SOCIO-ECONOMIC ANALYSIS OF SMALLHOLDER SWEET POTATO PRODUCTION AND ACCEPTABILITY OF ENTOMOPATHOGENIC NEMATODES AS A BIO-CONTROL OF SWEET POTATO WEEVIL IN SOUTH AFRICA

By

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DECLARATION

I declare that the full-dissertation hereby submitted to the University of Limpopo, for the degree ‘Master in Agriculture (Agricultural Economics)’ has not previously been submitted by me for the degree at this or any other university; that it is my own work in design and execution, and that all material contained herein has been duly acknowledged.

_ _ _18 September 2022___

Ms Matli MMW **Date**

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ABSTRACT

Food security, poverty and hunger issues, as well as methods of addressing remain a concern for many South Africans. Smallholder farmers' agricultural production is seen as the key to simultaneously alleviating poverty and ensuring food security, especially in rural areas. The sweet potato crop is commonly produced by smallholder farmers in rural areas as a staple in many South African households with the potential to reduce hunger and poverty. Nevertheless, just like other crops, the sweet potato is impaired by external factors such as extreme weather conditions, insects, pests and diseases, thus threatening food security. The most destructive pest to sweet potatoes acknowledged in the literature is the sweet potato weevil (SPW), which can cause between 5-100% in areas where it is not controlled. While there are many SPW control measures Entomopathogenic Nematodes (EPNs) are emerging as one of the Integrated Pest Management (IPM) bio-control techniques that have shown promise in controlling SPW infestations in South Africa and globally.

This study conducts a socio-economic analysis of smallholder sweet potato production and analyses the acceptability of EPNs as bio-control measures against the SPW in the Gauteng, Limpopo and North West Provinces of South Africa. This was done through an assessment of farmers' knowledge, attitudes, perception and practices (KAPP analysis), exploration of the acceptability of EPNs by farmers, determination of and factors influencing profitability and technical efficiency. Primary data was collected from 119 respondents who were selected through non-probability sampling techniques; purposive, census, and snowball. The analytical tools used to analyse the data were descriptive statistics, Gross Margin Analysis, Multiple linear regression model, Data Envelopment Analysis (DEA) and the Tobit regression model.

From the results, an average knowledge score of 2.30 based on a 3–point Likert scale revealed that sweet potato farmers are knowledgeable of the SPW, the impacts and the control measures. Despite this level of knowledge, the farmers were impartial about the attitudes and perceptions regarding the SPW and the control measures. This was based on the findings of a 5-point Likert scale, which yielded average scores of 2.53 and 2.74, respectively. The study also revealed that the majority of the farmers prefer the use of indigenous and physical practices to control SPW. With regards to acceptance of the EPNs bio-control innovation towards control of the SPW, a mean Composite Index of Acceptancy (CIA) of 0.77 revealed the willingness of farmers to accept the EPNs as a bio-control measure.

A Gross margin of R9 552.37 indicates that sweet potato farming is generally profitable, and this is influenced by socio-economic factors such as marital status, employment status, sweet potato output per cycle and access to machinery. On the other hand, while sweet potato farming was found to be profitable, the DEA score of 0.09 reveals that these farmers are technically inefficient. Their technical inefficiency is influenced by sweet potato output per cycle, gross margins, farm size, and access to credit, employment status, and chemical use.

Based on these findings, the study recommends farmers' support through capacity development initiatives for the sweet potato farmers with regards to general economics of sweet potato production and marketing to maximise and sustain their revenue generation, as well as their general efficiency. In addition, increased training and awareness of the EPNs and their benefits as bio-control measures towards SPW infestation will work towards changing farmers' mindset with regard to SPW control measures.

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LIST OF ACRONYMS

ARC – Agricultural Research Council

FAO – Food and Agriculture Organization

USAID - United States Agency for International Development

CoC-EARD – Centre of Collaboration on Economics of Agricultural Research and Development

SPW - Sweet potato weevil

EPNs – Entomopathogenic nematodes

US – United States

IPMs - Integrated pest management strategies

IJs - Infective juveniles' stage

TAM - Technology Acceptance Model

CIA – Composite Index of Acceptability

GDARD - Gauteng Department of Agriculture and Rural Development

DAFF - Department of Agriculture Forestry and Fisheries

KAPP – Knowledge, Attitudes, Perceptions and Practices

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CHAPTER ONE

INTRODUCTION

1.1. Background of the study

Food security, poverty and hunger issues; and methods of addressing them continue being of extraordinary worry in South Africa (Soffiantini, 2020). While the nation delivers sufficient food to take care of its population and has the ability to import food to accommodate its population, about 25% of the population is still food insecure, and about 50% of individuals living in South Africa are in danger of being food insecure (Nackerdien *et al*., 2022). In addition, the figure is anticipated to rise, given the impacts of the Covid-19 outbreak, the public violence and lootings that took place in July 2021 on agriculture and food systems (Afzal *et al.*, 2021). Nonetheless, there has been a pervasive paradigm in South Africa's development debate that sees smallholder farmers' agricultural production as the key to simultaneously alleviate poverty and ensure food security especially in the rural areas (Afzal *et al.*, 2021; Gassner *et al.*, 2019). Oluwatayo and Rachoene (2017) also assert that, smallholder agricultural farming can potentially play a critical role in reducing poverty and improving food security.

In Asia and Africa, where hunger and poverty is significantly high, smallholder farmers provide more than 80% of the food supply (Sinyolo and Mudhara, 2018). This is because the food produced by smallholder farmers is primarily consumed by people living in rural areas where hunger and poverty are prevalent (Mulovhedzi *et al.*, 2020). One of the crops commonly produced by the smallholder farmers is the sweet potato, which is a staple in many South African households (Laurie *et al.*, 2017).

Sweet potato has been identified as one of the food crops that has potential to contribute to food security and poverty alleviation (Mgcibelo, 2014). This is due to its widespread cultivation, and its ability to thrive in conditions where other crops, such as maize, will not thrive (Mgcibelo, 2014). Moreover, sweet potato is a multipurpose ingredient in the food industry as its roots, stems and leaves are edible parts with varying nutrient composition commonly consumed as nutrient-dense and health promoting parts of the crop (Danso-Abbeam *et al.*, 2020). Furthermore, the sweet potato can also be cooked in various ways including baking, boiling, dehydrating and frying, offering consumers with multiple ways of consumption (Mulovhedzi *et al.*, 2020).

In addition to the benefits provided by sweet potato, the crop can improve rural livelihoods, and consequently, contribute to food security especially at household level (Mgcibelo, 2014). This is as a result of sweet potato production, by smallholder farmers, being grown primarily for home consumption and in most cases for food security at household level (Afzal *et al*., 2021). Also, sweet potato helps to increase food supply by producing a high amount of food per unit of land, with yields of about 25 – 30 tons per hectare on average compared to 4 -6 tons per hectare reported for maize under similar management (Afzal *et al.*, 2021) and can grow well on marginal soils (Funnel *et al.*, 2018).

Sweet potato's potential position as a food security crop is bolstered by the fact that it has more energy than maize derivatives (Govender *et al.*, 2019) and it contributes significantly to Vitamin A supplementation (Laurie *et al.,* 2018). Since the crop is mostly consumed by households in rural areas where Vitamin A deficiency is more prevalent, this makes it a preferred crop by the rural households (Ndou *et al.,* 2020). In food security assessment, good health is considered an outcome predictor for food consumption, and sweet potato's high nutritional status qualifies the crop as a food security alternative thereof (FAO, 2019).

Additionally, the sweet potato's improved early maturing cultivars can be harvested in 3–5 months and can be harvested as needed over several months (Afzal *et al.*, 2021), making it a more desirable crop. Harvesting early and eating for several months has the advantage of ensuring a fast turnover and long-term supply of food, resulting in increased food access, affordability, and stability, especially for the rural folks. The above-mentioned food security benefits of sweet potato also contribute to it being a food security crop (Mwadzingeni *et al.,* 2020).

According to Funnel *et al*. (2018), sweet potato has also proven to be a lifesaver.When typhoons destroyed all of Japan's rice fields just before World War I, and when China was hit by famine in the early 1960s, it was the sweet potato that saved millions from starvation. In the early 1990s, when their local cassava varieties (Bao, Alodo-alodo Tim-tim), Nyaraboke, Fumba chai, and Ebwanaterak) were attacked rendering huge yield losses by an unknown virus, Ugandan rural communities relied on sweet potato as their staple food. These evidences support the claims that sweet potato is a food security crop and can potentially assist to alleviate hunger and poverty, as indicated by various authors (Amagloh *et al.*, 2012; Ebregt *et al.*, 2007; Mgcibelo, 2014).

Nevertheless, just like other crops, sweet potato is prone to harm from external factors such as extreme weather conditions, diseases, insects and pests (Malan and Moore, 2016). This can threaten food security in poorer countries, especially in countries where the sweet potato is a staple food. Laurie *et al.* (2017) reported that the most destructive pest to sweet potatoes is the sweet potato weevil (SPW), (*Cyclas formicarius elegantulus).* The adult SPW is about 1/4-inch-long; with a shiny, slender body, that resembles that of an insect, its middle body and legs are crimson, while the rest of the body is blue-black (see Figure 1.1). According to Liao *et al.* (2020), larvae are elongated to a slightly C-shaped form, legless, and dirty white to grey in colour with a distinct yellow-brown head capsule (see Figure 1.2).

Figure 1.1: The adult sweet potato weevil

Source: (Liao *et al.*, 2020)

Source: (Liao *et al.*, 2020)

Figure1.2: The larvae SPW

Mating can happen in as little as a few days in the SPW. Over the course of their lives, females lay between 56 and 340 eggs (Gapasin *et al.*, 2019). The adult female weevils lay their eggs singly in the roots or stems of sweet potatoes. Cavities are used to lay eggs and are covered with a waxy plug. Larvae go through three stages of development during which they feed continuously and tunnel extensively (Hua *et al*., 2021). Pupation takes place in the roots or stems of the plant. The adult emerges shortly after leaving the pupal stage. Without effective control methods, the SPW is anticipated to cause sweet potato yield losses ranging from 5% to 100% in areas where the weevil is heavily infested (Hua *et al.,* 2021; Laurie *et al.*, 2017).

One symptom of the SPW is the yellowing of the vines, but it normally takes a strong infestation before this is visible. As a result, early signs of trouble are easily missed, and damage is not visible until the tubers are harvested (Hlerema *et al.*, 2017). The most common cause of sweet potato damage is larvae mining the tubers, cavities abound in the infested tuber, which is spongy and dark in appearance (see Figure1.3). In addition to the direct damage caused by tunnelling, larvae indirectly causes damage by encouraging the entry of soil-borne pathogens (Gapasin *et al.*, 2017). Moreover, low levels of feeding trigger a chemical reaction in the tubers that gives them a bitter taste and a bad odour. Larvae causes it to darken, crack, or crumble and often mine the plant's vine. The adult may eat the tubers, leaving a trail of small holes about the length of its head (Jaoko *et al*., 2021; Okonya and Kroschel, 2013). All these damages lead to reduced sweet potato yields and a bitter taste in the crop, thereby threatening household food security (Laurie *et al*., 2017).

Figure 1.3: Damage to sweet potato tuber caused by larval feeding off the SPW, *Cylas formicarius* (Fabricius).

Source: (Hatting *et al*., 2019)

1.2. The evidence of the SPW damage across the world

In tropical and subtropical regions around the world the SPW is responsible for significant yield losses in sweet potato production (Hue and Low, 2015). Even slightly damaged roots have proven to contain a terpenoid that makes them unfit for human consumption (Beyene, 2015). The SPW is a problem in the field as well as in post-harvest storage (Hlerema *et al.*, 2017), as it further eats the entire host plant (Issa *et al.*, 2019). The 'undamaged' part of the root also becomes bitter and unmarketable, in addition to damaging large portions of the roots and causing unsightly harm (Ebregt *et al.*, 2007). The weevil larvae feed on the stems as well, creating large lumps and destroying the root connection (Ebregt *et al.*, 2007).

The SPW reduced sweet potato production in Taiwan by a 5% or 0.2tons/hectare of yield losses, this is according to a study done by the Taiwan Agricultural Chemical and Toxic Substances Research Institute Council of Agriculture (2019). The study reports that the damage in wide commercially produced fields account for up to 18%, which is close to four times higher than the damage experienced in the country as a whole. Yields in China's Guangdong Province fell by 20% (1 ton/hectare) on average, and by up to 80% (4 tons/hectare) in extreme circumstances (Kyreko *et al.*, 2019). In Vietnam, farm-level sweet potato losses have been reported to be up to 40% lower in yield which is close to 2tons per hectare (Hlerema *et al.*, 2017). In Indonesia, losses of 80% (which is 4 tons/ hectare of yield losses) have been reported in a variety of sites and seasons, with higher damage found during the dry season (Hue and Low, 2015).

The actual field losses have not been reported in Malaysia but the sole known figure is from a 1970 research that showed an 80% yield loss or 4 tons/hectare (Suhaizan *et al.,* 2019). Moreover, sweet potato yields in the Philippines were reduced by 50% (2.5 tons/hectare) due to the SPW infestation (Gapasin *et al.*, 2017).

In Dominican Republic, sweet potato farm damages owing to infestation of the SPW were reported to be 39%. The SPW is also prevalent in all areas of Cuba, where sweet potato crops are located and losses have been shown to reach up to 45% (close to 2.5 tons/hectare) in the absence of proper control (Hue and Low, 2015). The SPW was also discovered to be a major pest in Africa's tropical regions (Okonya *et al.*, 2016). In Uganda, losses have been reported as high as 73% which is close to 4 tons per hectare (Ebregt *et al.*, 2018), and yield losses have been reported as high as 20% in Tanzania. More evidence is indicated by a study conducted by Ngailo *et al.* (2016) in eastern Tanzania which discovered that losses associated to the SPW were as high as 100%.

Even with the evidence of reported losses in sweet potato by the SPW, most farmers around the world are still unaware of the threat posed by the SPW and the amount to which it damages sweet potato production (Kagimbo *et al*., 2018). Consequently, most farmers do not know how to control the infestation of SPW in the fields (Laurie *et al.*, 2017). Nottingham and Kays (2018) have asserted that farmers' knowledge of pests and insects, as well as control practices are therefore, critical in farming systems to avoid associated yield losses. This is because once a farmer is knowledgeable about an insect in their fields, they will find means to eradicate losses. The next sub-section therefore unpacks the importance of SPW knowledge and practices to control the SPW.

1.3. The importance of pests and insects knowledge and practices

According to Lucchi and Benelli (2018), when farmers have a thorough understanding or knowledge of an insect or pest that has plagued their fields, they can take steps to control it and limit its presence or infestation, and that in turn improves the performance of the crop. Studies on farmer knowledge of insects and pests concur with Lucchi and Benelli (2018)'s assertion. Tafesse *et al.* (2018), for example, investigated farmers' knowledge of *Ralstonia solanacearum* in Rwanda and discovered that while most potato farmers could detect the illness, only around half of those polled were knowledgeable that it spreads through the seed, soil and the use of infected farm instruments. Furthermore, those who understood how the disease propagated, devised indigenous and modern methods to alleviate and minimize the disease's spread as they strive to improve the crop's performance.

Similarly, Echodu *et al.* (2019) conducted a study on farmers' practices and their knowledge of biotic constraints to sweet potato production in East Africa. The study discovered that sweet potato farmers were incapable of correlating pest infestation symptoms such as curling, yellowing with viral, leaf wilting, fungal or bacterial as they did not have much knowledge on biotic constrains to sweet potato production. This had an impact on their crop performance due to high yield losses in their production due to biotic constraints.

Schreinemachers *et al.* (2015) also investigated farmers' knowledge and practices of plant viruses in vegetable crops in Thailand, Vietnam and India, and found that few farmers could associate typical pest infestation signs with viruses. The study discovered that few farmers could link normal pest infestation indicators to viruses, and that only those who could associate pest infestation signs with viruses were able to explore strategies to manage the virus using both traditional and new methods. The practices they adopted, to control the infestations in their production, had positive influences because their vegetable performance improved significantly after they tried them. This is also an important consideration in this context for the sweet potato farmers if they are to minimise losses associated with the SPW.

In conclusion, the literature on farmer knowledge about pests and insects demonstrate how farmers' accurate pest and disease knowledge has a significant impact on crop performance. The literature further shows that farmers' lack of knowledge on insects, pests and diseases may result in ineffective management techniques and possibly worsen the problem. Consequently, Tafesse *et al.* (2018), asserted that to enlighten the creation and distribution of suitable strategies of pests and insects management, a thorough understanding of farmers' knowledge of pests and insects, as well as the pest management approaches applied is required. This is because the lack of knowledge can lead to poor control strategies of the pests and diseases (Godina *et al.*, 2020), leading to increased yield losses (or poor quality), thus threatening household level food security. To put it to context, it is therefore important that farmers be knowledgeable of the SPW to ultimately have perceptions and later attitudes so that they can learn how to alleviate the SPW in the field. The following sub-section consequently discusses the farmers KAPP on the SPW.

1.4. Farmers' knowledge, attitude, perception and practices (KAPP) on the sweet potato weevil (SPW)

Knowledge, attitudes, perceptions and practices (KAPP) of the type of causative agent responsible for decreased yield and the appropriate pest control measures to mitigate the problem are critical to increasing sweet potato productivity (Ebregt *et al.,* 2014). Despite the established critical role of farmers' KAPP in the control and mitigation of pests and diseases, very few studies have focused on this subject. Thus, there remains a serious knowledge gap in the assessment of farmers' KAPP of the SPW.

Farmers' KAPP of diseases is well documented on cash crops like cotton and rice, as well as food crops such as millet beans, cowpea, and vegetables. Sweet potato documentation, on the other hand, is scarce and out of date (Bashaasha *et al.,* 2015; Gibson *et al*., 2012; Kapinga *et al*., 2015). Efforts to improve sweet potato management and pest control measures are likely to be hampered if farmers' knowledge of crop pests and handling practices is not known and considered as needed.

The current and existing pool of knowledge on the KAPP of farmers regarding the SPW reveals that generally, smallholder sweet potato farmers lack knowledge of the SPW, and have negative perceptions and attitudes regarding the SPW (Adam *et al*., 2015; Omeje, 2019). However, in the South African context, no literature focuses on the KAPP of the SPW amongst the smallholder sweet potato farmers. Hence, the SPW continues to pose a serious threat to the sweet potato industry. Consequently, there should be field trials to test new and innovative measures to control the SPW. With that being said, the next sub-section discusses one of the potential sustainable solutions to the SPW problem.

1.5. A sustainable solution to the SPW problem

In an attempt to combat the SPW in the field, farmers have attempted several methods including planting SPW-free cuttings, rotation of crops, and irrigation of fields before planting, as well as prompt harvesting four to five months after planting. Various degrees of success have been achieved using these techniques (Hlerema *et al.,* 2017). However, in terms of efficacy, cost-effectiveness, and environmental friendliness, none of these strategies have proven to be totally satisfactory to farmers (Issa *et al.*, 2019).

Another widely explored method used to tackle SPW is the use of licensed insecticides (Deltametrin) as soon as the weevil is discovered following a fortnightly spraying program (Walker *et al.*, 2019). However, this insecticide is expensive, harmful to both the atmosphere and the non-targeted species (Issa *et al.*, 2019). The risk awareness of these chemical pesticides has been sharply increasing (Chin *et al.*, 2019). For instance, since the late 1970's a number of chemical insecticides including the likes of monocrotophos, chloropyrifos, endosulfan, aldicarb and methyl bromine, have been restricted and eliminated by the South African Government (Hatting *et al.,* 2019).

South Africa's agricultural industry is heavily infested with a variety of invertebrate pests (Labaude and Griffin, 2018). Consequently, over 500 pesticides have been produced to try to reduce these pests. The Act 36 of 1947 under farm feeds, fertilizers, stock remedies and agricultural remedies has allowed utilization of these pesticides. However, these chemicals, on the other hand, remain on the ground and pose a threat to animals, humans, and the environment as a whole (AVCASA, 2018). As a result, there is a need for SPW control methods that are both less expensive and environmentally safer (Malan and Moore, 2016). One under-explored choice to control SPW is the use of Entomopathogenic Nematodes (EPNs), which serve as a bio- control (Gapasin *et al.*, 2019). The EPNs distribution and occurrence are discussed in the next sub-section.

1.6. EPNs distribution and occurrence

EPNs were first used in the biological control of Japanese beetle grubs, Popillia japonica in the United States, (Glaser and Farrell, 1935). EPNs are soft bodied, non-segmented roundworms that are facultative parasites of insects (see Figure 1.4). They are found naturally in the soil and respond to carbon dioxide, vibration, and other chemical cues to locate their host (Kaya *et al.*, 2018). Labaude and Griffin, (2018) further indicate that they are non-polluting, making them ecologically friendly and suitable. Infective juveniles (IJs) of the EPNs are applicable with standard apparatus and are safe to use with other pesticides (Labaude and Griffin, 2018; Ramakuwela *et al.*, 2015). They locate their host either actively or passively, and they have been shown to be more successful than pesticides in controlling the target insects in cryptic situations and occasionally in soil (James *et al.,* 2018). Grewal *et al.* (2005) summarizes their use, while Gaugler, (2002) describes their biology.

The EPNs species, which are essentially abundant have reportedly been recovered worldwide and are expected and likely to be distributed globally and (Kaya *et al*., 2008). Although some species appear to be more restricted to some regions, others are widely distributed in temperate regions, tropics and subtropics as well as some others in regions with continental and Mediterranean climates (Hominick *et al.*, 2018).

EPNs have been commercialized since the early 1980s in the United States then later, a semi-artificial medium of their production was developed, and this has encouraged researchers in other countries to evaluate the use of EPNs (Ehlers, 2001). For instance, vast developments and research has been undertaken in order to improve their production technology, storage and formulation in other parts of the world such as Benin and South Africa (Danso-Abbeam *et al.*, 2020; Ramakuwelaa *et al.,* 2015). Developments in the research of EPNs in all the countries indicate that they could potentially substitute chemicals.

Figure 1.4: An Entomopathogenic nematode

Source: Kaya and Gaugler (2013)

The black vine weevil in cranberries is a great instance of a condition in which EPNs have proven that they could substitute chemicals for insect mechanism (Gapasin *et al.*, 2017). The author further revealed that, when the *Heterorhabditis bacteriophora* strain was used in controlling the black wine weevil, it rapidly gave the black vine weevil 70% control, which was 30% more than the normally used chemical pesticides. The study further revealed that chemical insecticides in controlling the black vine weevils are either prohibited or ineffective in controlling black vine weevil larvae.

On that note, EPNs seem to have the greatest biological suppression capacity not only for the SPW, but also in other insects and pests (Platt *et al*., 2020). Similarly, Gapasin *et al.* (2017) conducted a study in the US which shows that certain EPNs of the genera *Heterorhabditis* and *Steinernema* are superior at suppressing or reducing the SPW populations than many other control measures. When *Heterorhabditid*s kill the insects, the cadaver turns red and; when *Steinernematids* kill the insects, the cadaver turns brown or tan (see Figure 1.5). The pigments formed by the monoculture of mutualistic bacteria growing in the host insects are responsible for the colour of the insect host body (Alramadan and Mamay, 2019).

Figure 1.5: Different colours of the dead *Curculio nucum* larvae on white traps after EPNs infection

Source: (Alramadan and Mamay, 2019)

A variety of other experiments have also been performed in other countries such as Benin and South Africa to see how effective these EPNs are at controlling the SPW in sweet potato (Malan and Moore, 2016; Ramakuwela *et al.*, 2018; Steyn *et al.*, 2019; Tshikala *et al.*, 2019), all of these studies' findings were consistent, indicating that EPNs were efficient in controlling SPW in the lab and during field trials. It is, therefore, critical that one knows how such promising bio-control work to combat the infestation of pests and insect, this is detailed further in the next sub-section.

1.7. How EPNs work to kill insects and pests

The Infective Juvenile (IJ), which is the EPNs third juvenile stage enters the insect host through the mouth, anus, spiracles, or thin sections of the host cuticle to find and infect suitable insect hosts (James *et al.*, 2018). The symbiotic bacteria are then released into the insect's haemocoel after infection, causing death to the problematic insect or pest, thus reducing them in the field and leading to less yield losses (le Vieux and Malan, 2015). The EPNs, their potential as an IPM strategy, how they work, and other topics were discussed in detail in the previous sub-sections. It is therefore critical to document the acceptance of their potential users (farmers) in order to determine whether or not they will be accepted once implemented. The farmers' acceptance innovations are discussed in the next section.

1.8. Farmers' acceptability of innovation

A number of innovations and productions have been introduced in the farming industry in recent years. Scholars have since attempted to document their acceptance by their potential users in different contexts to gauge whether farmers would be willing to accept the innovations after they have been implemented (Dolinski *et al*., 2012; Steyn *et al*., 2019). Such documentations came out with different assertions suggesting different conclusions and recommendations.

Mazzigo *et al*. (2019) conducted a study on Rice farmers' perceptions and acceptability in the use of a combination of biolarvicide (Bacillus thuringiensis var. israeliensis) and fertilizers application for malaria control to increase rice productivity in a rural district of central Tanzania. The study reported that, after participating in the survey, all 30 farmers stated that their rice yield per area had improved significantly. They credited their increased crop to the usage of a bio-larvicide and fertilizer blend. As a result, the study reported that 93% of farmers (28 farmers) accepted the bio-larvicide without hesitation.

Another study by Acholonu (2016) explored farmers 'acceptability of agricultural education innovations for improved productivity and national development. The study's findings revealed that farmers' embrace of innovative approaches is limited. This could be due to the technical packages, technical know-how, and cost of innovation acceptance, which farmers in the study area cannot afford (Acholonu, 2016). The majority of these farmers are small-scale farmers with limited land holdings who cannot afford most inputs or apply the technical knowledge and skills required for crop and livestock farming.

Dolinski *et al.* (2012) attempted to document acceptance of EPNs as a bio-control measure in Brazil, Korea and the United States of America (USA) and found that farmers would be willing to accept EPNs for pest control if it is more profitable than other options. However, in South African even though scholars have tried to document the efficacy of EPNs as bio-control measure in their farming systems (e.g.

Steyn *et al*., 2019), there is a need to explore farmer acceptability of EPNs, to address the gap in knowledge in the country's context.

Farmer acceptance of innovations is also documented (Collinson, 2019). Furthermore, the available data show that, on the whole, farmers are eager to adopt innovations in their farms as long as they are cost-effective and environmentally beneficial (Brugere *et al*., 2019). However, because different contexts can have different outcomes, it is necessary to document the acceptance of EPNs innovations in the South African environment.

1.9. Problem statement

Sweet potato is an important cultivated root and tuber crop in South Africa (Laurie *et al.*, 2018). Its production contributes to food and nutrition security (Mgcibelo, 2014) and is a source of income for many poor rural families (Laurie *et al.*, 2015). Despite the good prospects presented by this crop, it can still be wreaked by a number of pests and insects that are economically significant such as the SPW *(*Hlerema *et al.*, 2017). Despite the lucrative opportunity presented by the production of sweet potato to smallholder farmers and the use of EPNs as bio-control measures against the SPW, smallholder sweet potato production still continues to be characterised by low productivity and efficiency (Gasura *et al*., 2021).

In South Africa, research has therefore, been performed to see whether various Integrated Pest Management strategies (IPMs) can be used to combat the SPW infestation in fields (Hlerema *et al.,* 2017). Other studies have been carried out to see which of those techniques are successful and it was discovered that there are different levels of effectiveness for each IPM technique (Malan and Moore, 2016; Ramakuwela *et al.*, 2018; Steyn *et al.*, 2019; Tshikala *et al.*, 2019). Furthermore, previous IPMs have been reported to have some drawbacks, such as being expensive (Baimey *et al.*, 2017) , environmentally unfriendly (Ramakuwela *et al.*, 2018), and not particular to the target pests and insects (Gapasin *et al.*, 2019), implying that a new IPM technique which is less expensive, environmentally friendly and specific to the target pest is critical.

EPNs of the genera *Heterorhabditis* and *Steinernema*, on the other hand are one of the IPM techniques that are regarded to have shown promise to controlling SPW infestations in South Africa (Ramakuwela *et al.*, 2015). They are also regarded as a much safer alternative as they are environmentally friendly (Malan and Moore, 2016), specific to the target (Abd-Elgawad and Spiridonov, 2014) and less costly than the usually used chemical pesticides (Gapasin *et al.*, 2019). On that note, it is imperative to conduct farmer acceptability studies to gauge whether or not farmers are willing to accept the use of EPNs as bio control measures in their farms prior their execution. Literature has indicated that farmers' KAPP is important so that farmers can be aware of the type of pests they are dealing with for them to make means to control such pests (Kambey *et al*., 2021; Rani *et al*., 2014; Top *et al*., 2020). However, literature has further indicated that smallholder farmers KAPP is outdated and scant (Andrade, 2020; Nyairo, 2020). Therefore, there is a need to assess the acceptability of EPNs by sweet potato producers within South African context to fill that knowledge gap. This current study conducted a socio-economic analysis of sweet potato production among smallholder farmers, to determine their acceptability of EPNs as bio-control measures against the SPW.

1.10. Motivation of the study

The Gauteng Department of Agriculture and Rural Development (GDARD) believes that the use of the alternative sustainable strategy will contribute towards several South Africa Government Policies and Strategies objectives (DAFF, 2020). Moreover, the Pesticide Management Policy; the Department of Science and Technology Bio-economy Strategy; the Agricultural Policy Action Plan; the National Environmental Management Act through the development of a pesticide reduction strategy are some of the governmental policies objectives that the GDARD hopes the use of EPNs will contribute to (DAFF, 2020).

It is therefore crucial to investigate the farmers' acceptance of the EPNs as a component of the IPM Strategies as well as its implementation to determine the feasibility of implementing these EPNs. Acceptance of EPNs is imperative given its prospects in controlling SPW infestations in South Africa (Ramakuwela et al., 2015) as the sweet potato is one of the important staple crops with implication for food security. Moreover, in a world of environmental awareness where sustainable practices matter the most, EPNs that are safer and environmentally friendly (Malan and Moore, 2016) are crucial. This study pursues to gather information on sweet potato production and how farmers overcome the infestation of the SPW, in project intervention zones with indigenous methods and if farmers are willing to accept the introduction of the bio-control measure (EPNs) in their agricultural system.

This study aims to benefit sweet potato farmers by making them aware of how their sweet potatoes are performing in terms of profit and efficiency in general. The study also seeks to benefit smallholder sweet potato farmers by filling a knowledge gap about the feasibility of incorporating EPNs bio-pesticides into their farming systems. This will contribute to discussions about the use of hazardous chemical pesticides in farming production systems and the environment as a whole.

Moreover, this study will also provide smallholder farmers with knowledge and insights about current methods of controlling the SPW using both indigenous and modern practices. Additionally, knowledge of how to overcome the infestation of the SPW with indigenous practices can also help agricultural advisors when making recommendations for farmers.

The study will further provide insights on the potential of accepting the proposed IPM technique. The study could also provide new insights regarding the knowledge, attitudes, perceptions and practices regarding IPM strategies that smallholder sweet potato farmers make use of in terms of pest control, and thus, highlighting also the indigenous knowledge in pest management.

1.11. Aim

The aim of this study was to conduct a socio-economic analysis of sweet potato production, as well as determine acceptability of EPNs as a bio-control method against the SPW by smallholder sweet potato farmers in selected areas of Gauteng, Limpopo and North West Provinces.

1.11.1. Objectives

The specific objectives of the study are to:

i. Analyse smallholder farmers' Knowledge, Attitude, Perceptions and Practices towards sweet potato weevil and EPNs bio-control methods.
ii. Determine smallholder sweet potato farmers' acceptability of EPNs bio-pesticides as control measures against SPW.
iii. Assess the profitability of smallholder sweet potato farmers and its determinants.

iv. Determine the technical efficiency of sweet potato production and its determinants.

1.11.2. Hypotheses

i. Smallholder sweet potato farmers in the study areas will not accept the use of EPNs bio-pesticides as control measures against SPW

ii. Sweet potato farmers in the selected areas of study are not profitable.

iii. Socio-economic, institutional and technical factors do not influence sweet potato farmers' profitability.

iv. Sweet potato farmers in selected areas of study are technically inefficient.

v. Socio-economic, institutional and technical factors do not determine sweet potato farmers' technical efficiency.

1.12. Limitations of the study

Older farmers had trouble recalling the exact costs of their output and the amount of supplies they buy and this was addressed by asking other labours in the farm that may recall the exact figures. Other farmers refused to participate in the interviews because they were afraid of being infected by the Corona virus (COVID-19) effect which might have reduced the potential sample size. However, most of them still agreed to participate wearing masks and following sanitation measures.

1.13. Organisation of the thesis

The thesis has five chapters. In chapter 1, the introduction and background to the study as well as evidence of the SPW, EPNs, their occurrence and how they work, the problem statement and the rationale for the study was presented. The remaining chapters of the study are organized as follows: Chapter 2 represents the theoretical framework and a literature review, which outlines the theoretical framework adopted by the study and the literature on the objectives of this study. Chapter 3 presents the study's methodology and entails the study areas, the research design followed by the study, the techniques used to achieve the objectives and the statistical software used in the study. Chapter 4 presents the descriptive statistics results, and profiles the socio-economic characteristics of the farmers and, entails the Likers scale results on KAPP analysis and acceptability analysis. Chapter 5 presents the empirical results which were obtained from the Multiple Linear and the Tobit Regression, the chapter further discusses the significant variables from both models. Finally, Chapter 6 provides the study's summary, conclusions, and recommendations.

CHAPTER TWO

THEORETICAL FRAMEWORK AND LITERATURE REVIEW

2.1. Introduction

This chapter includes the definition of key concepts, the theoretical framework adopted by the study and the literature review on the KAPP on the SPW; the acceptability of EPNs and the economics of sweet potato. The purpose of theoretical framework is to narrow the scope of relevant data by focusing on specific variables and defining the specific viewpoint [framework] that the researcher will use in analysing and interpreting the data to be gathered (Rav-Marathe *et al*., 2016). The purpose of literature review is to become acquainted with and understand current research in a specific field before embarking on a new investigation. Conducting a literature review allows the researcher to learn about previous research and identify what is unknown about the topic of interest (Olushola and Abiola, 2017). Consequently, in this study literature was reviewed on smallholder farmers' characteristics; profitability and its drivers; technical efficiency and its drivers; the importance of KAPP of pests, insects and diseases and in order to contextualise the study or to get an overview of important variables

2.2. Definition of key concepts.

2.2.1. Sweet potato weevil (SPW)

The SPW, scientifically known as *Cylas formicarius*, belongs to the *Brentidae* family of beetles (Gapasin *et al.*, 2019). According to Ebregt *et al.* (2007), the SPW is the most extreme sweet potato pest on the planet. It damages crops in the field, in storage, and poses a quarantine risk. It has a remarkably colourful appearance and exceptionally long rostrum.

2.2.2. Entomopathogenic nematodes (EPNs)

EPNs are non-segmented roundworms with a lenient body. They live in soil habitats and use carbon dioxide, vibration, and other chemical cues to find a suitable host (Kaya *et al.,* 2008). The EPNs of the families *Heterorhabditidae* and *Steinernematida* have been used successfully in pest control programs. Moreover, they are not toxic to humans, are unique to their target pests, plus can be applied with regular pesticide apparatus, EPNs fit well into integrated pest management systems (Gapasin *et al.*, 2019).

2.2.3. Acceptability

Acceptability is a multi-faceted concept that represents how satisfactory an intervention is to people who are receiving it, based on expected or experienced cognitive and emotional reactions to the intervention (Maestre-andrés *et al.*, 2019). For the purpose of this study, i will refer to the extent to which smallholder sweet potato farmers accept the EPNs as a bio-control agent against the SPW based on the farmers' reactions towards the EPNs.

2.2.4. Profitability

Zhang and Wen (2017) described profitability as the degree to which a company or operation generates profit or financial benefit, which is the concept that this study has adopted. For the purposes of this study, sweet potato farmers will be considered profitable if their average gross margins exceed their average variable costs.

2.2.5. Technical efficiency

This refers to the efficiency with which a given set of inputs is used to produce optimum output (Zhang and Wen, 2017). In this context, a sweet potato farmer is technically efficient when they produce optimum yield with the available farm inputs, such as labour, capital and technology. In this study, a sweet potato farmer was said to be technically efficient when their farm is producing the maximum output from the minimum quantity of inputs, such as labour hours, sweet potato sales, and fertilizers and chemical use. Decision-making units (sweet potato farms) with an efficiency of less than 0.75 will be considered technically inefficient in this study, whereas those with an efficiency of 0.75 to 1 will be considered technically efficient after the DEA results have been run.

2.2.6. Infective juvenile stage (IJs)

IJs are the sole free-living and thus environmentally tolerant stage of nematodes. IJs range in length from 0.44-0.65 mm, with males ranging from 1-1.7 mm and females ranging from 2.8-5.1 mm. The IJS can be preserved for several months in tap water or buffer, or even frozen for long-term storage in liquid nitrogen. (Steyn *et al.*, 2019).

2.3. Theoretical framework

The theoretical framework is the structure that holds or supports a research study's theory. The theoretical framework introduces and describes the theory that explains why the research problem under study exists (Braidotti, 2019). This study was informed by the theory of profit maximization, which in this context suggests that farmers producing sweet potatoes have the ability to boost their farm revenue and food security as a result of improved farm profits, hence positively improving their livelihoods (Odah *et al.*, 2018). Secondly, the study was informed by the Technology Acceptance Model (TAM) which in this context suggests that acceptability of the EPNs by the sweet potato farmers depends on the perceived usefulness of the EPNs, their attitudes towards EPNs, behavioural intentions (acceptability of EPNs) and their perceived ease of use (Davis, 1980).

2.3.1. Theory of profit maximization and the theory of utility maximization

Profit maximization is the ability of a business or company to earn the greatest profit at the lowest possible cost, which is considered the goal of any business and one of the objectives of financial management (Kagimbo *et al.*, 2018). This study hypothesizes that a farmer producing sweet potatoes has the ability to boost their farm revenue as a result of improved farm profits (Odah *et al.*, 2018). As such, a rational sweet potato farmer will choose to produce where the estimated net benefit from this choice is greater than the situation without it (Rohwer, 2012).

This choice is described by the utility maximisation theory. If Ui and Uj represent a farmer's utility, then the model is specified as:

$$Ui = \beta nXn + ei \text{ and } Uj = \beta nXn + ei \qquad 1$$

Where Ui and Uj are the perceived utilities of sweet potato producers i and non-producers' choices j, respectively; Xn is the vector of explanatory variables that influence the perceived attractiveness of each choice; i and j are predicators to be estimated; and βi and βj coeffecients assumed to be independently and identically distributed (Greene, 2020) and ei represents the error term. If a farmer chooses option i for sweet potato production, the expected utility from option i is greater than the expected utility from option j, which is defined as:

$$U_{ni} (\beta nXn + ei) > (U_{nj} (\beta_j X_j + e_j) \; i \neq j \qquad 2$$

The probability that a farmer plants sweet potato and chooses option i instead of instead of j is then defined as:

$$P\ (Y = 1|X) = P\ (U_{ni} > U_{nj})$$

$$P\ (\beta'_i X_n + e_i - \beta'_j X_{n} + e_j > 0|X \qquad 3$$

$$P\ (\beta'_i X_n - \beta'_j X_{n} + e_j - e_j > 0|X\ )$$

$$P\ (X^{*} X_{n} + e^{*} > 0|X = F(\beta^{*} Xn))$$

Where P is a probability function, U_{ni} , U_{nj} represent a farmer's utility for two options, and Xn is a vector of explanatory variables that influence each option's perceived attractiveness. $F(\beta^{*} Xn)$ is a cumulative distribution function of e * evaluated at $\beta^{*} Xn$, where is a random disturbance term, is the net influence of the vector of independent factors affecting sweet potato production, and is the net impact of the vector of independent variables influencing sweet potato production. F's exact distribution is determined by the random disturbance term's distribution, $e * = e_i - e_j$. Several qualitative choice models can be calculated depending on the random disturbance term's anticipated distribution. The importance of any farmers' decision to produce an alternative is emphasized in this theoretical framework, and is further embedded in the Technology acceptance model discussed below.

2.3.2. Technology acceptance model (TAM)

The TAM is one of the most extensively used models to describe user acceptance behaviour innovations and was developed by Davis (1986). TAM specifically states that one's attitude toward a piece of innovation (EPNs bio-control innovation in this case) and, as a result, one's intention to accept that innovation is influenced by one's ideas about the perceived ease of use as well as usefulness of that piece of innovation (Charnkit, 2010).

Perceived ease of use, is described as "the degree to which a person believes that utilizing a specific system would be effort free" (Davis, 1989: 320). According to Davis (1980), perceived ease of use has a direct effect on perceived usefulness, whereas perceived usefulness has no effect on perceived ease of use. As a result, since perceived ease of use is a major factor informing perceived usefulness judgments (Charnkit, 2010), when a farmer believes EPNs are easy to use , they will have a greater chance of acceptance. The causal relationship between perceived ease of use and perceived usefulness has been proven in earlier studies (e.g. Davis, 1980; Olushola and Abiola, 2017). A number of factors constitute the development of the TAM and those include the individual, social, technical and institutional variables. This is discussed in detail in the next sub section.

2.3.2.1. Development of conceptual model (TAM)

2.3.2.1.1. Individual variables

Numerous individual factors (i.e. socio-economic, institutional, technical, etc.) have a significant impact on consumer behaviour, and regarded in this context, as choice or behaviour exhibited by a farmer towards acceptance of an innovation which are the EPNs.

2.3.2.1.2. Social variables

Social norms are one of the sub-categories of social factors that influence technology adoption by influencing an individual's attitude toward the acceptance of EPNs (Idioms *et al.*, 2021). The social norms include the farmers' educational level, their age, gender, household size, and their employment status.

A farmer's education level increases their ability to understand presented ease aspects and usefulness of an innovation. Acceptance of a new technology is determined by one's level of understanding of how to use it effectively, and complex technologies, such as EPNs, necessitate a higher level of understanding (Rogers, 2015). Early adopters of new technologies do have higher educational levels, which may reflect their ability to grasp "how-to" knowledge faster than those with less education (Rogers, 2020). In empirical studies, less educated people cite a lack of knowledge as one of the main reasons for their refusal to accept innovations (NTIA, 2020). They are anxious, and their cognitive structures are less sophisticated, making it difficult for them to learn in new situations (Hilgard and Bower, 2016). Furthermore, empirical studies show that education level and perceived ease of use have a significant positive relationship.

Age influences the acceptance of innovation. In comparison to younger farmers, older farmers are regarded as having gained knowledge and experience over time and are better able to evaluate technical information (Alzubi *et al*., 2019; Mannan *et al.*, 2017; Putra *et al.*, 2019). On the other hand, older farmers may be risk-averse in the sense that they may still be embedded in traditional way of doing things, and may not be interested in accepting an innovation. Younger farmers may also be risk-takers and willing to accept an innovation given that they are able to comprehend information available to them regarding new innovations. This study thus seeks to understand how age influences willingness to accept EPNs as a bio-control measure towards the SPW.

The acceptance of an innovation is influenced by the income level of farmers. Lower-income farmers are likely to view EPNs as expensive, resulting in a lower acceptance rate. Since these farmers do not have enough money, they will automatically assume they won't be able to afford EPNs. Higher-income farmers, on the other hand, are expected to accept EPNs more quickly because they would believe they are able to afford them. Kolodinsky *et al*. (2014) reported that married couples are more likely to accept new innovation than single males or females. This is because most married couples make decisions together and are more likely to make sound decisions such as trying new things in the best interests of their farms financial security.Krause *et al.* (1990), Immink and Alarcon (1993), and Iheke (2006), asserted that a lack of funds and credit prevents smallholder farmers from assuming financial leverage risks associated with the acceptance of new technology. Iheke and Nwaru (2013), supported these assertions by reporting that on-farm income increases innovation acceptance. Acceptance of new technology is higher in male-headed households (Iheke and Nwaru, 2013). One of the reason is reported by FAO (2005). It states that few extension services are targeted at rural women, that few of the world's extension agents are women, and that most extension services focus on commercial rather than subsistence crops—the primary concern of women.

2.3.2.1.3. Institutional variables

Access to support services such as credit, markets, extension services and participation in entrepreneurial training are also regarded as an important factor in innovation acceptance. Many authors have found a link between institutional services and automation acceptance (Suckling *et al.*, 2009). For instance, extension officers frequently inform farmers about the existence and benefits of innovations, hence may be more willing to accept new innovation than those who do not have access to extension officers because the benefits of the innovation have been disseminated to them by the extension officers.

In addition, farmers with access to credit may easily accept new innovations. This is because they have sufficient credit to purchase the innovations and may wish to put the credit to good use in order to improve their farming profits and efficiency. Farmers who do not have access to credit, on the other hand, may believe that adopting new technology will be costly, and thus may be hesitant to accept it.

Cooperative societies/farmers' associations are sources of good quality inputs, labour, credit, information, and organized marketing of products. Extension services provide informal training that helps to unlock the farmer's natural talents and inherent enterprising qualities, enhancing his ability to understand, evaluate, and adopt new production techniques leading to increased farm productivity (Ihekean and Nwaru, 2013).

2.3.2.1.4. Technical variables

Access to economic resources, such as farm implements, influences acceptance, indicate that a lack of access to these resources influences innovation acceptance.

For instance, Rogers (2020) reported that farmers who had access to proper irrigation systems and machinery in their farms indicated a little ease of acceptance to new innovation compared to those who did not. The author further indicated that it is because these farmers are always looking for new ways to improve their produce as they are not really worried about the farm basics such as irrigation and farm implements, their main worry is improving their produce.

2.3.2.2. Perceived usefulness

Regarding the numerous variables influencing innovation acceptance, perceived usefulness is regarded as a prerequisite for automation acceptance and behavioural intent. For example, Huang *et al*. (2018) asserted that when an individual perceives an innovation as useful, they are more likely to accept it quickly. In the current context, farmers are more likely to accept EPNs if they see them as useful.

2.3.2.3. Perceived ease of use

Perceived ease of use is the degree to which an individual believes that using a specific system will make his or her job easier. According to Nagy (2018), individuals who perceive an innovation as easy to use are more likely to accept it than those who perceive an innovation as difficult to use. In this context, farmers who believe EPNs are simple to use are more likely to accept them than those who do not.

2.3.2.4. Attitude

Attitude can be defined as one's perspective on the chosen act. Attitudes have a significant impact on a person's behaviour. According to Kim et al. (2009), the attitude only partially or completely mediates the relationship between salient beliefs and acceptance of an innovation. The empirical findings concerning the inconsistent role of attitude toward system use may be considered evidence for assigning attitude a minimal role in studies of innovation acceptance.

2.3.2.5. Behavioural intention to use

The intention to use is a critical factor in actual use. In terms of innovation acceptance, a decision to willingly use technology to its fullest extent is generally positive. Indivisuals whose intentions are to accept or use an innovation will be seen by how they behave towards its introduction.

2.4. Conceptualization of the TAM

Figure 2.1 shows a representation of the TAM model. According to the TAM, perceived usefulness has a direct and positive impact on perceived intention to use, whereas perceived ease of use has an indirect and direct impact on a user's intent to accept the EPNs, or perceived intention to use. Perceived ease of use influences perceived usefulness directly, and thus influences perceived intent to use both indirectly and directly (Thong *et al.,* 2012).

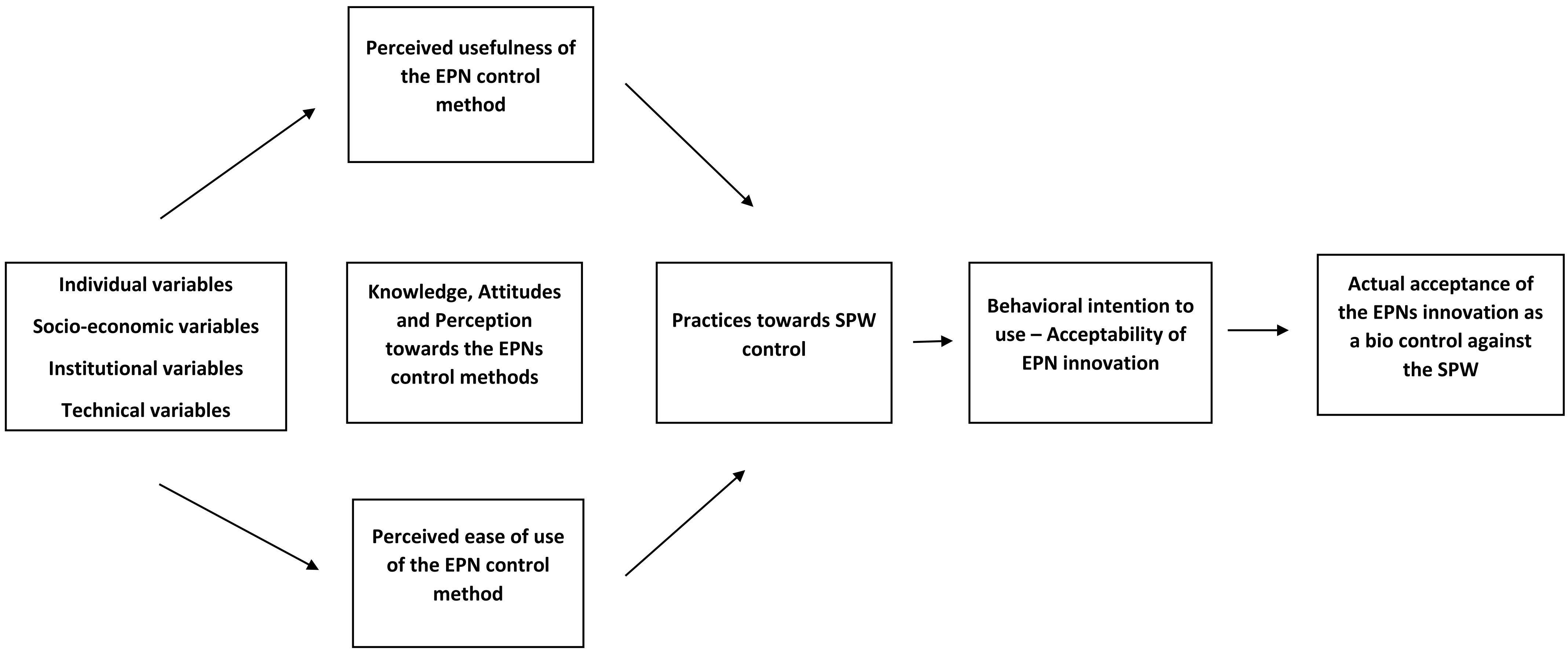

Figure 2.1: The TAM model proposed by Davis, (1986) adopted and modified by the author for this study

2.5. Literature review

This section elucidates the literature review on the smallholder farmers' characteristics, acceptability of innovation, farmers' knowledge, attitudes, perceptions and practices towards SPW, as well as its control. In addition, the section dwells on profitability and technical efficiency and further reviews its drivers.

2.5.1. Smallholder farmers' characteristics

Analysing the subjective perspectives of farmers, a population characteristic of smallholder farmers is critical to rural psychology. According to Boza *et al.* (2020), the lived experiences, problems, and relationships of smallholder farmers differ from those of commercial farmers, and this has largely gone unnoticed and understudied. Furthermore, a better understanding of subjective traits of farmers in a specific context, such as their socio-economic characteristics, enables more appropriate interventions. This literature on farmer traits also improves smallholder farmers' self-awareness of their own community (Roch *et al.*, 2021).

Several studies (e.g. Boza *et al*., 2020; Chin *et al.*, 2019; Roch *et al.*, 2021), have been conducted to profile the characteristics of smallholder farmers. According to the findings from the aforementioned studies, the majority of smallholder farmers are females and are elderly (generally with an average of plus/minus 50 years). Furthermore, the mentioned studies found that smallholder farmers have an average farm size of 2.5 hectares (ha) and farm primarily for home consumption. Furthermore, their results revealed that smallholder farmers have an average household size of 4 which is South Africa‘s average household size. .

Other studies (e.g. Boza *et al*., 2020; Danso-Abbeam *et al.*, 2020; Mugumaarhahama *et al.*, 2021), have revealed that smallholder farmers are distinguished by a lack of access to production resources that could aid in farm activities, such as farm machinery and implements (e.g. tractors, irrigation systems, etc.). These studies also revealed that smallholder farmers are characterized as subsistence farmers as they produce for home consumption although they only look to sell when they have surplus produce.

2.5.2. Profitability and technical efficiency: overview

Profitability is the primary goal of all commercial endeavours. Measuring current and past profitability, as well as projecting future profitability, is therefore critical in organizations (Abdulaleem *et al*., 2017). Therefore, profitability and technical efficiency are good indicators of a farm's productivity and efficiency of production and products sold, respectively. Hence, they will be used in this context to measure profitability and efficiency of sweet potato production by smallholder farmers. Generally, the existing body of knowledge on the profitability and technical efficiency regarding sweet potato production is scarce in South Africa (Onuwa *et al.,* 2021). However, it is acknowledged that scholars have attempted documenting profitability and technical efficiency of different organizations, farms and businesses in different locations across the world using different methodologies, and making different recommendations (i.e. Fawole and Ozkan, 2018; Hossain, 2019 Ogunmodede *et al*., 2020).

There are different methods of assessing profitability, technical efficiency and of businesses and organisations (Haralayya *et al.,* 2021; Zhao *et al*., 2021). Given this, it is critical to understand a farm's profitability and technical efficiency in order to assess its financial and technical performance. The following sections examine profitability and technical efficiency, as well as the methods and approaches used to achieve them and their drivers (determinants).

2.5.2.1. Approaches to determine profitability

To assess profitability, the widely used methodology that has been recommended by a number of scholars (e.g. Abdulaleem *et al.*, 2017; Douglas *et al*., 2014; Fani *et al.*, 2015; Mulaudzi, 2015) is the Gross Margin (GM) analysis, which is computed from the enterprise budget. These scholars have also indicated that they recommend Gross Margin analysis as the best method of determining profitability due to its easiness to compute and includes all costs directly related to the production of a specific product. Since the cost of goods produced is directly related to the goods being produced, the gross margin analysis therefore provides a more relevant figure of a farm's profitability (Abdulaleem *et al.*, 2017) as opposed to other methods (e.g. Cost Benefit Ratio and Net farm income) that include external costs that are not directly related to the costs of producing a particular good

2.5.2.2. Approaches to determine technical efficiency

Technical efficiency is an important component of economic profitability because it measures a firm's ability to produce the most output from a given set of inputs

(Adams *et al*., 2020). This will be reflected in the average cost of operation and, as a result, will have a direct impact on the firm's competitive position. Consequently, it will be used in this context, derived from the DEA scores to determine the technical efficiency of smallholder sweet potato farmers in South Africa.

To assess technical efficiency, Ahmad and Bravo-Ureta (1995) used the stochastic efficiency decomposition technique proposed by Bravo-Ureta, (1997). This technique was an extension of the Traditional Approach to Allocative Efficiency model originally implemented by Anandalingam and Nalin (1987) to decompose Production Efficiency into Technical, Allocative and Structural components. Due to scale biases introduced by enforcing an input-oriented system on output-oriented stochastic production frontier effects, Bravo-Ureta (1997) decomposition efficiency estimates either over-estimate or under-estimate true measures. Despite the fact that some scholars acknowledged the methodology's shortcomings, such as its nature, which requires to have a functional form and inability to incorporate multiple outputs, little effort has been made to develop it (Singh *et al.,* 2001).

Consequently, in order to overcome some of the challenges such as the requirement of the statistical form and inability to incorporate multiple outputs posed by the decomposition efficiency technique, the Data Envelopment Analysis (DEA) has been widely explored by scholars (e.g. Abdulai *et al*., 2018; Bulagi *et al*., 2019; Yannick *et al*., 2016). This current study therefore adopted the DEA to avoid these scale impacts (over and underestimations), requirement of a statistical form to determine the technical efficiency of the smallholder sweet potato farmers. This is because the DEA does not require a functional form, and its design allows for multiple inputs and outputs, as well as the use of Decision Making Units (DMUs) to mitigate scale effects.

2.5.3. Profitability of sweet potato production globally and in South Africa

Teshome *et al.* (2020) conducted a study to assess the factors influencing the profitability of smallholder common bean producers in Ethiopia's Central Rift Valley using both Gross Margin (GM) analysis and net farm income to assess thier profitability. The findings reveal an average GM and net farm income of R4 024/ha and R2 426/ha, respectively. The differences in the profitability results of the two methodologies were as a result of the different approaches the methodologies follow to attain the results, for instance, when calculating gross margins only the costs related to producing the good are included whereas with net farm income, all the costs related to a farm's expenses are included. According to the findings, distance from the nearest market, age, family size, off-farm income, and fertilizer source negatively influenced the profitability of smallholder common bean producers. Gender, farm experience, group membership, and target market channel, on the other hand, had a significant positive influence on smallholder common bean production profitability. However, drivers of profitability are contextual as well as vary between commodities. As such, the current study will also assess the influence of different factors on the profitability of sweet-potato production.

Anggraeni *et al.* (2021), conducted a study to analyse the cost, revenue, income, and profitability of sweet potato farming in Karanganyar Regency using implicit and explicit costs. Implicit costs included the cost of seeds and family labour, while explicit costs included labour outside the family, fertilizer, pesticides, taxes, equipment depreciation, and own capital interest. Generally, the findings of this study revealed that sweet potato farming was profitable. In the current study, both the implicit and explicit costs will be used during the gross margin analysis to determine profitability.

Oladimeji *et al.* (2017) conducted a study to examine efficiency and profitability of sweet potato production in North Central and North Western Nigeria using net farm incomes. The study asserted that sweet potato production in the two states were profitable and profitability was estimated to be N142364.3/ha which is R5 381.04/ha. The total variable costs and total fixed costs were used as cost indicators, which differed from the current study, which only considers the total variable costs. This is because current context is only concerned with the costs directly related to the production of the good in question (sweet potatoes), rather than total fixed costs. Oladimeji *et al.* (2017) used price by quantity as a measure of total revenue, which is similar to the method used in the current context.

Nabay *et al.* (2020) conducted a study to examine the profitability and channels of distribution of sweet potato in Sierra Leone using the benefit cost ratio (BCR). This indicated that the BCR was greater than 1, which means that the benefits were greater than the costs and therefore the sweet potato business was profitable. The cost indicators were total transaction costs (including costs from both market transaction and cost of the product) which are different from the current context since it only considers costs related to the goods produced. The indicator for benefits was the revenue which was represented by the sales per bag of sweet potato, which was the case for the current context as well. Overall, the study, sweet potato trading is a profitable and a lucrative business venture that is worth investing.

Ndou *et al*. (2020) conducted a study to investigate the viability of smallholder sweet potato enterprises for the South African rural communities. The study used formal market surveys and Gross margin analysis to address its research questions. The revenue was determined by the sales of sweet potato whereas the costs were determined using the inputs directly involved in the production of the sweet potato (labour, fertilizer and chemicals, cuttings/slips and machinery costs). The same approach was used in the current context because in terms of revenue and costs, the drivers are those directly involved with the goods being produced. The results revealed that the smallholder sweet potato farmers were profitable and made an average of R47 000/ha. The study further asserted that generally, sweet potato is viable, has a huge market across South Africa and is profitable.

According to the studies cited above, smallholder sweet potato profitability is generally affected or influenced by demographic, farming, institutional, and technical factors. As a result, these are the variables that will be used in the current study.

As seen from this section, the profitability of sweet potato production is fairly documented in across the world; however, not many scholars have conducted studies in the South African context in relation to the topic of concern. Nonetheless, according to the existing body of knowledge, sweet potato farming presents a number of lucrative opportunities. For example, it has the potential to be a food security crop, it has a number of health benefits, it also has potential in the trade industry, it has a market and is consequently worth investing in, most importantly, it is profitable.

2.5.3.1. Review of factors influencing profitability of smallholder farmers

The profitability of a farm is a good indicator of whether or not it is performing well in terms of profitability (Nunez *et al*., 2020). It is thus critical to document the factors that influence profitability in order to disseminate knowledge and make farmers aware of what influences their profitability so that they can know how to remedy or improve their farms. As a result, a number of scholars have attempted to document the factors influencing the profitability of smallholder farmers, and some of those studies are reviewed in this subsection. For example, Mariyono, (2018) and Teshome *et al.,* (2020) asserted that generally, distance from the nearest market, age, family size, off farm income, fertilizer source, gender, farm experience, group membership, and target market channel are the factors influencing the profitability of smallholder farmers. According to the authors cited in this sub-section, smallholder profitability is generally affected or influenced by demographic, farming, institutional and technical factors. As a result, these factors were also considered in the current study.

2.5.4. Technical efficiency of sweet potato production globally and in South Africa

Scholars across the world including South Africa have attempted to document the technical efficiency of sweet potato production in different locations and, using different methodologies within their contexts. For example, Onuwa *et al*. (2021) conducted a study to analyse the technical efficiency of sweet potato production in Bokkos Local Government Area of Plateau State, Nigeria. The study employed the stochastic frontier production function. The findings revealed an average technical efficiency of 0.62 (62%), indicating that sweet potato farmers were technically efficient to some extend even though there is room for improvement as the technically efficiency score indicates farmers in the study area were not producing at full capacity. The study recommended that improved, clean and disease resistant cultivars be used because most of farmers expressed that they were experiencing huge yield losses due to pests and diseases as a result of using dirty planting material. While these were the drivers of technical inefficiency in this context, the current study also sought to understand the determinants of technical efficiency. This was thought to be important to account for the South African contextual factors. Such evidence is important especially for informing targeted interventions. Moreover, the current study did not use the Stochastic frontier production function based on its shortcomings. Stochastic frontier production can sometimes over or underestimate technical efficiency levels. For these reasons, and to address these shortcomings, this study employed the DEA, which does not require a functional form; can accommodate multiple outputs and uses decision making units (DMUs). Thus, DEA reduce the risk of over and underestimation of technical efficiency scores.

Similarly, Wassihun *et al*. (2019) conducted a study to analyse the technical efficiency of sweet potato production in Chilga District, Amhara National Regional State, Ethiopia. The study made use of Cobb-Douglas functional form. In the findings, the average technical efficiency score was estimated to be (0.75) 75%, suggesting that farmers were technically efficient in general, although there was room for improvement. However, in the current context, the DEA is used instead of the Cobb-Douglass functional form because it takes returns to scale into account when calculating efficiency, allowing for the concept of increasing or decreasing efficiency based on size and output levels (Abate *et al.*, 2017). Consequently, the DEA was used in the study because the smallholder farming industry is unpredictable and their study was looking to focus more on the output hence assumed an output-oriented model. As seen from the above-reviewed studies, generally sweet potato production is technically inefficient. This indicates that there is room for improvement in the sweet potato production in terms of producing optimally locally and globally.

2.5.4.1. Review of factors influencing technical efficiency of smallholder farmers

Chirwa (2017) estimated technical efficiency among smallholder maize farmers in Malawi and identified sources of inefficiency. The Cobb–Douglas stochastic production frontier was used in the study to estimate the technical efficiency score, while the Tobit regression model was used to determine the factors influencing technical efficiency. To generate technical efficiencies of maize farms, the study used inputs and outputs to determine technical efficiency scores. The production function used was maize quantity, land, value of other inputs, and capital. Similarly, the current study generates technical efficiency scores using similar inputs (fertilizers and chemicals in addition) and outputs (sweet potato yields). Since these are good input-output indicators, they will also be used in the current study. The study asserted that smallholder maize farmers in Malawi were technically inefficient; with an average efficiency score of 53.11%. The study further revealed that education level, land size, labour hire, use of hybrid seeds and membership to a farmer club or association had an influence on smallholder maize farming in Malawi.

Chebil (2012), for instance investigated water-use efficiency and its variables among smallholder irrigation farmers in South Africa. The authors discovered inefficiencies with an average of 16% technical efficiency among farmers using the two-step DEA methodologies with VRS specifications. A second-stage Tobit regression found that farm size, land ownership, field fragmentation, crop choice, irrigation technology employed, and type of irrigation scheme were found to be all major drivers of water-use efficiency.

Weldegiorgis *et al.* (2018) looked at the TE of irrigated vegetable growing in Borno State, Nigeria. The study used the DEA and Tobit regression model to determine the technical efficiency of sole onion, sole tomato and sole pepper as well as the drivers of technical efficiency. The study discovered that technical inefficiency prevails across the board, with values of 0.99 (sole onion), 0.94 (sole tomato), 0.96 (sole pepper), 0.95 (onion/tomato), and 0.98 (onion/pepper). The most important elements determining efficiency were family labour, farm size, agrochemicals, and seed/seedling costs.

Madimamba *et al*. (2022) also conducted a study to assess technical efficiency and its determinants among sweet potato farmers in Western Uganda. The DEA was used to calculate technical efficiency and the average technical efficiency was found to be 55%. Tobit regression model was used to examine the factors that influence technical efficiency. Household size, farm location, group membership, and pesticide use had a positive and significant effect on technical efficiency, whereas farm size and input prices negatively influenced technical efficiency. However, different contexts might have different factors. Tan *et al*. (2010) claimed that families with a large number of members are better off in terms of sweet potato production labour allocation. Families with few household members, on the other hand, rely on paid hired labour, which reduced technical efficiency. Farmers who used pesticides were not technically efficient, according to Ayu and Aulia (2018), who also admitted that these farmers were not using the right quantities of pesticides for tomato production.

Ma *et al.* (2018) found a positive and significant link between group membership and technical efficiency among Chinese apple growers. Wongnaa and Awunyo-Vitor (2018) found that farmers' group membership has a positive impact on technical efficiency among maize farmers in Ghana. These contradicts the findings of Hakim *et al.* (2021), who found that group membership had no significant impact on technical efficiency among Indonesian farmers. Lindawati *et al.* (2018) found that farm input prices had a negative and statistically significant impact on the rice and livestock farming systems in Indonesia, implying that high input prices would lead to technical inefficiency. Briner and Finger (2013) found a negative relationship between input prices and resource use efficiency in the Swiss dairy production system in a study.

Okello *et al*. (2019) found that farm size has a negative impact on technical efficiency among cassava and rice farmers in Uganda's Gulu and Amuru districts. However, it contradicts Belete (2020)'s findings, which found a negative relationship between land size and technical efficiency among maize farmers in Guji zone. Similarly, Tipi *et al*. (2010) found that farm size has a positive impact on technical efficiency among rice farmers in Turkey.

Abate *et al*. (2019) also conducted research in the Amhara regional state of Ethiopia's North Gondar zone to determine the technical efficiency of smallholder farmers in red pepper production. The study used stochastic frontier Cobb–Douglas production and the OLS regression to determine the technical efficiency scores and asserted that the mean technical efficiency 79% ranging from 16% to 95% meaning that the farmers were generally technically efficient. The study further asserted that the variables age, education status, land size, land fragmentation, extension service, credit access, and market information were statistically and statistically significant.

The abovementioned studies documented the studies and literature on factors influencing technical efficiency and have revealed that generally smallholder farming is overall influenced by demographic, farming, institutional and technical variables. However, the studies and literature reviewed are for a variety of commodities with varying resource requirements as well as operational management from different countries, which can have an impact on technical efficiency. Moreover, due to the additional data requirements about price and input costs, efficiency studies of smallholder farmers focused on technical efficiency elements remains scarce in the literature (Zwdie *et al*., 2021). Thus, only a few researches on smallholder sweet potato technical efficiency, as well as its drivers, have been conducted in South

Africa (Belete *et al*., 2016; Gwebu and Matthews, 2018). As a result, sweet potato technical efficiency in South Africa must be determined as well.

2.5.5. Knowledge, Attitudes, Perceptions and Practices: overview

A KAPP survey is a representative study of a specific population (i.e. sweet potato farmers in this context) designed to gather information on what is known, believed, and done about a specific topic. The majority of KAPP surveys collect data orally by an interviewer using a standardized questionnaire (Kambey *et al.*, 2021). These data can then be analysed quantitatively or qualitatively, depending on the study's objectives and design (Bukachi *et al.*, 2018).

KAPP survey data is critical for planning, implementation, and evaluation of individuals' level of knowledge, attitudes, perceptions and practices. KAPP surveys can identify knowledge gaps, cultural beliefs, or behavioural patterns that can help with understanding and action, as well as problems or barriers to development efforts (Top *et al*., 2020). They can recognize commonly known information and commonly held attitudes. To some extent, they can identify factors influencing behaviour that most people are unaware of, as well as reasons for their attitudes and how and why people engage in certain behaviours (Rani *et al*., 2014). KAP surveys can also evaluate communication processes and sources, which are critical in defining effective activities and messages (Das *et al*., 2019). The next sub-section reviews the importance of farmer KAPP of pests and insects.

2.5.5.1. A review of KAPP studies

Mutsotso *et al.* (2011) conducted a study on farmers' knowledge, attitudes, perceptions and practices (KAPP) in Embu and Taita Sites before and after belowground biodiversity project intervention. The study revealed in its "limitations" that the KAPP results were extremely difficult to interpret without a benchmark. However, in the current study context; to allow ease of benchmarking scores, each KAPP component was treated and measured individually using the psychometric Likert scale.

Another study was undertaken by Rani *et al.* (2014) on farmers' knowledge, attitudes, and practices regarding rodent pest management. Their study, however, featured several open-ended questions, the study revealed that too many open-ended questions made data capturing challenging. Consequently, in this study, questions were scaled on a 5-point Likert scale to reduce the incapacity to obtain data and to facilitate analysis.

Wang *et al.* (2015) and Andrade *et al.* (2020) are other researchers who conducted KAPP investigations, and their investigations shared two flaws. The first was that such KAPP studies contained a lot of yes or no questions. This limits the respondents' responses since they are unable to express when they are unsure. In the context of this study, this constraint was addressed by omitting excessive yes or no questions and allowing respondents to express when they are doubtful or neutral about a specific item in the questionnaire. The second constraint was that there was bias in the results, which can be produced by respondents responding based on what they believe the enumerator wants to hear. To avoid this biasness in this study, respondents were advised before the interviews to be as honest as possible.

In summary, the literature on KAPP analysis studies reveals that, despite the limitations of each study, the KAPP analysis is still a useful tool for gathering individuals' knowledge, attitudes, perceptions, and practices about a specific topic of interest. Furthermore, the KAPP analysis provides a definite analysis of what one knows, thinks, and does about a particular topic of interest.

2.5.5.2. The importance of farmers' KAPP of pests and insects

Munyuli *et al.* (2017) asserted that farmer KAPP surveys of pests and insects are important because it is necessary to document and understand current farming practices being implemented by farmers in order to implement a good integrated pest management (IPM). Furthermore, Stefopoulou *et al*. (2021) stated that it is critical to understand farmers' KAPP regarding insects and pests because they are the end users of research products. For effective rapid adoption of technologies and practices, it is critical to build on existing local knowledge of the pests and insects, and this can be through a KAPP assessment, which is also the focus of the current study regarding the SPW and the control measures.

More scholars (e.g. Andrade *et al.* 2020; Munyili *et al*., 2017; Nyairo 2020; Stefopoulou *et al*., 2021) have also attempted to document the importance of farmers KAPP of insects and pests and discovered that farmers must be knowledgeable about the pests and insects infesting their fields. This is done so that farmers can develop indigenous methods of controlling economically important pests and insects. To elaborate, Andrade *et al.* (2020) claims that farmers who are familiar with pests and insects are more likely to devise traditional pest and insect control methods in order to save their yields. Furthermore, they are the most likely to accept new methods of pest and insect control because they are aware of the extent to which a particular pest or insect causes damage in their fields. Hence, the next sub-section reviews how KAPP are related to the acceptance of new innovation.

2.5.5.3. KAPP and acceptance of innovations

Extrinsic and intrinsic aspects influence the acceptability of new technologies and practices in the decision-making process for innovation acceptance (Rav-Marathe *et al.,* 2016). The existing literature on the role of knowledge, attitudes and perceptions in agricultural innovation acceptance tends to focus on extrinsic factors like economic considerations. However, intrinsic variables, on the other hand, may have an equal, if not greater, impact on smallholder communities in Sub-Saharan Africa's acceptance of agricultural advances (Bukachi *et al.*, 2018). A mix of extrinsic and intrinsic qualities can provide a more holistic understanding of farmers' opinions on technological acceptance (Bukachi *et al.*, 2018).

Farmers' attitudes about new technologies or innovations may be the most important factor in determining whether or not they accept new agricultural methods (Top *et al.,* 2020). In social psychology, attitude is a central, intrinsic construct that has been widely applied in the understanding of human behaviour. As a concept, attitudes are used to determine whether an object or practice is beneficial or harmful (Andrade *et al.*, 2020).

In a nutshell, attitude is an indicator of how strongly a person likes or dislikes an idea, a concept, or other people's viewpoints. What an individual views as true or incorrect shapes his or her attitudes (Friedman and Shepeard, 2007). Attitudes influence a person's conduct and are influenced by their behaviours and values. In agriculture, an individual farmer's decision-making process allows for the assessment and formulation of favourable or unfavourable views about agricultural practices, including new innovations (Meijer *et al.*, 2015).

Although it may not always be possible to measure the process of belief formation, attitudes can be seen through individual choices, according to core ideas on attitudes (Roussy *et al.*, 2017). Any variety of social or physical contextual elements can influence the configuration of attitude formation. Smallholder farmers in agricultural production have been found to evaluate agricultural innovations in the same way they do other technologies in terms of their utility. For instance, socio-demographic parameters such as age, gender, income, and education level have been indicated as key predictors of agricultural technology acceptance (Rav-Marathe *et al.*, 2016). Individual smallholder farmers have been shown to behave differently in practice depending on their production requirements or household conditions.

Nyairo (2020) looked at people's attitudes regarding precision agriculture technology and indicated that having a confident attitude helped people accept the technology. The intention to embrace agricultural precision technology was favourably influenced by attitudes of confidence in applying precision agriculture technologies, perceptions of net advantages, and farm size. According to these findings, economic benefits may not be the major motivation for farmers to accept agricultural technologies, but the attitudes they have towards such technologies. However, this does not imply that they are generalizable across all technologies, hence, it is important to explore the influence of farmer attitude in different contexts. There are numerous research on smallholder farmers' attitudes toward agricultural innovations (Mugumaarhahama *et al*., 2021; Mulimbi *et al.*, 2019; Obiero *et al*., 2019), yet farmer experiences vary among developing nations.

Mulimbi *et al.* (2019) used a cross-sectional study design to investigate the factors influencing the adoption of no-till conservation agriculture (CA) and farmers' perceptions of the technology. The study took place in the Democratic Republic of the Congo and used the logit models. The findings suggest that the farm's location, training, access to credit, membership in a farmers' group, and being a vulnerable female, all influenced adoption in different ways. However, it is critical to investigate the impact of farmer attitude in various context as this is not applicable to all the technologies because different farmers may express different attitudes in other regions.

When farmers are unsure about accepting a new technology owing to a lack of information or proper training, access to extension services can help them alter their minds about their farming practices (Morton *et al.*, 2017). This reasoning, however, is dependent on the socio-cultural setting in which the general belief system in a given social context operates. While socio-cultural norms are a factor in opposing the introduction of new practices, more information has not been found to be sufficient to respond to claims of uncertainty.(Shelby, 2014). Morton *et al.* (2019) suggested that scientific knowledge linked to local values and trusted agricultural networks would be more widely accepted in such a situation.

To reduce user resistance to new information, the message must be designed with local values and customs in mind. Extension service was revealed to be a determinant in the promotion of no-till conservation methods among farmers in a recent study (Andrade *et al.*, 2020). As a result, standard extension services' tactics may be more effective in reaching farmers if they involve social networks by paying attention to local views and values.

2.5.6. EPNs, their regulations, utilizations and acceptance by farmers

Surveys and studies must be conducted prior to the introduction of an innovation to determine its acceptance. In addition, the regulations governing the new innovation and its applications elsewhere must be documented. The use of chemical pesticides and the need to adjust bio-control measures are discussed in this section, as well as the use of EPNs as biocontrol agents, farmer acceptance of EPNs and other bio-control agents, and the regulatory environment surrounding the use and registration of EPNs and other bio-control measures in South Africa.

2.5.6.1. The use of chemical pesticides and the need to adjust to bio-control measures

The commonly used measures to control pest and insects of economic importance across the world have always been chemical pesticides (Baimey *et al.*, 2017). However, pesticides cause domestic animal contamination and death, loss of natural pest antagonists, pesticide resistance, honeybee and pollination declines, crop losses, fishery and bird losses, and groundwater contamination (Abate *et al.*, 2017; Dolinski *et al.,* 2012; Meijer *et al.,* 2015) . Farmers are also more likely to develop cancer if they work with pesticides on a regular basis. Pesticides are responsible for thousands of non-lethal poisonings and cancer cases each year (Sabarwal *et al.*, 2018). Consequently, to avoid relying solely on harmful insecticides, a variety of biological control strategies such as EPNs should be investigated and studied in order to shy away from these harmful chemical pesticides.

2.5.6.2. Utilization of EPNs as bio-control agents

The utilization of EPNs as bio-control agents started in the 1930 (Abate *et al.*, 2017). The production of these nematodes on a much bigger scale was then achieved in the 1980s (Platt *et al.,* 2020) and there has been an increase in the large-scale utilizations of EPNs ever since. Reasons for the large-scale utilizations are many and vary. For instance, increased demand for organic products in countries such as Brazil and Korea, as well as increased use of greenhouses to grow high-value crops, were the two most significant transformations that led to the adoption of EPNs as bio-control measures in these countries (Dolinski *et al.,* 2012). Other research showed that EPNs' wide ability to host and their perceived environmental friendliness compared to other chemical pesticides has led to their increased usage (Hlerema *et al.*, 2017). Consequently, due to these reasons, EPNs are regarded as environmentally friendly bio-control agents, which require no regulatory protocols for their application in many countries (Ehlers and Hokkanen, 1996; Elhers, 2012).

While vast studies have been conducted on the efficacy of EPNs and other IPMs (Malan and Moore, 2016; Ramakuwela *et al.*, 2018; Steyn *et al.*, 2019; Tshikala *et al.*, 2019), there is still a dearth of studies on smallholder farmers' willingness to accept the EPNs as a bio-control measures, and South Africa is not an exception. Such research is presented in this sub-section.

Yuksel *et al.* (2018) looked to test the efficacy of different EPNs class against the cutworm in Egypt. The study revealed that under research laboratory environments in the petri dish trial, the *heterorhabditiditis* nematodes proved a more effective control of the cutworm and upsurge in time of exposure led to more death of the nematode species tested. The study's findings indicate that EPNs have proven to be effective in controlling soil-borne pests in some parts of the world, and thus provide proof that they have the potential to control these pests in other parts of the world where they have been understudied, such as South Africa (Ramakuwela *et al.,* 2014).

Another study by Gozel and Gozel (2016) was conducted to assess the efficacy of EPNs in the red palm weevil against palms in Pakistan. The EPNs of the species

Steinernema were tried in contradiction to T. *absoluta*. Field trials were carried out in the training and research area of Agriculture Faculty in Canakkale. From the results, all EPNs used in the study were effective to all four larval instars of T. *absoluta* and caused higher mortality in all the instars.

Steyn *et al.* (2019) aimed to determine the susceptibility of leaf-mining H. *capensis* larvae to seven EPN species belonging to *Steinernematidae* and Heterorhabditidae in South African table and wine grapes vineyards. The study aimed to assess whether leaf-mining H. *capensis* larvae are susceptible to seven entomopathogenic nematode species from the *Steinernematidae* and Heterorhabditidae families. From their results, all species presented over 85% mortality of leaf-mining larvae. The study reported that the laboratory results were promising, especially in terms of the EPNs ability to penetrate the leaf-mining galleries and successfully infect the larvae.

Nderitu *et al.* (2009) also investigated the efficacy of two EPNs (Steinernematidea and *Heterorhabditis*) against the SPW (C. *puncticolis*) in Kibwezi, Eastern Kenya. In two consecutive growing seasons in 2002 and 2003, the experiment was performed in semi-field conditions using potted plants. The efficacy of the two species of EPNs was compared. From their results, adult weevil emergence from tubers was substantially reduced by the EPNs. According to the findings, seven insect species were discovered to be beneficial as predators or parasitoids of the insect pests, killing over 70% of the pests, implying that the EPNs were very successful on larvae, greatly reducing the number of pupae.

All of the studies mentioned above support Ramakuwela *et al.* (2015)'s assertion that EPNs have been successfully tested in fields and trials in other parts of the world, such as those mentioned in the studies above. This means that EPNs have great potential as IPM techniques and, more importantly, for controlling soil-borne pests like the SPW and others mentioned in the reviewed studies above. The context of the current study however focused on the farmers' acceptability of these bio-control measures (EPNs). This is because understanding the factors that will inform if the farmers will accept an innovation is critical to ensuring that the innovation is widely used and accepted by future users. Most studies on acceptance of EPNs and other bio-control measures have only been conducted outside of South Africa (Blake *et al.* 2017; Dolinski *et al.*, 2012; Meijer *et al.,* 2015).

2.5.6.3. Acceptability of EPNs and other bio-control agents by farmers

Since EPNs are being considered as potential bio-control agents against the SPW and other insect pests (Gapasin *et al.*, 2017), there is a need to evaluate acceptability of EPNs to the farmers to explore their willingness to accept and adopt them in their farming systems (Olushola and Abiola, 2017), which is the focus of this study as well. Despite the fact that EPNs have shown promise as IPM strategies for controlling soil-borne pests, there is no literature in South Africa that documents farmers' acceptance of these EPNs.

Scholars from around the world, however, have attempted to document farmer acceptance of EPNs in other parts of the world. For instance, Abate *et al.* (2017) conducted a study to review the occurrence of EPN species, including those that have been released globally for commercial purposes. In the study's review, it was noted that, there are mixed reactions about how farmers actually feel accepting and eventually adapting to EPNs as bio- control measures, and that most farmers expressed a bit of reluctance and discomfort to adapting to EPNs. Expression of discomfort by some farmers in Abate *et al*. (2017)'s study was related to concerns over unintended effects on non-targeted organisms.

Some studies (e.g. Abd-Elgawad and Spiridonov, 2014; Abate *et al.*, 2017) revealed that the main barriers to the adoption of EPNs in pest management systems are their inferior performance in comparison to chemical insecticides in certain cases, as well as their inconsistent performance due to product quality control deficiencies or environmental variation in some instances. Arif *et al.* (2017) reported that one of the major contributions fuelling the discomfort in adopting the use of EPNs within agricultural farming systems is farmers' lack of knowledge base of agricultural pests' biology and life history, identification skills, and awareness of multiple methods of monitoring and control that is needed for sustainable pest management. One of the focuses of this study is to also assess farmers' knowledge regarding pests, as well as control measures that farmers make use of.

Nonetheless, other studies have indicated farmers' willingness to accept new methods of controlling pests and insects in their farming systems. Dolinski *et al.* (2012), for instance, looked to assess the grower acceptance of EPNs in South America and Korea. In their study, the efficacy and prices of EPNs was compared to that of chemical pesticides using a comparison approach. The findings revealed that the farmers who participated in the study were generally willing to accept EPNs in their farming systems because they had indicated efficacy, affordability and have proven to be environmentally friendly (Ramakuwela *et al*., 2014).

Another study by Blake *et al.* (2017), using factor analysis, assessed growing perceptions and factors influencing adoption of IPMs in commercial cranberry production. The study revealed that farmers were willing to adopt IPMs as long as they demonstrated efficacy and were affordable and easily accessible in markets. The study also suggested that in future, when new control measures are developed, they should be affordable, simple to implement, and easily accessible in markets by farmers. From these studies, it can be argued that farmers' willingness to accept the EPNs is dependent on factors such as their efficacy as well as their affordability, as well as other factors like socio-economics, attitudes, knowledge, etc.

On the other hand, there are also farmers who have expressed dissatisfaction with the use of EPNs as bio-control agents in their farming systems, (Danso *et al*., 2019; Ibouh *et al*., 2019; Sharma *et al*., 2021). This could be due to a lack of awareness of their potential, as well as negative perceptions and attitudes toward acceptance. On the other hand, some studies review show that farmers are generally willing to accept EPNs and other bio-control measures if they are truly a safer alternative, cheap, and simple to implement in the field.

2.5.6.4. The regulatory environment around the utilization and registration of EPNs and other bio-control measures in South Africa.

In South Africa, the use of biocontrol measures still requires regulatory protocols according to Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act 36 of 1947 (DAFF, 2015). This act aims to:

- ✓ Provide for the registration of fertilizers, farm feeds, sterilizing plants and certain remedies.
- ✓ Regulate the importation and sale of fertilizers, farm feeds, seeds and certain remedies, and
- ✓ Provide for matters incidental thereto.

EPNs will therefore also be regulated by this Act once accepted and implemented. Acts are important because they lay out broad legal and policy principles.

Regulations, rules, codes, and the like, are commonly referred to as "subsidiary legislation" and must be published in the Government Gazette to become legally binding. These are the guidelines that govern how the Act's provisions are implemented.

2.6. Chapter summary

This chapter discussed the study's theoretical framework as well as a literature review. The sub-sections included key concept definitions and theoretical frameworks (theory of profit maximization; the theory of utility maximization and the technology acceptance model). The literature also looked at the characteristics of smallholder farmers, as well as their profitability, technical efficiency, and drivers. The literature revealed that Gross margins is a good indicator of profitability whereas the DEA is a good indicator of technical efficiency. The smallholder farmers were found to be generally elderly with relatively small land sizes, lack of resources, producing for home consumptions, generally profitable and ethnically inefficient. Furthermore, factors influencing profitability were found to be distance to market, age of farmer, farm size, on-farm income, fertilizer source, and gender and group membership. Whereas the drivers for technical efficiency were found to be educational level, land size, labour hire, membership to a farmer association, credit access and market information. The study also reviewed literature on KAPP and its role in innovation acceptability. Finally, literature on EPN regulations and farmer acceptance was reviewed, and it was discovered that KAPP surveys are critical for implementing, planning, and evaluating individuals'' level of knowledge, attitudes, perceptions and practices on a topic of interest. Furthermore, the literature on EPN efficacy revealed that EPNs have a high potential as an IPM for controlling a variety of soil-borne pests. Furthermore, the literature review revealed that farmers are generally willing to accept EPNs and other bio-control measures if they are truly a safer alternative, inexpensive, and simple to implement in the field.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1. Introduction

This chapter elucidates the research's study area and methodology. It includes a description of the research area, research techniques which include the research design, data collection methods, and data analysis methods, and lastly the chapter summary.

3.2. Description of study areas

The study was conducted in South Africa's Gauteng, Limpopo and North West provinces. These Provinces were selected as the study area because they are classified as prominent sweet potato producing provinces in South Africa (Nhlapho *et al.*, 2018).

3.2.1. Gauteng province

Gauteng is South Africa's smallest province, located on the Highveld. It is home to more than a fifth of the country's population despite accounting for just 1.5 % of the country's land area. The province is densely populated, with Johannesburg as the country's largest city, Pretoria as its administrative capital, and other major cities like Midrand and Vanderbijlpark. Gauteng was the most populated province in South Africa as of 2019, with a population of about 15 million people (Masegela, 2019).

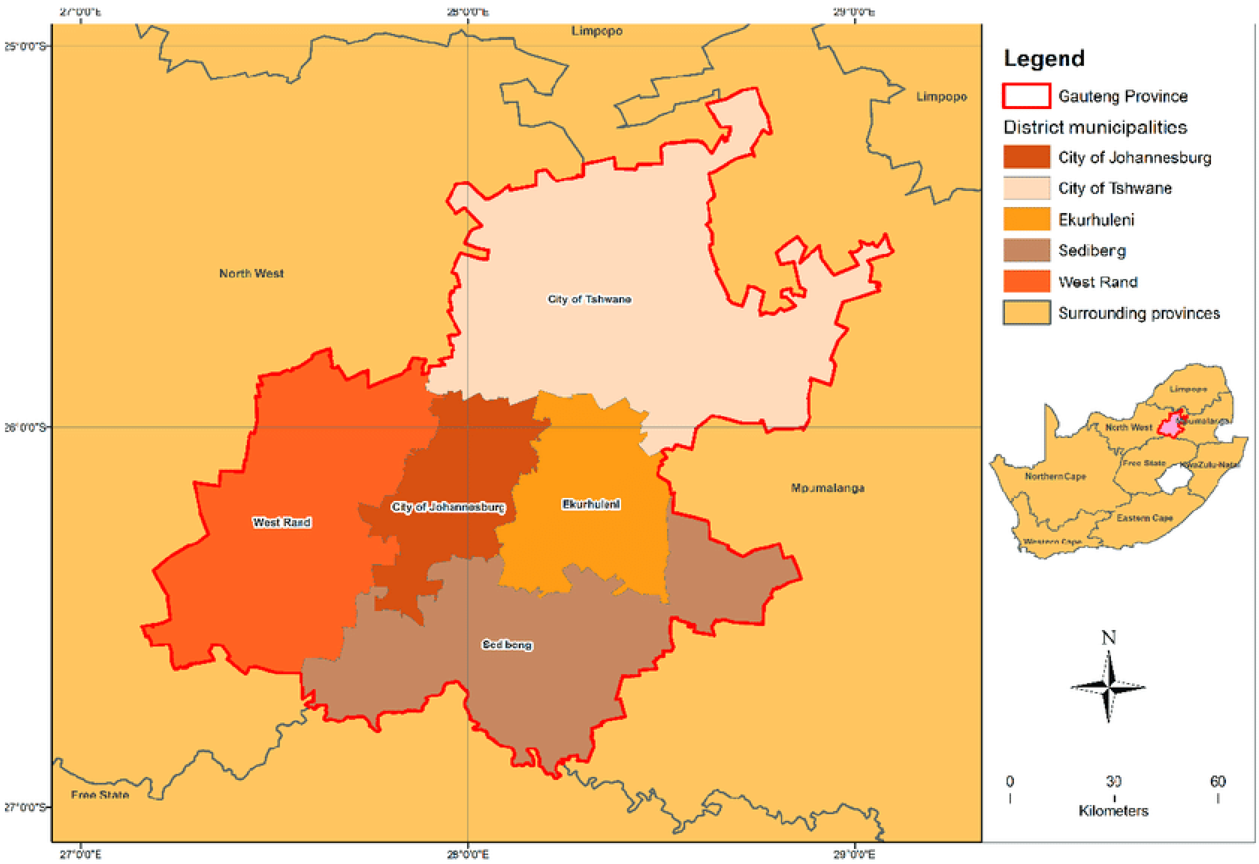

Figure 3.1: Map of the Gauteng Province

Source: (Gauteng Economic Development Plan, 2018)

Gauteng owns roughly 3% of the country's arable land. According to The Census of Comercial Agriculture (2017), Gauteng ranks last in terms of the number of farms (5,7%), commercial agricultural land (0.8%), and commercial agriculture employees (4,8%). It accounts for 4.7% of South Africa's agricultural production (Sihlobo, 2020). The agricultural sector in the province is primarily focused on providing regular fresh produce such as vegetables, fruit, meat, eggs, dairy products, and flowers to the province's cities and towns. The main crops are maize, soybeans and the sweet potatoes. This province is home to 4% of the country's commercial potato farmers (Department of Land Reform and Rural Development, 2019).

The City-Region Gauteng is a significant contributor to the economic performance of South Africa, with its various areas focussed on mining, manufacturing, finance and business services, innovation or trade and working together to form a functionally integrated urban economy and the internal labour market. This region is the trade centre of the country within and beyond South Africa. Gauteng manufactured 33.8% of national GDP at current prices in 2020. The wider City-Region of Gauteng is estimated at around 45% of the overall economic return in South Africa (Statistics South Africa, 2020).

3.2.2. Limpopo province

Limpopo province (Figure 3.2 has a population of 5.8 million people, making it the fifth most populous province in South Africa (Statistics South Africa, 2020). It is located in the country's north and shares borders with Zimbabwe, Mozambique, and Botswana. The province was previously known as Northern Transvaal, then Northern Province, before being renamed Limpopo Province in 2002. Limpopo Province was named after the Limpopo River, which forms the border between South Africa and Zimbabwe. Polokwane, formerly known as Pietersburg, is the capital city of Limpopo Province. Its name was changed at the same time as the province's name (Masegela, 2019).

Limpopo province has a total area of 125 755 km2, accounting for approximately 10.3 % of the country's total area. The Limpopo provincial review, (2019), explains that the province is the fifth largest in terms of population size in the country. Sepedi, Xitsonga, and Tshivenda are the most widely spoken languages in the province, accounting for 52.9 %, 17.7 % and 16.7 %, respectively. Limpopo is divided into five districts: Capricorn District, Waterberg District, Sekhukhune District, Mopani District, and Vhembe District, with local municipalities within each. However, for this study, only Capricorn (Mafefe, Ga-Moila, Kapa and Lebowakgomo) and Waterberg (Bela-Bela and Rust De Winter) districts were selected because of their availability of sweet potato farmers.

Figure 3. 2: Map of the Limpopo Province

Source: (Limpopo Department of transport 2017)

Limpopo is covered by an area of 12,46 million hectares, representing 10,2 % of South Africa's total area. This Province has ample agricultural resources and is one of the main agricultural regions of the country known as fruit and vegetable production, cereal production, tea and sugar production. The province consists of three distinct climate zones which are Low-level, Middle-level, High-level areas, Semi-arid, and Escarpment regions with an annual sub-humid climate with precipitation exceeding 700 mm. This diverse climate helps Limpopo to grow a broad range of foodstuffs, from tropical fruits such as banana, mangoes, maize and plant cereals (Oni *et al.*, 2012).

This province which has about 5,8 million residents, accounted for 10% of South Africa's population in 2018/2019, but contributed only 7% of GDP. The real economy (agriculture, mining, manufacturing, and construction) accounted for 33% of Limpopo's output in 2020, according to the most recent available data. At 25% of the provincial economy, mining dominated the real economy. Construction and manufacturing contributed 3%, and agriculture contributed only 2%. Limpopo accounted for 24% of national mining output, 7% of national agriculture output, 6% of national construction output, but only 2% of national manufacturing output (The Limpopo provincial review, 2019).

3.2.3. North West province

The North West is South Africa's fourth-smallest province, covering about 106 000 km^2. It is bordered to the north by Botswana, to the west by the Northern Cape, to the east by Gauteng, to the northeast by Limpopo, and to the south by the Free State. The Tswana, who speak Setswana, are the most populous ethnic group, with minority groups speaking Afrikaans, Sesotho, and isiXhosa. English is widely spoken in the province.

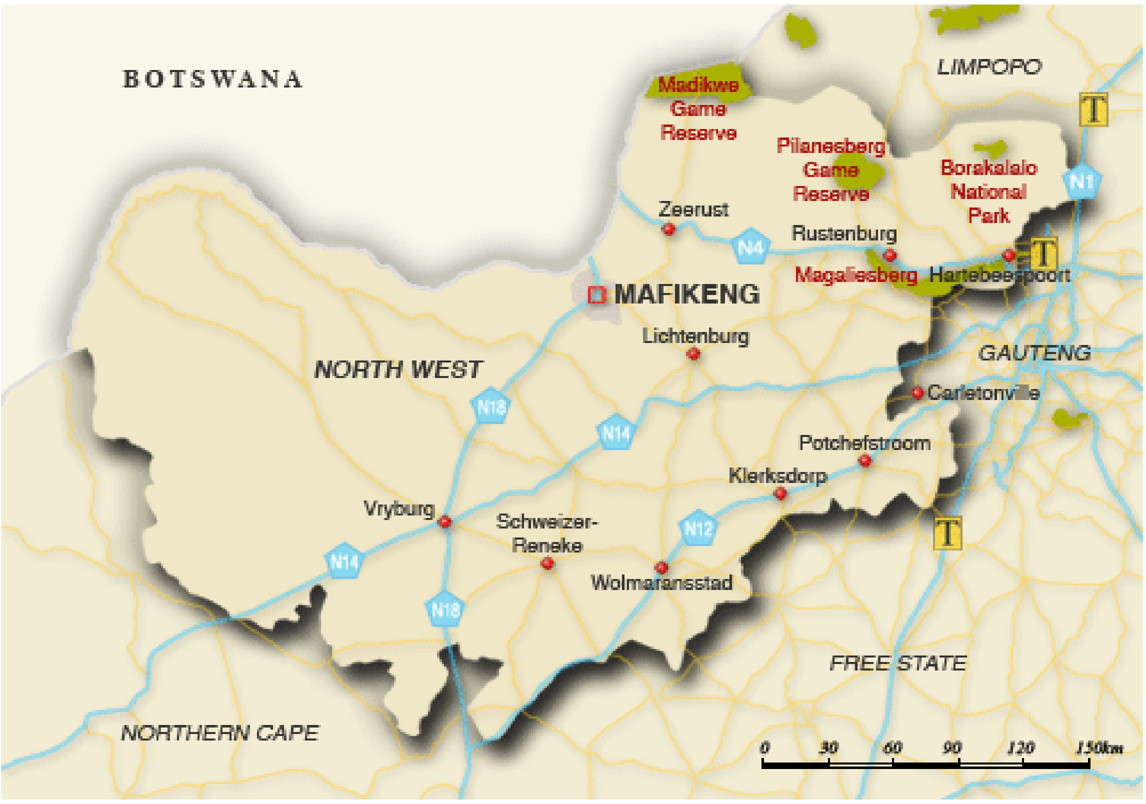

Figure 3. 3: Map of the North West province

Source: (Roomsforafria, 2019)

The North West Province is a highly productive agricultural region, accounting for roughly 20% of the country's arable land. It is responsible for 10.1 % of South Africa's agricultural production (Sihlobo, 2020). The North West Province has 4 920 farms (12.3%) and accounts for 11,5 % of the country's commercial agricultural land The Census of Comercial Agriclture, (2017). It generates R39,7 billion (11.9 %) of the country's total agricultural income and employs 57 758 people (7.6%) in commercial agriculture (Statistics South Africa, 2020).

Rustenburg and Brits are surrounded by fertile mixed-crop farming land. The province's eastern, wetter region is home to a combination of livestock and crop farming, while the semi-arid central and western regions are mostly livestock and wildlife farming. The Crocodile, Vaal, and Harts Rivers have three big irrigation schemes (The Census of Comercial Agriclture, 2017).

3.3. Conceptual framework

The conceptual framework for this study is portrayed in Figure 3.4 below. It is underpinned by the crucial role that knowledge, attitudes, perceptions and practices (KAPP) can play in determining farmers' behavioural intentions to accept an invention (Tiongco *et al.*, 2018). It also highlights the importance of comprehending the psychological, personality, and socioeconomic traits that can influence the smallholder farmers' KAPP and, as a result, smallholder farmers' willingness to accept an innovation. Shelby, (2014) also reported that farmers' mindsets and behaviours are examined through KAPP. It is however crucial to note that the vast majority of people desire a shift to a more cost efficient system (Rav-Marathe *et al.*, 2016).

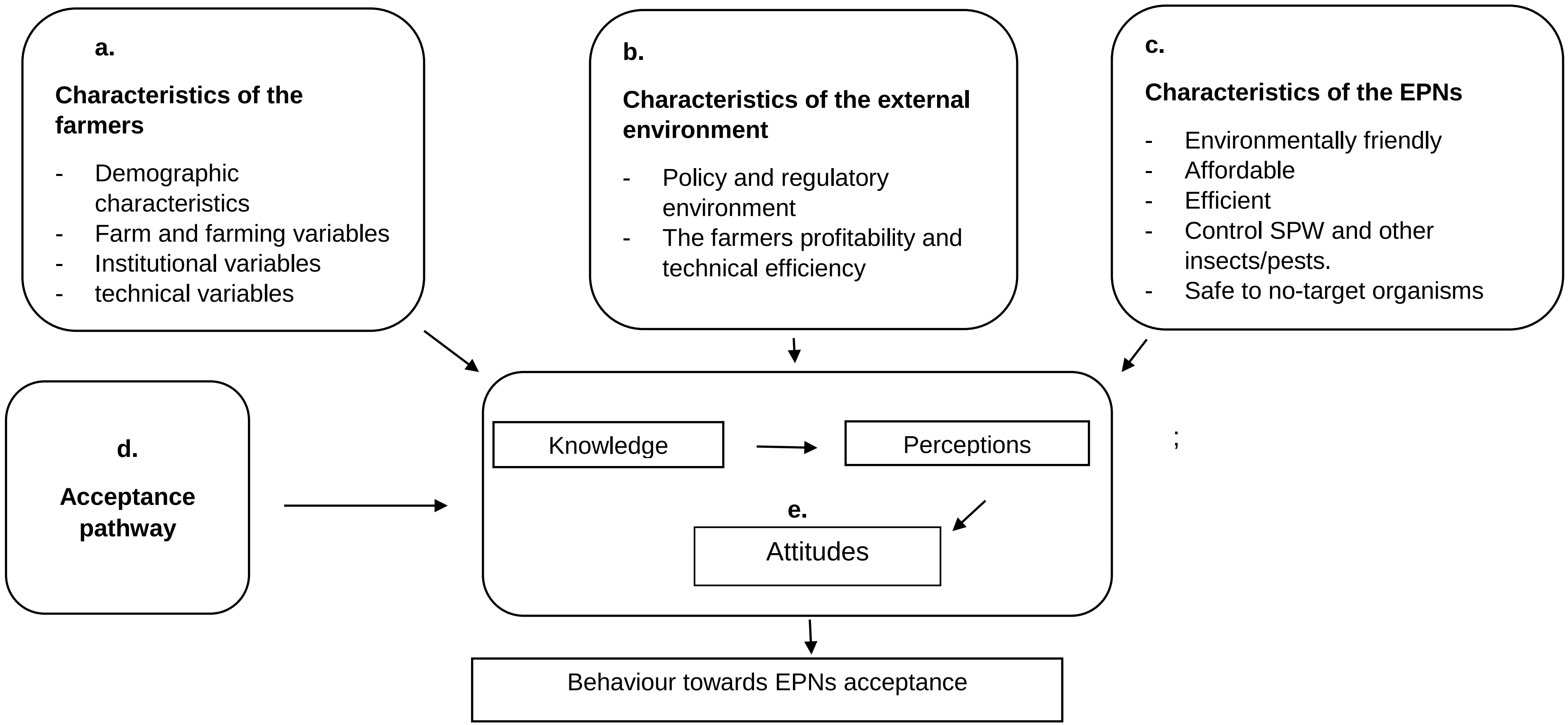

Figure 3. 4: Extrinsic variables (a–c) and intrinsic variables (d), as well as the influence of the intervening variable (e) in the decision-making process of agricultural innovation acceptance (EPNs), are depicted in this conceptual.

Source: (Rav-Marathe *et al.* 2016, modified by author)

3.4. Research design

According to Ong and Sui Pheng (2021), a research design is a strategy for choosing topics, research locations, and data collection procedures in order to address the research question(s) or hypotheses, in attempt to produce reliable results. The types of research are cohort study, which is a type of research in which a cross-section of a cohort is studied at predetermined time intervals. It's a type of panel research in which everyone in the group has something in common. The second type is a longitudinal study, in which the same variables are observed over a short or long time period. Lastly, the cross-sequential research design which combines longitudinal and cross-sectional research methods to compensate for some of the shortcomings of both. Finally, a cross-sectional study, which is common in social science, medical research, and biology, is common. This research method uses data from representative sample of the population at a specific point in time. The current study therefore employed a cross-sectional research design, using both the qualitative and quantitative methodological approaches which are explained in detail below.

3.4.1. Quantitative and qualitative approaches

The qualitative approach, according to Matthew and Huberman (1994), consists of words and observations. According to Neuman (1997), qualitative approaches take the shape of text, written words, phrases, or symbols that describe or present people's social activities and experiences. The qualitative information helped give underlying meanings regarding the knowledge, attitudes and practices towards sweet potato and the acceptability of EPNs by the sweet potato farmers in the study areas. Conversely, numbers were used in the quantitative approach.

3.4.2. Sampling techniques and sample size

There are two kinds of sampling techniques: probability sampling techniques and non-probability sampling techniques. Probability sampling is a sampling technique in which every member of the population has an equal chance of being chosen as a representative sample. Non-probability sampling is a method of sampling in which it is unknown which individual from the population will be chosen as a sample. The current study collected data from smallholder sweet potato farmers and used the non-probability sampling technique because the smallholder sweet potato farmers are not well documented and are dispersed (Sarstedt *et al.* 2018).

The study used three non-probability sampling techniques to select respondents for data collection: purposive, snowball, and census sampling methods. Since the numbers or figures of smallholder sweet potato farmers are not documented anywhere in the South African context; the study used a combination of purposive, census and snowball sampling methods in an attempt to include all smallholder sweet potato farmers in the three provinces, as well as referral by other farmers. As a result, a total of 119 smallholder sweet potato farmers were interviewed, where 22, 76 and 21 were from Gauteng, Limpopo and North West Provinces, respectively. Table 3.3 indicates a disaggregation of the smallholder farmers by province and villages.

3.4.2.1. Purposive sampling technique

The purposive sampling technique is a sampling strategy in which the researcher selects members of the population to take part in the study based on his or her own judgment (Etikan, 2016). It was used in this study because not all South African provinces are major sweet potato producing provinces, hence only sweet potato producing provinces were targeted. Consequently, Gauteng, Limpopo and North West Provinces as the major sweet potato producing provinces were considered (see Laurie *et al*., 2017).

In this study, the purposive sampling technique was used to purposively select smallholder sweet potato farmers in the Gauteng, Limpopo and North West provinces. These provinces were chosen because, according to Laurie *et al*. (2017), they are among the major sweet potato producing provinces. The study went on to use the census sampling method in an attempt to include all of the sweet potato farmers in the aforementioned provinces.

3.4.2.2. Census sampling method

The study went on to use the census sampling method in an attempt to include all of the sweet potato farmers in the aforementioned provinces. The census method is also known as a complete survey procedure because every sweet potato farmer is equally likely to be included in the sample selected in the fields of study (Willey *et al.*, 2017) . It is essentially an effort to have a study sample of all sweet potato farmers in the study areas. The census method was used because respondents' actual population was unknown and not documented. Hence, based on the available information from key informant and those working with these farmers (e.g. extension officers), this study attempted to exhaust the list of farmers provided to strengthen results of this study.

3.4.2.3. Snowball sampling technique

Lastly, and again circumventing the challenge of undocumented sweet potato farmers, the snowball sampling technique was also used to gain access to more sweet potato farmers from those farmers who were initially interviewed, with the farmer showing the data collectors where the next sweet potato producers are located. The snowball sampling technique is a method of recruitment in which participants are asked to assist researchers in locating additional potential subjects (Etikan, 2016). This was also found relevant to avoid biasness which may come from extension officers directing researchers to only areas they prefer the most.

Table 3.1: A disaggregation of the smallholder sweet potato farmers by Provinces and villages

Province	Region of province /Village	Number of smallholder sweet potato farmers.	Distribution of sweet potato farmers by percentage (%)
Gauteng	Bronkhorstspruit	15	**18.49%**
	Meyerton Ophir Estate	7	
Total		**22**	
Limpopo	Rust De Winter	1	**63.86%**
	Bela-Bela	2	
	Ga-Mafefe, Motsane village	25	
	Ga- Mampa	8	
	Ga-Moila	6	
	Ga-Kapa	8	
Total		**76**	
North West	Jericho	1	**17.65%**
	Rankotea	2	
	Kgabalatsane	2	
	Mmogaleskraal	1	
	Syferskuil	8	
	Transactie	5	
	Brits	2	
Total		**21**	
Gauteng, Limpopo and North West Total		**119**	**100%**

Source: (Author's compilation, 2022)

3.4.3. Data collection

Primary data were collected through the administration of a structured questionnaire (see Appendix 1). Primary data is data that has been generated by the researcher, surveys, interviews, experiments, and specifically designed for understanding and solving the research problem at hand (Dou and Toth, 2021). Aspects covered in the questionnaire included the smallholder sweet potato farmers' demographics (Section A), farm and farming variables (Section B), institutional information (Section C) and technical information (Section D). Other aspects in the questionnaire included the farmers' knowledge, attitudes, perceptions and practices (Section E), smallholder farmers' acceptability of EPNs (Section F) as well as the diversity, incidence and damage severity caused by the SPW in fields and in storage (Section G).

Data were collected with the assistance of the trained enumerators. Thus, two enumerators were trained in data collection prior to data collection (after ethical clearance was granted). Data were collected and handled in line with the ethical principles stipulated by the Turf loop Research Ethics Committee which provided the ethical clearance (see Appendix 3 for ethical clearance certificate). In order to safeguard the reliability and validity of the data collection instrument, the questionnaire was then piloted. During the pretesting, it was discovered that some of the questions were difficult for the enumerators to interpret for the farmers. Consequently, one of the corrective measures implemented following the piloting process was to modify some of the questions to clarify ambiguities for both the enumerators and the farmers. The data analysis methods framework is presented in Table 3.2 below.

Table 3.2: Framework for data analysis for specific objectives

Objective	**Data source**	**Method of analysis**
To determine the knowledge, attitudes, perceptions of smallholder sweet potato farmers regarding their currently adopted methods of controlling the SPW and their practices thereof.	Primary data	- Descriptive statistics (i.e. KAPP analysis and KAPP index score)
To determine the acceptability of EPNs bio-pesticides as control measures against SPW in selected areas of Gauteng, Limpopo and North West provinces	Primary data	- Descriptive statistics (i.e. Likert scale and Composite Index of Acceptability) -
To determine the profitability of smallholder sweet potato farmers and its determinants in selected areas of Gauteng, Limpopo and North West provinces.	Primary data	- Gross margin analysis - Multiple Linear Regression
To determine the technical efficiency of sweet potato production and its determinants in the selected areas of Gauteng, Limpopo and North West provinces.	Primary data	- Data envelopment analysis - Tobit regression analysis

Source: (Author's compilation, 2021)

3.5. Analytical tools

3.5.1. Descriptive statistics

Descriptive statistics are brief descriptive factors that summarize a specific data set, which can be a representation of the entire population or a sample of a population (Mishra *et al*., 2019). The quantitative data is described using measures of central tendency and dispersion (Sinyolo and Mudhara, 2018). The mean, median, and mode are examples of measures of central tendency, whereas standard deviation, variance, minimum and maximum variables, kurtosis, and skewness are examples of measures of variability (Mishra *et al.,* 2019). This study made use of the descriptive statistics to compute means, frequencies, percentages Likert scales, pie charts and graphs. The descriptive statistics will be used in this study to compute data for from the Likert scale, KAPP analysis and acceptability results which are explained in detail below.

3.5.1.1. Likert scale

The Likert scale is a psychometric scale that is commonly used in questionnaire-based research. It is the most commonly used approach to scaling responses in survey research, to the point where the term is frequently used interchangeably with rating scale, despite the fact that there are other types of rating scales (Beglar and Nemoto, 2014).

The Likert scale has been employed by a number of studies (e.g. Das *et al.,* 2019; Ntawuruhunga *et al.*, 2020) to scale the attitudes and perceptions of respondents regarding different subject matters. Moreover, the Likert scale has been widely employed in various studies across the world because it does not expect a simple yes/no response from the respondent, but rather allows for degrees of opinion, and even no opinion at all. As a result, quantitative data is obtained, implying that the data can be analysed relatively easily (Joshi *et al.*, 2015).

The Likert scale, however has flaws, one of which is acquiescence bias, which occurs when two people get the same value on the Likert scale despite selecting different options. Because respondents tend to agree with the statements shown, it is difficult to treat neutral opinions as “neither agree nor disagree” (Joshi *et al.*, 2015). To address the agreement bias in the current study, questions that could elicit a favourable response, such as binary response formats such as "Yes/No," were minimized. Subsequently, there were a number of 3- and 5-point Likert scale questions.

3.5.1.2. Determination of Knowledge, Attitude, Practices analysis

KAAP analysis is a quantitative method (predefined questions written in standardized questionnaires) for assessing quantitative and qualitative data. KAPP analysis uncovers misconceptions or misunderstandings that may be impediments to the actions the authors want to implement as well as potential hurdles to behaviour change (Cleland, 1973). KAPP analysis are easy to conduct, measurable, and easily interpretable. KAPP analysis are essential because they can yield data that can be used for a variety of purposes, including the following: to uncover knowledge gaps, cultural attitudes, and behavioural patterns that can assist design and implement treatments by identifying needs, issues, and impediments (Sheikhan, 2015). These types of analysis are a good way to assess the introduction of a new innovation or technologies in agricultural systems.

KAPP analysis are narrowly targeted evaluations that track changes in human knowledge, attitudes, and behaviours in response to a specified intervention (Das, *et al.*, 2019). In the 1950s, the KAPP research was initially employed in the disciplines of family planning, the adoption of innovations and population studies. Because KAPP investigations are extremely concentrated and limited in scope, they require fewer resources and are more cost-effective than other social research methodologies (Rani *et al.,* 2014) . KAPP studies reveal what people know about specific topics, how they feel, as well as react and each research is tailored to a unique situation and issue (Mutsotso *et al.*, 2011).

The appeal of KAPP analysis stems from features such as simple design, measurable data, clear presentation of results, generalizability of small sample results to a larger population, cross-cultural comparability, speed of deployment, and ease with which numerators may be trained (Houpis *et al*., 2015). Furthermore, KAPP research illuminates the social, cultural, and economic elements that can influence adoption to an innovation (Food and Agriculture Organisation, 2014). In addition, there is growing acknowledgment that boosting the acceptance of an invention among farmers worldwide is dependent on a thorough grasp of the socio-cultural and economic factors of the setting in which innovations are implemented

(Shekilah, 2015). Although such data has been acquired using many forms of cross-sectional surveys, the most common and frequent, utilized the knowledge, attitude, perception and practice (KAPP) framework.

Moreover, KAPP analysis and surveys in research enable the use of proper language and the logical framework of farmers to clarify definitions. All of these elements help with communication and are thus very important (Food and Agriculture Organisation, 2014). Consequently, the KAPP analysis was used in this study to determine the knowledge, attitudes, perceptions and practices of smallholder sweet potato farmers regarding the SPW infestations, EPNs acceptance. The concept KAPP, can be broken down into these components (Table 3.3):

- What the respondents know about it (K) – this has been solicited through administration of questions E1 to E8 in the survey tool.
- Respondents reactions and behaviour (A)
- How the respondents feel about it (P)
- What the respondents do about it (P)

Several authors (e.g. Andrade *et al*., 2020; Mutsotso *et al*., 2011; Rani *et al*., 2014; Wang *et al*., 2015;) have used KAPP analysis and found that, despite the limitations of each study, the KAPP analysis is still a useful tool for gathering individuals' knowledge, attitudes, perceptions, and practices about a particular topic of interest. Furthermore, the KAPP analysis provides a detailed breakdown of what a person knows, believes, and does about a specific topic of interest. Table 3.4 below presents the KAPP framework that this current study adopted.

Table 3.3: KAPP framework adopted by the study.

Component	Definition	Attributes	Unit of Measure	Sources
Knowledge	The knowledge possessed by the farmers refers to the understanding of the measures of controlling the SPW infestation.	- Farmers' knowledge about the SPW infestation and its effects on production. - Indigenous Knowledge about control of SPW. - Knowledge about the harm caused by chemical pesticides - Knowledge about the potential of EPNs as a biocontrol agent. - Farmers' knowledge about other SPW control measures besides the ones they have currently adopted.	**3-point Likert Scale.** Were scored as follows: t (1 = do not know; 2 = false; 3 = true), then scores were combined. For ease of analysis, for each question, a correct response (true) was awarded one while a wrong response (false) or "don't know", a zero, point. Where *1 – 1.5 = Not knowledgeable* *1.6 – 3 = Knowledgeable*	(Friedman and Shepeard, 2007); (Ong and Sui Pheng, 2021)
Attitudes	Attitude refers to the feeling towards the methods used for the control and management of the SPW as well as any preconceived ideas the farmers possess	- Farmers' assertiveness about new control method against SPW. - Farmers' assertiveness about their current control measures for SPW. - Farmers' assertiveness about the potential of new control measures as a SPW control measure. - Farmers' attitudes towards indigenous practises of controlling SPW.	**5-point Likert scale.** Were scored as follows: 5= strongly agree, 4= agree, 3= neutral, 2= disagree and 1= strongly disagree. Those who agree (4) or strongly agree (5) to the statements were considered to have a positive attitude (equated to 1) while the rest were considered to have a negative attitude (equated to 0).	(Friedman and Shepeard, 2007)
Perceptions	Perception refers to how to farmers contemplate to the potential of adoption of EPNs as a biocontrol agent against SPW	- Farmers' perceptions about the damage caused by SPW and its effects on SP production. - Farmers' perceptions towards the adoption of new innovations as a control method against SPW. - Farmers' perceptions about the hazardous chemicals generally used for the control of SPW. - Farmers' perceptions about the effectiveness of their current methods of managing SPW.	**5-point Likert scale.** Were scored as follows: 5= strongly agree, 4= agree, 3= neutral, 2= disagree and 1= strongly disagree. Those who agree (4) or strongly agree (5) to the statements were considered to have a good perception (equated to 1) while the rest were considered to have a bad perception (equated to 0).	(Friedman and Shepeard, 2007)
Practices	practices refers to the ways in which they utilize their knowledge and attitude for the management of the weevil	- The indigenous methods/practices and chemicals used by sweet potato farmers to manage the infestation of SPW. - Chemical pesticides the farmers' use to manage SPW. - SPW control measures that have been recommended by extension officers to the farmers. - Pest resistant cultivars that farmers plant to manage the infestation of SPW	Practice was measured using 8-item binary yes/no questions. Respondents were awarded one point for each practice mentioned, and zero otherwise.	(Friedman and Shepeard, 2007); (Ong and Sui Pheng, 2021)

Source: (Author's compilation, 2021)

3.5.1.3. Determination of acceptability of EPNs

Acceptability, in the context of this study, refers to how well the EPNs will be received and the extent to which they will be accepted by the smallholder sweet potato farmers (Zahedi *et al.*, 2020). Through the use of the Likert scale approach, an acceptability index score was computed to determine acceptability of EPNs as bio-pesticides against the SPW.

Acceptability index score measures the willingness of smallholder sweet potato farmers to accept EPNs as bio-control measures. The Composite Index of Acceptability (CIA) was] then used in to determine the acceptability score of the smallholder sweet potato farmers of the EPNs as bio-control measures

3.5.1.4. Composite Index of Acceptance (CIA)

The Composite Index was developed by Morris (1978); modified by Barungi and Maona (2011) as the CIA and was used to assess the acceptability of EPNs in the current study. This will aid in understanding the differences in EPN acceptance by smallholder sweet potato farmers. The following is how the CIA is calculated:

$$CIA = \frac{\sum_{\mathrm{t=1}}^{\mathrm{t=n}} (T\mathrm{a}/T)}{N} \qquad 9$$

Where: Where $T\mathrm{a}$ represents the maximum acceptability score derived using the Likert scale, T the total number of questions asked, N the sample size, and $T\mathrm{a}/T$ the index of EPN acceptance for a farm (CIA).

Rule of thumb for the CIA:

Farmers with a CIA between 0-0.49 were regarded as “not willing to accept” and those with the CIA of 0.50-1 were regarded as those “willing to accept”. The CIA scores were then regressed in the Tobit regression to determine the drivers of acceptability of EPNs amongst smallholder sweet potato farmers. Farmers with a CIA between 0-0.49 were regarded as “not willing to accept EPNs as bio-control measures and those with a CIA of 0.50-1 were regarded as willing to accept the EPNs as bio-control measures.

3.5.2. Gross margin analysis

According to Fani *et al.* (2015), gross margin, which excludes fixed costs, is a crucial financial measure used to evaluate profitability. It is the difference between the money obtained from produce sales and the variable costs of making that produce (Chirigo, 2014). Ogunleye *et al.* (2017) stated that gross margin budgets are meant to provide a guide to the relative profitability of similar firms as well as an indication of management operations in different firms. They also give a simple approach for comparing the performance of firms with almost equal capital and labour requirements (Oramas, 2016). The gross margin is calculated by deducting the cost of goods sold from the selling price of a product (Oramas, 2016).This methodology takes into account costs that are directly proportional to the kind and scale of production (Douglas *et al.,* 2014).

The advantage of the gross margin analysis in estimating profitability is the cost efficiency, financial health of the company, period review of direct costs of the company (Masegela, 2019). Ogunmodede and Awotide (2020) stated that Gross Margin analysis can be easily estimated, and it provides the basis on which other profit ratios can be calculated. For these reasons, various researchers (e.g. Douglas *et al.*, 2014; Sadiq, 2013) have applied the Gross Margin analysis to determine profitability in smallholder farming. According to Sanusi *et al*. (2010), the gross margin analysis is computed as follows:

$$GM = TR – TVC \qquad 10$$

Where: GM = Gross Margin

TR =Total Revenue, which is given by P_s x Q_s

Where P_s is the price of sweet potato and Q_s is the quantity of sweet potato

TVC = Total Variable Costs

The TVC were constituted by all the costs related to the produced good (sweet potato) which in the context of this study were costs of labour, fertilizer and chemical costs, costs of slips and machinery costs.

3.5.3. Data Envelopment Analysis (DEA)

Many methods developed as efficiency estimates have been classified as parametric and non-parametric approaches (Cooper *et al.*, 2011). Examples of these techniques are the Stochastic Frontier and the DEA. Stochastic frontier models are useful for analysing technical inefficiency in the context of production functions. Production units are assumed to use a common technology and reach the frontier when they produce the greatest amount of output for a given set of inputs. In contrast to Stochastic Frontier Analysis, most current efficiency studies favour the use of DEA because assumptions about the functional form and distribution of errors are not required. Unlike the Stochastic Frontier, DEA has several advantages, including the ability to deal with multiple outputs and inputs without requiring a previous specific functional form at the productive boundary, and the ability to identify the best practice for every farm. As such, this study used the DEA model to estimate the Technical Efficiency of the smallholder sweet potato farmers.

The DEA is a non-parametric mathematical method and linear programming (LP) methodology for determining relative efficiency among a group of decision-making units (DMUs) that are considered to be homogenous and use numerous input-outputs (Charnes *et al.* 1978; Sanusi *et al.,* 2010). The DEA was invented by Farrell (1957), and further developed by Charnes (1978) and modified by Banker *et al*. (1984). Farrell (1957) pioneered the concept of comparative efficiency, which allows one DMU's efficiency to be compared to that of another DMU in the same group. The assumption of DEA consists of cost returns to scale (CRS) and variable returns to scale (VRS) at optimal scale (Steiner *et al.,* 1968; Bulagi *et al*., 2019). Unless factors such as funding constraints and competition among other factors are present, companies cannot operate to the optimum scale (Top *et al.,* 2020).

The current study used the input-output oriented DEA because input comparability is greater than that of the output in this study (Adams *et al.,* 2020). Moreover, the DEA was adopted because the fundamental technology does not require or impose a prior parametric limit. The first step in the two-step technique to efficiency analysis is to calculate the scores of efficiency (Alemu, 2016), as specified below:

$$TE = \frac{\min \Theta_n}{\lambda_i \quad \Theta_i} \qquad 11$$

Subject to:

$$\sum_{i=1}^{n} X_{ij}\lambda_{j-\Theta_n\, X_{nj}} \leq O \qquad 12$$

$$\sum_{i=1}^{n} X_{ij}\lambda_{ik-\Theta_n x_{nk}} \geq O \qquad 13$$

$$\sum_{i=1}^{n} \lambda_{in} = 1 \qquad 14$$

$$\lambda_j \geq 0 \quad 7 \qquad 15$$

Where i = farmer i to farmer n

k = input 1 to input k

X_{ij} = the amount of input (j) used by farmer i

X_{nj} = the amount of inputs used by farmer n

λ_{ik} = the amount of outputs(k) produced by farmer i

λ_{in} = the amount of output (λ) produced by farmer n

On solving the model separately for each DMU in the sample, for efficiency, DMUs (sweet potato farms) whose efficiency are 0 - 0.49 will be considered technically inefficient and those that are 0.50 - 1 will be considered technically efficient (Sanusi *et al.,* 2010). The constant $\sum_{i=1}^{n} \lambda_i = 1$ ensures that the technical efficiency is computed under the Variable Returns to Scale (Charnes *et al.*, 1978).

3.5.4. Multiple Linear Regression Model

The Multiple Linear Regression Model is a statistical method for examining the association between one or more independent variables and a single continuous variable (Oramas, 2016). According to Samuel, (2019) a Multiple Linear Regression Model, amongst other methodologies, best explains the relationship between a continuous dependent variable and independent factors. The Multiple Linear Regression Model can detect outliers or anomalies, as well as estimate the relative importance of one or more predictor variables in determining the criteria value (Dospinescu *et al.*, 2019).

This technique was also used by Dospinescu *et al.* (2019) and Kučerová (2017) who employed a Multiple Regression Model to demonstrate the effects of age, gender, marital status, education level, household size, and distance on the relative profitability of smallholder sweet potato farming. Consequently, the Multiple Linear Regression Model was adopted and used in this study to determine the factors influencing sweet potato farmers' profitability.

The multiple linear regression model in this study is given by:

$$Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots\ldots \beta_{21} X_{21} + U_t \qquad 16$$

Where, Y_i = profitability (gross margins in Rand),

β_0 = Intercept of the model

β_1 to β_{21} = regression coefficients to be estimated.

X_1 to X_{21} = explanatory variables. These include; farmers' demographic, farm and farming variables, institutional and technical variables (Table 3.3).

Error term (U_t), which captures other factors that might have been excluded from the variables such as external factors that include extreme weather conditions and other unforeseen circumstances that might also had an effect on the dependant variable (profitability). On that note, Table 3.3 below describes the dependant and the independent variables, the units of measure and the expected signs.

Table 3.4: Variables used in the Multiple Linear Regression Model, their description, unit of measures and expected signs.

Variables	Description	Unit of measure	Expected signs
Dependent variable			
Profitability	Gross Margin	Rand	
Independent variables			
Demographic variables			
X_1: Age	Age of the farmer	Years	-
$X_{2:}$ Gender	1 = male and 0 = otherwise	Dummy	+
X_3:Years spent in school	Number of years spent in school	Years	+
X_4: Marital status	1 = married and 0 = otherwise (categories: single, widowed, divorced or separated)	Dummy	-
X_5: Household size	Number of people in the household	Number	-
$X_{6:}$ On farm income	Income generated from the farm's output	Rand	+
$X_{7:}$ Employment status	1 = formally employment and 0 = otherwise	Dummy	+
Farm & farming variables			
X_8: Output per production cycle	Sweet potato output produced per production cycle	Kilograms (kg)	+
X_9: Farm size	The size of the farm	Hectares	+
$X_{10:}$ Price of cuttings	The price of sweet potato cuttings/slips	Rand	-
X_{10}: Farming experience	Years spent in farming	Years	+
X_{11}: Land ownership	1 = farmer owns land 0 = otherwise	Dummy	-
X_{12}: Fertilizer and chemical use	1 = uses fertilizer and chemicals 0 = does not use fertilizer and chemical	Dummy	-
X_{13} : Labour Hire	1 = Hires labour 0 = Does not hire labour	Dummy	-
Institutional variables			
X_{14}: Access to extension services	1 = the farmer has access to extension services and 0 = otherwise	Dummy	+
X_{15}: Access to marketing agencies	1 = has access and 0 = has no access	Dummy	+
X_{16}: Distance to the market	Distance from the farm to the market	Kilometres	+
X_{17}: Marketing agency	1 = has access to a marketing agency and 0 = otherwise	Dummy	+
X_{18}: Access to credit	1 = has access and 0 =otherwise	Dummy	
$X_{19:}$ Participation in entrepreneurial training	1 = participates and 0 = otherwise	Dummy	+
Technical variables			
$X_{20:}$ Access to an irrigation system	1 = has access and 0 = otherwise	Dummy	+
X_{21}: Access to a tractor	1 = has access and 0 = otherwise	Dummy	+

Source: (Author's compilation, 2021)

3.5.5. Tobit regression model

The Tobit regression model was used to regress exogenous variables on predicted efficiency to determine the factors that influence technical efficiency (Alemu, 2016). Tobit Model is a regression model that describes the relationship between a continuous dependent variable y_i censored (or truncated in an even wider sense) and a vector with independent parametersX_i. Tobin (1958) initially proposed the model for modelling non-negative continuous variables with several observations of value 0. Tobit models have been used in a wide range of issues (Smith and Brame, 2003).

Several studies (e.g. Adams *et al.,* 2016; Alemu, 2016; Chebil, 2012; Weldegiorgis *et al.,* 2018) have used the Tobit regression model to determine the determinants of technical efficiency and found that, in general, the Tobit regression model is a widely recommended model for determining the relationship between technical efficiency and other factors (demographic, farming, institutional and technical factors). Consequently, the Tobit regression model was used to determine the determinants of technical efficiency in this study. In this analysis, a two-limit Tobit Model was used, since the scores were 0 to 1 (Maddala, 1993). The regression of Tobit can be mathematically written as follows:

$$y_{te} = \beta_i(X_i - X_n) + U_i \qquad 17$$

Where,

y_{te} = is the dependent variable, which, in this context are the technical efficiency scores.

$(X_i - X_n)$ = vector of explanatory variables (Table 3.4), β_i is a vector of unknown parameters and U_i is a disturbance term, which in the context of this study refers to unforeseen factors such as weather, impairment of output by livestock, theft of output produced. Ahmad and Bravo-Ureta (1995) further mathematically express the determinants of level of technical efficiency as:

$$y_{te} = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \ldots\ldots\ldots\ldots\ldots B_{22}X_{22} + U_i \qquad 18$$

Table 3.5: Tobit Regression Model: Determinants

Variables	Description	Unit of measure	Expected signs
Dependent variable			
Technical Efficiency (y_{te})	1 = farmer is technically efficient and 0=otherwise	Variable Returns to Scale	
Independent variables			
Demographic variables			
X_1: Age	Age of the farmer	Years	-
X_2: Education level	Years spent in school	Years	+
X_3: Gender	1 = male and 0 = otherwise	Dummy	
X_4: Marital status	1 = married and 0 = otherwise (categories = widowed, divorced, separated or single)	Dummy	-
X_5: Household size	The number of people in the household	Number	-
X_6: On-farm income	Income generated from the farm's output	Rand	+
X_7: Employment status	1 = formally employment and 0= otherwise	Dummy	+
Farm & farming variables			
X_8:Output	Output produced per production cycle	Kilograms (kg)	+
X_9: Farm size	Size of the farm	Hectares	+
X_{10}: Farming experience	Farmers' experience in producing sweet potato	Years	+
X_{11}: Gross margins	Farm profitability	Rand	+
X_{12}: Land ownership	1 = own land and 0 = otherwise	Dummy	-
X_{13}: Fertilizer and chemical use	1 = uses fertilizer and chemicals and 0 = Does not use fertilizer and chemical	Dummy	+
X_{14}: Cost of cuttings	Cost of sweet potato cuttings/ha	Rand	-
	Institutional variables		
X_{16}: Access to extension services	1 = if the farmer has access to extension services and 0 = otherwise	Dummy	+
X_{16}: Access to markets	1 = access to markets and 0 = otherwise	Dummy	+
X_{17}: Distance to the market	The distance from the farm to the market	Kilometres	+
X_{18}: Marketing agency	1 = farmer has access to a marketing agency and 0 = otherwise	Dummy	+

X_{19}: Participation in entrepreneurial training	1 = participates and 0 = otherwise	Dummy	+
X_{20}: Access to credit	1 = if has access and 0 = otherwise	Dummy	+
Technical variables			
X_{21}: Access to an irrigation system	1 = has access and 0 = otherwise	Dummy	+
X_{22}: Access to a tractor and other machinery	1=has access and 0=otherwise	Dummy	+

Source: (Author's compilation)

3.6. Chapter summary

This chapter starts off by describing the study areas and its economic activities, it further explains the study's research design in detail then the study's research approaches. The chapter further details the sample size and how it was attained, it then discusses the data collection process and the framework for data analysis for each specific objective. Furthermore, the chapter discussed the study's analytical too which are descriptive statistics, the non-parametric (the Gross Margin analysis) and the parametric approaches (the Multiple Linear regression and Tobit regression Model).

CHAPTER FOUR

DESCRIPTIVE STATISTICS RESULTS

4.1. Introduction

In this chapter, descriptive statistics on the technical, institutional, farm, and demographic factors affecting sweet potato farmers is presented. The attitudes and perceptions of farmers toward the current SPW control methods and their familiarity with the sweet potato weevil (SPW) were explored in this chapter. Additionally, how farmers have responded to the SPW invasion (control measures and their acceptability of EPNs were also discussed as well as the descriptive analysis on the economic viability and technical effectiveness of smallholder sweet potato production.

4.2. Socio-economic characteristics results

Socio-economics results from the descriptive statistics are presented in this section.

Table 4.1: Age and household size of the smallholder sweet potato farmers

N= 119				
Variable	**Mean**	**Standard deviation**	**Minimum**	**Maximum**
Age	56	13.36	26	81
Household size	5	2.76	1	15

Source: Field survey, (2021)

4.2.1. Age

From Table 4.1 above, the oldest farmer was 81 years old and the youngest farmer 26 years old, with an average age of 56. These results suggest that the majority of farmers were elderly. The results of Batrancea *et al*. (2021) are in line with those of this study, indicating that young people believe that sweet potato farming is an activity reserved for the old, who tend to be pleased with traditional methods and to be wary of adopting new ones. Additionally, as they age, farmers are less eager to accept new farming methods and are more risk-averse. For example, Gómez-Limón *et al*. (2003) and Tanaka *et al*. (2010) find that risk aversion increases with age.

On the other hand, farmers may be more receptive to the idea of embracing innovation as a result of their prior exposure to doing so and the advantages that come along with it. According to Gale (1994), farmers who have been operating for longer periods are frequently less resource-constrained and may thus have greater abilities to invest in cutting-edge technologies.

4.2.2. Household size

From Table 4.1 above, the average household size was found to be 5 and the smallest household size is one and the largest is fifteen. The implication that this finding has on acceptability of innovations is that they may be willing to accept EPNs in their farms, as they could assist one another in making sound decisions that could benefit their production in every way. However, this could also mean that the farmers are less likely to accept the EPNs because many family members may hold opposing viewpoints, which may lead to the farmers refusing to accept the EPNs altogether as a result of the uncertainty (Meijer *et al*., 2015). This result is consistent with research by De Giusti *et al*. (2019), which found that smallholder farmers have larger family sizes (larger than 7 on average). Mkuhlani *et al*. (2020), on the other hand, discovered that smallholder farmers typically have very small family sizes (usually three at most), and this is because they are typically elderly (pensioners) and their children are married and have moved to the urban areas to start their own families.

Table 4.2: Categorical demographic variables results

Variable	Measurement	Frequency (%)
Gender	Female	68.1%
	Male	31.9%
Highest education attained	No formal education	20.2%
	Primary education	26.9%
	Secondary education	37.8%
	Tertiary education	15.1%
Sources of income	On farm	31.1%
	Small, Medium and Micro Enterprises	5.9%
	Pension	10.1%
	Social grant	41.2%
	Remittances	2.5%
	Other (helpers, waiters and temporary office helper)	9.2%

Marital status	Not Married	28.6%
	Married	71.4%

Source: (Field survey, 2021)

4.2.3. Gender of the respondent

Gender equality in smallholder farming is a prerequisite for a just and sustainable world. It also helps with improved livelihoods and food security. The need for gender-transformative change that pervades social systems—from deeply ingrained attitudes to social structures and processes to the closing of visible gaps for instrumental purposes—is obvious (Manlosa *et al.*, 2019). The study's findings revealed that close to 68% of respondents were females, while almost 32% were males. These results are in line with those of Rao *et al*. (2020), who found that women are more likely to engage in smallholder farming because it is typically practiced in rural areas while the men are in urban areas in search of employment. Moreover, these results are similar to what was observed during the pre-testing of the questionnaire, majority of the respondents were female.

Moreover, Shikuku *et al*. (2019) reported that, women are more likely to engage in subsistence crop farming, such as the production of sweet potatoes, to ensure household food security production while their men are out in the cities looking for work. However, the results of this study and those of Rao *et al*. (2020) contrast with Iradukunda *et al*. (2019)'s findings, who found that men are more likely to engage in smallholder farming since the activity is often regarded as labour-intensive and because men are seen as physically fit for such work.

Males may be more likely than females to accept innovations (Gebre, 2019). This is due to the fact that males are more risk averse than females and may be willing to take the risk of trying new things for the sake of increasing their farm's productivity. This may also be related to the fact that there is gender inequality in the government's extension services because men are typically given priority. As a result, men may have greater access to information about innovations than women, making them more likely to adopt them (Staudt, 2019). Furthermore, due to resource restrictions and gender bias in extension service delivery, female farmers are less likely to accept innovations (Langyintuo and Mungoma, 2008). When it comes to the acceptance and transfer of technology, women are frequently overlooked and this is further supported by cultural institutions that encourage women to stay at home and care for their families while men look for work. According to Bazezew (2015), male farmers have easier access to information than female-headed households.

4.2.4. Farmers’ educational backgrounds

This study's findings on the educational backgrounds of the farmers’ shows that about 20% of respondents had no formal education, about 27% had completed primary education, about 38% had completed high school, and about 15% had completed tertiary education. However, this is in contrast to Boza *et al*. (2020) who indicates that smallholder farmers, in general, have no educational background at all with an implication on their literacy capabilities. These results show that the majority of farmers had secondary education. In terms, this may imply that these farmers can understand and interpret new information more easily and fast with regards to sweet potato production and have increased production as a result, moreover, they could embrace EPN innovation more readily than those with no educational backgrounds (Ofori *et al*., 2020). According to Carrer *et al*. (2017) and Ullah *et al.* (2018), educated farmers are more likely to accept innovations compared to those without education because higher education levels may improve farmers' capacity for information processing, decision-making, and acquisition of new management technologies.

4.2.5. Source of income

The findings show that the largest source of income was pensions (about 41%) followed by on-farm income (close to 31%) and pensions (approximately 10 %). The analysis of age shows that; the sampled farmers are older with an average age of 56 years. This could explain why majority depend on social grants and pensions in addition to farming. Other sources of income included small, medium, and micro enterprises (5.9%), piece-rate employees such helpers, waiters, and temporary office helpers (9.2%) and remittances (2.5%). These findings are consistent with those of Widi (2020), whose study revealed that the majority of smallholder farmers rely primarily on social grants, followed by farm income, as the majority of them are too old (also seen in this study’s results) to work in the corporate sector

Due to the high percentage of their income that comes from farming, farmers may, in some cases, be able to afford the inputs needed to increase their yield of sweet potatoes. This could imply that since they have the resources to pay for inputs, they will also be able to accept innovations. External off-farm income sources are also significant since they allow the farmer to engage in agricultural practices that could increase his subsistence income (Bannor *et al*., 2020). Off-farm income may even be used to finance the acquisition of a fixed-investment type of innovation, helping to overcome a working capital shortage (Feder,*et al*., 2015).

4.2.6. Farmers' marital status

The findings indicate that most respondents were married (approximately 71%). Farmers who are married tend to be more stable in their farming endeavours than farmers who are single, widowed, divorced, or separated and thus help each other in decision-making towards sweet potato farming. In support of these results is Widi (2020) who asserted that sweet potato production is more appealing to married couples who are engaged in various social and economic commitments such as ensuring food availability for family members. These findings may also suggest that married farmers may be open to sharing the benefits of collaborative decisions they make as a pair in order to try out innovations that may enhance their farming activities. This finding could also be attributed to the observation during the pre-testing of the questionnaire as majority of the respondents were also married.

4.2.7. Employment status

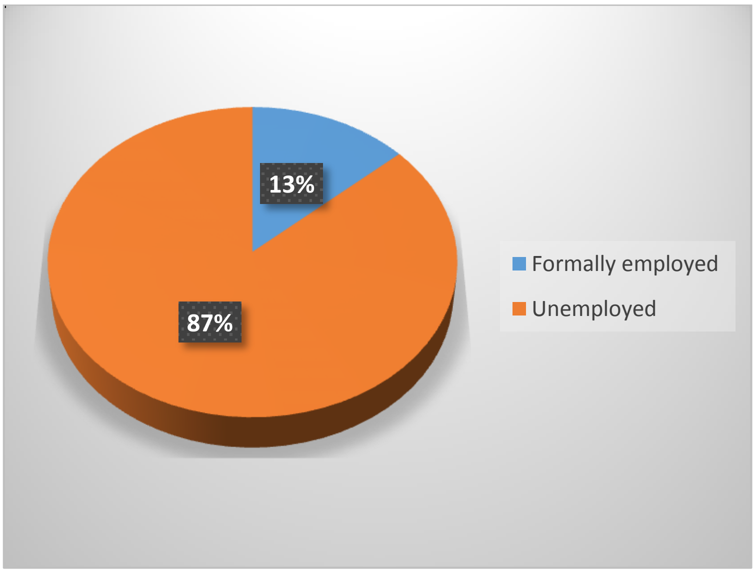

Figure 4.1: Smallholder sweet potato farmers' employment status

Source: (Field Survey, 2021)

Figure 4.1 indicates that majority of the smallholder sweet potato farmers in the study areas are unemployed (86%), and only a minority was formally employed (13%). This finding is consistent with those of several authors, including Falola and Achem (2017), Okoye *et al.* (2000), and Olagunju *et al*. (2013), whose studies also discovered that smallholder farmers are typically elderly and retired, making them formally unemployed as majority of them have been laid off work due to their advanced age. Due to their absence from the day-to-day operations of the farm, unemployed farmers may not be productive in terms of profits and efficiency (Okoye *et al*., 2020). As the income from off-farm employment eases cash liquidity restrictions on farm households, enabling them to possibly better afford improved seeds and necessary inputs, these farmers' likelihood of accepting innovations may be higher (Suvedi *et al*., 2017).

4.3. Farm and farming variables

The descriptive statistics on farms and farming variables, which are elements directly influencing agricultural output, are presented in this subsection. These are listed in Table 4.3 below and include years of experience in both general farming and sweet potato farming, the size of the farm dedicated to sweet potato production, and land ownership issues.

Table 4.3: Farm and farming variables

N = 119				
Variable	**Minimum**	**Mean**	**Maximum**	**Standard deviation**
Years in farming	1	11	47	10.92
Years in sweet potato farming	1	7	40	8.53
Farm size allocated to sweet potato	0.2	1.16	5	0.93

Source: (Field survey, 2021)

4.3.1. Years in farming

In this study, the number of years a farmer has been farming is used as a proxy for farming experience. From to the analysis, farmers had an average of 11 years of experience in general farming, with an average of 7 years of experience producing sweet potatoes. These results imply that farmers have more knowledge about farming in general. These results are in line with those of Rugube *et al*. (2019), who found that most smallholder farmers have experience with farms and farming activities because they were typically born into farming families and either joined the family business or simply decided to look for jobs in the farms at a young age to support their low-income families. Most of these farmers do not have educational backgrounds. The farming experience can be a major influence towards willingness to accept EPN as farmers are able to make sound decisions towards decisions that help them control pests and diseases. However, the more farming experience could also suggest farmers may be reluctant to accept the EPN innovations as they would rather stick to their traditional methods of controlling the SPW.

4.3.2. Farm size allocated to sweet potato production

The results show that farmers were using an average land size of 1.2ha for sweet potato production, with a minimum of 0.2ha and a maximum 5ha, suggesting that farmers were producing sweet potato on a small scale. Generally, smallholder farmers produce on very small lands and usually use their backyards because they frequently lack inputs, capacity, and resources to produce on large scales. These findings suggest that farmers should be willing to accept the EPN innovations to maximize their sweet potato production, especially given that they utilise small pieces of land on average.

4.3.3. Status of land ownership

The status of land ownership results is presented in Table 4.4 below. Land is a valuable resource in agriculture, and differences in land ownership have a greater impact on agricultural activities, e.g. income generation. Ahmed *et al.* (2018) argued persuasively that smallholder farmers' ownership of land improves their welfare, productivity, equality, and empowerment. Land ownership can help to protect cash flows over time and facilitate asset liquidation due to transferrable land rights, as well as improve access to resources like credit (Feder and Nishio, 1998). However, in smallholder agriculture, insufficient land tenure security and free rider issues associated with communal land ownership are widely regarded as barriers to agricultural development.

Table 4.4: Smallholder sweet potato farmers' type of land ownership

Land ownership	**Yes**	**No**
Own land	78%	22%
And for those who owned land (78%), the nature of ownership is illustrated below:		
Type of ownership	**Frequency**	**(%)**

Leasehold	10	8.4
Rented	10	8.4
Freehold	7	5.9
Bought	27	22.7
Inherited	44	37
Permission to occupy (PTO)	15	12.6
Other (backyard farms)	6	5
Total	**119**	**100**

Source: (Field survey, 2021)

In this study, "land ownership" refers to the condition or fact of possessing sole legal authority over the land the respondents occupy (sweet potato farmer). The study's findings showed that 78% of farmers owned their land, while 22 percent did not. From this perspective, it appears that the respondents exclusively own this land because the majority of farmers (37%) inherited land while close to 22 % indicated they purchased the land. The bulk of farmers reside in rural locations where acquiring land is not complicated or difficult, which is why such a high percentage of farmers were landowners (Biłozor, 2019). Given that the majority of these farmers received their land through inheritance, this could have a favourable effect on how well-received innovations are among the farmers. This is due to the fact that having exclusive land ownership can help farmers decide whether to make investments in their land as well as whether to accept innovations like EPNs to maximize their productivity, all because the land is theirs (Boahene *et al*., 2019).

These results could imply that the smallholder sweet potato farmers could be more than willing to make sound decisions regarding sweet potato activities on their farms, as well as accepting the EPN innovations as they can make investment decisions on those pieces of land as owning land encourages the acceptance of agricultural technology (Carte *et al*., 2019). However, Widi (2020) claimed that smallholder farmers are less likely to own the land they occupy because most of them cannot afford to purchase the property in order to have full ownership. In this case, the tenants may be excluded from future technology-induced benefits due to the risk of eviction if they do not own their land, which is usually reflected in land rentals (Zeng *et al*., 2018)

4.3.4. Reasons for producing sweet potato

Table 4.5: Reasons for producing sweet potatoes

N=119		
Reason	**Frequency**	**Percentage**
Income generation	52	43.7
Employment	20	16.8
Home consumption	47	39.5

Source: (Field survey, 2021)

The findings show that 43.7 percent of farmers produced for income generation and 16.8 percent produced for employment, which may have included farm workers hired to perform daily farming tasks. The results also show that 39.5 percent of the food was produced for domestic consumption, which is supported by Aliber and Hart's (2019) who estimate that about 3 million small-scale farmers in South Africa primarily grow food for domestic consumption.

4.4. Access to institutional services

Institutional variables results are indicated in the table below. In this study, these variables include access to markets, access to credit, access to extension services and participation in entrepreneurial training. The link between institutional variables and innovation acceptance is detailed in the study's' theoretical framework (See Chapter 2)

Table 4.6: Access to institutional services

Institutional service	Yes	No
Access to market	50%	50%
Access to credit	18%	82%
Participation in entrepreneurial training	21%	79%

Source: (Field survey, 2021)

4.4.1. Access to market

Access to markets refers to these farmers' ability to capitalize on available market opportunities. This could be a profit incentive for farmers, encouraging them to increase production and thus contribute to household income and food security

(Rueda *et al.*, 2018). The findings on table 4.6 above show that 50% of the respondents had access to markets. These findings may indicate that these farmers are productive in terms of their production of sweet potatoes because they have a market where they can sell their goods and thereby turn a profit (Ahmad *et al.,* 2014). Additionally, having access to markets could give them advantages like information sharing channels, opportunities to build social capital through the exchange of production and innovation-related experiences, etc. This could make it easier for them to accept new technologies as they might be better equipped in terms of information accessibility (Kabede, 2019). Generally, access to markets is an important factor in conditioning opportunities to marketing of farm products, as well as on technology or innovation acceptance by farmers (Kebebe, 2019).

4.4.2. Access to credit

Credit availability is one of the most important factors in smallholder farming as it improves input access and thus productivity, as well as their capacity to adopt new technologies. In this study, the majority of farmers (82%) indicated they did not have access to credit whereas 18% confirmed they had access to credit (See table 4.6). The high percentage of farmers who did not have access to credit could also be attributed to the fact that most farmers did not have title deeds to the fields they had occupied.

These findings are consistent with those of Aidon (2019); Kumar *et al*. (2020) and Zhang *et al*. (2020) who asserted that most smallholder farmers do not have access to credit because they are denied credit by financial institutions due to a lack of collateral. A lack of credit may imply that farmers may not be willing to accept EPN innovations based on that the majority of technologies necessitate substantial financial investment (Feder *et al.,* 2015). Farmer acceptance of these innovations may be further bolstered by the fact that over time, farmers know that they will have access to more money as a result of the increased profits from innovation's acceptance (Shao *et al*., 2020).

4.4.3. Access to- and frequency of extension services

Agricultural extension officers act as liaisons between researchers and farmers. They act as facilitators and communicators, assisting farmers in making decisions and ensuring that appropriate knowledge is implemented to achieve the best results in terms of sustainable production and overall rural development (Wan *et al*.,2018). The analysis of access to, and frequency of extension services is as depicted in Table 4.7 below.

Table 4.7: Access to and frequency of extension services

<table>
<tr><th colspan="2">Access to extension services</th><th colspan="2">Frequency of extension services</th></tr>
<tr><td rowspan="4">Yes</td><td rowspan="4">90%</td><td>Daily</td><td>3%</td></tr>
<tr><td>Weekly</td><td>29%</td></tr>
<tr><td>Fortnightly</td><td>1%</td></tr>
<tr><td>Monthly</td><td>67%</td></tr>
<tr><td>No</td><td>10%</td><td colspan="2">100%</td></tr>
</table>

Source: (Field survey, 2021)

The results in Table 4.7 shows that the majority of the farmers (90%) had access to extension services, mostly with monthly visits (67%). These findings are in line with that of Manlosa *et al.* (2019) who asserted that most smallholder farmers get regular visits from their local extension officers. This finding may indicate that these farmers are performing well in terms of productivity because having access to extension services is typically linked to having access to information and other benefits that go along with it. For example, when there is a new variety of a crop, they may provide the farmers with seedlings, which lowers their input costs and ultimately increases profitability and efficiency (Mugumaarhahama *et al.,* 2021).

The frequency of extension visits can influence farmers' willingness to accept EPNs where they get information that they can use to make informed decisions on production as well as acceptance of innovations through dissemination and sharing of agricultural information. As a result, the more information available to farmers, the more likely they are to accept and embrace sweet potato production innovations that reduce the impact of pests and diseases (Lee *et al*., 2021).

4.4.4. Participation in entrepreneurial training

Entrepreneurial training provides people with the ability to recognize business opportunities as well as the self-esteem, knowledge, and skills to capitalize on them. Moreover, it teaches one how to spot opportunities, commercialize a concept, manage resources, and launch a company (Khalid *et al.*, 2019). As a result of their ability to recognize opportunities, commercialize ideas, and manage resources, farmers who have received entrepreneurial training are expected to produce sweet potatoes that are profitable and technically efficient. The study found that only 21% of sweet potato farmers had received entrepreneurial training, while the majority (79%) did not receive training. Most smallholder farmers do not participate or take entrepreneurial trainings because they are old and believe that they are no longer fit to learn new skills or acquire new knowledge (Mckechnie and Wilson, 2021).

On the other hand, Mariyono (2019) reported that farmers who have not received entrepreneurial training may encounter difficulties in their production as a result of missing information regarding the economics of producing sweet potatoes as well as the potential pests and diseases, their impact, and the control strategies which could jeopardize their profits and efficiency. A lack of training has implications on farmer capacitation with regards to economics of sweet potato production, as well the potential pests and diseases, their impact and the control strategies. Due to the majority of farmers not having entrepreneurial training, it is highly likely that they may not be empowered to make proper decision-making skills with regards to production, as well as whether they will be willing to accept the EPNs.

4.5. Technical variables

In the context of this study, technical variables refer to the farm machinery and those include access to an irrigation system and access to farm machinery.

4.5.1. Access to an irrigation system

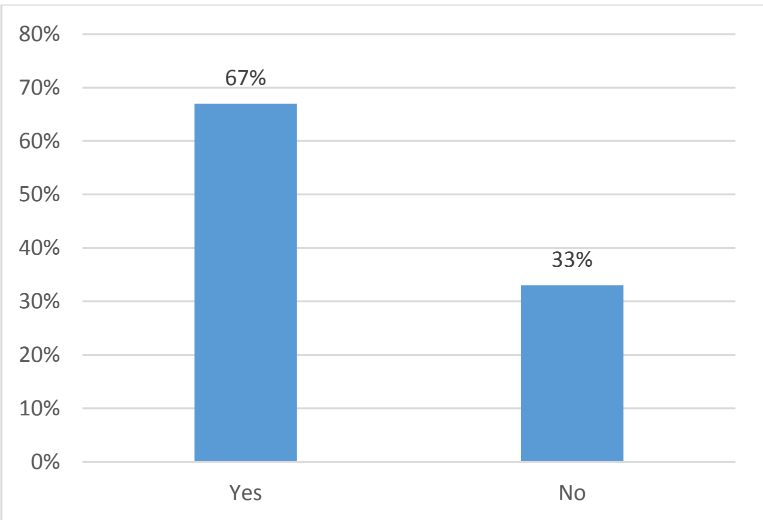

Figure 4.2: Smallholder sweet potato farmers' access to irrigation

Source: (Field survey, 2021)

According to Ahmed *et al.* (2018), access to irrigation by farmers is critical to the well-being of smallholder farmers because it improves the quality of their produce, particularly those that require frequent and proper irrigation. According to the study's findings, 67% of farmers had access to an irrigation system, while 33% did not (See Figure 4.2). Even those who indicated that they have access to irrigation systems alluded to the fact that they face numerous challenges with them, including maintenance issues, rat destruction of the systems, and the fact that water is still expensive despite their access to irrigation systems.

4.5.2. Access to farm machinery and implements

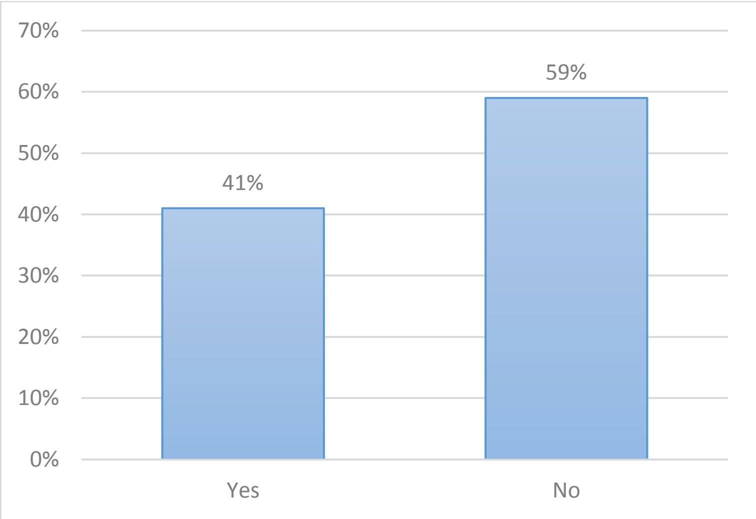

Figure 4.3: Smallholder sweet potato farmers' access to farm machinery and implements

Source: (Field survey, 2021)

Access to farm machinery refers to the state of having access to farm implements such as tractors, harvesters, and ridges in this study context (Issahaku and Abdulai, 2020). According to the results from figure 4.2 above, 41% had access to machinery, while 59% did not (See Figure 4.3). These findings imply that most farmers may have had to hire or use manual labour to carry out day-to-day farm activities because the majority of them did not have access to machinery, which may have resulted in high costs of goods produced and thus a negative impact on their profit. These findings are consistent with those of Douglas *et al*. (2014), who discovered that the majority of smallholder farmers lack access to machinery because they cannot afford to buy or rent it.

4.6. Analysis of farmers' Knowledge, Attitude, Perceptions and Practices

This section presents the results on the following:

- Sweet potato farmers' knowledge of the SPW and the extent to which it damages the sweet potato and the risk it poses to sweet potato production, as well as on the EPNs (Table 4.8).
- Sweet potato farmers' attitudes and perceptions about the SPW, its impact and current methods to control its infestations as well as their willingness to adopt the bio-control EPN innovation (Tables 4.9 and 4.10).
- Practices that sweet potato farmers are currently using to control SPW infestations in their fields (Table 4.11).

4.6.1. Knowledge

Table 4.8: Smallholder sweet potato farmers' farmers' knowledge

Attribute	**Measurement and**	**Average score**
Do you know what the SPW looks like?	***3 point Likert scale*** *1 = No* *2 = Not sure* *3 = Yes* ***Determination of whether farmer is knowledgeable:*** *1 – 1.5 = Not knowledgeable* *1.6 – 3 = Knowledgeable*	2.54
Do you know that the SPW is a very serious pest in sweet potato		2.48
Do you know the damage caused by the SPW?		2.47
Do you know how to control the occurrence of SPW?		2.20
Do you know that chemical pesticides normally used for SPW are harmful to the environment?		2.22
Do you know any indigenous practices to control SPW?		2.15
Do you know any other SPW control measure besides the one you have currently adopted?		2.03
Do you know or have you heard of the entomopathogenic nematodes?		0.00
Average knowledge score		**2.30**

Source: (Field survey, 2021)

Generally, the results in Table 4.8 indicate that smallholder sweet potato farmers are knowledgeable of the SPW, the extent to which it damages the sweet potato and the risk it poses to sweet potato production (average knowledge score of 2.30). Standing out is their high knowledge on what the SPW looks like (2.54), its significance (2.48) as well as the damage it causes (2.47). Additionally, the findings indicated that the farmers were fairly knowledgeable on how to control the SPW (2.20), including knowledge of the indigenous methods (2.15), as well as awareness of other SPW control measures than the ones they are currently using (2.03). Traditional rural farmers are knowledgeable to successfully detect sweet potato plant pests through observation informed by their farming experiences (Adam *et al*., 2015) even in the absence of a scientific process and equipment to conduct assessments of the SPW and its impacts.

An interesting observation is the knowledge farmers have regarding the environmental harmful effect of the chemicals that are used to control the SPW (Rani *et al.,* 2021; Mfarrej and Rara, 2019). As such, this can serve as a departure point towards engaging them to accept the bio-control measures (EPNs), for which none of farmers were aware of and had knowledge of EPNs (0.00). Smallholder farmers generally have little knowledge of other innovations for pest and disease control in their farms because they believe their traditional methods work better and thus have little interest in learning more about other control measures (Omeje, 2019).

4.6.2. Attitudes

Table 4.9: Smallholder sweet potato farmers' farmers' attitudes

<table>
<tr><th>Attribute</th><th>Measurement and</th><th>Average score</th></tr>
<tr><td>My current SPW control measures are effective in controlling SPW</td><td rowspan="4">5 point Likert scale
1 = Strongly disagree
2 = Disagree
3 = Neutral
4 = Agree
5 = Strongly
Determination of attitude
1 - 1.6 = Negative attitudes
1.7 – 3.3 = Neutral attitudes
3.4 – 5 = Positive attitudes</td><td>2.60</td></tr>
<tr><td>I would stick with current method to control SPW even if I had a choice to use other control measures</td><td>2.53</td></tr>
<tr><td>I think chemical pesticides are not harmful to the environment</td><td>2.50</td></tr>
<tr><td>There is not a need for me to try out other SPW control measures</td><td>2.49</td></tr>
<tr><td>Average attitude scores</td><td></td><td>2.53</td></tr>
</table>

Source: Field survey, (2021)

Generally, the sweet potato farmers were impartial (2.53) regarding the SPW control measures that they currently were using (2.60) and that they would stick to them

(2.53) without a need to try out other control measures if they had a choice to do so (2.49). The results further revealed that the farmers had neutral attitudes when it came to the dangers of chemical pesticides (2.49). Despite admitting that they are aware of the potential losses that the SPW could cause, these findings suggest that farmers were not overly confident in the SPW control methods they had implemented when asked about trying out new SPW control measures. These findings may imply that generally farmers are uncertain about their current control measures of the SPW in their farms as well as trying out new SPW control measures; and such impartial attitudes could have implications on their willingness to accept bio-control innovations. According to a study by Gautam *et al*. (2017), when switching from outdated to more modern methods of production, like managing insect pests, vegetable farmers generally show some level of uncertainty in their attitudes.

4.6.3. Perceptions

Table 4.10: Farmers' perceptions towards the SPW control

Attribute	**Measurement**	**Average score**
The current method for controlling SPW is useful	***5 point Likert scale*** *1 = Strongly disagree* *2 = Disagree* *3 = Neutral* *4 = Agree* *5 = Strongly* ***Determination of perception*** *1 - 1.6 = Bad perceptions* *1.7 – 3.3 = Neutral perception* *3.4 – 5 = Good perceptions*	2.56
SPW has a negative impact on sweet potato production		3.10
Chemical pesticides used in SPW control should continue being used even though they are not environmentally friendly		2.60
Indigenous practices are convenient in controlling SPW		2.87
Chemical pesticides used to control SPW are harmful to the environment.		2.97
Indigenous practices to control SPW are good		2.61
There are better SPW control measures besides the currently adopted		2.55
Average perception score		**2.74**

Source: Field survey, (2021)

In general, the respondents had impartial perceptions of their current SPW control methods, as well as how the SPW impacts their sweet potato production (2.74). Notably the farmer's perceptions on the impact of the SPW (3.10) and their view of the environmental harm caused by the chemicals towards control of the SPW (2.97), despite sharing their view that chemical control of the SPW should continue (2.60). In the same vein, farmers were of the view that the indigenous practices were convenient in controlling the SPW infestation (2.87) as they regard them as good (2.61). The farmers were also neutral regarding availability of better SPW control measures besides the ones currently adopted (2.55).

These findings imply that farmers generally have neutral perceptions of the harm that the SPW causes to the sweet potato crop and the current control measures they have adopted to control the SPW. This could imply that farmers are more open to accepting new technologies (Kagimbo *et al*., 2018) because farmers with neutral perceptions are more likely to be aware of the harm and the extent to which it reduces their yields. Additionally, they don't have much faith in the current control measures they have implemented. According to Kagimbo *et al*. (2018), farmers who are dissatisfied with the pest and insect control methods they employ (have negative perceptions) are most likely to readily accept new innovations that could solve their issues.

4.6.4. Practices

Table 4.11: Farmers' practices towards SPW control

Practice	**Frequency**	**Percentage**
Chemical control (Deltamethrin; hypermetric methomaxAdama and supermethrin)	6	5.1
Physical control (Clean planting material; Sanitation; Flooding fields; Mulching and catch and kill methods)	47	39.5
Indigenous Control (Bicarbonate of soda; chilies and sunlight liquid mixture and surf washing powder)	51	42.8
None	15	12.6
Total	**119**	**100**

Source: (Field survey, 2021)

From the results presented in Table 4.11, about 42% of the farmers used indigenous SPW control methods, such as bicarbonate of soda, a liquid mixture of chilies and sunlight, and surf washing powder. About 40% used physical control measures such as clean planting material; Sanitation; Flooding fields; Mulching and catch and kill methods; 12.6% used no control, which may have been the case for those who had no infestations at all which is worrisome because they can still use physical control measures which are cheaper to implement but they still decide not to implement any. About 14% used physical control measures, interestingly only 5% used chemical control measures which is also worrisome because of the impact these chemicals usually cause to the soil habitant.

The findings are in line with Kansiime's (2018) arguing that smallholder farmers typically use indigenous and physical control measures to fend off pests, insects, and diseases because they find other control methods like chemicals to be costly and difficult to use. This finding has implications for the acceptance of innovations because it suggests that farmers may be open to using these EPNs because they are relatively new, none of them are currently using IPM, and they might want to try new things to increase their output. Makate (2020) provided evidence for this claim by stating that smallholder farmers generally enjoy experimenting with and learning about new options, even though they typically use indigenous methods to control pests and diseases.

4.7. Acceptability analysis

Although the findings in Table 4.8 above indicated that the smallholder did not have any knowledge of the EPNs, they were presented with scenarios regarding the EPNs, their significance and benefits and probed on their willingness to accept the EPNs as a bio-control strategy against the sweet potato weevils. The results of this analysis are presented in Table 4.12 below. The acceptability attributes were informed by the TAM which states that one’s attitude toward a piece of innovation (EPNs bio-control innovation in this case) and one's intention to accept that innovation is influenced by one's ideas about the perceived ease of use as well as usefulness of that piece of innovation and is presented in detail in Chapter 2.

Table 4.12: Farmers’ acceptability of EPNs and Composite Index of Acceptability (CIA)

Attributes	Measurement	Score
Would you be willing to accept EPNs based on them being environmentally friendly	***5 point Likert scale*** *1 = Strongly unacceptable* *2 = Unacceptable* *3 = Neutral* *4 = Acceptable*	3.91
Would you be willing to accept EPN bio-pesticide if it leads to resistance against SPW		3.52
Would you be willing to accept EPN bio-pesticide based		3.88

on that it does not damage the soil		*5 = Strongly acceptable*		
EPN bio-pesticides are cheaper as most times they are applied once. Would you be willing to accept EPNs?		***Where:*** *1 - 1.6 = Unwillingness to accept* *1.7 – 3.3 = Moderate willingness to accept* *3.4 – 5 = Strong willingness to accept*		3.90
If EPNs are integrated into IPM programmes, would you be willing to accept the EPNs				3.95
The EPNs are compatible with other agro-chemicals, would you be willing to accept the EPNs				3.91
EPNs have a wide host range. Once established they can control other soil pests. E.g. during crop rotation. Would you be willing to accept?				3.99
Average acceptability score				**3.9**
	Min	**Mean**	**Max**	**Std. dev**
Acceptability Index Score	0.22	0.77	1	0.25

Source: (Filed survey, 2021)

The results in Table 4.12 illustrate the strong willingness of the smallholder sweet potato farmers to accept the EPNs as bio-control measures towards the infestation of the SPW as shown by an average acceptability score of 3.9 (and CIA = 0.77). Most smallholder farmers are constantly looking for new production methods to incorporate into their farming systems in order to increase productivity (Awazi and Tchamba, 2019). In addition, it was also observed in this study (see section 4.2.1) that farmers, generally, were highly educated and are highly likely able to process information quickly and make sound decisions, making them more than willing to accept EPNs.

However, it is interesting to note that there are other farmers who still have no intentions to accept the EPNs bio-control measures as shown by a minimum acceptability index score of 0.2. This suggests their unwillingness to accept the use of EPNs as bio-pesticides and could be attributed to a lack of knowledge of the EPNs, as well as them being content with their current control measures or not having SPW infestations (Yêyinou *et al*., 2017). Anders *et al*. (2021) claims that smallholder farmers are likely to be hesitant to accept innovations in their farms because they are afraid of worsening their current conditions. At the same time, there are farmers who are reluctant to accept innovation at a certain point in time (laggards) and some are late acceptors who are content with their traditional farming practices and only start appreciating innovations at a later stage (Blazquez *et al.*, 2018).

4.8. Profitability descriptive statistics

Gross margins were used as a proxy for profitability. Individual farmers' average, minimum, and maximum gross margins/ha were calculated and summarized as shown in Table 4.13 below.

Table 4.13: Smallholder sweet potato farmers' profitability/ha

N = 119				
Variable	**Mean**	**Std. Dev**	**Min**	**Max**
Total revenue (yield x price)	**R16 366.90**	**16182.70**	**R0.00**	**R66 500.00**
Sweet potato output (yield in Kgs)	1 410.94	2 506.89	12	19 000
Price of sweet potato per kg (*Rand*)	R11.60	7.65	R0.00	R55
Total variable costs (per ha)	**R3 072.36**	**7 943.36**	**R0.00**	**R73 600**
Price of slips	596.71	1538.77	0	14 000
Cost of labour	1 534.13	3 926.61	0	28 000
Cost of machinery hired	798.67	3 868.56	0	40 000
Manure	2.31	12.96	0	100
Chemicals	110.93	326.12	0	2000
Fertilizer	29.58	217.61	0	2300
Gross margins (TR-TVC)	**R13 294.54**	**13 0355.59**	**R-10 600**	**R59 400**

Source: Field survey, (2021)

4.8.1. Gross margins

Table 4.13 above shows an average gross margin of R9 552.37/ha from sweet potato production. Platanias *et al*. (2021) asserted that when a business's revenue is higher than the variable costs, it is then profitable. Since the results show that the farmers were making more revenue than the costs that they incurred, this suggests that they were profitable. The results further show a maximum gross margin of R59 400.00/ha indicates there are farmers making good returns on sweet potato production.

However, a minimum gross margin of –R10 600.00/ha implies some farmers were operating at a loss to some extent. This finding is supported by Dietz *et al*. (2020) and Sims and Kienzle (2016) who reported that smallholder farmers are most likely to have more costs than revenues as they consume majority of their produce for household food security which was also seen in this study that quite large number of farmers were producing for home consumption (see table 4.5). Nedumaran *et al*. (2020) also supported this claim and indicated that some farmers grow multiple crops at the same time, hence, it is difficult for them to keep track of one crop's returns at a time and are consequently, unaware of their profits and losses.

4.8.2. Total variable costs

On average, the TVCs incurred by farmers were R3 072.36/ha, which constitutes cost of slips (planting material), labour, hired machinery, manure, chemicals and fertilizers (See Table 4.13). However, the results also show that some farmers were not incurring any costs towards sweet potato production. For example, some farmers indicated they obtained their cuttings for free from the government. This situation could be explained by that smallholder farmers generally are regarded as resource-poor, and thus constrained when it comes to inputs access (Kamara *et al.,* 2019). Sims and Kienzle (2016) provide additional evidence to back up the claims that smallholder farmers frequently rely on the government through extension officers for inputs like seedlings, fertilizer, and other farming equipment due to a lack of resources, low incomes, and other factors.

4.9. Technical efficiency

The DEA model was used in the study to determine the Technical Efficiency of the sweet potato smallholder farmers. Table 4.14 below details the summary statistics of the DEA scores.

Table 4.14: Smallholder sweet potato farmers' DEA results (Technical efficiency scores)

N= 119				
Variable	**Mean**	**Standard deviation**	**Minimum**	**Maximum**
Technical efficiency	0.09	0.18	0.00	1

Source: (Field survey, 2021)

Table 4.14 illustrates the average technical efficiency of the farmers, which was found to be 0.09 suggesting that sweet potato farmers were technically inefficient in general. Similar findings were also noted by Gbigbi (2011). Bayan *et al*. (2013) provided evidence in support of this finding by asserting that smallholder farmers frequently employ traditional farming practices that may be out of date in this day, causing them to either overuse or underuse resources and, as a result, be technically inefficient. This finding is also supported by Sherlund *et al*. (2020), who discovered widespread technical inefficiency among smallholder producers and advised policymakers to reallocate limited resources to address what they perceived to be barriers to farmer technical efficiency through enhanced extension work, farmer education, land tenure reforms, etc.

The results further showed that, on average, smallholder sweet potato farmers were not making the best use of their inputs (See Table 4.14). Furthermore, the minimum technical efficiency was discovered to be 0.00 indicating that there were farmers who were not at all using their resources to their best ability. Lastly, the maximum technical efficiency was discovered to be 1, indicating that technically efficient farmers existed in the study areas, this finding is supported by Abate *et al*. (2019) who found out that smallholder farmers are generally technically efficient because they produce the best output out of their limited resource as they are resource constrained.

Table 4.15: Summary statistics of the inputs and outputs used in DEA (per ha)

Variable	**Mean**	**Standard deviation**	**Minimum**	**Maximum**
Output (*yield*) per ha				
Sweet potato (*Kgs*)	3 178.83	7 980.67	9	60 000
Inputs per hectare				
Cuttings/cuttings (*50kg bags*)	7.71	18.29	0.5	100
Pesticides (*ml*)	21.93	66.95	0	520
Fertilizers - NPK (*Kg*)	4.65	12.33	0	50
Labour hours (*Day*)	1.40	2.09	0	10
Area devoted to sweet potato (*hectares*)	1.16	0.94	0.06	5

Source: Field survey (2021)

4.9.1. Output (sweet potato production in kg)

According to the findings in Table 4.15, the farmers produced 3 178.83kg of sweet potato on average. Furthermore, a minimum of 9kg and a maximum of 60 000kg were produced. It is even argued that the average production in the rest of Sub-Saharan Africa, so is South Africa, much lower at less than 5 tonnes per hectare.

This is due to poor agronomic practices and challenging production conditions, such as late planting, inadequate weeding, incorrect spacing and inadequate soil fertility and water management (Putri *et al.,* 2017).

4.9.2. Inputs per hectare

Table 4.15 show that an average of eight 50 kg bags of cuttings were used to produce one hectare of sweet potatoes, which is not significantly different to the 600 kg of cuttings that Carey *et al*. (2021) reported were typically recommended for one hectare of sweet potato production. The results also showed that there was a range of 0.5, 50kg bags (25kg) to 100, 50kg bags (5000kg). Furthermore, farmers used 21.93ml of pesticides on average. The results further show a minimum of 0ml and this finding is supported by Putri *et al*., (2017)'s report, which asserted that in Africa, sweet potato under smallholder settings is usually grown without the use of pesticides, although many commercially oriented farmers recognize the need to use pesticides. A maximum of 520ml of pesticides was also discovered in the study. The application of fertilizer yielded results that ranged from 0 to 50 kg, with an average of 4.65 kg. The average fertilizer found by the study is comparable to that reported by Carey et al. (2021) to be the recommended application per hectare, who reported a 42g per square meter (4.2kg per hectare) which indicates that in terms of fertilizer application, the farmers in the study area were using that recommended.

While the study area used an average of 1.16 hectares, Echodu *et al*. (2019) found strong evidence that the majority of smallholder farmers grew sweet potatoes as a subsistence crop on plots of land less than 0.4 ha. They also noted that this could have implications for sweet potato production and household food security because relatively small areas of land are being used to cultivate sweet potatoes. If they don't grow other crops, these smallholder families run the risk of not having enough food. As a result of their average land size being relatively larger than the average size among other smallholder farmers, the farmers in the study areas have a better chance of increasing yields and improving the food security of their households. The results also show a minimum of 0.06 hectares and maximum of and 5 hectares used respectively in the study areas. With regards to labour hours per day, the findings show that farmers spend an average of 1 hour, 4 minutes a day and a maximum of 10 hours a day.

4.10. Chapter summary

The results of the smallholder sweet potato farmers' descriptive statistics were presented in Chapter 4. It was observed that the majority of these farmers were elderly and mostly female, educated, and had sizable households. Additionally, the majority of these farmers were both unemployed and married. Additionally, these farmers had extensive experience in both general farming and sweet potato farming. Additionally, it was noted that they had planted sweet potatoes in relatively smaller areas. In addition, most of these farmers are the owners of the land they planted on because most of them inherited it. Even though the majority of these farmers lacked access to credit and did not take part in entrepreneurial training, it was observed that half of them had access to markets. Additionally, it was observed that while the majority of farmers had access to irrigation systems, they lacked other equipment and implements. Additionally, farmers generally had a wealth of knowledge about SPW and its effects, but their attitudes and perceptions were neutral or impartial, and they frequently used indigenous SPW control methods. Even though these farmers claimed they were unaware of the EPNs, they were open to accepting them if they were introduced. Although they were technically inefficient, farmers were generally profitable.

CHAPTER FIVE

EMPIRICAL RESULTS

DETERMINANTS OF PROFITABILITY AND TECHNICAL EFFICIENCY

5.1. Introduction

The empirical results of the multiple linear regression and Tobit regression models used in the study are presented in this chapter. The farmers' gross margin (profitability) was used as the dependent variable in the multiple linear regression. The technical efficiency scores of smallholder sweet potato farmers were estimated using the DEA, and scores were used as the dependent variable in the Tobit regression model.

5.2. Multiple linear regression model: Determinants of profitability

Table 5.1 presents the empirical findings from the Multiple Linear Regression model of the determinants of smallholder sweet potato farmers' profitability.

Table 5.1: Multiple Linear Regression results: Determinants of the smallholder sweet potato farmers' profitability

Gross margins	Coefficient	Standard error	p-value
Age	-73.93	145.73	.614
Gender	-4420.45	3 194.99	.173
Years spent in school	-422.66	327.89	.203
Marital status	5 960.79	3 385.76	.084*
Household size	-843.95	605.28	.169
On-farm income	0.22	0.14	.125
Employment status	11 852.29	4368.48	.009***
Farm size	64.49	225.23	.776
Years in sweet potato farming	-59.78	122.89	.629
Sweet potato yield per cycle	0.32	0.16	.059**
Land ownership	-646.77	3727.43	.863
Access to extension services	-959.49	3 884.15	.806
Access to markets	2 706.6	3 230.24	.406
Distance to output markets	-403.71	1 242.14	.746
Access to credit	-1 295.76	3 898.97	.741
Participation in entrepreneurial training	1 672.20	2 674.81	.535
Access to irrigation systems	-2 385.07	2 976.39	.427
Access to farm machinery	8 590.75	3 300.85	.012**
Constant	1 3281.97	1 159.68	.256
R-squared	0.473		
****** p<.01, ** p<.05, * p<.1***			

Source: (Author's compilation, 2021)

5.2.1. Marital status

Marital status was found to be positive and statistically significant at the 10% level, suggesting that a one unit increase in married couples increases gross margins by R5 960.79. Balogun *et al*. (2012) also found a positive correlation between marital status and gross margins. This may be due to the fact that married couples can share farm duties and lower labour costs (Busari *et al*., 2012). According to Ngeywo *et al.* (2015), married couples can share input costs during off-seasons, which lessens the financial burden for their farming activities.

5.2.2. Employment status

The employment status was found to be positively and statistically significant at 1% level of significance indicating that an employed farmer's gross margins increased by R11 852.29. This could be attributed to the fact that income generated from off-farm activities such as employment is used to purchase production inputs during off-seasons (Tanaye, 2020), thus the positive influence on gross margins. These findings, however, contradict those of Mwangi and Kariuki (2015) who asserted that employment status negatively influences gross margins and further claimed that formally employed farmers' make less profits because they are not involved in the day-to-day operations of the farm and they do not see what is happening in the farm, hence, stand to lose profits.

5.2.3. Sweet potato yield per cycle

The sweet potato yield per cycle was found to be positive and statistically significant at 5% level of significance with a coefficient of 0.32 indicating that a 1kg increase in the yield will increase farmers' gross margins by 0.32 cents. This result is supported by Ogunmodede and Awotide (2020)'s assertion that an increase in output will result in higher gross margins as that would mean more produce to sell and later an increase in profits.

5.2.4. Access to farm machinery

Access to farm machinery was found to be positive and statistically significant at the 5% level of significance suggesting that a unit increase in access to farmer machinery is likely to increase gross margins by R8 590.75. This is because if a farmer has access to machinery; their gross margins are likely to increase because they pay less money for manual labour, allowing them to profit more from farm returns by saving money as a result of substituting manual labour for machinery (Arun *et al.* 2019).

5.3. Tobit regression model: determinants of technical efficiency

The Tobit regression results of the determinants of technical efficiency of smallholder sweet potato farmers is presented in Table 5.2.

Table 5.2: Tobit regression model results:

Technical efficiency scores	Coefficient	Std. error	p-value
Age	.001	.001	.511
Gender	-.004	.023	.87
Years in school	.003	.002	.116
Marital status	-.038	.025	.133
Household size	-.001	.004	.7
On-farm income	.000	.000	.326
Sweet potato yields per cycle (kg)	.000	.000	.000***
Land devoted to sweet potato	-.004	.002	.064*
Years in sweet potato farming	.000	.001	.693
Land ownership	.026	.026	.325
Access to extension services	.042	.033	.21
Access to markets	-.032	.023	.165
Distance to markets	-.006	.009	.514
Access to credit	-.064	.035	.069*
Participation in entrepreneurial training	.027	.021	.196
Access to irrigation systems	.013	.023	.566
Access to machinery	.022	.028	.439
Gross margins	.000	.000	.000***
Employment status	-.062	.035	.077*
Cost of cuttings	.000	.000	.439
Labour hire	-.012	.024	.626
Use of chemicals	-.068	.027	.013**
Constant	-.017	.076	.828
Pseudo r-squared	0.2		

****** p<.01, ** p<.05, * p<.1***

Source: (Author's compilation, 2021)

5.4. The determinants of technical efficiency

This section discusses the significant variables that influence technical efficiency of the sweet potato farmers. A pseudo R2 that falls between 0.2 and 0.4, according to McFadden (2014), indicates a very good fit. The results show that the pseudo R2 is

0.2, indicating that the model fits the data very well. Table 5.2 above presented the results of the technical efficiency drivers of the farmers.

5.4.1. Sweet potato output per cycle

At the 1% level of significance, the variable sweet potato output per cycle was found to be statistically significant with a coefficient of 0.000. This elucidates that there is no linear relationship between the farmers' sweet potato yields per cycle and their technical efficiencies.

5.4.2. Farm size

At the 10% level of significance, farm size was found to be negatively and statistically significant with a coefficient of -0.004. This means that increasing farm size results in a 0.004 decrease in technical efficiency. This could be due to that an increase in farm size requires a farmer to increase inputs such as farm machinery, farm labour, and other inputs such as cuttings and pesticides, resulting in a decrease in technical efficiency due to overuse of input resources. On the contrary, Chepng *et al.* (2015) found that land size devoted to a certain crop had a significant direct relationship on technical efficiency.

5.4.3. Access to credit

Access to credit enables a farmer to improve technical efficiency by overcoming financial constraints in order to purchase higher quality variable inputs such as fertilizer or a new technological package such as high-yielding seeds or a conventional pest and insect control method (Laurie *et al*., 2018). However, the findings of the current reveal at the 10% level, a significant, but negative relationship with a -0.06 implying that when a farmer has access to credit, their technical efficiency decreases by 0.06. These results could imply that farmers use the credit they access on other commitments others than those related to sweet potato production, e.g. buying inputs, and hence may end up producing less that what they should. On the contrary, Zhang *et al*. (2020) found that access to credit and technical efficiency are thought to have a positive relationship, and this may be true where farmers invest this credit into their farming activities that maximize yields and revenue.

5.4.4. Gross margins

The gross margin variable was found to be statistically significant at 1% significance level with a coefficient 0.000. This entails that there is no linear relationship between the farmers' gross margins and their technical efficiency.

5.4.5. Employment status

At the 1% significance level, the variable employment status was found to be negatively and statistically significant with a coefficient of -0.062. This implies that when a farmer is formally employed, his technical efficiency decreases by 0.062. Tenaye, (2020) reported that participation in off-farm employment can have both positive and negative effects on technical efficiency. If off-farm activity is scheduled during the off-season and the income generated is used to purchase production inputs, it may have a positive impact. However, if it is scheduled during the season and the income is used for non-production purposes, it may have a negative impact on technical efficiency.

5.4.6. Use of chemical use

At the 5% level of significance, chemical use was found to be significant and negatively related to technical efficiency, with a co-efficient of -0.068. This means that the more farmers use chemicals in their sweet potato production, their technical efficiencies are reduced by 0.068. Similar findings were made by Zuma *et al*. (2018), who suggested that this might be because adding an extra production factor will actually lead to smaller increases in output once a certain level of optimal capacity has been reached. This may be related to the assertion made by Nowruzi *et al.* in 2021 that chemicals are harmful to the organisms living in the soil, as well as Srinivasarao *et al*. in 2021 who further stated that an unproductive soil is one of the major causes of low or declining yields, which may be harmful to the output and consequently lower a producer's technical efficiency.

5.5. Insignificant variables

The variables age, years in farming, on-farm income, years spent in school, land ownership, access to extension services, participation in entrepreneurship, access to irrigation, access to machinery and cost of cuttings were found to be positively and statistically insignificant in influencing technical efficiency in the study areas. Whereas the variables gender, marital status, household size, access to markets, distance to markets and labour hire were found to be negatively and statistically insignificant. While these variables were found not to be significant in the current study, it does not imply they do not have an influence on the technical efficiency. This suggests that the drivers of technical efficiency differ from one context to the other, especially with regards to targeted farmer support interventions.

5.6. Chapter summary

This chapter presents the empirical results of the study from the multiple linear regression model and the Tobit regression model. From the results it was seen that generally, the smallholder sweet potato farmers in the study areas' profitability is influenced by marital status, employment status, sweet potato yield per cycle and access to machinery whereas their technical efficiencies were positively influenced by sweet potato yields per cycle, access to credits, gross margins, and employment status whereas it was negatively influenced by land size devoted to sweet potato and the use of chemicals.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1. Introduction

This chapter summarizes the study's main findings, discussions and draws implications (conclusion) of the study. Further to that, the chapter draws recommendations based on the implications from the study.

6.2. Summary and conclusions

The study was conducted in South Africa's Limpopo, Gauteng and North West provinces. The purpose of the study was to conduct a socio-economic analysis of smallholder sweet potato farming and analysis of the acceptability of EPNs as bio-control measures against the SPW. Specifically, the study had the following objectives:

- ✓ To determine the knowledge, attitudes, perceptions and practices of the smallholder sweet potato farmers
- ✓ To analyse the acceptability of EPNs by smallholder sweet potato farmers
- ✓ To analyse the profitability of smallholder sweet potato farmers and the determinants thereof.
- ✓ Analyse the technical efficiency of smallholder sweet potato farmers and the determinants thereof.

6.2.1. Smallholder sweet potato farmers' profiles

The smallholder sweet potato farmers were profiled using descriptive statistics. The farmer profiles included demographic information, farm and farming variables, institutional variables, and technical variables. According to the findings, the farmers were generally elderly, with most of them being female farmers and a majority were married. With regards to education, the farmers were found to be highly educated, and this could also explain why they were formally employed.

The study also discovered that farmers had more experience in general farming, as well as in sweet potato farming, and that they generally have smaller pieces of land devoted to sweet potato farming. A majority of the farmers owned land which they acquired through inheritance, as well as purchased land. The farmers generally had access to institutional support services that included extension services, as well as access to markets and training services from the organisations they had access to. A majority of the farmers also had access to hired machinery and irrigation facilities.

6.2.2. KAPP analysis

The KAPP analysis framework was used to assess the farmers' knowledge, attitudes, and perception using a three, five, and five-point Likert scales, respectively. The results generally showed that the sweet potato farmers had high levels of knowledge of the SPW and the extent to which it damages the sweet potato and the risk it poses to sweet potato production. However, the farmers did not have knowledge on the EPNs bio-control innovation. As research and development is imperative to increase awareness of the EPN innovations through disseminating results from EPN trials. This will ensure that farmers are presented with the benefits of EPNs and their potential towards SPW control. This will not only help farmers learn more about EPNs, but it will also help them adjust or enhance their attitudes and opinions about IPMs in general.

On the perceptions and attitudes towards the SPW and their willingness to accept the EPN innovations, farmers were generally impartial. This could be due to farmers' lack of confidence in their current SPW control measures (which is bolstered by their perceptions and attitudes toward those measures) and their estimated yield losses. Farmers were also found to be making use largely the indigenous and physical means to control the SPW. The KAPP analysis also provided insights towards the willingness to accept the EPNs, given their knowledge, attitudes, perceptions and the current practices they are using.

6.2.3. Acceptability and Composite Index of Acceptability: willingness to acceptability EPNs

Generally, the assessment showed that farmers were highly willing to accept the EPNs bio-control measures towards control of the SPW within their farming systems. This is despite that they did not have knowledge on the EPNs. This also suggests that farmers are willing to incorporate EPNs into their sweet potato farming for the control of the SPW. Generally, evidence from literature shows that smallholder farmers are always willing to accept new methods of controlling problematic pests and insects in their farms in order to improve their yields and profits.

- Hypothesis 1: Smallholder sweet potato farmers will not accept the use of new inventions (EPNs)

The study therefore rejects this hypothesis since the results show that farmers are willing to accept the use of EPNs to control SPW infestations in their fields.

6.2.4. Profitability and its determinants

Gross margin was used to assess the profitability of the smallholder sweet potato farmers. Generally, farmers were found to be profitable, although there were farmers who had negative gross margins. A number of factors were found to influence the farmers' gross margins at different levels of significance. These included marital status, and employment status, sweet potato yield per cycle and access to machinery. As a result, potential investors may look into supporting sweet potato production activities as these could potentially generate returns for the smallholder farmers.

- Hypothesis 2: smallholder sweet potato enterprise/farming is not profitable.
- Hypothesis 3: socio-economic factors do not influence sweet potato farmers' profitability.

These hypotheses are rejected because the smallholder sweet potato farming were found to be profitable, and this is influenced by socio-economic factors.

6.2.5. Technical efficiency and its determinants

The smallholder sweet potato farmers were found to be technically inefficient, even though they were a few who were technically efficient. This technical inefficient situation was driven by socio-economic factors such as employment status, sweet potato yield per cycle, farm size, and access to credit, gross margin, and chemical use. In light of this, it is imperative that farmers prioritize minimisation of costs, while maximizing their outputs to improve their technical efficiency. They can increase their yields by using improved cultivars (high yielding cultivars).

- Hypothesis 4: Sweet potato farmers in selected areas of study are not technically efficient.
- Hypothesis 5: socio-economic factors do not influence smallholder sweet potato farmers' technical efficiency.

Hypothesis 4 is accepted as farmers were found to be technically inefficient, while hypothesis 5 is rejected socio-economic variables were discovered to have an impact on technical efficiency.

6.3. Recommendations

The policy recommendations and implications of the study based on the specific objectives are presented in this section.

6.3.1. Smallholder sweet potato farmers' profiles

- The study revealed that there were more females than males involved in sweet potato production. It is therefore recommended that workshops be held to educate young farmers and males on the benefits of sweet potato farming to enhance food security status, as well as incomes. This is based on the positive gross margins that farmers realise in sweet potato farming. In addition, based on the farmers' profiles, it also recommended that contextual factors be considered when providing support to the sweet potato farmers. For instance, capacity development programs be initiated by advisors to educate farmers to consider selling the majority of their produce rather than producing for personal consumption in order to make a profit. Furthermore, policies to regulate the allocation of production resources to farmers are recommended, as this could improve their productivity. In addition, as seen that farmers generally lacked access to credit, there should be lending institutions that must be supported by the government in order to allow crediting smallholder farmers.

6.3.2. KAPP analysis

- While the study found that farmers are aware of the SPW, the damage it causes and the dangers of chemical pesticides utilisation, they are unaware of the EPNs and associated benefits. And because they were also impartial on attitudes and perceptions on SPW and control measures, it is therefore recommended that EPN producing companies and specialists hold capacity-building workshops in order to capacitate smallholder farmers about the benefits of EPNs as new bio-innovations of controlling SPW.

- Based on the current practises farmers used, it is recommended that they try a wide range of viable and accessible control measures to enhance their yields.

6.3.3. Acceptability of EPNs

- It is recommended that EPNs for field applications in South Africa be produced in accordance with proper regulatory protocols, such as EPN registration under Act 36 of 1947. This is also in response to ongoing research and trials in South African provinces such as North West, Gauteng, and Limpopo by companies such as the ARC, NemLab, and NemaBio.
- A wide range of stakeholders can have an impact on EPN innovation; for example, policymakers should develop new policies to help regulate the use of such IPMs. Furthermore, extension officers can play an important role in disseminating such information to farmers, especially since EPNs can eradicate other soil-borne pests in addition to the SPW.

6.3.4. Profitability and its determinants

- Farmers were profitable, and thus can consider minimising costs and maximising their output in order to increase their profits. As such, the study recommends farmer support initiatives with regards to training, provision of implements such as machinery which they can share amongst themselves in order to reduce the costs spent on manual/hired labour.

6.3.5. Technical efficiency and its determinants

- The study recommends farmer capacity development initiatives with regards to economics of sweet potato production, as well as the impacts of the pests and diseases, as well as the control measures. This will assist farmers to maximise their output towards attaining food security and maximising revenue generation.
- Another recommendation made by the study is that farmers be trained on how to best utilize their inputs while avoiding overuse. For example, the amount of fertilizer and chemicals to be applied to a specific area of land.

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APPENDIX 1: QUESTIONNAIRE

Questionnaire ID:

Dear respondent, my name is Mankaba Whitney Matli, an M. Agric in Agricultural Economics student in the Department of Agricultural Economics and Animal production, School of Agricultural and Environmental Sciences, Faculty of Science and Agriculture, at the University of Limpopo and PDP student at the Agricultural Research Council. My M. Agric includes research and for this reason, I am conducting a research titled:

Socio-economic analysis of sweet potato production and acceptability of Entomopathogenic Nematodes as a bio-control of sweet potato weevil in South Africa.

The research project sorely seeks to understand the socio-economics of sweet potato production as well as the acceptability of Entomopathogenic Nematodes as a bio-control of sweet potato weevil in the selected areas of Gauteng, North West and Limpopo provinces hence

I ask a few minutes of your time to discuss this. Since I understand that you are very busy, our discussion will take approximately 15-20 minutes of your time. The information to be discussed will be kept strictly confidential and will be used for the purpose of this study.

Should you have any concerns regarding this study please contact either of following people:

Researcher: Ms MMW Matli (matshidisowhitney@gmail.com)

Supervisory Team: Prof MP Senyolo (mmapatla.senyolo@ul.ac.za) and Prof A Belete (abenet.belete@ul.ac.za), or Dr K Nhundu (NhunduK@arc.agric.za)

This questionnaire is to be completed by the farmers with the help of the enumerators.

Name of enumerator: ………………………………………………………………………

Name of province: ……………………………………………………………………….

Region of province: ………………………………………………………………….

Date of interview: …………………………………………………………………………

SECTION A: FARMERS DEMOGRAPHICS

A1	A2	A3	A4	A5	A6	A7	A8
Year of birth	Gender 1 = male 0 = female	Marital status 1 = married 0 = [1]not married	Years spend in school ………………………… What is your highest level of education? 1 = no formal education 2 = primary education 3 = secondary education 4 = tertiary education	Household[2] size	Sources of income (per month) *(you can tick more than 1 if applicable)* 1 = on-farm (R……………………) 2 = small business (R……………..……) 3 = pension money (R…………………..) 4 = social grants (R…………………...) 5 = remittances (R…………………..) 6 = other (specify) (R…………………...) ……………………. (R…………………...) ……………………. (R…………………...) ……………………. (R…………………...)	Employment status 1 = [3]formal 0 = [4]informal	Are you a full time farmer? 1 = yes 0 = no

SECTION B: FARM AND FARMING INFORMATION

B1	B2	B3	B4	B5	B6	B7	B8
Years in farming 1=general …….. 2=SP…………...	Main reasons for producing SP 1 = income generation 2 = employment 3 = home consumption 4 = other *(specify)*	Farm size	Hectares put on SP production	Land ownership 1 = yes 0 = no	Type of ownership 1 = leasehold 2 = rent 3 = freehold 4 = bought 5 = inherited 6 =[5] PTO 7 = other (specify)	SP production cycle	SP output per annum (kgs)

[1] Not married: widowed, divorced or single
[2] Household size: refers to the number of persons in a private household.
[3] Formal employment: When a farmer is hired under an established working agreement that includes salary or wages, health benefits and defined work hour and workdays
[4] Informal employment: When a farmer has no formal contract with any company, and without worker benefits or social protection and no fixed employer.
[5] PTO: A PTO is permission granted by the government to occupy land (not a tittle deed)

<table>
<tr><th>B9</th><th>B10</th><th>B11</th><th>B12</th><th>B13</th><th>B14</th><th>B15</th><th>B16</th></tr>
<tr>
<td>Cost of 1 pack/sack[6]
R</td>
<td>Cuttings/slips used per/ha during planting?</td>
<td>Cost of cuttings/slips (R)</td>
<td>Do you hire labour
1 = yes
0 = no
If yes, are they
1 = part timers
2 = permanent

And how many
Part timers ….
Permanent ….</td>
<td>If yes, for what purpose
1 = land preparation
2 = planting
3 = fertilizing
4 = watering
5 = harvesting
6 = other (specify)</td>
<td><table><tr><th>Quantity</th><th>Hrs/day</th><th>Activity</th><th>Cost</th></tr><tr><td></td><td></td><td></td><td></td></tr><tr><td></td><td></td><td></td><td></td></tr><tr><td></td><td></td><td></td><td></td></tr><tr><td></td><td></td><td></td><td></td></tr></table>
If no, how do you manage daily activities?</td>
<td>Do you use the following?
Fertiliser
1 = yes 0 = no
Chemical
1 = yes 0 = no
If yes to any of above, please complete table below</td>
<td>If no, what do you use, and for what purpose?</td>
</tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Name of fertiliser/chemical	For what	Application/ha	Cost (Rands)/unit

SECTION C: INSTITUTIONAL INFORMATION

C1	C2	C3	C4	C5	C6	C7	C8
Are you [7]affiliated to any organisation or farming cooperative? *1 = yes* *0 = no*	If yes, what services do they offer? *1 = training* *2 = record keeping* *3 = other (specify)*	How long have been affiliated?	Do you have access to extension services? *1 = yes; 0 = no* Frequency of visits *1 = daily* *2 = weekly* *3 = fortnightly* *4 = monthly* *5 = other (specify)*	If yes, what kind of services do they offer? (*You can tick more than one service if applicable*) *1 = production* *2 = marketing* *3 = training* *4 = information provision* *5 = other (specify)*	Have you received any credit support in the past 12 months? And from who? *1 = yes* *0 = no* **<u>Sources:</u>** *1 = financial institution* *2 = relatives* *3 = money lenders* *4 = other (specify)*	If yes, what is the source? **Source** | **Amt** | **Amount (p.a.)** *1= <R3,500* *2 = R3,501–R5,000* *3 = >R5 000*	What is the purpose of the credit?
C9	**C10**	**C11**	**C12**	**C13**	**C14**	**C15**	**C16**
Access to market *1 = yes* *0 = no*	Markets accessed *1 = formal (specify)* *2 = informal (specify)*	Transport use to markets? *1 = own car* *2 = hire* *3 = taxi* *4 = other (specify)*	Distance between farm and the input market? *1 = 0 – 5km* *2 = 5,1 – 10km* *3 = 10,1 – 15km* *4 = 15,1 – 20km* *5 = >20km* Distance between farm and the output market? *1 = 0 – 5km* *2 = 5,1 – 10km* *3 = 10,1 – 15km* *4 = 15,1 – 20km* *5 = >20km*	Who pays or covers for transport to market? *1 = farmer* *2 = marketing agency* *3 = other (specify)*	Are you aware of SP grades at the markets? *1 = yes; 0 = no* If yes, please elaborate	Do you like the market grading system? 1 = yes 0 = no What are your views regarding the grades required by the market? What challenges do you face in meeting the grades?	What do you think you can do to meet the market grades?

[7] Affiliated: officially attached or connected to an organisation/ to be part of an organisation

SECTION D: TECHNICAL INFORMATION

<table>
<tr><th>D1</th><th>D2</th><th>D3</th><th>D4</th><th>D5</th><th>D6</th><th>D7</th></tr>
<tr>
<td>Do you have an irrigation system?
1 = yes
0 = no</td>
<td>If yes, what type of system?
1 = drip
2 = gravity
3 = sprinkler
4 = centre pivot
5 = other (specify)</td>
<td>How often do you irrigate per week?
1 = once
2 = twice
3 = thrice
4 = > thrice</td>
<td>What challenges do you face with your irrigation system (elaborate)</td>
<td>Do you have access to a machinery?
1 = yes
0 = no</td>
<td>If yes, please state what type?
1 = tractor
2 = harvester
3 = other (specify)</td>
<td>Do you hire any machinery and for what purpose?
<table>
<tr><th>Machinery hired</th><th>Purpose</th></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
</table>
</td>
</tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

SECTION E: FARMERS KNOWLEDGE, ATTITUDES, PERCEPTION AND PRACTICES

E1	E2	E3	E4	E5	E6	E7	E8
Farmers' Knowledge							
Do you know what a SPW is? And what it looks like? *3 = yes* *2 = no* *1= don't know*	Do you know that the SPW is a very serious pest of sweet potato? *3 = yes* *2 = no* *1 = don't know*	Do you know the damage caused by the SPW? *3 = yes* *2 = no* *1 = don't know*	Do you know how to control the occurrence of SPW? *3 = yes* *2 = no* *1 = don't know*	Do you know that the chemical pesticides used to control SPW are harmful to the environment? *3 = yes* *2 = no* *1 = don't know*	Do you know of any indigenous practices to control SPW? *3 = yes* *2 = no* *1 = don't know*	Do you know any other SPW control measures besides the ones you have currently adopted? *3 = yes* *2 = no* *1 = don't know*	Do you know or have you heard of the entomopathogenic nematodes? *3 = yes* *2 = no* *1 = don't know*
E8	**E9**		**E10**		**E11**		
Farmers' Attitudes							
My current SPW control measures are effective in controlling SPW *1 = strongly agree* *2 = agree* *3 = not sure* *4 = disagree* *5 = strongly disagree*	I would stick with current method to control SPW even if I had a choice to use other control measures *5 = strongly agree* *4 = agree* *3 = not sure* *2 = disagree* *1 = strongly disagree*		I think Chemical pesticides are not harmful to the environment *5 = strongly agree* *4 = agree* *3 = not sure* *2 = disagree* *1 = strongly disagree*		There is not a need for me to try out other SPW control measures *5 = strongly agree* *4 = agree* *3 = not sure* *2 = disagree* *1 = strongly disagree*		
E12	**E13**		**E14**	**E15**	**E16**	**E17**	**E18**
Farmers' Perceptions							

The current method for controlling SPW is useful *5 = strongly agree* *4 = agree* *3 = not sure* *2 = disagree* *1 = strongly disagree*	SPW has a negative impact on produces production *5 = strongly agree* *4 = agree* *3 = not sure* *2 = disagree* *1 = strongly disagree*	Chemical pesticides used in SPW control should continue being used even though they are not environmentally friendly *5 = strongly agree* *4 = agree* *3 = not sure* *2 = disagree* *1 = strongly disagree*	Indigenous practices are convenient in controlling SPW *5 = strongly agree* *4 = agree* *3 = not sure* *2 = disagree* *1 = strongly disagree*	Chemical pesticides used to control SPW are harmful to the environment. *5 = strongly agree* *4 = agree* *3 = not sure* *2 = disagree* *1 = strongly disagree*	I know other indigenous practices to control SPW *5 = strongly agree* *4 = agree* *3 = not sure* *2 = disagree* *1 = strongly disagree*	There are better SPW control measures besides the currently adopted *5 = strongly agree* *4 = agree* *3 = not sure* *2 = disagree* *1 = strongly disagree*
E19						

Farmers' Practices

Cultural/indigenous practises *(tick all that apply)* *1 = sanitation* *2 = mulching* *3 = early harvesting* *4 = flooding* *5 = clean planting material* *6 = resistant cultivars* *7 = other (specify)*	**Biological controls** *1 = predators* *2 = parasitoid* *3 = entomopathogenic namatodes* *4 = entomopathogenic fungi* *5 = other (specify)*	**Chemical control** *1 = parathion* *2 = chloropyrofos* *3 = deltamethin* *4 = pirimiphos methyl* *5 = other (specify)*	**Other control measures that you use (specify)**

E20	**E21**	**E22**	**E23**	**E24**	**E25**

Based on the following, kindly rate your acceptability of the EPN bio-pesticide as a control measure for SPW (5 being high and 1 being low acceptance)

EPN is environmentally friendly	EPN bio-pesticide leads to resistance against SPW	EPN bio-pesticide leads to increased sustainability as it does not damage the soil	EPN bio-pesticides are cheaper as most times they are applied once	EPNs can be integrated into IPM programmes	EPNs are compatible with other agrochemicals
E26					
EPNs have a wide host range. Once established they can control other soil pests. E.g. during crop rotation.					

SECTION F: DIVERSITY, INCIDENCE AND DAMAGE SEVERITY CAUSED TO SWEET POTATO BY SWEET POTATO WEEVILS IN FIELDS AND IN STORAGE

<table>
<tr><th>F1</th><th>F2</th><th>F3</th><th>F4</th></tr>
<tr>
<td>Do you have problems with insect pests?
<table><tr><td>Yes</td><td>1</td><td>No</td><td>0</td></tr></table>
If yes, where do you mostly experience pests?
<table><tr><td>Below ground</td><td>1</td><td>Above ground</td><td>0</td></tr></table>
</td>
<td>Which pest is more important in the production of sweet potato?
<table><tr><td>Sweet potato weevil</td><td>1</td><td>Rats</td><td>2</td><td>Porcupines</td><td>3</td></tr></table>
</td>
<td>Estimated yield loss at harvest
<table><tr><td>Quarter of the yield</td><td>1</td><td>Quarter – half of the yield</td><td>2</td><td>Half of the yield</td><td>3</td></tr></table>
</td>
<td>Estimated yield loss during storage
<table><tr><td>Quarter of the yield</td><td>1</td><td>Quarter – half of the yield</td><td>2</td><td>Half of the yield</td><td>3</td></tr></table>
</td>
</tr>
<tr><td></td><td></td><td></td><td></td></tr>
</table>

FARM INPUTS AND OUTPUTS ANALYSIS

INPUTS	**Irrigation**	**Fertilizer**	**Planting (cuttings/slips)**	**Spraying**	**Other (Specify)**
Quantity used					
Average unit price					

LABOUR AND MACHINERY COSTS	**Ploughing**	**Planting**	**Weeding**	**Fertilizing**	**Irrigating**	**Harvesting**	**Sorting, packaging & storing**
Labour rate (Rand) per hour							
Number of days							
Number of hours							
Machinery rate/ hour							

OUTPUTS

HARVEST	**Sold**	**In store**	**Consumed**	**Given away**
Average value/ kg per production cycle				
Number of kgs per production cycle				
Total				

Is there anything you would like to add or would like me to know? It could be about your future plans regarding the sweet potato production, marketing and processing?

………
………
……

Thank you very much for your patience and for taking time off your busy schedules to be a part of this interview

APPENDIX 2: FACULTY APPROVAL OF PROPOSAL

06/05/2021

NAME OF STUDENT: Matli MMW

STUDENT NUMBER: 201507022

DEPARTMENT: Agricultural Economics and Animal ProductionSCHOOL: Agricultural and Environmental Sciences

QUALIFICATION: MSD02

Dear Ms Matli

FACULTY APPROVAL OF PROPOSAL (PROPOSAL NO. 44 OF 2021)

I have pleasure in informing you that your **masters** proposal served at the Faculty Higher Degrees Committee meeting on **04 February 2021** and your title was approvedas follows:

"Socio-economic analysis of smallholder sweet potato production and acceptability of entomopathogenic nematodes as a bio control of sweet potatoweevil in selected provinces of South Africa."

Note the following: The study

Ethical Clearance	**Tick One**
Requires no ethical clearance Proceed with the study	
Requires ethical clearance (Human) (TREC) (apply online) Proceed with the study only after receipt of ethical clearance certificate	√
Requires ethical clearance (Animal) (AREC) Proceed with the study only after receipt of ethical clearance certificate	

Yours faithfully

Prof P Masoko

Secretariat: Faculty Higher Degrees Committee

CC: **Dr MP Senyolo**

Prof JJ Hlongwane
Prof TP Mafeo

APPENDIX 3:
ETHICAL CLEARANCE

University of Limpopo
Department of Research Administration and Development
Private Bag X1106, Sovenga, 0727, South Africa
Tel: (015) 268 3935, Fax: (015) 268 2306,
Email:anastasia.ngobe@ul.ac.za

TURFLOOP RESEARCH ETHICS COMMITTEE

ETHICS CLEARANCE CERTIFICATE

MEETING: **08 June 2021**

PROJECT NUMBER: TREC/101/2021: PG

PROJECT:

Title: Socio-Economic Analysis of Smallholder Sweet Potato Production and Acceptability of *Entomopathogenic* Nematodes as a Bio-Control Of SweetPotato Weevil In South Africa.

Researcher: MMW Matli

Supervisor: Dr MP Senyolo

Co-Supervisor/s: Dr K Nhundu (ARC)

School: **Agricultural and Environmental Sciences**

Degree: Master of Agricultural Management (Agricultural Economics)

PROF P MASOKO
CHAIRPERSON: TURFLOOP RESEARCH ETHICS COMMITTEE

The Turfloop Research Ethics Committee (TREC) is registered with the National Health

Note:

i) **This Ethics Clearance Certificate will be valid for one (1) year, as from the abovementioneddate. Application for annual renewal (or annual review) need to be received by TREC one month before lapse of this period.**

ii) **Should any departure be contemplated from the research procedure as approved, the researcher(s) must re-submit the protocol to the committee, together with the Application forAmendment form.**

iii) **PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES.**

Research EthicsCouncil, Registration Number: **REC-0310111-031**