GROWING AND AGRO-PROCESSING OF
MORINGA OLEIFERA
WITH COMMERCIAL POTENTIAL IN SOUTH AFRICA

LUHLAZA INTEGRATED SUSTAINABLE SOLUTIONS

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Research | Environmental Lab Work | Feasibility Studies | Technical Due Diligence

EXECUTIVE SUMMARY

The research study on the agricultural development of *Moringa oleifera* in South Africa was initiated under the Agro-Processing Competitiveness Fund (APCF) by the Industrial Development Corporation of South Africa (IDC) after a response to an EOI by Luhlaza-ISS on undertaking the study. The primary objective of the research study was to investigate formalising trading of *Moringa oleifera* and investigate viability for commercialising *Moringa oleifera* in South Africa. The research study was undertaken over a period of two years in different work packages that are summarised below under different chapters in this report.

CHAPTER SUMMARY

Chapter 1 - Literature Review

This chapter briefly introduces the Moringa genus and explains various plant species with the focus on *Moringa oleifera*. The literature and data are reviewed emphasising cultivation, harvesting, pests and diseases, agro-processing and its uses.

Chapter 2: Situational Analysis (*Moringa oleifera* in a South African context)

The situational analysis focused on documenting geographical position and how *Moringa oleifera* is grown in South Africa. The climatic conditions under which *Moringa oleifera* is grown are also highlighted in this chapter. This chapter contextualises the overview of *Moringa oleifera* trading in South Africa.

Chapter 3: Sampling and Chemical Analysis

Chapter 3 details an integral part of the research study, which provides scientific empirical data on *Moringa oleifera* leaves, seeds and the soil on which it is grown. *Moringa oleifera* leaves, seeds and soil of all ten farms that constitute the research sample, were sampled according to the sampling protocol developed for this study (annexure 1).

Analytical testing was conducted at two reputable labs, specifically Agricultural Research Council (ARC) and University of the Witwatersrand (Wits) and results thereof are discussed in detail in this chapter.

Chapter 4: Industry Analysis

The Moringa has the potential to play a central role in a number of industries, making the plant of much industrial significance. Several industries where *Moringa oleifera* can be utilised and applied are discussed, as well as potential products and value streams.

Chapter 5: Market Analysis

The market analysis detailed in this chapter, was conducted in terms of the following for potential commercialisation.

- Market size
- Products
- Pricing
- Point of sales
- Barriers of entry and constraints

Chapter 6: Economic Analysis

Luhlaza-ISS has identified entrepreneurs in different parts of the country that are already involved in upstream activities of Moringa. The entrepreneurs implement different business models and thus in undertaking this research study, Luhlaza-ISS also investigated the most viable business models on the basis of:

- Creating more sustainable job opportunities
- Scalability
- Easily replicable in other areas of the country at a low cost

Chapter 7: Conclusion and recommendations

This chapter concludes on the research findings and recommends further studies that may provide conclusive evidence on *Moringa oleifera* toxicity.

TABLES OF REFERENCE

ACCRONYMS

AOAC	Association of Analytical Chemists
APCF	Agro-Processing Competitiveness Fund
ARC	Agricultural Research Council
As	Arsenic
BES	Biodiversity Economy Strategy
Ca	Calcium
CAPEX	Capital Expenditure
Cd	Cadmium
CLEA 2009	Contaminated Land Exposure Assessment Soil Guideline Value (SGV)
Cm	Measure of length in metric centimetres
Cr	Chromium
CSIR	Council for Scientific and Industrial Research
Cu	Copper
DEA	Department of Environmental Affairs
Degree (°) C	Measure of temperature in degrees Celsius
DIM	Daily Intake of Metal
EF	Exposure Frequency
EU	European Union
EWRP	eMalahleni Water Reclamation Plant
Fe	Iron

FEPA	Federal Environmental Protection Agency
FOA	Food and Agriculture Organisation
G	Measure of weight in metric grams
GDP	Gross Domestic Product
HI	Hazard Index
HiPro	High-Recovery Precipitation Reverse Osmosis
IDC	Industrial Development Corporation of South Africa
K	Potassium
Kg	Measure of weight in metric kilograms
MDASA	Moringa Development Association of South Africa
Mg	Magnesium
Mg	Measure of weight in metric milligrams
MOE	*Moringa oleifera* Extract
MUFA/SFA	The ratio of monounsaturated fatty acid to saturated fatty acid.
Na	Sodium
NEMBA	National Environmental Management of Biodiversity Act 10 of 2004
NUST	Namibia University of Science and Technology
OPEX	Operational Expenditure
RfD	Reference oral dose that is an estimation of the daily exposure of a contaminant to which the human population may be continually exposed to over a lifetime without an appreciable risk of harmful effects.
RO	Reverse Osmosis
SABS	South African Bureau of Standards

SANAS	South Africa National Accreditation System
SDI	Silt Density Index
SWOT	Strengths, Weaknesses, Opportunities and Threats
T	Average age exposure time for no carcinogens (365 days year x number of exposure).
TDS	Total Dissolved Solids
THQ	Target Hazard Quotients
TR	Temperature Regime
™	Officially registered trademark under license.
USA	The United States of America
USD	The currency for the United States of America expressed in dollars.
W	Average Body Weight (kg)
WHO	World Health Organisation
WP	Work Package
Zn	Zinc

GLOSSARY

Agglomeration	A cluster or mass of various parts.
Agitation	Brisk stirring or disturbance of a liquid.
Aluminium Sulphate	A white or colourless crystalline solid used as a flocculating agent in water treatment.
Alzheimer's disease	A form of dementia beginning in middle age and characterised by lapse of memory, confusion, emotional instability and loss of mental ability.
Amino acids	A class of organic compounds containing at minimum one amino group and one carboxyl group.
Anionic	A negatively charged ion attracted to the anode in electrolysis.

Anthropogenic	Environmental pollution and pollutants originating in human activity.
Anti-carcinogenic	A substance which counteracts or inhibits the development of cancer causing cells.
Anti-inflammatory	A substance used to reduce inflammation; a localised physical condition whereby parts of the body become swollen, hot and painful, usually caused by injury or infection.
Antibiotic	An agent or substance which acts against all types of bacteria including microorganisms.
Antifungal	A substance used to prevent fungal growth.
Antimicrobial	An agent which actively kills or prevents the growth of microorganisms.
Antioxidant	A substance which inhibits oxidation, especially one used to counteract deterioration of stored food products in the body.
Aquaculture	Agriculture taking place in water through cultivation of aquatic animals and plants (especially fish) in natural or controlled marine or fresh water environments.
Arachidic acid	A crystalline, water insoluble solid obtained from peanut oil with chemical formula: $C_{20}H_{40}O_2$. Used in the manufacture of waxes, plastics and lubricants.
Arginine acid	An alpha amino acid used in biosynthesis of proteins, essential in the human diet.
Aromatherapy	Cosmetic, medicinal, mood or behavioural treatments making use of the natural oils extracted from flowers, bark, stems, leaves, roots or other parts of a plant to enhance psychological and physical well-being.
Arrhythmia	An irregular/ abnormal heartbeat.
Arthritis	A disease causing painful inflammation and stiffness of the joints.
Ascorbic acid	A vitamin found particularly in citrus fruits and green vegetables. It is essential in maintaining healthy connective tissue and is also thought to act as an antioxidant. Severe deficiency causes scurvy.
Behenic acid	A carboxylic acid, the saturated fatty acid with formula $C_{22}H_{44}O_2$. It is a white or cream, crystalline or powder in appearance, with a melting point of 80 °C and boiling point of 306 °C. Used mainly in the manufacture of cosmetics.
Bioprospecting	The exploration of biodiversity for commercially valuable genetic resources and biochemicals regulated In South Africa by NEMBA, BABS Regulations.

Botanical	A substance obtained from plants and used typically in medicinal or cosmetic products.
Caprylic acid	A liquid fatty acid present in animal and some plant fats with chemical formula $C_8H_{16}O_2$.
Cardiovascular	Relating to the heart and blood vessels.
Carotenoids	Any of a class of mainly yellow, orange, or red fat-soluble pigments which play an important role in plant, animal and human health.
Cerotic acid	A white, crystalline, water-insoluble and odourless wax usually obtained from beeswax, with chemical formula: $C_{26}H_{52}0_2$.
Chlorosis	A condition during which leaves produce insufficient chlorophyll. Given that chlorophyll is responsible for the green colour of leaves; chlorotic leaves are pale, yellow, or yellow-white.
Coagulant	A substance which causes a liquid compound to transform into a solid or semi-solid state; a thickening agent.
Colloid	A homogenous non-crystalline substance consisting of large molecules or ultramicroscopic particles dispersed through another substance. Particles do not settle and cannot be separated out be ordinary filtering.
Daltons	Atomic mass unit in measurement of weight in proteins.
Diabetes	A disease in which the body's ability to produce or respond to the hormone insulin is impaired, resulting in abnormal metabolism of carbohydrates and elevated levels of glucose in the blood.
Embryonic	Relating to the stage of development in offspring (in particular human offspring) from the second to the eighth week after fertilisation.
Enfleurage	Extraction of essential oils and perfumes from flowers using odourless animal or vegetable fats.
Erucic acid	A solid unsaturated fatty acid present in plant oils associated cardiac muscle damage to the human body, with chemical formula: $C_{22}H_{42}O_2$.
Flavonoids	A sub-class of plant or fungus secondary metabolites with a yellow pigment.
Flocculation	The process in chemistry whereby particles are separated from a liquid to clump together into masses.
Gadoleic acid	An unsaturated fatty acid predominant in fish oil with chemical formula $C_{20}H_{38}O_2$.

Glutamic acid	A crystalline amino acid with chemical formula $C_5H_9NO_4$ that is widely distributed in plant and animal proteins and that acts throughout the central nervous system especially in the form of a salt or ester as a neurotransmitter which excites postsynaptic neurons.
Hepatoprotective	Any substance with the ability to prevent damage to the liver. Opposite to hepatotoxicity.
Hydrolysis	Chemical decomposition whereby compounds are split through a reaction with water.
Hypercholesterolemia	Medical condition whereby an excess of cholesterol; a sterol compound found in most body tissues, is present in the blood stream.
Hypertension	A long term medical condition in which blood pressure is persistently elevated to a level higher than 130 over 80 millimetres of mercury.
Hypoglycemic	Relating to hypoglycemia, an abnormally low level of sugar glucose in the blood, usually a complication of diabetes, in which the body does not produce enough insulin to fully metabolise glucose.
Hypokalaemia	A condition when blood's potassium levels are too low.
Iodine	The chemical element of atomic number 53, a non-metallic element forming black crystals and violet vapour.
Isothiocyanates	The chemical group –N=C=S, formed by substituting oxygen in the socyanate group with a sulphur.
LD_{50}	LD stands for 'Lethal Dose' (LD_{50}) and is the amount of a material given all at once which caused the death of 50% of a group of test animals. The LD_{50} is one way to measure the short-term poisoning potential (toxicity) of a material.
Lignoceric acid	A saturated fatty acid found in cerebrosides and most natural fats, with chemical formula $C_{23}H_{47}COOH$.
Linoleic acid	A polyunsaturated fatty acid present as a glyceride in plant oils, essential to the human diet.
Linolenic acid	A polyunsaturated fatty acid containing an additional double bond to that of linoleic acid, present as a glycerine in plant oils, essential to the human diet.
Macronutrient	A chemical element or substance which is essential in relatively large volumes to sustain growth and health of a living organism.

Malnutrition	Lack of adequate nutrition caused by lack of sufficient food, lack of sufficient healthy nutritious food, or the inability to extract nutrition from available food.
Methionine acid	An amino acid, one of the building blocks of protein, essential for the human diet.
Micronutrient	A chemical element or substance which is required in trace amounts for normal growth and development of living organisms.
Microorganism	A microscopic organism unable to be viewed with an unaided eye, usually bacterium or fungus.
Mineral oil	Oil extracted from distillation of petroleum, used in cosmetics and medicines.
Monounsaturated	An organic fatty compound lacking a hydrogen bond in one link of the carbon chain, associated low cholesterol in the blood.
Myristic acid	A common saturated fatty acid present in natural fats, with chemical formula $CH_3(CH_2)$12COOH.
N: P: K	Used in reference to soil quality, specifically used in artificial fertilisers. The values N, P and K are expressed as value percentages, indicating the ratio of macro nutrients present, namely Nitrogen (N), Phosphorus (P) and Potassium (K); elements necessary for healthy soil and plant growth.
Neuroprotection	Activity resulting in the salvage, recovery or regeneration of the nervous system, its cells, structure and function.
n-hexane	A colourless liquid hydrocarbon made from crude oil and is present in petroleum spirit. Usually mixed with solvents for a number of uses.
Non-drying oil	An oil that does not harden when exposed to air
Nutraceutical	A food item or dietary supplement which provides health or medicinal benefits.
Oleic acid	An unsaturated odourless and colourless fatty acid present in many fats and soaps.
Oxidation	The process whereby elements are converted into an oxide by adding oxygen or removing hydrogen.
Palmitic acid	A solid waxy and crystalline saturated fatty acid obtained from vegetable oils or animal fats with chemical formula $CH_3(CH_2)_{14}COOH$. Also referred to as hexadecanoic acid.
Palmitoleic acid	An unsaturated fatty acid common in glycerides of human tissue with chemical formula: $CH_3(CH_2)_5CH = CH(CH_2)_7COOH$.

Pharmaceutical	A compound manufactured for use as a medicinal drug.
Pharmacological	The branch of medicine concerned with use, effects and mode of action of drugs.
Phenolic	A class of bioactive chemical compound with a hydroxyl group bonded to an aromatic hydrocarbon group, occurring widely in food plants.
Polyelectrolyte	A natural or synthetic electrolyte of a high molecular weight.
Polymer	A substance consisting of large numbers of similar units bonded together.
Polypeptides	A chain of amino acids linked together by common compounds containing two or more amino acids which the carboxyl group of one acid is linked to the amino group of the other and having a molecular weight of up to 10,000.
Polyunsaturated fatty acid	A class of animal or vegetable fats whose molecules consist of carbon chains with double bonds unsaturated by hydrogen atoms, associated with low cholesterol content in the blood.
Reverse osmosis	The process in chemistry whereby untreated water is forced through a semi permeable membrane to produce pure water.
Rheumatism	A disease marked by inflammation and pain in the joints, muscles or fibrous tissue.
Ruminant	A mammal with hoofed even toes of the suborder Ruminant, comprised of cloven-hoofed and cud-chewing quadrupeds including cattle, bison, buffalo, dear, antelope, giraffe, camels and chevrotains.
Saponification	Hydrolysis of a fat by an alkali with the formation of a soap and glycerol.
Sedimentation	The deposition and accumulation of small particles settling in a body of water.
Silt Density Index	A measure to estimate the rate of colloidal and particle (suspended solids) fouling in water purification systems.
Socioeconomic	Relating to or concerned with the interaction of social and economic factors.
Spirulina	A form of cyanobacteria containing high volumes of vitamins and minerals usually dried and prepared for nutritional consumption.
Stearic acid	A colourless, odourless, waxy and water soluble fatty acid occurring as glycerine in animal fats and oils, with chemical formula CH18H3602.

Synergistic effect	An affect arising between two or more elements or substances, when they are combined together producing a greater effect than the sum of the individual effect.
Total dissolved solids	Measures the quantity of all compounds dissolved in water.
Turbid	The presence of suspended matter or sediments in a liquid which creates a cloudy opaque or thick appearance.
Ultra-filtration	Filtration utilising fine mediums to retain colloidal particles, viruses and large molecules.
Utero	Inside the female uterus prior to birth.
Viscosity	A thick, sticky and semi-fluid consistency caused by internal friction in a liquid. Measured by force per unit area resisting uniform flow.
Weevil	A small beetle with an elongated snout, the larvae of which typically develop inside seeds, stems, or other plant parts. Many are pests of crops or stored foodstuffs.

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1. LITERATURE REVIEW

1.1. INTRODUCTION

Moringa is an ontogenetic family of shrubs and trees and the Moringa genus comprises 13 species. *Moringa ceace* was first discovered in India, Asia and was then naturalised in tropical and subtropical Africa (Nadkarni, 1976). Moringa has three classes; slender trees, bottle trees, shrubs and herbs. The bottle trees are the *Moringa ovalifolia, Moringa hilderbrandtii* and *Moringa drouhardii*. The slender trees group is further categorised into three species, namely the *Moringa concanensis*, *Moringa peregrina* and *Moringa oleifera*. These are predominantly found in Arabia, the Red Sea and the Indian subcontinent. The third group of Moringa, classed as shrubs and herbs, are found in the North-East Africa and constitute eight of the total thirteen species of Moringa species, namely; *Moringa rivae*, *Moringa ruspoliana*, *Moringa longituba, Moringa borziana, Moringa arborea, Moringa stenopetala* and *Moringa pygmaea*. Some of these Moringa species have only been collected or exploited a few times such as the *Moringa arborea* which has been collected less than twenty times by botanists.

1.2. *Moringa oleifera*

Moringa oleifera has been the most extensively researched and studied species of the Moringa genus, thus making it the focus of this research study. Research studies indicate that not only are the leaves of the *Moringa oleifera* highly nutritious, but the entire *Moringa oleifera* tree (with the exception of the roots) is edible and highly nutritious with above average levels of carbohydrates, protein, minerals, and vitamins (Fuglie, 2001). The leaves contain more vitamin C than oranges, more potassium than bananas and more protein than eggs and milk (table 1.2.a). The plant has primarily been used for its medicinal and nutritional benefits. For instance, in Africa, Moringa has been used by breastfeeding mothers as a supplement due to its ability to increase lactation and assist them in managing childhood malnutrition, thus decreasing the mortality rate amongst young children (Sambou, 2001).

Table 1.2.a: *Moringa oleifera* properties, applications and benefits

***Moringa oleifera* leaves**		
Properties	**Applications**	**Benefits**
Antioxidant Flavonoids Minerals and vitamins Amino acids	Food supplement Source of protein	Therapeutic Stabilizes cell structure Promotes metabolism

Moringa oleifera seeds are also valuable. Ben oil can be extracted from them through the processes of solvent extraction and CO_2 supercritical extraction. The seeds harvested from their pods can yield approximately 35 to 40% of non-drying Moringa oil. The use of an n-hexane (Mani et al., 2007), petroleum ether and acetone solvents for experimental oil extraction and supercritical extraction with CO_2 on Moringa seeds have also been reported (Nguyen et al., 2001).

Moringa seed oil is clear with a nutty aroma and because of its antioxidant properties, does not turn rancid for longer periods post-production. The oil content of de-hulled seed (kernel) is approximately 42% and commonly used as a lubricant for fine machinery such as time pieces, due to its non-rancid property (Ramachandran et al., 1980). The seed oil also has several health and beauty applications and contains approximately 70% of oleic acid. It is a monounsaturated fatty acid that possesses good oxidative stability when compared with polyunsaturated fatty acids. Ben oil is also more stable than canola oil, soybean oil and palm oil when used in frying. Consequently, blending Ben oil with sunflower oil and soybean oil enhances the oxidative stability of the mixture. In addition, Moringa seed oil's chemical properties are comparably equivalent to those of olive oil. Table 1.2.b. highlights the properties, applications and benefits Ben oil (Mani et al., 2007).

Table 1.2.b: *Moringa oleifera* seeds and ben oil properties, applications and benefits.

1.2.1. *Moringa oleifera* cultivation

Product	Properties	Applications	Benefits
***Moringa oleifera* seeds**	• Antioxidant • Anti–microbial • Anti–inflammatory • Phenolic • Bio active • Compounds • Anti-fungal	• Oil extraction • Water purification • Lubricant • Medicinal (treating diarrhoea)	• Skin remedies • Liver health
Ben oil	• Antioxidant • Anti-microbial • Anti-aging • Exfoliant • Preservative • Anti-inflammatory • High oxidation stability	• Soap • Lubricant • Food (edible oil) • Cosmetics (skin, hair, perfume base)	• Skin remedies • Rheumatic oil for arthritic joints • Excellent moisturiser

Moringa oleifera is a deciduous tree which within the first year of planting can grow up to 3 metres in height and can subsequently grow as tall as 15 metres. In the first 6-12 months, the *Moringa* tree can produce fruit, however, on average, it takes a period of two years to produce seeds. The favourable conditions under which to grow *Moringa oleifera* are temperatures between 25- 30^{0}C, although the plant is capable of withstanding temperatures of up to 48˚C.
However, temperature also has an effect on the germination and seedlings. A germination trial study conducted at the University of Pretoria on *Moringa oleifera* seeds under three different temperature regimes (*TR) 10/20˚C ± 2˚C, 15/25˚C ± 2˚C and 20/30˚C ± 2˚C* revealed temperature to be a contributing factor in the variation of germination percentages (Muhl, 2009). The germination trial highlighted that higher TR (20/30˚C) also favoured seedling growth whereby the seedlings' growth increased exponentially with an increase in

temperature. Accordingly, the 20/30˚*C* TR was found to be the most favourable regime for both germination and seedling growth (Muhl, 2009).

Figure 1.2.1.a: *Moringa oleifera* Tree (NBEF Organics Farm Tzaneen).

The most favourable soil type for *Moringa oleifera* cultivation is well-drained sandy loam soil. The *Moringa oleifera* plant can grow in both acidic and basic soil types, with pH levels ranging from 5.0 to 9.0. The plant can withstand a range of climatic conditions. However, it cannot survive in flood prone areas or areas with poor drainage. Thus, 250 to 300mm of rainfall is sufficient for *Moringa oleifera* water requirements (Palada and Chang, 2003).

1.2.2. *Moringa oleifera* value

Moringa oleifera is considered a highly nutritive component in many parts of Africa and Asian countries. The various health benefits of *Moringa oleifera* are well-researched, documented and confirmed in several studies, particularly on the leaves, pods and seeds as discussed below.

1.2.2.1. Leaves

The leaves of the *Moringa oleifera* are known to contain amino acids (Mishra et al., 2000) that were previously only found in animals. The leaves (figure 1.2.2.a.) have also been proven to be a rich source of B-carotene, protein, vitamin C, calcium, potassium, antioxidant and flavonoids (Sambou, 2001).

1.2.2.2. Moringa Pods & Seeds

The *Moringa* pods are a good source of calcium and phosphorus. The oil extracted from *Moringa oleifera* seeds contains approximately 13% saturated fatty acids and 82% unsaturated fatty acids. It also has a particularly high level of oleic acid (70%) in comparison to other vegetable oils, which usually contain approximately 40% oleic acid (Foidl et al., 2001).

The roots of the *Moringa oleifera* are characterised to have medicinal properties. However, consumption in high dosages can be fatal due to the presence of spirochinalkaloid, a fatal nerve paralysing agent (Nellis, 1997).

Figure 1.2.2.a: *Moringa oleifera* leaves

Figure 2.2.b: *Moringa oleifera* seeds

Figure 1.2.2.c: *Moringa oleifera* pods.

1.2.3. *Moringa oleifera* uses

Several studies have been conducted in exploring the use of *Moringa* for various industries. The most well-studied and exploited uses of *Moringa oleifera* are medicinal and nutritional in nature. However, in recent years other uses of *Moringa oleifera* have been studied and their application explored in other industries such as water treatment and animal feed.

1.2.3.1. Water Treatment

Moringa oleifera seeds are known to contain coagulation properties for treating water and wastewater (Lata and Rohindra, 2002). Figures 1.2.3.1.a & b indicate the effects of *Moringa oleifera* seeds utilised in water treatment. Recently, academic institutions such as the Namibia University of Science and Technology (NUST) and the University of Developmental Studies in Ghana have independently conducted studies on the effectiveness of *Moringa oleifera* seeds as a coagulant for water purification. The study from NUST concluded that Moringa seeds have the following properties when utilised for water treatment (Kwaambwa, 2016):

Figure 1.2.3.1.a: Effects of *Moringa oleifera* seeds utilised in water treatment

i. Removal of heavy metals.
ii. 92-99% reduction in turbidity.
iii. Coagulant protein interacts with surfacts in the order of anionic to cation to non-ionic.
iv. The coagulant forms biodegradable sludge whose volume is lower when compared to chemical coagulants such as aluminium sulphate.
v. Decreases clay and bacteria content in raw water.

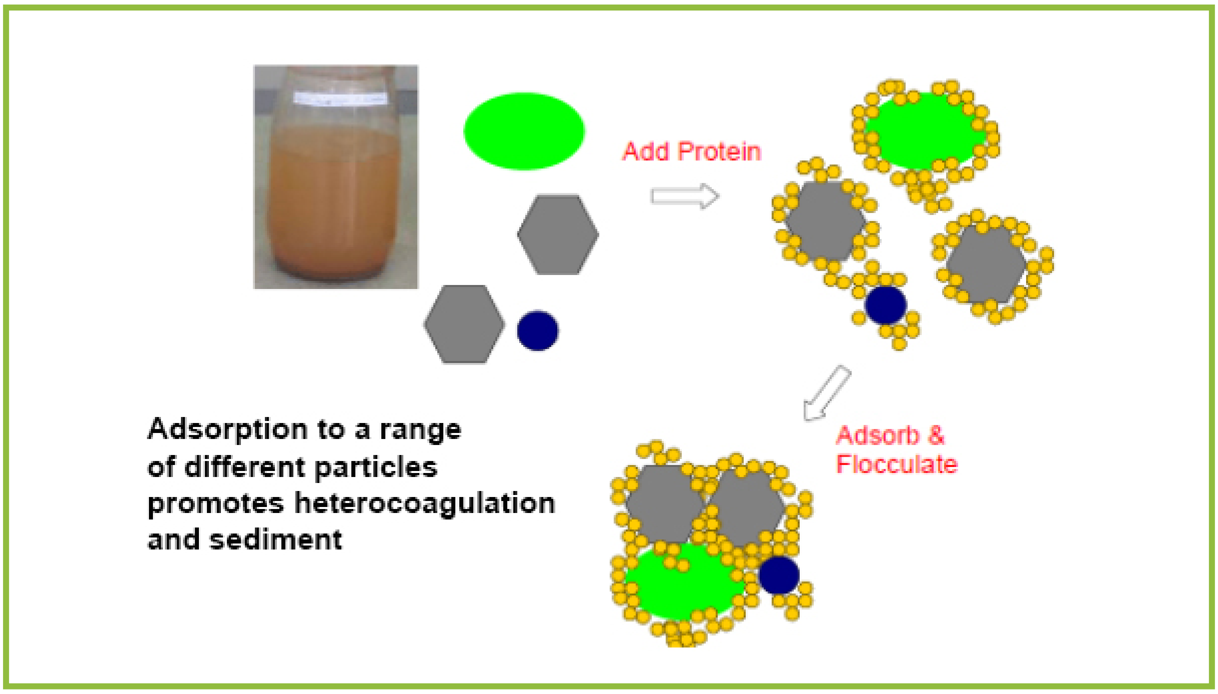


Figure 1.2.3.1.b: Mechanism of *Moringa oleifera* seeds protein in water treatment.

1.2.3.2. Animal Feed (Moringa leaves and seeds)

The *Moringa oleifera* plant can be recommended as a protein supplementary in animal feed for livestock based on recent studies conducted goats and broiler chickens. A study was conducted at the University of Fort Hare's Honeydale farm on cross-bred Xhosa lop-eared goats to determine the effect of feeding *Moringa oleifera* leaf meal on the physio-chemical characteristics of goat meat (Moyo et al., 2014). The study findings and results indicated that the cross-bred Xhosa lop-eared goats that were fed a meal supplement with *Moringa oleifera* leaf produced goat meat of comparable quality to cross-bred Xhosa lop-eared goats fed sunflower seed cake meal.

At the University of Limpopo, a study was conducted to determine the effects of a *Moringa oleifera* seed-supplemented diet on the productivity of Ross 308 broiler chickens. The study findings and results indicated that the *Moringa oleifera* seed diet improved growth rate in Ross 308 broiler chickens aged 1 to 21 days and reduced mortality rate as no deaths were observed over the period of the study (Molepo, 2014). Therefore, both studies provided evidence of positive effects to animals fed a *Moringa* leaf and seed supplemented diet.

1.2.4. Toxicology

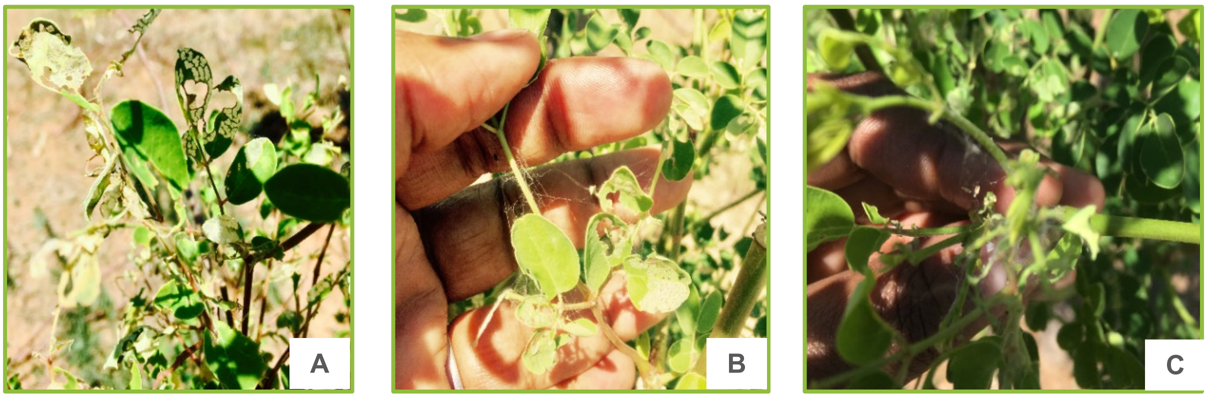
There is very limited research and information on the toxicity of the *Moringa oleifera*, however one study on the acute and chronic toxicity of *Moringa oleifera* leaf extract was conducted as a clinical trial on mice in 2011 in Thailand. This research study revealed that *Moringa oleifera* extract (MOE) caused no acute toxic effect and had median lethal dose (LD_{50}) value in mice more than 20g/kg (Chivapatet al., 2011). The different MOE doses did not affect growth, organ weight, haematological values nor almost all other clinical chemistry values. The results of the study however, revealed a decrease in potassium levels to the female mice that received the highest dose of MOE, suggesting that long-term ingestion or exposure to MOE may affect potassium levels and it may not be suitable for patients suffering from hypokalaemia and arrhythmia (Chivapat et al., 2011).

1.3. *Moringa oleifera* PESTS AND DISEASES

Moringa oleifera is a resilient and adaptable crop tree that is known not to succumb too easily to serious diseases and pests (Ramachandran et al., 1980). However, a study conducted in India identified *Moringa oleifera* as a host to *Leveillula taurica,* a powdery mildew (Ullasa and Rawal, 1984). In some instances, the presence of pests was observed as a result of root rot, fruit rot, stem rot and twig canker (*Fusarium pallidoroseum)*. Most research studies have been conducted on *Moringa oleifera* pests and consequently, little is known about diseases affecting *Moringa oleifera* with the exception of the *Drechslera hawaiiensis,* which attacks the edible pods of *Moringa oleifera* in India (Kshirsagar et al., 1989). A number of pests that infest *Moringa oleifera* are well documented in India and other African countries. Some of the more common pests discussed below are the *Noorda moringae, Myllocerus spp., Noorda blitealis, Eupterote mollifera*, *Batocera rubus* and *Gitona distigma*. The less common pests, based on the nature of damage and sporadic occurrence, are the *Aphis craccivoca*, white fly, mites and flower thrips. In recent years, Yusuf and Yusif (2014) identified the leaf feeding pest *Ulopeza phaeothoracica* in Nigeria and the pest caused severe leaf damage on *Moringa oleifera*. Further studies were also conducted by Kotikal and Math (2016) reviewing *Moringa oleifera* pests' infestation at different growth stages, from different regions across the world.

1.3.1. Defoliators or Leaf feeders

Noorda blitealis is the most commonly found leaf herbivory insect that infests on *Moringa oleifera* across different geographical regions. According to Munj et al., (1998) the insect is active throughout the year, but its lowest infestation occurs during the months of May-June in Konkan region of Maharashtra, on the western coastline of India. The *Noorda blitealis* affects the quality and quantity of leaves and the larvae attaches onto the underside of the leaf and feeds on the leaflets. This causes the leaves to dry to a papery texture and severe infestation ultimately leading to defoliation of the entire tree.



Figures 1.3.1.a, b & c: Leaf feeders' symptoms with a network of silken threads on *Moringa oleifera* leaves at Nyala Farm.

During a farm visit at Nyala farm in the North West Province, *Moringa oleifera* leaf damage resembled that similar to the leaf defoliators, *Noorda blitealis* (figure 1.3. a, b and c) with silken threads on the infested leaves.

Figure 1.3.1: *Moringa oleifera* leaves depicting the effects of Ulopeza phaeothoracica.

The findings from Sati et al., (2012) demonstrate that the larvae of the *Noorda blitealis* feed off the leaves with the network of silken threads by hanging onto the leaves. Leaf feeders such as the *Noorda blitealis* and the *Ulopeza phaeothoracica* have been recorded to cause severe damage to the Moringa leaves in Niger (Litsinger, 2014), Sudan (Satti et al., 2013), Burkina Faso (Dao et al., 2015) and Nigeria (Ratnadass et al., 2011). The *Ulopeza phaeothoracica* as shown in figure 1.3.1. feeds on the leaf lamina creating window like openings on the leaf. The other pest that infests Moringa leaves is the *Eupterote mollifera*, a hairy caterpillar that caused complete leaf defoliation on *Moringa oleifera* in Sudan (TNAU Agritech, 2014). This type of caterpillar infests the leaves by scraping and gnawing on the folia.

1.3.2. Sap or Sucking feeders

The sap or sucking insects attack the crop by sucking or draining the plant sap directly and are potentially the source of viral diseases. In Kamalaka, India the plant lice *Aphis craccivora* was observed to have infested the tender shoots of *Moringa oleifera* on the underside of the leaflets (David, 1958), resulting in the yellowing and drying of the leaves. The white flies, *Trialeurodes rara* and the scale insects (i.e. *Ceroplastodes cajani and Diaspidiotus sp.*) are known to infest *Moringa oleifera* by sucking the sap from the surface beneath the leaflets and tender twigs. The *Aphis gossypii* commonly known as the cotton aphid infests the *Moringa oleifera* by attacking the crop's shoots (Ayyar, 1929). These sucking insects are often controlled with the use of dimethoate or malathion.

Figure 1.3.2: Plant lice *Aphis craccivora* feeding on the under surface of the *Moringa oleifera* leaves.

1.3.3. Flower or bud or fruits feeders

The bud worm, *Noorda moringae* and the pod fly*, Gitona distigma* are the most common bud feeders that infest *Moringa oleifera* (TNA Agritech, 2014). The bud worm *Noorda moringae* infests Moringa by boring into the flower buds and causes the shedding of the buds. Severe infestation of *Noorda moringae* has been observed in South India and it caused approximately 78% bud damage, occurring throughout the year except during the month of December (TNA Agritech, 2014). The fruit fly or pod fly *Gitona distigma* was noted to infest *Moringa oleifera* from fruit initiation up to the harvesting stage. The common symptoms of the pod fly infestation on Moringa are the splitting of pods, oozing out of gum from the fruit and drying of the pods (Honnalingappa, 2001). The *Gitona distigma* pod flies can be controlled by attractants such as acetic acids (vinegar) or lactic acids. Usha rani et al., (2010) found the bud midge, *Stictodiplosis moringae* larvae to be feeding on the internal content of the flower buds causing shedding of buds in large numbers.

Figure 1.3.3: *Gitona distigma,* pod fly and young larvae on pods of *Moringa oleifera.*

1.3.4. Mites

The *Tetranychus neocaledonicus* are mites that feed on *Moringa oleifera* causing the formation of white spots, that are visible through the chlorosis of the leaves. These mites are vagrants on the leaf and stem, showing minimal observable damage on their host. However, the affected leaves often exhibit chlorophyll loss and subsequently the leaves dry out and fall off (Palada and Chang, 2009).

1.3.5. Weevils

Several species of weevils *Myllocerus* have been reported to cause damage on the leaves of *Moringa oleifera* (Subramanian, 1965). The ash weevils such as *Myllocerus viridanus, Myllocerus discolour* and *Myllocerus sp.*, are known to cause the notching of leaves on *Moringa oleifera* (Mahesh and Kotikal, 2014).

1.3.6. Beetles

The *Batocera rubus* and *Monohammus spp.* are longhorn beetles that bore into the stems of *Moringa oleifera.* The longhorn beetle's female species of *Monohammus spp*. affect the Moringa plant by excavating the cavity in the stems, causing growing points to wilt and dry, ultimately resulting on the shedding of leaves (Butani and Verma, 1998). The white grub of *Holotrichia insularis* feed on the Moringa roots (Usha rani et al., 2010). The grubs pupate in the soil and the adult grubs are known to be nocturnal. They stay in the soil until the early monsoon showers, then come out at night to feed on the plant foliage (Srivastava and Khan, 1963).

1.4. CHAPTER SUMMARY

Generally, insects and fungi pose potential risk to tree plantations. The *Stenocarpella maydis* fungus, causes Diplodia stalk and ear rot which can destroy *Moringa oleifera.* In South Africa, Diplodia stalk rot commonly occurs in early rainfall season that is followed by midseason drought periods during grain fill. The *Stenocarpella maydis* fungus produces specific mycotoxins that affect species differently in various studies conducted and the initial field symptoms of diplodiosis were reported in South Africa.

Diplodia root rot may occur in waterlogged soils as a result of excessive irrigation of *Moringa oleifera* plant. It can affect leaves causing discolouration from green to yellow, resulting severe wilting that ultimately destroys the plant. Other insects and pests present in several farms around South Africa have the potential to affect *Moringa oleifera* and they include termites, aphids, leaf miners, and whiteflies. These pests can affect *Moringa oleifera* plant at different growing stages in different parts of the tree and thus destroy the plant.

Therefore, research conducted on the pests affecting *Moringa oleifera* has found that various pests described above, may pose significant threats to crop cultivation. These pests are seasonal and location specific, and research and investigation on pests and diseases of *Moringa oleifera* in South Africa is ongoing. Thus, it may be beneficial for farmers to gain a better understanding of their occurrence and the extent of the damage to enable them to take effective control measures during the cultivation of moringa.

2. SOUTH AFRICA'S CONTEXT: *Moringa oleifera*

2.1. REGIONAL POSITION OF *Moringa oleifera* FARMS

The research study commissioned in South Africa about *Moringa oleifera* focused on studying its cultivation and agro-processing aspects across the country. *Moringa oleifera* in South Africa is farmed in Gauteng, Limpopo, the Lowveld Mpumalanga and KwaZulu-Natal provinces, however is mostly farmed in the Limpopo province. The representative sample for the study constituted of ten farms in the Gauteng, Limpopo, Mpumalanga Lowveld, North West and KwaZulu-Natal provinces. Six farms were identified and sampled in Limpopo province as this is an area where *Moringa oleifera* is grown in abundance. The farms in relation to the province regional positions are presented below.

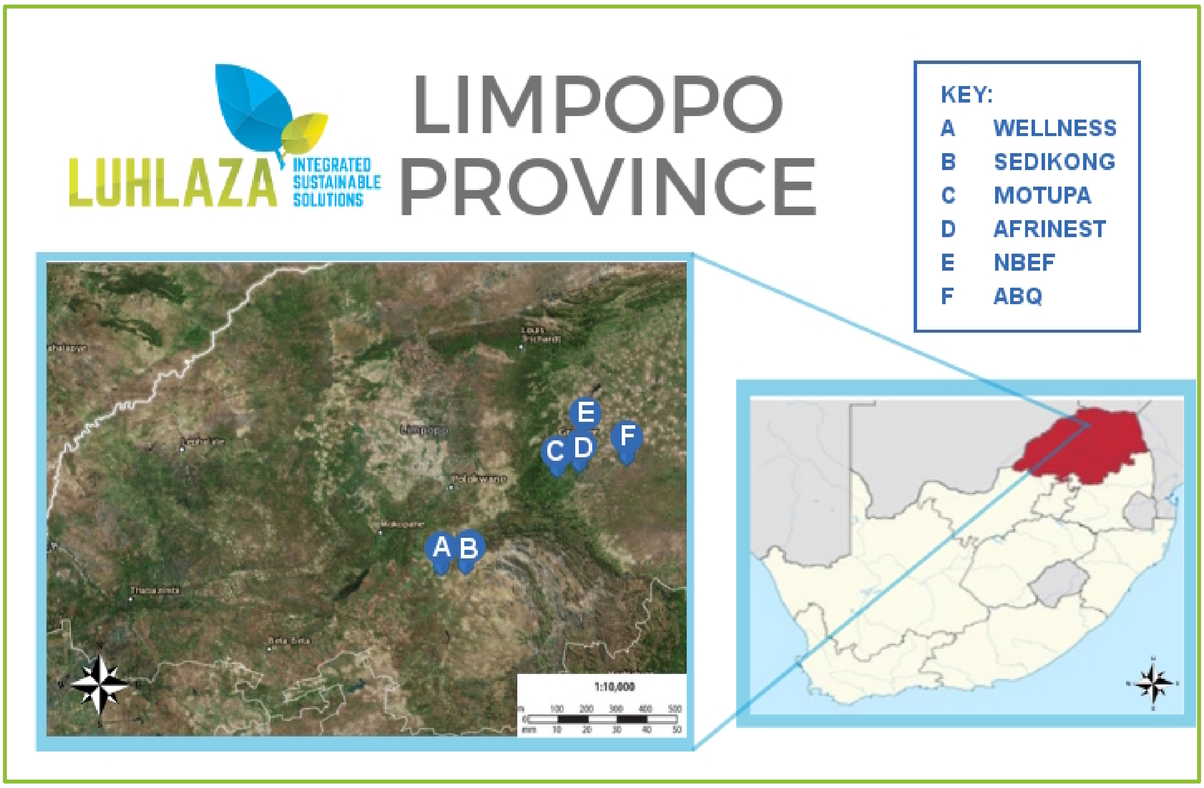


Figure 2.1.a: Regional map of Limpopo farms.

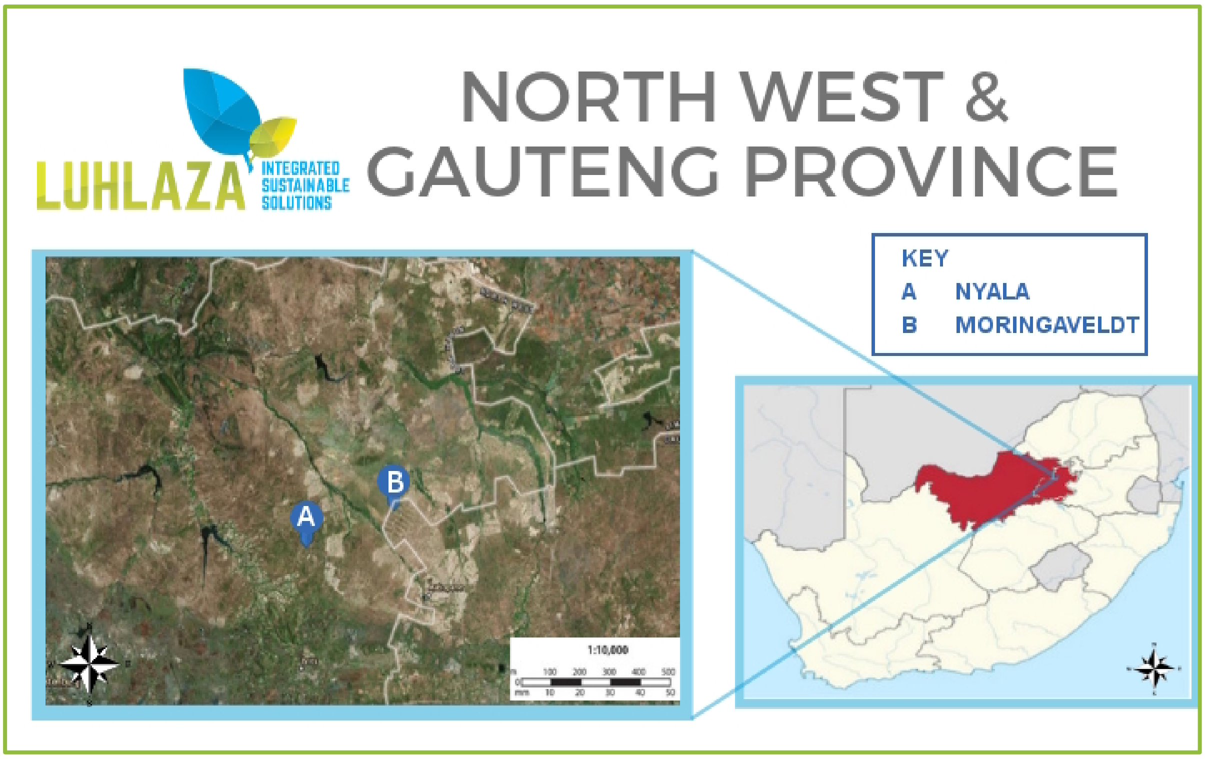


Figure 2.1.b: Regional map of farms in the North West and Gauteng Provinces.

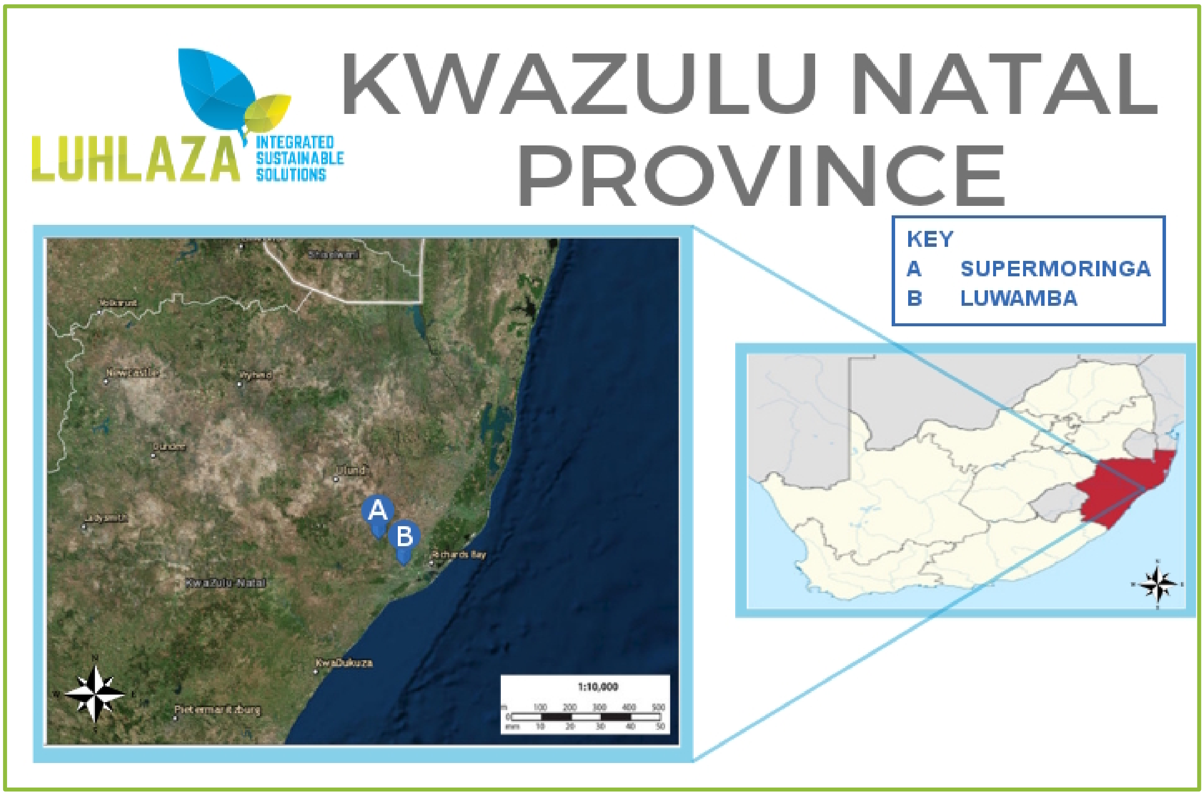


Figure 2.1.c: Regional map of KwaZulu-Natal farms.

2.1.1. Regional climatic conditions - South Africa

These provinces are in different climatic zones as represented in Figure 2.1.1 but experience similar climatic conditions such as wet summers and drier winters. The study sample comprised farms in Gauteng, North West, Limpopo and Kwazulu-Natal Provinces. In total ten farms were visited and as highlighted by the farmers, the climatic conditions have a significant effect on the yields of *Moringa oleifera*. In the Gauteng area where it is dry and cold in winter, the Moringa trees lose their leaves and there is no harvesting during the winter months *(June, July and August)*. In Limpopo province, Tzaneen area which is in the Subtropical Lowveld climate region *(hot rainy summers and warm dry winters)* the *Moringa oleifera* trees retain their leaves throughout the year, however the yield decreases during the winter months.

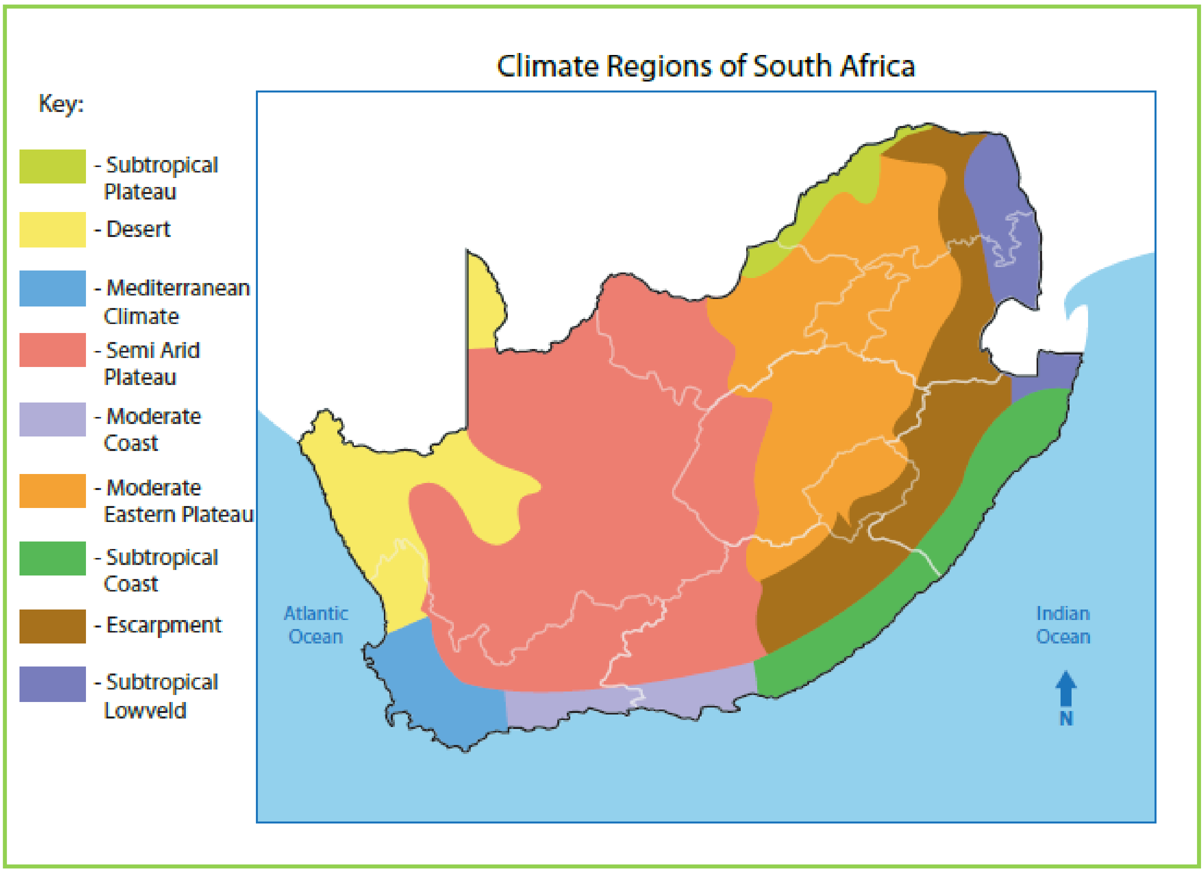


Figure 2.1.1: Climate regions of South Africa.

2.2. *Moringa oleifera*

2.2.1. Cultivation

Based on the literature and findings on Moringa plantation visits, Moringa leaves can be harvested within a minimum period of four months from planting time. In planting the Moringa, farmers experimented with different tree spacing to investigate whether spacing has any significant effect on the growth and yields of Moringa trees planted primarily for leaf harvesting. Results and findings from experiments indicated that tree spacing has no significant effect on the growth but increases the yield because of the increased number of densely planted

Moringa trees. Three out of ten farms visited have employed the drip irrigation method, whilst the third farmer has not implemented a specific irrigation method. This was evident on review of the third farmer's survival of *Moringa oleifera* and the yield, as his Moringa tree survival was low.

The farmers also indicated that Moringa trees are prone to termite infestation; however, one farmer experimented with spraying the plant with Moringa leaf-infused water as a pesticide on a termite infested Moringa tree. The farmer claimed recovery and survival of the tree, suggesting the *Moringa oleifera* exhibits self-healing properties. However, such properties in *Moringa oleifera* will be verified when conducting further analytical studies.

2.2.2. Harvesting and Agro-processing

The *Moringa oleifera* leaves are harvested once a week. During harvesting, care is taken to minimise contamination and remove any residue that may have accumulated on the leaves by washing them three times with clean water. The leaves are then dried and notably, the three farms visited employed different drying methods. One farmer used a two-stage drying system; firstly, by air drying on mesh trays to allow drainage of excess water from the washing process and secondly in the oven set at 45^{0}C for a period of up to a maximum of two days (figure 2.2.a). The other two farmers employ only a single-stage air drying system.

Two Stage Drying System

Air Dried Mesh Trays **Oven**

Figure 2.2.2.a: *Moringa oleifera* two-stage drying system at NBEF farm.

When the drying process is complete, the *Moringa oleifera* leaves are milled and then packaged as various products such as capsules, tea and powder (figure 2.2.2.b.).

Figure 2.2.2.b: *Moringa oleifera* leaf products (capsules and tea).

2.2.3. Research Sample - GIS Maps of South Africa's farms

The maps of the farms that constitute the research sample have been developed and are presented below in Figures 2.2.3.a-h. They provide the geographic locations of the farms visited and sampled for the study.

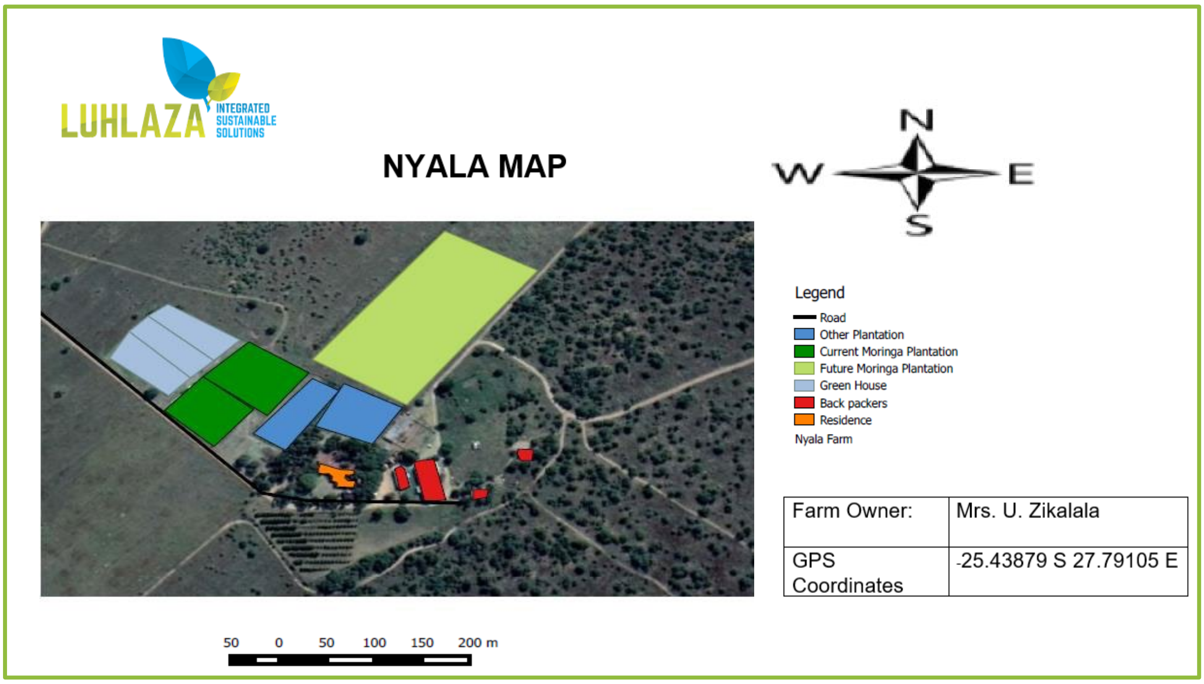
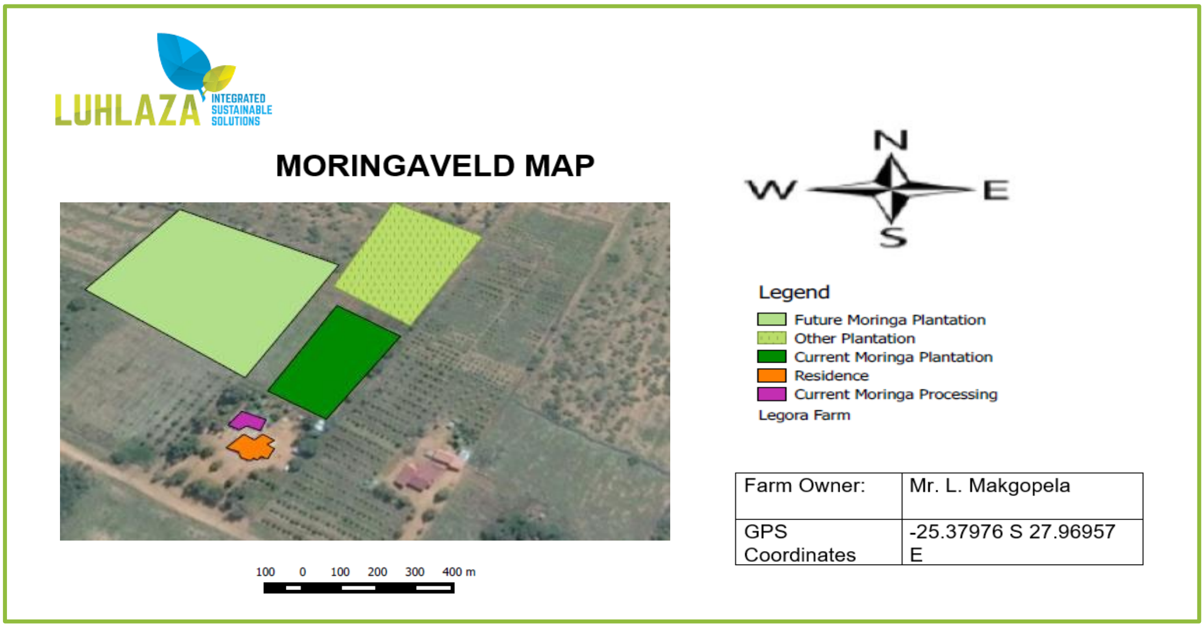
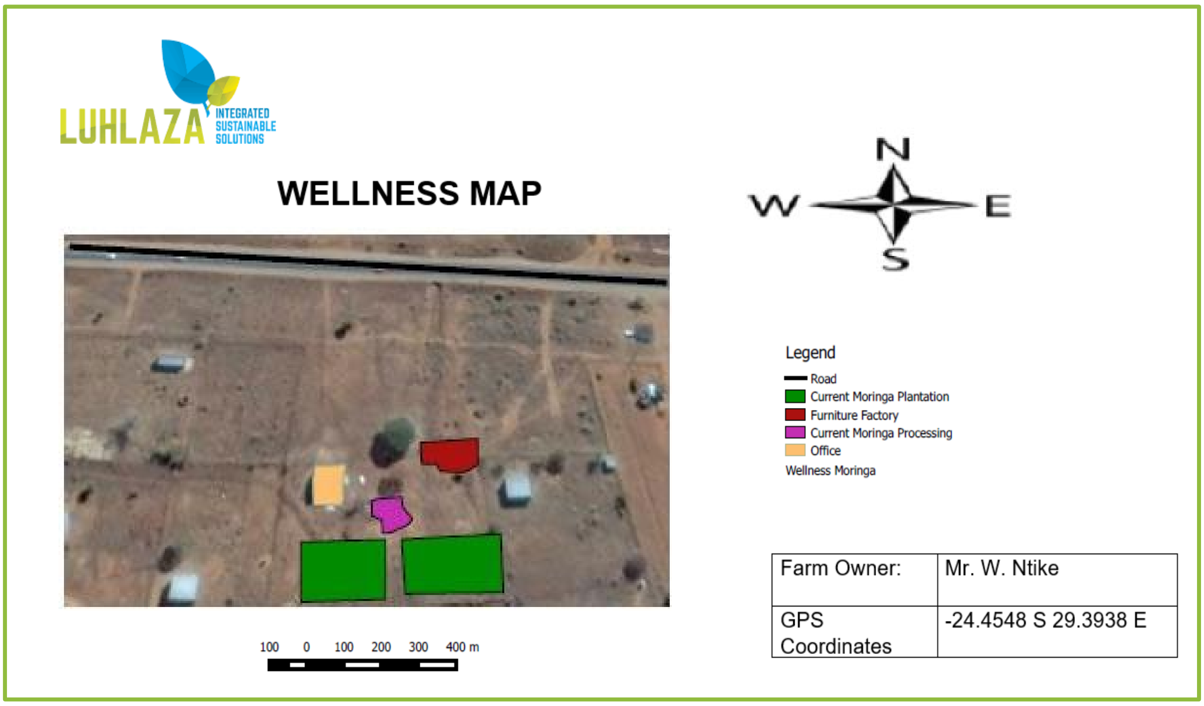


Figure: 2.2.3.a: Nyala farm (Brits) – North West Province.



Farm Owner:	Mr. L. Makgopela
GPS Coordinates	-25.37976 S 27.96957 E

Figure 2.2.3.b: Moringaveldt farm (Winterveldt) – Gauteng Province.



Farm Owner:	Mr. W. Ntike
GPS Coordinates	-24.4548 S 29.3938 E

Figure 2.2.3.c: Wellness Moringa farm (Lebowakgomo) – Limpopo

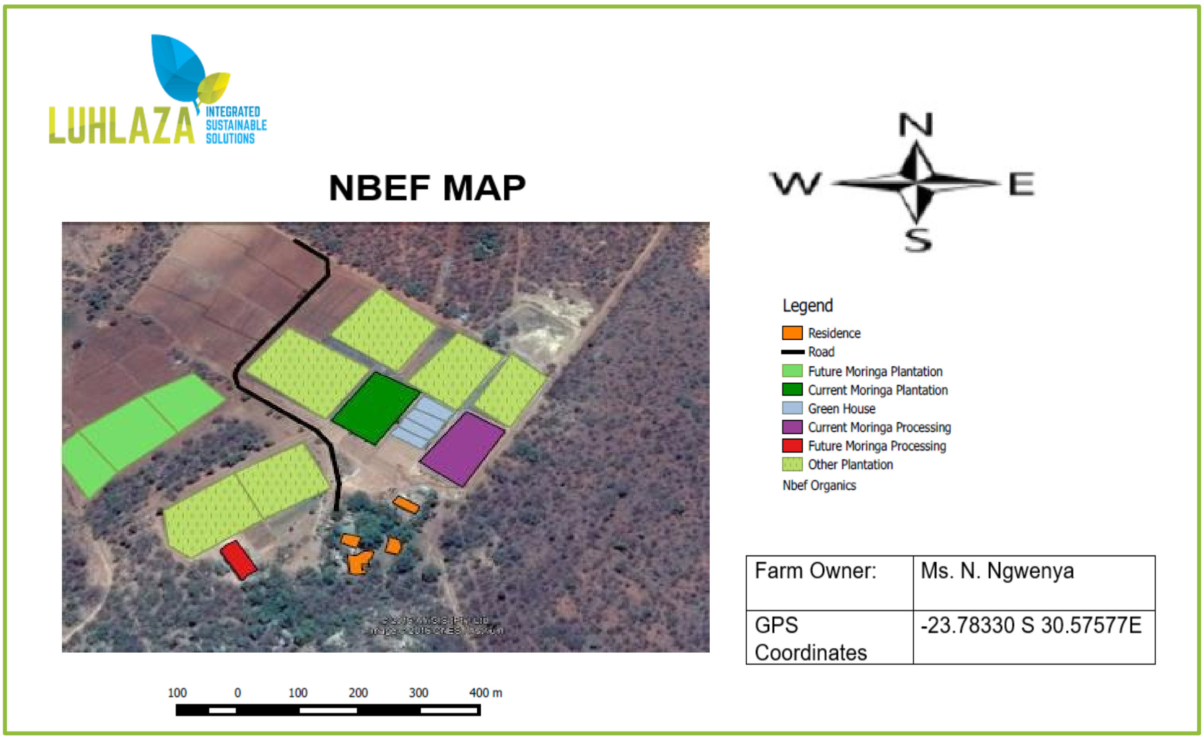


Figure 2.2.3.d: NBEF organic farm (Tzaneen) – Limpopo Province.

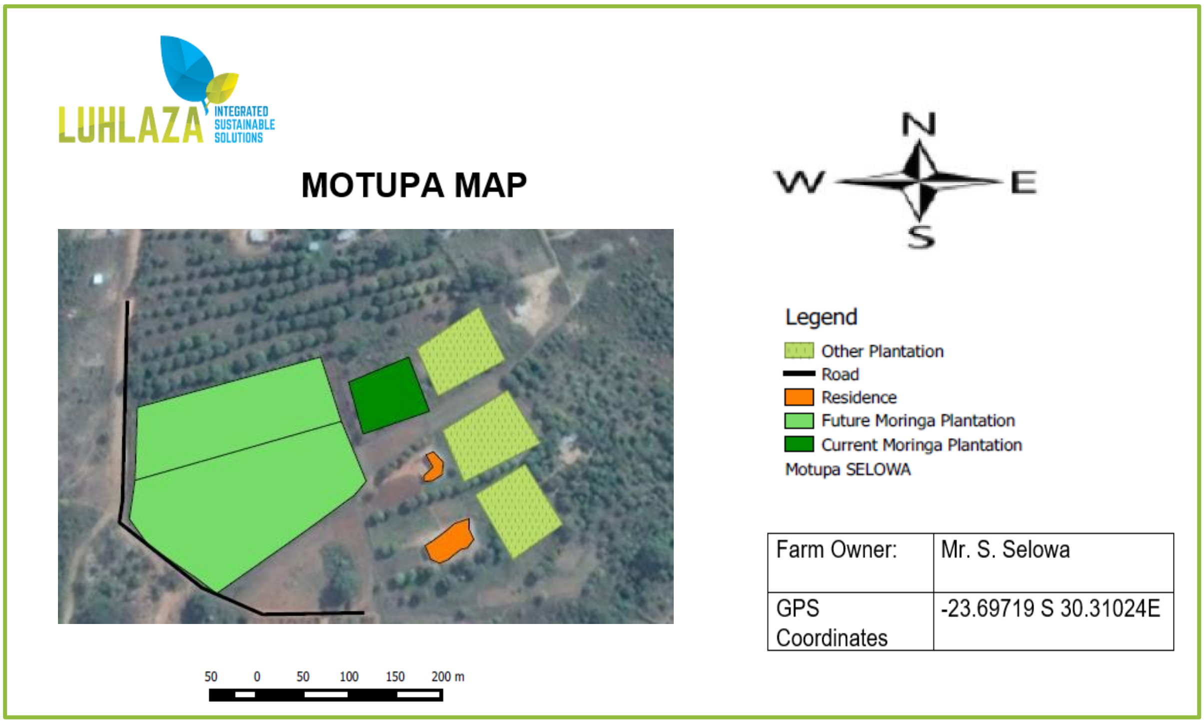


Figure 2.2.3.e: Motupa farm (Tzaneen) – Limpopo Province.

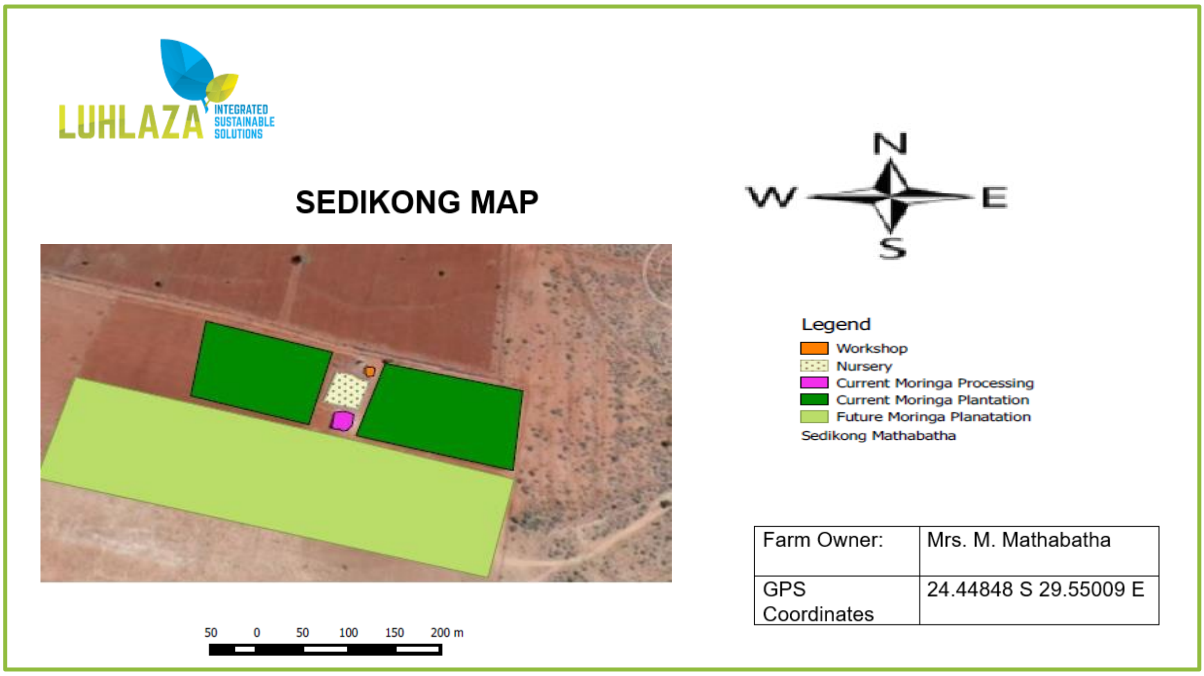


Figure 2.2.3.f: Sedikong farm (Lebowakgomo) – Limpopo Province

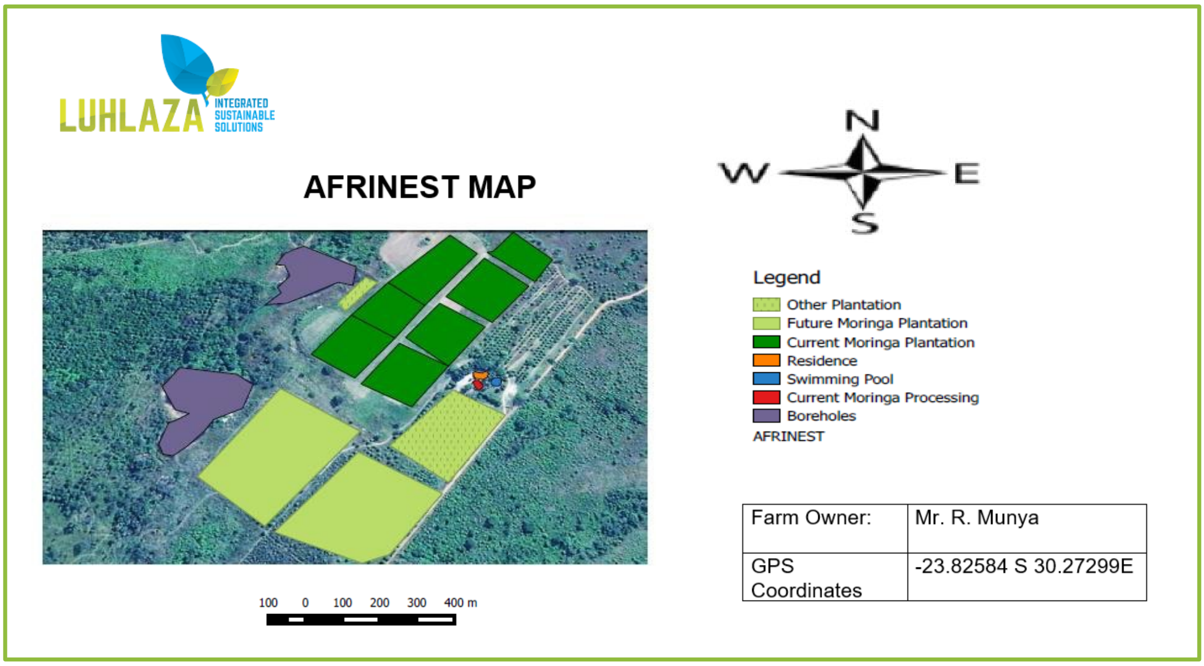


Figure 2.2.3.g: Afrinest farm (Tzaneen_ - Limpopo Province.

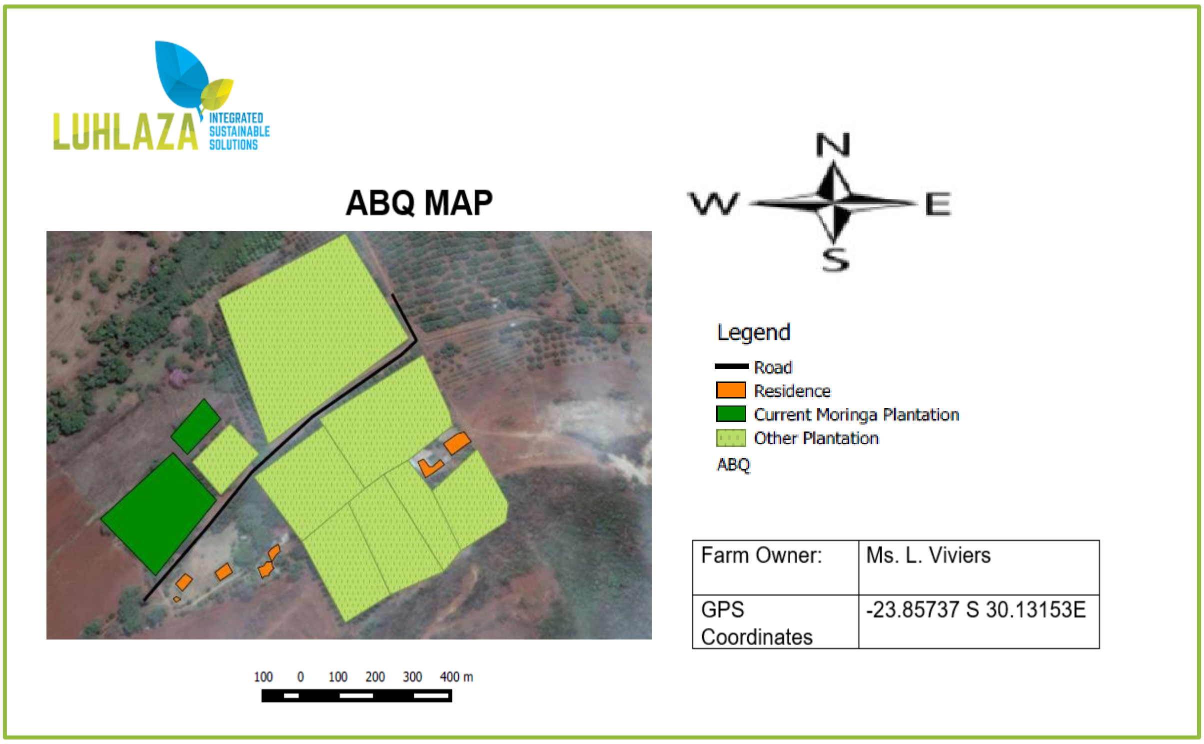


Figure 2.2.3.h: ABQ farm (Tzaneen) – Limpopo Province.

Five out of ten farms are currently operating (farming and agro-processing) on a small-scale and have indicated plans to scale-up operations for commercialisation. Most of the Moringa farmers are planting Moringa primarily for harvesting leaves to produce leaf-based products such as capsules and tea. Thus, this presents a potential constraint on the supply of Moringa seeds for industries that require Moringa seeds for oil production and water purification purposes.

3. SAMPLING AND CHEMICAL ANALYSIS

3.1. SAMPLING OF THE *Moringa oleifera* FARMS IN SOUTH AFRICA

The ten farms that constituted a representative sample for the research study were sampled for *Moringa oleifera* plant (leaves and seeds) and soil*.* A sampling protocol that was developed (annexure 1) and was applied when sampling *Moringa oleifera* leaves and seeds.

3.1.1. Leaves

The sampling of *Moringa oleifera* occurred on various farms in South Africa, across four provinces; Limpopo, North West, Gauteng and Kwazulu-Natal. The sampling of farms was conducted in the period between June/July and November 2017 based on the accessibility of the farms. The fresh green leaves were sampled randomly and removed from the stem. Approximately 500g of leaf samples were collected from each farm, placed in the polyethylene plastic bags, then labelled and transported to the two contracted laboratories at Agricultural Research Council (ARC) and University of the Witwatersrand (Wits) for further treatment.

Once in the laboratories, they were treated with distilled water to remove all impurities. The leaves were put in an air dryer to dehydrate, then ground and kept in air-tight plastic containers at room temperature for further analysis. The dry leaves were ground to powder with a pestle and mortar, put in a Ziploc plastic bag and stored in a refrigerator at 4ºC. The leaves from each farm were assayed and analysed individually in triplicate.

3.1.2. Seeds

Moringa oleifera seed samples were collected from the seven farms that had seed bearing trees; Motupa Moringa Farm, NBEF Organic Farm, Sedikong Moringa Farm, Wellness Moringa World Farm, Moringaveld, Luwamba and Super Moringa Farm. Mature, dry seeds were selected, removed from their pods and wood shells. Approximately 300g of seed samples were collected from each farm and were placed in polyethylene plastic bags, labelled and transported to the laboratory for further treatment. Once in the laboratory, they were weighed and put into an air dryer. After the drying process, the seeds were weighed again, and the water content was determined. Then, the seeds were ground using a pestle and mortar and kept in air-tight plastic containers at room temperature for further analysis. The seeds from each farm were assayed and analysed individually in triplicate.

3.1.3. Soil

Soil samples at all the ten farms were collected from surface soil layers with a depth of about 0 to 15 cm at the point where *Moringa oleifera* leaves were picked. Approximately 1kg of soil samples were collected from each farm into polyethylene plastic bags, labelled and transported to the laboratory for further treatment.

3.2. CHEMICAL ANALYSIS OF THE *Moringa oleifera* RESEARCH SAMPLE

The chemical analysis was also conducted to determine the nutritional composition of *Moringa oleifera* plant and the metal content present in *Moringa oleifera* leaves and soil. The analysis was carried out by the two contracted laboratories, the Environmental Analytical Chemistry Laboratory at Wits under the guidance of Professor Luke Chimuka and the ARC Institute for Soil, Climate and Water under the guidance of Dr Garry Peterson. The concentrations of heavy metals, including major and trace elements were investigated in the soil, leaves and seeds of *Moringa oleifera* grown from the ten farms in South Africa. Proximate analysis was performed on the samples, including moisture content, crude protein, crude fat, ash content, crude fibre, vitamin C, total phenolic and flavonoids percentages as per the Association of Official Analytical Chemists methods (AOAC,1990). For the soil laboratory analysis only, Wits data was considered because the analysis processes followed by the ARC did not provide full extraction of metals from the soil samples.

3.2.1. Nutritional composition of *Moringa oleifera* leaves and seeds

An investigation of the nutritional composition of *Moringa oleifera* leaves and seeds was conducted on the sampled farms as per the representative sample, around South Africa. The proximate analysis was conducted on *Moringa oleifera*; ten leaf samples and seven seed samples as presented in table 3.2.1. below. The bioactive compounds present in the *Moringa oleifera* leaves and seeds were determined and the distribution of the phytochemicals from different farms was assessed (figure 3.2.1.a.). The chemical analysis results indicate variable protein, lipids, phenol, fibre, flavonoids and vitamin C contents from the farm samples. *Moringa oleifera* leaves from NBEF farm indicated the highest nutritional composition on most parameters except for protein and vitamin C which were the highest at Super Moringa and Nyala farms.

The distribution of bioactive compounds in the seeds collected on seven farms (Luwamba, Super Moringa, Moringaveld, Wellness Moringa, Sedikong, NBEF and Motupa farms) also indicated the highest number of bioactive compounds in the seed samples collected from NBEF Farm with the exception of protein and lipids which are the highest from the seed samples of farms Luwamba and Super Moringa, respectively (table 3.2.1.a.).

Therefore, the amount of the bioactive compounds found from different farms show a strong correlation with the agricultural practice applied. It should be emphasised that the farms with a good agricultural practice produce a high quality of *Moringa oleifera* trees (table 3.2.1.a.). In general, *Moringa oleifera* leaves sampled indicate an excellent source of protein, polyphenolic, flavonoid, fibre and vitamin C. Moreover, the seeds are an excellent source of lipid and carbohydrate, and a good source of protein, polyphenolic, flavonoid, fibre and vitamin C.

The study clearly supports *Moringa oleifera* leaves to be an excellent source of protein, a unique feature for any herbs and leafy greens in the plant kingdom. The 100g of raw leaves collected from all ten farms carry between 16.35 and 35.32% (table 3.2.1.) of protein, approximately 17.5% of the required daily protein intake for humans. Due to their high protein content, leaves of *Moringa oleifera* can be used as food products and offer excellent dietary benefits for those suffering from malnutrition.

The average protein content of 27.5% observed in this study, although lower than that of the sunflower seed cake's (35.88%) most commonly used as protein concentrate (Mapiye et al., 2010), makes the *Moringa oleifera* leaves a good potential source of supplementary protein in animal diets (Moyo et al., 2013).The protein content found in the leaf samples of the 10 farms is of nutritional significance to animal protein and energy requirements, as it has the potential to boost their immune systems against diseases (Kyriazakis and Houdijk, 2006; Brisibe et al., 2009). This is especially true for growing ruminants such as goats that require protein content of 16% (Luginbuhl and Poore, 1998).

Moringa oleifera leaves are also an excellent source of fibre and the samples analysed contain fibre levels ranging from 3.89 to 10.09%. The levels of fibre found in *Moringa oleifera* leaf samples are similar to those found in leaves collected in India, Tanzania and Nigeria. The aforementioned reports have mentioned the range of 5.89-28% of the fibre contained in *Moringa oleifera* leaves (Ojiako, 2014). Foidl et al., (2001) and Sanchez-Machado et al., (2009) reported a higher level of 39% of crude fibre in *Moringa oleifera* leaves. This variation may be explained by several factors, including crop cultivation climate and location.

Table 3.2.1.a: Nutritional composition of *Moringa oleifera* leaves and seeds.

Farm Name	Location Province	% Fibre	% N	% Protein	% Lipid	% Carbohydrate	Vitamin C (mg/100g)	Total Phenolic (mg/100g)	Total Flavonoid (mg/100g)
Leaves:									
Nyala	North West	4.56	5.32	33.32	5.56	5.09	286	3430	3060
Luwamba	KZN	5.09	4.61	28.96	2.53	3.45	170	2720	1830
Super Moringa	KZN	4.56	5.64	35.32	4.66	4.3	233	3400	2940
Moringaveld	Gauteng	3.89	5.02	31.72	4.27	4.2	207	3040	2600
Wellness	Limpopo	5.84	2.61	16.35	2.28	6.21	137	2890	3070
NBEF	Limpopo	10.09	5.51	34.47	5.35	13.23	266	6910	5950
Motupa	Limpopo	8.29	3.01	18.83	2.88	6.64	221	3710	3680
Sedikong	Limpopo	9.24	4.75	29.73	4.85	10.22	237	5390	5410
Afri-Nest	Limpopo	7.26	3.50	21.89	4.53	9.21	201	4680	4110
ABQ	Limpopo	7.28	3.91	24.44	4.23	7.68	197	4890	4950
Mean±SD		6.61±2.15	4.38±1.07	27.50±6.74	4.11±1.16	7.02±3.10	215±0.44	4100±1.34	3760±1.32
Seeds:									
Luwamba	KZN	8.96	5.02	31.32	34.87	9.86	95	1020	1040
Super Moringa	KZN	9.14	3.28	20.52	38.62	12.39	125	1900	1320
Moringaveld	Gauteng	9.06	4.85	30.35	37.61	10.54	105	1550	1190
Wellness	Limpopo	6.73	1.67	10.90	18.25	15.52	94	1310	1370
NBEF	Limpopo	13.47	3.67	22.98	32.77	31.68	149	4090	2650
Motupa	Limpopo	7.89	1.92	12.50	20.40	16.60	130	1640	1640
Sedikong	Limpopo	11.78	1.93	12.55	26.79	25.55	137	2320	2410
Mean±SD		9.58±2.30	3.19±1.41	20.16±8.55	29.90±8.21	17.45±8.20	119±0.22	1980±1.02	1660±0.63

The polyphenolic and flavonoids compounds contained in the leaves of *Moringa oleifera* are responsible for the plant's antioxidant, anti-inflator and antimicrobial activities. The leaf samples collected from the ten farms contain the polyphenolic and flavonoid contents that range from 2720 to 6910 mg/100g and 1830 to 5950mg/100g (table 3.2.1.a). Previous research studies have shown that high amounts of these phytochemicals can be used to treat cancer and other disease caused by the oxidative stress. *Moringa oleifera* leaves and seeds are also excellent sources of vitamin C. Respectively the samples of leaves from the ten farms and seeds from seven farms contain 137 to 286 mg/100g and 94 to 149 mg/100g (table 3.2.1.a), which is approximately 300% of daily human required levels of vitamin C. The vitamin C content from the leaves and seed samples is well within the tolerable upper intake level set by The Institute of Medicine's Food and Nutrition Board, USA of 2000mg.

Research studies have shown that consumption of fruits and vegetables rich in vitamin C aids the human body in developing immunity to combat infectious agents, and scavenge harmful oxygen-free radicals (Anwar and Rashid, 2007; Asante, Nasare and Tom-Dery, 2014; Rolim et al., 2016). *Moringa oleifera* seeds are rich in lipid percentage, a health-benefiting monounsaturated fat, as well as carbohydrates. The analysis conducted on the seed samples collected contain fat percentages of between 18.25 (Wellness) and 38.61 (Super Moringa) in comparison to the fat percentages of between 28.62 and 30.06 reported in Moringa seeds collected in Egypt by Hassan and Ghazal (2016). We can observe that both results are slightly lower than the amount of 44.67% of fat reported by Alessandro Leone et al., (2016) from the seeds collected in Nigeria.

The variation in the nutritional values observed in the analysis of the collected leaf and seed samples across different regions will differ because of factors such as, cultivated regions, growing conditions, soil characteristics, seasonal changes and genetically different cultivars. However, the high lipid percentages in seeds demonstrate that *Moringa oleifera* is a high-quality oil-seed crop and can be a feasible alternative to improve nutrition levels of populations in many drought-prone regions of Africa.

Table 3.2.1.b: Comparison of nutritional composition between *Moringa oleifera* and other plants.

Vegetable	% Protein	% Carbo-hydrate	Vitamin C (mg/100g)	Total Phenolic (mg/100g)	Total Flavonoid (mg/100g)	Authors
Moringa leaves	27.03 ± 6.74	7.028 ± 3.09	216 ± 4.00	4106 ± 1337.64	3760 ± 1323.82	Current study
Cabbage	20.0 ± 0.2	13.89 ± 0.42	2.87 ± 0.39	1180 ± 60	980 ± 61	Pakade, Cukrowska and Chimuka. (2013)
Broccoli	5.00	2.00	N/A	1760 ± 29	1570 ± 22	Pakade, Cukrowska and Chimuka. (2013)
Lemon	2.00	3.00	198.8 ± 23.45	579.41	9.90	Rudy et al. (2016)
Orange	1.00	4.00	242.1 ±1.03	523.44	5.90	Jae-Hee et al. (2014)
Tomato	1.00	1.00	8.60 ± 3.89	76.9 ± 12.89	12.8 ± 2.34	Devanand et al. (2006)
Lettuce	2.00	N/A	2.59 ± 3.45	124.5 ± 34.56	97.2 ± 11.34	Pakade, Cukrowska and Chimuka. (2013)
Red onion	2.20	14.20	18.70 ± 7.56	154.1 ± 21.53	18.7 ± 9.89	Anwei et al. (2013)
Green bean	48.00	21.00	N/A	35.5 ± 8.90	4.1 ± 1.23	Maria et al. (2016)

When comparing the nutritional composition of *Moringa oleifera* with other vegetables and citrus fruits as presented in table 3.2.1.b, *Moringa oleifera* undoubtedly is a rich source of total phenolic, flavonoid and protein, whilst the amount of vitamin C from *Moringa oleifera* leaves is comparable to that of lemons and oranges. *Moringa oleifera* is not as rich a source of carbohydrate as cabbage, red onion and green bean.
The distribution of bioactive compounds analyses of *Moringa oleifera* leaves and seeds in relation to the geographic distribution of the farms is presented in a multivariate analysis plot (figures 3.2.1. a & b) below.

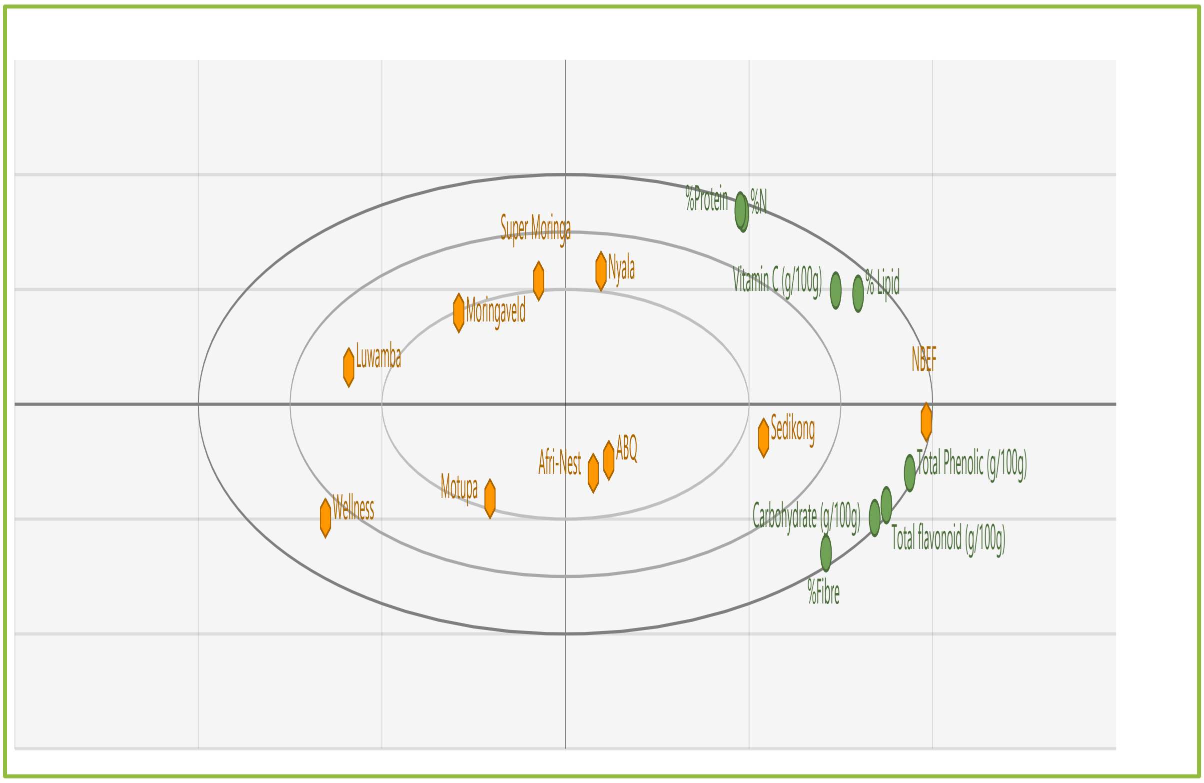


Figure 3.2.1.a: The distribution of bioactive compound from *Moringa oleifera* leaves collected from the ten farms.

In the multivariate analysis plot, the leaf and seed samples are grouped according to the quantity of the analysed parameters. The samples (leaves and seeds) with similar amounts of the analysed compounds tend to cluster together, thus the plots (figures 3.2.1.a and b) make a distinction between high quality and low quality *Moringa oleifera* leaves and seeds based on the phytochemical analysis. The farms with high or low quality of *Moringa oleifera* will cluster together, for instance NBEF and Sedikong Farms are clustering together because of the higher level of phenol, flavonoid and carbohydrates present in their leaves.

The multivariate analysis plot presented in figure 3.2.1.a. shows a clustering of farms Nyala, Super Moringa and Moringaveldt on the basis of higher similar amounts of protein in their leaves. Also, the NBEF and Sedikong Farms are grouping in a region of high content of bioactive compounds which may be attributed to good agricultural practices applied in their farms as observed during the farm visits.

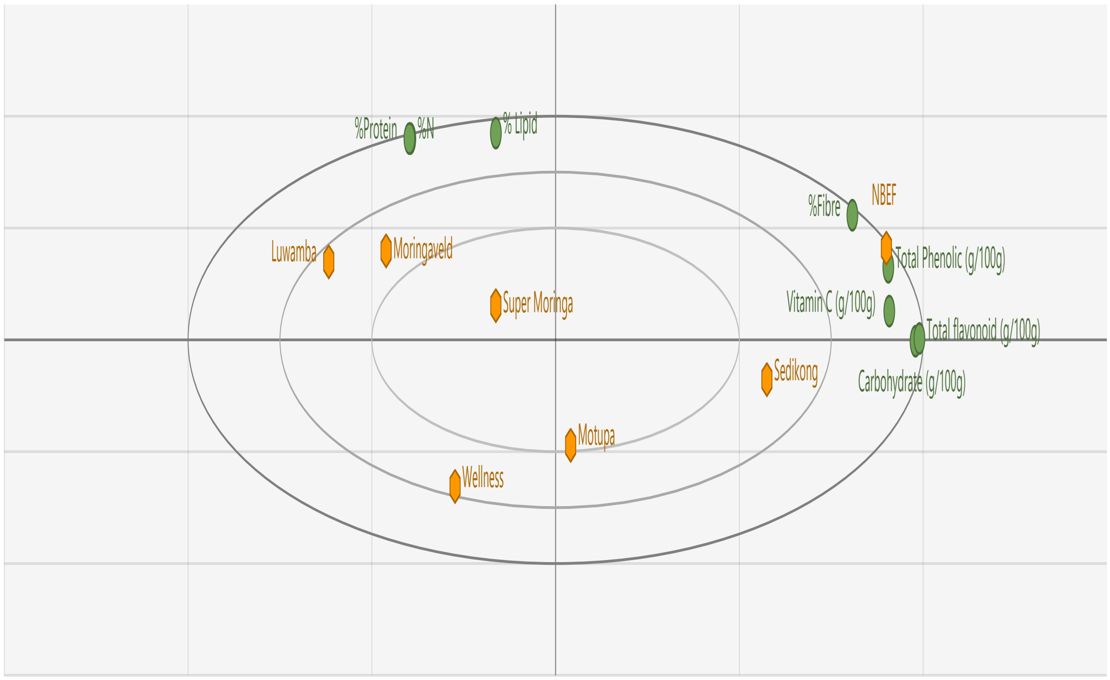


Figure 3.2.1.b: The distribution of bioactive compounds from *Moringa oleifera* seeds collected from the seven farms.

The multivariate analysis plot of seeds (figure 3.2.1.b) collected from the seven farms clusters the seed samples with similar levels of bioactive compounds. The Luwamba, Moringaveldt and Super Moringa Farms cluster closer to each on the basis of similar higher levels of protein and lipids present in their seeds.

3.2.2. Mineral composition of the *Moringa oleifera* leaves and soil

The macro-elements; calcium (Ca), potassium (K), magnesium (Mg) and sodium (Na) are essential to life as living organisms use them to activate enzymes and for the production of hormones. They also function as constituents of bones and teeth, form part of other organic molecules that participate in growth function.

The Moringa leaves and soil samples collected from the ten farms were analysed for metal content and both the macro-element (Ca, K, Mg, Na and P) and micro-elements (As, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn) were analysed as reported in tables 3.2.2 a & b. The amount of the metals accumulated in the leaves correlate to their concentration in the soils. Whilst micro-elements; cobalt (Co), copper (Cu), iron (Fe) and zinc (Zn) play an important role in various metabolic processes and their deficiency or excesses may interrupt the normal biochemical function of the body (Akhter et al., 2004). These elements (macro and micro) are not synthesised by humans, but must be derived from plants, animals or mineral rich water sources (Prasad, 1998). However, some of the elements (As, Mn, Pb, Cd and Cr) are known to be toxic to the human body, and even the known essential elements are likely to exhibit toxic effects on the body when ingested in excess.

The major route of entry for essential and toxic elements into living organisms is via the food chain. Due to the health hazards that minerals may pose when taken in excess, the World Health Organisation (WHO) and other international bodies such as Food and Agriculture Organisation of the United Nations (FOA) and Federal Environmental Protection Agency (FEPA) have set standards relating to daily allowances or tolerable intake of elements. Therefore, all elements entering humans via food intake need to be monitored and evaluated to ensure that they are within the limits of set standards (Dermelj et al., 1996) as the composition of elements in plants play a crucial role in the medicinal values of plants and their therapeutic effects on health and diseases (Kaneez et al., 2001).

As a result of increased awareness of the vital role of elements in human health, there has been a revival of interest in the use of plants as a source of macro and micro-elements. *Moringa oleifera* is one such plant, as its leaves are known to be rich in minerals such as Ca, Co, Cu, Fe, K, Mg, Na, Zn and others. Therefore, it is important to know the levels of these elements in the leaves of the plants

Table 3.2.2.a: Mineral composition (macro and micro Elements) of *Moringa oleifera* leaves (mg/kg)

Farm Name	Location	As	Cd 0.2*	Cr 1.5*	Cu	Fe 20*	Zn 99.4*	Ca	K	Mg	Mn	Na	Ni	P	Pb 0.3*
Nyala	North West	0.80	0.42	4.63	6.64	50.89	30.24	10471.81	15959.89	4452.41	47.26	354.66	1.52	3377.21	1.63
Luwamba	KZN	2.11	0.82	1.42	9.62	283.02	51.64	5751.38	9017.62	4386.42	39.98	312.88	2.22	5530.42	1.86
Super Moringa	KZN	0.83	0.39	1.13	10.34	208.47	46.31	8577.71	10290.95	6458.00	59.30	488.71	2.49	4567.80	1.66
Moringaveldt	Gauteng	5.23	2.12	3.67	7.92	204.96	32.44	13162.68	18729.02	3363.10	70.39	139.12	2.19	2739.06	1.91
Wellness	Limpopo	1.40	0.01	1.91	4.20	86.60	33.10	2986.00	13749.75	2087.60	32.79	764.39	0.96	3875.14	0.86
NBEF	Limpopo	1.20	0.01	1.55	9.40	255.80	36.40	5886.00	34530.30	1425.40	21.76	970.00	1.22	9731.80	1.92
Motupa	Limpopo	2.06	0.01	2.36	6.60	70.60	30.20	1388.80	19616.31	1969.80	30.83	630.75	0.79	5528.54	1.35
Sedikong	Limpopo	1.03	0.01	1.20	3.59	88.80	28.00	3117.60	25080.30	2902.60	43.38	857.38	1.07	7068.47	0.73
Afri-Nest	Limpopo	0.97	0.01	0.98	7.00	157.20	32.20	1836.00	22143.24	1022.00	16.03	671.87	0.84	6240.71	1.43
ABQ	Limpopo	2.40	0.01	0.59	2.98	77.40	22.00	1586.00	14089.95	2022.00	29.70	710.09	0.89	3971.02	0.61

*WHO/FAO permissible limits

3.2.2.1. Macro-element composition in leaves

The macro-element analysis results indicate the concentration of K and Na in the samples of *Moringa oleifera* leaves from ten different farms across South Africa to be between 9017.62 and 34530.30 mg/kg; 139.12 and 970 mg/kg (table 3.2.2.a.). The leaf samples from NBEF and Sedikong farms were found to be rich in K and Na content, when compared with those of other sampled farms. Whereas the lowest amount of Na and K were found to be present in the sample of Moringaveld farm. The variability of Na and K contents in the leaf samples from different farms may be attributed to the farming practices.

Sodium is vital in maintaining turgidity within the plant stem. The higher the concentrations of sodium in the stem, the higher the osmotic pressure, and water flows into the stem to maintain concentration equilibrium.(Anjorin et al., 2010). However, for tree crops the sodium content in the leaf tissue in excess of 2500 to 5000 mg/kg (dry weight basis) is often associated with sodium toxicity (FAO, 1995). Although sodium is not a plant nutrient, it is significant for the health of the soil and high sodium content may have adverse effects on plant growth.

Potassium is important for reducing blood pressure, increasing blood circulation and its presence is also a general measure of heart health (Asante et al., 2014). The concentration of Ca in *Moringa oleifera* leaves from the ten different farms ranged from 1388.80 to 13162.68 mg/kg. The Ca content of the leaves from the Moringaveld farm was generally higher compared to other farms (table 4.2.2.a). High concentration of Ca is important because of its role in the health of bones, teeth, muscle systems and heart function. The present study shows a satisfactory level of Ca accumulation as compared to those in earlier reports of *Moringa oleifera* leaf samples (Anjorin et al., 2010).

The level of Mg in the samples of *Moringa oleifera* leaves, ranged from 1022 to 6458 mg/kg, with a study sample average of 3008 mg/kg. A study conducted by Chimuka et al., (2013) comparing *Moringa oleifera* leaves and vegetables (i.e. spinach, broccoli, cabbage and cauliflower) found that the *Moringa oleifera* leaves contained more Mg (an average of 6000 mg/kg) than the vegetables (below 1500 mg/kg), except for spinach (7500 mg/kg).The highest level of Mg was noted in the sample from Super Moringa farm and the lowest amount was observed in the sample from Afri-Nest farm (table 3.2.2.a.). The magnesium together with calcium assists in transmitting nerve impulses in the brain, whilst the Mg also has calming effect on the nervous system, particularly for individuals suffering from depression (Idris and Jami, 2016). The Chimuka et al., (2013) study on the three farms in South Africa exhibit similar flavonoids in *Moringa oleifera* leaves to those found in the ten farms for this study.

3.2.2.2. Micro-element composition in leaves

The concentrations of micro–elements from the ten different farms are shown in (table 4.2.2.a.). The ranking of essential element concentrations in *Moringa oleifera* leaves is Fe>Zn>Cu in all the farms however for toxic heavy metal concentrations there is no ranking order of As, Cd and Cr. The amount of the metals (As, Cd, Cr, Cu, Fe and Zn) from the ten farms sampled ranged from 0.80 to 2.4 mg/kg, 0.01 to 0.82 mg/kg, 0.59 to 4.63 mg/kg, 2.98 to 10.34 mg/kg, 50.89 to 283.47 mg/kg and 22.00 to 51.64 mg/kg.

Fe is an essential micronutrient essential for human growth and development. *Moringa oleifera* leaves can be an excellent source of iron, however the iron content in all the collected leaf

samples (50.89–283.47 mg/kg) was found to be high and above the FAO/WHO permissible iron level of 20 mg/kg for medicinal plants (FAO/WHO, 1984).
The zinc content from the ten sampled leaves was found to be within the prescribed limits, as per the permissible limit set by FAO/WHO in edible plants is 50mg/kg and according to Jabeen et al. (2010) the range of Zn in agricultural products should be between 15 and 200 mg/kg.

The copper concentration in all the leaf samples was below the maximum permissible limit of 40 mg/kg dry weight (FAO/WHO, 1995). Thus, the sampled *Moringa oleifera* leaves were found to be well within FAO permissible limits. The study analysis results of Cu (6.83 mg/kg) and Zn (34.29 mg/kg) correlate with the Cu (8.28 mg/kg) and Zn (31.03 mg/kg) results from a study conducted by Moyo et al. (2013) on the two *Moringa oleifera* farms in the Limpopo area. The grouping of micro and macro elemental composition of *Moringa oleifera* leaves and soil may be presented graphically on the multivariate analysis plots as shown in figures 3.2.2.a & b below. The farms that have clustered together indicate similar composition of metals in the soil that may be as result of either agrochemicals or fertiliser used. Leaf and soil samples of *Moringa oleifera* collected from the farms in the Limpopo province exhibit higher levels of Na and P than those from other provinces (figures 3.2.2.a & b).

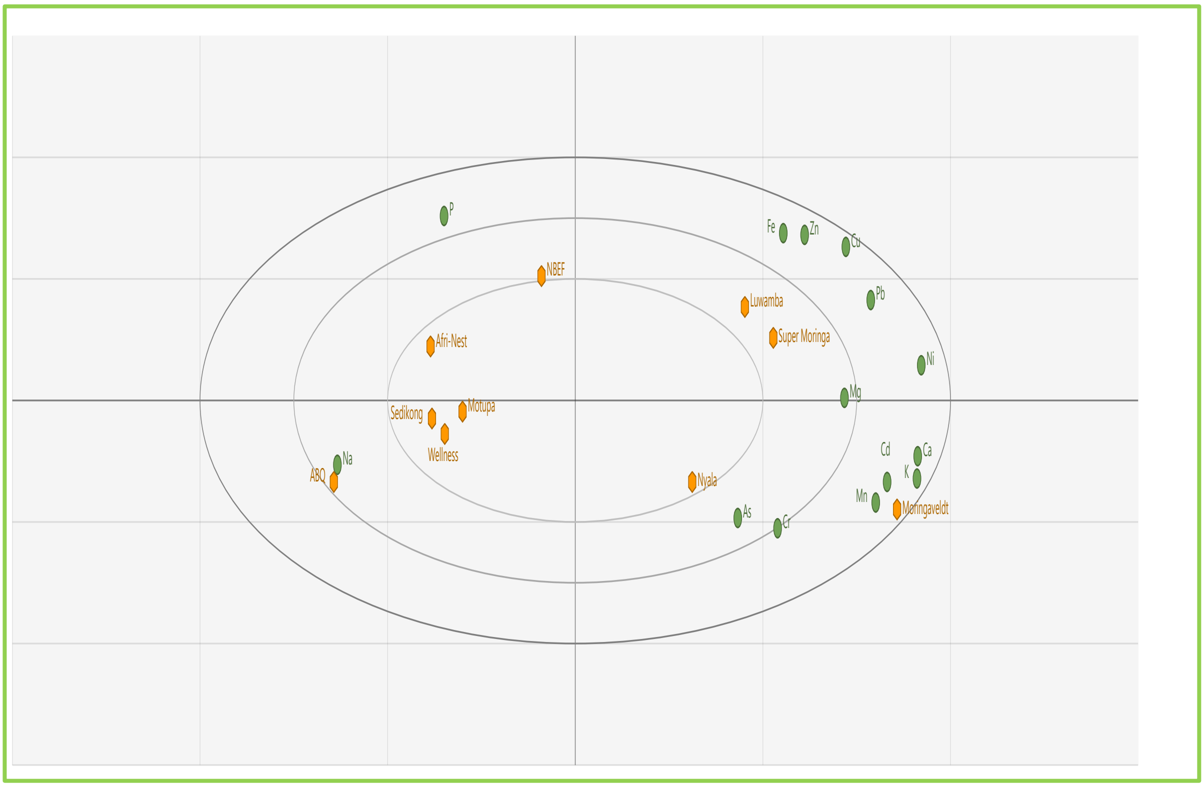


Figure 3.2.2.a: The distribution of metals from *Moringa oleifera* leaves collected from the ten farms.

The leaves collected at the Nyala and Moringaveldt farms have higher levels of As, Ca, Cr, Cd and Mn. The leaves from Luwamba and Super Moringa (KwaZulu Natal) have higher levels of Fe, Cu and Zn, whilst higher Mg levels are present in the leaves from Luwamba, Nyala, Super Moringa and Moringaveldt.

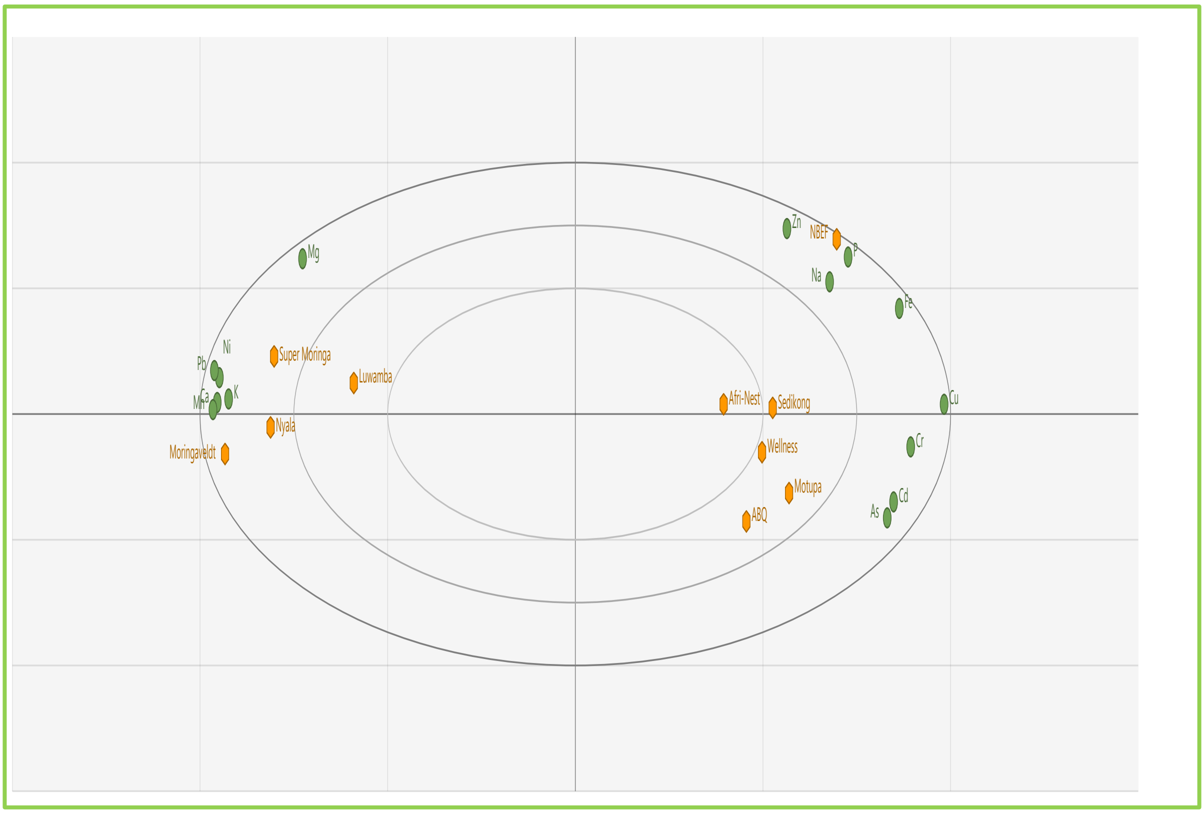


Figure 3.2.2.b: The distribution of metals from *Moringa oleifera* soil collected from the ten farms.

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Table 3.2.2. b: Mineral composition of the *Moringa oleifera* soil (mg/kg)

Farm Name	Location	As *20	Cd *3	Cr **130	Cu *** 70 - 80	Zn *** 300 – 400	Fe *** 400	Ca	K	Mg	Mn	Na	Ni	P	Pb *** 1.6
Nyala	North West	3.64	1.90	21.12	30.29	137.91	232.04	47751.44	72777.11	203.03	215.51	1617.26	6.91	15400.06	7.44
Luwamba	KZN	9.64	3.74	6.49	43.88	235.46	1290.55	26226.28	41120.34	200.02	182.32	1426.75	10.10	25218.73	8.48
Super Moringa	KZN	3.76	1.78	5.15	47.15	211.18	950.63	39114.37	46926.75	294.48	270.40	2228.52	11.35	20829.19	7.56
Moringaveldt	Gauteng	3.83	9.67	16.75	36.11	147.90	934.63	60021.80	85404.35	153.36	320.97	634.40	10.00	12490.12	8.73
Wellness	Limpopo	20.75	13.00	292.00	17.75	259.75	643.77	2986	6244.50	398.05	47.55	4296.5	1.33	22389.45	1.19
NBEF	Limpopo	16.75	14.50	202.00	20.48	375.50	1654.89	5886.00	17822.50	187.52	31.55	8481.50	1.69	56227.52	2.67
Motupa	Limpopo	29.50	18.75	296.25	19.03	219.75	631.63	1388.80	9429.25	348.40	44.70	2010.75	1.10	31942.28	1.88
Sedikong	Limpopo	15.50	17.75	199.25	16.70	205.75	741.05	3117.60	13022.75	491.63	62.90	7661.25	1.49	40839.59	1.02
Afri-Nest	Limpopo	13.75	14.00	148.75	19.20	251.00	862.51	1836.00	10811.00	113.37	23.25	2350.50	1.17	36057.01	1.99
ABQ	Limpopo	30.25	22.50	128.50	15.88	162.50	643.38	1586.00	6532.50	393.73	43.07	3362.50	1.77	22943.41	1.21

* EU Agricultural Soil limit ** CLEA Soil Guideline Value (SGV) *** FEPA Guidelines Threshold

3.2.2.3. Macro element composition in soil

As shown in table 3.2.2.b, the concentrations of K, Na, Mg and Ca across the ten farms ranged from 9017.62 to 34530.30 mg/kg, 2010.75 to 8481.50 mg/kg, 3937.25 to 18752.00 mg/kg and 8205 to 19770.75 mg/kg, respectively. The concentration of metals was higher in the NBEF soil samples. We can observe a significant difference among the concentration of the macro-elements in the soils from different farms. These differences could be attributed to soil conditions in different provinces and individual farming practices at different farms.

3.2.2.4. Micro–element composition in soil

The micro element concentrations in the soil (As, Cd, Cr, Cu, Fe and Zn) range from 15.5 to 30.25 mg/kg, 12.5 to 18.75 mg/kg, 14.87 to 29.62 mg/kg, 58.75 to 204.75 mg/kg, 63163.75 to 165489 mg/kg and 162.5 to 375.5 mg/kg, respectively. The concentration of all the heavy metals in all the soil samples collected at the farms, with the exception of arsenic and cadmium (As, Cd) are within the acceptable limits of the EU agricultural soil limit and FEPA guidelines threshold for agricultural land use.

The majority of soil samples from the farms presented high levels of cadmium and this poses a great health risk to human beings. Even at very low concentrations prolonged human exposure to cadmium and its accumulation in the body may lead to diseases mainly affecting lungs and kidneys (Sarkar, et al., 2013). The source Cd may be either natural or anthropogenic. The concentration of the metals in the soil correlates directly with the heavy metal content in the plants. Plants absorb water and minerals from the soil through the ascent of sap; as a result, the metals uptake by medicinal plants such as *Moringa oleifera* also occurs in the same way. After absorption, these metals are accumulated in various parts of the medicinal plants and are entered into the biological chain after ingestion of these medicinal plants by humans or animals.

A clinical study conducted on rats in Ghana assessed the elemental content of *Moringa oleifera* and ascertained any adverse effects over a trial period of 14 days. The findings of the study suggested that the consumption of *Moringa oleifera* leaves be limited to a maximum of 70g/day (Asante et al., 2014). The metals content in the soil where *Moringa oleifera* is grown is higher than the recommended permitted limits set by WHO/FAO and consequently the significant accumulation of metals in *Moringa oleifera* plant posing potential health risks to consumers.

Therefore, there is a need for a remediation process to remove the accumulation of high metals before cultivating *Moringa oleifera* plant. The use of vegetables such as cabbage which have a high propensity for accumulating metals (Yannick et al., 2017) can be used in the remediation process to reduce the amount of metal accumulation at farms intended for growing *Moringa oleifera*. The amount of metal accumulation in the leaves correlates to the metal concentration in the soils. Thus, *Moringa oleifera* is considered to have a high propensity of metal accumulation as reported in several publications, hence farms with high concentrations of metals in their soil will yield correspondingly high metals content in *Moringa oleifera* products (i.e. leaves).

Furthermore, the amount of the Cd, Cr, Fe and Zn were observed to be higher than the permissible limit set by the WHO/FAO. The presence of these metals in *Moringa oleifera* leaves could be harmful to the consumer. Therefore, it is critical to assess the health risks associated with the extended use of *Moringa oleifera* products particularly for the above-mentioned toxic metals.

3.3. AN ASSESSMENT OF ADVERSE EFFECTS OF *Moringa oleifera* ON HUMAN HEALTH

The following assessment on negative effects of the inorganic or organic compounds in *Moringa oleifera*, aims to determine the quantitative health risks associated with extended consumption of *Moringa oleifera*. The assessments of negative effects are often based on the scientific consideration of the chemical activities, exposure, amount and toxicity. Also, the overall health risks may be associated with the quantity of a compounds that exist in the environmental, food and/or a product (IPCS, 2004). However, the data often required to conduct health risks assessment is not always available, so risk assessments are often linked to uncertainties (IPCS, 2004).

The variables or indices discussed below have been used to assess the level at which consumers are exposed to the metals risk when ingesting *Moringa oleifera* leaves.

3.3.1. The daily intake of metal (DIM)

The Daily Intake of Metal (DIM) is the evaluation of the level of the pollutants contained in food eaten per day measured in mg/kg per body weight. It depends on the metal level in the yields and consumption quantity of the respective food crop. DIM is calculated by the multiplication of the amount of the pollutants measured in the food sample with the estimated amount of the food intake daily, divided by the average body weight of an individual.

This index assists in determining the amount of heavy metals consumed daily in certain foods. *Moringa oleifera* leaves are classified as consumer vegetables and its food consumption rate is approximately 85.00 g/person/day, respectively (Vorster et al., 2013). The daily intake of metal estimates is calculated by multiplying the food consumption rate with the metals concentrations determined in this report. The estimates of the daily intake of metals are then compared with the upper tolerable daily intake for metals set by the Food and Drug Administration (FDA, 2001).

The estimated daily intake of metals for each *Moringa oleifera* leaf sample shown in table 3.3.1. are compared to the upper tolerable limit set by WHO/FAO (2000). Therefore, the estimated DIM for all the collected samples at the *Moringa oleifera* farms were high for As, Cd and Cr. Whilst, the daily intake measure for Cu, Fe, Mn, Ni, Pb and Zn were below the upper tolerable daily intake limits (UL), except for the Fe content at Luwamba Farm.

Table 3.3.1: Estimated daily intake of metal (DIM) *Moringa oleifera* leaves.

Farm Name	DIM As	DIM Cd	DIM Cr	DIM Cu	DIM Fe	DIM Mn	DIM Ni	DIM Pb	DIM Zn
Nyala	0.0680	0.0357	0.393	0.564	4.323	4.017	0.129	0.138	2.570
Luwamba	0.1791	0.0697	0.120	0.817	24.056	3.398	0.188	0.158	4.389
Super Moringa	0.0710	0.0330	0.096	0.878	17.719	5.040	0.213	0.141	3.936
Moringaveldt	0.4450	0.1800	0.311	0.673	17.423	5.983	0.186	0.162	2.757
Wellness	0.1190	0.0010	0.162	0.357	7.361	2.787	0.082	0.073	2.813
NBEF	0.1020	0.0010	0.132	0.799	21.743	1.849	0.104	0.163	3.094
Motupa	0.1750	0.0010	0.201	0.561	6.001	2.623	0.067	0.115	2.567
Sedikong	0.0870	0.0010	0.102	0.305	7.548	3.687	0.091	0.062	2.380
Afri-Nest	0.0820	0.0010	0.083	0.595	13.362	1.363	0.071	0.121	2.737
Recommended daily intake (mg per day per person) [a]	0.0040	0.0012	0.039	10.000	19 – 22	11.000	0.250	0.240	40.000

3.3.2. Target Hazard Quotients (THQ)

The Target Hazard Quotients (THQ) is a measure of the potential risk to one's health as a result of a mixture of chemical constituents in various food samples. When exposure implicates more than one chemical, the amount of the individual hazard quotient for each chemical is used as a measure of potential harm and the sum of individual THQs is referred to as the Hazard Index (Caylak, 2012). THQ is calculated by a general formula established by the United States Environmental Protection Agency (US EPA) using the following equation:

THQ = (EF x FD x DIM)/ (RfD x W x T) where:

EF is the exposure frequency (365 days per year).

FD is the exposure duration set at 59.1 for males and 63.1 for females in South Africa (Vorster et al., 2013).

DIM is the daily intake of metal (mg $person^{-1} day^{-1}$).

W is the average body weight (kg) set at 62.4 kg for males and 70.84 kg for females in South Africa.

T is the average age exposure time for no carcinogens (365 days $year^{-1}$ x number of exposure years).

RfD represents reference oral dose that is an estimation of the daily exposure of a contaminant to which the human population may be continually exposed to over a lifetime without an appreciable risk of harmful effects (Akoto et al., 2014).The RfD values for As, Cd, Cr, Cu, Fe, Mn, Pb, Ni, and Zn are 0.003, 0.001, 0.003, 0.040, 0.700, 0.014, 0.0035, 0.020 and 0.300 (mg $kg^{-1} day^{-1}$), respectively (USEPA, 2006).

The Hazard Index (**HI**) is the sum of the target hazard quotients as represented in the following equation:
HI = ∑THQ = THQAs + THQCd+ THQCu +THQCr+ THQFe+ THQZn + THQMn+ THQNi + THQPb + THQZn.

Where **∑THQ** is the summation of the target hazard quotients of metals.

It is assumed that the magnitude of the adverse effect will be proportional to the sum of multiple metal exposures. If the ∑THQ measure is less than 1, no potential health risk may be encountered, however if the ∑THQ is equal to or greater than 1, some level of health risk may be encountered (figures 3.3.2. a & b).

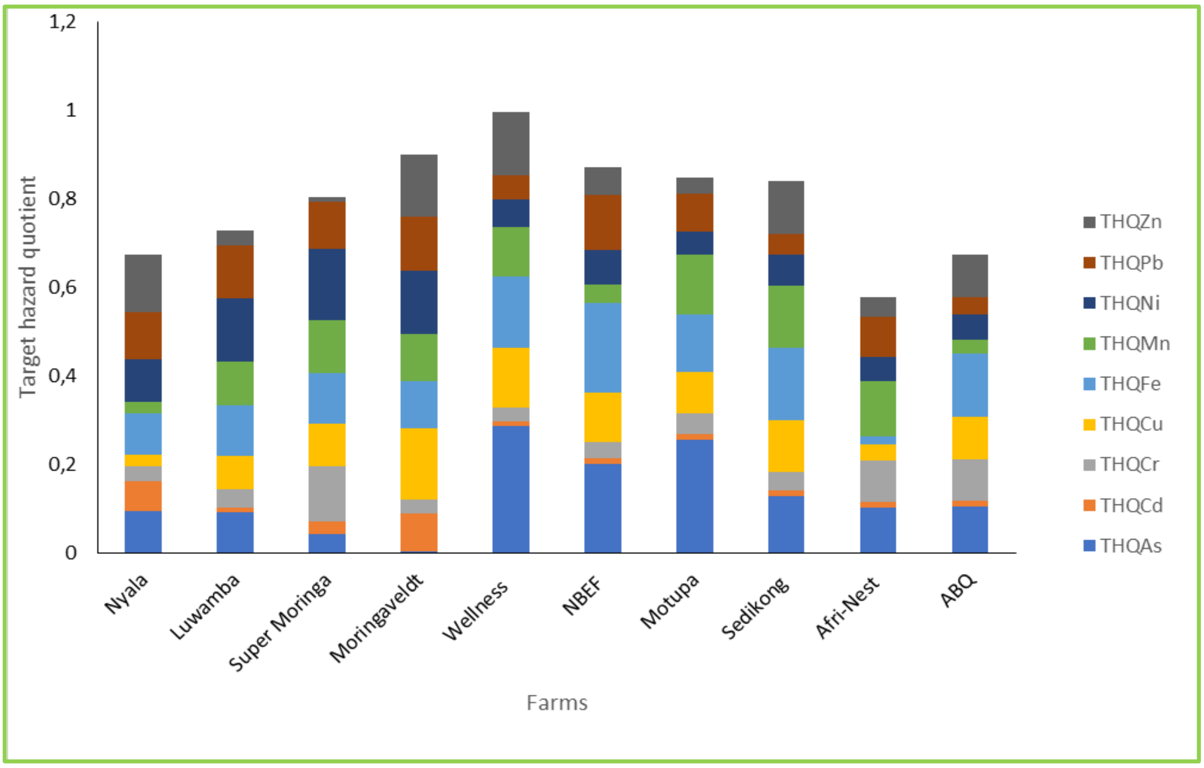

Figure 3.3.2.a: Target Hazard Quotients (THQ) of *Moringa oleifera* leaves in human males.

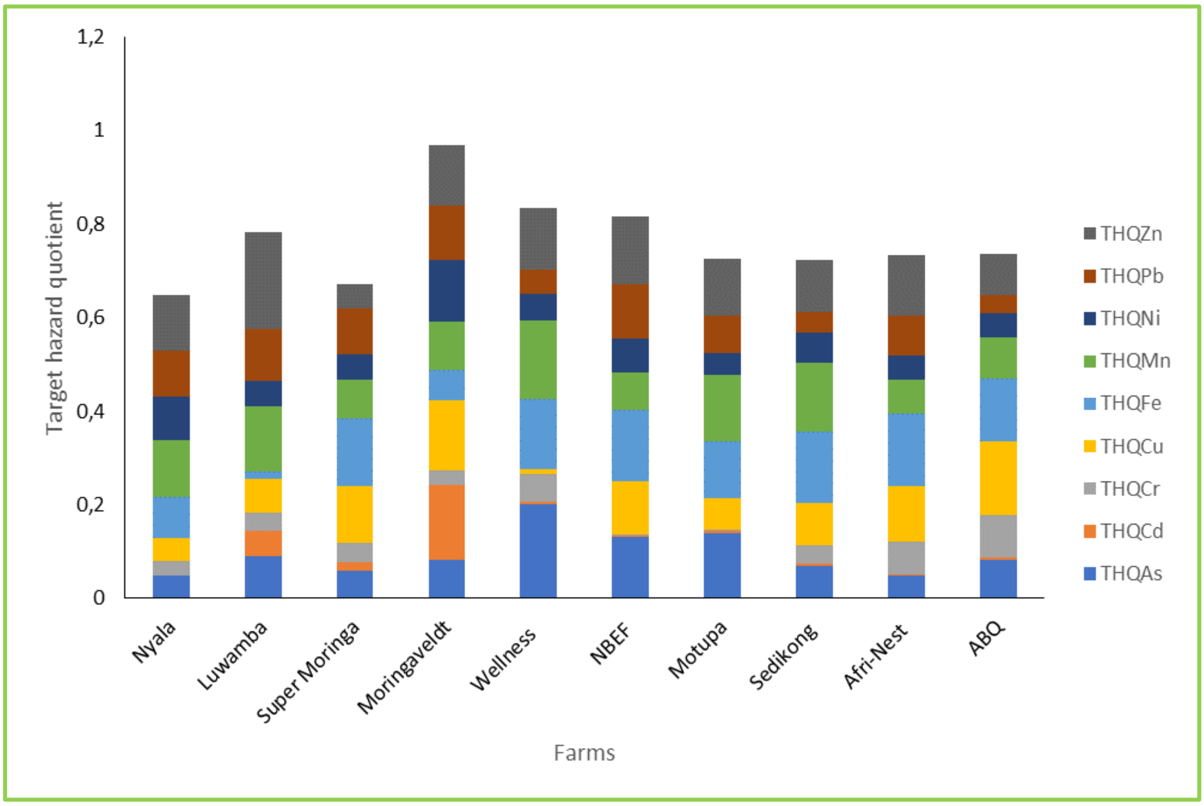

Figure 3.3.2.b: Target Hazard Quotients (THQ) of *Moringa oleifera* leaves in human females.

The Target Hazard Quotient is a complex parameter used for the estimation of potential health risk associated with long term exposure to chemical pollutants (US EPA, 2006; Hague et al., 2008; Petroczi et al., 2009). Figures 3.3.2.a and b above present the values of target hazard quotient. The calculated individual THQ and ∑THQ for all leaf samples collected are less than 1, indicating no potential health risk associated with the consumption of *Moringa oleifera* grown at the selected ten farms, however exposure to more than one contaminant may produce a synergistic effect on consumer health.

The above health risk assessment is based on data of the mineral composition in *Moringa oleifera* to estimate the measures of DIM and THQ, however further toxicological studies need to be conducted on *Moringa oleifera* in order to determine comparative safety for human consumption.

4. INDUSTRY ANALYSIS

4.1. INTRODUCTION

Moringa oleifera has been reported on extensively in literature as an excellent source of antioxidants, protein, unsaturated fatty acids and vitamins (Kathivashan et al., 2015). The nutritional and medicinal properties of *Moringa oleifera* products have recently attracted attention from several industries worldwide.

The current global market value of *Moringa oleifera* products is estimated to be billions of US dollars (Leone et al., 2015). This is the result of several health trends as outlined below. Consumers are becoming increasingly interested in new and exotic products, particularly when they have traditional health benefits (Pakade, Cukrowska, & Chimuka, 2013). Due to several recent developments, the potential utilisation of *Moringa oleifera* in products is vast and constantly expanding (Nouman et al., 2014). In the first instance *Moringa oleifera* leaf powder is used as a nutritional source of proteins, minerals and vitamins for children, pregnant women and the elderly (Leone et al., 2015.).

In developing countries, the leaf powder is also administered medicinally as an anti-inflammatory, anti-carcinogen, antioxidant and antibacterial agent. Globally 578.23billion tons of *Moringa oleifera* leaf powder are sold each year, with the largest supplies emanating from Asia (Dayal et al., 2013). Secondly, *Moringa oleifera* seed oil is extracted for use in cosmetics and food products. Available literature reports that *Moringa oleifera* seed oil is an excellent source of vitamin E, antioxidants and unsaturated fatty acids and in addition possesses anti-inflammatory properties (Louis et al., 2017). These pharmacological properties position *Moringa oleifera* seed oil as a key ingredient in the manufacturing of soaps, lotions and pharmaceutical ointments (McCarthy & O'Gara, 2015). Finally, *Moringa oleifera* seedcakes, which are produced from residues by pressing seeds to extract oil, are utilised in water treatment (Oladeji et al., 2017), fertilizers, animal feed and as a coagulant (natural cationic polyelectrolyte). *Moringa oleifera* seed cakes contain approximately 58% crude protein (Leone et al., 2015).

The following are the industries where *Moringa oleifera* can potentially be applied (figure 4.1.):

- Food industry (food supplements & nutraceutical)
- Cosmetics
- Household products
- Animal feed
- Fertiliser
- Water purification

Figure 4.1: Potential applications for *Moringa oleifera.*

4.2. SWOT ANALYSIS

The nutritional and medicinal benefits of *Moringa oleifera* are well documented in the literature. However, to further determine the feasibility of unlocking the economic value and use of *Moringa oleifera* in other industries, a SWOT analysis was conducted as presented in table 4.2.

Table 4.2: SWOT analysis on feasibility of *Moringa oleifera.*

Strengths	Weaknesses
• Easy and fast growth • Requires limited resources (i.e. water, pesticides and fertilisers) in subtropical regions • Nutritional value • Medicinal value • Economic value	• No legislation that regulates the trading of *Moringa oleifera* • Moringa trading in South Africa is very fragmented and informal • Concentrated trading focuses mainly on one element of Moringa (i.e. leaves) • Price positioning: Moringa products are very highly priced and prices are also not regulated • Awareness: Very little is known in broader society about the nutritional benefits of Moringa • Security of supply, particularly seeds for other industries • Perceived high barriers to entering local retail and pharmacies • SABS certification accreditation pending
Opportunities	**Threats**
• Moringa commercialisation in other industries (i.e. oil, water purification and animal feed) • Product positioning (i.e. health product vs. consumer product • Incorporation of trading of Moringa into the mainstream economy by formalising its trade.	•Influx of *Moringa oleifer*a (leaves, powder and seeds) imports •Lack of traceability of Moringa products sold to the market

The opportunities and strengths were identified for optimal exploitation of *Moringa oleifera* and incorporation of its trading into the mainstream economy. One of the opportunities is the commercialisation of *Moringa oleifera* in other industries such as water treatment However, a major threat to trading of *Moringa oleifera* is traceability due to lack of regulation of moringa trading in South Africa.

4.3. FOOD INDUSTRY

4.3.1. Food supplements from *Moringa oleifera* leaves

Malnutrition is associated with developmental abnormalities, potentially originating in utero and can continue from birth throughout the life of an individual (Muhl et al., 2013). Research aimed at eliminating developmental deficits linked to poor nutrition, especially in developing countries where malnutrition is prevalent, remains insufficient (Sulaiman et al., 2015).

In many cases natural sources of nutrients are able to provide adequate dietary amounts of vitamins, minerals and proteins. Supplementing diets with vitamins and minerals from sustainable regional plant sources is critical in areas where agriculture and livestock production are limited due to socio-economic or environmental challenges. Lack of access to natural nutrients is known to largely affect human development from birth to adulthood (Marrufo et al., 2013).

To overcome this situation *Moringa oleifera* leaf powder is found to be an excellent source of proteins, vitamins, antioxidants and minerals for developing communities (Vázquez-León et al., 2017). It is currently used as a food source in countries lacking essential dietary nutrients (Nkya, Erasto, & Chacha, n.d.). Also, in several tropical and subtropical countries dietary supplementation with *Moringa oleifera* leaf powder has presented significant improvement in human health, development and nutrition from embryonic stages through to adulthood. *Moringa oleifera* leaves contain a high level of phenolic compounds, macro-nutrients and micro-nutrients, as well as having antifungal and anti-inflammatory properties. *Moringa oleifera* has also become well known for its medicinal applications in reducing hypertension, cancer, diabetes, cardiovascular disease, and hypercholesterolemia (Vázquez-León et al., 2017).

4.3.2. Nutraceutical food

Nutraceutical food is defined as food that provides medical or health benefits, including the prevention and treatment of disease (Vázquez-León et al., 2017). It should be noted that the term nutraceutical as commonly used in marketing has no regulatory definition (Berkovich et al., 2013). Nutraceuticals thus differ from dietary supplements in the following aspects: nutraceutical foods must not only supplement the diet but should also aid in the prevention and treatment of diseases and disorders.

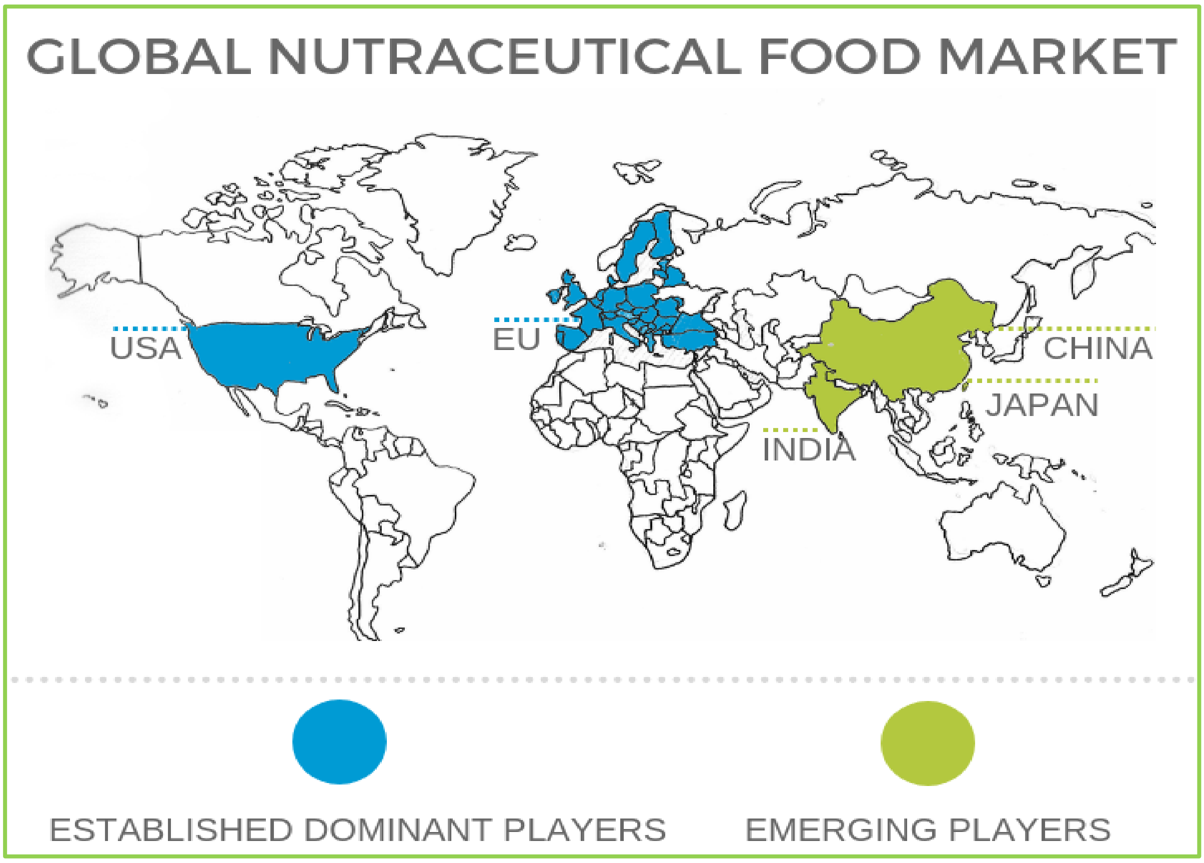

Figure 4.3.2: Global market of Nutraceutical food.

Improvements in the socio-economic lifestyles of the global population have led consumers to seek out health products which provide a plethora of nutritional benefits. As such, nutraceutical food has become a fast growing sector in the global food market (Amaglo et al., 2010). It has been reported that the global nutraceutical market will grow at a compound annual growth rate (CAGR) of 9.53% during the period 2018 to 2022. Market growth has primarily been driven by the exponential increase in the ageing population, along with a growing awareness of the importance of health and wellness on a global scale (Dayal et al., 2013). Rising disposable incomes, along with the escalating incidences of preventable lifestyle related diseases has further increased spending on healthy dietary consumption (Smith-Hall, Larsen, & Pouliot, 2012).

Moreover, a growth in the market value of nutraceuticals in South Africa is associated with the growing trend of proactive healthy living (Gairola, et al., 2010). This growing awareness of the importance of consumption of healthy foods has resulted in increased global demand for nutraceuticals. In Europe, innovations in high-performance natural ingredients for use in nutraceuticals is seen as a market driver (Cuellar-Nuñez et al., 2018). Profits from the global nutraceutical industry have risen from 30 million USD in 2006 to 50 million USD in 2012, and are projected to reach 578.23 billion USD by 2025 (Philippe, Leon and Serge, 2015).

Many cultures and communities in developing countries have claimed astonishing medicinal uses for *Moringa oleifera* (Ken Research, 2017). Research has found that *Moringa oleifera* contains many essential nutrients including vitamins, phenolic compounds and proteins (M. A. Ali, Yusof, Chin, Ibrahim, & Muneer, 2018). Nutritional properties of plants play an essential function in development of medicinal, nutritional, and therapeutic applications. *Moringa oleifera* leaf is an excellent source of potassium, calcium, magnesium, iron and zinc as well as protein, ascorbic acid and carotenoids (Oladeji et al., 2017). In accordance with the nutraceutical definition, *Moringa oleifera* leaves can be used as nutraceutical food because the leaf powder is applied as a food supplement to aid in the prevention and treatment of several diseases (Karthivashan et al., 2015). A series of investigations have been conducted to evaluate the antimicrobial, anti-inflammatory, anti-carcinogenic and antioxidant properties of *Moringa oleifera* leaves (Gopalakrishnan, Doriya, & Kumar, 2016). The results from studies have been very promising, opening a wide range of potential applications in the food and pharmaceutical industries from the benefits that the *Moringa oleifera* leaf provides.

4.3.3. *Moringa oleifera* seed oil

The *Moringa oleifera* seed, harvested from the pods of the *Moringa oleifera* tree, is a globular seed approximately 1 cm in diameter with an average weight of 0.3g. Leaf-like wings, emanating from the base of the seed to the apex, are approximately 2.25cm long and 0.55cm wide, separating the globe into three segments or sides. The kernel accounts for approximately 72.5% of the weight (Gopalakrishnan et al., 2016).

Moringa oleifera seeds are sown during the rainy season and can germinate and grow without irrigation. However, for commercial purposes, irrigation through a drip system is recommended to allow for seed production during the dry season (Omotoso et al., 2018). The *Moringa oleifera* tree can produce a large quantity of seeds when fertilisation is adequate, although no exhaustive research on this issue is available. Several studies focused on leaf or biomass production suggest that the vegetative growth of *Moringa oleifera* is best supported by 120kg N: P: K per hectare per year (Belwal et al., 2018; Hamany Djande et al., 2018; Khoza et al., 2016; Ogundiran, Mekwunyei, & Adejumo, 2018; Van Wyk, 2015). Seed production generally varies tremendously and yields range from 4 to 24 tons of seeds per hectare depending on location, soil type, vegetation and climate conditions (Kushwaha et al., 2018).

As an excellent source of edible oil, seeds contain up to 40% oil with a high quality of fatty acid composition and more than 70% oleic acid and 38% crude protein (Koheil, Hussein, Othman, & El-haddad, 2011). The oil is mostly extracted through cold press technology. Apart from the oil the seed has a high protein content averaging 31.4%, while carbohydrates, fibre and ash contents are 18.4%, 7.3% and 6.2%, respectively. The defatted seeds of *Moringa oleifera* could therefore provide an economical source of protein as a supplement to traditional diets where protein intake is insufficient (Lalas & Tsaknis, 2002). *Moringa oleifera* seeds have a high content of methionine and cysteine, similar to levels reported in milk and eggs (Koheil et al., 2011). They can therefore be consumed together with legumes, which are deficient in sulphur containing amino acids. Additionally, the seeds appear to be free of trypsin inhibitors and urease activity, affirming a protein digestibility of 93%.

"Seed cakes" are produced from the residues generated when pressing seeds to extract oil. It is used as a fertiliser, coagulant (natural cationic polyelectrolyte), animal feed and in water purification. The cake contains about 58% crude protein. The seed of the *Moringa oleifera* tree has attracted scientific interest due to its significant oil content (up to 40%), vitamin E content, high-quality fatty acid composition (with oleic acid > 70%) and its notable resistance to oxidative degradation once refined. These properties make it suitable for both human consumption and commercial purposes (Porto, Porretto, & Decorti, 2013).

It is reported that the quality of the oil is comparable to olive oil (Nadeem & Imran, 2016). *Moringa oleifera* oil, known commercially as "Ben oil" or "Behen oil", is also used as an antibiotic and anti-inflammatory against arthritis, rheumatism and cramps (Koheil et al., 2011).Although cold pressing is the most common oil extraction technique, fewer yields are obtained through this method. A significantly more efficient technique is through solvent extraction, generally n-hexane, which is able to extract almost the entire volume of oil from the seed. In fact, an average of only 69% of the total oil contained in seeds can be extracted through the cold press technique (Nadeem & Imran, 2016). Among rural dwellers, the edible oil is extracted by boiling de-husked seeds with water, and collecting the oil from the surface of the water (Barakat & Ghazal, 2016).

Moringa oleifera oil is in a liquid state at room temperature and golden-yellow in colour (Anwar, Zafar, & Rashid, 2006). The smoke point is approximately 11°C higher than olive oil (Capuzzo, Maffei, & Occhipinti, 2013), suggesting a greater stability during the frying process (Nadeem & Imran, 2016). The oil obtained by cold pressure extraction is higher in viscosity and acidity than that obtained by solvent-extraction (Porto et al., 2013). This higher viscosity is due to water being bound in the oil during extraction, while the higher acidity is attributed to the water being added during the milling of the seeds prior to cold pressing (Palafox et al., 2012). Indeed, the addition of water enhances lipolytic enzyme activity and prolongs the contact of the seed with air and temperature (Leone et al., n.d.). Nevertheless, the acidity of cold-pressed oil is generally moderate, indicative of its good resistance to hydrolysis (Lalas & Tsaknis, 2002). Iodine levels are lower than that of olive oil, as *Moringa oleifera* oil contains more saturated fatty acid than olive oil (Nadeem & Imran, 2016).

The saponification value, regardless of the extraction method, is similar to that of olive oil (Anwar et al., 2006). The saturated fatty acid content is 21.18%, with palmitic acid dominating, closely followed by behenic, stearic and arachidic acids. The high behenic acid content is the reason why *Moringa oleifera* oil is commercially known as "Ben" or "Behen" oil.

Small traces of cerotic, lignoceric, myristic, margaric and caprylic acids have also been reported (Koheil et al., 2011). The oil contains a high level of monounsaturated fatty acids, up to 76.73%. Oleic acid is the predominant fatty acid, and accounts for 73.57% of the total fatty acids (Barakat & Ghazal, 2016). Additional monounsaturated fatty acids present in the oil are gadoleic and palmitoleic acids (Koheil et al., 2011). Small traces of erucic acid are reported by some studies (Anwar et al., 2006). There is a very low content of polyunsaturated fatty acids, on average 1.18%, and the content of linoleic and linolenic acids is 0.76% and 0.46% respectively (Palafox et al., 2012).

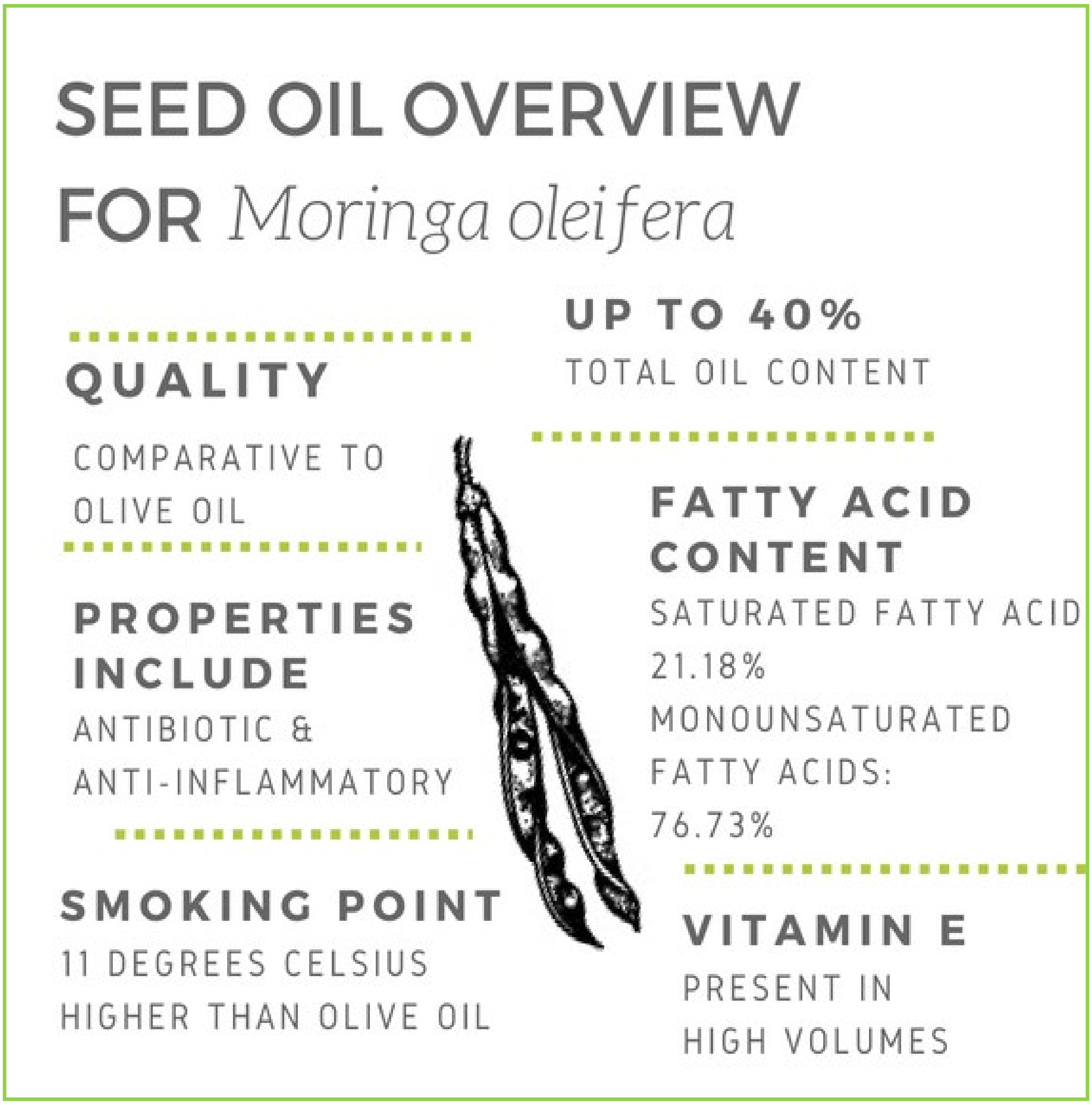

Figure 4.3.3: Overview of *Moringa oleifera* seed oil.

The present fatty acid composition shows that *Moringa oleifera* seed oil falls in the category of high oleic oils and contains a high ratio of monounsaturated to saturated fatty acids (MUFA/SFA). The MUFA/SFA ratio is characteristic of several oils, particularly olive oil, and has been associated with a reduced risk of all-cause mortality, cardiovascular mortality, cardiovascular events, and stroke (Leone et al., 2015). *Moringa oleifera* seed oil could therefore be an acceptable substitute for olive oil as the main dietary fat in countries where the tree grows. The seed oil has a monounsaturated fatty acid content similar to that of olive oil. From a nutritional point of view a lower content of polyunsaturated fatty acids is a limiting factor, which needs to be offset by the consumption of alternative sources rich in polyunsaturated fatty acids. However, from a technological perspective, the low content of polyunsaturated fatty acids ensures greater resistance and stability to oxygen (Koheil et al., 2011).

Moringa oleifera oil is one of the most exotic and highly searched for oils in the world; its exceptional characteristics make it a highly valued ingredient in a variety of applications ranging from vegetable food oil to cosmetic products and other industrial applications including lubricants for fine machinery (Premi & Sharma, 2013).

4.3.3.1. *Moringa oleifera* oil for human consumption

Moringa oleifera oil can be used as high-quality vegetable food oil. It has a somewhat nutty flavour and a structure similar to olive oil (America, 2003). A highly stable oil, it is considered by many to be a healthier alternative to most other frying oils, making it suitable for use in stir-fry dishes and marinades (Zhao & Zhang, 2013). *Moringa oleifera* oil is a concentrated source of food energy. Small amounts of the oil added to the diet of young children has been shown to provide them with a more varied and nutritious diet. As stated, *Moringa oleifera* oil is rich in vitamins E, A and C and unsaturated fatty acids (Eman & Muhamad, 2016).

4.4. *Moringa oleifera* OIL IN COSMETIC PRODUCTS

Moringa oleifera oil is a most valuable oil in the production of skin care products and cosmetics because of its various antioxidant and skin rejuvenating qualities (Ali, Akhtar, & Chowdhary, 2014). Antioxidants help prevent skin and cell damage as well as premature aging caused by free radicals. The incorporation of antioxidants into skin care products is one of the latest trends in the cosmetics and skin care industry (Ali et al., 2013). Due to its high levels of oleic acid (72%), *Moringa oleifera* oil absorbs rapidly into the skin, moisturising and providing it with important nutrients (Kleiman, Ashley, & Brown, 2008). *Moringa oleifera* oil is light and spreads easily on the skin, making it highly suitable for massage and aromatherapy applications (Rahaman et al., 2017). The perfume industry highly values *Moringa oleifera* oil because it has the ability to absorb and retain even the most volatile scents and it is one of the choice oils for perfume manufacturers that still employ the enfleurage process (Zeitoun et al., 2016). This, in combination with its high oleic acid level and enduring shelf life, make it a popular choice for use in the production of expensive and natural perfumes and fragrances (Guon & Chung, 2017).

Finally, *Moringa oleifera* oil contains antiseptic and anti-inflammatory properties which help heal minor skin complaints such as cuts, bruises, burns, insect bites, rashes and scrapes (Zaffer et al., 2001).

4.5. *Moringa oleifera* IN LIVESTOCK AND AQUACULTURE FEED INDUSTRY

Animal feeds are generally referred to as food products that are used to feed farm livestock (Nouala et al., 2006). However, in technical terms animal feed may be explained as highly nutritious food components which are specially prepared for animals and can be fed to them as a sole source of ration for their proper growth and development in order to enhance their productivity (Soliva et al., 2005). Animal feeds play a significant role in the global food industry, allowing economic production of animal proteins throughout the world (Qwele et al., 2013). Animal feed is the largest and most important component to ensuring safe, abundant and affordable animal proteins (Ogbe & Affiku, 2011).

The leaves and seed cake produced by the *Moringa oleifera* tree have become known for their high protein content and potential benefits for human consumption. These nutritional attributes may also provide benefits for livestock feed (Makkar & Becker, 1996). Feeding animals *Moringa oleifera* products has been linked to increased milk production, increased nutrient uptake, and faster weight gain compared to other feeds (Onu & Aniebo, 2011).

4.5.1. *Moringa oleifera* leaves as animal feed supplement

In a study conducted by Reyes-Sanchez at the Swedish University of Agricultural Sciences in Uppsala, milk production of dairy cattle fed only hay was compared to that of cattle fed hay with a *Moringa oleifera* supplement. The results showed that adding 3 kg of the *Moringa oleifera* supplement to the hay increased milk production from 3.1 kg milk per day to 5.1 kg milk per day; an increase of 65%. Results also showed that the inclusion of *Moringa oleifera* as a protein supplement to low quality diets improved dry matter intake, digestibility of the diet, and increased milk production without affecting milk composition (Reyes Sánchez, Sporndly and Ledin, 2006).

Another study conducted in 2001 by Nikolas Foidl (Foild, & Km, 2001) showed that cattle fed with between 15 to 17 kg of *Moringa oleifera* leaves mixed with their regular feed daily resulted in a 32% increase in daily weight gains for beef cattle. A 3 to 5 kg increase in birth weights for Jersey cows, whose average normal birth weight is 22 kg, was also observed. These examples confirm the benefits of the incorporation of *Moringa oleifera* products into animal feed.

4.5.2. *Moringa oleifera* seedcake as an ingredient into animal feed

Moringa oleifera seedcakes are a source of high quality protein in animal feed (Reyes Sánchez, Sporndly and Ledin, 2006). South Africa produces soybean, groundnut, cotton, sunflower, and canola seedcakes, all major ingredients in animal feeds. Soybean and sunflower oilseed meal are the most frequently used in both cattle and poultry feed (Eman and Muhamad, 2016). Cotton seedcake as a feed ingredient has all but vanished in South Africa over the past three years. Groundnut and canola meal have limited contributions to the total oilcake production in South Africa. *Moringa oleifera* seedcakes have been reported to contain 78% crude protein (Busani et al., 2011). Compared to others, *Moringa oleifera* oil cakes contain higher levels of protein, antioxidants and minerals. These high levels of proteins and essential nutrients position *Moringa oleifera* seedcakes as an important potential ingredient in the animal feed industry (Makkar and Becker, 1996).

4.6. *Moringa oleifera* IN WATER TREATMENT

Water is a vital resource for human wellbeing. However, access to safe and clean drinking water is a major concern throughout the world (Bakare, 2016). Raw water from dams, mines, streams, rivers and lakes is usually turbid and contaminated with microorganisms and metals, therefore requires purification to avoid various diseases. Producing potable water from surface water or ground water involves several processes in removing unwanted substances (Kwaambwa et al., 2010). Turbidity removal is often an essential part of the treatment process (Barajas & Pagsuyoin, 2015). In order to make clean water resources available for as many people as possible, cheap, simple, robust and efficient process methods are necessary.

Coagulation is one of the most common water purification methods, enabling treatment of turbidity, colour and organic matter (Futi et al., 2011). Coagulation is also used to reduce the metal ion content in water. Separation of colloids can be achieved through the addition of a synthetic or bio coagulants followed by slow agitation (flocculation), causing coagulation of colloidal particles so they can be separated by sedimentation (Kansal & Kumari, 2014). Water purification using synthetic materials such as aluminium sulphate (alum) and calcium hypochlorite are not efficient as the materials need to be imported.

The cost of purification is therefore driven up in economically developed countries and becomes unfeasible for most rural populations (Futi et al., 2011). Additionally, research has observed that the use of synthetic materials for water purification can be severely hazardous to human health if something were to go wrong during processing (Barakat & Ghazal, 2016). The report considers high levels of aluminium in the brain is a risk factor, causing Alzheimer's disease (Muyibi and Alfugara, 2001; Amagloh and Benang, 2009; Kansal and Kumari, 2014). Other studies have raised concerns over the environmental impacts of continual introduction of aluminium sulphates, which used as a coagulant in the water treatment process, into the environment (Narasiah, 1998).

Natural ingredients from plants can be used as coagulants as an alternative to synthetic chemicals. The use of natural coagulants to clear turbid water is not a new concept. Four thousand years , Nirmali tree seeds (*Strychnos potatorum*) were used in India for clarifying turbid river water (Deshmukh et al., 2013). Peruvian soldiers used powdered roasted maize grains (Zea mays) to purify the water (Nesmith & Ritchie, 1992). Other effective plant-based coagulants include Okra (Agarwal, Srinivasan, and Mishra, 2001), *Castus latifaira* and *Prosopis juliflora* (Bodlund et al., 2014), Valonia (Ozacar and Sengil, 2002), orange peels, apricot, peach kernel, beans and maize (Annadurai et al., 2014).

Of all plants used in water purification, the seeds of *Moringa oleifera* have drawn special attention due to their ability to treat water by acting both as a coagulant and as an antimicrobial agent. Investigations to evaluate *Moringa oleifera's* efficiency for water treatment have been carried out since the early 1970s (Futi et al., 2011). Several studies have established the antimicrobial and non-toxic properties of *Moringa oleifera* seeds (Kansal and Kumari, 2014) recommending their use for water purification in developing countries.

In South Africa, Acid Mine Drainage occurs as a result of groundwater pollution from mining activities, thus rendering groundwater unsafe for consumption and ultimately requires treatment to human consumption quality through various processes. The eMalahleni Water Reclamation Plant (EWRP) is a water treatment facility that treats water from several mines in the eMalahleni (Witbank) area and provides potable drinking water back to the community using Keyplan's High Recovery Precipitation Reverse Osmosis (HiPro™) water treatment technology. HiPro™ utilises multiple stages of ultra-filtration and reverse osmosis membrane systems as well as an anionic polymer flocculent, which is applied into the clarifier water feed to precipitate the solid agglomeration. This process produces super-saturated brine streams from which soluble salts can be released into precipitation reactors.
Whilst undertaking this research, a site visit was conducted to gain an understanding of the water treatment processes and investigate the potential of *Moringa oleifera* seedcakes as a substitute for synthetic coagulant agents currently used in EWRP. Coagulation is an

established method applied widely in water treatment (Nand, 2012). The technique is based on the precipitation of suspended and dissolved particles. Natural coagulants are being investigated as a means of avoiding the adverse effects of synthetic chemical use (Nand, 2012). *Moringa oleifera* seeds are a potential coagulant due their ability to absorb and neutralise charges of inter-particles (Kwaambwa et al., 2010).

Developing a strategic plan for new eco-friendly water treatment technologies requires the characterisation of coagulants and identification of active compounds. Proteins have been identified as the predominant water dissolving constituent in water purification plants (Kansal and Kumari, 2014). It was also found that the coagulative properties of the seed are increased by removing the oil (Amagloh and Benang, 2009; Barajas and Pagsuyoin, 2015; Futi et al., 2011; Kansal and Kumari, 2014; Kwaambwa et al., 2010; Nand, 2012; Nkurunziza et al., 2009; R et al., 2017). This is beneficial for the farmer because the *Moringa oleifera* seed discard referred to as seedcake can be used for water purification after oil extraction.

Investigations into the coagulative properties of *Moringa oleifera* for waste water treatment were carried out at laboratory scale and have shown positive results. *Moringa oleifera* has also proven to be effective in reducing turbidity. The EWRP process is divided into three stages, from which low salinity water is generated by the membrane process in each of the three stages. The purification process is described below (figure 4.6.a.) provides a schematic summary of the water purification process in the EWRP.

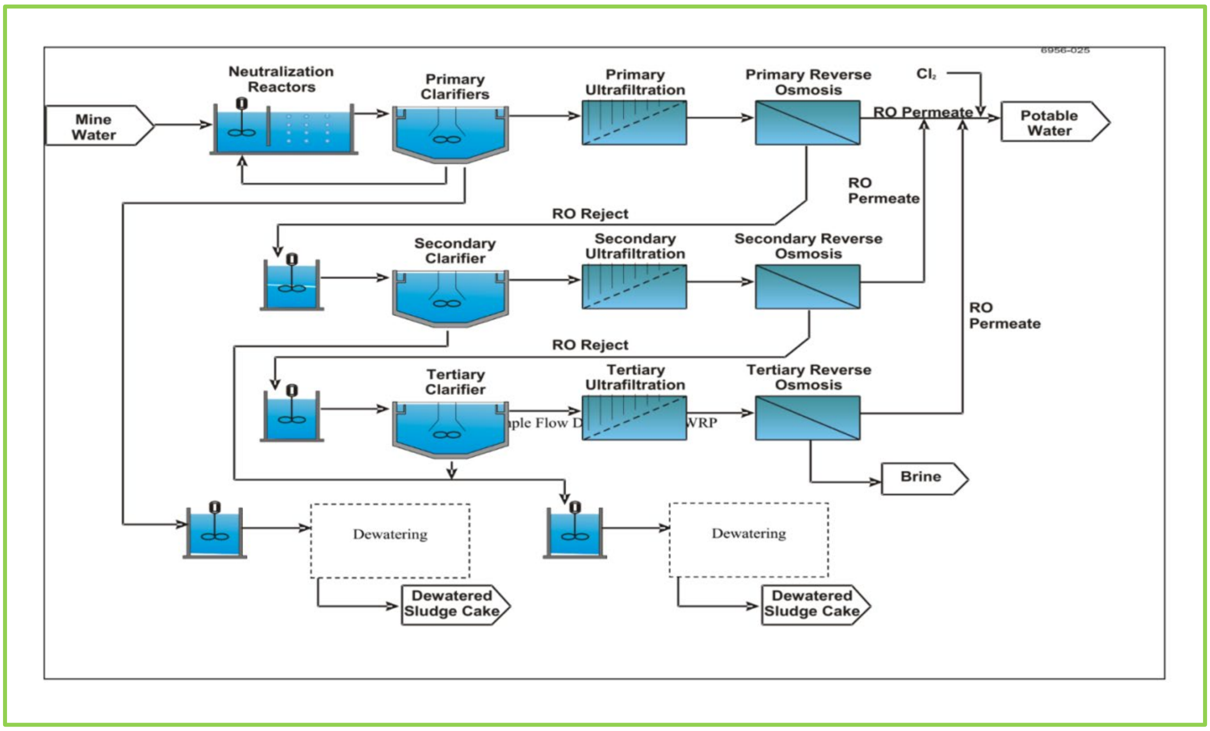

Figure 4.6.a: Schematic diagram of a typical water treatment.

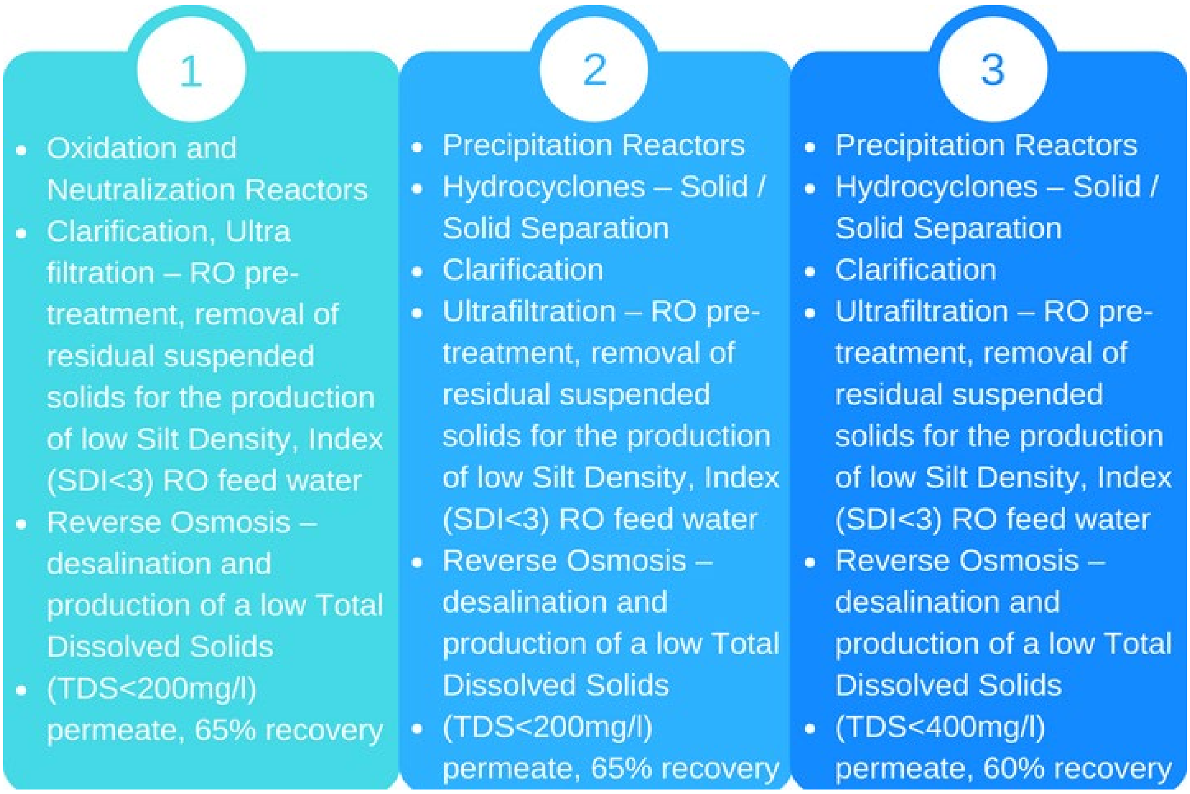

Figure 4.6.b: Summary of stages of EWRP water purification.

4.6.1. *Moringa oleifera* seed as a natural coagulant

Moringa oleifera seeds exhibit coagulative properties equivalent to the alternative method using aluminium salt in water purification. *Moringa oleifera* seed can therefore provide an effective substitute for synthetic coagulants and antimicrobial chemicals currently used at the EWRP. During stage one at the EWRP facility, synthetic chemicals are applied to precipitate metals and organic matter from the water. It is at this stage that *Moringa oleifera* could execute the same action as aluminium salts. This has been demonstrated through the investigations contained in the literature cited in this review. Total dissolved solids (TDS) are a measure of the quantity of all compounds dissolved in water. It was found that *Moringa oleifera* seeds are able to reduce both the TDS and acidity of the water (Futi et al., 2011). The total dissolved salts concentration is a measure of the quantity of all dissolved compounds in water that carry an electrical charge. Since most dissolved substances in water carry an electrical charge, the total dissolved salts concentration is usually used as an estimate of the concentration of total dissolved solids in the water.

A study on the use of *Moringa oleifera* in water purification showed a significant decrease of TDS from between 700 and 800 mg per litre to between 200 mg and 350 mg per litre. This is within the standard limits recommended by the World Health Organisation (Muyibi and Alfugara, 2002). *Moringa oleifera* seed is known to be a natural cationic polyelectrolyte and flocculent. The seeds have a chemical composition of basic polypeptides and molecular weights ranging from 6000 to 16,000 Daltons (Da). *Moringa oleifera* seeds contain up to six amino acids, mainly glutamic acid, methionine and arginine (Patil Rohan et al., 2017). *Moringa oleifera* has the ability to reduce acidity in water, which is well suited to the acidic nature of acid mine water.

Barajas and Pagsuyoin (2015) evaluated the reduction of acidity in river water samples treated with *Moringa oleifera* seeds. Samples which initially contained an acidity of 35 mg per litre were treated with various masses of *Moringa oleifera* crushed seed. They have found that the acidity of water was decreased in the range of 5 to 20 mg per litre, which is within the standard limits set by the WHO. Water soluble proteins in *Moringa oleifera* seeds have a low molecular weight and carry a positive charge. When seeds are crushed and added to water, the protein produces positive charges, acting like magnets and attracting predominately negatively charged particles. This assists in maintaining acidity within the required range.

Available literature indicates that much of the research and use of *Moringa oleifera* in water treatment technologies has been carried out at a laboratory scale as there are insufficient large-scale projects such as EWRP to investigate. The use of the *Moringa oleifera* seed on a macro scale requires a proper study. Further investigations will provide an opportunity to substitute toxic synthetic chemicals with natural and locally sourced coagulants such as *Moringa oleifera* seed. This will also provide benefits to the ecological community.

5. MARKET ANALYSIS

5.1. *Moringa oleifera* LEAF POWDER MARKET SIZE

On a global scale *Moringa oleifera* leaf powder is used as a dietary supplement, falling into the same market category of 'green super foods' like spirulina, barley grass and wheat grass. The global market for nutritional supplements has seen rapid growth in the past years, with the trend expected to continue (Philippe, Leon and Serge, 2015). Interestingly, the tremendous growth of the nutraceutical market is strongly driven by the rising consumption of dietary supplements, and in particular a sharp increase in the sales of herbal and botanical supplements (RNCOS, 2013). Overall, the international herbal supplement and remedies market is expected to reach 578.23 billion USD by 2025 (Philippe, Leon and Serge, 2015).

The major markets for dietary supplements are in the United States, followed by Western Europe and Japan - all with an affluent middle class willing to invest in alternative health and food products (Philippe, Leon and Serge, 2015). Whilst the United States dominates the overall market in nutritional supplements, Europe accounts for the largest share of the world market in herbal and botanical specific supplements and remedies. Asia Pacific, including Japan, China and India are other important markets for botanicals and are set to pave the way with the highest growth rate at 10.5% for 2017.

Although trading of *Moringa oleifera* leaf powder is steadily increasing on global scale, market data on trade volumes and market share is not available. However, by observing the increasing number of products available on the international market as well as the growing number of international producers, the demand for *Moringa oleifera* leaf powder products seems to be growing. Various potential international *Moringa oleifera* product suppliers confirm that the demand for this product is increasing year on year (Philippe, Leon and Serge, 2015).

In South Africa *Moringa oleifera* leaf powder is becoming increasingly available in health shops, both online and offline. While the leaf powder has been available for years, whole food stores and online retailers such as Faithful-to-Nature are also starting to carry 'consumer ready' products including capsules and tablets. Various South African farmers have started to increase growing of the *Moringa oleifera* tree. Although *Moringa oleifera* leaf powder as a dietary supplement is growing in popularity, the leaves of the tree are currently mostly used in teas or energy drinks. They are marketed as caffeine free energy boosters and as a 'super food', with a composition comparable to other energy drinks.

The current global market supply of *Moringa oleifera* leaf powder is dominated by India, which meets more than 80% of global demand (figure 5.1.). This percentage of global production by India is largely due to the country's longstanding tradition of including *Moringa oleifera* in its food consumption (Omotoso et al., 2018). As a result of the high demand, Indian *Moringa oleifera* is grown on large plantations. This makes it possible for Indian wholesalers to sell *Moringa oleifera* leaf powder at a comparatively low price, predominantly through online platforms.

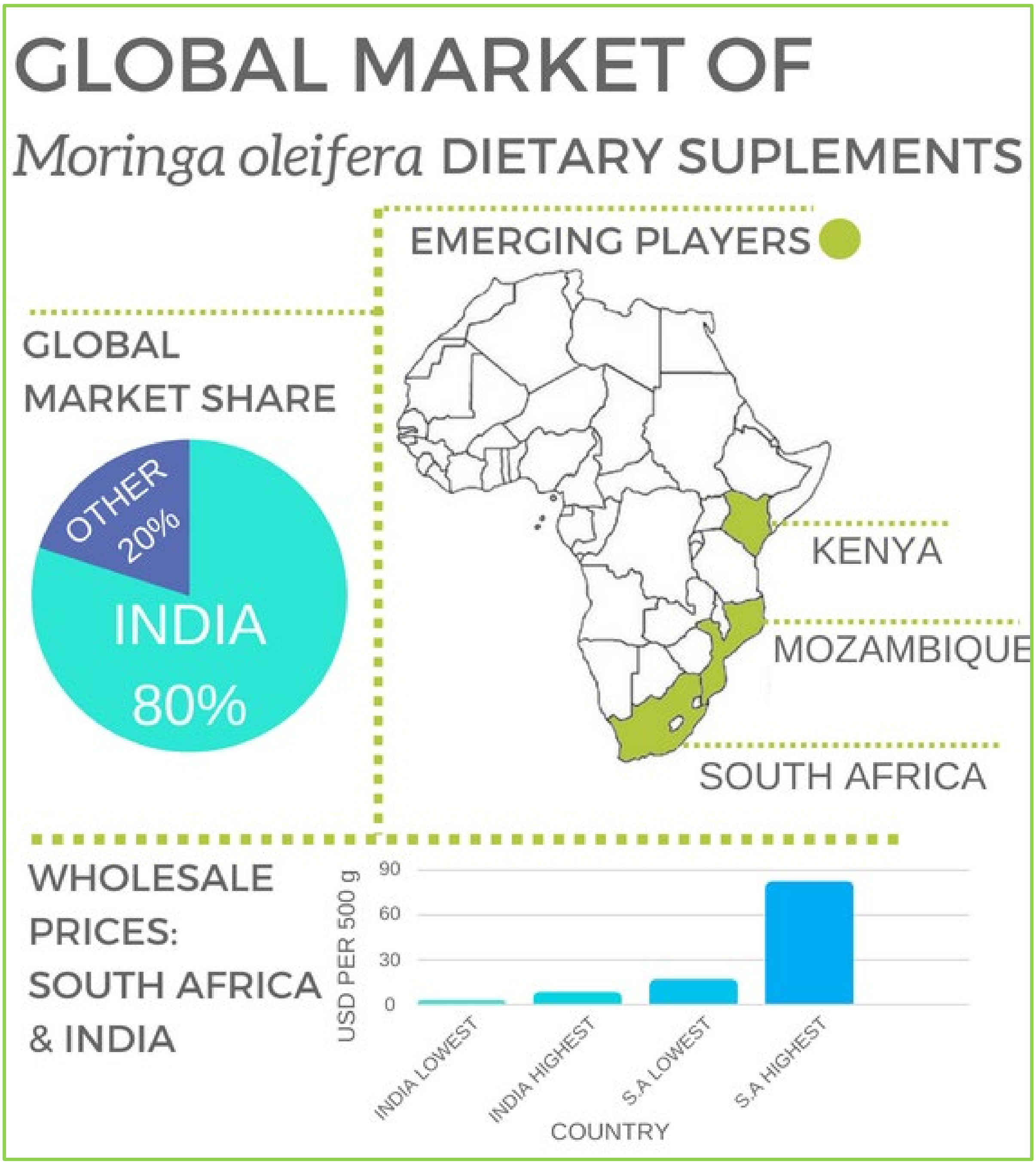

Figure 5.1: Global market of *Moringa oleifera* dietary supplements.

Whilst strong market growth provides space for new entrants into the market for *Moringa oleifera* leaf products, it will be essential for new players such as South Africa to differentiate themselves from the current major suppliers. Strategies to avoid competition with India and increasingly China, who have the ability to offer *Moringa oleifera* leaf powder at a competitively lower price, are most likely to be successful by targeting niche markets. Here, new market players will be less subject to rivals and have a greater ability to demand higher prices. Examples of such niches are companies or retailers that target the high-pend of the market with high quality exotic products that are certified sustainable, fair-trade and organic.

Moringa oleifera leaf powder is marketed as a 'super food' in international markets (Cohen-Zinder et al., 2017). The chemical composition of *Moringa oleifera* leaves contain high levels of antioxidants (Hamany Djande, et al., 2018), with research indicating that it outperforms other antioxidant rich 'super foods' such as açai and blueberries. The leaf powder is increasingly popular on the global market as a food supplement (Khoza et al., 2016). India is currently the main global supplier; however, buyers have concerns about the quality of Indian *Moringa oleifera* leaves. African suppliers including South Africa, Kenya and Mozambique are increasingly entering the growing market.

The South African market for *Moringa oleifera* leaf powder is complimented by a variety of farmers that sell smaller packages to the end consumer. Locally, *Moringa oleifera* market has started to grow with the increase in the number of farms and available products on the market. *Moringa oleifera* leaves are sold in different forms, from capsules and tablets to powders. There are relatively few barriers in the market for *Moringa oleifera* leaf powder, enabling access for new entrants. **The main barriers to market entry include:**

- Scale of production: Although there is a strong demand for *Moringa oleifera*, competition (especially from large-scale suppliers such as India) is fierce.
- Processing of *Moringa oleifera* leaves: Leaves need to be dried close to the harvest site directly after harvesting to prevent deterioration of quality.

5.2. *Moringa oleifera* ANIMAL FEED POTENTIAL MARKET SIZE

Animal feed is an important component to global food production processes (Vibhute et al., 2015). Normally, production occurs in industrial mills or in simple on-farm mixers. The animal feed market is expanding owing to the growing demand for animal based products, as presented in figure 5.2.a. (Vibhute et al., 2015). Growth in animal-based product consumption in the developing world has also contributed to a rapid demand for animal feed recently. Global animal feed production was found to be around 962.62 million tons in 2013, showing a growth of 0.9% from the previous year. China is the leader in global feed production producing 189 million tons per annum, followed by the USA, Brazil and Mexico, while South Africa is ranked number 21 in the world. However, compared to other African countries, South Africa is the largest animal feed producer on the continent and in 2017 contributed more than 13 million tons of animal feed to global animal feed production (Reyes Sánchez, Spörndly, and Ledin, 2006). Poultry feed, which accounts for 46% has the biggest share in global feed consumption, followed by ruminant (comprising dairy, beef and small ruminants), pig and aquaculture feed. Pig and ruminant feeds account for 25% and 21% of the total animal feed consumption respectively.

The trends recorded by the Food and Agriculture Organisation (FAO) of the United Nations suggest that the total global consumption of aquaculture products is increasing, and farmed fish and shellfish now exceeds beef on a weight basis, hence aquaculture feed now contributes 4% to the overall animal feed production globally. Pet and equine feed have shares of 2% and 1% respectively (Kholif et al., 2015).

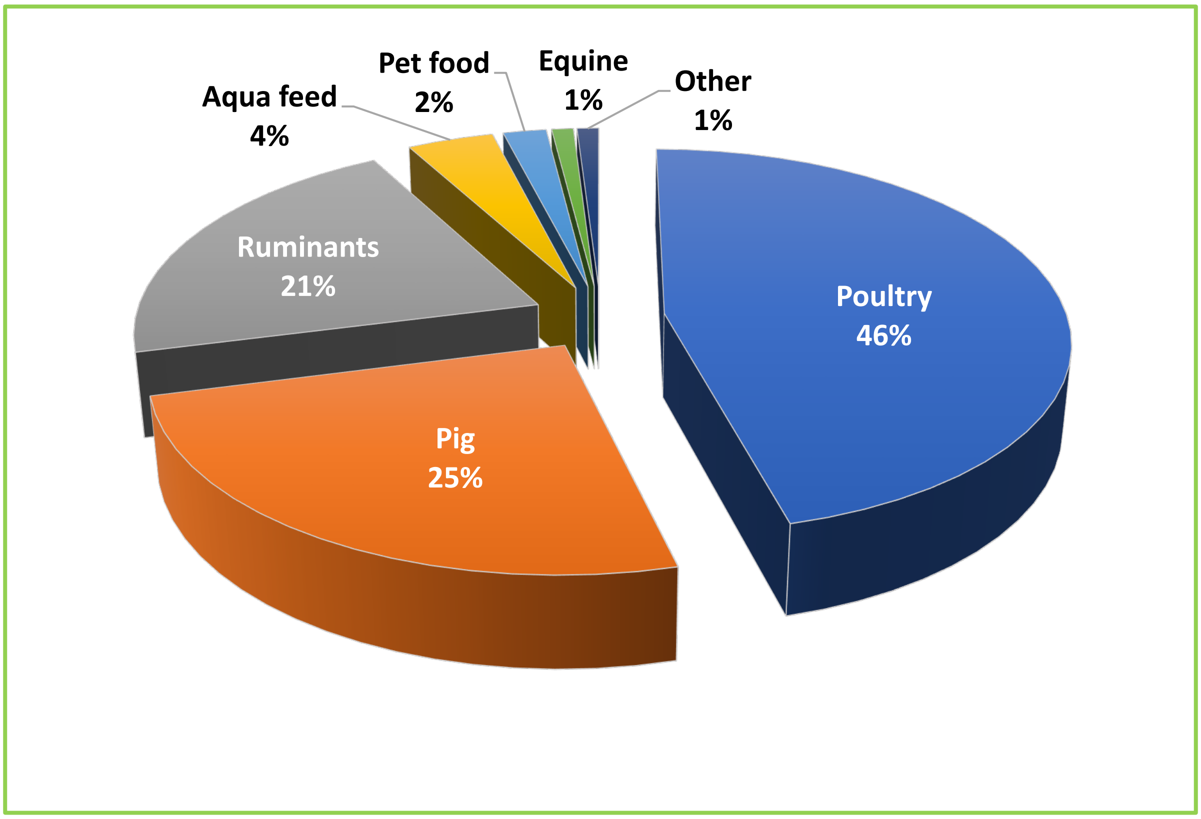

Figure 5.2.a: Global feed consumption per species.

The South African animal feed industry is about 85 years old. The industry came into existence after severe droughts and depression that transpired during the 1930's (DAFF, 2016). The industry produces a variety of feed for various animals including poultry (layer and broiler breeders), dairy, beef and sheep and pigs. The quality of South African feeds are high and meet international standards (DAFF, 2016). Raw materials for animal feed are generally adequately available in South Africa, particularly maize which is the main ingredient in many animal feeds. The industry's average production is about 3.5 million tons per annum. Based on information from animal feed manufacturers, maize accounts for an average of 50% of total feed sales. Soya bean meal and sunflower seed and oilcake account for averages of 14% and 4.5% of total feed sales respectively, with fish meal at about 0.5%.

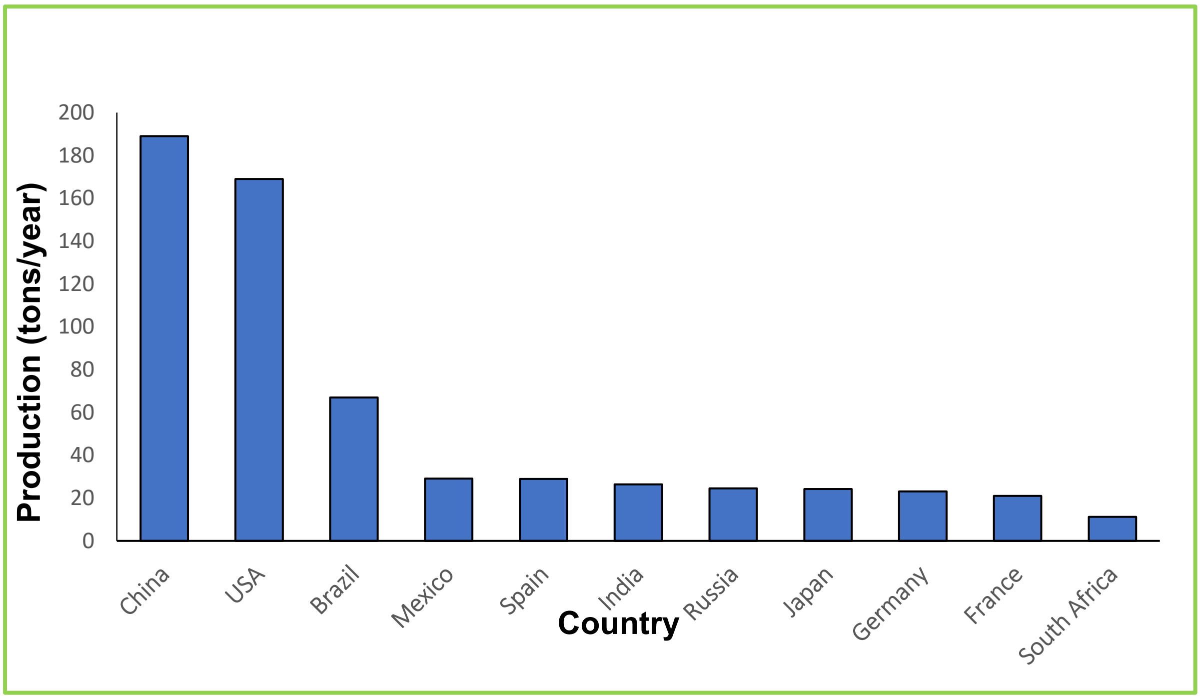

Figure 5.2.b: Global feed production rankings.

The production of compound feed requires use of various agricultural raw materials (Ben Salem & Makkar, 2009). However, it must be noted that not all raw materials are used in all compound feeds (Nouala et al., 2006). The inclusion rates of different raw materials vary from formulation to formulation, as well as between different species (Busani, et al., 2011).

5.3. *Moringa oleifera* LEAF POWDER PRICING

Prices for *Moringa oleifera* leaf powder on the global market fluctuate enormously, depending on quantity, quality and end use of the product (Boulaadjoul, et al.). With the largest share of the global market, Indian *Moringa oleifera* leaf powder wholesale prices range from 2.26 to 7.90 USD per kg, whereas South African *Moringa oleifera* prices range from 16.39 to 81.96 USD per kg. Wholesale costs in South African are still high compared to the market leader, India.

5.4. *Moringa oleifera* SEED OIL MARKET SIZE

Plant-based oils including aloe, morula and *Moringa oleifera* often have specific active and functional properties, making them particularly valuable for use in cosmetic products. Following health and wellness trends, consumers increasingly prefer cosmetics with ingredients derived from plants, rather than mineral oils (Al-asmari et al., 2015). This trend to consume 'natural' cosmetic products is in line with other social patterns, where consumers are increasingly adopting green values and seek out companies that accept responsibility for social issues and the environment (Rao et al., 2011). In response to these trends, the cosmetic industry has begun to differentiate its products by using more exotic vegetable oils, in turn triggering a growing international demand and thus higher prices for oils derived from sources like *Moringa oleifera*. However, in South Africa, *Moringa oleifera* oil has not been fully incorporated in the cosmetic products; only a few companies were identified to incorporate *Moringa oleifera* oil into their products such as creams and lotions.

The global trade statistics do not segment the market; thus, statistics are aggregated for exotic vegetable oils which include apricot kernel, argon, baobab and papaya seed oils. The volume of global imports of exotic vegetable oils was at a high in 2007 (approximately 700,000 tons) and maintained a quite constant level during 2010 and 2017 (approximately 600,000 tons). The single most important importer was the EU (European Union), who imported around half of the volume from developing countries. The value of global imports of exotic vegetable oils increased from around 1.05 billion USD in 2009 to almost 5.7 billion USD in 2017 (CBI, 2009). This indicates that exotic vegetable oils are an increasingly attractive high value-added commodity. Although global statistics draw no comparison between different plant oils, locally a comparison can be drawn between the three plant oils, *Moringa oleifera,* Sunflower and Olive (figure 5.4). This comparison highlights that there is a gap in the market for another plant oil that will fill production of *Moringa oleifera* (figure 5.4) and be price positioned at mid-range price.

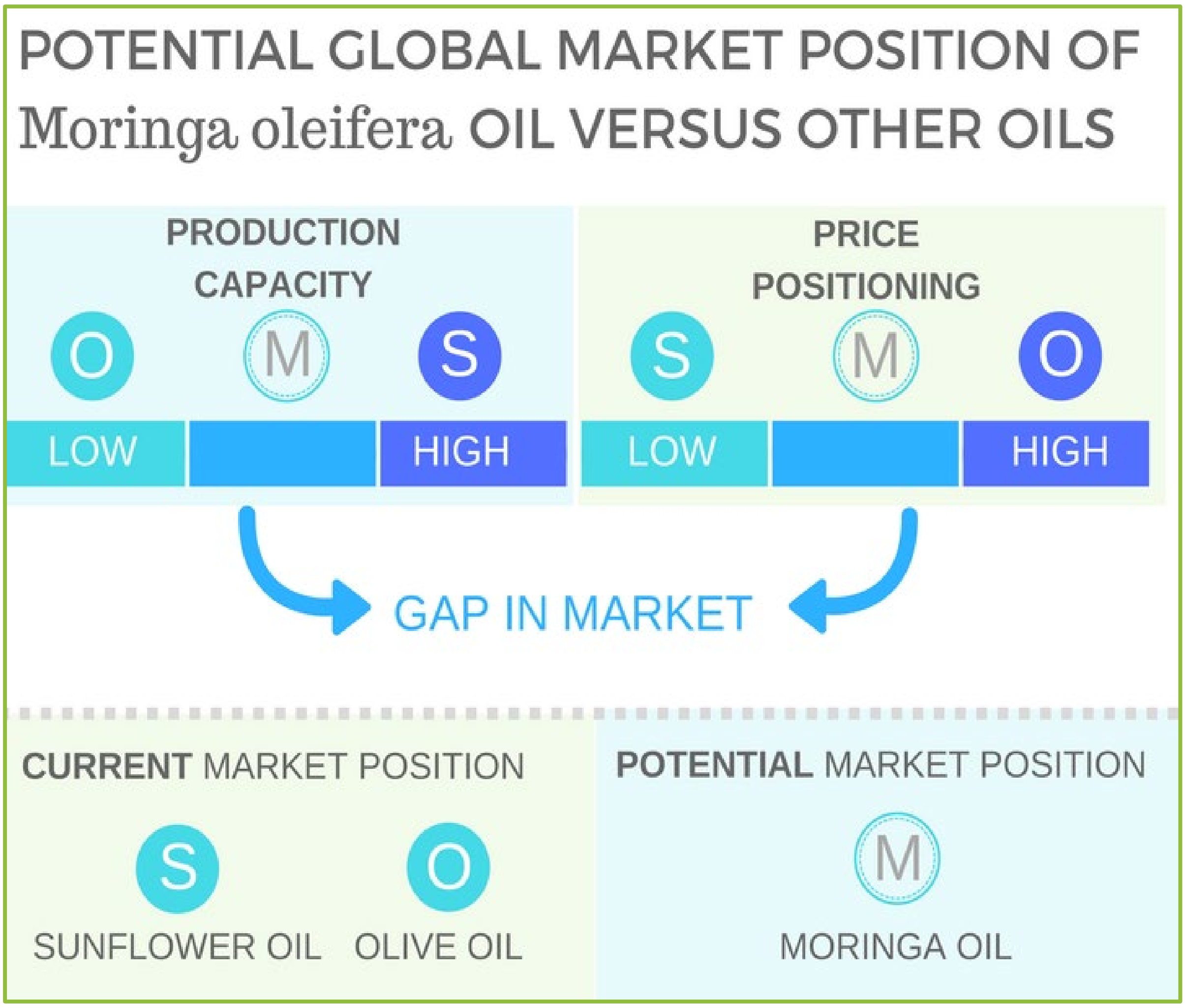

Figure 5.4: Global market position for *Moringa oleifera* in relation to sunflower and olive oils.

5.5. *Moringa oleifera* SEED OIL PRICING

In the worldwide market, *Moringa oleifera* oil, together with argon and papaya seed oils, is at the very high end of the spectrum price (CBI, 2009). One reason is the small amount of *Moringa oleifera* oil that is currently available on the world market, which renders it a rare and expensive commodity (Anwar et al., 2006). Moreover, the price point for *Moringa oleifera* oil varies depending on the quality of the oil (Anwar & Rashid, 2007). High demand for *Moringa oleifera* oil is observed in the cosmetics industry. In South Africa, sunflower oil is still the largest seed oil produced within the country. An average of about 667 thousand tons of sunflower seed are produced per annum, while the gross value was approximated to be R2.5billion per annum.

In the South African context, the observation is that few farmers extract the oil from the seed and thus very limited data is available on the production volume of *Moringa oleifera* oil. As a result, the price of *Moringa oleifera* oil is far higher than other plant oils that are currently available in the South African market (table 5.5) as a result of high demand and limited supply. Where the high demand cannot keep up with supply. In small quantities *Moringa oleifera* oil is priced slightly closer to olive oil, but as the quantities increase, *Moringa oleifera* increases correspondingly in price. This is as a result of an extremely limited availability of *Moringa oleifera* seeds for oil production in South Africa.

Table 5.5: South Africa's plant oil price comparison- *Moringa oleifera*, sunflower and olive

Quantities	Ben Oil (Moringa Oil)	Canola Oil	Olive Oil	Sunflower Oil
500ml	R80.00	R16.45	R64.95	R11.95
1L	R450	R32.40	R129.95	R28.60

5.6. POINT OF SALES

In South Africa the majority of *Moringa oleifera* traders are still employing traditional point of sales such as retail and direct marketing for their products. However, online trading platforms such as e-commerce in recent years have gained significant popularity and India as a market leader in trading *Moringa oleifera* has also adopted the online platform approach.

5.7. CONSTRAINTS AND BARRIERS TO MARKET

The growers of Moringa highlighted that they experienced the following constraints and barriers to market:

5.7.1. Challenges/constraints

- Access to land, particularly for *Moringa oleifera* oil producers, poses a challenge when there is a need to expand and increase production.
- Water as a scarce and limited resource is a potential risk to the yields of *Moringa oleifera*. However, a farm such as NBEF Organics farm in Tzaneen Limpopo is mitigating this risk by employing sustainable water use practices like water recycling.
- Limited space and resources for agro-processing due to lack of funds to scale-up the agro-processing facilities creates a bottleneck in the value chain. The agro-processing facilities are constrained to meet the supply of harvested leaves and the demand of products to market.
- Based on the research thus far, there appears to be more farming of leaf-bearing trees than seed-bearing Moringa trees in the country. This occurrence was also observed in practice during the site visits, where only one farm of the three had both leaf and seed producing Moringa trees. During the Moringa Development Association of South Africa (MDASA) Stakeholder Workshop presentations and discussions also highlighted the limited availability of Moringa seed-bearing trees in South Africa.
- Regulation - Trading of *Moringa oleifera* is not regulated in South Africa and currently trading is fragmented and relatively informal. However, the growing trend of *Moringa oleifera* trading presents an opportunity to formalise the sector. Therefore, constant engagement and participation of organisations such as MDASA presents platforms to formalise *Moringa oleifera* trading in South Africa.

5.7.2. Barriers to market

Almost all *Moringa oleifera* farmers highlighted the nutritional and element analyses as the biggest barrier to market. Nutritional and element analyses of the products are fundamental for providing assurance, quality and integrity of the products to the consumer. *Moringa oleifera* farmers and traders have highlighted that providing such assurance to consumers is complicated by the high costs associated with assessment, accreditation and certification for products from reputable bodies such as South African Bureau of Standards (SABS).

6. ECONOMIC ANALYSIS

6.1. BUSINESS MODELS

In developing countries, *Moringa oleifera* has been introduced trading in an informal sector. In South Africa, the majority of *Moringa oleifera* traders are in an informal sector, where farmers trade directly with their customers. There is still a limited number of *Moringa oleifera* traders in the formal sector, for example retailers such as Dischem. However, *Moringa oleifera* farmers have highlighted the nutritional and element analyses of their products to be the biggest barrier to entering the formal sector.

This research has identified three key business models that can be utilised as viable vehicles for trading of *Moringa oleifera* in South Africa:

- Private/sole proprietary
- Agri-business hub
- Co-operatives

6.1.1. Private (Pty) Ltd) / Sole proprietary business model

A private / sole proprietary business model (figure 6.1.1) is typically owned by one individual. The owner of the business may focus either only on farming *Moringa oleifera* or adopt the entire value chain as per the NBEF farm Tzaneen, Limpopo (annexure 3)

6.1.2. Agri-business hub business model

An agri-business hub is a business development centre that provides a wide range of business development services, communal facilities, and financial support services to assist and promote small, medium and micro-sized enterprises. This model can capacitate small sized businesses through programmes that provide technical, financial support and a trading platform to support *Moringa oleifera* production. In addition to the above, the hub provides valuable business development support services (BDS) to both new and expanding micro and small business enterprises in communities, thus creating employment.

An agri-hub would have agro-processing equipment and could procure farmers' produce for processing into products that are ready for the market. Smaller farmers also often have limited resources and skills particularly on sustainable farming practice. The agri-hub can train small farmers and capacitate them with farming skills (figure 6.1.2). This model is easily scalable and thus has the potential to create additional job opportunities. It also encourages the mentorship and business support that are key drivers to the success of entrepreneurs and small-to-medium enterprises.

Figure 6.1.1: Private (Pty) Ltd / sole proprietary business model.

Figure 6.1.2: Agri-business hub business model.

6.1.3. Co-operative business model

A co-operative is type of business model where a group of people with common business ideas and interests collaborate voluntarily to address their common needs. The strength of cooperatives lies in their multispectral grassroots organisation which pervades every aspect of human endeavour in both rural and urban areas. Co-operatives have demonstrated the capacity to group together (figure 6.1.3.). This provides an opportunity for small producers to tackle the challenges of financing, production, processing and marketing as a collective, as opposed to the individualistic approach of a sole proprietary business. The cooperative business model can also be easily incorporated into current farming of *Moringa oleifera* in cases where existing *Moringa oleifera* farmers are already self-sufficient and have good farming practices in place.

In light of the study conducted across South Africa, farming challenges, lack of funding, land and machinery, three business models have been identified that can be employed in the commercialisation of *Moringa oleifera* in South Africa.

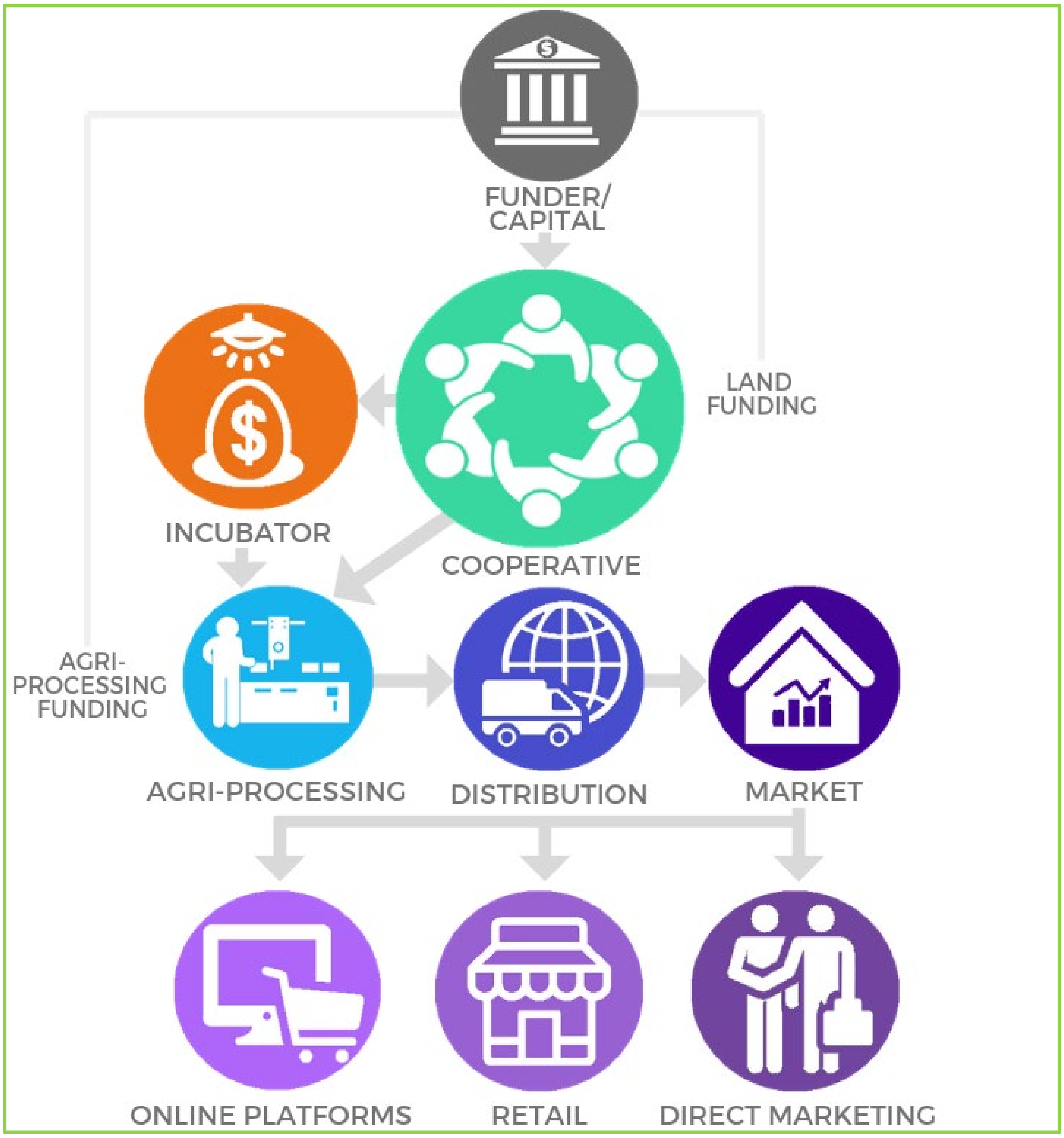

Figure 6.1.3: Co-operative business model.

6.2. *Moringa oleifera:* PRIMARY OPERATIONAL DATA AND FINANCIAL MODEL

During site visits of the ten farms, data that relates primarily to the cultivation and agro-processing business of *Moringa oleifera* was collected as follows:

a. Size (hectares) of available agricultural land
b. *Moringa oleifera* farming, harvesting and processing
c. Farming practices
d. Costs (CAPEX and OPEX)

The data collected is presented in table 6.2. below and when analysing the data, it was deduced that the majority of *Moringa oleifera* growers in South Africa often begin as informal operators without any systematic approach. Most of the farmers from the study sample have not kept the required records such as production, yields and operational costs incurred, since they could not provide some of the data on their daily operations. Farms that were able to provide detailed operational information were either already established farmers as observed at NBEF, Wellness and Sedikong farms or the currently small-scale *Moringa oleifera* growers with a solid business plan and aspirations to scale their operations and commercialise their products (Nyala and Moringaveldt). In other instances, the farmers refused to provide financial data citing it to be part of their business' competitive advantage (table 6.2.).

Table 6.2.: *Moringa oleifera* farming and agro-processing data.

#	Farm Name	Location	Available Land size (ha)	Spacing of Moringa planted (m)	PRODUCTION		COSTS	AGRO-PROCESSING	
					YIELD	IRRIGATION			
1	Nyala	Brits	10	3x2 for 1000 leaf trees	Summer: Leaves harvested weekly to produce 8-10kg of dried leaves Winter: No yield	Drip using borehole water. 2 litres of water per tree once a week No fertilisers/ pesticides used	CAPEX- Milling Machinery: R150 000 OPEX- N/A	Leaves harvested, washed & air-dried Leaves milled into powder	Supplies *Moringa oleifera* leaf powder
2	Luwamba	Richards Bay	2.5	1.5x2	Summer: Leaves harvested every four months 15 harvested trees produce 500g of powder	Manual irrigation once a week	CAPEX- N/A OPEX- Labour of 2 seasonal farm workers: R1320/month	Leaves harvested, washed & air-dried. Leaves milled into powder	
3	Super Moringa	Richards Bay	1.0	2x2	Summer: Leaves harvested every four months	Manual irrigation once a month	N/A	Leaves and seeds are harvested, washed & air-dried Leaves and seeds are milled into powder	*Moringa oleifera* leaves and seeds powder

#	Farm Name	Location	Available Land size (ha)	Spacing of Moringa planted (m)	PRODUCTION		COSTS	AGRO-PROCESSING	
					YIELD	IRRIGATION			
4	Moringaveldt	Winterveldt	8.6	1x1 for 250 trees	Summer: Leaves harvested twice a week to produce 2500 bottles of capsules (90 capsules per bottle) Winter: No yield	Drip using 2 litres of water per tree twice a week No fertilisers/ pesticides used	CAPEX- Milling Machinery: R65 000 OPEX- Labour of 2 seasonal farm workers R1800/month	Leaves harvested, washed & air-dried Leaves milled into powder	Packaged capsules
5	Wellness Moringa	Lebowakgo mo	14	Leaf trees: Random Seed trees: 3x3	Summer: Leaves harvested weekly to produce a monthly supply of 2 tons of powder Seeds harvested to produce 2400 litres of oil annually Winter: No significant change to the summer yield	Drip, using borehole water. 4 litres/hour of water per hectare once a week. No fertilisers/ pesticides used	CAPEX- Oil press Machinery: R240000 OPEX- 90% allocated to labour of 25 contract farm workers earning R1600/month 10% of costs allocated to electricity for the machinery and fuel for the water pump	Leaves are harvested, washed & dried indoors using mobile dryers. Leaves are milled into powder Seeds are removed from pods and pressed with the press machine to extract *Moringa oleifera* oil	Packaged capsules and bottled *Moringa oleifera* oil

#	Farm Name	Location	Available Land size (ha)	Spacing of Moringa planted (m)	PRODUCTION		COSTS	AGRO-PROCESSING	
					YIELD	IRRIGATION			
6	NBEF	Tzaneen	42	2x2 for leaf trees 2,5x2,5 for seed bearing trees	Summer: Leaves are harvested every week, to yield 1000kg/month of dried leaves	Drip, 2litres of water per tree once a week No pesticide only organic compost used	Not shared	Leaves have a two-stage drying method First the leaves are air-dried on a drying line and then dried in an oven	Packaged Capsules and packaged *Moringa oleifera* leaf teabags
7	Motupa	Tzaneen	5	1x1	Summer: Leaves are harvested every two months, to yield 4kg/month of dried leaves	Manual irrigation using a watering can and water usage of 5 litres/$m^{2.}$	N/A	No agro-processing	
8	Sedikong	Lebowakgomo	41	2x2	**Summer:** Leaves are harvested every three months, to yield 2400kg/ three-month cycle of dried leaves **Winter:** Leaves harvested every four months in winter to yield 800kg/month of dried leaves	Drip, 2 litres of water per tree once a week No pesticide only organic compost used	Not shared	Leaves harvested, washed & air-dried Leaves milled into powder	Packaged Capsules

#	Farm Name	Location	Available Land size (ha)	Spacing of Moringa planted (m)	PRODUCTION		COSTS	AGRO-PROCESSING	
					YIELD	IRRIGATION			
9	Afri-Nest	Tzaneen	86	0.5x0.5	Random (no harvesting pattern employed).	Manual irrigation using a watering hose	N/A	Leaves harvested, washed & air-dried Leaves milled into powder	Packaged Capsules
10	ABQ	Tzaneen	8.5	1x1	**Summer:** Leaves harvested weekly to produce 60kg of dried leaves **Winter**: No significant change to the summer yield	Drip, using water from the nearby dam. 1,5hactares irrigated twice a week for an hour. No fertilisers/pesticides used	N/A	No agro-processing	

A financial model applicable to both co-operative and sole proprietary business entities in figure 6.2.a and b presented below was developed in the absence of business data or poor business data. The model was developed using secondary data as inputs. Two scenarios are presented below in figures 6.2.a and b, referred to as the optimal scenario and non-optimal scenario based on growing *Moringa oleifera* on a 1ha area of land.

Scenario 1 (figure 6.2.a.) presents an optimal business model with an average annual leaf production of 200kg, that generates an annual revenue of R190,000. The annual income of R190,000 is generated from selling R200kg of *Moringa oleifera* at R950/kg, resulting in a gross margin of R85,300.00.

Scenario 2 (figure 6.2.b.) despite projecting a gross margin of R1925,00, is not optimal due to a low average annual leaf production of 100kg, generating an annual revenue of only R95,000.

The initial capital investment for both is R78,200.00 to purchase land, seed, mill and an irrigation system.

SCENARIO 1- 200kg annual yield						
CO-OPORATIVE AND SOLE PROPRIETARY						
Moringa oleifera leaf powder						
ACTIVITY	Unit	Quantity	Cost/unit (R)	Price/unit (R)	Revenue/ha (R)	Cost/ha (R)
1. Average Annual Yield	kg	200				
2. Gross Revenue	R				190000	
3. Pre-harvest Costs						15700
- Compost	t	3		700		2100
- Labour (2 labourers)	season		3400			13600
4. Agri-processing Costs						69200
- Marketing	month	12		400		4800
- Packaging	count	2		700		1400
- Transport	km	12600	5			63000
5. Utilities Costs						19800
- Electricity	month	12	700			8400
- Water	month	12	300			3600
- Communication	month	12	650			7800
Total OPEX						104700
Total CAPEX						78200
- Land	ha	1	9500			9500
- Seed	kg	1		1200		1200
- Mill		1	4500			65000
- Irrigation system		1	2500			2500

Gross Margin	**R85 300,00**

Model based on 1 hectare (ha), per annum

INPUTS	
Moringa/kg	950
Seed 2kg/ha, R600/kg	1200
Seasons	4

Figure 6.2.a: Scenario 1- financial model for a co-operative and sole proprietary entity.

SCENARIO 2- 100kg annual yield

CO-OPORATIVE AND SOLE PROPRIETY

Moringa oleifera leaf powder

ACTIVITY		Unit	Quantity	Cost/unit (R)	Price/unit (R)	Revenue/ha (R	Cost/ha (R)
1. Average Annual Yield		kg	100				
2. Gross Revenue		R				95000	
3. Pre-harvest Costs							14125
- Compost		t	1,5		350		525
- Labour (2 labourers)		season		3400			13600
4. Agri-processing Costs							68150
- Marketing		month	12		400		4800
- Packaging		count	1		350		350
- Transport		km	12600	5			63000
5. Utilities Costs							10800
- Electricity		month	12	350			4200
- Water		month	12	150			1800
- Communication		month	12	400			4800
Total OPEX							93075
Total CAPEX							77600
- Land		ha	1	9500			9500
- Seed		kg	1		600		600
- Mill			1	4500			65000
- Irrigation system			1	2500			2500

Gross Margin	**R1 925,00**

***Model based on 1 hectare (ha), per annum**

INPUTS	
Moringa/kg	950
Seed 2kg/ha, R600/kg	1200
Seasons	4

Figure 6.2.b: Scenario 2- financial model for a co-operative and sole proprietary entity.

7. CONCLUSION AND RECOMMENDATIONS

Moringa oleifera plant primarily is globally used for its medicinal and nutritional benefits. Its leaves contain more vitamin C than oranges, more potassium than bananas and more protein than eggs and milk, whilst ben oil extracted from *Moringa oleifera* seeds has anti-inflammatory elements. Thus, more applications of *Moringa oleifera* are being explored in other industries such as the pharmaceutical, cosmetic, animal feed and water treatment industries.

Although known for being a resilient plant, *Moringa oleifera* can be susceptible to pests and diseases. These pests and diseases present significant threats to tree crop cultivation. In South African particularly, Diplodia rot may occur in waterlogged soils as a result of excessive irrigation of *Moringa oleifera* plant causing discolouration of the leaves from green to yellow and results in severe wilting that ultimately destroys the plant.

In recent years, the exploration of other applications of *Moringa oleifera* have led to *Moringa oleifera* being included in water treatment and animal feed industries. In water treatment, *Moringa oleifera* seeds can be used as a coagulant. Laboratory based studies have shown positive results on the effectiveness of *Moringa oleifera* seeds as a coagulant for water purification. A study conducted at the University in Namibia concluded that Moringa seeds in water treatment can reduce turbidity up to 92-99% and also decrease clay and bacteria content in raw water. The viability of using *Moringa oleifera* seeds in a large-scale water treatment such as that of eMalahleni Water Treatment Plant still needs to be investigated and piloted. However, a major constraint identified is the availability of a consistent supply of large volumes of *Moringa oleifera* seeds.

Also, the use of *Moringa oleifera* plant as an ingredient into the production of animal feed has been recently explored. Due to the high levels of protein in *Moringa oleifera* leaves, studies have recommended that it be fed to goats and dairy cows as a supplementary diet. In South Africa, a study conducted by the University of Fort Hare on Honeydale farm on cross-bred Xhosa lop-eared goats showed an increase in the quality of goat meat from goats that were fed a meal supplement with *Moringa oleifera* leaf when compared to the quality of meat that of goats fed sunflower seed cake meal.
Another study was conducted by the University of Limpopo to determine the effects of a *Moringa oleifera* seed-supplemented diet on the productivity of Ross 308 broiler chickens. From the study, Ross 308 broiler chickens aged 1 to 21 days that were fed *Moringa oleifera* seed diet showed an improved growth rate and reduced mortality rate. Both studies provide an indication of positive effects that *Moringa oleifera* may have on animals when fed a *Moringa oleifera* leaf and seed supplemented diet.

It is evident the applications of *Moringa oleifera* may be explored in various industries such as pharmaceuticals, cosmetics, food and environmental management. Thus, an integral part in the application *Moringa oleifera* in the industries highlighted above is to understand its chemical composition and what role the soil composition plays when growing *Moringa oleifera*. The chemical analysis conducted on *Moringa oleifera* plant (leaves and seeds) and soil in this research study displayed variability in the nutritional composition on the samples collected from the ten farms. Generally, the chemical composition of leaves and seeds from various

farms throughout South Africa indicated *Moringa oleifera* to be a good source of protein, fibre, lipids, polyphenolic, flavonoids and vitamins.
Furthermore, the leaves were noted as an excellent source of minerals such as Ca, Cu, Co, Fe, K, Mg, Na and Zn. High nutritional data derived from the nutrient characterisation of *Moringa oleifera* clearly indicates that the plant's leaves have the potential to be used as a food supplement with multiple purposes. However, the results of the macro-elements from the leaves exhibited concerning high content of macro-elements and iron when compared to the maximum limit set by different international organisations. Thus, the high content of macro-elements and iron need to be further investigated in order to understand the dynamic extraction mechanism of these macro-elements and iron from the leaves that are often harvested to produce *Moringa oleifera* based products for human ingestion. In addition, the clinical implication of these elements must be investigated to determine the toxicology of *Moringa oleifera* ingested over a period of time.

Moringa oleifera trading has grown to be a billion Rands sector, with India having the highest market share of *Moringa oleifera*. The growing trend to consume plant-based herbal products such as *Moringa oleifera* products presents an opportunity to formalise trading and commercialisation of *Moringa oleifera.* Therefore, there is opportunity for South Africa to increase its trading of *Moringa oleifera* in the formal sector.

The three proposed business models can be implemented to further develop and formalise the trading of *Moringa oleifera*. Although most Moringa growers lack the technical agricultural knowledge, it is recommended that support be provided through the implementation agri-hubs or business incubators. *Moringa oleifera* farmers may gain better understanding of good framing practices and most importantly, effective pest control measures.

The chemical analysis conducted on *Moringa oleifera* revealed high content of macro-elements and iron. It is recommended that further research be conducted with the objective to understand the dynamic extraction mechanism of these macro-elements and iron from the leaves that are often harvested to produce *Moringa oleifera* based products for human ingestion. The toxicology of *Moringa oleifera* was not part of the scope of this study, thus, targeted study with clinical trials on these elements needs to be investigated to determine the toxicology of *Moringa oleifera* when ingested over a period of time.

Finally, the application of *Moringa oleifera* in water treatment has only been proven to work at a small scale. The viability of applying of *Moringa oleifera* at a large scale could not be established as part of this study. Therefore, the feasibility of *Moringa oleifera* application on a large scale in water treatment, still needs to be investigated through a pilot study.

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9. ANNEXURES

9.1. ANNEXURE 1 - SAMPLING AND ANALYSIS PROTOCOL

9.1.1. Scope

This section summarises the procedure used during the collection and analysis of leaf, soil and seed samples of *Moringa oleifera*.

9.1.2. Objective

The objective of sampling and analysis is to determine the biological and medicinal properties of the Moringa plant on a scientific basis as per Table 9.1.2.1 below.

Table 9.1.2.1: *Moringa oleifera* Analytical Characteristics

Phytochemical Analysis	Biological Activity
Nutritional content	Antioxidant
Mineral content	Anti-inflammatory
Active ingredients	Anti-microbial

The following instructions for taking samples must be strictly adhered to since analytical results are only as good as the samples being analysed:

9.1.3. Monitoring techniques and procedures

Sampling must be conducted by qualified personnel in order to obtain a representative sample and achieve the highest possible scientific integrity.

Sampling protocol is based on the following guideline and procedure:

- SANS 1683:2015: Moringa
- Guide and instructions for soil and leaf sampling for tropical and subtropical crops

9.1.4. Sampling of leaves and soil in established orchards

When a leaf sample from a particular plantation is submitted for the first time, it must be accompanied by a soil sample. Thereafter, it would be advisable to also submit soil samples annually. When making fertiliser adjustments, it is essential to take into consideration the analysis results of both the soil and the leaf samples.

A leaf and soil sample must not represent an orchard of more than 3 hectares. Should soil variations be apparent in such an orchard, separate leaf and soil samples must be taken. The following instructions must be strictly adhered to:

9.1.4.1. Leaf sampling

- Select approximately 20 healthy trees that are distributed throughout the orchard, homogenous in appearance and representative of the orchard as a whole.
- Exceptionally good or poor trees must not be sampled.
- The 20 selected trees must be clearly marked, for example with paint, so that both the soil and leaf samples can be taken from the same marked trees every year.
- At about shoulder height, where possible, pick four leaves from alternative sides of the tree.
- Sometimes the youngest leaf is small and malformed. In this case, the next leaf, which must be at least a metre long, should be regarded as the first leaf.
- A total of about 80 leaves per sample is sufficient.
- Leaf samples should preferably be collected in the morning after the dew has dried off.
- Leaves sampled must be free of sunburn, disease and insect damage.
- Leaf samples should not be taken too soon after a tree has undergone stress or been exposed to any abnormal circumstances such as drought, heat or heavy rainfall – wait at least two weeks.

9.1.4.2. Leaf sampling: washing and drying

Solution A:

250 ml Phosphate free soap (e.g. Deacon 75 or Ekon D.) + 500 m acetic acid CP +250 ml Distilled water and mix well.

Solution B:

Add 10 ml of Solution A to 1 litre of water and mix well.

Procedure - Rinse leaves in:

- Running tap water
- Solution B for 3 minutes
- Running tap water

Then:

- Rinse each leaf in three separate buckets filled with distilled water
- After every fifth sample, the first bucket with distilled water is replaced and bucket No. 2 becomes No.1
- Lightly rub each leaf with absorbent cotton wool
- Place leaves in a clean brown paper bag and dry for 48 to 72 hours at 65°C (± 5°C)

9.1.4.3. Seeds sampling

- Good quality seeds must be identified from those, which are not rotten, old, infected with diseases, brownish and dried once opened.
- The seeds must be left at room temperature to dry.

9.1.4.4. Soil sampling

- A composite soil sample should be taken from the top-soil (0 to 30 cm) under the drip (tree canopy) of the tree basins.
- In irrigated orchards, samples should be taken in the wetted area of the irrigation under the canopy of the tree.
- In drip irrigation should be beneath the dripper.
- A composite top-soil (0 to 30 cm) sample should also be taken 50 cm from the stem, in the plant row.

9.1.4.5. Packaging of soil and leaf samples

9.1.4.5.1. Leaf

- Leaf samples must be placed in clean, perforated plastic bags or brown paper bags.
- After sampling, the bag must be tightly closed and leaves must be stored in a refrigerator (not freezer), if samples cannot be delivered immediately.

Sampling shall be in accordance with Table 9.1.4.2 below:

Table 9.1.4.2: Sampling Requirements (Source: SANAS 1683: 2015)

Lot size	Sample size
Up to 25	3
26 to 100	5
101 to 300	7
301 to 500	10
501 to 1000	15
Over 1000	20

9.1.4.5.2. Soil

- Soil samples should consist of about 2 kg of soil and be placed in a strong plastic or linen bag.
- Avoid paper bags as they break when damp.
- Do not use fertiliser bags as they will contaminate the sample.
- Topsoil, subsoil samples must be packed separately and be properly marked.
- Sample containers must be clearly marked with the block/orchard number.

9.1.4.6. Sample Identification Data

The following information must accompany the samples or be filled in on the questionnaire:

- Name, address and telephone number of the farmer
- Cultivar
- Tree age
- Sample number

9.1.4.7. Analysis

Table 9.1.4.2: Parameters for Analysis

	Physical Analysis	Chemical Analysis
Leaf and Seed	N/A	• % Moisture • Nitrogen (N) • Phosphorus (P) • Potassium (K) • Calcium (Ca) • Magnesium (Mg) • Zinc (Zn) • Copper (Cu) • Manganese (Mn) • Iron (Fe) • Boron (B)
Soil	• % Sand, Silt and Clay • Water retention curve	• ph. • Resistance • Potassium (K) • Calcium (Ca) • Magnesium (Mg) • Phosphorus (P) • Aluminium (Al) • Sodium (Na)

9.2. ANNEXURE 2

9.2.1. THQ calculations for Males

THQ = (EF xFDxDIM)/(RfDxWxT) For Males									
Farm Name	**THQAs**	**THQCd**	**THQCr**	**THQCu**	**THQFe**	**THQMn**	**THQNi**	**THQPb**	**THQZn**
RfD	0,003	0,001		0,04	0,7	0,014	0,02	0,0035	0,3
Nyala	0,09390	0,06830	0,03375	0,02474	0,09379	0,02548	0,09805	0,10515	0,13005
Luwamba	0,09074	0,01108	0,04240	0,07350	0,11572	0,09877	0,14321	0,11998	0,03265
Super Moringa	0,04123	0,02960	0,12395	0,09672	0,11362	0,12023	0,16062	0,10708	0,00973
Moringaveldt	0,00392	0,08409	0,03132	0,16074	0,10715	0,10746	0,14127	0,12321	0,13951
Wellness	0,28636	0,01006	0,03213	0,13546	0,15961	0,11270	0,06193	0,05548	0,14235
NBEF	0,20035	0,01290	0,03516	0,11376	0,20085	0,04337	0,07870	0,12385	0,06183
Motupa	0,25449	0,01290	0,04655	0,09448	0,13012	0,13503	0,05096	0,08708	0,03516
Sedikong	0,12724	0,01290	0,04250	0,11579	0,16366	0,14148	0,06902	0,04709	0,12041
Afri-Nest	0,10144	0,01290	0,09269	0,03635	0,01912	0,12419	0,05419	0,09225	0,04376
ABQ	0,10321	0,01290	0,09588	0,09612	0,14265	0,03090	0,05741	0,03935	0,09461

Ef = 365 day per year; FD = 63,1 for males; W = 70,84 kg for males, T = 365 days per year

9.2.2. THQ calculations for Females

THQ = (EF xFDxDIM)/(RfDxWxT) For Females									
Farm Name	**THQAs**	**THQCd**	**THQCr**	**THQCu**	**THQFe**	**THQMn**	**THQNi**	**THQPb**	**THQZn**
RfD	0,003	0,001		0,04	0,7	0,014	0,02	0,0035	0,3
Nyala	0,04747929	0,001174	0,031737	0,0497	0,087232	0,121904	0,091191	0,0978	0,120949
Luwamba	0,08959705	0,054605	0,039874	0,0721	0,013703	0,14082	0,053187	0,1116	0,206541
Super Moringa	0,05816716	0,020177	0,041349	0,1208	0,143058	0,082379	0,054386	0,0996	0,051889
Moringaveldt	0,08177269	0,16145	0,029453	0,1494	0,065613	0,104289	0,131388	0,1146	0,129748
Wellness	0,20185405	0,003563	0,059906	0,0117	0,148443	0,16745	0,057595	0,0516	0,132388
NBEF	0,13060159	0,003563	0,003378	0,1125	0,152759	0,079253	0,073193	0,1152	0,145586
Motupa	0,14007397	0,003563	0,004378	0,0651	0,121017	0,142323	0,047396	0,081	0,120789
Sedikong	0,07003699	0,003563	0,039969	0,0913	0,152214	0,146507	0,064194	0,0438	0,111989
Afri-Nest	0,04866125	0,003563	0,069756	0,1185	0,155175	0,072442	0,050395	0,0858	0,128788
ABQ	0,08305523	0,003563	0,090168	0,159	0,132673	0,088332	0,053395	0,0366	0,087992

Ef = 365 day per year; FD = 59,1 for females; w = 62,4 kg for females, T = 365 days per year

9.3. ANNEXURE 3

9.3.1. Box 1: Sustainable farming of Moringa (NBEF Organics Farm)

The NBEF Organics Farm is situated in Tzaneen, Mopani District in the Limpopo Province (figure A and annexure 2). The NBEF farm Organics Farm is within the Sub-tropical Lowveld climate region associated with summer rainfalls and dry winters. The region is suitable for growing various produce including tomatoes, bananas, tea and mangoes. Growing of Moringa at the NBEF started as a risk mitigating strategy during a drought season when the production of other farm produces was reduced

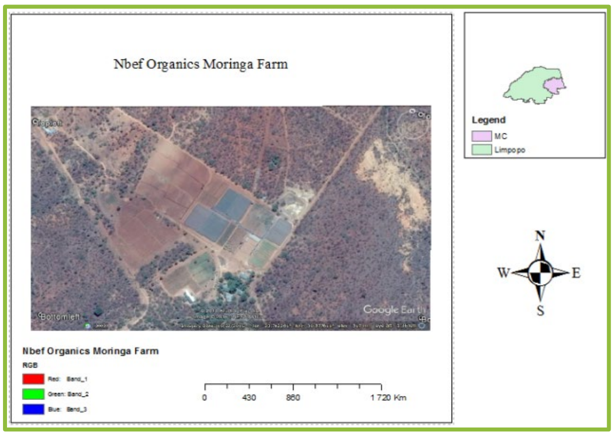

Figure A: Farm GIS Position

Figure B: Densely spaced Moringa planta

The growing of Moringa has proven to be an additional revenue stream for the NBEF farm. At the farm, Moringa is densely planted with a spacing of 50cm between the trees (figure B) and the drip irrigation system is employed. The NBEF farm adopts sustainable, smart agriculture practices, whereby cow manure is used as an organic fertiliser instead of commercial fertilisers. To retain water within the Moringa plant root system and reduce evaporation, mulching is adopted (figure C).

Figure C: Moringa mulching at NBEF farm

The NBEF adopts the entire value chain of the Moringa starting from farming of Moringa agro-processing to market ready product (e.g. capsules & Moringa powder) as indicated in Figure D

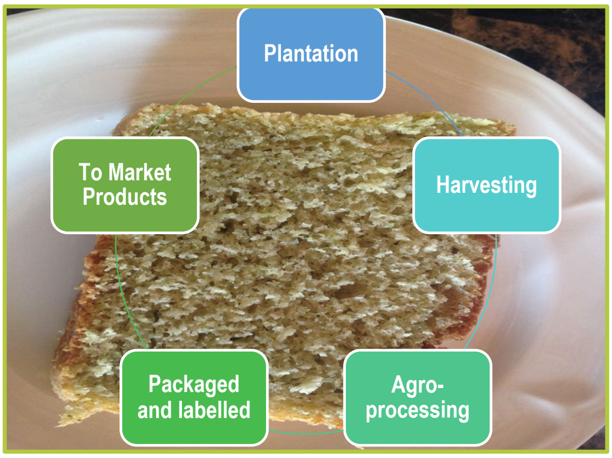

Figure D: Moringa value chain at NBEF farm