washed 3 times with de-ionized hot water. The remaining residues were dried at 105^{o}C to constant weight in a conventional oven, cooled in a desiccator and weighed to obtain the acid detergent fibre content. The ADF was calculated using the formula:

$$\text{ADF \%} = \frac{W_r}{W_s} \times 100 \quad (2)$$

where w_r and w_s are the weights of the residue after heating and w_s is the weight of the sample (AgriLASA, 1993; AOAC, 1996).

Neutral detergent fibres (NDF) were determined using the Weende method in which a FIWE Raw Fibre Extractor was used. A ground sample of approximately 1g was weighed in glass crucible, inserted into the extractor machine, then 100 mL of sodium borate decahydrate ($Na_2B_4O_{7\cdot10}H_2O$), disodium ethylenediaminetetraacetate (DTA, $C_{10}H_{14}Na_2O_{8)}$, sodium lauryl sulfate neutral ($C_{12}H_{25}NaO_4S$), 2-ethoxyethanol (Ethylene glycol monoethyl ether, cellosolve, $C_4H_{10}O_2$), and disodium phosphate anhydrous (Na_2HPO_4) with 4 drops of n-octanol (antifoam agent). The mixture was allowed to boil for one hour. The boiled mixture was filtered and washed 3 times with de-ionized hot water. The washed residue was dried at 105^oC to constant weight in a conventional oven, cooled in desiccator and weighed to obtain the neutral detergent fibre content. The NDF was calculated using equation (2) used for ADF above.

Moisture was determined by heating samples in a vacuum oven at a temperature of 105^oC to constant weight and cooling them in a desiccator as used by Sanchez *et al*. (2006). Then the weight lost from the heated samples were used to calculate the moisture content as

$$\text{Moisture (\%)} = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \qquad (3)$$

where W_1 is the dish (without lid) weight, W_2 is the sample plus dish and W_3 is the sample plus dish after drying (AgriLASA, 1993).

Fat content was determined using the Solvent Extractor Machine (VELP Scientifica, Italy). Three grams of sample were weighed in the extraction thimbles and hooked into the Solvent Extractor Machine. Beakers were weighed with a boiling stone in each of them and 60 mL of petroleum ether was added and then put in the extractor machine in which the extraction thimbles were submerged. The tap was open for condensation and the machine knob was moved to level one (immersion) and boiled at 110^{o}C temperature for an hour, then the knob was moved to level two (washing) for another hour of boiling and finally, the knob was moved to level three (recovery) for the last one-hour of boiling. A boiling stone was used to create a calm boiling process. After boiling, the beakers with the recovered samples were placed in a conventional oven at 105^{o}C temperature to dry for 30 minutes. Subsequently, beakers were removed and placed in a desiccator, cooled and weighed, and the fat content was calculated as

$$\text{Crude fat (\%)} = \frac{\text{MFR} - \text{MF}}{\text{m}} \times 100 \qquad (4)$$

where m, MF and MFR represent mass of sample used, mass of flask, and mass of flask with extracted reside, all in grams, respectively (AgriLASA, 1993; AOAC, 2006).

Mineral analysis was determined by the Atomic Emission Spectroscopy (AES) method using an Inductively Coupled Plasma (ICP) instrument, Thermo Fisher Scientific, United Kingdom. Calcium, phosphorus, sodium, potassium, magnesium, manganese, iron, zinc and copper content were analysed. This analytical method allows the isolation of minerals from organic matter by first ashing samples prior to the analysis. The ashed samples were digested consecutively by hydrochloric and nitric acids to decompose them. The digested samples were filtered before being diluted with de-ionized water.

The sample diluents were injected into ICP-MS instrument for analysis, which gave the concentration of individual minerals.

Water soluble tannins were determined using an in-house method of aqueous extraction, followed by colorimetric determination (Folin and Ciocalteu's phenol regent). Non-structural carbohydrates were determined using calculated differences; total digestible nutrients, digestible energy and metabolisable energy were also determined by calculation (AOAC, 1996; Galyean, 2010).

4.3.4 Data Analysis

An independent sample t-test analysis was used to compare *M. oleifera* and *M. ovalifolia* nutrient composition. A one-sample t-test was used to compare individual species of moringa based on fertilizer treatment levels in which the means of the control treatment nutrient composition were compared to those of fertilized treatment levels using the Statistical Package for Social Sciences (SPSS® version 23). All statistical analyses were only considered significantly different at the alpha levels of $p \leq 0.05$ and all p-values above these alpha levels were considered non-significant. Means of treatments were derived using the Microsoft Office Excel® program that compared the nutrient composition of *M. oleifera* and *M. ovalifolia*.

4.4. Results and Discussion

The results from this research include the proximate and mineral compositions of *M. oleifera* leaves and flowers and those of *M. ovalifolia* leaves obtained in the analysis. The results for moisture, ash, fat, crude fibre, crude protein, acid detergent fibre, neutral

detergent fibre, calcium, phosphorus, potassium, sodium, magnesium were presented in percent dry weight (% DW), while copper, iron, manganese and zinc were in parts per million (ppm), with total digestible nutrients g/100g, digestible energy MJ/kg, metabolisable energy MJ/kg and water-soluble tannins g/100g and results are presented on "as is" basis as discussed by Barnhart & Hoyer (2010) and Mason (n.d.).

4.4.1 Nutrient Composition of *M. oleifera* and *M. ovalifolia*

Tables 4.1 and 4.2 present the proximate composition of *M. oleifera* and *M. ovalifolia* leaves in a descriptive statistics and an independent sample t-test analysis. The results (Table 4.1) show that for both *Moringa* species CP levels were the highest, followed by NDF, ADF, ash, CF, fat, and moisture in this order among the two species. *M. oleifera* had a higher overall mean value in CP (30.99%) than *M. ovalifolia* (28.68%). Crude protein in both *Moringa* species in this research was higher than 27.10% and 18.49% as reported by Fuglie (2001) and Mutiara, Estiasih and Sriwahyuni (2013), respectively for *M. oleifera*. According to Mpofu (2004), a CP content of less than 7% is known to limit forage intake and small ruminant performance, which normally occurs during dry months, leading to the search for alternative protein sources. The CP content in the two *Moringa* species was 28.86-30.99%; thus, making both of these species good alternative sources for protein supplements. Foidl *et al*. (2011) pointed out that due to the high crude protein content of *M. oleifera* leaves (43.50%), it is a good source of protein for livestock. However, *M. ovalifolia* was higher in NDF (13.92%), ADF (11.78%) and ash (11.32%) than *M. oleifera*, which makes *M. ovalifolia* more suitable for animal feed supplement. Tisch (2006) explained that structural carbohydrate, measured as NDF, constitutes the cell wall of a plant and includes the fibre fractions of cellulose,

hemicellulose, lignin and neutral detergent fibre insoluble protein (NDFIP). When a feedstuff's ADF is high, however, it will be of low digestibility to animals. *Moringa oleifera* leaves' proximate analysis results showed that CP had higher nutrient value of 43.53% than of all other nutrients (Fagwalawa *et al.*, 2014). On the other hand, the nutrient values obtained were higher than those obtained in Nigeria with *M. oleifera* leaves by Ogbe and Affifu (2011). Moisture contents of 6.200% and 6.025% for *M. ovalifolia* and *M. oleifera* were lower than the 7.50% reported by Fuglie (2001) for *M. oleifera*. Moisture (6.98%) and Fat (4.19%) of *M. oleifera* as reported by Romuald *et al*. (2016) were in concurrence with the present study result but CP (25.8%) was lower; however, CP (43.53%) reported by Fagwalawa *et al.* (2014) was much higher than the levels found in this study in both species of moringa. Ash and CP contents (4.48%) and (15.93%) respectively, reported by Fayomi *et al*. (2014) were much lower compared to those found in the current study, but CF was comparatively higher (11.84%). Statistically (Table 4.2), *M. oleifera*'s proximate nutrient values of DM, ash, fat, CP, CF, ADF and NDF had no significant differences ($P > 0.05$) from those of *M. ovalifolia*. This means that proximate nutrient values are similar in both *Moringa* species. Thus, the hypothesis (H_{03}) that *M. oleifera* and *M. ovalifolia* do not significantly differ in proximate compositions was accepted because both *Moringa* species do not differ nutrient values.

Table 4.1: Descriptive statistics for *Moringa* species leaves proximate composition

Nutrients	*Moringa* spp.	N	Mean	Standard Deviation	Standard Error Mean
Moisture	*M. oleifera*	4	6.03	0.19	0.09
	M. ovalifolia	4	6.20	0.27	0.13
Ash	*M. oleifera*	4	10.65	0.37	0.18
	M. ovalifolia	4	11.32	1.40	0.70
Fat	*M. oleifera*	4	6.61	1.23	0.61
	M. ovalifolia	4	5.80	0.88	0.44
CP	*M. oleifera*	4	30.99	0.22	0.11
	M. ovalifolia	4	28.68	3.50	1.75
CF	*M. oleifera*	4	8.12	0.18	0.09
	M. ovalifolia	4	8.46	1.45	0.73
ADF	*M. oleifera*	4	10.96	1.48	0.74
	M. ovalifolia	4	11.78	1.25	0.63
NDF	*M. oleifera*	4	12.84	2.23	1.11
	M. ovalifolia	4	13.92	2.98	1.49

Note: Mean of nutrient contents

Table 4.2: Independent sample t-test of *M. oleifera* and *M. ovalifolia* leaves proximate composition

Nutrients	Mean Difference	Pooled Standard Error Difference	t	df	P-values
Moisture	0.18	0.16	1.07	6	0.326ns
Ash	0.67	0.72	0.92	6	0.394ns
Fat	-0.81	0.77	-1.08	6	0.323ns
CP	-2.31	1.75	-1.32	6	0.235ns
CF	0.34	0.73	0.47	6	0.655ns
ADF	0.81	0.97	0.84	6	0.434ns
NDF	1.08	1.86	0.58	6	0.582ns

Moist=Moisture, CP = Crude protein, CF = Crude fibre, ADF = Acid detergent fibre and NDF = Neutral detergent fibre and measured in g/100 g DM. Results are presented 'as is'.
Note: Mean difference of nutrient contents; ns = non-significant at 0.05 alpha level

Tables 4.3 and 4.4 present a descriptive statistics and an independent sample t-test of *M. oleifera* and *M. ovalifolia* leaves' mineral composition in which analysis was done for Ca, P, K, Mg, Na as macro-nutrients and Cu, Fe, Mn and Zn as micro-nutrients. Macro-minerals are needed in relatively larger amounts in animal diets, while the micro-minerals (trace elements) are needed in very small amount in diets (Jurgens *et al.,* 2012). Among micro-nutrients, Fe had the highest mean, with 174.70 ppm and 177.11 ppm,

followed by Zn (13.51 ppm and 20.50 ppm) and Cu (13.10 ppm and 15.10 ppm). Manganese (0.001 ppm and 0.36 ppm) was found to be the least for *M. oleifera* and *M. ovalifolia*. Iron (28.20) and Cu (0.57) values reported by Fuglie (2001) were lower than the values found in this study (see Table 4.3). However, Ca, K, Mg and P were higher in this study than those found in the current research. For macro-nutrients, Ca (1.71% and 1.26%) for *M. ovalifolia* and *M oleifera* had the highest values, while P, K, Mg and Na were all < 1% for both species. An elemental composition of *M. oleifera* leaves from Chad reported by Mbailao *et al.* (2014) showed the following values: Na (0.08%), K (1.73%), Ca (1.23%), Mg (0.39%), P (0.32%), Fe (97.12 ppm), Mn (29.33 ppm), Zn (19.14 ppm) and Cu (9.07 ppm), which are concurrent with the present research findings, except for Fe and Cu which were much lower in value compared to the current findings (see Table 4.3). However, Mn was higher than that was found in that previous work. Statistically, *M. oleifera* was significantly different ($P < 0.05$) from *M. ovalifolia* in Ca, Mg and Zn content, but there were no differences ($P > 0.05$) in K, Na, P, Cu, Fe and Mn mineral values (Table 4.4). This implies that both *Moringa* species have a similar quantity of Na, P, Fe and Mn in their leaf tissues. The differences in mineral nutrient values can be attributed to the higher ash content of *M. ovalifolia* as compared to *M. oleifera*, because it is an approximation of the total mineral (inorganic) portion of the feed sample as defined by Tisch (2006). Therefore, the hypothesis (H_{03}) that *M. oleifera* and *M. ovalifolia* do not significantly differ in mineral compositions was rejected because both *Moringa* species differ in Ca, Mg and Zn content; but, the same hypothesis was accepted because both species of moringa do not differ in K, Na, P, Cu, Fe and Mn mineral values.

Table 4.3: Descriptive statistics for *Moringa* species leaf mineral composition

Nutrients	*Moringa* spp.	N	Mean	Standard Deviation	Standard Error Mean
Macro-nutrients (% DM)					
Ca	*M. oleifera*	4	1.21	0.36	0.18
	M. ovalifolia	4	1.71	0.18	0.09
K	*M. oleifera*	4	0.58	0.21	0.10
	M. ovalifolia	4	0.80	0.08	0.04
Mg	*M. oleifera*	4	0.07	0.03	0.01
	M. ovalifolia	4	0.18	0.08	0.04
Na	*M. oleifera*	4	0.66	0.97	0.49
	M. ovalifolia	4	0.22	0.14	0.07
P	*M. oleifera*	4	0.27	0.13	0.06
	M. ovalifolia	4	0.37	0.07	0.04
Micro-nutrients (ppm)					
Cu	*M. oleifera*	4	15.09	1.25	0.62
	M. ovalifolia	4	13.10	2.93	1.47
Fe	*M. oleifera*	4	177.11	4.21	2.11
	M. ovalifolia	4	174.73	22.85	11.43
Mn	*M. oleifera*	4	0.36	0.72	0.36
	M. ovalifolia	4	0.001	0.00	0.00
Zn	*M. oleifera*	2	20.35	0.51	0.36
	M. ovalifolia	4	13.51	1.01	0.50

Note: mean of nutrient values

Table 4.4: Independent sample t-test for *M. ovalifolia* and *M. oleifera* leaves mineral composition

Nutrients	Mean Difference	Pooled Standard Error Difference	t	df	P-values
Macro-nutrients (% DM)					
Ca	0.51	0.20	2.52	6	0.046*
K	0.22	0.11	1.97	6	0.097ns
Mg	0.11	0.04	2.67	6	0.037*
Na	-0.43	0.49	-0.88	6	0.413ns
P	0.10	0.07	1.42	6	0.207ns
Micro-nutrients (ppm)					
Cu	-2.00	1.59	-1.25	6	0.257ns
Fe	-2.37	11.62	-0.20	6	0.845ns
Mn	-0.36	0.36	-1.00	6	0.356ns
Zn	-6.84	0.79	-8.69	4	0.001***

Ca = Calcium, P = Phosphorus, K = Potassium, Mg=Magnesium, Na=Sodium = % and Cu = Copper, Fe = Iron, Mn = Manganese, Zn = Zinc = ppm, DM = Dry Matter (g/100 g DW). Results are presented 'as is'. Note: ns = non-significant 0.05; * = significant at 0.05; *** = extremely significant to ≤ 0.001 at alpha levels; mean difference of nutrient values

Table 4.5 reveals TDN, DE, ME and Tannin contents in *M. oleifera* and *M. ovalifolia* leaves. The results obtained showed that *M. oleifera* leaves had higher TDN content (67%) and ME content (11 MJ/kg), while DE (12 MJ/kg) was equal in both species of moringa, which is higher than 9.20 MJ/kg of ME from an extracted *M. oleifera* leaves as reported by Makkar and Becker (1996). Tannin (tannic acid) content was higher in *M. ovalifolia* leaves (4.40%) than in *M. oleifera* leaves (3.90%). Total digestible nutrient had the highest means and standard error of the mean (SEM) (64.50% and 2.50% respectively), followed by DE mean (12% MJ/kg), ME mean and SEM contents (10.50% and 0.50% respectively). However, *M. ovalifolia* had a higher tannin mean (4.40 g/100g) than *M. oleifera* (3.90 g/100g), with a total mean of 4.15 g/100g. The tannins of *M. oleifera* (3.90 g/100g) in this study concurred with the condensed tannins result (3.20%) of *M. oleifera* leaves analysed by Moyo *et al*. (2010) from South Africa. A study of *M. oleifera* leaves and soft twigs by Kakengi *et al*. (2005) found a low tannin concentration of ≤ 2%, lower than the results of both *Moringa* species in this study. Ojiako's (2014) study on quantitative analysis of phytochemical compounds present in the leaf extract of *M. oleifera* shows an 8.22% tannin content, which is higher than that obtained in either *Moringa* species in the current study.

Table 4.5: Total digestible nutrients, digestible energy, metabolisable energy and tannin contents in *M. oleifera and M. ovalifolia* leaves

Nutrients (g/100 g)	*M. oleifera*	*M. ovalifolia*	Total Mean	Standard Deviation	SEM
Total digestible nutrients	67	62	64.50	3.54	2.50
Digestible energy	12	12	12.00	0.00	0.00
Metabolisable energy	11	10	10.50	0.71	0.50
Tannins (tannic acid)	3.90	4.40	4.15	0.35	0.25

TDN = Total Digestible Nutrients g/100g; DE = Digestible Energy MJ/kg; and ME = Metabolisable Energy MJ/kg; Tannins = Tannic Acid. Results are presented 'as is'. Note: mean of nutrient values

4.4.2 Comparison of *M. oleifera* Nutritional Compositions at Different Treatment Levels

Table 4.6 shows the proximate composition of *M. oleifera* leaves, in which all the fertilizer treatment levels (treatment2, treatment3 and treatment4)'s means were compared with the treatment1 (control)'s means to determine the mean differences in nutrient values. *Moringa oleifera* seedlings were transplanted into two plots and four microplots with four fertiliser treatment levels. The treatment levels were treatment1 (0 g), treatment2 (100 g), treatment3 (200 g) and treatment4 (300 g) of superphosphate fertilizer with a P content of 83 g/kg (Wonder superphosphate granular, AGRO-SERVE (Pty) Ltd., Bryanston, South Africa was applied for root development. Also, Nitrogen fertilizer with an N content of 280 g/kg (Limestone Ammonium Nitrate - LAN), WONDER HORTICULTURAL PRODUCTS (Pty) Ltd., Silverton, South Africa, was applied at the aforementioned treatment levels for leaves and canopy development. The results of the proximate composition show that the means of moisture (6.04%), fat (6.91%), ADF (11.26%) and CP (31%) were higher for treatment2, treatment3 and treatment4 than for the control treatment; it similarly reveals a progressive increment as the level of applied fertilizers increased. On the contrary, CF (8.15%), ash (10.78%) and NDF (15.73%) were higher in the control treatment, an indication that *M. oleifera* naturally contains high CF, ash and NDF without fertilizer application as discussed by Fuglie (2001). Crude fibre in this study was lower than 11.84% reported by Fayomi *et al*. (2014); however, CP and ash were higher in this study than what they reported (15.93% and 4.89% against 31% and 10.78%). The moisture and ash contents 6.98% and 8.35% reported by Romuald *et al*. (2016) from Ivory Coast concur with the results of this research, but the CP they reported was lower (25.81% against 31.00%).

Statistically, only NDF was significantly different ($P < 0.05$) from the control treatment, which might be attributed to either *M. oleifera*'s naturally high level of NDF or fertilizer effect.

Table 4.6: Proximate composition of *M. oleifera* leaves at different treatments

Nutrients (% DM)	Mean: Control treatment	Mean: Fertilizer treatments	Standard Deviation	Standard Error Mean	t	P-values
Moisture	5.98	6.04	0.23	0.13	0.51	0.661n.s
Ash	10.78	10.61	0.44	0.25	-0.64	0.585ns
Fat	5.70	6.91	1.30	0.75	1.62	0.247n.s
CP	30.95	31.00	0.27	0.15	0.33	0.775n.s
CF	8.15	8.10	0.22	0.12	-0.38	0.743n.s
ADF	10.06	11.26	1.66	0.96	1.26	0.334n.s
NDF	15.73	11.87	1.34	0.77	-4.98	0.038*

Moist = Moisture, CP = Crude protein, CF = Crude fibre, ADF = Acid detergent fibre and NDF = Neutral detergent fibre, DM = Dry Matter (g/100 g DW). Results are presented 'as is'. Note: ns = non-significant at 0.05; *= significant at 0.05 alpha levels.

Table 4.7 shows the mineral composition of *M. oleifera* leaves in which the fertilizer treatment levels (treatment2, treatment3 and treatment4) means were compared with the control (treatment1) mean to determine the mean differences in nutrient values. The means of Mg (0.08%), Mn (0.48 ppm), K (0.58%), Cu (15.26 ppm), and Zn (21.01 ppm) mineral nutrient values were higher for treatments where fertilizers were applied in comparison with the control (treatment1). Phosphorus (0.29%), Ca (1.42%), Na (2.11%) and Fe (181.72%) were higher in the control treatment. Statistically, Mg was highly significantly different ($P < 0.001$) from the control treatment.

Table 4.7: Mineral composition of *M. oleifera* leaves at different treatment levels

Nutrient	Mean: Control treatment	Mean: Fertilizer treatments	Standard Deviation	Standard Error Mean	t	P-values
Macro-nutrients (% DM)						
Ca	1.42	1.14	0.40	0.23	-1.22	0.347ns
P	0.29	0.26	0.15	0.09	0.07	0.951ns
K	0.57	0.58	0.25	0.15	0.86	0.482ns
Mg	0.06	0.08	0.03	0.02	-35.37	0.001***
Na	2.11	0.17	0.10	0.06	-0.33	0.773ns
Micro-nutrients (ppm)						
Cu	14.59	15.26	1.47	0.85	0.80	0.508ns
Fe	181.72	175.57	3.52	2.03	-3.03	0.094ns
Mn	0.001	0.48	0.83	0.48	1.00	0.423ns
Zn	18.96	21.01	1.21	0.70	-1.22	0.098ns

Ca = Calcium, P = Phosphorus, K = Potassium, Mg=Magnesium, Na=Sodium = % & Cu = Copper, Fe = Iron, Mn = Manganese, Zn = Zinc = ppm, DM = Dry Matter (g/100 g DW). Results are presented 'as is'. Note: ns = non-significant at 0.05; *** = extremely significant to ≤ 0.001 alpha levels.

Table 4.8 shows the comparison of proximate composition of *M. oleifera* treatment levels (treatment1, treatment2, treatment3 and treatment4). Phosphorus and N fertilizers were applied as treatments as follows: treatment1 (0 g), treatment2 (100 g), treatment3 (200 g) and treatment4 (300 g), in which treatment1 served as a control. The results for proximate composition show that CP was the highest followed by NDF, ADF and ash while the DM, fat and CF nutrient values were < 9%. Among the four treatments, CP values were almost the same; in treatment3 (30.70), treatment1 (30.95), treatment2 (31.10) and treatment4 (31.20), which indicates that *M. oleifera* needs little or no inorganic fertilizers to maintain its protein content level. NDF was indirectly proportional to fertilizer levels as it had declining values as the fertilizer levels increased. This means that the higher the amount of applied fertilizers, the lesser nutrients it yields. For ADF, treatment3 had the highest nutrient value (13.18%) which was followed by treatment4 (10.31%), treatment2 (10.31%) and treatment1 (10.06%) respectively. The highest Ash content was found in leaves from treatment2 (11.07),

followed by those from treatment1 (10.78%), from treatment4 (10.57%) and from treatment3 (10.20%), respectively. Ash is the total mineral content of plants or animals (Jurgens *et al*., 2012).

Table 4.8: Proximate composition of *M. oleifera* leaves at different fertilizer treatment levels

Fertilizer treatment levels	Moist	Ash	Fat	CP	CF	ADF	NDF
Treatment1 (0 g)	5.98	10.78	5.70	30.95	8.15	10.06	15.73
Treatment2 (100 g)	6.19	11.07	6.11	31.10	8.03	10.31	13.42
Treatment3 (200 g)	5.78	10.20	8.42	30.70	8.35	13.18	11.20
Treatment4 (300 g)	6.16	10.57	6.21	31.20	7.94	10.31	11.00

Moist=Moisture, CP = Crude protein, CF = Crude fibre, ADF = Acid detergent fibre and NDF = Neutral detergent fibre and measured in g/100 g DW. Results are presented 'as is'.

Table 4.9 presents the comparison of the mineral composition of *M. oleifera* leaves harvested from microplots with four levels of phosphorus and nitrogen fertilizer treatments (treatment1= 0 g, treatment2 = 100 g, treatment3 = 200 g and treatment4 = 300 g) each. The results revealed that Fe had the highest values among the minerals, followed by Zn and Cu, while Ca, K, Mg, Na, P and Mn were < 3% in values. The control treatment (treatment1) had the highest content of Fe (181.72 ppm), followed by treatment4 (178.97 ppm), treatment2 (175.80% ppm) and treatment3 (171.93 ppm), consecutively. This implies that *M. oleifera* naturally contains Fe in large quantity and fertilizer application may have little or no effect at all. Interestingly, Zn was the second highest mineral component, increased in values as the levels of fertilizers increased according to treatment levels, that is, treatment1 (18.96 ppm), treatment2 (19.99 ppm), treatment3 (20.71 ppm) and treatment4 (22.34 ppm). This means that an increase in fertilizer levels resulted in an increment in Zn values. Like Fe, Cu increased randomly;

treatment2 (16.89 ppm), treatment3 (14.86 ppm), treatment1 (14.59 ppm) and treatment4 (14.04 ppm). Minerals make up only a relatively small amount of the diet of animals. Nevertheless, they are vital to the animals' diet, and their supplementation is required in most situations for high-producing animals (Church, 1991).

Table 4.9: Mineral composition of *M. oleifera* leaves at different fertilizer treatment levels

Fertilizer treatment levels	Ca	P	K	Mg	Na	Cu	Fe	Mn	Zn
	Macro-nutrients (% DM)					Micro-nutrients (ppm)			
Treatment1 (0 g)	1.42	0.29	0.57	0.06	2.11	14.59	181.72	<0.001	18.96
Treatment2 (100 g)	1.30	0.43	0.76	0.12	0.21	16.89	175.80	<0.001	19.99
Treatment3 (200 g)	1.43	0.22	0.69	0.05	0.25	14.86	171.93	1.43	20.71
Treatment4 (300 g)	0.67	0.13	0.29	0.07	0.06	14.04	178.97	<0.001	22.34

Note: g/100 g DW

Table 4.10 compares the proximate and mineral composition of flowers and leaves from *M. oleifera* fertilized with organic (cow manure) and inorganic (P and N) compounds. The proximate compositions analysis considered moisture, Ash, Fat, CP, CF, ADF and NDF while the mineral composition analysis targeted Ca, P, K, Mg, Na, Cu, Fe, Mn and Zn. In comparison, *M. oleifera* leaves from inorganic fertilizer treatments and from organic fertilizer treatments had higher nutrient values in NDF (55.68% and 33.28%), CP (33.90% and 33.90%) and Ash (10.39% and 10.78%), respectively. Flowers from plants fertilized with inorganic and organic compounds were higher in Fe (295.71 ppm and 270.44 ppm), Zn (41.65 ppm and 34.07 ppm) and Cu (13.73 ppm and 15.79 ppm) micro-nutrients. Even though the content of many minerals was higher in flowers, leaves had higher Mn (34.48 ppm and 25.22 ppm) than flowers (0.001 ppm and 0.001 ppm). Macro-nutrients such as Ca, P, K and Mg were quite high in the manured *M. oleifera* plants leaves Ca (5.08%), P (3.01%) and K (2.86%) sequentially. As observed from the

nutrient values, *M. oleifera* leaves are higher in proximate values than flowers; on the other hand, flowers are richer in minerals than in leaves. Among the minerals, micro-minerals (Fe, Cu, Zn and Mn) had higher values than macro-minerals (Ca, P, K, Mg and Na).

Table 4.10: Organic and inorganic leaf and flower nutrient compositions of *M. oleifera*

Nutrients	Inorganic flower	Inorganic leaves	Organic leaves	Organic flowers
Moisture	6.12	4.18	4.24	5.98
(%DM)				
Ash	8.08	10.39	10.78	7.83
Fat	5.57	0.92	1.69	3.71
CP	22.90	33.90	33.90	21.10
CF	10.47	10.90	8.47	8.36
ADF	15.49	17.17	12.35	17.06
NDF	21.08	55.68	33.28	21.08
Macro-nutrients (%DM)				
Ca	1.5810	1.54	5.08	2.04
P	0.38	1.42	3.01	0.45
K	0.74	1.18	2.86	0.91
Mg	0.12	0.34	1.01	0.12
Na	0.15	0.001	0.04	0.20
Micro-nutrients (ppm)				
Cu	13.73	7.19	8.21	15.79
Fe	295.72	95.02	104.97	270.44
Mn	0.001	34.48	25.22	0.001
Zn	41.65	10.66	10.63	34.07

Moist=Moisture, CP = Crude protein, CF = Crude fibre, ADF = Acid detergent fibre and DF = Neutral detergent fibre and measured in g/100 g DM. Ca=Calcium, P=Phosphorus, K=Potassium, Mg=Magnesium, Na=Sodium = % & Cu=Copper, Fe=Iron, Mn=Manganese, Zn=Zinc (g/100 g DW). Results are presented 'as is'.

4.4.3 Proximate and Mineral Composition of *M. oleifera* from Different Regions of Namibia and Africa

Table 4.9 shows the manured grown *M. oleifera* leaf proximate composition which were collected from four locations in Namibia: the Neudamm (NEU.) cultivated field, the Neudamm Campus, Rundu (Kaisosi), and Windhoek city. The Neudamm Field is an agronomic field about 1.5 km outside the Neudamm Campus where moringa was

cultivated. The Neudamm Campus itself has three old *M. oleifera* trees. Kaisosi is a location in Rundu Town, and Windhoek is the capital city of Namibia. The parameters considered were DM, Ash, Fat, CP, CF, ADF and NDF. *Moringa oleifera* leaves from the Neudamm cultivated field had the highest values in NDF (14.77%) and CP (30.95%), followed by the leaves harvested from the Neudamm Campus trees in Fat (5.81%), CF (9.73%) and NDF (13.88%). Leaves from Windhoek City had a higher content of moisture (6.30%) and were second in CP (29%), while leaves from Rundu (Kaisosi) had the highest content of NDF (16.39%).

Table 4.11: Proximate composition of *M. oleifera* leaves from four locations of Namibia

Locations	Moisture	Ash	Fat	CP	CF	ADF	NDF
NEU. Field	5.98	10.78	5.70	30.95	8.15	10.06	15.73
NEU. Trees	6.16	13.55	5.81	21.90	9.73	13.88	14.77
Rundu (Kaisosi)	6.11	10.64	5.64	27.20	7.76	8.91	16.39
Windhoek	6.30	15.50	4.45	29.00	8.15	8.70	15.52

Moist=Moisture, CP = Crude protein, CF = Crude fibre, ADF = Acid detergent fibre and NDF = Neutral detergent fibre and measured in g/100 g DW. Results are presented 'as is'.

Table 4.10 shows the mineral compositions of *M. oleifera* from four locations in Namibia, which were Neudamm cultivated field, Neudamm Campus, Rundu (Kaisosi) and Windhoek city. Iron, Zn, Cu and Mn had high values among the micro-minerals. Neudamm Campus trees had the highest Fe content (196.84 ppm), followed by those from Rundu, Kaisosi (182.97 ppm), then from Neudamm cultivated field (181.72 ppm), and finally from Windhoek City (150.50). The highest values for Cu were found in leaves from Windhoek City (14.59 ppm). This was followed by leaves from Neudamm cultivated field (12.37 ppm), Rundu, Kaisosi (10.51 ppm), and Neudamm Campus had the least content (9.40 ppm). Concerning Zn values, leaves collected from Neudamm

Campus trees had 10.60 ppm, leaves from Neudamm cultivated field - 18.96 ppm, leaves from Windhoek City - 20.50 ppm and leaves from Kaisosi, Rundu - 20.71 ppm. On the other hand, *M. oleifera* leaves from Neudamm trees had higher Mn value of 76.50 ppm as an outlier while leaves from other locations had less than 0.001 ppm of Mn. As seen in Table 3.9, *M. oleifera* leaves from trees found in the four locations of Namibia have quite similar nutrient profiles. Among macro-minerals such as Ca, P, K, Mg and Na, Windhoek City had the highest P value of 2.11% while Neudamm Campus had the lowest Na value of 0.05%. This means that location has very little or no impact on their nutrient contents. Statistically, there were no significant differences ($P > 0.05$) in *M. oleifera* leaves nutrient values although leaves were collected from different locations of Namibia.

Table 4.12: Mineral composition of *M. oleifera* leaves from four locations of Namibia

	Macro-nutrients (% DM)					Micro-nutrients (ppm)			
Locations	Ca	P	K	Mg	Na	Cu	Fe	Mn	Zn
NEU. field	1.76	0.32	0.70	0.17	0.13	12.37	182.97	<0.001	20.71
NEU. trees	0.83	0.31	1.76	0.65	0.05	9.40	150.50	76.50	20.50
Rundu	1.92	0.38	0.78	0.14	0.15	10.51	196.84	<0.001	10.60
Windhoek	1.42	2.11	0.29	0.57	0.06	14.59	181.72	<0.001	18.96

Ca=Calcium, P=Phosphorus, K=Potassium, Mg=Magnesium, Na=Sodium = % & Cu=Copper, Fe=Iron, Mn=Manganese, Zn=Zinc in g/100 g DW. Results are presented 'as is'.

Moringa oleifera tree has a very high concentration of nutrients. It is native to India, but has been planted around the world. Thus, this tree has become naturalized in many countries, of which Africa is no exception (Fuglie, 2001; Sanchez *et al*., 2006; Prince, 2007). Table 4.11 presents *M. oleifera* leaves proximate composition from four regions of Sub-Saharan Africa, namely: Central (Chad), East (Ethiopia), South (Namibia), and West (Nigeria). Moisture ranges from 3.21% to 6.16%, with leaves from Nigeria having

less moisture percentage than those from Namibia, while leaves from Chad had 20.92% moisture content. Leaves from Namibia and Ethiopia had the highest content of ash (13.55% and 13.20% respectively), with those from Chad having the least ash content (6.73%). Leaves from Ethiopia and Namibia had the highest Fat content (6.73% and 5.81% respectively) with those from Chad and Nigeria having 2.11% and 2.34% fat content, respectively. Leaves from Chad and Ethiopia had higher CP (32.06% and 28.90%), while those from Namibia and Nigeria were lower (21.90% and 17.01%). Leaves' crude fibre had similar content across the four regions, ranging from 7.09% to 9.73%, with leaves from Namibia having the highest content and Nigeria, the least.

Leaves from Namibia had higher ADF contents (13.88%) and NDF (14.77%) than those from Ethiopia (8.49% and 11.40% for ADF and NDF, respectively). These results were reported by Melesse (2011) from Ethiopia; Ogbe and Affifu (2012) from Nigeria; and Mbailao *et al*. (2014) from Chad. Leaves from Namibia were the highest in most proximate composition except for fat and CP, for which Ethiopia and Chad had the highest contents correspondingly. Among the four regional nations, leaves from Nigeria had the lowest nutrient values.

Table 4.13: Proximate composition of *M. oleifera* leaves from different African regions

Locations	Moisture	Ash	Fat	CP	CF	ADF	NDF
Chad	20.92 (DM)	6.73	2.34	32.06	8.07	---	---
Ethiopia	---	13.20	6.73	28.90	8.51	12.10	16.70
Namibia	6.16	13.55	5.81	21.90	9.73	13.88	14.77
Nigeria	3.21	7.93	2.11	17.01	7.09	----	----

Nutrients were measured in (g/100g DW) for all analyses
Source: Melesse (2011) from Ethiopia; Ogbe and Affifu (2012) from Nigeria; and Mbailao *et al*. (2014) from Chad.

The mineral composition of *M. oleifera* leaves from the four regions of Sub-Saharan Africa which include Central (Chad), East (Ethiopia), South (Namibia) and West (Nigeria) is summarised in Table 4.12. It shows *M. oleifera* leaves' composition in terms of macronutrients (Ca, P, K, Mg and Na) and micronutrients (Cu, Fe, Mn and Zn). These results were reported by the same authors as for the proximate analysis of *M. oleifera* leaves (see Table 4.10), while the data for Namibia were generated by the current research. The results presented show that moringa leaves from Nigeria had the highest content of macro-nutrients such as Ca (1.91%), P (30.15%) and Na (192.95%), while leaves from Chad, Ethiopia and Namibia had quite similar values. Concerning micro-nutrient contents, leaves from Nigeria also had the highest values of Mn (81.65 ppm) and Zn (60.06 ppm), and leaves from Namibia had the highest content of Fe (150.50 ppm). On the other hand, leaves from Chad and Namibia had the higher values of Cu (9.07 ppm and 9.40 ppm) respectively, while those from Nigeria had the lowest Cu values. Moringa leaves from Ethiopia were not analysed for micro-nutrients. The slight differences in mineral composition might be attributed to soil nutrient compositions at production sites, as discussed by Grusak (2001). However, *M. oleifera* maintains its nutritional values at almost the same level despite regional ecological differences among the four countries.

Table 4.14: Mineral composition of *M. oleifera* leaves from different African regions

	Macro-nutrients				Micro-nutrients				
Locations	Ca	P	K	Mg	Na	Cu	Fe	Mn	Zn
Chad	1.23	0.32	1.73	0.39	0.08	9.07	97.12	29.33	29.14
Ethiopia	2.62	0.43	2.00	0.56	0.03	--	--	--	--
Namibia	0.83	0.31	1.76	0.65	0.05	9.40	150.50	76.50	20.50
Nigeria	1.91	30.15	0.79	0.38	192.95	6.18	107.48	81.65	60.06

In Namibia, Ca=Calcium, P=Phosphorus, K=Potassium, Mg=Magnesium, Na=Sodium = % & Cu=Copper, Fe=Iron, Mn=Manganese, Zn=Zinc = ppm (g/100 g DW); Nigeria, Ca = %, P = ppm, K = ppm, Mg = ppm, Na =% & Cu =ppm, Fe = ppm, Mn = ppm, Zn = ppm; Ethiopia, Ca, P, K, Mg, Na = % & Cu, Fe, Mn, Zn = % DM; and Chad, Ca, P, K, Mg, Na = % DM; Cu, Fe, Mn, Zn =ppm. Source: Melesse (2011) from Ethiopia; Ogbe and Affifu (2012) from Nigeria; and Mbailao *et al*. (2014) from Chad

4.4.4 Comparison of *M. ovalifolia* Nutrient Compositions at Different Treatment Levels

The comparison of *M. ovalifolia* leaf proximate composition within fertilizer treatment levels using the control treatment mean as a test value in a one-sample t-test is found in Table 4.15. Just as *M. oleifera*, *M. ovalifolia* was transplanted in plots with four fertilizer treatment levels in which treatment1 was the control (0 g); treatment2 received 100 g, treatment3 - 200 g and treatment4 - 300 g phosphorus and nitrogen fertilizer application. The analysis of the results shows that leaves from the control (treatment1) had higher moisture content (6.37%), ash (12.61%), fat (6.17%), CP (31.50%), CF (10.08%) ADF (12.87%) and NDF (16.72%) values in comparison to experimental treatments (treatment2, treatment3 and treatment4). The higher proximate composition of leaves from control treatment is a clear indication that *M. ovalifolia* needs neither phosphorus, nor nitrogen fertilizers to produce quality/nutrient-rich leaf biomass. *Moringa ovalifolia*, like *M. oleifera*, contains a high level of CP under organic production, which makes it a better alternative feed supplement for animals without human-livestock conflict and high cost. Church (1991) and Tisch (2006) emphasized that protein sources for livestock

rations are more expensive than carbohydrate sources and the most costly component of a finished feed. The same author mentioned that most plant sources of CP (beans, alfalfa, coconut, sunflower, and so on) range from 20% to 40+ %, and the CP content in both *Moringa* species confirms this rule with 31.00% and 31.50% for *M. oleifera* and *M. ovalifolia*, respectively. There were no significant differences (P > 0.05) between the control treatment and the experimental treatments in all nutrient values, which is in agreement with the findings of Fuglie and Sreeja (2001) Radovich (2007) that moringa needs little or no fertilizers.

Table 4.15: Proximate composition of *M. ovalifolia* leaves at different treatment levels

	Treatment Means		Standard	Standard		
Nutrient	Control	Fertilized	Deviation	Error Mean	t	P-values
Moist	6.37	6.1430	0.30	0.17	-1.32	0.317ns
Ash	12.61	10.89	1.35	0.78	-2.20	0.158ns
Fat	6.17	5.67	1.04	0.60	-0.83	0.492ns
CP	31.50	27.73	3.61	2.08	-1.81	0.212ns
CF	10.08	7.92	1.18	0.68	-3.17	0.087ns
ADF	12.87	11.41	1.25	0.72	-2.03	0.180ns
NDF	16.72	12.98	2.84	1.64	-2.28	0.150ns

Moisture = % Dry Matter; CP = % Crude Protein; CF = % Crude Fibre; ADF = % Acid Detergent Fibre; NDF = % Neutral Detergent Fibre; Fat = % Fat; Ash = % Ash (100 – Ash) = Organic Matter (g/100 g DW). Results are presented 'as is'. Note: ns = non-significa 0.05 alpha levels.

The comparison of *M. ovalifolia* leaves' mineral analysis within treatments is found in Table 4.16. The results reveal that mineral values of Ca (1.77%), K (0.82%), P (0.37%), Na (0.25%), and Zn (13.80 ppm) were higher in leaves from the experimental treatments (treatments 2, 3 and 4) than the values in the leaves from the control treatment (treatment1). However, Mg (0.27%), Fe (184.83 ppm), and Cu (15.11 ppm) were higher in the control treatment, while Mn had the same value of 0.001 ppm in both

experimental and control treatments. Statistically, there were no significant differences ($P > 0.05$) between the control and the other treatments levels.

Table 4.16: Mineral composition of *M. ovalifolia* leaves at different treatment levels

	Treatment Means		Standard	Standard Error		
Nutrient	Control	Fertilized	Deviation	Mean	t	P-values
Ca	1.54	1.77	0.17	0.10	2.29	0.149ns
P	0.36	0.37	0.09	0.05	1.74	0.225ns
K	0.74	0.82	0.08	0.05	-3.90	0.060ns
Mg	0.27	0.15	0.06	0.03	1.19	0.356ns
Na	0.14	0.25	0.16	0.09	0.16	0.889ns
Cu	15.11	12.43	3.19	1.84	-1.46	0.283ns
Fe	184.83	171.37	26.75	15.44	-0.87	0.475ns
Mn	0.001	0.001	0.00	0.00	1.96	0.189ns
Zn	12.65	13.80	1.01	0.59	2.29	0.149ns

Ca = % calcium; Na = % Sodium; K = %Potassium; Mg = %Magnesium; P = % Phosphorous; Mn = Manganese (ppm); Cu = Copper (ppm); Fe = Iron (ppm); Zn = Zinc (ppm) (g/100 g DW). esults are presented 'as is'. Note: ns = non-significant at 0.05 alpha level.

Table 4.17 compares the proximate and mineral composition of *M. ovalifolia* leaves within treatments as the nitrogen and phosphorus fertilizers were applied. The same experimental design was used as in the case of *M. oleifera* (see Table 4.6). *Moringa ovalifolia* seedlings were transplanted in plots with four treatment levels: treatment1 (0 g), treatment2 (100 g), treatment3 (200 g) and treatment4 (300 g) of superphosphate fertilizer with a P content of 83 g/kg (Wonder superphosphate granular, AGRO-SERVE (Pty) Ltd., Bryanston, South Africa) and nitrogen fertilizer with an N content of 280 g/kg (Limestone Ammonium Nitrate – LAN, WONDER HORTICULTURAL PRODUCTS (Pty) Ltd., Silverton, South Africa) for root and leaf development. The proximate composition analysis of *M. ovalifolia* leaves shows that leaves from treatment1 had the highest values in ash (12.61%), CP (31.50%), CF (10.08%), ADF (12.87%) and NDF (16.72%). Leaves from treatment2 had the second highest content of

moisture (6.47%), ash (12.45%), CP (9.16%) and NDF (16.12%). These were followed by leaves from treatment3: fat content (6.48%), CF content (7.78%) and ADF content (12.85%), while leaves from treatment4 had the least nutrient values. The high proximate values in leaves from treatment1 is an indication that *M. ovalifolia,* like its counterpart *M. oleifera,* is a nutrient-rich plant source with low demand for fertilizers and can serve as a suitable supplement for ruminants. In addition, CF showed declining nutrient values as the fertilizer levels increased (treatment1 =10.08, treatment2 = 9.16, treatment3 = 7.78 and treatment4 = 6.81). Since leaves from the control (treatment1) had the highest content of nutrients besides fat and moisture, it is evident that *M. ovalifolia* can be grown without phosphorus and nitrogen fertilizers and still maintain high nutrient content for use as an animal supplement, as suggested by Fuglie (2001).

Moreover, the comparison of the mineral composition of *M. ovalifolia* leaves within treatments shows a quite random distribution. The minerals considered in this analysis were Ca, P, K, Mg, Na, Cu, Fe, Mn and Zn. Among these, only Fe, Cu and Zn were found in large quantities while Ca was less than 2%; K, Mg, Na and P were less than 1% and Mn was less than 0.001 ppm for all treatments (treatment1, treatment2, treatment3 and treatment4). Leaves from treatment3 had the highest mineral contents of Fe (201.83 ppm) and Cu (15.22 ppm), followed by treatment1 with Fe (184.83 ppm) and Cu (15.11 ppm). Leaves from treatment4 had the highest content only in Zn (14.66 ppm), while those from treatment2 had the lowest content of these elements. Zinc had increasing values as the fertilizer levels increased: treatment1 = 12.65%, treatment2 = 12.68%, treatment3 =13.05% and treatment4 = 14.66%, respectively. This implies that Zn composition could be dependent on the levels of fertilizers.

Table 4.17: Proximate and mineral composition of *M. ovalifolia* leaves at different treatment levels

Nutrients	Treatment1 (0 g)	Treatment2 (100 g)	Treatment3 (200 g)	Treatment4 (300 g)
Moisture (% DM)	6.37	6.47	5.89	6.07
Ash	12.61	12.45	10.06	10.15
Fat	6.17	4.50	6.48	6.03
CP	31.50	24.00	31.20	28.00
CF	10.08	9.16	7.78	6.81
ADF	12.87	10.75	12.85	10.63
NDF	16.72	16.12	10.58	12.24
Macro-nutrients (% DM)				
Ca	1.54	1.57	1.88	1.86
P	0.36	0.27	0.42	0.43
K	0.74	0.72	0.87	0.86
Mg	0.27	0.20	0.09	0.16
Na	0.14	0.17	0.15	0.44
Micro-nutrients (ppm)				
Cu	15.11	8.95	15.22	13.11
Fe	184.83	151.71	201.83	160.57
Mn	<0.001	<0.001	<0.001	<0.001
Zn	12.65	12.68	14.05	14.66

Moist = % Moisture (100 - Moisture) = % Dry Matter); CP = % Crude Protein; CF = % Crude Fibre; ADF = % Acid Detergent Fibre; NDF = % Neutral Detergent Fibre; Fat = % Fat; Ash = % Ash (100 – Ash) = Organic Matter). Ca = % calcium; Na = % Sodium; K = %Potassium; Mg = %Magnesium; P = % Phosphorous; Mn = Manganese (ppm); Cu = Copper (ppm); Fe = Iron (ppm); Zn = Zinc (ppm) (g/100 g DW). Results are presented 'as is'.

4.5 Conclusion

Moringa plant species contain almost all the essential nutrients and minerals needed by humans and livestock for growth and development. Substantial amounts of macro- and micro-nutrients were found in both *Moringa* species, showing them to be fit to be used as feed supplements. Their proximate analysis showed nutrients desirable for animal feeds. Although there is a possible human-livestock conflict in the use of *Moringa* species (especially *M. oleifera*), if adopted by livestock farmers, both *Moringa* species have the potential to eliminate the need for purchasing of protein and mineral feed supplements for their animals, since they contain almost all essential nutrients and minerals. Hence, its availability on the farms for supplementation during periods of low-

nutrient grasses and browse species in rangelands (i.e., winter and drought) will improve livestock production. Moringa leaves from different African regions and different regions of Namibia have proved to contain closely similar nutritional values despite the geographical or ecological conditions in which they were cultivated. Therefore, cultivation of moringa trees as nutrient-rich plant species should be encouraged, principally for their uses as food/feedstuff for both humans and livestock. Amino acid tests and vitro digestibility trials are recommended for future studies with the leaf biomass of the same moringa trees.

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Chapter 5

Assessment of the Anthelmintic Effect of *Moringa Oleifera* Leaf-supplemented Diet on Gastrointestinal Parasites in Boer Goats

5.1 Abstract

The objective of this study was to compare the efficacy of *Moringa oleifera* (*M. oleifera*) leaf supplements with the drug ecomectin® on the reduction of the gastrointestinal parasites (GIP) load of Boer goats for 74 days at Neudamm Experimental Farm. A completely randomized design (CRD) was used for this experiment, in which 16 lactating does were randomly selected from 51 lactating does. The experiment used four *M. oleifera* leaf-supplemented treatment levels (0%, 10%, 20% and 30%) and randomly assigned four goats to each treatment level. The quasi-control group (0%) was given ecomectin to compare the efficacy with that of *M. oleifera* as an ethno-medicinal treatment. The results revealed that *M. oleifera* leaf supplements had anthelmintic effects against trichostrongyle worms, coccidia, *Monezia*, *Trichuris* and *Strongyloides* species. Statistical analysis showed significant differences ($P > 0.001$) at 10%, 20% and 30% inclusion levels for trichostrongyle-type eggs, coccidia oocysts, *Trichuris* species, *Moniezia* species and *Strongyloides papillosus* in the goats' faeces. Therefore, the hypothesis (H_{04}) that *M. oleifera* does not have anthelmintic properties was rejected because *M. oleifera* has anthelmintic properties and reduced GIPs in goats. However, a further research is needed to investigate if GIPs in goats will develop resistance against *M. oleifera* leaves as an ethno-anthelmintic supplement.

Keywords: Boer goats, ecomectin drug, ethno-anthelmintic drug, helminthes, lucerne, *Moringa oleifera*

5.2 Introduction

Goats are found in almost all parts of the world, reared by both rural subsistence and commercial farmers as a sustainable source of household income and protein-food supply [Boer Goat Breeder's Society of Namibia (BGBSN, 2008)]. About 913,999 thousand heads of goats and kids are found worldwide and about 263,474 thousand heads of goats and kids are found in Africa (FAO, 2013). Livestock production is the second largest agricultural activity in Namibia next to crop production in which 39% of agricultural households are engaged with the total of 872,228 cattle, 1618,204 goats and 163,905 sheep [Namibia Statistics Agency (NSA, 2015)]. Goats are very sensitive to the effects of internal parasitism which can cause decreased fertility, abortion, unthriftiness, increased susceptibility to disease and death (Jansen & Burg, 2004; Stehman & Smith, 2004). Some commonly found helminths in ruminants include, but are not limited to nematodes (roundworms), trematodes (flukes) and protozoa (unicellular organisms) (Hendrix & Sirois, 2007). It has been confirmed that coccidiosis is a common and damaging illness of sheep, goats, and cattle, particularly of young lambs, kids, and calves (Coffey, 2014). Trichostrongylosis (trichostrongyliasis), a disease caused by *Trichostrongylus* species has also been cited in much of the literature (Machen *et al*., 1993; Sleeman *et al*., 2000; Kumba *et al*., 2003). These parasites have developed resistance to many dewormers due to overuse and improper use of the available anthelmintics, and they have become difficult to control (Roeber *et al*., 2013). In this light, livestock producers are no longer relying on drugs alone to control internal parasites. Instead, they tend to employ an integrated approach that relies on sustainable methods (Hale, 2006) such as stringent hygiene of stables, rotational grazing and ethno-veterinary medicines.

Moringa oleifera is considered to be effective in the treatment of many diseases (Caceres *et al.*, 1991). The roots, leaves and pods are said to have medicinal properties and contain antimicrobial and antioxidant substances that are important for both humans and animals (Alhakman *et al*., 2013; Hassan & Ibrahim, 2013). The curative effect of *M. oleifera* may explain its extensive use for nutritional and health benefits (Prince, 2007; Moyo *et al*., 2012). The medicinal characteristics of *M. oleifera* make it a potential source for improving small ruminants and other livestock production in Namibia and the world at large. The problems faced by many small ruminant farmers in this regard are the availability of anthelmintics, as well as parasites' developed resistance to commonly used conventional drugs, due to repeated use (Hepworth *et al*., 2006). The *in vitro* studies of an anthelminthic activity of *M. oleifera* leaf extracts at five different concentrations (0.625, 1.25, 2.50, 3.75 and 5 mg/ml) against *Haemonchus contortus* and gastrointestinal trichostrongyle-type eggs in goats showed that at 0.625, ethanolic extract inhibited 51.7% egg embryonation, reaching 92.80%, at 5 mg/ml; infused and macerated aqueous extracts also inhibited embryonation with mean efficacy of 69% and 94.50% at 5 mg/ml; macerated aqueous extract and ethanol extract inhibited more than 60% egg hatch at 2.50 mg/ml, reaching 90.20% and 99% at 5 mg/ml; the infused aqueous extract inhibited 69.2% and 97.9% egg hatch at 3.75 and 5 mg/ml, respectively. For larvicidal activity, infused aqueous extract showed weak activity on L_1 larvae, inducing only 50.50% mortality at 5 mg/ml. However, macerated aqueous extract induced 89.60% at 5 mg/ml while at the same concentration ethanolic extract registered 98.8% L_1 larva mortality (Abreu *et al*., 2014; Tayo *et al*., 2014).

Goats suffer from gastrointestinal parasites (GIPs) which can be treated using different approaches. *Moringa oleifera* is one of the ethno-veterinary medicinal plants which can be used for the treatment of GIPs in animals. The purpose of this study was therefore to determine the anthelmintic effect of *M. oleifera* on GIPs of Boer goats in Namibia. In Namibia, little is known in terms of documented studies about the controlled use of herbs in the fight against goats' internal parasites as well as their nutritional values. Therefore, this study was aimed at assessing the use of *M. oleifera* leaf supplement as an ethno-anthelmintic drug as demonstrated by Abreu *et al*. (2014) and Tayo *et al*. (2014) in comparison to ecomectin (ivermectin 0.08% m/v), the medicine that is conventionally used for goats as a dewormer.

5.3. Materials and Methods

5.3.1 Study Area

This study was conducted from October 2015 to January 2016 at the Neudamm Campus of the University of Namibia, about 30 km east of Windhoek, with an area of 10, 187 hectares. Neudamm Campus is located at 22° 30′ 07″ S and 17° 22′ 14″ E**,** and at an altitude of 1762 meters above sea level. The farm's temperature ranges between a minimum of -7°C in winter and a maximum of 44°C in summer (University of Namibia, 2011), and received an annual average rainfall of 247.8 mm in 2015/2016 summer season (P. Beukes, 2017).

The vegetation of Neudamm Farm is classified as highland savannah (semi-arid savannah) and characterized by grasses, shrubs and trees that are well spread over the

farm. An annual grass like *Melinis repens* and perennial grasses like *Schmidtia pappophoporoides*, *Anthephora pubescens* and *Brachiaria nigropedata* are well represented on the farm. Different types of trees like *Acacia brownii*, *Acacia erioloba*, *Acacia mellifera*, as well as shrubs like *Grevia flava*, are found on Neudamm Experimental Farm. The estimated carrying capacity is about 12 hectares per large stock unit or 45 kg per hectare biomass (Kahumba, 2010; Kapu, 2012; A. Beukes, 2017).

5.3.2 Research Design

A completely randomized design (CRD) consisting of a one-way treatment structure was used to test statistical differences at different levels of inclusion of *M. oleifera* leaf supplement. The *M. oleifera* leaves were harvested from an organic *M. oleifera* farm in Rundu, Namibia (about 714 km from Windhoek), at 30-day intervals and shade-dried over plastic sheets within two weeks. Four treatment levels of *M. oleifera* inclusion were used, with four replicates in each (0%, 10%, 20%, and 30%) in isocaloric and isonitrogenous diets. The four treatment levels were decided to develop levels at which *M. oleifera* leaves would sustainably serve as ethno-anthelminthic doses as well as nutritional supplemental levels in goats suggested by Gebregiorgis, Negesse and Nurfeta (2011). Sixteen (16) lactating Boer goats with the age range of 12–50 (29.38 ± 11.15) months old and body weight range of 27.6 - 50.5 (37.06 ± 6.62) kg were used in this study to assess the effect of *M. oleifera* leaf supplement on intestinal parasites, in comparison to the ecomectin drug. Taking into consideration an average weight of 37 kg per goat, the percentages of inclusion translated into 0% (0 g), 10% (150 g), 20% (300 g) and 30% (450 g) of *M. oleifera* dry leaves per day. The four goats in the quasi-control group (0%) were treated with ecomectin® [ECO Animal Health Southern Africa (Pty)

Ltd., Faerie Glen, South Africa] with a composition of ivermectin 0.08% m/v as a conventional dewormer, for comparison of the efficacy of *M. oleifera* as an ethno-medicinal treatment. Dry lucerne (*Medicago sativa)* was used as a basal diet for all goats supplemented with 300 g Ram-Lamb-Ewe pellets, and mineral licks were fed *ad libitum* throughout the research period. For the lactating goats, the total daily feed (*M. oleifera*, lucerne and pellets) given to each was 4% of its average body weight, considering the wastes during feeding as recommended by Coffey (2006). At the Neudamm Experimental Farm, lucerne is being used as a sole feed to lactating goats during winter or drought and is supplemented with Ram-Lamb-Ewe Pellets® [Feedmaster (Pty) Ltd., Windhoek, Namibia]. The nutritional compositions of the feed and mineral lick block fed to study goats are shown in Table 5.1.

Table 5.1: Nutrient compositions of feeds and lick block fed to the goats

Nutrients	*M. oleifera*	Lucerne	Pellets	Lick block
Moisture	6.25 g/100g	6.35 g/100g	120 (60 mg/kg)	120 g/kg
Ash	10.64 g/100g	6.75 g/100g	140 (50 mg/kg)	----
Fat	5.64 g/100g	1.02 g/100g	70 (1 mg/kg)	----
Crude protein	27.20 g/100g	20.35 g/100g	----	160 g/kg
Protein ex. NPN	----	----	----	100%
Crude Fiber	7.76 g/100g	23.45 g/100g	150 (1 mg/kg)	120 g/kg
Acid detergent fiber	8.91 g/100g	26.98 g/100g	----	----
Neutral detergent fiber	16.39 g/100g	39.19 g/100g	----	----
Metabolisable Energy	11 MJ/kg	9.50 MJ/kg	9.4 MJ/kg	----
Total Digestible Nutrient	67 g/100g	61 g/100g	----	----
Digestible energy	12 MJ/kg	11.30 MJ/kg	----	----
Calcium	1.76 g/100g	0.43 g/100g	12 (0.3 mg/kg)	75 g/kg
Phosphorus	0.32 g/100g	0.18 g/100g	----	50 g/kg
Sodium	0.13g/100g	0.01 g/100g	----	----
Potassium	0.70 g/100g	0.65 g/100g	----	----
Magnesium	0.17 g/100g	0.06 g/kg	220 mg/kg	----
Iron	182.97 mg/kg	104.20 mg/kg	0.05 mg/kg	----
Copper	12.38 g/100g	6.77 mg/kg	----	----
Manganese	0.001 mg/kg	32 mg/kg	0.03 mg/kg	----
Zinc	----	----	0.05 mg/kg	----
Cobalt	----	----	0.001 mg/kg	----
Iodine	----	----	0.001 mg/kg	----
Selenium	----	----	0.0003 mg/kg	----
Vitamin A (IU)	----	----	5,000 (3 mg/kg)	----

Moist = % Moisture (100 - Moisture) = % Dry Matter); CP = % Crude Protein; CF = % Crude Fibre; ADF = % Acid Detergent Fibre; NDF = % Neutral Detergent Fibre; Fat = % Fat; Ash = % Ash (100 – Ash) = Organic Matter); TDN = Total Digestible Nutrients; DE = Digestible Energy; and ME = Metabolisable Energy, NSC = Non-structural Carbohydrate. Ca = % calcium; Na = % Sodium; K = %Potassium; Mg = %Magnesium; P = % Phosphorous; Mn = Manganese (ppm); Cu = Copper (ppm); Fe = Iron (ppm); Zn = Zinc (ppm); Tannins = Tannic Acid. Results are presented 'as is'. Source for pellets and lick block data: Feedmaster Namibia

The quasi-control group (0% *M. oleifera*) was fed with lucerne and pellets only, while the three other groups were supplemented with *M. oleifera* leaf at three inclusion levels (10%, 20% and 30%). All goats were fed twice a day (08:00 am and 15:00 pm), as suggested by Gebregiorgis *et al*. (2011) and Yayneshet *et al*. (2008) for 74 days (October 19, 2015 to January 5, 2016), and clean water was available *ad libitum* in all cages. Coprological analysis was done at the Central Veterinary Laboratory of Namibia in Windhoek.

5.3.3 Data Collection Procedures

At the commencement of this study, all the does and their kids were treated with COOPERS SUPADIP® (Cooper Ltd., Isando, South Africa) at a dilution ratio of 50 mL : 10 L of water against ectoparasites. The COOPERS SUPADIP® contains chlorfenvinphos 30% m/v. The 16 lactating does were clinically examined, and temperature, pulse and respiratory rates were taken fortnightly throughout the research period before faecal sample collection, as described by Rumosa-Gwaze *et al.* (2012). Initial faecal samples were collected from the rectum of each goat before the introduction of the *M. oleifera* leaf-supplemented diets. All four goats in the control group (0% *M. oleifera*) were injected with ecomectin® (10 mL per doe and 2 mL per kid), based on their body weights, while the 12 goats in the other three groups (10%, 20% and 30%) were given a *M. oleifera* leaf-supplemented diet for the purpose of comparison.

A 14-day adaptation/adjustment period was observed, after which fortnightly faecal samples were collected in containers from the rectum by 7:00 am, which were then placed in a cooler box and taken within an hour to the Central Veterinary Laboratory of Namibia in Windhoek for analysis. In the laboratory, combined sedimentation and flotation techniques were used (Pancholy, Carter, Thomas, & Donald, 2007; Reinemeyer & Nielsen, 2013) to determine faecal egg count.

Ninety-six (96) faecal samples were collected from the 16 Boer goats at two-week intervals over the 74 days for the assessment of GIP infestation. For faecal analysis, three grams (3 g) of faeces was measured on an electronic balance, put in a mortar,

mashed and mixed thoroughly with a pestle. One hundred mL of water was added to the mashed faeces and filtered through strainer into a cylindrical container. A period of 30 minutes was allowed for the sediments to settle at the bottom of the container. Afterwards, the water was poured out leaving the sediment at the bottom of the containers. The containers were then shaken and the sediments were poured into labelled test tubes. The test tubes were then filled to the brim with sugar solution and covered with cover slides. Finally, the eggs were allowed to float over the sugar solution for another 30 minutes and then stuck onto the cover slides. Then, the cover slides were taken and placed on new microscope slides for examination under a light microscope at a magnification of x40.

5.3.4 Data Analysis

Regression and Chi-Square analyses were used to analyse the collected data for statistical differences. The quadratic and linear regression functions were used to determine the inclusion level at which *M. oleifera* leaf supplementation was efficient in treating helminths in the goats under study. The Chi-Square test was used to determine the mean difference of *M. oleifera* leaf supplementation and time effect on GIPs. In the analysis, parasite eggs or oocysts were used as dependent variables while *M. oleifera* leaf inclusion levels were used as independent variables. Statistical Package for Social Sciences (SPSS® version 23), as well as Microsoft Excel® (version 13) were used for all analyses at the alpha levels of $p \leq 0.05$ and all p-values above these alpha levels were considered non-significant.

5.4. Results and Discussion

The results of the faecal samples analysis conducted during the entire research period of 74 days detected trichostrongyle-type eggs, coccidia oocysts, *Trichuris* species, *Moniezia* species and *Strongyloides papillosus* present in the gastro-intestinal tracts of goats on the Neudamm Experimental Farm. However, the two most common types of GIPs found in all 16 goats were trichostrongyle-type eggs and coccidia oocysts, meaning that they had the highest infestation rates, as observed by Pancholy *et al*. (2007). On the other hand, *Trichuris* species, *Moniezia* species and *Strongyloides papillosus* were found in only a few goats. As suggested by Turner and Getz (2010), this study observed parasites' eggs and oocysts in their taxonomic groupings in order to avoid identification errors; therefore, trichostrongyle-type eggs, coccidia oocysts, *Trichuris* species, *Moniezia* species were not identified further to species levels.

5.4.1 Adjustment Period and Parasite Prevalence

During the 14 day adaptation/adjustment period, it was observed that 15 out of the 16 goats showed a liking for *M. oleifera* leaves within less than a week, and consumed their entire ration. Only one goat resisted immediate adjustment to *M. oleifera* leaves, but gradually began to eat them. This quick adaptation of goats to the *M. oleifera* leaf-supplemented diet serves as an advantage for using it as an alternative to hay, nutritional supplement, or anthelmintic drug for goats and other livestock, as reported in several literary studies (Sanchez, Sporndly, & Ledin, 2005; Bey, 2010; Jain *et al*., 2013; Akinbamijo, Adediran, Nouala, & Saecker, n.d.).

The prevalence of GIPs in this study was calculated for each genus of parasites, as suggested by Rumosa Gwaze *et al*. (2012) and Tamboura *et al*. (2006). As seen in Table 5.2, trichostrongyle-type eggs and coccidia oocysts had very high prevalence rates (100% each), while *Trichuris, Moniezia* and *Strongyloides papillosus* had lower prevalence rates of 68.75%, 37.50%, and 43.75%, respectively. This suggests that trichostrongylid infection and coccidiosis are the major parasitic infestations in goats kept at Neudamm Experimental Farm. A seasonal research study conducted earlier in eastern Namibia with communal goats showed that trichostrongylid infection and, to a lesser extent, S*trongyloides* species are predominant during all seasons in all experimental flocks (Kumba *et al*., 2003). A study conducted in the Etosha National Park, Namibia, revealed the infestation of ungulates by strongyle nematodes, *Strongyloides* species, Coccidia and *Eimeria* species, as well as anoplocephalid cestodes (Turner and Getz, 2010).

Table 5.2: Parasite prevalence in the experimental goats

Parasites	Total number of Goats	Infected Goats	Prevalence (%)
Trichostrongyle-type eggs	16	16	100
Coccidia oocysts	16	16	100
Trichuris species	16	11	68.75
Moniezia species	16	6	37.50
Strongyloides papillosus	16	7	43.75

The prevalence of the parasite eggs was calculated using the formula (p = d/n x 100) suggested by Tamboura *et al*. (2006) where:

P = prevalence

d = number of goats infested with the gastrointestinal parasite at a given time

n = number of animals in the population at risk at that particular time.

5.4.2 Infestation by Trichostrongylid Helminths

The notations used at the Central Veterinary Laboratory of Namibia in Windhoek where the samples were analysed have the following interpretations: 0 (no parasite eggs detected), 1+ (very low infestation), 2+ (low to moderate infestation), 3+ (moderate to high infestation) and 4+ (very high to heavy infestation). Trichostrongyle-type eggs were the second largest infestation, after coccidia oocysts, in all 16 goats, and ranged from very low to very high infestation rates. From 96 faecal samples collected, 34 samples had zero (35.40%), 22 samples (22.90%) had 1+, 16 (16.70%) had 2+, 18 (18.80%) had 3+ and 6 samples (6.30%) had 4+ infestation rates, respectively. This indicates that the overall infestation levels were around 1+, 3+ and 2+, representing 22.90%, 18.80% and 16.70%, which means that the entire herd was moderately infested with trichostrongylid species eggs (Figure 5.1). Hendrix and Sirois (2007) discussed that bovine trichostrongylids, which are in the group of roundworms, are composed of several genera of nematodes that infest the abomasum and the small and large intestine of cattle and other ruminants.

The genera that produce trichostrongyle-type eggs are *Bunostomum*, *Cooperia*, *Chabertia*, *Haemonchus*, *Oesophagostomum*, *Ostertagia*, and *Trichostrongylus*. These seven genera (and others) produce oval, thin-shelled eggs that contain four or more cells and are 70 to 120 µm long. Some of these ova may be identified to their respective genera; however, identification is usually difficult because mixed infections of bovine trichostrongylids are quite common. Many literatures concurred that nematodes produce trichostrongyle-type eggs that are similar, and difficult to distinguish and egg shapes range from 64-100 µm x 27-55 µm (Sleeman *et al*., 2000; Indre *et al*., 2010).

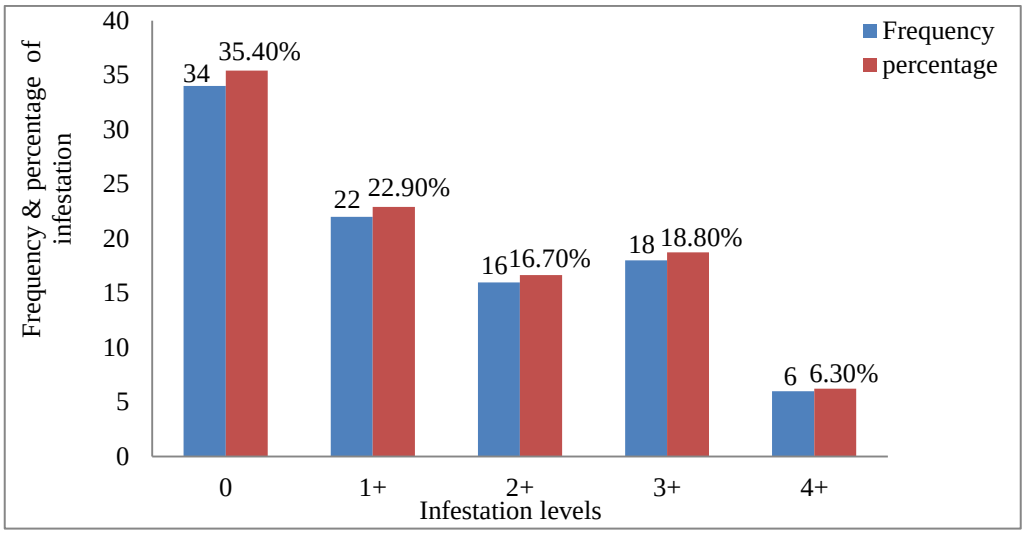

Figure 5.1: Infestation level of trichostrongyle-type eggs in study goats

Table 5.3 presents mean of the trichostrongyle-type eggs load before and during treatment with *M. oleifera* and ecomectin. Day one (before treatment) faecal analytical result for the means showed high infestation rates of trichostrongyle-type eggs among all 16 goats (2.75+, 2.75+, 2.75+ and 3+). This is an indication that all 16 goats were highly infested with trichostrongyle-type eggs (also see Table 5.2) at the commencement of this research. The infestation gradually dropped after ecomectin was given to quasi-control group and *M. oleifera* leaf was supplemented to the three experimental groups. The results also showed that *M. oleifera* had a higher efficacy rate at 10% and 20% than ecomectin, as seen in the faecal analysis results on days 16, 30, 59 and 73, respectively. Thus, there was an equal reduction in the infestation rates for both ecomectin- and *M. oleifera*-treated goats, which signifies that *M. oleifera* leaves have anthelmintic properties. However, as time went by, there was a slight rise in the infestation rates as seen in faecal analysis results on days 59 and 73.

Table 5.3: Before and during treatment means of trichostrongyle-type egg load

Faecal collection days	0% *M. oleifera* (ecomectin)	10% *M. oleifera*	20% *M. oleifera*	30% *M. oleifera*
1 (before treatment)	2.75	3.00	2.75	2.75
16	1.50	0.50	0.00	0.25
30	1.00	0.75	1.25	1.25
44	0.00	0.00	0.00	0.00
59	1.75	2.00	1.50	2.00
73	2.25	1.75	1.50	2.25

The Chi-Square analysis using the Pearson Chi-Square and Likelihood Ratio test was carried out using *M. oleifera* inclusion levels over time in weeks (Table 5.4). The results showed that *M. oleifera* leaf supplement had a mean significant difference ($P < 0.05$) at all three levels of inclusion (10%, 20% and 30%). The Chi-Square test is a function of trichostrongyle-type eggs, *M. oleifera* leaf inclusion levels and time (weeks), which showed that as time passed, there was a mass reduction of trichostrongyle-type eggs in comparison with the quasi-control group that was dewormed with ecomectin, a conventional anthelmintic drug.

Table 5.4: Chi-Square tests of *M. oleifera* levels on trichostrongyle-type eggs over time (weeks)

Inclusion level (%)		Chi-Square Value	df	Asymptotic Significance (2-sided)
0 (Ecomectin)	Pearson Chi-Square	26.83[b]	20	0.140ns
	Likelihood Ratio	29.29	20	0.082ns
	N of Valid Cases	24		
10	Pearson Chi-Square	45.33[c]	20	0.001***
	Likelihood Ratio	45.41	20	0.001***
	N of Valid Cases	24		
20	Pearson Chi-Square	36.00[b]	20	0.015*
	Likelihood Ratio	41.04	20	0.004***
	N of Valid Cases	24		
30	Pearson Chi-Square	36.64[b]	20	0.013*
	Likelihood Ratio	38.31	20	0.008**
	N of Valid Cases	24		
Total	N of Valid Cases	96		

a. 24 cells (80.0%) have expected count less than 5. The minimum expected count is 1.00.
b. 30 cells (100.0%) have expected count less than 5. The minimum expected count is .17.
c. 30 cells (100.0%) have expected count less than 5. The minimum expected count is .33.
Note: ns = non-significant at 0.05; * = significant at 0.05; ** = highly significant at 0.01;
*** = extremely significant to ≤ 0.001 alpha level

The histogram (Figure 5.2) shows the frequency distribution of trichostrongyle-type eggs in the studied goats. It presents a positively skewed distribution of parasites in the research goats. That is, although the concentration of parasites is around 0 to ±1, some parasites were dispersedly found around +3 in a positive row of the histogram indicating an uneven distribution of parasites.

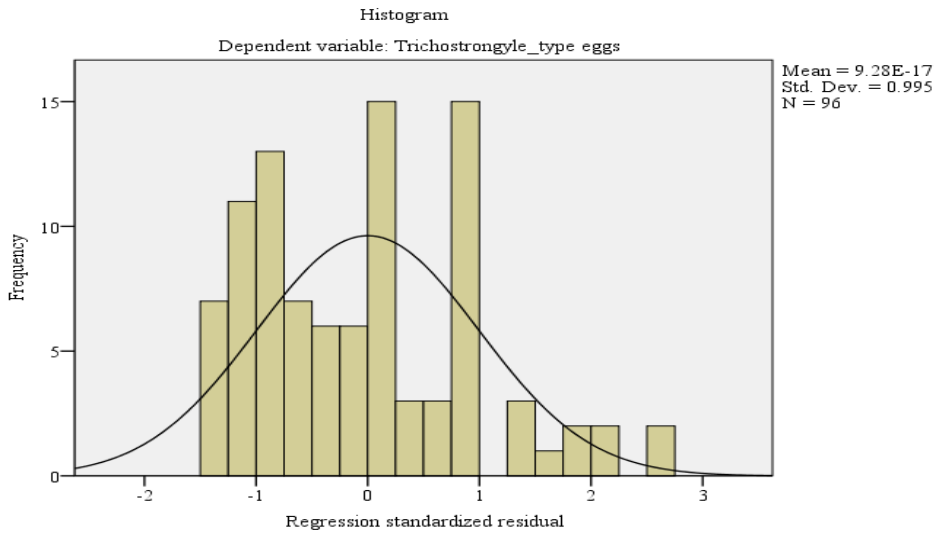

Figure 5.2: Distribution of trichostrongyle-type eggs in study goats

5.4.3 Infestation by Coccidia Species

Coccidia oocysts were the largest occurring parasite eggs found from the 96 faecal samples collected in the 74-day study period. The result shows that out of the 96 faecal samples collected, 27(28.10%) had zero coccidia oocysts, 30(31.30%) had 1+, 18(18.80%) had 2+, 12(12.50%) had 3+, and 9(9.40%) had 4+ infestation levels, respectively. Coccidia, just as trichostrongyles-type eggs, constitute major problems on this farm and need to be controlled continuously. Levels one plus (1+) and two plus (2+) were the largest infestation rates of coccidia oocysts, although on the overall, infestation ranged from very low to very heavy infestation rates (Figure 5.3). The very high and heavy infestation rates were observed at the initial stages of this research. Coccidiosis is a disease of intensification due to the build-up of sporulated oocysts in accumulated faeces, facilitating ingestion of large infective doses. A further factor is immunosuppression of the host, due to stress (Junker *et al*., 2015). Despite the high GIPs intensity, goats were in good body conditions, as *M. oleifera* leaf supplement built up

their immune systems. The fact that coccidia and trichostrongylid worms were the most common GIPs in this study on goats is supported by the findings of Regassa *et al.* (2006), who stated that the most frequent combination of parasites in goats, sheep and cattle were trichostrongyle-type eggs and *Eimeria* species. Although there are two genera of the subclass coccidia (*Eimeria* and *Cryptosporidium*), *Cryptosporidium* species infest cattle, sheep and goats while *Eimeria* species affect mainly cattle (Hendrix and Sirois, 2007).

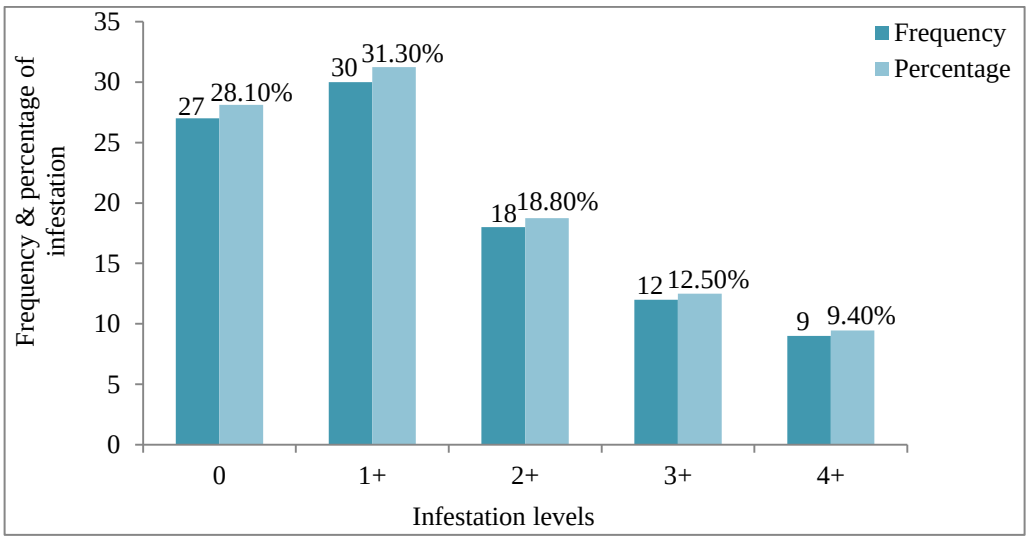

Figure 5.3: Infestation levels of coccidia oocysts in study goats

Table 5.5 presents the means of coccidia oocyst load before and during treatments with *M. oleifera*. The control group (0% *M. oleifera*) was not considered because ecomectin drug does not treat coccidia oocysts. The three groups (10%, 20% and 30%) given *M. oleifera*-leaf supplement as a natural anti-coccidia treatment were observed for the reduction of coccidia load. The treatment with *M. oleifera* and ecomectin was done as described earlier as seen in Table 5.3. On day one (before treatment), the mean faecal

sample analysis result showed a high to heavy infestation rates of coccidia oocysts among all the 16 goats (3+, 3.25+ and 3+); which is an indication that coccidia oocysts had the highest infestation rate among all the parasites found. With time, the infestation rate dropped considerably after *M. oleifera* leaf was given as a supplement, as the results have shown over time. Although there was reduction at all *M. oleifera* inclusion levels, 30% *M. oleifera* treatment level had greater efficacy in coccidia oocyst load-reduction rate than 10% and 20% in the research goats. This clearly revealed that *M. oleifera* leaf as a medicinal plant has higher efficacy against coccidia oocysts and could be very useful as a treatment against coccidiosis in goats.

Table 5.5: Before and during treatment means of coccidia oocyst load

Faecal collection days	10% *M. oleifera*	20% *M. oleifera*	30% *M. oleifera*
1 (before treatment)	3.00	3.25	3.00
16	1.25	0.75	0.75
30	1.00	1.75	2.25
44	0.75	1.50	1.75
59	2.00	0.75	0.75
73	1.00	1.00	0.75

Chi-Square test analysis of coccidia oocyst infestation rates in interaction with *M. oleifera* leaf inclusion levels over time in weeks indicated that *M. oleifera* had significant differences ($P < 0.05$) in reducing coccidia oocysts at all levels over time (Table 5.6). The Chi-Square test is a function of coccidia oocysts, *M. oleifera* leaf inclusion levels and time in weeks. This means that using *M. oleifera* leaf meal inclusion as an anti-coccidia supplement was able to reduce the load of coccidia oocysts at all three inclusion levels (10%, 20% and 30%). It is important to note that ecomectin drugs do not retreat coccidia oocysts; therefore, comparison was only done among the three

moringa treatment levels. There was a great reduction in parasite loads as weeks progressed throughout the duration of the study.

Table 5.6: Chi-Square Tests of *M. oleifera* levels on coccidia oocysts over time (weeks)

Level of inclusion (%)		Value	df	Asymptotic Significance (2-sided)
10	Pearson Chi-Square	39.00[c]	25	0.037*
	Likelihood Ratio	39.86	25	0.030*
20	Pearson Chi-Square	34.76[b]	20	0.021*
	Likelihood Ratio	36.44	20	0.014*
30	Pearson Chi-Square	32.49[b]	20	0.038*
	Likelihood Ratio	36.44	20	0.014*
Total	N of Valid Cases	96		

a. 30 cells (83.3%) have expected count less than 5. The minimum expected count is .17.
b. 30 cells (100.0%) have expected count less than 5. The minimum expected count is .33.
c. 36 cells (100.0%) have expected count less than 5. The minimum expected count is .17.
Note: * = significant at 0.05; *** = extremely significant to ≤ 0.05 alpha level; n = 24

Table 5.7 presents a linear regression of coccidia oocysts as dependent variable and *M. oleifera* leaf supplement inclusions as independent variables. *Moringa oleifera* had no significant mean difference ($P < 0.05$) at all inclusion levels. Although *M. oleifera* leaf-inclusion levels were non-significant statistically on coccidia oocysts, 150 g (10%) and 300 g (20%) inclusion levels had equal efficacy with p-values of 0.052 and 0.052, respectively, but had a decline at 450 g (30%) with a p-value of 0.069. This is an indication that *M. oleifera* leaf supplement inclusion levels at 150 g and 300 g may serve as a natural anthelmintic substance for Boer goats holding all other parameters constant. However, a marginal change by one per cent increase led to decline in parasite load reduction.

Table 5.7: Regression analysis of *M. oleifera* on coccidia oocysts

	Standardized Coefficients		
M. oleifera inclusion level, g (%)	Beta	t	P-value
150 g (10)	-0.22	-1.97	0.052ns
300 g (20)	-0.22	-1.97	0.052ns
450 g (30)	-0.20	-1.84	0.069ns

R square = 0.067; F – statistic = 2.196 and n = 96; ns = significant at 0.05; ***= extremely significant to ≤ 0.001 alpha level

Figure 5.4 is a histogram that shows the frequency distribution of coccidia oocysts in the 16 goats. Coccidia oocysts being the largest infestation on this farm, the histogram shows a normal distribution of coccidia oocysts infestation among the study animals. This means that they evenly occurred in almost all the goats tested. Therefore, the hypothesis (H_{04}) that states that *M. oleifera* had no significant effect on the reduction of trichostrongyle-type eggs and coccidia oocysts parasite loads over time is rejected based on the results presented in Tables 5.4 and 5.6.

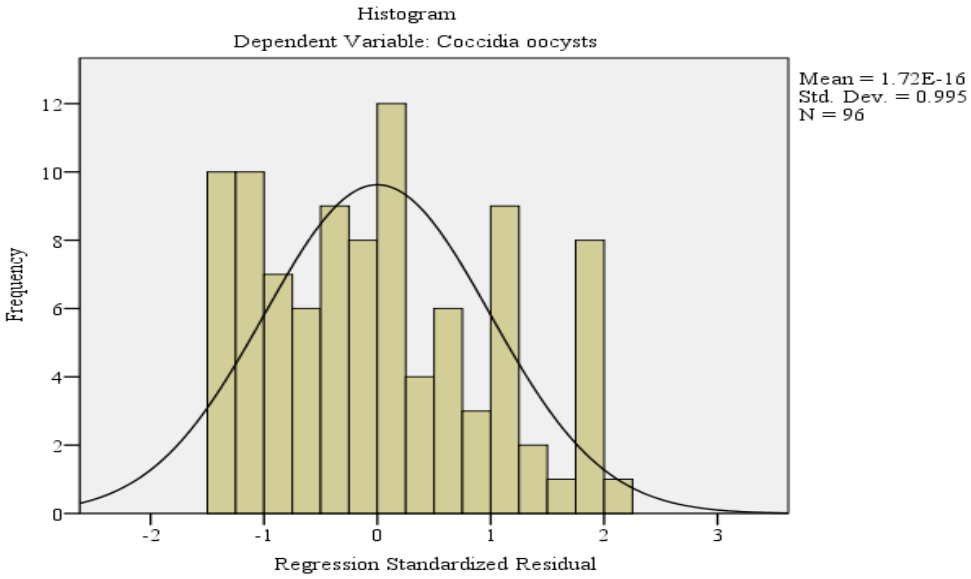

Figure 5.4: Distribution of coccidia oocysts in study goats

5.4.4 Infestation by *Trichuris* Species

Figure 4.5 indicates the frequencies and percentages of each infestation level of *Trichuris* species for the entire research period. Out of 96 faecal samples collected, 80 (83.30%) faecal samples had zero infestation rate, 5 (5.20%) had 1+, 2+ and 3+ with the exception of 1(1%) that had 4+ infestation levels. Therefore, *Trichuris* species infestation rates range from very low to very high but in a very small number of goats at Neudamm Experimental Farm compared to trichostrongylid species and coccidia oocysts.

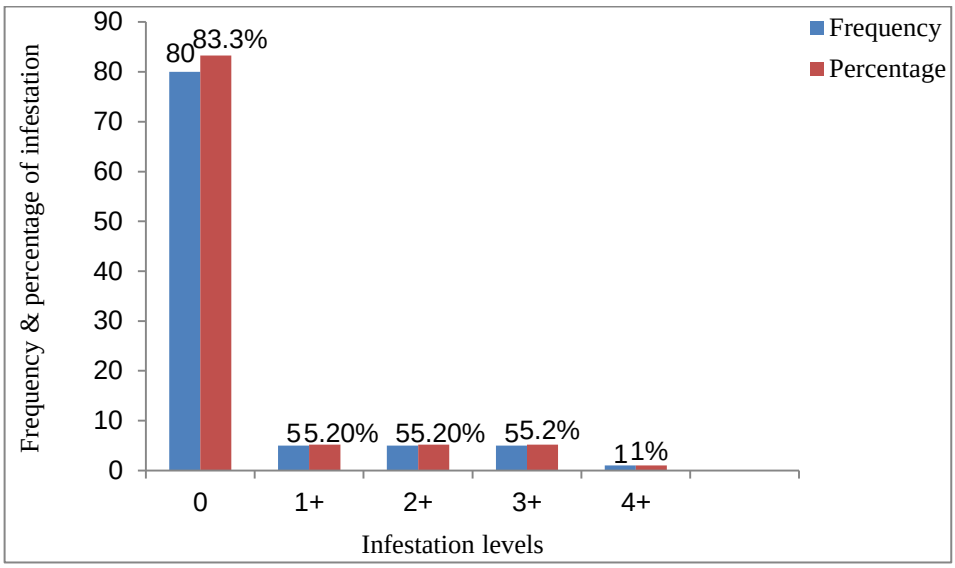

Figure 5.5: Infestation of study goats by *Trichuris* species

Table 5.8 presents the means of *Trichuris* species load before and during treatments with *M. oleifera* and ecomectin. As mentioned in Tables 5.2 and 5.3 for other species of GIPs, *Trichuris* species had very low infestation among a few goats (0.00+, 0.75+, 0.75+, and 1.75+). This means that *Trichuris* species was not a major parasite problem of goats on the Neudamm Experimental Farm during this study period. Although they

were not among the major helminthic problems on the farm, the 5% infestation rate was completely minimized after ecomectin was given to the control group and *M. oleifera* leaf was supplemented to the three experimental groups. On scale, *M. oleifera* leaf supplement and ecomectin treatments had equal efficacies on *Trichuris* species load reduction rate in the studied goats. This is an indication that *M. oleifera* leaf would serve as an ethno-medicinal treatment against *Trichuris* species as well as ecomectin, the conventional treatment.

Table 5.8: Before and during treatment means of *Trichuris* species load

Faecal collection days	0% *M. oleifera* (ecomectin)	10% *M. oleifera*	20% *M. oleifera*	30% *M. oleifera*
1(before treatment)	1.75	0.75	0.00	0.75
16	0.00	0.25	0.25	0.75
30	1.50	1.25	0.00	1.00
44	0.50	0.00	0.50	0.00
59	0.00	0.00	0.00	0.00
73	0.00	0.00	0.00	0.00

Table 5.9 presents a Pearson Chi-Square Test in which the Likelihood Ratio of *M. oleifera* leaf inclusion levels and time had no significant differences ($P > 0.05$) in *Trichuris* species. However, the infestation rate at the beginning of the research was moderate, but as time passed (weeks 8 and 10), *Trichuris* species eggs were totally absent in all faecal samples. Although *Trichuris* species occurred very moderately during the entire research, the *M. oleifera* leaf-supplemented diet led to a load reduction of this parasite to zero. This Chi-Square test triangulates the result obtained from the regression analysis (Table 5.10) very well. Though, the infestation rate was very low at the beginning of the research, it was completely reduced to an undetectable level as time

passed. This further shows the efficacy of *M. oleifera* as an ethno-veterinary-medicinal treatment for GIPs in goats.

Table 5.9: Chi-Square Test of *M. oleifera* levels on *Trichuris* species over time (weeks)

M. oleifera inclusion level (%)		Value	df	Asymptotic Significance (2-sided)
0 (ecomectin)	Pearson Chi-Square	20.67[b]	20	0.417ns
	Likelihood Ratio	19.04	20	0.519ns
10	Pearson Chi-Square	21.16[c]	15	0.132ns
	Likelihood Ratio	17.80	15	0.273ns
20	Pearson Chi-Square	10.36[d]	10	0.409ns
	Likelihood Ratio	7.54	10	0.673ns
30	Pearson Chi-Square	10.00[d]	10	0.440ns
	Likelihood Ratio	9.09	10	0.524ns
Total	N of Valid Cases	96		

a. 24 cells (80.0%) have expected count less than 5. The minimum expected count is .17.
b. 30 cells (100.0%) have expected count less than 5. The minimum expected count is .17.
c. 24 cells (100.0%) have expected count less than 5. The minimum expected count is .17.
d. 18 cells (100.0%) have expected count less than 5. The minimum expected count is .17.
Note: ns = non-significant at 0.05 alpha level; n = 24

Table 5.10 presents the results of a regression analysis of *Trichuris* species and *M. oleifera* inclusion levels in which *Trichuris* species was a dependent variable while *M. oleifera* was an independent variable. The result indicates that *Trichuris* species had no significant difference ($P > 0.05$) at all *M. oleifera* leaf inclusion levels (10%, 20% and 30%), which proves the very small number of goats infested on this farm. The quasi-control group which was treated with ecomectin and to which no *M. oleifera* leaves were supplemented (0% inclusion level) was highly significantly different ($P < 0.05$) in helminth load reduction. This might be attributed to a very moderate infestation rate by *Trichuris* species among experimental animals, making it difficult to notice the effect of *M. oleifera* on parasite load reduction. Similarly, a Chi-Square test (Table 5.9) with *Trichuris* species, *M. oleifera* and weeks result showed no significant difference (P >

0.05) statistically. This might be attributed to the low prevalence rate of *Trichuris* species (see Table 5.2) among experimental animals on this farm.

Table 5.10: Regression analysis of *M. oleifera* levels on *Trichuris* species in study goats

	Standardized Coefficients		
M. oleifera Inclusion level g (%)	Beta	t	P-value
0 (ecomectin)	0.521	3.59	0.001***
150 (10)	-0.110	-0.97	0.336ns
300 (20)	-0.170	-1.50	0.138ns
450 (30)	-0.095	-0.84	0.406ns

R square = 0.027; F – statistic = 0.840 and n = 96; ns = non-significant at 0.05; *** = highly significant to ≤ 0.05 alpha level

5.4.5 Infestation by *Moniezia* Species

Out of 96 faecal samples collected, 90 (93.80%) faecal samples had zero eggs of *Moniezia* species (0% infestation rate). This means that only 6.20% of faecal samples were infected in the following sequence: 4 (4.20%) had 2+, 1 (1%) had 3+ and 1 (1%) had 4+ (see figure 4.6). This is a clear indication of a very low prevalence rate of 37.50% of the *Moniezia* species in 6 goats (Figure 5.1), possibly due to the mature age of goats used in this study. Indeed, it has been reported that young goats are particularly susceptible to tapeworm infestation in which the mature worms are found in the small intestines. However, animals only get sick when infestation is severe, especially if they are malnourished or already have a bacterial infection (Jansen and Burg, 2004). Furthermore, it was found that the most common tapeworm of sheep is *Moniezia expansa*. This parasite is found in the intestine and grows to around one meter long. Despite their size, tapeworms are generally regarded as relatively harmless.

The other tapeworms of major importance in small ruminants are hydatid parasites such as *Echinococcus granulosis* and *Taenia ovis* (Southwell *et al*., 2008). *Moniezia* species are tapeworms (cestodes) found in all intestines of cattle, sheep and goats. The common two species of *Moniezia* are *Moniezia benedeni* in cattle and *Moniezia expansa* in cattle, sheep and goats. The eggs of *M. expansa* appear triangular and measure 56 to 67µm in diameter, while those of *M. benedeni* are square and approximately 75 µm in diameter with a prepatent period of approximately 40 days (Hendrix and Sirois, 2007). There is not much literature on the infestation of goats by *Moniezia* species in comparison to other GIPs.

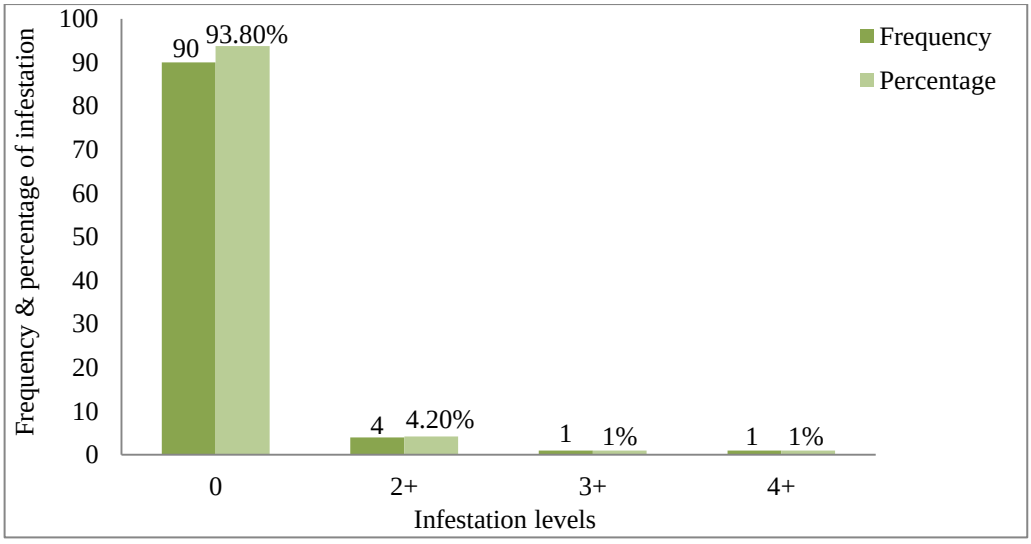

Figure 5.6: Infestation levels of *Moniezia* species eggs in study goats

Table 5.11 presents the means of *Moniezia* species load before and during treatments with *M. oleifera*. At the commencement of this study, only one goat was infected with *Moniezia* species among the 16 goats (0.00+, 0.00+, and 0.75+). *Moniezia* species, like *Trichuris* species, were not a major parasite problem among goats on the Neudamm

Experimental Farm. They occurred sparsely (4.2%) from the beginning of the research and were completely minimized at days 44, 59 and 73 of the experiment based on the faecal analytical results for *M. oleifera* leaf-supplemented goats. Possibly, the complete minimization of *Moniezia* species in the middle part of the research might be due to the efficacy of *M. oleifera* leaf-supplemented treatment. Just as coccidia oocysts, ecomectin drug does not treat *Moniezia* parasites.

Table 5.11: Before and during treatment means of *Moniezia* species load

Faecal collection days	10% *M. oleifera*	20% *M. oleifera*	30% *M. oleifera*
1 (before treatment)	0.75	0.00	0.00
16	0.00	0.00	1.00
30	0.00	0.50	0.00
44	0.00	0.00	0.00
59	0.00	0.00	0.00
73	0.00	0.00	0.00

A Chi-Square test (Table 5.12) and linear regression analysis (Table 5.13) results show that *M. oleifera* inclusion levels (10%, 20% and 30%) over time in weeks had no significant effect ($P > 0.05$) at all on *Moniezia* species. Fewer goats (6 samples out of 96) were infested with *Moniezia* species as compared to trichostrongyle-type eggs and coccidia oocysts. This very low presence of *Moniezia* eggs in faeces might be attributed to the age-associated resistance of goats used in this study to *Moniezia* species (15 months to 4 years); that is, older goats are more resistant than younger ones. A research conducted with nine Angora goats in South Africa found that eight goats between the ages of 3 and 5 months were infected with *M. expansa,* and one was infected with other cestode species. It was observed that the virtual absence of cestodes in kids older than 6 months indicates an age resistance to infection in Angora goats (Horak *et al.*, 2001).

Another study conducted in southern Nigeria concurred that *Moniezia* infection in goats and sheep was common in young animals between ages zero to four and four to eight months. However, after eight months, the presence of *Moniezia* eggs in faeces diminished drastically (Fagbemi and Dipeolu, 2011). Although more research needs to be done, these results show that *M. oleifera* leaf supplement could help reduce the number of *Moniezia* eggs over time. Overall, this means that the *M. oleifera* leaf-supplemented diet had some effect on the *Moniezia* parasites.

Table 5.12: Chi-Square Tests of *M. oleifera* levels on *Moniezia* species over time (weeks)

Level of inclusion (%)		Value	df	Asymptotic Significance (2-sided)
10	Pearson Chi-Square	5.22[c]	5	0.390ns
	Likelihood Ratio	3.82	5	0.576ns
20	Pearson Chi-Square	5.22[c]	5	0.390ns
	Likelihood Ratio	3.82	5	0.576ns
30	Pearson Chi-Square	5.22[c]	5	0.390ns
	Likelihood Ratio	3.82	5	0.576ns
Total	N of Valid Cases	96		

a. 18 cells (75.0%) have expected count less than 5. The minimum expected count is .17.
b. 12 cells (100.0%) have expected count less than 5. The minimum expected count is .50.
c. 12 cells (100.0%) have expected count less than 5. The minimum expected count is .17.
Note: ns = non-significant at 0.05 alpha level; n = 24

Table 5.13: Regression analysis of *M. oleifera* on *Moniezia* species eggs

	Standardized Coefficients		
Level of inclusion, g (%)	Beta	t	P-value
M. oleifera 150 (10)	-0.17	-1.51	0.136ns
M. oleifera 300 (20)	-0.11	-0.94	0.348ns
M. oleifera 450 (30)	-0.07	-0.60	0.553ns

R square = 0.03; F – statistic = 0.82 and n = 96; ns = non-significant at 0.05; * = significant at 0.05 alpha level

5.4.6 Infestation by *Strongyloides papillosus*

No eggs of *Strongyloides papillosus* (0% infestation) were found in 88 (92%) of faecal samples, while 6 (6%) had 1+, 1(1%) had 2+ and 1(1%) had 3+ infestation rates, respectively. This means that only 8 (8.30%) of the 96 faecal samples collected were infested by *Strongyloides papillosus* (Figure 5.7). Similar to *Trichuris* species and *Moniezia* species, *Strongyloides papillosus* had low prevalence rate (43.70%), with a moderate infestation rate. Kumba *et al*. (2003) detected *Strongyloides* in communal goats in all seasons in eastern Namibia, though to a lesser extent compared to the present study. Love and Hutchinson (2003) pointed out that *Strongyloides papillosus* eggs are often seen in faecal counts in sheep, but this parasite is of doubtful significance.

Their importance if any is overshadowed by parasites such as *Ostertagia* and *Trichostrongylus* species. *Strongyloides papillosus* can infect animals through ingestion, skin penetration in wet conditions, and through milk for lactating ewes. Such infects are common during the wet season. Hendrix and Sirois (2007) pointed out that *Strongyloides papillosus* is often referred to as the "intestinal threadworm". These nematodes are unique in that only a parthenogenetic female (female that lays eggs without copulating with a male) is parasitic in the host.

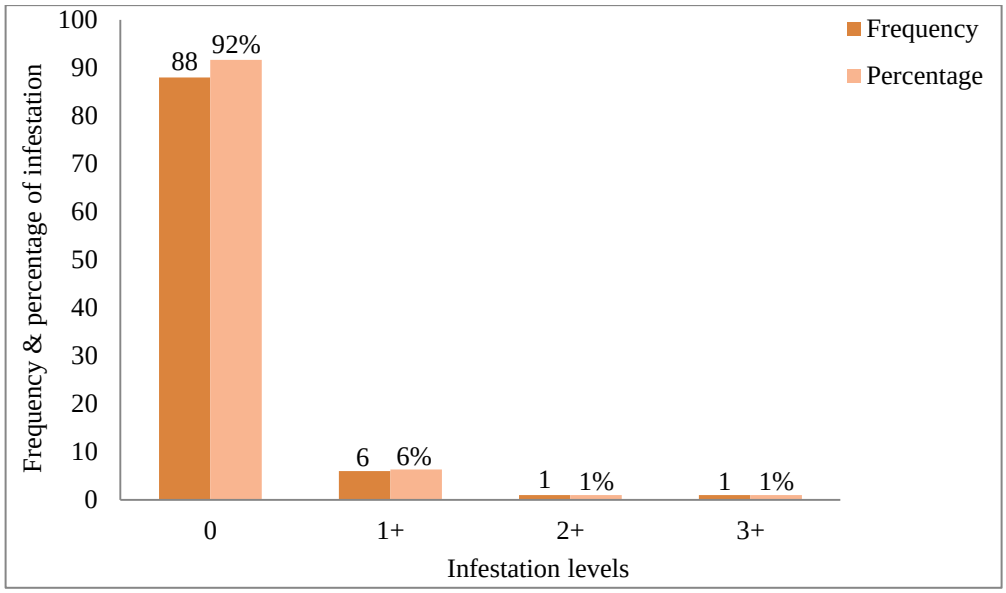

Figure 5.7: Infestation levels of *Strongyloides papillosus* in study goats

Table 5.14 presents the means of *Strongyloides papillosus* load infestation before and during treatments with *M. oleifera* and ecomectin. The research goats had very low infestation rates of *Strongyloides papillosus* (0.00+, 0.00+, 0.00+, and 0.75+) before treatment and had only an 8.2% infestation rate (see Figure 7) throughout the research period. Infestations were rare from the beginning of the research and was completely absent at days 59 and 73 as *M. oleifera* leaf supplemented to the three experimental groups and ecomectin given to the quasi-control group. The elimination of *Strongyloides papillosus* might be due to the low infestation rate at the start, coupled with the efficacy of the *M. oleifera* leaf-supplemented diet, as well as the ecomectin treatments.

Table 5.14: Before and during treatment means of *Strongyloides papillosus* load

Faecal collection days	0% *M. oleifera* (ecomectin)	10% *M. oleifera*	20% *M. oleifera*	30% *M. oleifera*
1 (before treatment)	0.00	0.75	0.00	0.00
16	0.50	0.00	0.00	0.25
30	0.25	0.00	0.50	0.00
44	0.50	0.50	0.50	1.00
59	0.00	0.00	0.00	0.00
73	0.00	0.00	0.00	0.00

The Chi-Square test (Table 5.15) and linear regression analysis (Table 5.16) of the effect of a *M. oleifera* leaf-supplemented diet on *Strongyloides papillosus* indicated that *M. oleifera* had no significant difference ($P > 0.05$) on the *Strongyloides papillosus* infestation rate over time. This might be attributed to the low prevalence rate (Figure 5.1) among the 16 goats used for this research at the Neudamm Experimental Farm. A research study conducted in Namibia reported no severe cases of *Strongyloides papillosus* among goats (Kumba *et al*., 2003) just as in the present study. Therefore, the hypothesis (H_{04}) that states that *M. oleifera* inclusion has no significant effect on the reduction of *Trichuris* species, *Moniezia* species and *Strongyloides papillosus* parasite loads over time failed to be rejected.

Table 5.15: Chi-Square Test of *M. oleifera* on *Strongyloides papillosus* over time (weeks)

Level of inclusion (%)		Value	df	Asymptotic Significance (2-sided)
0	Pearson Chi-Square	5.217	5	0.390ns
	Likelihood Ratio	3.815	5	0.576ns
10	Pearson Chi-Square	10.909	5	0.053ns
	Likelihood Ratio	8.223	5	0.144ns
20	Pearson Chi-Square	10.909	10	0.365ns
	Likelihood Ratio	8.223	10	0.607ns
30	Pearson Chi-Square	10.000	10	0.440ns
	Likelihood Ratio	9.088	10	0.524ns
Total	N of Valid Cases	96		

a. 18 cells (75.0%) have expected count less than 5. The minimum expected count is .17.
b. 12 cells (100.0%) have expected count less than 5. The minimum expected count is .17.
c. 12 cells (100.0%) have expected count less than 5. The minimum expected count is .33.
d. 18 cells (100.0%) have expected count less than 5. The minimum expected count is .17
Note: ns = non-significant at 0.05 alpha level; n = 24

Table 5.16: Regression analysis of *M. oleifera* on *Strongyloides papillosus*

	Standardized Coefficients		
Level of Inclusion, g (%)	Beta	t	P-value
M. oleifera 0 (ecomectin)	0.03	0.43	0.667ns
M. oleifera 150 (10)	0.07	0.61	0.545ns
M. oleifera 300 (20)	0.12	1.07	0.288ns
M. oleifera 450 (30)	0.20	1.74	0.085ns

R square = 0.04; F – statistic = 1.10 and n = 96; ns = non-significant at 0.05 alpha level

To a great extent, as deduced from the results, this study was able to address the research question posed at the beginning of the study. *Moringa oleifera* leaf supplement had a significant effect on infestation reduction ($P < 0.05$) at 300 g (20%) and 450 g (30%). The efficacy of *M. oleifera* leaf supplement as an anthelmintic substance is apparent at 450 g (30%) inclusion level, at which the greatest reduction was observed on trichostrongyle-type eggs. Furthermore, the analysis revealed that *M. oleifera* had a significant mean difference ($P < 0.05$) in the reduction of coccidia oocyst infestation. Interestingly for coccidia oocysts, *M. oleifera* leaf-supplement inclusion had an equal efficacy at 150 g (10%) and 300 g (20%), respectively, with a decline at 450 g (30%).

This suggests that *M. oleifera* leaf supplement inclusion levels at 150 g or 300 g may serve as an anthelmintic drug for Boer goats, holding all things constant. Economically speaking, an inclusion rate of 150 g may suffice for reduction of coccidia oocyst infestation. Thus, from this study, *M. oleifera* can serve as an ethno-veterinary medicinal plant for the treatment of GIPs in goats. Coincidentally, *M. oleifera* has been used by many researchers as an animal feed supplement (Sanchez et al., 2005; Soliva, Kreuzer *et al*., 2005; Adegun, Aye, & Dairo, 2011); therefore, with the outcome of this study, farmers may now use *M. oleifera* not only as a feed supplement but also as an anthelmintic treatment for various gastrointestinal infestations. Henceforth, the hypothesis (H_{04}) that *M. oleifera* does not have anthelmintic properties was rejected because *M. oleifera* contains anthelmintic properties as it reduced GIPs in goats.

5.5 Conclusion

This study revealed that *M. oleifera* has the ability to reduce GIP loads in Boer goats to a large extent, in comparison to the ecomectin drug. *Moringa oleifera* leaf supplement significantly reduced trichostrongyle-type eggs, coccidia oocyst, *Trichuris* species, *Moniezia* species eggs and, to a lesser extent, *Strongyloides* parasite species in goats. Goats like *M. oleifera* leaves, so feeding it to these animals would cause no difficulty. Although *M. oleifera* is an exotic plant in Namibia and mainly unfamiliar to animals, its leaves were easily accepted by the goats, which adapted to it as feed very easily. Feeding about 300 g (20%) and 450 g (30%) to goats would serve as an anthelmintic drug. Since *M. oleifera* is in high demand for both human and animal consumption, it needs to be used carefully just for its purpose. Finally, *M. oleifera* would serve as a good natural remedy and supplement for goats in the fight against gastrointestinal helminths,

especially since they have developed resistance to many commercial anthelmintics over the years. A further research is needed for investigating if GIPs in goats will develop resistance against *M. oleifera* leaf-ethno-anthelmintic supplement of over time.

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Chapter 6

Indirect Effect of a *Moringa oleifera* Leaf-Supplemented Diet on Growth Rates of Pre-Weaning Boer Goat Kids

6.1 Abstract

The objective of this study was to evaluate the indirect effects of feeding a *Moringa oleifera* (*M. oleifera*) leaf-supplemented diet on growth rates in pre-weaning Boer goat kids. Because Namibia is semi-arid and the driest country in Africa south of the Sahel, lactating does in Namibia are challenged with acquiring the required amount of forage in the rangelands to meet milk production and nutritional needs for their kids. This scarcity of forage, along with the low nutritional quality of the available grasses and/or browses, creates the need to supplement lactating does with nutritionally-rich fodders.

A completely randomized design (CRD) was used for this experiment in which a total of 16 lactating does with their 20 kids (four does had twins) were randomly selected from 51 lactating goats. The experiment used four *M. oleifera* leaf supplemented treatment levels (0%, 10%, 20% and 30%) and randomly assigned four goats to each treatment level to assess if different levels of *M. oleifera* have an effect on growth parameters of Boer goat's kids. The results revealed that there were significant differences ($P < 0.05$) in heart girth, body length and weight of kids, which were measured as growth rate parameters along with body condition scores (BCS). Although Boer goats are known for their fast growth under favourable conditions, feed supplementation of pregnant and lactating does could be advantageous for maximum milk production to support their kids' healthy early growth and development, especially under unfavourable conditions

such as during winter and drought. Therefore, in a semi-arid and persistently drought-affected country like Namibia, *M. oleifera* would bring a possible solution for animal supplementation during adverse climatic conditions, since it grows very fast and produces a lot of leaf-dry matter per hectare; thus, alleviating the farmers' stress of purchasing feed-supplements during the pregnancy and lactation period.

Finally, the hypothesis (H_{05}) that feeding *M. oleifera* as a supplement to lactating goats does not affect the growth rate parameters of their pre-weaning kids was rejected because it does have a significant effect on all growth parameters of pre-weaning kids.

Keywords: Boer goat kids, growth rates, lactating does, *Moringa oleifera,* supplemented diet

6.2 Introduction

Goats are very important in areas where feed resources are limited because they can consume a wide variety of plant species and parts and have a great ability to select high quality diets in these circumstances (Huston & Hart, 2002; Mpofu, 2004). Namibia has about 2 million goats nationwide, most of which are found in communal areas and they play an important economic role for sustainability of subsistence farming. Officially, 200,000 to 250,000 goats are marketed annually, of which 95% is exported to South Africa. Boer goat breed is one of the breeds found in Namibia and is considered to be most resilient small stock breed, with a great capacity for adaptation (BGBSN, 2008). Despite their resilience, they are equally affected by the scarcity of forage and the low nutritional quality of the available grasses in winter and in drought. Therefore, drought and cold-resistant fodder plants like moringa would serve as a best option to solve this

problem as suggested by Huque and Sarker (2014). It is however of paramount importance to avail easily adaptable nutrient-rich plant species for maximum production and growth of goats. One of such plants is the *Moringa oleifera* (*M. oleifera*) tree. *Moringa oleifera* leaves are readily eaten by cattle, sheep, goats, pigs and rabbits (United Caribbean Trust, 2013).

A feeding trial conducted with West African dwarf goats in Nigeria showed that *M. oleifera* leaf-supplementation resulted in an average weight gain of 20.83 gram/animal/day (Asaolu *et al.*, 2012). A similar feeding trial revealed that supplementation of beef and dairy cows' diet with 40-50% of *M. oleifera* leaves led to an increase in milk yields for dairy cows and daily weight gains for beef cattle by 30%. Birth weight increased by 3-5 kg (Prince, 2007). *Moringa oleifera* is well known for its enormous biomass production and it promises to be the plant of the future in ruminant animal supplementation strategy. Under high density cultivation, it yielded biomass in excess of 15 tonnes dry matter/hectare (DM/ha) in a 60-day growing cycle under the International Trypanotolerance Centre conditions in Banjul (Akinbamijo *et al*., n.d.).

Research shows that every 100 grams of *M. oleifera* contains: 6.7 g of protein in leaves, 2.5 g of protein in pods, 27.1 g of protein in leaf powder, 259 mg of mineral potassium (K) in leaves, 259 mg K in pods, 1,324 mg of K in leaf powder and 6.8 mg of vitamin A, β-carotene in leaves, 0.11 mg in pods and 16.3 mg in leaf powder (Price, 2007). In a study by Sánchez-Machado *et al*. (2009), the chemical composition of moringa dry leaves ranged from 19.34% to 22.42% for protein and 30.97% to 46.78% for dietary fiber. They concluded that the leaves are a protein source with an adequate profile of

amino acids. The crude protein content of extracted and unextracted moringa leaves was 43.5 and 25.1%, respectively, suggesting that both the extracted and unextracted leaves are good sources of protein for livestock (Foidl *et al.,* 2011). *Moringa oleifera* has proved to be a valuable supplement for animals in other countries (Mendieta *et al*., 2007). This means that feeding it to goats at the appropriate period of nutritional needs is necessary, especially during pregnancy for proper foetus development, and during lactation for kids' development. *Moringa oleifera* leaves have a high potential as a protein source supplement for ruminants, and their feeding value is similar to that of the widely used soybean meal and rapeseed meal (Soliva *et al*., 2005).

In Namibia, *M. oleifera* has not found much use as human food or feed for ruminants, in comparison with other regions such as Asia and Western Africa (Radovich, 2007; Adegun, Aye, & Dairo, 2011). In addition, the time of kidding determines the period of the highest nutritional demand, as late pregnancy and early lactation are critical times for the does and kids (Coffey, 2006). Hence, the need for nutritional supplementation of does during this critical period, as well as during winter and drought when rangelands are less productive and provide lower nutritional value. Therefore, this study was aimed at evaluating the use of *M. oleifera* as a nutritional supplement for lactating does to meet their milk production requirement for proper development of their kids, as suggested by Soliva *et al*. (2005).

6.3 Materials and Methods

6.3.1 Study Area

This study was conducted from October 2015 to January 2016 at the Neudamm Campus of the University of Namibia, about 30 km east of Windhoek, with an area of 10,187 hectares. Neudamm Campus is located at 22° 30′ 07″ S and at 17° 22′ 14″ E, and at an altitude of 1762 meter above sea level. The farm's temperature ranges between a minimum of -7°C and a maximum of 44°C (University of Namibia, 2011), and the area received an annual average rainfall of 247.8 mm in 2015/2016 summer season (P. Beukes, 2017).

The vegetation of Neudamm Experimental Farm is classified as highland savannah (semi-arid savannah) and characterized by grasses, shrubs and trees that are well spread over the farm. An annual grass like *Melinis repens* and perennial grasses like *Schmidtia pappophoporoides*, *Anthephora pubescens* and *Brachiaria nigropedata* are well represented on the farm. Different types of trees like *Acacia brownii*, *Acacia erioloba*, *Acacia mellifera* as well as shrubs like *Grevia flava*, are also found on this farm. The estimated carrying capacity is about 12 hectares per large stock unit or 45 kg per hectare biomass (A. Beukes, 2017; Kahumba, 2010; Kapu, 2012).

6.3.2 Study Design

A completely randomized design (CRD) consisting of a one-way treatment structure was used in this trial to determine the mean significant differences at different levels of inclusion of *M. oleifera* leaf supplement. The *M. oleifera* leaves were harvested from an

organic *M. oleifera* farm in Rundu (about 714 km from Windhoek), Namibia, at 30-day intervals and shade-dried over plastic sheets within two weeks. Four treatment levels of *M. oleifera* inclusions, with four replicates in each (0%, 10%, 20%, and 30%) in isocaloric and isonitrogenous diets were used. Sixteen (16) lactating Boer goats with age range of 12-50 months old (29.375 ± 11.146 months) and body weight range of 27.6-50.5 kg (37.056 ± 6.619 kg) were used along with their 20 kids in this study. Taking into consideration an average weight of 37 kg per goat, the inclusion levels translated into 0% (0 g), 10% (150 g), 20% (300 g) and 30% (450 g) of *M. oleifera* dry leaves per day as described by Gebregiorgis, Negesse, & Nurfeta (2011). The basic background information about the study goats is presented in Table 6.1.

Table 6.1: Basic information about study goats

Doe ID	Doe's age in months	Date of kidding	Kid's birth type	Kid's sex	Research start date	*M. oleifera* inclusion levels
3634	22	05/10/2015	Single	Male	15/ 10/ 2015	0%
3482	38	03/09/2015	Twins	Male & female	15/ 10/ 2015	0%
3644	20	09/10/2015	Single	Female	15/ 10/ 2015	0%
3631	12	09/10/2015	Single	Male	15/ 10/ 2015	0%
911	50	03/09/2015	Single	Male	15/ 10/ 2015	10%
3500	36	31/08/2015	Twins	Male & female	15/ 10/ 2015	10%
1420	50	09/10/2015	Single	Female	15/ 10/ 2015	10%
3581	24	13/10/2015	Single	Female	15/ 10/ 2015	10%
3573	25	05/10/2015	Single	Male	15/ 10/ 2015	20%
3480	38	31/08/2015	Twins	Male & male	15/ 10/ 2015	20%
3628	21	09/10/2015	Single	Male	15/ 10/ 2015	20%
3641	20	09/10/2015	Single	Female	15/ 10/ 2015	20%
3584	25	08/10/2015	Single	Male	15/ 10/ 2015	30%
3448	43	03/09/2015	Twins	Male & female	15/ 10/ 2015	30%
3629	21	09/10/2015	Single	Female	15/ 10/ 2015	30%
3576	25	09/10/2015	Single	Female	15/ 10/ 2015	30%

Dry lucerne (*Medicago sativa*) was used as a basal diet for all goats, supplemented with 300 g Ram-Lamb-Ewe Pellets® [Feedmaster (Pty) Ltd., Windhoek, Namibia] along with the mineral lick. At the Neudamm Experimental Farm, during winter or drought, lucerne

is being used as a sole feed to lactating goats and is supplemented with Ram-Lamb-Ewe pellets. The nutritional compositions of the feed and mineral lick block fed to the studied goats are given in Table 6.2.

Table 6.2: Nutrient compositions of feeds and lick block fed to the goats

Nutrients	*M. oleifera*	Lucerne	Pellets	Lick block
Moisture	6.25 g/100g	6.35 g/100g	120 (60 mg/kg)	120 g/kg
Ash	10.64 g/100g	6.75 g/100g	140 (50 mg/kg)	----
Fat	5.64 g/100g	1.02 g/100g	70 (1 mg/kg)	----
Crude protein	27.20 g/100g	20.35 g/100g	----	160 g/kg
Protein ex. NPN	----	----	----	100%
Crude Fiber	7.76 g/100g	23.45 g/100g	150 (1 mg/kg)	120 g/kg
Acid detergent fiber	8.91 g/100g	26.98 g/100g	----	----
Neutral detergent fiber	16.39 g/100g	39.19 g/100g	----	----
Metabolisable Energy	11 MJ/kg	9.50 MJ/kg	9.4 MJ/kg	----
Total Digestible Nutrient	67 g/100g	61 g/100g	----	----
Digestible energy	12 MJ/kg	11.30 MJ/kg	----	----
Calcium	1.76 g/100g	0.43 g/100g	12 (0.3 mg/kg)	75 g/kg
Phosphorus	0.32 g/100g	0.18 g/100g	----	50 g/kg
Sodium	0.13 g/100g	0.01 g/100g	----	----
Potassium	0.70 g/100g	0.65g/100g	----	----
Magnesium	0.17 g/100g	0.06 g/kg	220 mg/kg	----
Iron	182.97 mg/kg	104.20 mg/kg	0.05 mg/kg	----
Copper	12.38 g/100g	6.77 mg/kg	----	----
Manganese	0.001 mg/kg	32 mg/kg	0.03 mg/kg	----
Zinc	----	----	0.05 mg/kg	----
Cobalt	----	----	0.001 mg/kg	----
Iodine	----	----	0.001 mg/kg	----
Selenium	----	----	0.0003 mg/kg	----
Vitamin A (IU)	----	----	5,000 (3 mg/kg)	----

Moist = % Moisture (100 - Moisture) = % Dry Matter); CP = % Crude Protein; CF = % Crude Fibre; DF = % Acid Detergent Fibre; NDF = % Neutral Detergent Fibre; Fat = % Fat; Ash = % Ash (100 – A = Organic Matter); TDN = Total Digestible Nutrients; DE = Digestible Energy; and ME = Metabolisal Energy, NSC = Non-structural Carbohydrate. Ca = % calcium; Na = % Sodium; K = %Potassium; Mg = %Magnesium; P = % Phosphorous; Mn = Manganese (ppm); Cu = Copper (ppm); Fe = Iron (pp Zn = Zinc (ppm); Tannins = Tannic Acid. Results are presented 'as is'. Source for pellets and lick bloc data: Feedmaster Namibia

A control group (0% *M. oleifera*) was fed with only lucerne and pellets, while the three experimental groups were supplemented with *M. oleifera* leaves at three inclusion levels (10%, 20% and 30%). All goats were fed twice a day (08:00 and 15:00) for 74 days and clean water was available *ad libitum* in all cages. Sixteen lactating Boer goats were

randomly allocated to each treatment (4 per treatment) to assess the effect of a *M. oleifera* leaf-supplemented diet on growth rates of their pre-weaning kids. The goats were housed in individual wire mesh cages and introduced to the *M. oleifera* leaf-supplemented diet between two weeks and one month after birth. Both does and kids were weighed prior to the introduction of the *M. oleifera*-supplemented diet. An adjustment period of 14 days, as suggested by Sarwatt *et al*. (2002), was observed to get animals used to the new diet, after which a 60-day trial period commenced. Feed given and refusals were recorded daily for the determination of daily feed intake (Gebregiorgis *et al*., 2011; Pulina *et al*., 2013). Heart girth, body length and body weights of kids were measured and body condition scores (BCS) observed and recorded weekly throughout the 60-day trial period. For does, only body weights and BCS of were taken weekly. Table 6.3 displays the experimental layout of this study.

Table 6.3: Experimental layout of *M. oleifera* supplementation to lactating does

Treatments, *M. oleifera*: % (g)	0 (0)	10 (150)	20 (300)	30 (450)	Total
Replications	4 goats	4 goats	4 goats	4 goats	N = 16 goats

6.3.3 Experimental Animals

Lactating goats were purposefully targeted in the current study. Among these, 16 lactating Boer goats from a total population of 51 lactating goats at Neudamm Experimental Farm were randomly sampled for the present feeding trial since most nutritional deficiencies are common among lactating does and their kids (Coffey, 2006). The trial had four treatment levels with four goats in each treatment level as replicates. The does were enclosed in individual pens with their kids. All 16 pens were of equal size

(430 cm length x 13 cm width) with taps providing water *ad libitum* and trace mineral salt blocks throughout the research period, as discussed by Juhnke (2011).

Boer goats are more sensitive to external parasites than to internal parasites (Agra Professional Services, 2013). Therefore, at the beginning of this research, both does and kids were treated against ectoparasites (Gebregiorgis *et al*., 2011; Rumosa Gwaze *et al*., 2012) using COOPERS SUPADIP (500 mL) at a dilution ratio of 50 mL: 10 L of water. The COOPERS SUPADIP® [Cooper Veterinary Products (Pty) Ltd., Isando, South Africa] contains chlorfenvinphos 30% m/v. At Neudamm Experimental Farm, Ivermectin (1 mL: 50 kg) and Dectomax (1 mL : 50 kg) are used to treat both ectoparasites and endoparasites.

6.3.4 Data Collection Procedures

Lactating Boer goats with their kids and *M. oleifera* leaves were used as instruments for data collection. Collected data included weekly growth rates of kids and *M. oleifera* leaf supplemented rations as suggested by Abdulrazak *et al*. (2001) and Sanchez *et al*. (2005). Similarly, weekly BCS were assessed and recorded as described by Frost *et al*. (2008) for both does and kids. A weighing scale and tapeline were used to weigh and measure weekly growth rates (heart girth, body length and weight) of kids as demonstrated by Olatunji-Akioye and Adeyemo (2009). Lactating goats were fed *M. oleifera* leaf-supplemented rations twice a day by 08:00 and 15:00, as suggested by Yayneshet, Eik, and Moe (2008), using 4% body weight, which considered the wastes during feeding as deliberated by Coffey (2006). Daily rations were divided into two equal parts: one portion given by 08:00 and the other by 15:00, as described by

Gebregiorgis *et al*. (2011). During the feeding of *M. oleifera* leaf-supplemented rations, kids were separated from their mothers to prevent them from consuming them directly. The separation was done to observe the indirect effect of *M. oleifera* on the kids' growth parameters and BCS. *Moringa oleifera* leaf rations were then given to and consumed by the mothers within 10 to 20 minutes. Upon completion of the *M. oleifera* rations, the kids were re-united with their mothers and lucerne and pellets were given together. Kids were weighed and measured weekly to assess body weight gain, increase in body length and girth, as well as BCS.

6.3.5 Data Analysis

The linear regression model and general linear model (GLM) were used to analyse data to establish if the different diets significantly affected the kids' growth rates at the 5% alpha level of significance (Gebregiorgis *et al*., 2011; Olatunji-Akioye & Adeyemo, 2009). The body weight, length, heart girth and body condition scores of the kids served as dependent variables while the *M. oleifera* leaf supplement served as an explanatory (factor) variable. The Statistical Package for Social Sciences (SPSS® version 23) and Microsoft Office Excel® program were used for all data analyses.

6.4 Results and Discussion

The results obtained from this study include growth performance parameters (heart girths, body lengths, and weights, as well as BCS) of kids used in the study that suckled from does fed *M. oleifera*-supplemented rations, compared to a control group taken weekly for the 74-day period. Figures and tables were used to compare the growth parameters of kids, both descriptively and statistically. The results of the statistical

analyses reveal significant differences of growth parameters of kids whose mothers were fed with a *M. oleifera* leaf-supplemented diet compared to the control group (kids not indirectly fed *M. oleifera*).

6.4.1 Adjustment Period of Does and Kids' Birth Types and Sex

A 14-day adaptation/adjustment period was considered, as suggested by Sarwatt *et al*. (2002) and Yayneshet *et al*. (2008), during which the goats were gradually introduced to the *M. oleifera* leaf-supplement diet. During this period, it was observed that in less than a week, 15 out of the 16 (93.8%) goats liked *M. oleifera* leaves and consumed their entire rations. This confirms the view of Mpofu (2004), who noted that goats feed on a wide variety of feeds ranging from tree and shrub leaves to grasses. This dietary flexibility is a factor which accounts for the hardiness of goats and one which increases their ability to survive under difficult conditions. Although one of the goats could not adjust immediately, but it did so gradually. The quick adaptation of goats to a *M. oleifera* leaf-supplemented diet serves as an advantage of using it as fodder, nutritional supplement or anthelmintic substance for goats and other livestock species, as reported in a number of studies (Sanchez *et al*., 2005; Bey, 2010; Jain *et al*., 2013; Akinbamijo *et al*., n.d.).

Does used in the study had both single and twin birth types, with kids comprising both males and females. Figure 6.1 shows the birth types and sex of kids. A total of 20 kids were used in this research, in which 12 (60%) were of single birth, and eight (40%) were twins, with 11 (55%) males and nine (45%) females. Thus, from the 16 lactating does used in the study, 12 had single births while four had twins.

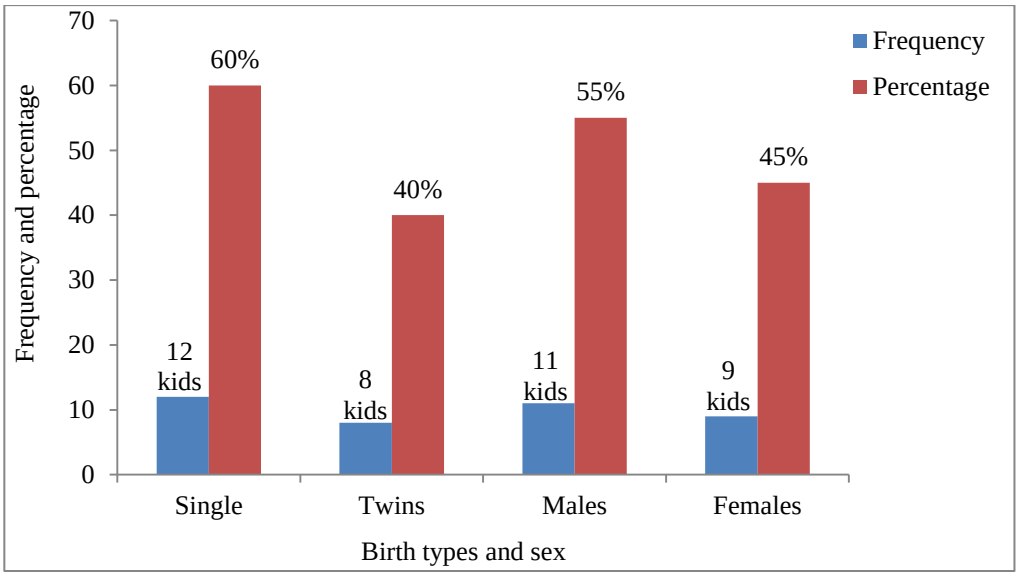

Figure 6.1: Distribution of kids by birth type and sex

6.4.2 Heart Girths of Kids

The average growth of kids' heart girths based on *M. oleifera* inclusion levels are presented in Figure 6.2. The result revealed that the 10% *M. oleifera* inclusion level provided the highest growth in kids' heart girth of 50.43 cm, followed by 20% inclusion level with 48.89 cm, and then 30% inclusion level with 48.09 cm. The control group, 0% *M. oleifera* inclusion level had the lowest growth in kids' heart girth of 47.49 cm. This clearly indicates that 10% (150 g) and 20% (300 g) *M. oleifera* inclusion levels can meet the nutritional needs of lactating Boer goats *ceteris paribus*, while 30% (450 g) resulted into diminishing returns to scale. Thus, it means that it is no longer economical to feed more than a 20% inclusion level of *M. oleifera*. Although Boer goats have gained worldwide recognition for its excellent fast growing rate (Lu, 2002), the results of this study evidently shows that *M. oleifera* leaf supplementation to does boosted the fast-growing rates of their kids.

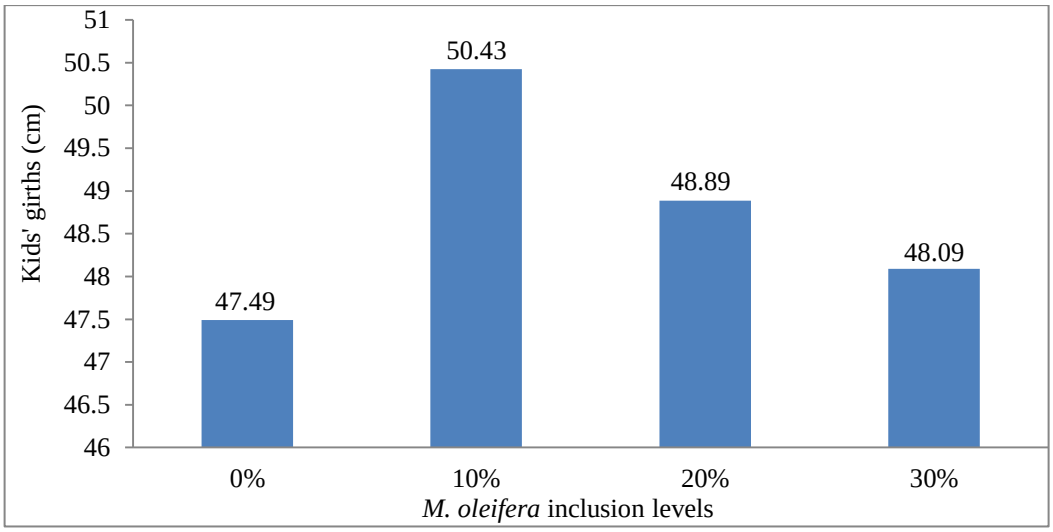

Figure 6.2: Kids' average heart girths at different *M. oleifera* inclusion levels

The results of statistical analyses reveal significant differences of growth parameters of kids whose mothers were fed with a *M. oleifera* leaf-supplemented diet compared to the control (kids not indirectly fed *M. oleifera*). Table 6.4 presents the result of a linear regression analysis of *M. oleifera* inclusion levels on the kids' heart girth growth over time in weeks. Weeks were considered to evaluate the extent of weekly kids' growth since the assessment of growth parameters was done on a weekly basis. The result reveals that *M. oleifera* level of 10% (150 g) had a positive effect ($P < 0.001$) on the kids' girth increase over time, but 20% (300 g) and 30% (450 g) inclusion levels had no significant effect ($P < 0.05$) on kids' girth increase. This means that feeding 150 g of *M. oleifera* to lactating goats would economically result into maximum productivity of does and increase of kids' girth. On the contrary, any rate of increase of supplement beyond these inclusion levels would result into economic loss since *M. oleifera* is costly, scarce and in demand for human use as well, as emphasized by Radovich (2007) and Edward *et al*. (2014). Furthermore, heart girth growth over time was also significantly different (P

< 0.05) except in week one, where there was no statistically significant increase in girth at the different *M. oleifera* inclusion levels and the control.

Table 6.4: Result of regression analysis on factors influencing kids' heart girth

Model	Unstandardized Coefficients		Standardized Coefficients		
	B	Standard Error	Beta	t	Sig.
(Constant)	40.53	0.83		48.93	0.000
Dum level 10%	2.09	0.63	0.17	3.34	0.001***
Dum level 20%	1.11	0.63	0.09	1.77	0.078ns
Dum level 30%	0.69	0.63	0.05	1.10	0.271ns
Week1	0.60	1.04	0.03	0.58	0.564ns
Week2	2.05	1.04	0.11	1.97	0.050*
Week3	4.05	1.04	0.21	3.90	0.000***
Week4	6.00	1.04	0.31	5.78	0.000***
Week5	7.70	1.04	0.40	7.41	0.000***
Week6	8.55	1.04	0.45	8.24	0.000***
Week7	9.25	1.04	0.48	8.91	0.000***
Week8	10.70	1.04	0.56	10.31	0.000***
Week9	12.00	1.04	0.63	11.56	0.000***
Week10	13.70	1.04	0.72	13.20	0.000***

Dependent Variable: Kid girth (cm); F-statistics = 31.61; R-square = 0.67; N = 220; & Durbin-Watson Test= 1.03; ns = non-significant at 0.05; * = significant at 0.05; *** = extremely significant to ≤ 0.001 alpha levels

Figure 6.3 presents the average weekly aggregate growth in kids' heart girths (cm). The result indicates that asides weeks zero (initial girths) and one, growth in kids' heart girth continued over time by weeks arithmetically. This means there was an additional growth in heart girth throughout the research weeks on aggregate although kids grew bigger in some weeks than others.

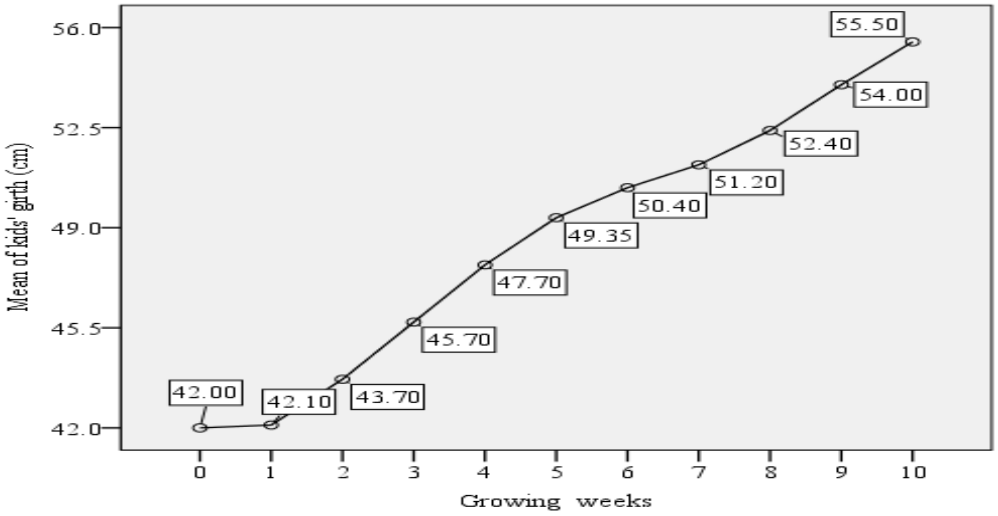

Figure 6.3: Overall average weekly growth in kids' heart girth

Table 6.5 presents the interaction of kids' growth in girth over time in weeks using a Duncan Multiple Range Test analysis. The result shows the means for groups in homogeneous subsets, which had no significant differences (P > 0.05) in kids' growth in girths over time in weeks. Although kids' growth occurs every week, the growth was not large enough to be statistically different.

Table 6.5: Duncan's multiple range tests for weekly growth in kids' heart girth (cm)

		Subset for alpha = 0.05							
Week	N	1	2	3	4	5	6	7	8
0.0	20	42.00							
1.0	20	42.10							
2.0	20	43.70	43.70						
3.0	20		45.70	45.70					
4.0	20			47.70	47.70				
5.0	20				49.35	49.35			
6.0	20					50.40	50.40		
7.0	20					51.20	51.20		
8.0	20						52.40	52.40	
9.0	20							54.00	54.00
10.0	20								55.50
P-value		0.140ns	0.066ns	0.066ns	0.129ns	0.108ns	0.082ns	0.141ns	0.167ns

Means for groups in homogeneous subsets are displayed; uses Harmonic Mean Sample size = 20
Note: ns = non-significant at 0.05 alpha level

Table 6.6 presents the descriptive statistics of weekly growth in kids' heart girths (cm). As seen in the table, the mean ranges from 42.00 cm in week 0 to 55.50 cm in week 10 while maximum girth ranges from 48 cm to 60 cm, respectively. This indicates significant increase in girths among kids.

Table 6.6: Descriptive statistics of weekly growth in kids' heart girth (cm)

					95% Confidence Interval for Mean			
Week	N	Mean	Standard Deviation	Standard Error	Lower Bound	Upper Bound	Minimum	Maximum
0	20	42.00	4.41	0.99	39.94	44.07	36.00	48.00
1	20	42.10	4.36	0.98	40.06	44.14	36.00	48.00
2	20	43.70	3.99	0.89	41.83	45.57	37.00	50.00
3	20	45.70	3.92	0.88	43.87	47.54	40.00	53.00
4	20	47.70	3.44	0.77	46.09	49.31	42.00	53.00
5	20	49.35	3.51	0.79	47.71	50.99	42.00	55.00
6	20	50.40	2.85	0.64	49.06	51.74	45.00	55.00
7	20	51.20	2.73	0.61	49.92	52.48	45.00	55.00
8	20	52.40	2.44	0.54	51.26	53.54	48.00	56.00
9	20	54.00	2.53	0.57	52.81	55.19	48.00	59.00
10	20	55.50	2.63	0.59	54.27	56.73	50.00	60.00
Total	220	48.55	5.60	0.38	47.81	49.29	36.00	60.00

6.4.3 Body Lengths of Kids

The average growth rates of kids' body length based on the four *M. oleifera* inclusion levels are found in Figure 6.4. The result shows that the 20% inclusion level resulted in the highest increase in body length of 45.20 cm. Thirty percent had the second highest increase in length of 45.13 cm, followed by the 10% inclusion level with 44.92 cm, and the control (0% inclusion level) had the least increase in length of 42.71 cm, respectively. This implies that kids' growth in body length corresponded more to the *M. oleifera* inclusion levels compared to the control, an indication that *M. oleifera* leaf-supplemented diet increased the growth in kids' body length.

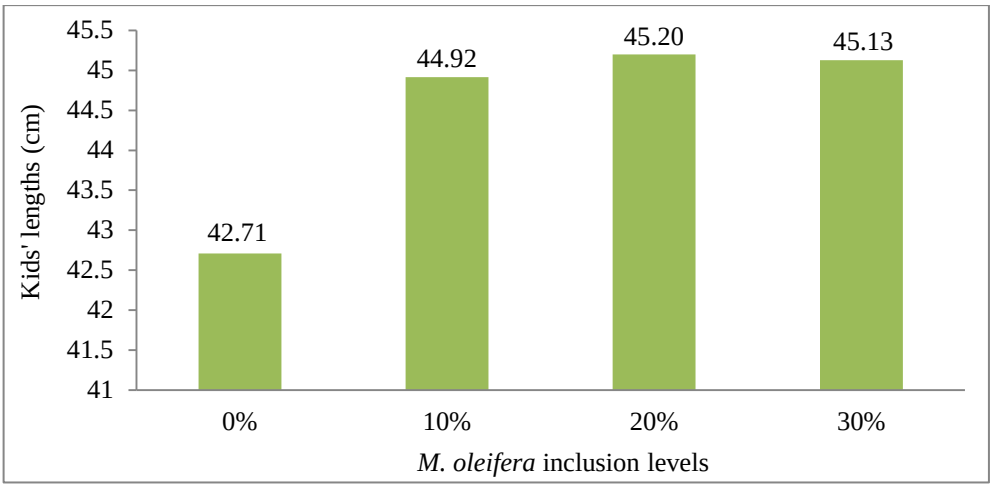

Figure 6.4: Kids' average body length at different *M. oleifera* inclusion levels

Table 6.7 presents the result of a linear regression analysis of *M. oleifera* inclusion levels on the kids' growth in length over time in weeks using the Durbin-Watson Test. The result shows that *M. oleifera* inclusion levels had a significant effect ($P < 0.05$) on kids' growth in length at all three inclusion levels over time (weeks), although 10% (150 g) was less significant (p-value = 0.029) than 20% (300 g) and 30% (450 g), respectively. There were also significant differences ($P < 0.05$) in kids' weekly growth in length, except for weeks one and two that had no differences ($P > 0.05$). Economically, kids' length growth was achieved from weeks 0 to 6 and diminished over time from weeks 7 to 10, which means that continuous feeding of does resulted in less effect on the kids' growth in length. This lesser effect could be attributed to lower intake of milk as the kids grew bigger towards weaning period and were exposed to consuming concentrates (pellets) and fodder (lucerne) by themselves, as suggested by Mpofu (2004).

Table 6.7: Result of regression analysis of factors influencing kids' body length

Model	Unstandardized Coefficients		Standardized Coefficients		
	B	Standard Error	Beta	t	P-value
(Constant)	37.41	0.73		51.06	0.000
Dum level 10%	1.22	0.55	0.11	2.20	0.029*
Dum level 20%	2.15	0.55	0.19	3.87	0.000***
Dum level 30%	2.20	0.55	0.19	3.97	0.000***
Week1	0.40	0.92	0.02	0.44	0.664ns
Week2	0.30	0.92	0.02	0.33	0.744ns
Week3	2.65	0.92	0.16	2.89	0.004***
Week4	2.90	0.92	0.17	3.16	0.002***
Week5	4.10	0.92	0.24	4.46	0.000***
Week6	5.95	0.92	0.35	6.48	0.000***
Week7	9.05	0.92	0.53	9.85	0.000***
Week8	8.80	0.92	0.52	9.58	0.000***
Week9	10.10	0.92	0.59	11.00	0.000***
Week10	10.65	0.92	0.63	11.60	0.000***

Dependent Variable: Kid length; R-Square= 0.67; F-Statistics= 32.36; N= 220 & Durbin-Watson Test = 1.32; ns = non-significant at 0.05; * = significant at 0.05; *** = extremely significant to ≤ 0.001 alpha level

The weekly aggregate average growth in kids' body length (cm) is shown in Figure 6.5. Just as with the heart girths (Figure 6.3), there is a linear and consistent growth in kids' body lengths per week. However, weeks zero (initial week), one and two had the least differences in aggregate increase in kids' growth in body length.

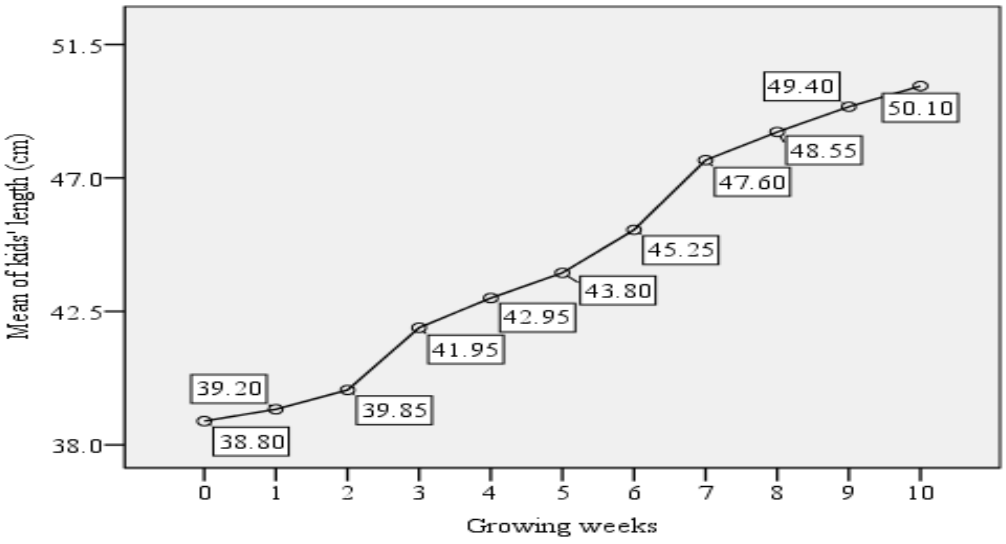

Figure 6.5: Overall average weekly growth in kids' body length

Table 6.8 presents the Duncan Multiple Comparison test analysis of kids' weekly growth rates in body length. The result shows means for groups in 5 homogeneous subsets. The result revealed that there were no mean significant differences ($P > 0.05$) within all subsets in kids' length growth. Even though kids' growth in length did occur every week, there was no statistical difference as in the case with growth in heart girth (Table 6.5).

Table 6.8: Duncan's multiple range tests for weekly growth in kids' body lengths (cm)

		Subset for alpha = 0.05				
Week	N	1	2	3	4	5
0	20	38.80				
1	20	39.20				
2	20	39.85				
3	20		41.95			
4	20		42.95			
5	20		43.80	43.80		
6	20			45.25		
7	20				47.60	
8	20				48.55	48.55
9	20				49.40	49.40
10	20					50.10
Sig.		0.310ns	0.071ns	0.135ns	0.079ns	0.132ns

Means for groups in homogeneous subsets are displayed; uses Harmonic Mean Sample size = 20. Note: ns = non-significant at 0.05 alpha level

The descriptive statistics for kids' weekly growth in body length (cm) is presented in Table 6.9. The mean ranges from 38.80 cm to 50.10 cm with maximum length ranging from 46 cm to 54 cm from week 0 to 10, respectively.

Table 6.9: Descriptive statistics of weekly growth in kids' body length (cm)

					95% Confidence Interval for Mean			
Weeks	N	Mean	Standard Deviation	Standard Error	Lower Bound	Upper Bound	Min.	Max.
0	20	38.80	4.42	0.99	36.73	40.87	31.00	46.00
1	20	39.20	4.23	0.94	37.22	41.18	31.00	46.00
2	20	39.85	3.67	0.82	38.13	41.57	33.00	46.00
3	20	41.95	2.98	0.67	40.55	43.35	36.00	47.00
4	20	42.95	2.68	0.60	41.69	44.21	39.00	48.00
5	20	43.80	2.38	0.53	42.69	44.91	40.00	49.00
6	20	45.25	2.29	0.51	44.18	46.32	40.00	49.00
7	20	47.60	2.70	0.60	46.34	48.87	43.00	53.00
8	20	48.55	2.33	0.52	47.46	49.64	44.00	53.00
9	20	49.40	2.37	0.53	48.29	50.51	45.00	54.00
10	20	50.10	2.57	0.58	48.90	51.30	45.00	54.00
Total	220	44.31	4.97	0.35	43.65	44.98	31.00	54.00

6.4.4 Body Weight Gains of Kids

The average body weight gains of kids according to *M. oleifera* inclusion levels are found in Figure 6.6. The analysis confirms that a 10% inclusion level led to the highest weight gain in kids of 10.49 kg. The 20% inclusion level yielded the second highest weight gain of 10.28 kg, which was followed by the 30% inclusion level with 9.99 kg. Finally, the 0% inclusion level generated the lowest weight gain of 8.98 kg. The fact that the 0% inclusion level (control) generated the lowest of kids' weight gain compared to the experimental groups demonstrates the effectiveness of *M. oleifera* on growth parameters. Lu (2002) reported that among all superior traits, heavier body weight and faster growth rate are the most notable characteristics of Boer goat kids. In a study with West African Dwarf goat kids, Asaolu *et al*. (2012) concurred that supplementing *M. oleifera* resulted in a significant weight gain, compared to *Gliricidia sepium* and *Leucaena leucocephala* fodders. In the present study, the *M. oleifera* leaf-supplemented diet increased weight gain more than those whose mothers were fed with only lucerne and pellets.

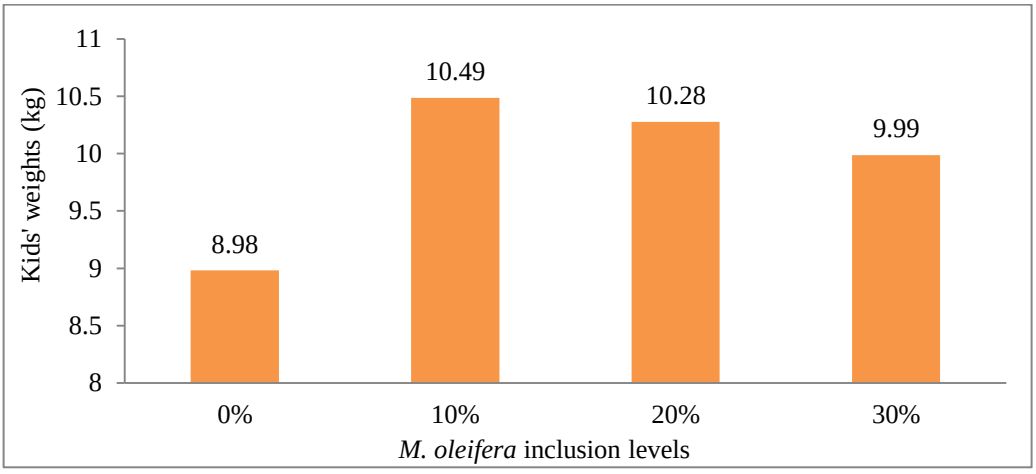

Figure 6.6: Kids' average body weights gain at different *M. oleifera* inclusion

Table 6.10 presents a linear regression analysis result of kids' weekly weight gain as explained by *M. oleifera* inclusion levels using a Durbin-Watson test. The result shows that *M. oleifera* and time resulted in significant differences ($P < 0.05$) in kids' weight gain, except for week 1 that had no effect statistically. This means that *M. oleifera* inclusion levels had an effect on weight gain of kids over time (weeks), which indicates that all inclusion levels were economically potential contributors to weight gain as time progressed. Gebregiorgis *et al*. (2011) affirmed that feeding moringa leaves to sheep increased their body weight gain ($P < 0.05$) corresponding to increasing levels of moringa leaves (300 g and 450 g), but not in the control group. Also, a research by Asaolu *et al*. (2012) with West African Dwarf growing goats indicated that supplementing with *M. oleifera* resulted in a significant weight gain compared to using *Gliricidia sepium* and *Leucaena leucocephala* fodders.

Table 6.10: Result of regression analysis on factors influencing kids' body weight (kg)

	Unstandardized Coefficients		Standardized Coefficients		
Model	B	Standard Error	Beta	t	Sig.
(Constant)	4.87	0.45		10.847	0.000***
Dum level 10%	1.13	0.34	0.145	3.320	0.001***
Dum level 20%	1.30	0.34	0.167	3.812	0.000***
Dum level 30%	1.01	0.34	0.130	2.966	0.003***
Week1	0.44	0.56	0.038	0.781	0.435ns
Week2	1.37	0.56	0.117	2.424	0.016*
Week3	2.03	0.56	0.174	3.605	0.000***
Week4	3.03	0.56	0.260	5.381	0.000***
Week5	4.37	0.56	0.374	7.761	0.000***
Week6	5.10	0.56	0.437	9.048	0.000***
Week7	5.73	0.56	0.491	10.176	0.000***
Week8	6.62	0.56	0.567	11.756	0.000***
Week9	7.74	0.56	0.663	13.745	0.000***
Week10	8.78	0.56	0.752	15.592	0.000***

Dependent Variable: Kid weight; R-Square= 0.74; F-Statistic= 44.22; N= 214 & Durbin-Watson Test = 1.25; ns = non-significant at 0.05; * = significant at 0.05; *** = extremely significant to ≤ 0.001 alpha levels

Figure 6.7 shows a graphic presentation of the weekly kids' body weight gains. On aggregate, kids gained weight linearly with time, which means that kids' body weight gain was an addition per week although the increased weight gains were greater in some weeks than others.

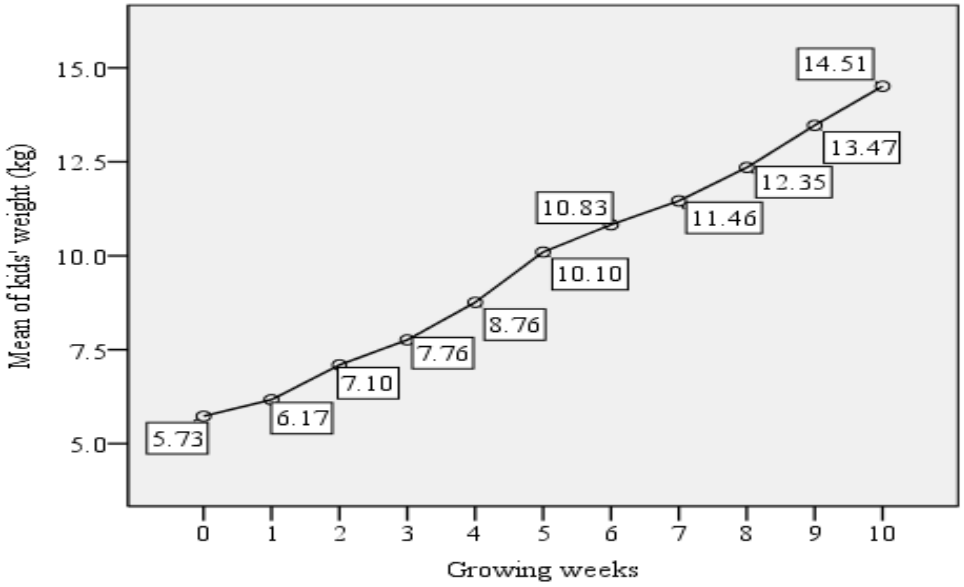

Figure 6.7: Overall average weekly growth in kids' body weight gain

Table 6.11 presents the Duncan Multiple Range tests of kids' weekly weight gains. It contains nine mean homogenous subsets with levels of significant differences. The result shows that all subsets were not significantly different ($P > 0.05$) in kids' weight gains over time in weeks.

Table 6.11: Duncan's multiple range tests for weekly growth in kids' body weight gains (kg)

		Subset for alpha = 0.05								
Week	N	1	2	3	4	5	6	7	8	9
0	20	5.73								
1	20	6.17	6.17							
2	20		7.10	7.10						
3	20			7.76	7.76					
4	20				8.76					
5	20					10.10				
6	20					10.83	10.83			
7	20						11.46	11.46		
8	20							12.35	12.35	
9	20								13.47	13.47
10	20									14.51
P-value		0.451ns	0.114ns	0.255ns	0.088ns	0.215ns	0.277ns	0.128ns	0.056ns	0.076ns

Means for groups in homogeneous subsets are displayed; uses Harmonic Mean Sample size = 20
Note: ns = non-significant at 0.05 alpha level

The descriptive statistics of weekly kids' weight gains is found in Table 6.12. The result reveals that there was a continuous increase in weight gains among kids, as the mean ranges from 5.73 kg to 14.51 kg (13.50 kg difference), just like the mean of 42.00 cm at initial kids' heart girth to 48.55 cm (see Table 6.6) at the end of the research (6.55 cm difference in heart girth), and mean of 38.80 cm kids' body length to 50.10 cm (see Table 6.9) with a difference of 11.3 cm in body length, respectively.

Table 6.12: Descriptive statistics of weekly growth in kids' body weight gains (kg)

Week	N	Mean	Standard Deviation	Standard Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
0.0	20	5.73	1.81	0.41	4.88	6.58	2.80	8.40
1.0	20	6.17	1.87	0.42	5.30	7.04	3.20	8.60
2.0	20	7.10	1.88	0.42	6.22	7.97	4.00	9.60
3.0	20	7.76	1.91	0.43	6.87	8.65	4.40	10.20
4.0	20	8.76	1.62	0.36	8.00	9.52	5.40	10.80
5.0	20	10.10	1.70	0.38	9.30	10.90	6.40	12.40
6.0	20	10.83	1.64	0.37	10.06	11.59	8.00	13.60
7.0	20	11.46	1.69	0.38	10.67	12.25	8.60	14.60
8.0	20	12.35	1.77	0.39	11.52	13.18	9.40	16.20
9.0	20	13.47	2.01	0.45	12.53	14.41	10.00	17.80
10.0	20	14.51	2.27	0.51	13.45	15.57	11.20	20.00
Total	220	9.84	3.36	0.23	9.39	10.29	2.80	20.00

6.4.5 Body Condition Scores of Kids

The average of kids' body condition scores (BCS) according to *M. oleifera* inclusion levels are shown in Figure 6.8. The analysis of body condition scores indicates that 10% *M. oleifera* inclusion level led to the highest BCS of 3.35 points, while 20% and 30% had equal BCS of 3 point each, and the lowest among the kids BCS was the 0% (control) with two 2.80 points. Just as the kids' heart girth, body length and body weight gain, BCS were the least at 0% inclusion level. Body condition scores range from 1 to 5, with 0.5 increments and were assessed by visual observation and palpation method as suggested by Frost *et al*. (2008). In the present study, the kids' BCS lie between 2.50 to 3.35 points. This suggests that most of the kids ranged from moderate to good body condition scores as BCS of below 2 is considered thin (Mellado, 2002). These good BCS of kids are an indirect indication that kids had sufficient milk from their mothers to sustain proper early growth and development. Villaquiran *et al*. (2015) explained that in most cases, healthy goats should have a BCS of 2.5 to 4.0. The BCS of 1.0, 1.5, or 2.0 indicate a management or health problem. A BCS of 4.5 or 5 is almost never observed in

goats under normal management conditions; however, it can sometimes be observed in show goats. On the other hand, a BCS of 1 is extremely thin and 5 is considered as obese or very over-conditioned (Mellado, 2002; Villaquiran *et al*., 2015).

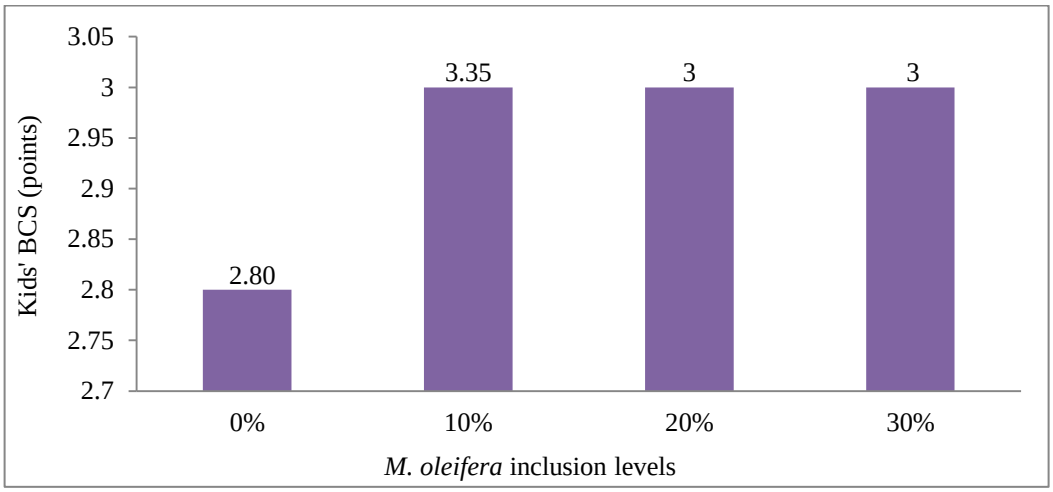

Figure 6.8: Kids' average body condition scores at different *M. oleifera* inclusion levels

Table 6.13 presents the result of a linear regression analysis of BCS of kids whose mothers were fed *M. oleifera* over time (weeks) to observe the indirect effect on kids. The result indicates that *M. oleifera* had significant effects ($P < 0.05$) on the BCS of kids over time in weeks. The BCS were higher at the 30% inclusion level (450 g) compared to 10% (150 g) and 20% (300 g) levels, respectively over time (weeks). This may be attributed to the fact that as the kids grew, the demand for the quantity of milk increased while the milk was still being produced at the same level; thus, leading to a negative change in BCS.

Table 6.13: Result of regression analysis on factors influencing kids' body condition scores

Model	Unstandardized Coefficients		Standardized Coefficients		
	B	Standard Error	Beta	t	Sig.
(Constant)	2.47	0.08		29.30	0.000
Dum level 10%	0.13	0.06	0.12	2.00	0.047*
Dum level 20%	0.11	0.06	0.10	1.71	0.089ns
Dum level 30%	0.17	0.06	0.16	2.71	0.007***
Week1	0.38	0.11	0.24	3.55	0.000***
Week2	0.48	0.11	0.30	4.49	0.000***
Week3	-0.41	0.11	-0.27	-4.02	0.000***
Week4	0.30	0.11	0.19	2.84	0.005***
Week5	0.45	0.11	0.28	4.25	0.000***
Week6	0.61	0.11	0.39	5.91	0.000***
Week7	0.60	0.11	0.38	5.67	0.000***
Week8	0.45	0.11	0.28	4.25	0.000***
Week9	0.58	0.11	0.36	5.44	0.000***
Week10	0.78	0.11	0.49	7.33	0.000***

Dependent Variable: Kid BCS; R-Square = 0.50; F-Statistic = 16.01; N = 220 & Durbin-Watson Test = 1.65 Note: ns = significant at 0.05; * = significant at 0.05; *** = extremely significant to ≤ 0.001 alpha level

The aggregate mean plots of weekly kids' BCS are found in figure 6.9. Kids' BCS range from 2.58 to 3.35 in this study, which means that most had between moderate to good body conditions since below 2 is considered thin. Mellado (2002) stated that kids' BCS of 3 to 3.50 points are considered moderate to good. In the present study, the kids' BCS lies between 3 to 3.35 points except for the first few weeks when they were below 3 points.

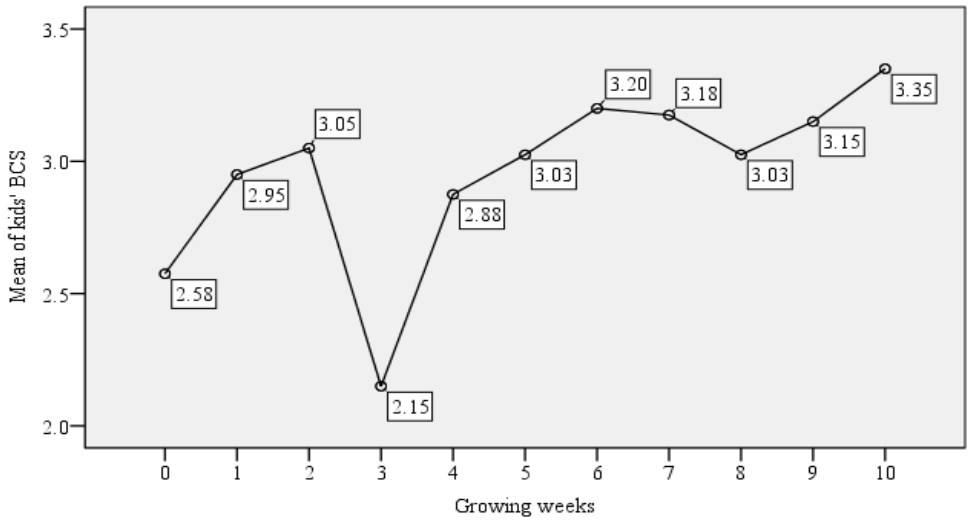

Figure 6.9: Overall average weekly growth in kids' body condition scores

Table 6.14 presents the Duncan Multiple Comparison test analysis of kids' BCS over time in weeks. The result reveals means for groups in 6 homogeneous subsets. All subsets had no mean significant differences ($P > 0.05$) within kids' BCS. Although not statistically significant, at first kids' BCS were changing weekly but as they grew bigger, the BCS began dropping, causing subsets to have many weeks without differences. This might be attributed to the demand for more milk and other sources of rations as the mothers' milk was no longer meeting the demand. Table 6.15 presents descriptive statistics of weekly kids' BCS. The mean ranges from 2.58 to 3.35, with a maximum BCS of 4 among the kids.

Table 6.14: Duncan's multiple range tests for weekly growth in kids' body condition scores

		Subset for alpha = 0.05					
Week	N	1	2	3	4	5	6
3.0	20	2.15					
0.0	20		2.58				
4.0	20			2.88			
1.0	20			2.95	2.95		
5.0	20			3.03	3.03	3.03	
8.0	20			3.03	3.03	3.03	
2.0	20			3.05	3.05	3.05	
9.0	20				3.15	3.15	3.15
7.0	20				3.18	3.18	3.18
6.0	20					3.20	3.20
10.0	20						3.35
P-value	---	1.000ns	1.000ns	0.149ns	0.066ns	0.158ns	0.089ns

Means for groups in homogeneous subsets are displayed; uses Harmonic Mean Sample Size = 20. Note: ns = non-significant at 0.05 alpha level

Table 6.15: Descriptive statistics of weekly growth in kids' body condition scores

					95% Confidence Interval for Mean			
Weeks	N	Mean	Standard Deviation	Standard Error	Lower Bound	Upper Bound	Min.	Max.
0.0	20	2.58	0.54	0.12	2.32	2.83	1.50	3.0
1.0	20	2.95	0.22	0.05	2.85	3.06	2.00	3.00
2.0	20	3.05	0.22	0.05	2.95	3.16	3.00	4.00
3.0	20	2.15	0.24	0.05	2.04	2.26	2.00	2.50
4.0	20	2.88	0.22	0.05	2.77	2.98	2.50	3.00
5.0	20	3.03	0.20	0.04	2.93	3.12	2.50	3.50
6.0	20	3.20	0.25	0.06	3.08	3.32	3.00	3.50
7.0	20	3.18	0.29	0.07	3.04	3.31	2.50	3.50
8.0	20	3.03	0.47	0.11	2.80	3.25	2.00	3.50
9.0	20	3.15	0.46	0.10	2.93	3.37	2.00	3.50
10.0	20	3.35	0.37	0.08	3.18	3.52	2.50	4.00
Total	220	2.96	0.46	0.03	2.90	3.02	1.50	4.00

6.4.6 Growth Differences Between and Within Sex and Birth Types

Table 6.16 presents the average growth parameters of kids, which revealed that males grew faster and bigger than females in heart girth, body length, body weight gain and they even had better body condition scores. As per birth types, single males had the highest average growth parameters (heart girth 54.24 cm, body length 48.72 cm and

body weight 13.07 kg), followed by twin males in girth (51.99 cm) and weight gains (11.04 cm) but not length (44.31 cm). This confirms the findings by Lu (2002) who stated that Boer goats' male kids have a higher body weight and post-weaning growth rate under standardized conditions. Conversely, single females had greater length (45.67 cm) and body condition scores (3.18), while twin females had the lowest growth parameters of all the groups. Individually, the heart girth ranges between 50 cm to 60 cm, length between 45 cm and 54 cm and weight between 11.20 kg and 20 kg. Weight range in the present study is lower than what was estimated by Agra Professional Services (2013) which reported that 100 day-old kids weigh between 25 kg to 32 kg. The aggregate for birth types shows that singles grew bigger and faster than twins, even though statistical analysis showed that twins had bigger parameters compared to singles (Table 6.18).

Table 6.16: Average growth parameters of kids by birth type and sex

Birth	Sex	No. of kids	Heart girth (cm)	Body length (cm)	Body weight (kg)	Body Condition Scores (points)
Single	Male	6	54.24	48.72	13.07	3.43
Single	Female	6	49.98	45.67	10.84	3.18
Twin	Male	5	51.99	44.31	11.04	2.73
Twin	Female	3	50.74	43.69	9.45	2.47
Single	Aggregate	12	52.11	47.19	11.96	3.90
Twin	Aggregate	8	51.36	44.00	10.25	2.60

Table 6.17 presents a General Linear Model (GLM) Multivariate Pairwise Comparisons of *M. oleifera*'s effects on kids' heart girth, body length, body weight and BCS using a least significant difference (LSD) post hoc analysis with weeks as covariate on the male and female kids. There were significant differences ($P < 0.01$) between male kids and female kids in all growth parameters (heart girth, body length, body weight gains) as

well as BCS over time regardless of the *M. oleifera* levels. This implies that the growth parameters of male kids measured in this study were better than that of the female kids although their mothers were fed with equal levels of *M. oleifera*.

Table 6.17: Pairwise comparisons of *M. oleifera* effect on kids' growth parameters by sex

Dependent Variable	(I) Sex	(J) Sex	Mean Difference (I-J)	Standard Error	Sig.[c]	95% Confidence Interval for Difference[c] Lower Bound	Upper Bound
	Female	Male	-3.07***	0.39	0.000	-3.84	-2.31
Kid girth	Male	Female	3.07***	0.39	0.000	2.31	3.84
	Female	Male	-2.28***	0.37	0.000	-3.012	-1.54
Kid length	Male	Female	2.28***	0.37	0.000	1.54	3.01
	Female	Male	-2.20***	0.30	0.000	-2.59	-1.81
Kid weight	Male	Female	2.20***	0.20	0.000	1.81	2.59
	Female	Male	-0.12***	0.04	0.006	-0.20	-0.04
Kid BCS	Male	Female	0.12***	0.04	0.006	0.04	0.20

Based on estimated marginal means

***. The mean difference is significant to ≤ 0.001 levels.

a. Weighted Least Squares Regression - Weighted by MOL consumed

c. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Table 6.18 presents GLM Multivariate Pairwise Comparisons of *M. oleifera* effects on kids' heart girth, length, weight and BCS using a least significant difference (LSD) post hoc analysis with weeks as covariate on birth-types (single and twin birth) of kids over time in weeks. The LSD multiple comparisons results indicate that the growth parameters were significantly different ($P < 0.01$) by birth-types; that is, between single and twin births. These differences might be attributed to the fact that singles were born bigger and heavier and suckled their mothers alone no matter how much milk they produced, while twins were smaller and lighter and had to share the milk produced by their mothers. This offers chances for single kids to grow faster and bigger than twins. Zhang *et al*. (2008) concurred that singles have the heaviest birth weight and larger body

size. Although in this study, the result indicated that twins had greater growth parameter values than single births contrary to the expectation, this could be supported by the fact that males grow faster and bigger than females. This was pointed out in this study where there were more twin males than twin females and single births.

Table 6.18: Pairwise comparisons of *M. oleifera* effect on kids growth parameters by birth type

Dependent Variable	(I) birth type	(J) birth type	Mean Difference (I-J)	Standard Error	Sig.[c]	95% Confidence Interval for Difference[c]	
						Lower Bound	Upper Bound
Kid girth	Single	Twins	-1.81***	0.39	0.000	-2.56	-1.05
	Twins	Single	1.81***	0.39	0.000	1.05	2.56
Kid length	Single	Twins	-1.48***	0.37	0.000	-2.22	-0.75
	Twins	Single	1.48***	0.37	0.000	0.75	2.22
Kid weight	Single	Twins	-0.52***	0.20	0.009	-0.91	-0.13
	Twins	Single	0.52***	0.20	0.009	0.13	0.91
Kid BCS	Single	Twins	0.11***	0.04	0.007	0.03	0.20
	Twins	Single	-0.11***	0.04	0.007	-0.20	-0.03

Based on estimated marginal means

***. The mean difference is highly significant to ≤ 0.001 level.

a. Weighted Least Squares Regression - Weighted by MOL consumed

c. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

The results of this study to a large extent revealed that a *M. oleifera* leaf-supplemented diet for lactating does had a positive effect on their pre-weaning kids' growth in heart girth, body length, and body weight gain as growth parameters as well as their body conditions. The growth effects were observed at all inclusion levels of *M. oleifera* leaf-supplemented diet. This subsequently resulted into the failure to accept the hypothesis (H_{05}) that feeding *M. oleifera* as a supplement to lactating goats does not affect the growth parameters of their pre-weaning kids, because there was a significant effect on all growth parameters as well as BCS of pre-weaning kids.

6.5 Conclusion

The supplementation of *M. oleifera* to lactating Boer does at all three different inclusion levels had positive indirect effect on all growth parameters of their kids which included heart girth, body length and weight as well as body condition scores. The indirect effect of *M. oleifera* on kids' growth parameters was based on the feeding of *M. oleifera* leaf-supplemented diets to lactating does whose kids indirectly benefited through the suckling of the amount of milk produced by their mothers since *M. oleifera* is believed to increase milk production due to its nutritional quality. All growth parameters were all statistically significant ($P < 0.05$). Although Boer goats are known for their fast growth under favourable conditions, feed supplementation of pregnant and lactating does could be advantageous for maximum milk production to support their kids' healthy early growth and development especially under unfavourable conditions such as during winter and drought. This study was done under severe drought conditions after the 2015 winter season, demonstrating that in a semi-arid, dry, and drought-persistent country like Namibia, *M. oleifera* would be a possible solution for animal supplementation during drought and winter periods. The study shows that *M. oleifera* grows very fast and produces more leaf-dry matter per hectare, thus alleviating farmer's stress of purchasing feed-supplement during pregnancy and lactation period. This was demonstrated by the present study where *M. oleifera* leaf-supplemented diet of lactating Boer goats had positive effect on growth parameters (girth, length and weight) of their kids as well as their BCS. Finally, growth increment was more evident at 10% (150 g) and 20% (300 g) dry *M. oleifera* leaf-inclusion levels compared to 30% (450 g), which means that a daily ration of 150 g or 300 g of *M. oleifera* leaf-supplemented diets are recommended for each lactating goat.

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Chapter 7

Conclusions and Recommendations

This chapter presents conclusions and recommendations of the five experimental chapters, which are chapters 2 to 6 that have been discussed and concluded sequentially. Since chapter 1 is an introductory chapter of the study it has no conclusion, neither does it have recommendations.

7.1 Conclusions

Based on the findings from this study, the following conclusions have been drawn according to the sequence of chapters:

7.1.1 Chapter 2 Conclusion

In this study, the *Moringa oleifera* seeds used had a poor emergence in the nursery compared to *Moringa ovalifolia* seeds. However, *M. oleifera* seedlings had faster growth than *M. ovalifolia* which grew at a slower pace over time. Thinned and transplanted seedlings of both *M. oleifera* and *M. ovalifolia* had high EoE and low mortality rates. Based on its fast growth, *M. oleifera* cultivation can be encouraged in Namibia, which is predominantly semi-arid. In addition, *M. oleifera*, being a "never-die" tree, has the ability to withstand drought and water shortages that are frequent in Namibia. *Moringa ovalifolia* cultivation should be encouraged since it is indigenous to Namibia and has the ability to grow in the wild and endure on its own with little care. Ecologically, it will have an edge of endurance due to its adaptability to this region, compared to *M. oleifera* which is exotic to Namibia. The major challenge to the cultivation of *M. oleifera* in

Namibia is frost susceptibility. Nevertheless, the cultivation of both *Moringa* species is of paramount importance to the Namibian dry environmental conditions.

7.1.2 Chapter 3 Conclusion

Moringa oleifera and *M. ovalifolia* have the ability to grow, endure and yield under harsh conditions at the field level. *Moringa oleifera* reaches maximum heights within four to five months, while *M. ovalifolia* takes longer to develop into a fully grown tree. Both species need little water to grow and survive, which makes them suitable for an arid and semi-arid climates found in Namibia. *Moringa oleifera* had an EoE of 97.50% and *M. ovalifolia* of 71.63% in the 2015/2016 summer season. They can both yield considerable amount of leaf-dry matter each summer season that may be used as a feed supplement. *Moringa oleifera* had maximum yields of 379.36 kg/ha and 268.53 kg/ha for 2015/2016 and 2014/2016, while *M. ovalifolia*'s maximum yields were 94.67 kg/ha and 76.81 for 2014/2014 and 2015/2016 seasons. Therefore, *M. oleifera*, especially and *M. ovalifolia* are possible alternative trees that can be planted to improve rangeland productivity in terms of fodder.

7.1.3 Chapter 4 Conclusion

Moringa plant species are nutritious and contain almost all the essential nutrients needed by livestock for growth and development. An increase in moringa production and use would improve food security and minimize malnutrition, especially in third-world countries. Although there is a human-livestock conflict in the use of moringa, if adopted by livestock farmers, both *M. oleifera* and *M. ovalifolia* have the potential to eliminate the purchasing of animal feed supplements and to enhance livestock production, since it

will be readily available on the farm for supplementation during low-nutrient periods of rangelands. Therefore, the cultivation of moringa as a nutrient-rich plant species should be encouraged along with their uses as livestock feed for improved productivity.

7.1.4 Chapter 5 Conclusion

This study revealed that *M. oleifera* has the ability to reduce to a large extent gastrointestinal parasite (GIP) loads in Boer goats in comparison to the conventional ecomectin drug. *Moringa oleifera* leaf-supplemented diet significantly reduced trichostrongyles-type eggs, coccidia oocyst, *Trichuris* species, *Moniezia* species eggs and to a lesser extent *Strongyloides* species in goats. Goats like *M. oleifera* leaves, and feeding them to these animals would cause no difficulty. Although *M. oleifera* is exotic to Namibia and unfamiliar to animals at large, its leaves were easily adopted by the goats. Feeding about 300 g (20%) and 450 g (30%) to goats would serve as an anthelmintic remedy. *Moringa oleifera*, being in high demand for both human and animal consumption needs, it should be used carefully and just for the purpose set forth in this study. Finally, *M. oleifera* would serve as a good natural remedy and supplement for goats in the fight against gastrointestinal helminths, especially since they have developed resistance to many commercial anthelmintics over the years.

7.1.5 Chapter 6 Conclusion

The supplementation of *M. oleifera* to lactating Boer does at all 3 different levels had a positive effect on all considered growth parameters of their kids which included girth, length and body weight as well as body condition scores. Although Boer goats are known for their fast growth under favourable conditions, feed supplementation of

pregnant and lactating does could be advantageous for proper milk production to support their kids' early growth and development, especially under unfavourable conditions such as during winter and drought. Therefore, in a drought-persistent country like Namibia, *M. oleifera* would serve as a possible solution for animal supplementation during drought and winter periods since it grows very fast and produces high biomass per hectare. Thus, it would be effective in alleviating the farmer's stress of purchasing supplements during their does' pregnancy and lactation periods. This was demonstrated by the present study where a *M. oleifera* leaf-supplemented diet of lactating Boer goat does had a positive effect on growth parameters (girth, length and weight) of their kids. Finally, growth increment was more evident at 10% (150 g) and 20% (300 g) dry *M. oleifera* leaf-inclusion levels compared to 30% (450 g), which means that a daily ration of 150 g or 300 g of *M. oleifera* leaf-supplemented diets are recommended for each lactating goat.

7.2 Recommendations

Based on the findings from this study, the following recommendations are put forward according to the sequence of chapters:

7.2.1 Chapter 2 Recommendations

Moringa oleifera and *M. ovalifolia* seeds should be sown and grown in the nursery before being transplanted in the field under these harsh Namibian environmental conditions. It is easy to care for emerged seedlings in the nursery because they can be moved from one location to another based on weather circumstances. In addition, pests can also be controlled easily in the nursery. These favourable conditions in the nursery prevent the mortality of seedlings and gradually adapt to the environmental challenges within 1-2 months at which time they are ready for transplanting in the field. When doing so, farmers should always prepare a nursery and grow moringa seedlings before transplanting in the field.

7.2.2 Chapter 3 Recommendations

Moringa oleifera, as a drought resistant tree, should be used to improve rangeland conditions since it has the ability to produce a large quantity of leaf-dry matter per hectare. When established in two to three years, they need less water (once fortnightly) to endure and, most importantly, endure well under the Namibian winter conditions. On the other hand, *M. ovalifolia*, although it produced less leaf-dry matter than *M. oleifera*, it is resistant to many insects and endures better in its native environment. As a result, farmers should be encouraged to cultivate both *M. oleifera* and *M. ovalifolia* trees on their farms and homesteads for use as supplements. Further research is recommended on

the LSB heights, EoE and leaf-dry-matter yield of both *Moringa* species especially in the central Namibian climate since the trees were young during this study period.

7.2.3 Chapter 4 Recommendations

Moringa oleifera and *M. ovalifolia* contain almost equal quantities of nutrients and may be used for similar purposes. The nutritional components of *M. oleifera* and *M. ovalifolia* are very high, thus, making them suitable fodder crops in an environment that is prone to drought and cold winters when the grasses in the rangelands are poor in nutrient contents. Thus, moringa trees can be recommended as a good alternative feed supplement likely to improve the livestock sector in Namibia, since they contain a substantial amount of needed nutrients.

7.2.4 Chapter 5 Recommendations

The leaves of *M. oleifera* can be recommended to use as a medicinal supplement for livestock since it has medicinal properties against many maladies. Indeed, research findings showed that *M. oleifera* has anthelmintic substances that reduced helminth loads in Boer goats. Therefore, taking into consideration the high prevalence of helminths among livestock, the overuse of conventional anthelmintic drugs and the development of resistance to such drugs, *M. oleifera* could serve as a natural anthelmintic as well as a remedy for other livestock diseases. This could subsequently enhance livestock productivity for communal farmers who cannot afford to purchase drugs for their animals, and could save extra money for those farmers who could afford to purchase them.

7.2.5 Chapter 6 Recommendations

Moringa *oleifera* could be used as supplement for livestock since it contains almost all the essential nutrients needed for growth and development. *Moringa oleifera* leaves must be harvested, stored and used as a supplement during critical stages like pregnancy and lactation, when does' demand for quality feed is high. With the supplementation of *M. oleifera* to livestock, lactating animals can maintain good body condition scores throughout the lactation period. This will minimize the purchasing of feed supplements for livestock and save farmers extra expense. Henceforth, the livelihoods of farmers will improve since the money that would have been used for purchasing supplements for livestock will be diverted to other basic needs.