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Allelopathic effects and bio-insecticidal potential of sphaeranthus suaveolens in common bean farming in Northern Tanzania

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ALLELOPATHIC EFFECTS AND BIO-INSECTICIDAL POTENTIAL OF *Sphaeranthus suaveolens* IN COMMON BEAN FARMING IN NORTHERN TANZANIA

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ABSTRACT

Weeds and insect pests are amongst the serious constraints in common bean farming in most parts of Tanzania. However, weeds with allelopathic and insecticidal properties if well manipulated can be used to manage insect pests, weeds and other challenges in agriculture. Therefore, this study assessed the allelopathic effects of a weed *Sphaeranthus suaveolens* in common bean seed germination and seedling growth, as well as its bio-insecticidal potential in managing *Acanthoscelides obtectus*, an insect pest of stored legumes. Social survey to smallholder farmers in Arumeru and Moshi rural districts, seed germination and post-harvest loss experiments, as well as the phytochemical screening of secondary metabolites were conducted in order to gather local knowledge on weed and insect pest management practices, assess the allelopathic effects of different concentration of *S. suaveolens* crude extracts, evaluate the bio-insecticidal properties and identify the secondary metabolites present in *S. suaveolens* crude extract. Results showed that, insect pests and weeds were the main constraints in common bean farming and chemical spray and mechanical weeding were the main methods used by farmers to manage them respectively. Furthermore, *S. suaveolens* in the surveyed villages was more distributed in farmlands and swampy areas and density was high during the rainy season. Results further showed that seed germination, seedling growth and chlorophyll content of common bean seedlings were significantly affected by the high concentration of *S. suaveolens* crude extracts which suggests the presence of water soluble allelochemicals. Moreover, the mortality of *A. obtectus* in common bean seeds treated with high dose of *S. suaveolens* powder was higher compared with the control experiment, signifying the insecticidal properties of *S. suaveolens* powder and its potential in managing *A. obtectus* in storage facilities. Additionally, the phytochemical analysis of *S. suaveolens* crude revealed the presence of terpenes, alkaloids, flavonoids, saponins, glycosides, steroids and anthraquinones. Thus, the findings from this study showed the allelopathic effects of *S. suaveolens* extracts on common bean seed germination and growth, as well as potential of its powder in managing *A. obtectus* in storage facilities thereby reducing post-harvest loss particularly among smallholder farmers with limited access to synthetic pesticides.

DECLARATION

I, Hudson Laizer do hereby declare to the Senate of the Nelson Mandela African Institution of Science and Technology that this dissertation is my own original work and that it has neither been submitted nor presented for similar degree award in any other Institution.

Hudson Laizer (Candidate)	Date

The above declaration is confirmed

Prof. Patrick A Ndakidemi (Supervisor 1)	Date
Dr. Musa Chacha (Supervisor 2)	Date

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CERTIFICATION

The undersigned certify that they have read and found the dissertation titled "Allelopathic effects and bio-insecticidal potential of *Sphaeranthus suaveolens* in common bean farming in northern Tanzania" conforming to the standard and format acceptable by the Nelson Mandela African Institution of Science and Technology.

__________________________________ _____________

Prof. Patrick A Ndakidemi Date

(Supervisor 1)

__________________________________ _____________

Dr. Musa Chacha Date

(Supervisor 2)

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DEDICATION

I dedicate this thesis to my late parents; Mr. and Mrs. Christopher Laizer.

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LIST OF ABBREVIATIONS AND SYMBOLS

%	Percentage
^{o}C	Degrees Celsius
ANOVA	Analysis of Variance
Conc	Concentrated
DAAD	Deutscher Akademischer Austausch Dienst
df	Degree of Freedom
DMSO	Dimethyl Sulfoxide
E	East
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistics
FGD	Focus Group Discussion
g	Gram
GC-MS	Gas Chromatography-Mass Spectrometry
GPS	Global Positioning System
h	Hour
ha	Hectare
HHS	Household Survey
HSD	Honestly Significant Difference
i.e.	id est (that is)
kg/ha	Kilogram per Hectare
LiSBE	Life Sciences and Bioengineering
LSD	Least Significant Difference
mL	Millilitres
MUST	Mbeya University of Science and Technology
NIST	National Institute of Standards and Technology
NM-AIST	Nelson Mandela African Institution of Science and Technology
RUFORUM	Regional Universities Forum for Capacity Building in Agriculture
S	South
SARI	Selian Agricultural Research Institute
SD	Standard Deviation
SE	Standard Error

SPSS	Statistical Package for the Social Sciences
UV/VIS	Ultraviolet Visible Spectrophotometry
x^2	Chi-Square

CHAPTER ONE

INTRODUCTION

1.1 Background of the Problem

Common bean (*Phaseolus vulgaris*) is among the most important grain legumes globally (Food and Agriculture Organization Statistis [FAOSTAT], 2019). In Africa, the crop is largely grown for food consumption and income generation by most smallholder famers (Diana *et al*., 2019; Kansiime *et al.*, 2018). Common bean also plays a significant role in soil health improvement through biological nitrogen fixation (Latati *et al*., 2017; Reinprecht *et al*., 2020). Despite its importance in food security, income generation and soil nitrogen fixation, common bean production in most parts of Africa is low and mostly affected by pests, diseases and weeds among other factors (Alemán, 2001; Diana *et al*., 2019; Nations, 2016; Singh *et al*., 2003). The potential annual yield losses due to weeds, insect pests and diseases are estimated to be around 45%, 30% and 20% respectively (Oerke, 2006; Sharma *et al*., 2017).

Majority of the farmers respond to these constraints through the use of chemicals such as herbicides, pesticide, fungicides, and so on (Kelly *et al*., 2003; Zhang, 2018). The extensive use of these chemicals in managing and controlling insect pests, weeds and diseases, however, have alarmed the public on the effects they might bring to human health and the environment at large (Bourguet & Guillemaud, 2016; Khanh *et al.*, 2005). Such concerns are putting pressure on agricultural sector to reduce the use of chemicals and as a result, much attention is paid to alternative methods and techniques for controlling and managing insect pests, weeds and diseases through non-chemical methods and/or use of natural products such as botanical extracts (Isman, 2006; Williamson *et al.*, 2008).

In Tanzania, common bean is grown mostly in northern and southern highlands regions (Arusha, Kilimanjaro and Mbeya) with an average yield ranging from 700 to 990 kg/ha (Hillocks *et al.*, 2006). This is lower as compared with the potential yields which ranges from 1500 to 3000 kg/ha under favorable conditions (Hillocks *et al.*, 2006). The lower yields in the mentioned regions are mostly linked to weeds and insect pests such among other factors (FAOSTAT, 2017; Katungi *et al*., 2009; Laizer *et al.*, 2019; Mkenda *et al.*, 2017). The low yield obtained is also under insect pest attack during storage which further threatens the food security and household income for smallholder farmers The most destructive insect pest of common bean in storage facilities is bean bruchids (*Acanthoscelides obtectus*), originally from

America, but now widely distributed in Asia, Africa including Tanzania and reported to cause significant loss to most farmers (Abate & Ampofo, 1996; Laizer *et al.*, 2019). The loss is estimated to range from mild (20%) to total loss (100%) in situations where the post-harvest management is poor (Alemayehu & Getu, 2017; Kamanula *et al*., 2011; Mishili *et al*., 2011). Therefore, there is a need to develop an insect pest management strategy that will be effective and affordable to most resource constraints smallholder farmers (Hummel *et al.*, 2018; Laizer *et al*., 2019; Ndakidemi *et al.*, 2006).

Prior to the discovery and commercialization of synthetic chemicals, approaches such as biological and mechanical control as well as cultural practices were successfully applied and reported to be effective in crops protection against weeds and insect pests (Abouziena & Haggag, 2016; El-Wakeil, 2013). The use of botanical pesticides for example, was considered the easiest and affordable method for most smallholder farmers in the developing countries (Jabran & Chauhan, 2018; Pannacci *et al.*, 2017; Pannacci & Tei, 2014). Different plants parts and crude extracts from various plants were applied in making botanical pesticides (Benner, 1993; Godfrey, 1994). However, due to limited knowledge and lack of awareness on the effectiveness of botanical pesticides, the method was only applied by a handful of farmers (Dimetry, 2012; Isman & Grieneisen, 2014).

The secondary metabolites in these botanical plants are responsible for the biological activities that offer defense against diseases, pests, fungi, bacteria, insects among others (Dewick, 2009; Schoonhoven *et al.*, 2005). These naturally occurring chemicals are the byproduct of major metabolic pathways in plants and can be isolated and used as perfect pesticides (Céspedes *et al.*, 2014). These plants secondary metabolites are reported to be more pronounced in weeds and play a significant role in their successful invasion and spread by suppressing other surrounding plants, tolerating diseases, insects and other organisms (Keeley, 2010; Kong *et al.*, 2007; Kremer & Ben-Hammouda, 2009; Martin, 2017; Xuan *et al.*, 2004). The secondary metabolites from either weeds or other botanical plants, can be well manipulated and used as the best alternative in the management of insect pests both in the field and during storage, weeds, diseases etc. (Batish *et al.*, 2001; Frabboni *et al.*, 2019; Lowry & Smith, 2018; Mkindi *et al.*, 2017; Nattudurai *et al.*, 2012).

Sphaeranthus suaveolens is a widespread plant in swampy and river banks, and usually considered a weed in cultivated farmlands (Beentje, 2002). A heavy infestation of this plant has been reported and claimed worse in crops such as rice and common bean (Fahmy, 1997;

Laizer *et al.*, 2019). It has also been observed that farms infested with *S. suaveolens* are difficult to cultivate and provide lower yields as compared with the non-invaded farms (Ivens, 1989; Laizer *et al.*, 2019). Despite the widespread of *S. suaveolens* in most cultivated areas, there is very limited information on its ecological interactions with crops particularly common bean and weather the interactions have effects on growth and survival of crops. Also, the secondary metabolites from *S. suaveolens* are largely unknown and their potential application in managing weeds and/or insect pests need to be explored (Laizer *et al.*, 2020). Therefore, the phytochemical screening and identification of the secondary metabolites from the *S. suaveolens* plant particularly compounds with pesticidal properties could considerably justify the practical application of botanical based insect pest management techniques for most smallholder farmers in areas where *S. suaveolens* is growing.

1.2 Statement of the Problem

Common bean (*Phaseolus vulgaris*) is an important food and income generating crop in Tanzania (Hillocks *et al.*, 2006). The crop ranks third in terms of area cultivated after maize and cassava, accounting for 7.5% of the total area under annual crops (Nassary *et al.*, 2020). Common bean is mostly cultivated by smallholder farmers in northern zone (Kilimanjaro, Arusha, Manyara and Tanga), lake zone (Kagera and Kigoma) and southern highlands zone (Mbeya, Ruvuma, Iringa, Songwe and Rukwa). Common bean is also exported in neighboring countries mainly Rwanda, Kenya and Democratic Republic of Congo. Despite the importance of common bean in the agricultural sector and peoples' livelihood in the country, yields are generally low with the average ranging from 700 to 990 kg/ha (FAOSTAT, 2017; Hillocks *et al.*, 2006). Among the reasons behind the low yields are weed infestation, poor crop management skills and insect pest attacks (Kumar & Kalita, 2017; Lalani *et al.*, 2016; Rusinamhodzi *et al.*, 2016). The low harvests obtained are also under insect pest attack during storage particularly by *A. obtectus* and cause further loss of 20% to 40% and sometimes a total loss (100%) when the post-harvest management is poor (Ebinu *et al.*, 2016; Laizer *et al.*, 2019).

Likewise, the control of insect pests both in the field and during storage is mostly done using synthetic pesticides (Lenné, 2000; Nukenine, 2010). Farmers have been reported to frequently use chemical pesticides in the field and during storage regardless of the safety concerns and threats they pose due to their toxicity and other adverse effects to human health (Jallow *et al.*, 2017; Mahmood *et al.*, 2016; Pelosi *et al.*, 2017) and the environment at large (Dhineshkumar *et al.*, 2017; Gianessi & Reigner, 2007). Furthermore, the accessibility and affordability of most synthetic pesticides to a larger proportion of smallholder farmers in developing countries is limited (Laizer *et al.*, 2019; Mulungu *et al.*, 2007). Therefore, there is a need to develop a viable insect pest management strategy particularly in storage facilities that is affordable, easily accessible and safe to people and the environment so as to enhance food security to smallholder farmers (Stevenson *et al.*, 2017; Tembo *et al*., 2018).

Weeds on the other hand, despite the fact that are considered by farmers as unwanted and harmful plants with adverse effects to crops in the fields (Vissoh *et al.*, 2004), contain important chemicals that may be used to manage insect pests and other weeds (Pino *et al.*, 2013). Studies conducted by Mkindi *et al.* (2017), Rao *et al.* (2018) and Stevenson *et al.* (2017) reported the potential of using invasive plants with pesticidal properties in managing insect pests both in the field and during storage particularly in smallholder farming systems. Thus, the identification of weeds with pesticidal properties is of great potential in areas where other insect pest control methods failed due to farmer's limited knowledge, high cost and accessibility (Laizer *et al.*, 2019; Midega *et al.*, 2016; Mkenda *et al.*, 2020).

Most studies have reported weeds that affects crop production, but a paltry have gone further to identifying the phytochemicals involved and investigate their practical applications in managing weeds, insect pests, diseases among others, in smallholder farming systems. Considering the importance of common bean in the household food supply and income generation for most smallholder farmers in Tanzania, there is a need to propose an effective, affordable and environmentally friendly strategy for managing weeds and insect pests so as to improve the crop production. The present study was therefore carried out to assess farmers knowledge and practices in managing insect pests and weeds in common bean farming, map the spatial distribution of weeds particularly *S. suaveolens*, investigate effects of *S. suaveolens* crude extracts on seed germination and seedling growth of common bean, screen and identify the phytochemicals present in *S. suaveolens* crude extract as well as the potential of using *S. suaveolens* powder in managing selected storage insect pest (*A. obtectus*) of common beans in northern Tanzania.

1.3 Rationale of the Study

In the era where the global food production is a big challenge, strategies to increase yields and prevent post-harvest loss are of great importance. The demand for food is high due to population increase and most developing countries in Africa, of which food shortage is already experienced need to cope with the demand by enabling smallholder farmers adopt effective and affordable strategies that will help to increase crop production and control yield loss both in the field and during storage.

Therefore, this study attempted to assess the allelopathic effects of extracts from the *S. suaveolens* to common bean seed germination and seedling growth, and explored the insecticidal potential of *S. suaveolens* extracts in managing storage insect pests of the common bean (*A. obtectus*). The findings on insecticidal activities of *S. suaveolens* powder from this study provide valuable knowledge to smallholder farmers that will enable them to manage *A. obtectus* in storage facilities in an affordable and environmentally friendly manner.

1.4 Research Objectives

1.4.1 Main Objective

The overall objective of this study was to assess the allelopathic effects and insecticidal potential of *S. suaveolens* extracts on the germination, seedling growth and insect pest management in common bean fields in northern Tanzania.

1.4.2 Specific Objectives

(i) To assess farmer's perception, knowledge and practices in managing insect pests and weeds in common bean farming.

(ii) To map the spatial distribution of *S. suaveolens* in Arumeru and Moshi rural districts.

(iii) To assess the allelopathic effects of *S. suaveolens* on seed germination and seedling growth of common bean.

(iv) To determine insecticidal activities of *S. suaveolens* on storage insect pest *A. obtectus*.

(v) To screen and analyze the phytochemicals present in the crude extracts of *S. suaveolens*.

1.5 Research Questions

(i) What knowledge and perception do common bean farmers have on managing insects' pests and weeds?

(ii) Which areas/fields are currently infested with *S. suaveolens* in Arumeru and Moshi rural districts?

(iii) Does extract from *S. suaveolens* have allelopathic effects on seed germination and seedling growth of common beans?

(iv) Does *S. suaveolens* have insecticidal activities towards *A. obtectus*?

(v) Which classes of phytochemicals are present in the crude extract of *S. suaveolens*?

1.6 Significance of the Study

The major contribution of this study is the phytochemical analysis of secondary metabolites and identification of compounds that are found in the crude extracts of *S. suaveolens*. These secondary metabolites and compounds may play a key role in the development of botanical based herbicides and pesticides for the management of weeds and insect pests respectively.

Furthermore, this study has identified the knowledge gap among common bean smallholder farmers particularly in the management of weeds and insect pests of common beans and suggest a need for sensitization and trainings to key players specifically farmers, extension officers and agro-input dealers on the sustainable agriculture.

In the like manner, the study also contributed to the understanding of ecological interactions particularly the allelopathic effects *S. suaveolens* has to common bean, and how these interactions affect seed germination and seedling growth and eventually yields in the smallholder farming systems.

Moreover, the study has proposed a workable framework that will help smallholder farmers and other stakeholders in agriculture in planning the proper and effective strategies for managing insect pests, weeds and diseases hence increase crop yields.

Lastly, the study provides a better theoretical understanding and practical application of botanical based pesticides in managing insect pests (*A. obtectus*) of common beans.

1.7 Delineation of the Study

This study focused on assessing the allelopathic effects of *S. suaveolens* on common bean in northern Tanzania under both laboratory and field conditions. Thus, the study didn't consider the interactions between *S. suaveolens* and other crops such as maize, sunflower, banana and so on which are also cultivated by smallholder farmers in northern Tanzania. Also, the study evaluated the insecticidal potential of *S. suaveolens* in the management of *A. obtectus* under the controlled environment within 90 days of the experiment.

CHAPTER TWO

LITERATURE REVIEW

2.1 The Concept of Allelopathy

Allelopathy is a phenomenon, whereby one plant influences the growth of another one, including microorganisms by the release of chemical compounds into the environment (Keeley, 2010; Rice, 1983; Whittaker & Feeny, 1971). The term allelopathy is not new in agriculture, it was first coined by Molsch in 1937, and now broadly applied by researchers around the world (Latif *et al*., 2017). The International Allelopathy Society (IAS) considers allelopathy as the chemical interactions among plants and other organisms, excluding herbivores (Scavo *et al*., 2018). Allelopathy is the result of chemical compounds known as allelochemicals, which are usually plants' secondary metabolites or byproducts of the principal metabolic pathways in plants (Chancellor, 1987; Dayan *et al.*, 2009; Macías *et al.*, 2007).

The secondary metabolites are naturally produced by plants for biological and ecological interactions with neighboring plants and/or the environment (Ooka & Owens, 2018; Rice, 1983). The biological and ecological interactions are diverse, complex and mostly offer advantages to the donor plant and harm to the receiver species (Zeng, 2014; Zhang *et al.*, 2020). Keeley (2010) and Zohaib *et al.* (2016) reported that most allelochemicals are released into the environment from the plant parts through leaching, root exudation, residue decomposition, volatilization and other processes (Fig. 1).

The effects caused by allelopathy depend upon the chemical compounds i.e. allelochemicals released into the environment which may either promote or suppress the growth of the neighboring plants (Haig, 2008; Mushtaq *et al.*, 2020). Allelopathy is different from competition in a sense that, it does not involve the removal or reduction of resources such as light, nutrients and so on but rather release chemicals into the environment and influence the growth and survival of surrounding plants (Scavo *et al.*, 2018; Singh *et al*., 2003). The challenges in agriculture such as seed germination problem, low crop yields in rotation, harmful effects of plants and/or their decomposition on plant growth and crop yields, and direct interference by certain weeds and crops form an important area that need to be further studied and how these impacts can be mitigated particularly in smallholder farming systems.

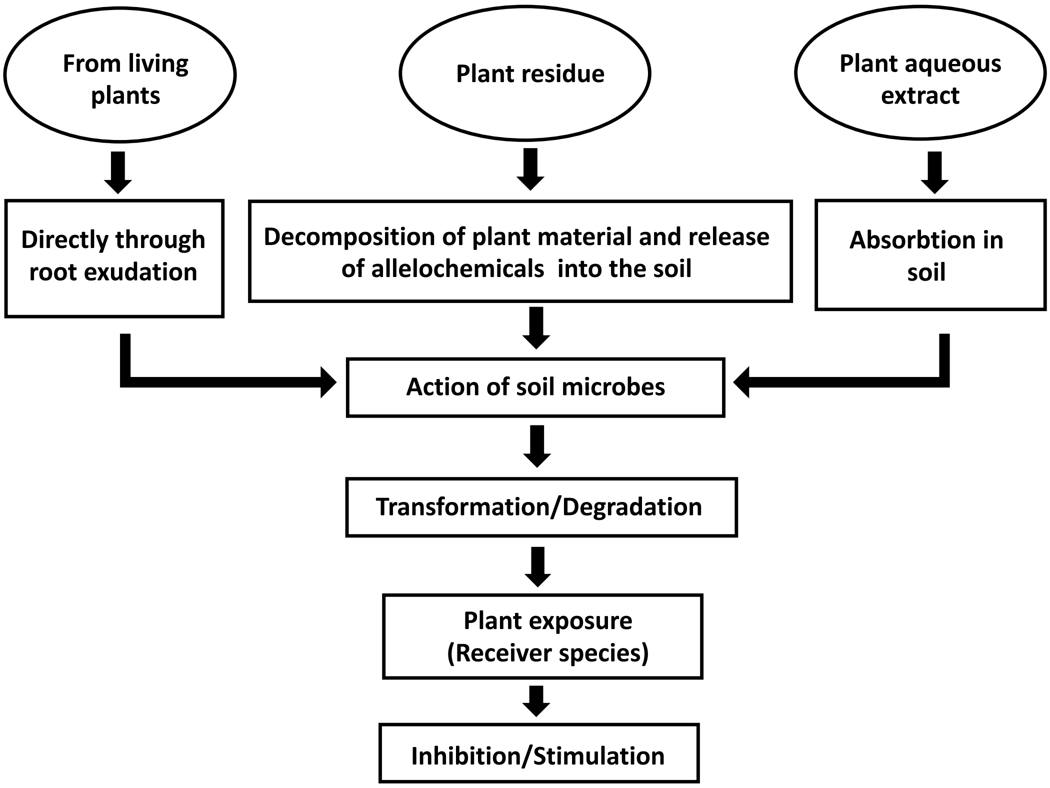


Figure 1: Possible mechanisms for allelochemicals release and transformation

2.2 Allelopathy in Agriculture

Allelopathy plays a significant role in natural ecosystems, and has the potential to become an important aspect in agro-ecosystems as well (Lowry & Smith, 2018). If well manipulated, allelopathy in agriculture can be used to: (a) control insects pests, weeds and diseases (Kong, 2010); (b) enhance soil quality by adding nutrients for crop plants during decomposition from residues (Ullah *et al*., 2020); (c) increasing crop diversity and soil quality through crop rotation while reducing weeds and insect pests (Jabran *et al.*, 2015) and (d) development of botanical pesticides with novel modes of action from allelopathic plants (Latif *et al.*, 2017). In recent years, allelopathy has become a research hotspot for making comprehensive analysis about the mechanism of weed invasion and their success (Azirak & Karaman, 2008; Bais *et al.*, 2003; Einhellig & Leather, 1988). However, most allelopathic plants have been observed to negatively affect the growth, productivity and yield of other crops by causing soil sickness and nutrient imbalance (Kohli *et al.*, 2008), as well as affecting the microbial population (Batish *et al.*, 2001). Several studies have indicated that, most weeds possess allelopathic effects which play a significant role in their invasion success (Macías *et al.*, 2014; Qasem & Foy, 2001; Zhou *et al.*, 2013).

Numerous weeds from the family Asteraceae have been reported by many researchers to possess allelopathy and these weeds can significantly inhibit crop production in agricultural land (Ilori *et al.*, 2010; Kong *et al.*, 2007). The invasive weed for example, *Sphaeranthus indicus* which shares genus with *S. suaveolens* has been reported in most parts of Asia particularly India to inhibit seed germination and growth of wheat (*Triticum aestivum),* rice (*Oryza sativa*) and mung bean (*Vigna radiata*) in different farming systems (Lodha, 2004). Recently, Mahajan *et al.* (2015) reviewed the allelopathic potential of *S. indicus* and found that the germination and seedling growth of several crops were significantly decreased with increase in concentration of its extract.

Despite of the negative effects allelopathy have to cultivated crops, the secondary metabolites particularly allelochemicals can be used to control weeds of various crops in agriculture particularly smallholder farming system. For example, Khanh *et al.* (2006) noted that the allelochemicals contained in tissues of *Passiflora edulis* can significantly suppress the two noxious paddy rice weeds (*Echinochloa crusgalli* and *Monochoria vaginalis*). Other studies have also reported the successful use of extracts from plants with allelopathic effects such as *Desmodium spp.* and *Secale cereale* in controlling weed both in the laboratory and field conditions (Jabran *et al.*, 2015; Ngondya *et al.*, 2016; Ojija *et al.*, 2019b). Jamil *et al.* (2009) described the utilization of allelopathic water extracts from *Eucalyptus sp*, *Sesamum indicum, Nicotiana tabacum* and *Helianthus annuus* as important and useful ways of exploiting the allelopathic potential in managing wild oat and canary grass in wheat fields. Moreover, the allelochemicals such as Lycorine from the plant *Hymenocallis littoralis* were found to be effective in inhibiting the germination and root length of most rice weeds (Iqbal *et al.*, 2006). The allelopathic crops when used as cover crop, mulch, smother crops, green manures, or grown in rotational sequences maybe helpful in reducing noxious weeds and plant pathogens, improving soil quality and enhancing crop yields (Khanh *et al.*, 2005).

Furthermore, the application of allelopathic extracts may give an efficient alternative control over weeds similar to that offered by synthetic herbicides (Xuan *et al.*, 2004). Interactions among potential allelopathic plants, target pests and other non- target organisms in a cropping system also need to be considered and fully realized to avoid detrimental effects to desired crops and non-target species (Farooq *et al.*, 2013). The allelochemicals involved in weed suppression can serve as basic templates for developing new generation of biopesticides with low or no toxic effects to the environment and human health (Ferguson *et al.*, 2009). The allelopathic effects of invasive weeds such as *S. suaveolens* to crops such as common bean need to be investigated, and the allelochemicals involved should be screened and identified to serve as candidates for developing effective and environmentally friendly weed and insect pest management strategies particularly in smallholder farming systems.

2.2 Insecticidal Potential of Invasive Plants to Storage Insect Pests

Insecticides, weather natural or synthetic are developed to either kill, repel, or interfere with the damaging behavior of insect pests (Environmental Protection Agency [EPA], 2009). Due to intensity of plant-insect interactions, plants have well developed defense mechanisms against insect pests by producing secondary metabolites inform of natural compounds which acts as pesticides (Després *et al.*, 2007). The most exciting concept is to screen these compounds and use them as candidates in making safer pesticides (Maia & Moore, 2011). Plant extracts with pesticidal properties can offer several benefits (compared to their counterpart i.e. synthetic pesticides) such as active against killing specific targeted insect pests, biodegradable, have low to non-toxic effects, cheap and can be prepared easily even by smallholder farmers themselves (Kim *et al.*, 2003; Mkindi *et al.*, 2017). Due to these facts, such plant extracts could lead to the development of new classes of safer pesticides (Céspedes *et al.*, 2014; Tembo *et al.*, 2018).

In agriculture, insect pests cause crop damage both in the field and during storage. The estimated global losses of various crops due to insect pest ranges from 19% to 55%, and in most severe case it may reach 100% i.e. total loss (FAOSTAT, 2017; Pratt *et al*., 2017). Damage to stored grains is a serious concern as well particularly to smallholder farmers in Africa who store their yields to ensure food supplies for their households and seeds for planting in the subsequent season (Midega *et al*., 2016; Nukenine, 2010). Synthetic pesticides have been reported as the method of choice to most farmers in trying to control insect pests both in the field and during storage (Kedia *et al.*, 2015). However, the continuous use of these chemical pesticides has resulted into toxicological effects to the environment particularly the non-targeted organisms as well as humans (Pretty & Bharucha, 2015; Singh & Kaur, 2018). These adverse effects have raised interest to many researchers and scientists on the use of natural compounds as botanical insecticides for controlling insect pests (Dimetry, 2012; Maia & Moore, 2011).

The natural compounds from the plants' secondary metabolites are considered safe and most important they can be used to make botanical pesticides which are economically feasible to smallholder famers who in most cases cannot afford their synthetic counterparts (Céspedes *et al.*, 2014; Stevenson *et al.*, 2017). The identification of plant families with pesticidal properties became an important step towards the development of botanical pesticides (Pant *et al.*, 2016). Plant families *Maliceae, Asteraceae* and *Euphorbiaceae* among others, were documented to contain insecticidal properties and were used to control storage insect pests (Dhale, 2013; Green *et al.*, 2017; Sosa *et al.*, 2019). The control method gained popularity among farmers in different parts of the world, and most farmers were reported to use various powder from botanical plants and apply them in storage facilities (Nukenine, 2010; Silva *et al.*, 2012; Tiwari *et al.*, 2018). The technique was very effective in controlling insect pest such as rice weevil (Patole *et al.*, 2008), cowpea weevil (Singh & Shrivastava, 2012) and red flour beetle (Pugazhvendan *et al.*, 2012). The presence of secondary metabolites with pesticidal properties from invasive plants particularly weeds are responsible for different activities against insect pests. However, further investigation is needed particularly on the practical application of botanical pesticides from weeds and how smallholder farmers can use these weeds to manage and control insect pests both in the field and during storage without compromising the crop production as far as weeds invasion is concerned.

2.3 Extraction and Identification of Secondary Metabolites in Plant

Plants are known to have natural ability to perform several biological and ecological functions including fighting diseases, defense against other plants and insect pests (Pagare *et al.*, 2015; Ramakrishna & Ravishankar, 2011). These different functions are the results of various active compounds in the plants' secondary metabolite and most of them are synthesized during the shikimate pathway (Hussain & Reigosa, 2011) or, in the case of essential oils, from the isoprenoid pathway (Rehman *et al.*, 2016). These active compounds can be classified based on their structures and properties into phenolics, cinnamic acid and its derivatives, coumarins, flavonoids, tannins, steroids and terpenoids (Li *et al.*, 2010). The pesticidal and herbicidal activities of most plants are linked to the presence of different chemical groups of the active compounds (Shitan, 2016) and most of them works by acting as allelochemicals, larvicides, plants and insect growth regulators, feeding and oviposition deterrents (Miresmailli & Isman, 2014).

The active compounds in plant secondary metabolites can be manipulated to offer benefits in agriculture such as management and control of insect pests and weeds particularly to smallholder farmers who cannot afford wide spectrum pesticides and herbicides (Ahmed *et al.*, 2017; Macías *et al*., 2007; Zaynab *et al*., 2018). The screening and identification of secondary metabolites responsible for the pesticidal and/or herbicidal activities is important during the bio pesticidal development (Pendota *et al*., 2018; Sasidharan *et al*., 2011). The extraction of secondary metabolites involve the use of different solvents, and the choice depends on the nature of the active compounds to be extracted i.e. polar compounds are extracted with polar solvents while for non-polar compounds, non-polar solvents are used (Zuorro *et al*., 2019). The use of several solvents has been commonly practiced to extract secondary metabolites, and researchers usually soaked dried powder of plants to extract these active compounds (Altemimi *et al*., 2017). The use of multiple solvents in chronological order is recommended starting with non-polar, less polar to polar solvent in order to maximize the extraction of compounds (Pendota *et al.*, 2018). The polarity of the commonly used solvents in extraction of secondary metabolites from the less polar to the most polar is as follows: Hexane < Chloroform < Ethylacetate < Acetone < Methanol < Water (Sasidharan *et al.*, 2011; Zuorro *et al.*, 2019).

The efforts to screen and identify the secondary metabolites from various plants were carried out by many researchers, however, much of the work focused on medicinal applications while a paltry investigated on the pesticidal and herbicidal potentials of secondary metabolites from invasive plants (Altemimi *et al.*, 2017; Kleinowski *et al.*, 2016). The identifications of these secondary metabolites will justify the practical applicability of plant based botanicals as well as help in selecting best candidates for making safer and more effective pesticides and herbicides (Kremer & Ben-Hammouda, 2009), therefore, further work is required to investigate the application of these secondary metabolites particularly from an invasive plant *S. suaveolens* which is currently invading most agricultural lands in northern Tanzania.

2.4 Farmers Knowledge, Perception and Practices towards Insect Pests and Weeds Management

The diversity of insect pests and weeds in most agricultural lands need a multi-control strategies to produce satisfactory results in a sustainable manner (Parker *et al.*, 2013). The goals and values of long-term sustainability must be reflected in the combinations of practices and methods consistent with an individual farmer's resources, knowledge and farming practices (Ikerd, 1993; Tittonell *et al.*, 2010). Unfortunately, most smallholder farmers in developing countries are resource constraint and have limited knowledge on pest and weed management strategies, thus limit their capacity to manage weeds and insect pests in a sustainable manner (Laizer *et al.,* 2019*;* Whitbread *et al.*, 2010).

Pest management practices by most smallholder farmers are mainly based on use of chemical pesticides, though this alone does not give the desired results (Toda & Morishita, 2009). Few of these farmers have combined such method with some cultural practices such as intercropping and crop rotation (Ajeigbe *et al.*, 2010; Ngowi *et al.*, 2007). Other studies reported that limited technical knowledge among smallholder famers and shortage of extension services are among the limiting factors that hinder the adoption of suitable pest management practices (Midega *et al.*, 2012; Mkenda *et al.*, 2020). Most farmers still relying on past experience and traditional farming practices despite the fact that they have not attained fruitful results over the years (Khan & Damalas, 2015). Integrating different pest management practices has long been proposed as the long term solution and future for sustainable agriculture (Pretty & Bharucha, 2015).

The development of pest and weed management approaches need to incorporate farmer's knowledge, perceptions and practices in every stage during the designing for their easy adoption and implementation (Chitere & Omolo, 2008; Hashemi & Damalas, 2010; Huis, 2014). Most farmers are well aware of species interactions and how these interactions affect crop production, for example, Khan *et al.* (2010) reported that some farmers are aware of the role played by companion crops with repellent or toxic characteristics in pests control, as well as harboring natural enemies and in this regard, *S. suaveolens* may have considerable potential. Also, Isman and Grieneisen (2014) pointed out that smallholder farmers use several plant species from the *Asteraceae* and other families with pesticidal properties to control and manage insect pests and weeds.

Despite the fact that various plant species with pesticidal properties are known to farmers, only a handful of smallholder farmers are applying them. The research on botanicals should now focus on farmers knowledge gap and what hinders the adoption of botanical pesticides despite the benefits offered as the feasible alternative particularly to smallholder farmers in Africa (Mkenda *et al*., 2020; Mkindi *et al*., 2020; Stevenson *et al*., 2017). There is a need for training and sensitizing farmers on the importance of local knowledge and sustainable practices in weed and pest management and how best to integrate such knowledge and practices with science and research findings during the designing of weed and insect pest management strategies.

2.5 Spatial Distribution of *Sphaeranthus suaveolens* in Tanzania

Invasive plants can pose challenges to crop production particularly in smallholder farming systems (Martin, 2017; Pratt *et al.*, 2017). The management of most invasive plants such as weeds have been through the use of chemicals which pose some health effects to farmers and the environment (Céspedes *et al.*, 2014; Corriher-Olson *et al.*, 2019). The effective crop production in agricultural systems does not depend on only application of chemical fertilizers and pesticides but rather on judicious use of various resources such as agricultural inputs (including seeds, fertilizers, pesticides etc.), tools for decision support (soil fertility analysis, weather and climate, weed population maps, market trends, etc.) (Blank *et al.*, 2019). In Tanzania however, tools for decision support have not been extensively applied particularly in smallholder farming systems which leads to poor crop productions and yields losses.

Mapping of weed population is among the decision support tool which can be adopted in the localized control of weeds since the technique allows close monitoring of the infestation over time, enabling the development of management strategies that minimize the effect of competition with the crop, as well as saving of resources due to the application of varying volumes according to the infestation (Papadopoulos *et al.*, 2018; Thiney *et al*., 2019). Therefore, mapping the distribution of the weeds particularly in farmlands is vital for the effective management and monitoring (Kayitete *et al.*, 2018). Studies that explored the spatial and temporal variability of weeds in farmlands and other areas observed that, most weeds show a defined spatial distribution with an aggregated structure of occurrence (localized groups) and weed distribution rarely occurs at random, rather influenced by certain conditions which differs in each environment (Metcalfe *et al.*, 2019; Somerville *et al*., 2020). This suggests that mapping the spatial distribution of weeds such as *S. suaveolens* may serve as an important tool for the effective monitoring and control as well as making the use of herbicide more rational and economic.

Currently, the *S. suaveolens* is reported widespread in tropical and sub-tropical areas of Asia, Africa and Australia and mostly grows in wetlands and thrives well in medium clay soils, but also common in and around irrigation ditches and rice fields (Laizer *et al*., 2020). In Africa, this weed is distributed over a range of altitudes from Rwanda, Burundi, Sudan, Ethiopia, Zambia, Malawi, Mozambique, Egypt, Uganda, Kenya to Tanzania (Everard *et al*., 2002; Fahmy, 1997). In Tanzania, the distribution of *S. suaveolens* is not well known and only few studies have mapped its distribution in Songea (Brenan, 1960), Mpwapwa (Launert, 2003), Mkata and Mandela in Wami River Ecosystem (Mligo, 2016). The spatial distribution of *S. suaveolens* in northern Tanzania particularly Arusha and Kilimanjaro regions need to be mapped to help locating possible areas where the plant is densely populated for either eradicating or utilization as botanical plant.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

3.1.1 Description of the Study Area

The study was conducted in Arumeru (3°08′S, 36°52′E) and Moshi rural (3°21′43.2″S, 37°27′32.4″E) districts in Arusha and Kilimanjaro regions respectively in northern Tanzania. The household surveys (HHS) were conducted from October 2018 to February 2019 in 13 villages (7 from Arumeru and 6 from Moshi rural as highlighted in green and blue in the Fig. 2) covering the key common bean growing areas which are highly affected by weeds and insect pests in the two districts. The villages covered were Nambala, Lekitatu, Ndato, Kikatiti, Malula, Maroroni and King'ori in Arumeru district while Boro, Kirima kati, Umbwe sinde, Maua, Uchau kusini, and Sambarai were visited in Moshi rural district. These areas experience a bi-modal rainfall pattern, with the main cropping season running from March to May and the short cropping season from November to January. The zone is also considered high potential for agriculture, with both high and medium elevation (1035 - 1724 m above sea level). The main farming systems comprise of crops such as banana, coffee, and cereals such as rice, maize intercropped with legumes such as common beans.

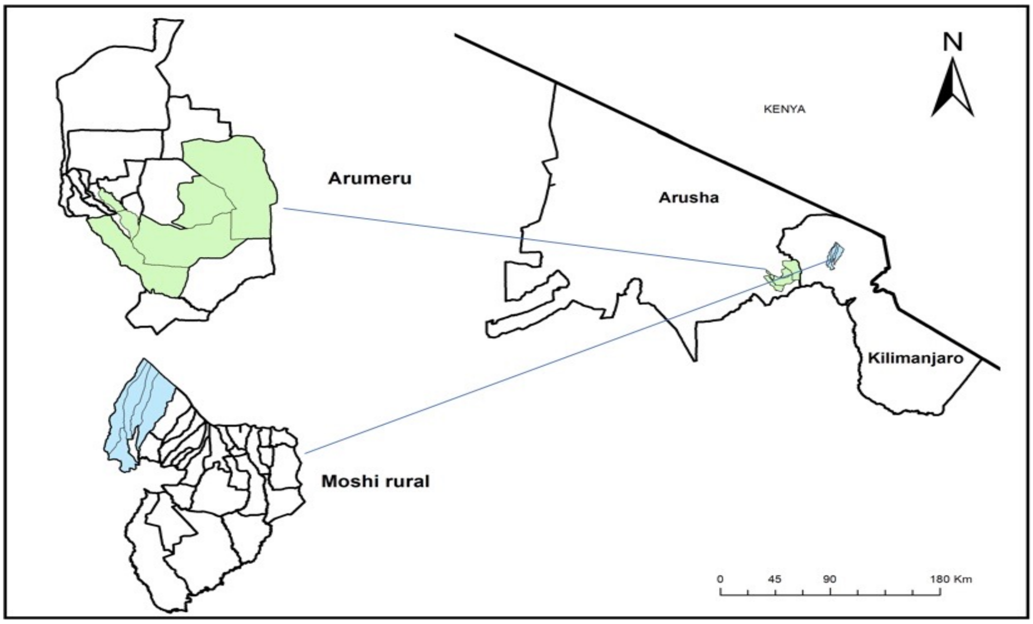


Figure 2: Location of the study area i.e. Arumeru and Moshi rural districts

3.1.2 Plant Materials

Freshly matured plants of *S. suaveolens* (Plate 1) were collected from different places such as farmlands, swampy areas and river banks in Arumeru and Moshi rural districts in both dry and rainy season from June to November 2018. The healthy plants were then sorted and shade dried for 14 days under room temperature to avoid the influence of direct sunlight and temperature on plants chemical composition (Dodia *et al.*, 2010; Pagare *et al*., 2015). The dry plants from different localities were mixed up, grounded into powder to form a composite sample which was stored in plastic container prior to the experiments. The reason for mixing the samples was to diversify the concentration and content of the secondary metabolites as they differ from place to place (Mkenda *et al*., 2015).

Plate 1: *Sphaeranthus suaveolens* plant with leaves and flowers (purple round heads)

3.1.3 Seeds Preparation and Storage

Seeds of three commonly grown bean varieties in northern Tanzania i.e. Jesca, Lyamungu 90 and Selian 97 (Plate 2) were collected from Selian Agricultural Research Institute (SARI) in Arusha, Tanzania. Prior to the experiment, the seeds were checked for any signs of damage, then sorted, air dried and stored in plastic bags.

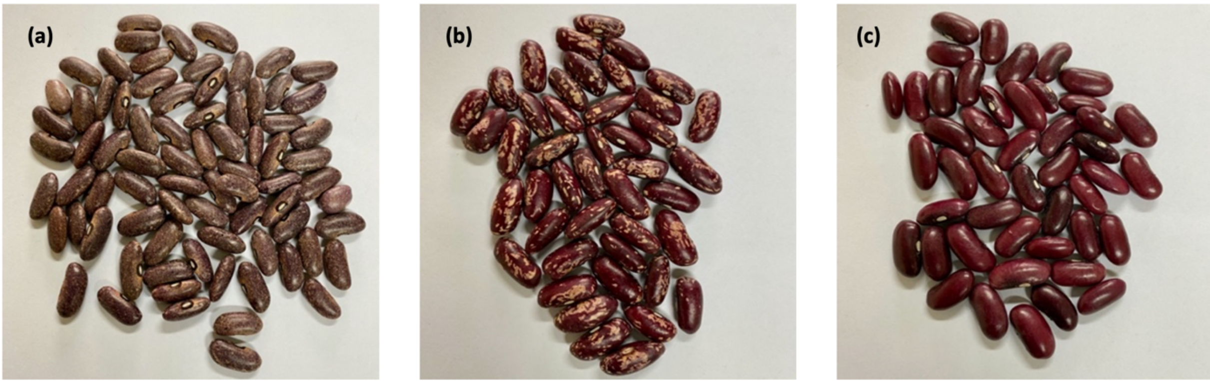


Plate 2: The three bean varieties used in the storage insect pest experiment (a) Jesca (b) Lyamungu 90 (c) Selian 97

3.1.4 Insects

Adult *A. obtectus* were collected from infested common bean seeds purchased from local market and brought to the laboratory (Plate 3). The insects were reared with common bean seeds and kept at temperature of 28 to 30 °C and relative humidity of 70% and continuously maintained throughout the study period (Mulungu *et al.*, 2007). Since adult *A. obtectus* play dead when disturbed (Alemayehu & Getu, 2017), it was easy to separate the adults from the rest using tweezers and a lens.

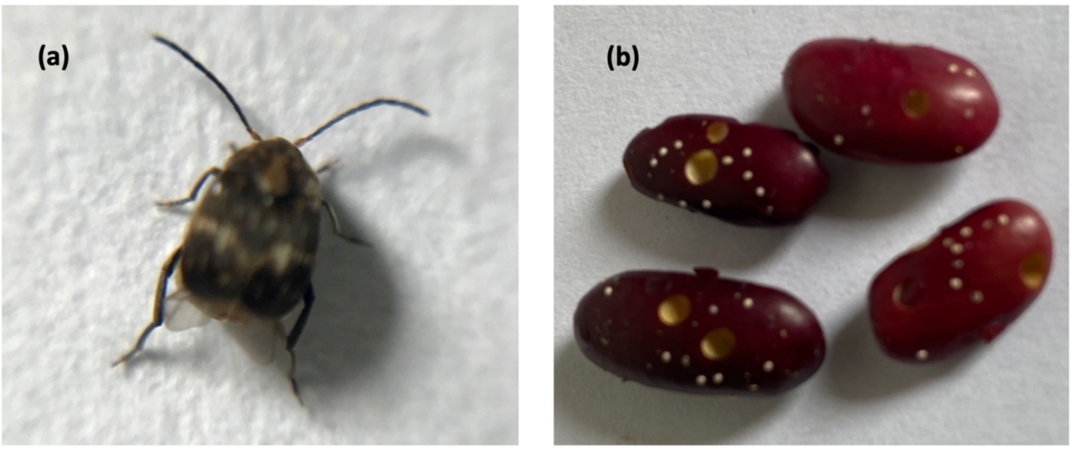


Plate 3: (a) An adult *A. obtectus* (b) Common bean seeds damaged by *A. obtectus*

3.2 Methods

3.2.1 Assessing Farmers Knowledge and Practices in Managing Insect Pests and Weeds

(i) Household Interviews

Data on common beans farming and its constraints, particularly insect pests and weeds in northern Tanzania were collected through household surveys as per Midega *et al.* (2016). In each of the 13 villages visited, the respondents for the interviews were randomly selected using sampling lists provided by the village leaders in the two districts. A total of 169 farmers were interviewed from Arumeru and Moshi rural districts. The semi-structured questionnaire used comprised of questions on households' demographic characteristics, economic profile, farm characteristics, yields, percentage of yields damaged by pests and weeds, knowledge and perceptions of common bean pests and weeds, pest control methods and practices (Table 1). The questionnaire was pre-tested in a pilot study before being used in the targeted districts. Before starting an interview, a consent form was provided to the respondent, which introduced and explained the aim of the research and asked for approval to continue with the interview.

Table 1: Overview of the questions included in the questionnaire used

Data Group	Description
Personal data, economic profile and farms characteristics	Gender; Age; Education; Household size; Yields; Land ownership
Knowledge of common bean pests and weeds	Most common insect pests and weeds; common and scientific names of each species; perceptions of impact on common bean yields
Pest and weed management practices	Common methods of pest and weed control; Criteria for the selection of weed and pest control strategy; Decisions on which methods should be used and for what periods; Pros and cons of different control methods; Pesticide use; Pesticide products; Pesticide rates applied in the field; Perceptions of the effects of pesticide use (synthetic vs. botanical); Levels of knowledge about pesticide safety (synthetic vs. botanical)

(ii) Focus Group Discussion

The focus group discussion (FGD) was conducted in each village to supplement data from the household interviews. The FGD involved 6 to 12 farmers from different age groups, gender, sub-villages and farming experience (Plate 4). Guiding questions were asked to provoke a discussion on farmers' perceptions, knowledge and opinions on the key aspects of common bean farming and their constraints, particularly weeds and insect pests, their management and challenges. Farmers in the FGD were free to air out their views and talk with other group members. Data were collected using both audio recorder and note taking. A total of 13 FGD were conducted in this study.

Plate 4: Focus group discussion in (a) Arumeru and (b) Moshi rural districts

(iii) Key Informant Interview

Key informant interviews were conducted in each ward with the agricultural officers, ward executive officers and agro-input dealers in the two districts. The purpose of key informant interviews was to collect more information on knowledge and practices in common bean farming particularly in managing weeds and common bean pests. Information on pesticides used, planting and weeding calendar, common been varieties, average yields per hectare, types of weeds and insect pests were gathered using audio recorder and note taking. The summary from the collected data provided an insight on the challenges in common bean farming in the two districts. A total of nine key informant interviews were conducted.

3.2.2 Mapping the Spatial Distribution of *Sphaeranthus suaveolens*

A field survey was conducted in nine villages from the Arumeru and Moshi rural districts during rainy (March to June) and dry (August to November) seasons to collect distribution data of *S. suaveolens*. The survey in farmlands and adjacent areas where *S. suaveolens* is growing was conducted using a vehicle and motorcycle. Farms, grazing areas, settlements, swamps and other areas within the villages were scanned for the presence of *S. suaveolens* and stops were made after every 30 to 50 m. Global Positioning System (GPS) coordinates were taken and recorded in the notebook whenever the *S. suaveolens* was seen using the Garmin GPSMap 65 device. Points sampled per village ranged from 20 to 60 depending on the level of invasiveness by *S. suaveolens*. Other data recorded included elevation, date, land use type and density per square meter. A quadrat of 1x1 meter was used in estimation of density of *S. suaveolens*. The density was considered as low, medium and high depending on the number of plants in the quadrat i.e., 1 - 2, 3 - 4, more than 4 respectively (Ojija *et al*., 2019b). The collected coordinates/points were downloaded from GPS to the computer using Garmin MapSource software and saved in xsv file format. The data were then loaded to ArcGIS version 10 software to show the distribution of pints in the maps. Shape files for the districts and villages boundaries were extracted from the National Bureau of Statistics database.

3.2.3 Assessing the Allelopathic Effects of *Sphaeranthus suaveolens* on Common Beans Seed Germination and Seedling Growth

(i) Crude Extract Preparation

The extracts from the whole plant of *S. suaveolens* dry powder were prepared according to Ngondya *et al.* (2016) with few modifications as follows: 100 g of *S. suaveolens* powder were soaked separately in one liter of distilled water and left for 72 hours. Afterwards, crude extracts were filtered using Whatman filter paper number 1 to obtain a final volume of one liter each. Both crude extracts (mL) were diluted with distilled water (mL) in the ratio of 25:75, 50:50, 75:25 and 100:0 (extract:distilled water) to obtain different concentrations of 25%, 50%, 75% and 100%. The diluted extracts were kept in the refrigerator at 4 °C prior to the experiment.

(ii) Pre-germination Test and Seed Preparations

The common bean seeds from the three varieties used in this study were pre tested for germination prior to the experiment. Seed viability was determined by germination testing (Wildfong, 2015), in which all the 10 seeds (100%) that were selected randomly from a seed stock with the three varieties and planted in a petri dish lined with cotton wool in early September 2019, germinated. There was no significant difference in seed germination between the three bean varieties used in this experiment, therefore Selian 97 bean variety was selected for the germination experiment.

(iii) Laboratory Experiment

The effects of *S. suaveolens* crude extracts on the seed germination, seedling height and leaf chlorophyll content of common bean were studied using a completely randomized design (CRD) from October to November 2019. Ten seeds of common bean were placed in each of the five petri dishes lined with cotton wool and irrigated once a day with 10 mL of five different concentration treatments; 0%, 25%, 50%, 75% and 100%. Each petri dish was irrigated treatment was replicated three times. Seeds were observed every day and the number of germinated seeds were recorded and counted for seven days. Seedlings were harvested after seven days and fresh weight, seedling height and leaf total chlorophyll content were determined for each germinated seedling. The entire experiment was repeated three times.

(iv) Screenhouse Experiment

The effects of crude extracts of *S. suaveolens* on the seed germination, seedling height, leaf total chlorophyll content, fresh and dry weight of common bean were studied using a completely randomized design in a screen house from October to November 2019. Six seeds of common bean were placed in five pots and irrigated once a day with 100 mL of five different concentration treatments; 0%, 25%, 50%, 75% and 100%. Each treatment was replicated three times. Seeds were observed every day and the number of germinated seeds were recorded and counted for the first seven days. Seedlings were then harvested after 14 days and the fresh weight of root and shoot, seedling height (root and shoot length) and leaf total chlorophyll content were measured for each germinated seedling. Similar to the laboratory experiment, this experiment was also repeated three times.

(v) Chlorophyll Content Determination

Leaf chlorophyll of the common bean seedlings was extracted according to Hiscox and Israelstam (1978) with some modifications: 50 mg of common bean fresh leaves of 2.25 cm^2 surface area were immersed in 4 mL of Dimethyl Sulfoxide (DMSO) and incubated at 65 °C for 12 h. The extract was transferred to glass cuvettes for absorbance determination. The absorbance of blank liquid (DMSO) and samples were determined under 2000 UV/VIS spectrophotometer (UNICO®) at 645 and 663 nm (Hiscox & Israelstam, 1978), and the leaf total chlorophyll content (Chl) calculated according to Arnon (1949) using the following equation:

$$Total\ Chl = 0.0202A_{663} + 0.00802A_{645}$$

where A_{663} and A_{645} are absorbance readings at 663 nm and 645 nm, respectively.

3.2.4 Assessing the Insecticidal Activities of *Sphaeranthus suaveolens* Powder towards *Acanthoscelides obtectus*

(i) Layout of the Experiment

The experiment was set in 54 (6 treatments x 3 replicates x 3 bean varieties) plastic containers (16 cm x 20 cm) arranged in a completely randomized design each containing 150 g of common bean seeds. 10% of *S. suaveolens* powder to weight ratio of seeds will be considered as 100% (15 g) (Kawuki *et al.*, 2005). Then different treatments 25% (3.75 g), 50% (7.5 g), and 75% (11.25 g) will be prepared. For controls, 0 g will serve as negative control while 0.25 g of Actellic super dust will serve as positive control. Then different treatments and controls were added in the containers with common bean seeds and mixed thoroughly. Afterwards, 15 unsexed adult *A. obtectus* were introduced into each of the container. Data on effects of *A. obtectus* as influenced by different treatments in each common bean variety were recorded after the first 24 h, then once after every 30 days for a period of 90 days. Data collected include number of live and dead insects, number of holes per seed, number of damaged seeds and weight loss.

3.2.5 Phytochemical Screening of Secondary Metabolites from *Sphaeranthus suaveolens* Extracts

The phytochemical screening and analysis of secondary metabolites in *S. suaveolens* extracts were carried out using standard procedures for identifying the phytochemicals (Table 2). The procedures which show sample preparations and test for the presence of tannins, terpenes, saponins, flavonoids, glycosides, steroids, alkaloids, anthraquinones and coumarins were adopted and slightly modified from the methodology described by Kumar and Thampi (2015). Two crude *S. suaveolens* extracts from water and methanolic solvents were used in this experiment. Each test was repeated three times to confirm the presence of tested phytochemical.

Table 2: Summary of the procedures used in the phytochemical screening of secondary metabolites

Phytochemical	Procedures	Inference for presence
Tannins	1 mL of distilled water added to 0.5 g of extract then the mixture was stirred, filtered and few drops of ferric chloride were added to the filtrate.	Blue-black precipitates.
Terpenes	2 mL of the chloroform was added to the 2mL alcoholic solution of extract and then evaporated to dryness, then 2 mL of conc sulphuric acid was added and heated for 2 min.	A greyish color.
Saponins	0.5 g of extract was added to 5 mL of distilled water and shaken well then gently warmed.	Persistent formed of froth.
Flavonoids	Distilled water was added to the acetone filtrate of the extracts and then the mixture was filtered. 5 mL of the filtrate was collected and added in a test tube. Afterwards, 5 mL of 20% sodium hydroxide was added to 5 mL of the filtrate.	Yellow.
Glycosides	About 0.1 g of extract was dissolved in 1 mL of glacial acetic acid containing one drop of ferric chloride solution. Then 1 mL of conc sulphuric acid was added in the mixture.	The brown ring.
Steroids	About 2 mL of extracts was added to 2mL chloroform and 2mL of conc sulphuric acid.	Reddish brown in the junction.
Alkaloids	About 0.5 g of the extract was added to 3 mL of 1% aqueous hydrochloric acid and stirred in a steam bath. The mixture was then filtered, and 1 mL of the filtrate was poured in a test tube containing 0.5 mL and 3 drops of Wagner's reagent was added.	Brown/reddish precipitate.
Anthraquinones	50 mg of extract was heated with 1 mL 10% ferric chloride solution and 1 mL of conc hydrochloric acid. Then the mixture was then shaken with equal amount of diethyl ether followed with strong ammonia.	Pink-red aqueous layer.
Coumarins	0.5 g of the moistened extract was placed in a test tube and covered with filter paper treated with 1 N NaOH solution. The test tube was then placed in boiling water for few minutes and the filter paper was removed and examined under the UV light.	Yellow fluorescence.

3.2.6 Gas Chromatography-Mass Spectrometry Analysis of Secondary Metabolites

Phytochemical analysis of water extract from *S. suaveolens* was performed using GC-MS Agilent Technology (7693) consisting 7890B Gas Chromatography (GC) coupled with 7010 Triple Quadruple Mass Spectrometer (Plate 5). The split less mode was employed to inject 2 µl of each sample. The HP-5 column (30 m long, 0.250 mm internal diameter and 0.25 µm film thickness, Agilent Technology) was employed to separate phytochemical compounds. The flow rate of the mobile phase (carrier gas: Helium) was set at constant of 1 mL/min. The samples were dissolved in water, the Electron Ionization (EI) mode for Mass Spectrometer was set at 70 eV with FID at the scan range between m/z 40 and m/z 500 so as to produce mass spectra. The oven temperature was held at 40 ºC for 4 min then increased to 250/280 ºC at the rate of 5 ºC/min and maintained at this temperature for 2 min. The solvent peak was delayed for 4 min and the maximum total running time was 30 min. Compounds were interpreted by comparing spectral peaks in GC-MS chromatogram with the library database.

Plate 5: The GC-MS analysis of *S. suaveolens* extracts

3.2.5 Data Analysis

Survey data for assessing farmer's knowledge, perceptions and practices in managing weeds and insects pests of common bean were summarized and descriptive statistics (means, standard deviation, and percentages) were calculated using the Statistical Package for the Social Sciences (SPSS) version 25. The audio data recorded during the FGD and KII were first converted into texts (transcription), thereafter a content analysis was done to identify common themes. The common themes were then coded and analyzed with the rest of the data using SPSS. For multiple answered questions, the percentages were calculated for each group of similar responses. The percentages of farmers in the two districts (Arumeru and Moshi rural) who gave similar responses to a question were calculated based on the total number of farmers who responded to such question. Comparative statistical tools, such as chi-square and one-way analysis of variance (ANOVA), were conducted to assess differences regarding socio-demographic, farm characteristics, knowledge, perceptions and management practices of common bean pests and weeds. The level of significance was set at 5% and means were separated by Tukey's honestly significant difference (HSD) test.

Data on allelopathic effects of *S. suaveolens* on seed germination, seedling growth (shoot length, root length, fresh weight of shoot, fresh weight of root and chlorophyll content) of common bean were compared using one-way ANOVA while data on storage insect pest experiment as well as the correlations coefficients for the investigated variables (number of live insects, number of dead insects, number of seeds with holes, number of holes per seed and weight loss) were statistically analyzed by two-way ANOVA. The identification of compounds was done by comparing mass spectra of the compounds with either pure standards or published spectra in the NIST GC-MS library.

The normality and homogeneity of variance for data from the allelopathy experiment were verified using Shapiro–Wilk test and Levene's test respectively. Fisher's least significant difference (LSD) test was used to compare the significance differences between the group means from the treatments and varieties. The statistical software used in allelopathy and storage insect pest experiments was Origin (version 2018b) at a significance level of 5%.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Socio-Economic Characteristics of Farmers in Arumeru and Moshi Rural Districts

The results from the social survey conducted in the two districts indicate that most of the farmers (71%) were male. The average age of the farmers did not vary ($p<0.18$) across the surveyed districts, and ranged from 49 years in Arumeru to 51 years in Moshi rural. The mean age for all districts combined was 50 years, which is in the middle age category (Table 3). The majority of the respondents (78%) had primary education, while 8% had non-formal education but were able to read and write. There was only a paltry of respondents (1%) with tertiary education (college and university) (Table 3). The average household size of farmers in both districts surveyed comprised of 5 individuals and the household size ranged from 2 to11 individuals. The respondents in both districts were smallholder farmers owning an average land size of 0.44 ha. Additionally, the average area allocated to common bean by most farmers was less than 0.2 ha. Common bean was grown mainly for home consumption and for sale as reported by 70% of the farmers. On the other hand, 20% of the farmers reported growing common bean solely for home consumption while the remaining 10% of the farmers reported selling all their produce. Yields of common bean varied significantly ($p<0.001$) across districts, with a mean yield of 242 kg/ha for all districts (Table 3).

Table 3: Socio-economic characteristics of the respondents and common bean yields

Variables		Districts		Mean (SD)	Chi Square
		Arumeru	Moshi Rural		
Gender (%)	Male	75	67	71 (5.37)	x^2 = 1.197; df = 1; p = 0.27
	Female	25	33	29 (5.37)	
Education level (%)	None	6	11	8.5 (3.75)	
	Primary	77	79	78 (1.63)	
	Secondary	15	10	12.5 (3.61)	
	College	2	0	1 (1.63)	
Education (years)	Mean (SD)	7.07 (2.55)	6.29 (2.74)	6.68 (2.65)	x^2 = 8.73; df = 7; p = 0.27
Age (%)	18-45	45	37	41 (3.54)	
	45-60	36	41	39 (0.71)	
	>60	19	22	20 (2.83)	
Age (years)	Mean (SD)	48.95 (12.51)	51.29 (10.13)	50.12 (11.32)	x^2 = 50.27; df = 42; p = 0.18
Household size (%)	1–5	66	56	61 (4.24)	
	6–10	34	43	38.5 (2.83)	
	>10	0	1	0.5 (1.41)	
Household size	Mean (SD)	5 (1.57)	6 (1.74)	5.5 (1.66)	x^2 = 14.36; df = 8; p = 0.07
Land owned per household (%)	0–1	92	100	96 (5.65)	
	2–3	8	0	4 (5.65)	
Land owned per household (ha)	Mean (SD)	0.5 (0.53)	0.38 (0.18)	0.44 (0.2)	x^2 = 18.95; df = 9; p = 0.02
Yields (kg/ha)	Common bean	306 (188.11)	178 (81.98)	242 (135)	x^2 = 79.88; df = 15; p = 0.001

4.1.2 Common Bean Cultivation Practices Applied by Farmers in Arumeru and Moshi Rural Districts

On average, common bean was grown on 0.44 ha per household in both the districts. This ranged from 0.34 ha to 0.63 ha in Moshi rural and Arumeru districts, respectively. Intercropping was the most common farming practice reported by majority of farmers (98%) visited in the two districts. On average, farmers in both districts reported intercropping common bean with maize and banana as a traditional practice. Crop rotation, on the other hand, was only practiced by few farmers (16%) in the Arumeru district only, with common bean being rotated mostly with vegetables, such as African eggplant (*Solanum aethiopicum*) and Green pepper (*Capsicum annuum*). The majority of the respondents (96%) had experience in common bean farming, with an average of 17 years, but the farming experience varied significantly across districts, ranging from 9 to 25 years in the Moshi rural and Arumeru districts, respectively. However, despite the years of experience in common bean farming, yields remained low and varied significantly across districts, with Moshi rural recording the lowest yields (178 kg/ha) and Arumeru with the highest yields (306 kg/ha) in the year 2019 (Table 3). Most of the farmers (89%) in the two districts indicated that they check and sort common bean seeds that are not damaged by insect pests to be used as seeds in the subsequent season.

4.1.3 Farmers' Knowledge of Weed and Pest Problems in Common Bean Farming

In this study, 88% of the respondents reported that insect pests were the major constraint to effective production of common bean, followed by weeds as mentioned by 73% of farmers and diseases was reported by 14% of farmers visited (Table 4). Amongst the three most common insect pests, bean aphid (*Aphis fabae*) was mentioned by 86% (x^2 = 0.1; df = 1; p = 0.752) of the farmers as the main insect pest of common bean, followed by bean bruchid (*A. obtectus*) (49%) (x^2=4.043; df=1; p=0.044) and ootheca (*Ootheca bennigseni*) (44%) (x^2=4.975; df = 1; p=0.026) (Fig. 3). On the other hand, the three most common weeds mentioned by respondents were *Cyperus rotundus* reported by 80% (x^2=0.276; df=1; p=0.599), followed by *Bidens pilosa* (45%) (x^2=57.703; df=1; p=0.001) and *S. suaveolens* (38%) (x^2=0.638; df=1; p=0.424) (Fig. 4). The majority of farmers (92%) were able to identify and describe common bean weeds and insect pests by their local names. Only 2% did not know the names and were only able to identify the insect pests and weeds upon seeing the pictures. A significant proportion of farmers (77%) also mentioned beneficial insects such as ladybird beetle and honey bee as insect pests.

Additionally, most of the farmers (84%) reported insect pest occurrence in the field, while 72% of farmers experienced insect pest attacks during storage. A huge proportion of farmers (98%) claimed that insect pests are causing significant loss of income, shortage of food (77%) and damage of seeds (62%) for planting in the subsequent season. On the other hand, 56% of the farmers visited in the two districts described insect pest and weed challenges as worse at present as compared with the past 10 - 20 years.

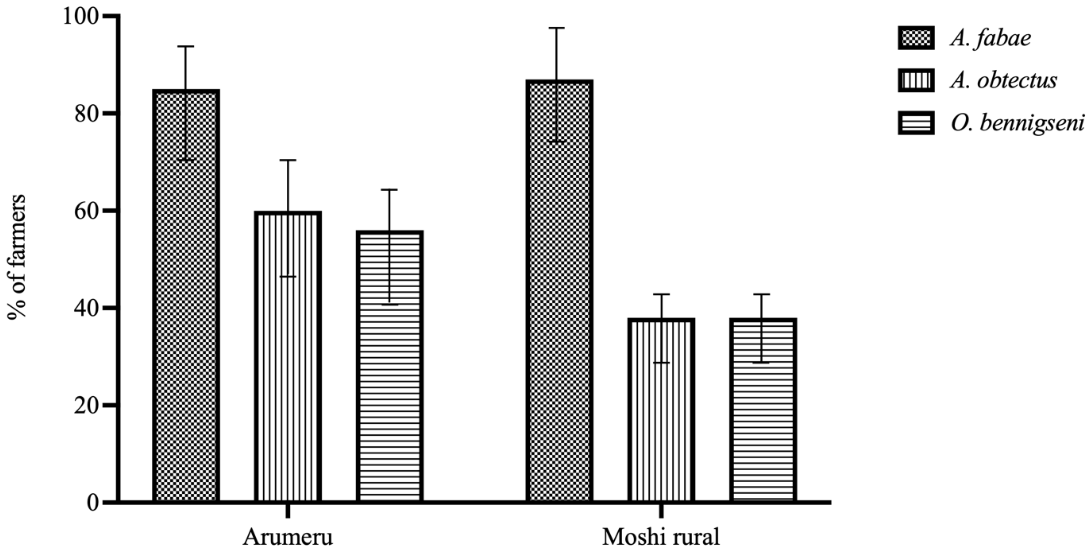


Figure 3: Major pests in common bean farming as reported by farmers in Arumeru and Moshi rural districts

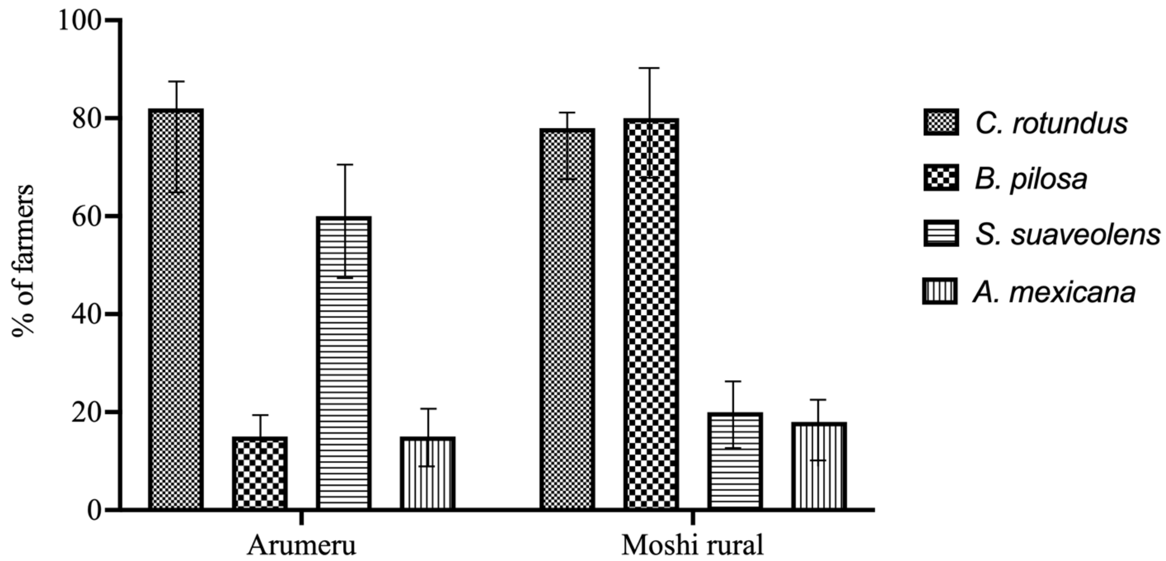


Figure 4: Major weeds in common bean farming as reported by farmers in Arumeru and Moshi rural districts

4.1.4 Insect Pests and Weeds Management Practices Applied by Farmers in Arumeru and Moshi Rural Districts

In this study, it was found that farmers in both Arumeru and Moshi rural districts applied chemical, mechanical and cultural methods to eradicate the damage caused to common beans by insect pests and weeds (Fig. 5). The use of chemical sprays was reported by 79% of farmers as the main insect pest control method while mechanical weeding using hand hoe was reported by 86% of farmers as the main weed control method (Table 4). The cultural methods, such as intercropping and crop rotation, were practiced by most farmers in the surveyed districts, however, only 6% of farmers regarded them as insect pest and weed control strategies. In both surveyed districts, Profenofos was the most commonly used synthetic insecticide, reported by 33% of farmers, while Glyphosate was reported by 17% of farmers as the most commonly utilized synthetic herbicide. Despite the use of chemical spray in managing weeds and insect pests, about 67% and 83% of farmers did not know the names or type of insecticide and herbicide respectively. Furthermore, farmers described the use of other different insect pest management techniques such as an increase in dosage of application (22%), increase rate of application (14%), and using a cocktail of synthetic pesticide/herbicide mixed with washing powder (laundry detergent) and kerosene (3%). On the shortcomings of chemical sprays, most of the respondents (88%) mentioned harmful effects to human health, while 21% reported that most pesticides are non-selective and kill all insects including harmless ones such as butterflies. On the other hand, only 24% of the farmers were able to afford synthetic pesticides and herbicides, and about 67% complained about high price of the pesticides while 60% reported availability and accessibility as the major challenge. Despite the effectiveness of different pest and weed management practices, 3% of farmers in Arumeru and 1% in the Moshi rural districts did not apply any control methods against insect pests both in the field and during storage (Table 4).

Table 4: Perception of farmers on insect pest and weed control strategies in common bean farming

Variables	Districts		Mean	Chi squares
	Arumeru	Moshi Rural		
(a) Insect Pest Control Methods				
Chemical sprays (pesticides)	86	72	79	$x^2 = 2.87$; df = 1; p = 0.09
Cultural	07	06	06	$x^2 = 0.13$; df = 1; p = 0.72
Do nothing	03	01	02	$x^2 = 3.72$; df = 1; p = 0.05
(b) Weed Control Methods				
Mechanical weeding	85	87	86	$x^2 = 3.52$; df = 1; p = 0.03
Chemical sprays (herbicides)	67	26	47	$x^2 = 18.71$; df = 1; p = 0.00
Cultural	07	0	03	$x^2 = 2.00$; df = 1; p = 0.16

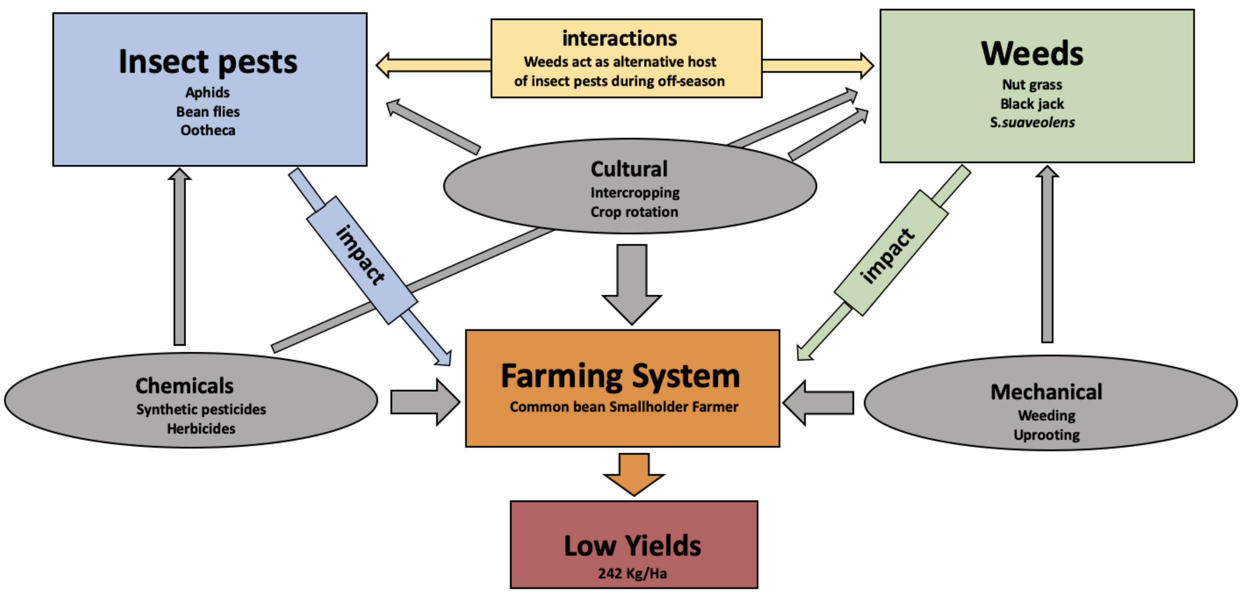


Figure 5: Summary of impact and management strategies for insect pests and weeds in common bean smallholder farming system in northern Tanzania

4.1.5 The Distribution of *Sphaeranthus suaveolens* in Arumeru and Moshi Rural Districts

The field survey indicated that *S. suaveolens* is found in all the villages visited in the two districts. High distribution of *S. suaveolens* was found in the farmlands and swampy area compared with other areas, and the density was much higher during rainy season than during dry season (Fig. 6 and 7). The most infested village was Malula while the least infested village was Uchau kusini in Arumeru and Moshi rural districts respectively. The weed was also observed to infest farmlands and other areas in villages nearby the study areas particularly in Moshi rural district (Fig. 6).

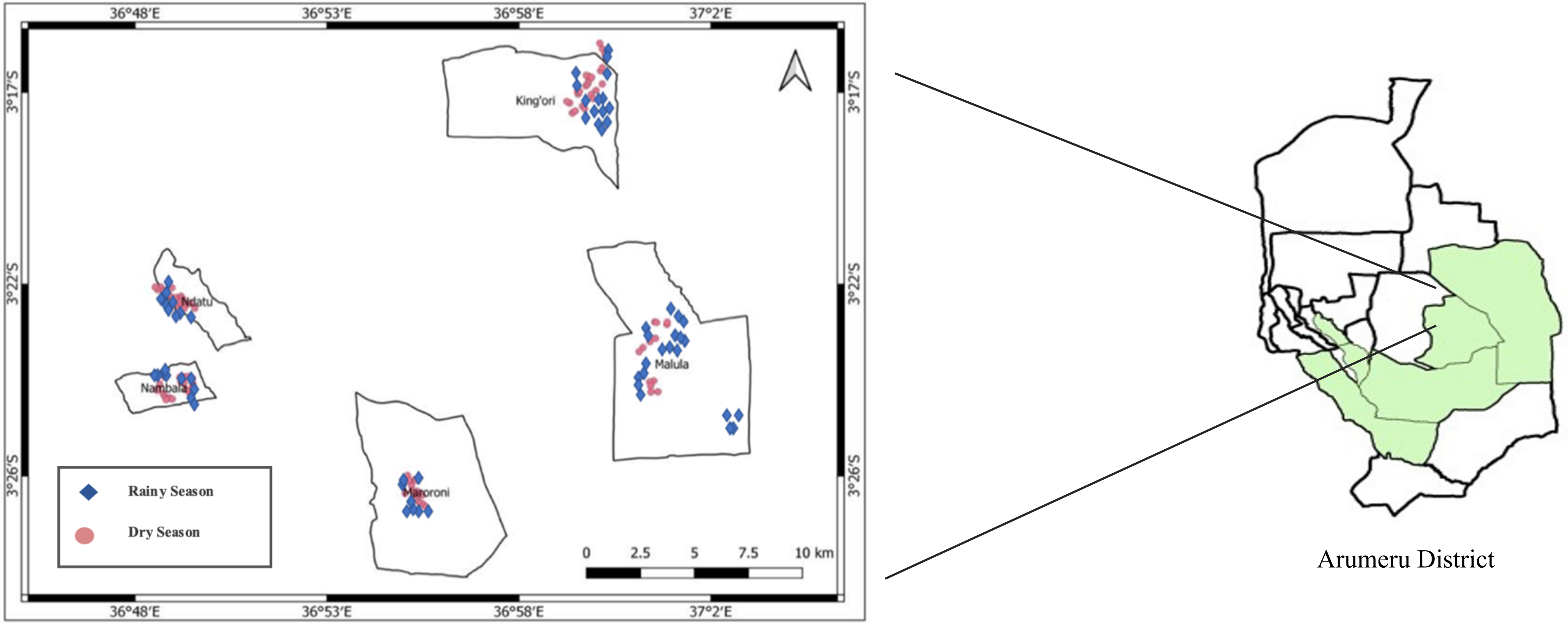


Figure 6: Spatial Distribution of *S. suaveolens* in Arumeru district

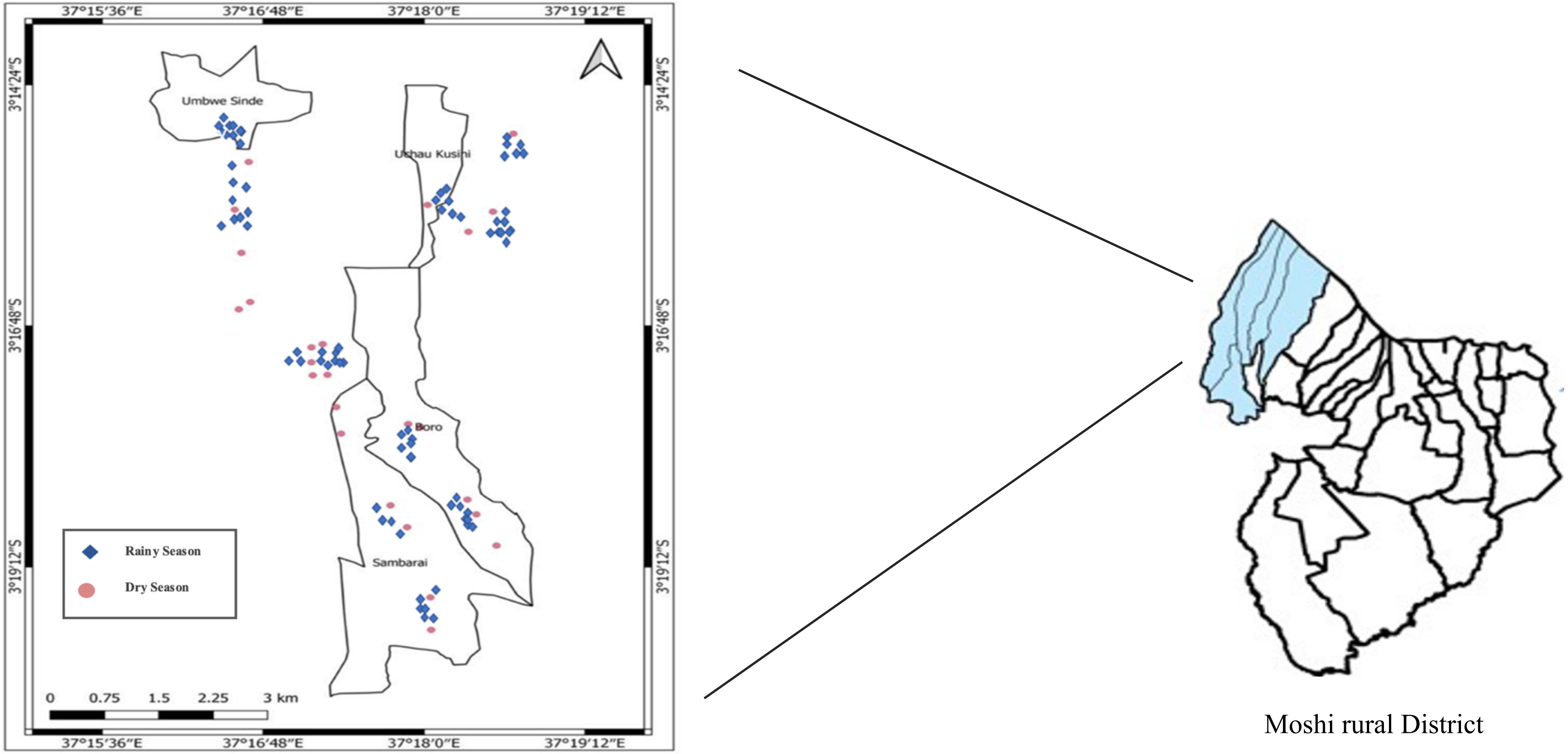


Figure 7: Spatial Distribution of *S. suaveolens* in Moshi rural district

4.1.6 Effect of *Sphaeranthus suaveolens* Extracts on Seed Germination of Common Bean

The results from the experiment carried out to evaluate the allelopathic effects of *S. suaveolens* in common bean seed germination showed that, higher concentrations (75% and 100%) of *S. suaveolens* crude extract in both laboratory and screen house experiments significantly suppressed common bean seed germination. The germination of common bean seeds was much more delayed at higher concentrations (75% and 100%) compared with lower concentrations (0% and 25%) of the *S. suaveolens* crude extract. The mean percentage germination under 0% concentration (control) was 100% both in the laboratory and screen house experiments. Additionally, under the higher concentration (100%), the mean percentage germination for common bean was 10% and 0% for laboratory and screen house experiments respectively (Table 5). In general, the seed germination for common bean decreased significantly ($p<0.001$) with the increase in concentration of *S. suaveolens* crude extract (Table 5).

Table 5: Mean percentage germination (± SE) of common bean seeds after 7 days of *S. suaveolens* treatments in a laboratory and screen house experiments

Concentration (%)	Germination (%)	
	Laboratory	Screen house
0	100 ± 0.2^{a}	100 ± 0.1^{a}
25	80 ± 0.4^{b}	83 ± 0.4^{b}
50	70 ± 0.4^{c}	50 ± 0.4^{c}
75	20 ± 0.4^{d}	17 ± 0.2^{d}
100	10 ± 0.2^{e}	0 ± 0.2^{e}
F- Statistics	$F_{(4,40)} = 142*$	$F_{(4,40)} = 53*$

Values with different superscript letter(s) are significantly different by Fisher LSD at $p<0.05$
*$p<0.001$

4.1.7 Effects of *Sphaeranthus suaveolens* Extracts on Shoot Length of Common Bean Seedlings

Shoot length of common bean seedlings sprayed with *S. suaveolens* concentrations differed significantly in both the laboratory ($F_{(4, 40)}=56.64$, $p<0.0001$) and screen house ($F_{(4, 40)}=$,$p<0.0001$) experiments (Fig. 8). Mean (±SE) seedling lengths of common bean in 0% treatments (16 ± 1 cm) were 5 times longer than the ones in 100% treatments (3 ± 0 cm) in both laboratory and screen house experiments. In general, the shoot length for common bean seedlings decreased significantly (p<0.001) with the increase in concentration of *S. suaveolens* crude extract in both the laboratory and screen house experiments.

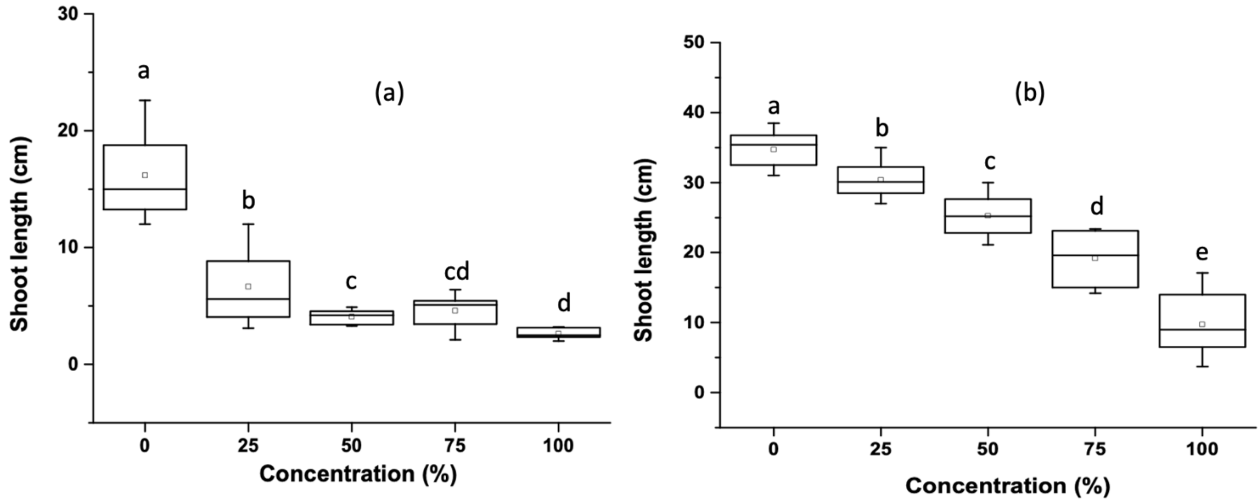


Figure 8: Shoot length of germinated common bean seedlings in (a) laboratory and (b) screen house experiments after 7 and 14 days of treatment with *S. suaveolens* extracts respectively

4.1.8 Effects of *Sphaeranthus suaveolens* Extracts on Root Length of Common Bean Seedlings

The root length of common bean seedlings sprayed with *S. suaveolens* crude extract concentrations differed significantly in both laboratory ($F_{(4, 40)}=165.89$, $p<0.001$) and screen house ($F_{(4, 40)}=10.37$, $p<0.001$) experiments (Fig. 9). At higher concentration (100%) of *S. suaveolens* crude extract, the mean root length (± SE) in common bean seeds (0 ± 0.1 cm and 2 ± 0.3 cm) were significantly reduced (p<0.001) as compared with lower (0%) concentrations (8 ± 0.4 cm and 7 ± 0.9 cm) in both laboratory and screen house experiments respectively (Fig. 9). Generally, it was observed that, the root length for common bean seedlings in both laboratory and screen house experiments were significantly reduced (p<0.001) as the concentration of *S. suaveolens* crude extract increased.

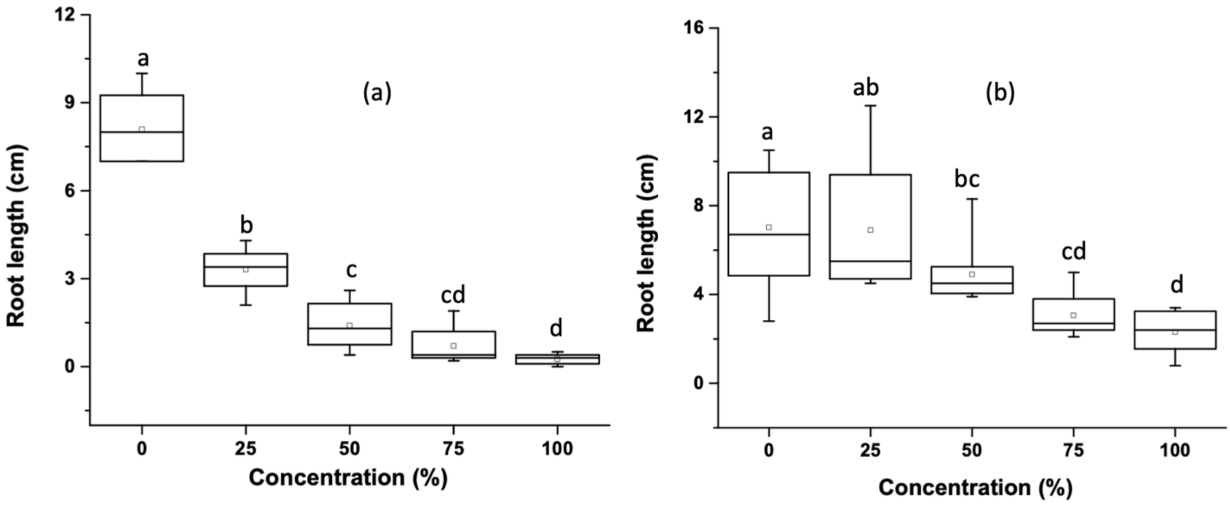


Figure 9: Root length of germinated common bean seedlings in (a) laboratory and (b) screen house experiment after 7 and 14 days of treatment with *S. suaveolens* extracts respectively

4.1.9 Effects of *S. suaveolens* Extracts on Fresh Weight of Roots and Shoots of Common Bean Seedlings

The average fresh weight of roots (FWR) for common bean differed significantly with *S. suaveolens* treatment in both laboratory ($F_{(4, 40)}$=284.23, p<0.001) and screen house ($F_{(4, 40)}$=435.35, p<0.001) experiments. The fresh weight of shoots (FWS) also differed significantly in both laboratory ($F_{(4, 40)}$=399.39, p<0.001) and screen house ($F_{(4, 40)}$=504.51, p<0.001) experiments. Seedlings treated with higher concentrations of *S. suaveolens* extracts were observed to have lower fresh weights of both roots and shoots than those treated with lower concentrations in both laboratory and screen house experimentations (Fig. 10 and 11).

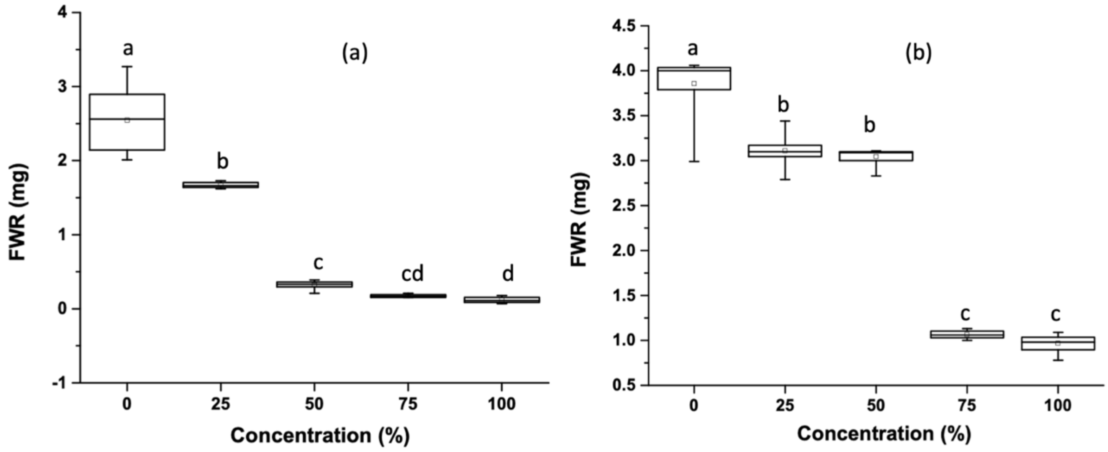


Figure 10: Fresh weight of root (FWR) of germinated common bean seedlings in (a) laboratory and (b) screen house experiments after 7 and 14 days of treatment with *S. suaveolens* extracts respectively

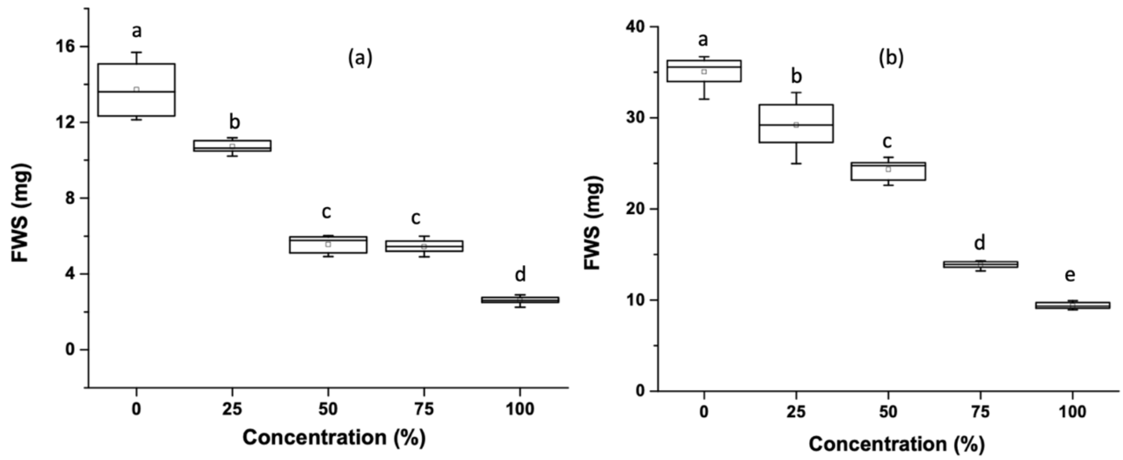


Figure 11: Fresh weight of shoot (FWS) of germinated common bean seedlings in (a) laboratory and (b) screen house experiment after 7 and 14 days of treatment with *S. suaveolens* extracts respectively

4.1.10 Effects of *Sphaeranthus suaveolens* Extracts on Total Chlorophyll Content of Common Bean

Total leaf chlorophyll content of common bean seedlings differed significantly in both laboratory ($F_{(4, 40)}$=21.53, p<0.00004) and screen house ($F_{(4, 40)}$=18.38, p<0.00001) experiments under different *S. suaveolens* crude extract treatments (Fig. 12). In general, seedlings that were treated with higher concentration (100%) of *S. suaveolens* crude extracts had lower total chlorophyll content than those sprayed with lower concentrations (0%) in both laboratory and screen house experiments (Fig. 12).

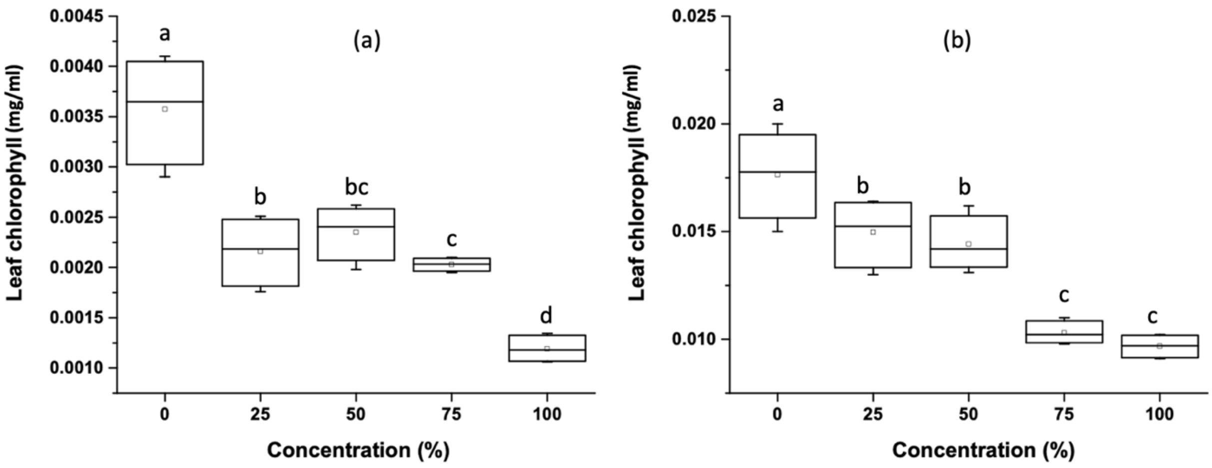


Figure 12: Leaf chlorophyll content of common bean seedlings in (a) laboratory and (b) screen house experiment after 7 and 14 days of treatment with *S. suaveolens* extracts respectively

4.1.11 Mortality of Acanthoscelides obtectus as Influenced by Sphaeranthus suaveolens Powder

Highest mean percentage mortality (100%) for *A. obtectus* was observed in the bean varieties treated with 0.25 g of actellic super dust followed by bean varieties treated with 11.25 g and 15 g of *S. suaveolens* powder (90%) (Table 6). Lowest mortality (21%) on the other hand, was observed in the control (0 g) treatment followed by bean varieties treated with 3.75 g of *S. suaveolens* powder (44%). The mean percentage mortality of *A. obtectus* did not differ significantly across the three bean varieties (Jesca, Lyamungu 90 and Selian 97) ($p<0.05$) (Tables 7 and 8). In general, the mean percentage mortality of *A. obtectus* in all three bean varieties increased significantly ($p<0.001$) with the increase in *S. suaveolens* powder amount and in seeds treated with the 0.25 g actellic super dust (Table 6).

Table 6: Effects of treatments (Mean percentage ± SE) on variables investigated

Treatments	Variables				
	Damaged seeds (%)	Dead insects (%)	Seeds with eggs (%)	Holes per seed	Weight loss (%)
0g	$18^{a} \pm 2$	$21^{a} \pm 3$	$42^{a} \pm 4$	$4^{a} \pm 1$	$9^{a} \pm 2$
3.75g	$8^{b} \pm 1$	$44^{b} \pm 4$	$13^{b} \pm 2$	$2^{b} \pm 1$	$5^{b} \pm 1$
7.5g	$1^{c} \pm 0$	$66^{c} \pm 5$	$2^{c} \pm 1$	$0^{c} \pm 0$	$2^{c} \pm 0$
11.25g	$1^{c} \pm 1$	$90^{d} \pm 3$	$1^{c} \pm 0$	$0^{c} \pm 0$	$1^{c} \pm 0$
15g	$0^{c} \pm 0$	$90^{d} \pm 3$	$0^{c} \pm 0$	$0^{c} \pm 0$	$1^{c} \pm 0$
Actellic (0.25g)	$0^{c} \pm 0$	$100^{d} \pm 0$	$0^{c} \pm 0$	$0^{c} \pm 0$	$1^{c} \pm 0$

Values with different superscript letter(s) are significantly different by Fisher LSD at $p<0.05$

4.1.12 Damaged Seeds, Seeds with Eggs and Holes per Seed in Bean Varieties Treated with *Sphaeranthus suaveolens* Powder

The mean percentages for damaged seeds were higher in the control (0 g) and in common bean seeds treated with 3.75 g of *S. suaveolens* powder (Table 6). The percentage mean (±SE) for damaged seeds between Jesca and Selian 97 bean varieties differed significantly ($p<0.001$) (Table 7). Jesca bean variety had the highest seed damage (6 ± 1) while Selian 97 had the lowest seed damage (3 ± 1) followed by Lyamungu 90 (4 ± 1) (Table 7). Similarly, percentage means and means (± SE) for seeds with eggs and holes per seed respectively were higher in the control experiment (42 ± 4 and 4 ± 1). However, this was observed to decrease significantly in the common bean seeds treated with actellic super dust (0 ± 0) and in seeds treated with 11.25 g and 15 g of *S. suaveolens* powder (Table 6). Generally, damaged seeds, number of holes per seed and seeds with eggs were higher in the control (0 g) and in 3.75 g of *S. suaveolens* treatments as compared with other treatments, and the percentage damaged seeds differed significantly ($p<0.001$) across the bean varieties (Tables 7 and 8).

Table 7: Effects of bean varieties (Mean percentage ± SE) on variables investigated

Common bean varieties	Variables				
	Damaged seeds (%)	Dead insects (%)	Seeds with eggs (%)	Holes per seed	Weight loss (%)
Jesca	$6^{a} \pm 1$	$68^{a} \pm 3$	$10^{a} \pm 1$	$1^{a} \pm 0$	$4^{a} \pm 1$
Lyamungu 90	$4^{ab} \pm 1$	$67^{a} \pm 3$	$9^{a} \pm 1$	$1^{a} \pm 0$	$3^{ab} \pm 1$
Selian 97	$3^{b} \pm 1$	$70^{a} \pm 3$	$9^{a} \pm 1$	$1^{a} \pm 0$	$2^{b} \pm 1$

Values with different superscript letter(s) are significantly different by Fisher LSD at $p<0.05$

4.1.13 Weight Loss for Common Bean Seeds Treated with *Sphaeranthus suaveolens* Powder

The percentage weight loss for common bean seed varieties tested in this study differed significantly across the treatments (p<0.001) and was higher (9%) in the control treatment (0 g) followed by seed varieties treated with 3.75 g of *S. suaveolens* powder (5%) (Table 6). On the contrary, common bean seeds treated with actellic super dust, 11.25 g and 15 g of *S. suaveolens* recorded lowest percentage weight loss (1%) in all the experiments (Table 6). The weight loss in all treatments and among the three bean varieties differed significantly (p<0.001) (Table 8) with Jesca recording the highest weight loss of 4% whereas Selian 97 had the lowest weight loss of 2% among the three varieties tested (Table 7).

Table 8: ANOVA summary (Mean squares) on variables investigated

Source of variation	d.f.	Mean Square				
		Damaged seeds	Dead insects	Seeds with eggs	Holes per seed	Weight loss
Replication	2	1.906	79.9	54.36	0.963	0.863
Treatments	5	454.219***	8610.9***	2463.38***	29.63***	88.566***
Varieties	2	36.628	24.7	6.3	0.685	14.057***
Treat. x Var.	10	15.258	143.8	8.24	0.752	13.311***
Error	34	7.686	108.8	44.2	1.041	1.285
Total	53					

*** Significant at p<0.001

Furthermore, results from this study indicate that there are significant (p<0.001) and positive correlations among the variables investigated such as live insects, percentage damaged seeds, holes per seed, seeds with eggs and weight loss as shown in the Table 9.

Table 9: Correlation coefficient among variables investigated

Variables	1	2	3	4	5
1. Live insect	1	0.77***	0.82***	0.94***	0.69***
2. Damaged seeds		1	0.85***	0.85***	0.85***
3. Holes per seed			1	0.79***	0.76***
4. Seeds with eggs				1	0.75***
5. Weight loss					1

*** Significant at p<0.001

4.1.14 Classes of Secondary Metabolites Present in *Sphaeranthus suaveolens* Extracts

The phytochemical analysis of aqueous and methanolic extracts of *S. suaveolens* revealed the presence of tannins, saponins, flavonoids, alkaloids and glycosides. The aqueous extract of *S. suaveolens* further contained steroids and anthraquinones (Table 10). In general, the aqueous extract of *S. suaveolens* had more groups of phytochemicals as compared with the methanolic extract (Table 10).

Table 10: Class of secondary metabolites present in *Sphaeranthus suaveolens*

Phytochemical tested	Extracts	
	Aqueous	Methanolic
Tannins	+	+
Terpenes	+	+
Saponins	+	+
Flavonoids	+	+
Alkaloids	+	+
Glycosides	+	+
Steroids	+	+
Anthraquinones	+	-
Coumarins	-	-

+ Presence, - Absence

4.1.15 Compounds Identified from *Sphaeranthus suaveolens* Water Extract Using Gas Chromatography-Mass Spectrometry

The GC-MS analysis of *S. suaveolens* water extract revealed the presence of various phytochemicals and a total of 14 compounds were identified (Table 11). The chromatogram of *S. suaveolens* extract showed various higher peaks on which 14 were considered during the identification (Fig. 13). The compounds identified from the *S. suaveolens* extract were p-cymene-2,5-diol; thymoquinone; geranyl acetate; 2,6-octadienal, 3,7-dimethyl-; eugenol; cubenol; guaiol; dihydroagarofurane; camphor; 4H-pyran-4-one, 2,3-dihydro-3,5-dihydroxy-6-methyl-; methylparaben; caffeine and 1-tetradecene (Table 11).

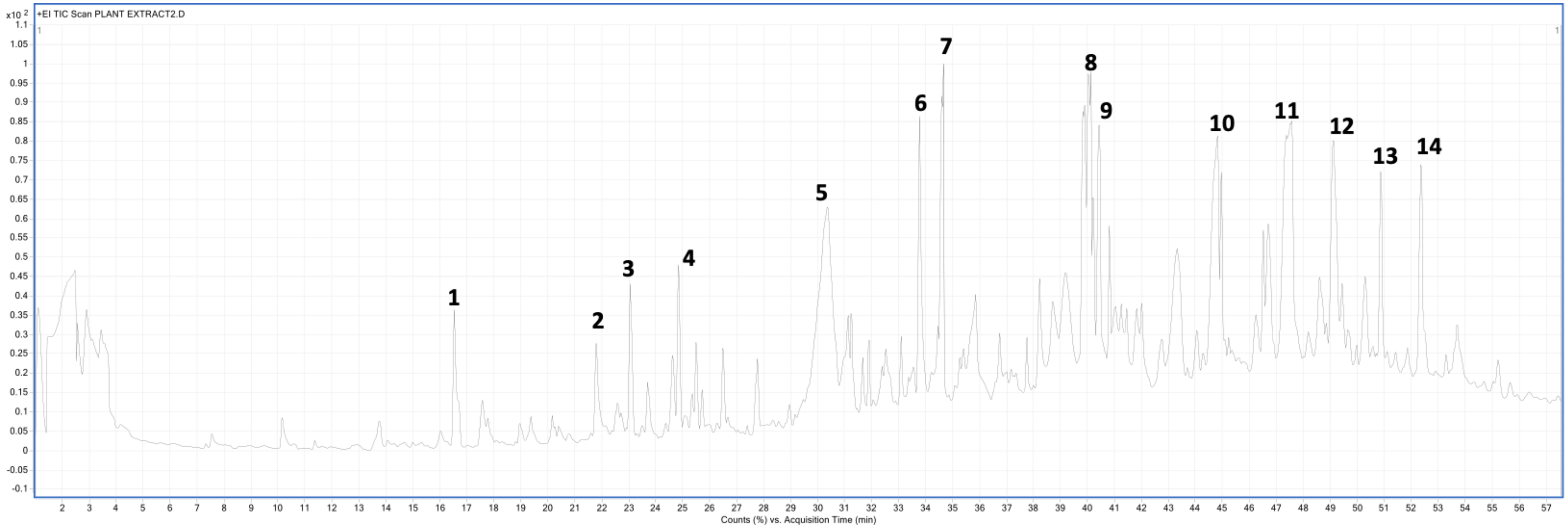
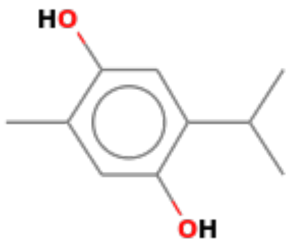
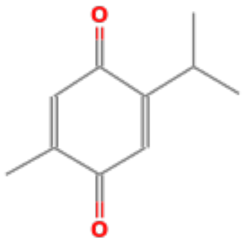
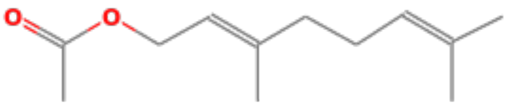
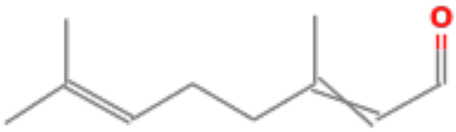
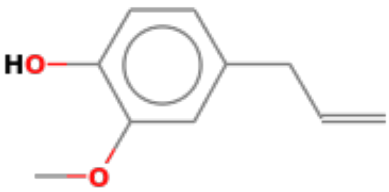
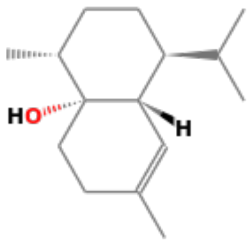
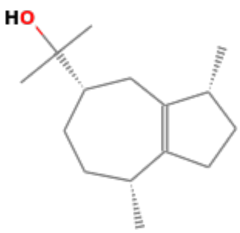
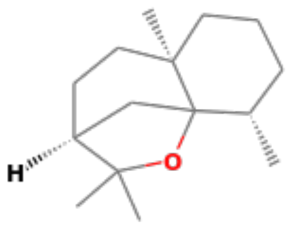
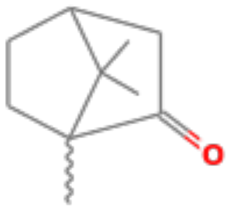


Figure 13: The GC-MS chromatogram of *S. suaveolens* extract

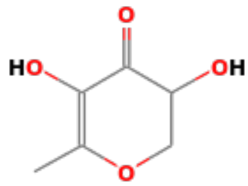
Table 11: Compounds identified from the *S. suaveolens* extract using GC-MS

(i) p-Cymene-2,5-diol Formula:$C_{10}H_{14}O_2$ Molecular weight: 166 	(ii) Thymoquinone Formula:$C_{10}H_{12}O_2$ Molecular weight:164 
(iii) Geranyl acetate Formula:$C_{12}H_{20}O_2$ Molecular weight:196 	(iv) 2,6-Octadienal, 3,7-dimethyl- Formula: $C_{10}H_{16}O$ Molecular weight: 152 
(v) Eugenol Formula: $C_{10}H_{12}O_2$ Molecular weight: 164 	(vi) Cubenol Formula: $C_{15}H_{26}O$ Molecular weight: 222 
(vii) Guaiol Formula: $C_{15}H_{26}O$ Molecular weight: 222 	(viii) Dihydroagarofurane Formula: $C_{15}H_{26}O$ Molecular weight: 222 

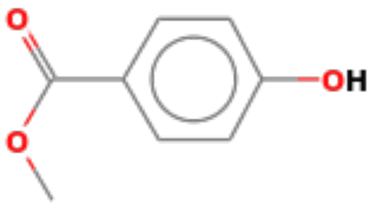
(ix) Camphor
Formula: $C_{10}H_{16}O$
Molecular weight: 152



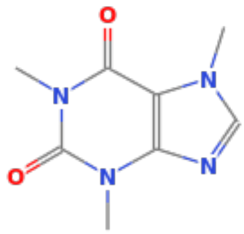
(x) 4H-Pyran-4-one, 2,3-dihydro-3,5-dihydroxy-6-methyl-
Formula: $C_6H_8O_4$
Molecular weight: 144



(xi) Methylparaben
Formula: $C_8H_8O_3$
Molecular weight: 152

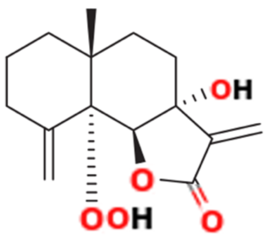


(xii) Caffeine
Formula: $C_8H_{10}N_4O_2$
Molecular weight: 194



(xiii) 1-Tetradecene
Formula: $C_{14}H_{28}$
Molecular weight: 196

(xiv) 5α- hydroperoxy-7α-hydroxy-isosphaerantholide
Formula: $C_{15}H_{20}O_5$
Molecular weight: 279



4.2 Discussion

4.2.1 Farmers Perceptions, Knowledge and Practices in Managing Common Bean's Insect Pests and Weeds

The findings from this study revealed that majority of farmers mentioned insect pests as a serious constraint to effective production of common bean in their farms. *A. fabae, A. obtectus* and *O. bennigseni* were alleged to cause an average to major loss on yields, with the responses varying among the pest groups. Similar results were previously reported in common bean and pea smallholder farming systems in Ethiopia, Kenya, and South Africa (Abtew *et al.*, 2016; Mendesil *et al.*, 2016; Ojwang' *et al.*, 2011). Moreover, smallholder farmers of common bean have been experiencing loss of food, low value and marketability of damaged of seeds, and loss of seeds to be planted in the subsequent season as a result of insect pest attack particularly the *A. obtectus*. Karungi *et al.* (2000) suggested that, if no serious measures are taken to manage the insect pest attacks yield losses can reach up to 100%. Therefore, managing insect pests such as *A. obtectus* in storage facilities should be given special attention as it could have serious impacts on food security and income of smallholder farmers.

The perception of farmers that insects are the most dangerous pests in common bean production may be related to the great number of destructive insect species such as *A. fabae, A. obtectus* and *O. bennigseni* (Fig. 3). This corroborates with a study by Ochilo and Nyamasyo (2011) that *A. fabae* can account for total yield losses. These insect pests have a high chance of damaging crops and reducing yields, thus causing visible and economical losses that can greatly affect smallholder farmers (Mwanauta *et al.*, 2015; Ssekandi *et al.*, 2016). During the focus group discussions, farmers explained that the major loss of their common bean is caused by insect pests. This further confirms that insect pests are the major constraint in common bean production.

On the other hand, weeds were considered to cause a moderate to low effect on common bean production by competing for nutrients, water, space, and sunlight among others. Interestingly, most farmers were aware of the importance of managing weeds in their farms. Pannacci *et al.* (2017) stressed on the importance of combining different weed management strategies for smallholder farmers. The proper weed management strategies enhance crop yields by increasing sprouting of desired crops as well as reducing insect pest population (Fufa & Mariam, 2016). However, in the absence of proper management practice, weeds may interfere with the normal growth of the desired crops and cause a significant loss in yields (Avola *et al.*, 2008; Datta *et al.*, 2017). This emphasis on the need to train farmers on the different strategies for sustainable weed management.

Furthermore, farmers in the study area were able to identify some of the weeds such as *C. rotundus*, *B. pilosa* and *S. suaveolens* among others as the top three problematic weeds in common bean production. Furthermore, *B. pilosa* was mentioned by farmers as an alternative host to insect pests during the off season. Similar observations were also noted by Capinera (2005) who pointed out that weeds are potential vectors and hosts for harmful parasites and insect pests. Weeds may also distract beneficial insects such as pollinators during the flowering stage. This subsequently reduces chances of desired crops to be pollinated thereby decreasing yields at large (Ojija *et al*., 2019a). Takim (2010) reported that weeding in and around the farm greatly reduced the population densities of legume pests such as pod borer (*M. vitrata*). However, none of the farmers and agricultural officers in the study area reported on knew about the interactions between *S. suaveolens* and common bean, therefore, knowledge on how this weed interacts with crops and insect pests is very important in developing sustainable and cost-effective management strategies for smallholder farmers.

The most common method used to control insect pests and perceived as effective by most farmers in the two districts was the use of synthetic insecticides. However, this study discovered a knowledge gap in pesticide use. For example, among the farmers visited, most did not remember the name of the pesticides they applied. Farmers also get recommendations on pesticide use from other farmers in the village and local agro-input dealers who are not competent enough to analyze the effectiveness as well as the impacts of such pesticides to the farmers, other people and the environment at large. It was also found that 43% of the agro-input dealers have only attained primary education and have had no formal training on pesticide use and safety. Therefore, their recommendations on pesticide uses might affect common bean production in one way or another. The current results are similar to those reported by Abtew *et al.* (2016), Damalas and Koutroubas (2018) and Ngowi *et al.* (2007). In addition, some farmers reported to mix pesticide with kerosene, detergent (soap), and other pesticides in order to increase their efficiency. Such strategies of improving the effectiveness of pesticides were also reported by Matthews *et al.* (2003) and Oparaeke *et al.* (2006). However, the effects that these cocktails of pesticides may pose to human health, environment and to the pests are largely unknown and need further investigation.

Additionally, 43% of farmers did not see the need to consult extension officers despite the challenges faced on pesticide use and safety. As a result, it was observed that farmers were using non-recommended pesticides, not wearing personal protective equipment when spraying chemicals, as well as increased dosage and rate application of insecticides. These practices may lead to economic loss to smallholder farmers, and may also pose adverse effects to the environment and to people particularly the health-related problems associated with pesticide use (Damalas & Koutroubas, 2018; Ngowi *et al.*, 2007; Rother, 2018; Schreinemachers *et al.*, 2017; Vryzas, 2018; Williamson *et al.*, 2008). It is, therefore, important to sensitize farmers on importance of consulting extension officers on issues related to pesticide use and safety as this may help to manage pests and weeds effectively and ultimately increase crop production and protection during storage.

On the contrary, mechanical method (weeding) using hand hoe was perceived by the majority of farmers as the most effective weed control strategy in the two districts visited. Similarly, Pannacci and Tei (2014) showed that, mechanical methods can be an effective and fast non-chemical techniques of controlling weeds in different agro-ecosystems. Furthermore, majority of farmers in the study area perceived mechanical weeding using hand hoe as the most effective and affordable method for weed control in common bean and maize farms as compared with the use of chemicals. Additionally, other weed control methods such as use of herbicides (glyphosate) was only reported by few farmers. Similar observation was reported by Sims *et al.* (2018) that mechanical weeding methods are the affordable and effective options to most smallholder farmers in developing countries. Other non-chemical methods for weed management in common bean farming such as the use of saline water and organic fertilizers were also reported in the study by Bilalis *et al.* (2014), where weeds such as *C. rotundus* were found to be more affected by saline water as compared to common bean due to high sensitivity to salinity. Moreover, the sequential and control release of nutrients such as nitrogen from the organic fertilizers was also reported to favor crops such as common bean and found useful in controlling weed biomass as compared with inorganic fertilizers (Pannacci *et al*., 2017). Thus, smallholder legume farmers should be encouraged to use these non-chemical weed control strategies, as they are cost-effective and safe compared with other strategies such as the use of chemicals.

Cultural practices such as intercropping and crop rotation were also practiced by most farmers in the study area, and common bean was intercropped with maize and sometimes sunflower, while for crop rotation, maize and common bean were rotated with vegetables such as African eggplant and green pepper. The main reasons for practicing intercropping and crop rotation reported, were for increasing productivity of farmland, enhance soil fertility and risk minimization in case one crop fails. Correspondingly, legume farmers in Ethiopia gave similar reasons for practicing intercropping and were not aware of the other benefits such as pest and weed control (Mendesil *et al.*, 2016; Triberti *et al.*, 2016). Nevertheless, only few farmers were aware that intercropping and crop rotation can be used as pest and weed management practices.

The knowledge gap identified on the integrated pest management strategies for controlling damage caused by weeds and insect pests in common bean production could be the reason for the low common bean harvest experienced by smallholder farmers in the study area (Fig. 5). There is a need to sensitize farmers on the newly improved and more effective strategies for managing and control pest, weeds and other challenges in order to enhance crop production. However, most of these strategies come from research organizations (public and private), and are often communicated to the public through publications, conferences and media outlets. Majority of smallholder farmers in the two districts for example, had only attained primary education at most, meaning they may not be able to digest the information on newly improved techniques for managing weeds and insect pests presented in scientific articles. Therefore, there is a great need to equip agricultural extension officers with new knowledge and findings so as to assist farmers understand these new findings and eventually turning them into sustainable agricultural practices that can be easily adopted by smallholder farmers in developing countries to enhance agricultural production. Thus, this study has proposed a framework (Fig. 14) which stresses the importance of integrating extension services in smallholder farming systems.

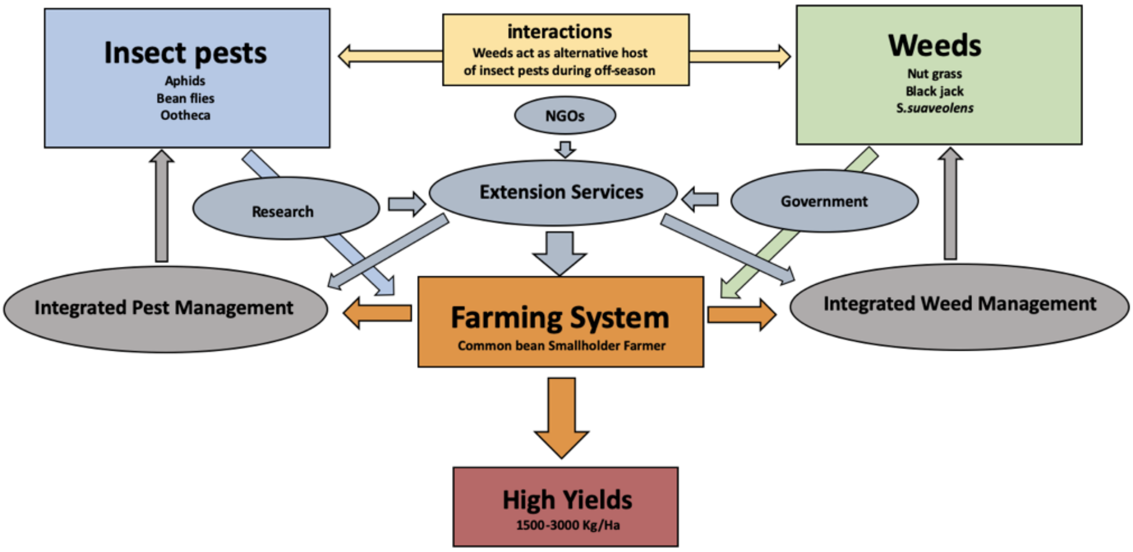


Figure 14: Proposed framework for the management of insect pests and weeds in common bean smallholder farming system in northern Tanzania

4.2.2 The Distribution of *Sphaeranthus suaveolens* in Villages within Arumeru and Moshi Rural Districts

This study revealed that *S. suaveolens* was found in all the villages visited particularly in farmlands, swampy, rangelands and settlement areas. The presence of more *S. suaveolens* in farmlands might be due to easy spread of seeds during cultivation. Most villagers during social survey regarded *S. suaveolens* as a green manure and it is normally left to decompose in the farms during cultivation. However, this may significantly affect seed germination and seedling growth since the *S. suaveolens* contains water soluble allelochemicals which proved to delay germination and reduce the growth of common bean (Laizer *et al.*, 2021; Zohaib *et al.*, 2016). The *S. suaveolens* was also found in settlement area and was considered ornamental plants as well as mosquito repellents. The use of *Sphaeranthus sp* as mosquito repellent has also been reported by Chellappandian *et al.* (2018) and Mahajan *et al.* (2015) in their studies to investigate the repellent and toxicological effects of *Sphaeranthus indicus* in southern house mosquito (*Culex quinquefasciatus*).

The results from this study further showed that *S. suaveolens* is growing in river banks and irrigation canal banks. Similar distribution was reported by Ramachandran (2013) in his review on the *Sphaeranthus sp* and described its extensively distribution in wetlands and river banks. This could be due to the fact that *Sphaeranthus sp* may be well adapted to grow in wetlands due to presence of succulent stem and leaves (De Pooter *et al*., 1991). Other physiological and behavioral responses such as tolerance to low soil oxygen, as well as reproductive strategies such as delay or speed up of flowering may also explain the successful invasion of *S. suaveolens* in swampy areas (Laizer *et al*., 2020; Mahajan *et al*., 2015).

This study also reported the presence of *S. suaveolens* in grazing areas particularly in Arumeru district. The invasion of this weed in rangelands significantly reduce and replace species that are preferred by animals as fodder. Since the *S. suaveolens* is not preferred as food by most domestic animals, there is a need to control the spread of this weed in areas where animals are grazed. Furthermore, the allelopathic effects and insecticidal potential of *S. suaveolens* if well used might be the best control strategy since the weeds will be demanded by farmers in the management of other weeds and insect pests both in the field and during storage. These findings are similar to what Kong (2010) recommended on the use of allelopathic weeds and their allelochemicals for ecological weed and insect pest management and control.

The results from this study also showed the distribution of *S. suaveolens* in non-cultivated areas especially areas bordering farmlands. The presence of this weed in non-cultivated areas near farmlands could serve as field margins and help to shelter beneficial insects such as pollinators and natural enemies which may help to increase crop production and control pests. Similar findings on the importance of field margins with pesticidal properties in hosting pollinators and natural enemies of common beans were also reported by Elisante *et al.* (2020), Mkenda *et al.* (2019) and Godifrey *et al.* (2018).

4.2.3 Effects of *Sphaeranthus suaveolens* in Germination and Seedling Growth of Common Bean

This study revealed that crude extract of *S. suaveolens* significantly reduced seed germination of common bean. This suggests that *S. suaveolens* possess water soluble allelochemicals which showed inhibitory effects on the tested crops. Moreover, at higher concentrations (75% and 100%), the *S. suaveolens* extracts showed maximum inhibition in common bean seed germination. These results are in agreement with the study conducted by Lodha (2004) on effects of *S. indicus* weed on seed germination of various crops. The reduced common bean seed germination might be caused by the allelopathic stress of different extract concentrations resulting from different abnormalities in metabolic activities and cell division due to effect of allelochemicals (Siyar *et al*., 2019). Delaying and inhibiting seed germination has been reported to affect the crop productivity in different farming systems thereby lowering yields and eventually affecting food security particularly to smallholder farmers.

The findings in this study also indicate that root and shoot lengths of common bean seedlings were significantly reduced by the *S. suaveolens* crude extracts. However, the effects were concentration dependent and differed between the low and high concentrations. The roots and shoots of common bean were found to be more sensitive to the applied allelopathic stress whereby at high concentration (100%) of crude *S. suaveolens* extract, root and shoot length were reduced considerably as compared with those in lower concentrations and in the control treatments. These results corroborates with findings from Lodha (2004) who revealed that extracts of different plant parts of *S. indicus* weeds had strong inhibitory effects on germination, root and stem length. Root and shoot lengths are very important parameters in plants growth and health due to the fact that they play crucial role in nutrients uptakes and physical strength and support of the plant against mechanical stress such as wind, floods among others, so reducing shoot and root length of crops such as common bean could significantly affect their ability to grow well and withstand mechanical stress which may result into low harvest.

The reduced root and shoot lengths observed in this study negatively affect crop production particularly in smallholder farming systems. The roots of common bean are associated with rhizobium bacteria in the soil, which form root nodules and help to fix atmospheric nitrogen to form ammonia (Ndakidemi *et al.*, 2006). This process help to improve soil health and benefits the common bean plant since it uses ammonia as a source of nitrogen hence reducing the need for externally applied fertilizers (Diana *et al*., 2019; Sofi *et al*., 2018). However, the nitrogen-fixing capacity of a legume generally depends on the size of the root nodule i.e. higher in plants with long and big root nodules and less in plants with smaller root nodules. Additionally, longer roots are reported to help the plant to search for water, minerals and other nutrients in the soil giving a better competitive advantage over other plants with shorter roots. The association between shorter roots and failure of plants to compete and search for water and minerals from the ground have been well reported by Sofi *et al.* (2018), Subudhi *et al.* (2019) and Yamane *et al.* (2018). Thus, the reduced root length of common bean could significantly affect its ability to fix atmospheric nitrogen and reach for water and minerals in the soil. This may increase the need for applying fertilizers to supplement for the nitrogen and other minerals needed by the plant.

On the other hand, shorter shoots have been associated with plants inability to withstand environmental stresses such as drought (Shi *et al.*, 2019). Also, shorter shoots hinders plants ability to compete for space, light and air which are important parameters during photosynthesis and their shortage may result into poor plant growth (Ngondya *et al.*, 2016). Additionally, Laizer *et al.* (2019) and Lodha (2004) reported lower yields in farms that were invaded with *Sphaeranthus sp*. The low yields may have been attributed by the allelopathic effects of *S. suaveolens* which negatively affects shoot lengths which may lower its ability to compete for resources such as light among others.

Furthermore, results from this study show that, fresh weights of shoots and roots for common bean seedlings were significantly affected by the higher concentrations of *S. suaveolens* in both laboratory and screen house experiments. The effects observed could be due to influences of allelochemicals on different essential processes of plant metabolism by repressing the plant's growth hormone such as gibberellins, and halt the mitotic division in plant roots which in turns affects its growth and health. The reduced plant growth directly affects its fresh weight which is an important factor for a plant to withstand physical stresses from the environment (Ngondya *et al.*, 2016). Therefore, affecting the fresh weight of the crop may affect their ability to withstand harsh environmental conditions and thereby leading to poor harvest.

The lower chlorophyll content observed in this study was due to the presence of allelochemicals found in the *S. suaveolens*. Similar findings were also reported by Frabboni *et al.* (2019), Ngondya *et al.* (2016a), Ojija *et al.* (2019), Rawat *et al*. (2012) and Siyar *et al.* (2019). Reduced chlorophyll content may negatively affect plant's ability to perform photosynthetic functions hence lowers the chance to survive or compete for resources such as light with other neighboring plants (Fonseca *et al*., 2013).

4.2.4 Bio-insecticidal Potential of *Sphaeranthus suaveolens* in the Management of *Acanthoscelides obtectus*

The effects of *S. suaveolens* powder on *A. obtectus*, suggests that it may possess natural chemicals with insecticidal properties. Additionally, maximum insecticidal activities were observed in the common bean seeds treated with 11.25 g and 15 g of the *S. suaveolens* powder and 0.25 g of actellic super dust. These results are in agreement with the study conducted by Pugazhvendan *et al.* (2012) and Badgujar *et al.* (2011) with regard to the insecticidal effects of *S. indicus* on the management of stored insect pest of grains. The reduced seed damage in common bean seeds treated with *S. suaveolens* powder might be caused by the presence of different compounds with toxic and antifeedant properties. Most of the botanical pesticides affect insect pest by either deterring them from eating the stored seeds or causing direct toxic effects that lead to death (Hikal *et al.*, 2017; Rodríguez-González *et al.*, 2019). The death of adult insects is very important in the management of post-harvest loss since it significantly reduce the egg-laying capabilities and progeny development.

The results in this study also show that the number of seeds with eggs and holes per seed were significantly reduced by the *S. suaveolens* and actellic super dust pesticide as compared with the seeds in control treatment. However, the effects were treatment dependent and did not differ between the three tested common bean varieties (Jesca, Lyamungu 90 and Selian 97). These results are similar to what Koona and Dorn (2005) reported on reduced number of eggs for adult females in *A. obtectus* due to the effects of botanicals. This reduced egg laying capacity may cause population decline thereby help to minimize the damaging effects of *A. obtectus* to common bean seeds.

The weight loss on the other hand, differed significantly among the treatments and the three bean varieties tested. The Jesca bean variety was more damaged by *A. obtectus* as compared with Lyamungu 90 and Selian 97 varieties. These results corroborates with findings from a post-harvest loss experiment reported by Mulungu *et al.* (2007) who revealed that Jesca bean variety was highly affected by insect pest compared with the other varieties tested. This might be due to soft seed coat of Jesca which made it easier for *A. obtectus* larva to penetrate through inside the seed. However, as a tradeoff between softer seed coat and insect pest damage, Jesca seed variety cooks more quickly and has a good taste as compared with Lyamungu 90 and Selian 97 bean varieties.

Furthermore, actellic super dust acted fast in the post-harvest loss experiment, and all *A. obtectus* were killed within the first 24 hours. The effectiveness of *S. suaveolens* powder on the contrary was slow acting, and mortality of *A. obtectus* was recorded from the fourth day onwards. The fast action of actellic super dust is due to the presence of pirimiphos-methyl and permethrin compounds which act on the nervous system of insects by interfering with sodium channels thereby disrupting the function of neurons and cause paralysis and sudden death (Diaz, 2016). On the other hand, the effect of *S. suaveolens* powder to *A. obtectus* was slow as in most botanical pesticides due to the presence of secondary metabolites with repellant and antifeedant properties which acts by keeping the insects away from the seeds or by inhibits feeding (Hikal *et al.*, 2017). Similar findings were reported by Nattudurai *et al.* (2014) during the assessment of insecticidal and repellent activities of *Toddalia asiatica* (L.) extracts against stored product pests. Furthermore, Alemayehu and Getu (2017) in their study involving management of *A. obtectus* using botanicals noted that, the effectiveness of the botanical pesticides took longer to kill adult insects.

The effectiveness of *S. suaveolens* powder in killing *A. obtectus* observed in this study might be due to the presence of volatile compounds with toxic, antifeeding and larvicidal effects. These naturally occurring compounds have been reported in several plants from genus *Sphaeranthus* and were found to be effective in controlling the stored insect pests such as *Callosobruchus chinensis* (Patole *et al.*, 2008) and *Sitophilus oryzae* (Pugazhvendan *et al.*, 2012). Furthermore, aromatic essential oils with insecticidal and larvicidal properties which are popular among organic farmers and environmentally conscious customers have been reported in plant species from the genus *Sphaeranthus* (Badgujar *et al.*, 2011). The compounds with larvicidal activities are very important in the management of insect pest of storage facilities since the larva bore holes into the seeds to hide and feed, therefore effective control measures should target the larvae as it is the most destructive stage of *A. obtectus*.

4.2.5 Phytochemical Analysis of *Sphaeranthus suaveolens* Extracts

Plants are known to be a good source of useful compounds which are used as candidates in the manufacture of many products, pesticides included. The analysis of the plant extracts is a crucial step towards the realization of such compounds or group of secondary metabolites. Analysis of *S. suaveolens* extracts revealed the presence of phytochemicals namely tannins, flavonoids, steroids, terpenoids, alkaloids, saponin, anthraquinones and glycosides which are known to exhibit medicinal, allelopathic and insecticidal activities. Similar results were reported by Zaynab *et al.* (2018) and Subramaniam *et al.* (2016) on the categories of plants secondary metabolites, their roles in plants as well as their applications in medicine and in agriculture.

Alkaloids were among the plants secondary metabolites identified in this study. This group of compounds is well known for possessing insecticidal activities even at low concentrations. Their mode of action varies but mostly affect the acetylcholine receptors in the nervous system or the membrane sodium channels of nerves hence cause death (Rattan, 2010). The presence of alkaloid such as caffeine in the *S. suaveolens* extract even in small amount proves that the plant can be toxic to insects including pests. Furthermore, studies conducted by Laranja *et al.* (2003) and Araque *et al.* (2007) showed that caffeine possess insecticidal activities and it can be used as a model compound for the development of insecticides. Alkaloids are also found in many members of *Asteraceae, Malvaceae*, *Fabaceae* and *Solanaceae* among other plant families, and have been reported to be mostly used as botanical pesticides and insect repellents (Tuenter *et al.*, 2017). Additionally, alkaloids play other important roles in plants life such as protection against water loss, prevention of leach of important minerals as well as protection of plant against harmful bacteria and fungi (Kumar & Thampi, 2015).

Terpenoids were also among the secondary metabolites found in the S. *suaveolens* extracts in this study. This group of secondary metabolites is found to be useful in agriculture particularly in the development of natural and synthetic products for the management and control of weeds and insect pests. The findings from this study showed that, more terpenoids were identified from the *S. suaveolens* extract compared with other secondary metabolites. These findings further justify the toxic and suppressive nature of *S. suaveolens* extracts on common bean's seedlings and *A. obtectus* since terpenoids have been widely reported to possess allelopathic and insecticidal properties (Ahmed, 2018; Sarwar, 2015).

Flavonoids on the other hand, were another group of secondary metabolites identified from the *S. suaveolens* extract in this study. The presence of flavonoids explains the allelopathic effects of aqueous extract of *S. suaveolens* and insecticidal activities since water-soluble allelochemicals and insecticidal chemicals are found in this group of secondary metabolites (García-Calderón *et al.*, 2020). Also, flavonoids have been reported to actively prevent the growth and survival of other organisms such as bacteria, fungi, as well as other plants and insects (Céspedes *et al.*, 2014; Hikal *et al.*, 2017). Apart from their allelopathic and insecticidal properties, flavonoids have also been reported to play a key role in pollination as well. Flavonoids such as flavones and flavonols give flowers different pigments and colors which help to attract more than one type of pollinators (Scavo *et al.*, 2018). The presence of flavonoids in the *S. suaveolens* extracts could be the reason for the plants ability to attract different pollinators such as bees as reported by Godifrey *et al*. (2018).

Common bean production in Tanzania is mostly done by smallholder farmers, and often intercropped with cereal crops such as maize. Areas such as northern Tanzania, with favorable conditions and receiving two rainfall patterns are considered high potentials for common bean cultivations and higher yields. However, yields from the study area were low and this was mostly attributed to weed infestations and insect pest attacks. Likewise, in most developing countries, significant yield losses are linked to diseases, insect pests, weeds and low soil fertility (Venance *et al*., 2016). Additionally, many smallholder farmers in developing countries are resource constraint, and have to allocate scarce resources to different crops, which can result into poor management of insect pests, weeds, diseases among other constraints (Kelly *et al*., 2003). Therefore, weed and insect management strategies that are affordable and effective should be developed and adopted by smallholder farmers.

Mechanical weeding and chemical spray methods were reported by farmers as the major weeds and insect pest management strategies respectively. However, to most smallholder farmers, chemical spray seemed impractical due to higher cost, limited accessibility and adverse effects to human and the environment (Crop *et al.*, 2015; Dougoud *et al*., 2019), hence, arose the need to develop new or improve the existing approaches. This study has shown that, plant species with allelopathic and pesticidal properties such as *S. suaveolens* can offer promising outcomes in addressing various problems such as insect pests. These findings will help common bean smallholder farmers to protect their harvest which can be sold later to generate income, or used as food or seeds to be planted in the next season. Also, information on effectiveness of botanicals from weeds and other plant species will help to improve their practicability particularly in areas where they are growing. Therefore, there is a need for more research and demonstrations to farmers on how botanical plants particularly weeds with allelopathic and pesticidal properties can be used to manage other weeds and insect pests in smallholder farming systems.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The current study has confirmed that farmers in northern Tanzania perceive insect pest and weeds as the major setback in effective common bean production. The use of chemicals such as synthetic pesticide was reported as the main method for insect pest control. However, most smallholder farmers were not able to apply these chemicals due to reasons such as accessibility and affordability. There exists a knowledge gap in the area of integrated weed and pest management among most smallholder farmers in the surveyed districts. Most farmers were not aware on the allelopathic effects of weeds such as *S. suaveolens* on crops such as common bean and how this interaction can affect crop production by influencing seed germination and growth. The findings further urge on the need to consider extension officers as key players in linking farmers with government programs, non-governmental organizations (NGOs) and agricultural research findings, as proposed in Fig. 5. This will contribute to adoption new and improved pest and weed management strategies which are efficient, affordable and environmentally friendly for sustainable common bean production.

This study further demonstrated the bio-insecticidal potential of *S. suaveolens* in post-harvest management of *A. obtectus*. The findings show that, 10% of *S. suaveolens* powder to weight ratio of seeds significantly reduced the seed damage caused by *A. obtectus* similar to synthetic insecticides such as actellic super dust during the 90 days of the experiment. The effective utilization of *S. suaveolens* as a botanical pesticide could minimize use of hazardous chemicals in stored product pest control. Furthermore, the resource poor farmers in developing countries particularly in Africa and elsewhere where *S. suaveolens* is growing could easily prepare the powder and use it to effectively reduce post-harvest loss caused by *A. obtectus*.

The phytochemical screening of *S. suaveolens* methanolic and aqueous extracts revealed the presence of various secondary metabolites including Terpenes, Alkaloids and Flavonoids among others. The GC-MS analysis of *S. suaveolens* extracts further showed the presence of 14 compounds with allelopathic, insecticidal, antimicrobial and other properties. Thus, the *S. suaveolens* is found to possess significant compounds responsible for various activities which may explain its allelopathic effects as well as justify the practical application of this weed as a botanical insecticide particularly in the management of *A. obtectus*.

5.2 Recommendations

The knowledge gap on sustainable agriculture practices particularly in the management of insect pests and weeds identified in this study calls for multi stakeholder involvement particularly researchers, NGOs and extension officers to sensitize and encourage farmers to adopt integrated pest management strategies that will help to increase crop production and protect harvest during storage without compromising the wellbeing of the farmers, consumers and the environment at large.

The study also observed that, farmers mix insecticide with other insecticides and/or substances such as powder soap and kerosene in order to increase effectiveness in killing insect pests. Although reported working but the cocktail of insecticide could have significant health effects to people and the environment. Therefore, the study recommends further research on the safety, possible adverse effects and implications of using these cocktails of insecticides to human health, the environment and to the insect pests as well as these practices may cause the generation of insect pests resistant to the existing pesticides.

The results from the laboratory and screen house experiments revealed that aqueous extracts from *S. suaveolens* significantly affected seed germination and seedling growth of common bean. This might be due to the presence of water-soluble allelochemicals in *S. suaveolens* crude extracts which inhibits seed germination and interfere with the process of plant growth. Therefore, this study recommends the isolation, characterization and further investigations on the applications of these allelochemicals and other compounds in agriculture, medicine, cosmetics and other potential and valuable uses of *S. suaveolens*.

Furthermore, petri dish and pot experiments showed that higher concentration of crude extracts of *S. suaveolens* significantly reduced seed germination and seedling growth of common bean. This study therefore recommends further research on the interactions between *S. suaveolens* and common bean under the field conditions.

The post-harvest loss experiment from this study has revealed that bean variety Selian 97 was less damaged by *A. obtectus* compared with Jesca and Lyamungu 90 bean varieties, therefore the study recommends to seed agencies and research organizations to carry out further analysis on seed coat physical strength and chemical compositions of Selian 97 bean variety, and how these play part in reducing the seed damage caused by insect pests such as *A. obtectus*.

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APPENDICIES

Appendix 1: Farmers Registration Form

THE NELSON MANDELA AFRICAN INSTITUTION OF SCIENCE AND TECHNOLOGY
DISTRICT__________________________ **WARD** ______________________________
DATE_____________________________ **VILLAGE**____________________________

SN	NAME	SEX	AGE	EDUCATION	HH SIZE	FARM SIZE
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
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22						
23						
24						
25						

Appendix 2: Questionnaire used in the Social Survey

THE NELSON MANDELA AFRICAN INSTITUTION OF SCIENCE AND TECHNOLOGY (NM-AIST)

Baseline HHS Questionnaire

Introduction

Good morning/afternoon. My name is _____________________. Thank you for sparing time to come and meet with me today. I'm a PhD student from the Nelson Mandela African Institution of Science and Technology. I'm running studies and experiments to assess allelopathic and insecticidal potential of *Sphaeranthus suaveolens*. We are requesting to interview you for about 45 to 60 minutes in order to obtain information which will help us to come up with lessons and strategies for managing weeds and insect pests.

Do you consent for us to continue with this interview? Yes ( ) No ( ).

Note: In case the farmer replies '**NO**' to the above question, then the interview should be terminated and the farmer dropped from the list.

Village ____________________________ Date _________________________

Name of the respondent _____________________________ Gender: M/F

Education ________________ Age __________ Household size ________

1. Tenure (1.1) Owner (1.2) Tenant (1.3) Leasee (1.4) Mixed [own and rent]

2. Major crops grown
   2.1 Maize
   2.2 Common beans
   2.3 Rice
   2.4 Sunflower
   2.5 Others: __________ ___________ __________

3. Major weeds in general
   3.1 *Bidens pilosa/* Mashona nguo
   3.2 *Parthenium hysterophorus*/Gugu karoti
   3.3 *Digitaria abyssinica*/Sangari
   3.4 *Cyperus rotundus*/Ndago
   3.5 *Argemone mexicana*
   3.6 *Sphaeranthus suaveolens*/ Kidokomu
   3.6 Others: ____

4. Major weeds in common bean farming
   4.1 *Bidens pilosa*/Mashona ngui
   4.2 *Parthenium hysterophorus*/Gugu karoti
   4.3 *Digitaria abyssinica*/Sangari
   4.4 *Cyperus rotundus*/Ndago
   4.5 *Argemone mexicana*
   4.6 *Sphaeranthus suaveolens*/ Kidokomu
   4.7 _________________________ 4.8 _______________________ 4.9 _______________________

5. 5.1 Common bean sowing time _____________________ 5.2 Best sowing time _______________

6. 6.1 Rain fed 6.2 Irrigated 6.3 Mixed [Rain + Irrigation]
   6.3Estimated yield per acre (in kg)
   Common bean _________________
   Reasons: ____

7. Crop rotation? (7.1) Yes (7.2) No

8. 8.1 Last grown crop ____________________ 8.2 Next grown crop _________________________

9. Intercropping? (9.1) Yes (9.2) No
   9.3 If Yes which crops? ______________________________

10. Do you know this plant? (*Sphaeranthus suaveolens)? Kidokomu* (10.1) Yes (10.2) No

11. Is it a problem in common bean farming? (11.1) Yes (11.2) No

12. If it is a problem, what is the estimated loss due to *S. suaveolens*? (Minor, Normal, Major)
    12.1 Common bean a. Minor b. Average c. Major
    12.2 Rice a. Minor b. Average c. Major
    12.3 I don't know

13. How was it in the past? Probe for past 5, 10 years
    13.1 Increasing now compared to the past
    13.2 Decreasing now compare to the past
    13.3 Similar
    13.4 It was not there in the past
    13.5 I don't know

14. How do you control it?
    14.1 Weeding
    14.2 Synthetic herbicides
    14.3 Botanical extracts
    14.4 Do nothing
    14.5 ________________

15. Uses of *S. suaveolens* (Probe for uses such as)
    15.1 Fodder
    15.2 Medicine
    15.3 Sweeping broom
    15.4 Fuel
    15.5 Ornamental
    15.6 Others
    ____

16. Major pests in common beans (field and storage)
    16.1 Aphids
    16.2 Bean stem maggot or Bean fly
    16.3 Bean foliage beetle
    16.4 Bean pod borers or Moth
    16.5 White flies
    16.6 Bean bruchid/Bean weevil
    16.7 ____

17. Please mention the varieties of synthetic pesticides that you know:

18.1 Actellic	18.3 Dursban	18.5 Selecron	18.7 Duduall	18.9 I don't know
18.2 Dudukill	18.4 Duduba	18.6 Karate	18.8 Duducron	18.10 None

    18.11 List others: ____

18. Please mention the varieties of plant pesticides that you know:
    19.1 Leaves of neem tree
    19.2 Leaves of wild sunflower
    19.3 I don't know
    19.4 List others: ____

19. What do you perceive are the advantages of using synthetic pesticides to improve your bean farming?
    20.1 Easy to obtain
    20.2 Cheap
    20.3 Easy to use
    20.4 Effective to eradicate pests quickly
    20.5 I don't know
    20.6 List other advantages: ____

20. What do you perceive as the disadvantages of using synthetic pesticides to improve your bean farming?
    21.1 Toxic
    21.2 Expensive
    21.3 Difficult to obtain
    21.4 I don't know
    21.5 List other disadvantages: ____

21. What do you perceive as is the advantage of using botanical pesticides to improve your bean farming?
    22.1 Affordable
    22.2 Easy to obtain
    22.3 Effective to eradicate pests quickly
    22.4 Non-toxic
    22.5 I don't know
    22.6 List other advantages: ____

22. What do you perceive as the disadvantages of using botanical pesticides to improve your bean farming?
    23.1 Hard to process or prepare
    23.2 Difficult to obtain
    23.3 Less/Not effective to eradicate pests
    23.4 I don't know
    23.5 List other disadvantages: ____

23. Which method of weed control do you consider the most effective?
    24.1 Synthetic herbicide
    24.2 Botanical herbicide
    24.3 Weeding
    24.4 Other methods: ____
    Why? ____

24. Which method of pest control do you consider the most effective?
    25.1 Synthetic pesticide
    25.2 Botanical pesticide
    25.3 Biological
    25.4 Other methods: ____
    Why? ____

25. Your general comments on insect pest and weeds management
    ____
    ____
    ____
    ____

Appendix 3: Geo Training Attendance Certificate

DAAD Deutscher Akademischer Austauschdienst
German Academic Exchange Service

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Philipps Universität Marburg

CONFIRMATION OF PARTICIPATION

Hudson Christopher Laizer

has successfully participated in the summer school

GeoTraining: Environmental and Remote Sensing Data Analysis via Geospatial Technologies in Research and Teaching

This four-week training programme for scholarship holders from the German Academic Exchange Service (DAAD) was held at the Goethe-Universität Frankfurt am Main, Germany, at the Department of Human Geography, September 2nd – 28th, 2018. The summer school covered the following topics:

Module 1: Geospatial Technologies (4 days / 32 hrs.)
Introduction to R studio; create boxplots; classify remote sensing systems; compute land-cover classifications, using machine learning algorithms; model predictions.
Project 1: Geospatial Technologies (4 days / 32 hrs.)
Methods for the analysis and communication of environmental and remote sensing data, applied in the context of case-based project work performed in small groups.
Module 2: Academic Communication (2 days / 16 hrs.)
Academic writing in English; academic vocabulary; self-editing strategies; structuring academic texts; referencing and quoting; publishing and copyright issues.
Module 3: Support and Guidance (1 day / 8 hrs.)
Peer-teaching, tutoring, mentoring, and supervising in higher education; conversation techniques; communication rules; structuring guidance discussions; feedback culture.
Module 4: Higher Education Didactics (2 days / 16 hrs.)
Action-oriented teaching; course planning; activating forms of learning in large-group and small-group events; service learning and citizen science in higher education.
Project 2: Teaching Project (3 days / 24 hrs.)
Development of a course concept for higher education on the topic of "Geospatial Technologies" in the context of case-based project work performed in small groups.

Frankfurt am Main, September 2018

Dr. Ursula Paintner
German Academic Exchange Service (DAAD)
Head of Section Development Cooperation (P32)

Prof. Dr. Detlef Kanwischer
Goethe-Universität Frankfurt am Main
Training Programme Leader

This event was supported by the DAAD with funds from the Federal Ministry for Economic Cooperation and Development (BMZ).

Appendix 4: Intersol 2021 Conference Certificate of Presentation

Certificate

of Presentation

This is to certify that

Hudson C Laizer

has delivered during the Intersol 2021, a presentation entitled:

Farmer's knowledge, perceptions and practices in managing weeds and insect pests of common bean in Northern Tanzania

Facilitated online conference on the 12th and 13th April 2021

Theme: Nature based solutions, gender equity and interconnectivity for climate resilience in Africa

General Chair

Dr. Jessica Thorn

University of York, Department of Environment and Geography

University of Cape Town, African Climate and Development initiative

RESEARCH OUTPUTS

(i) Publications

Laizer, H. C., Chacha, M. N., & Ndakidemi, P. A. (2019). Farmers' Knowledge, Perceptions and Practices in Managing Weeds and Insect Pests of Common Bean in Northern Tanzania. *Sustainability*, *11*(15), 4076. https://doi.org/10.3390/su11154076

Laizer, H., Chacha, M., & Ndakidemi, P. (2020). Insights of Allelopathic, Insecticidal and Repellent Potential of an Invasive Plant *Sphaeranthus suaveolens* in Pest and Weed Management. *Journal of Biodiversity and Environmental Sciences*, *17*(2), 101–112.

Laizer, H. C., Chacha, M. N., & Ndakidemi, P. A. (2021). Allelopathic Effects of *Sphaeranthus suaveolens* on Seed Germination and Seedling Growth of *Phaseolus vulgaris* and *Oryza sativa*. *Advances in Agriculture*, *2021*, 1–9.

Laizer, H. C., Chacha, M. N., & Ndakidemi, P. A. (2021). Bio-pesticidal potential of *Sphaeranthus suaveolens* in the management of storage insect pest of common bean (*Acanthoscelides obtectus*) in Northern Tanzania. *International Journal of Pest Management.* Manuscript under review

(ii) Leaflet for common bean farmers in Arumeru and Moshi Rural districts

(iii) Poster presentation

Review Article

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REVIEW PAPER OPEN ACCESS

Insights of allelopathic, insecticidal and repellent potential of an invasive plant *Sphaeranthus suaveolens* in pest and weed management

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Article published on August 30, 2020

Key words: Botanical extracts, Secondary metabolites, Sustainable agriculture, Smallholder farmers, Terpene

Abstract

Sphaeranthus suaveolens is a weed from the family Asteraceae, it grows abundantly in wet areas and most common in rice fields. The extracts from plants closely related to *S. suaveolens* have been reported to have allelopathic, insecticidal, antifeedant, repellent, and other biological activities. Currently, the use of synthetic chemicals to control weeds and insect pests raise several concerns related to environment and human health. Extracts from plants with pesticidal properties can offer the best and an environmentally friendly alternative. Some of these extracts have been extensively tested to assess their applications as valuable natural resources in sustainable agriculture. This review article therefore explores the potential of *S. suaveolens* extracts in controlling insect pests and managing weeds by smallholder farmers.

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Introduction

Agricultural production in most part of the world is affected by pests, diseases and weeds among other factors (Nations, 2016; Singh *et al.*, 2003). Majority of the farmers respond to these constraints through the use of synthetic chemicals such as herbicides and pesticide (Kelly *et al.*, 2003). The extensive use of these chemicals in controlling insect pests and managing weeds, however, have alarmed the public on the effects they might bring to human health and the environment at large (Khanh *et al.*, 2005). Such concerns are putting pressure on agricultural sector to reduce the use of chemicals and as a result, much attention is paid to alternative methods and techniques for controlling and managing weeds and insect pests, through non-chemical methods and/or use of natural products such as botanical extracts (Isman, 2006a; Williamson *et al.*, 2008).

Prior to the discovery and commercialization of synthetic pesticides, botanical extracts, among other methods, were used by most farmers in crop protection against insect pests, weeds and diseases (El-Wakeil, 2013). Extracts from plants with allelopathic or pesticidal properties were of great importance in making natural herbicides and pesticides (Benner, 1993; Godfrey, 1994). There is also increasingly evidence from literatures that plant extracts can be manipulated and used as perfect agrochemicals in controlling insect pests and managing weeds (Hoagland, 2001; Macías *et al.*, 2001; Mkenda *et al.*, 2015; Nattudurai *et al.*, 2012; Ngondya *et al.*, 2016; Singh *et al.*, 2003; Stephen *et al.*, 2002; Vyvyan, 2002).

The secondary metabolites in plants are responsible to biological activities that offer defense against predators, fungi and bacteria, also these metabolites may act as natural herbicides by suppressing other plant species (Dewick, 2009; Schoonhoven *et al.*, 2005). These biological activities from the plants secondary metabolites can be exploited and manipulated for various human uses, and in this respect *Sphaeranthus suaveolens* has a considerable potential. *S. suaveolens* is a widespread weed in swampy and irrigated farmlands, and usually infests cultivated fields and reduces crop productivity (Beentje, 2002). A heavy infestation of this weed results in adverse effects on the growth and yield of crops, particularly in rice fields (Fahmy, 1997).

It has been observed that *S. suaveolens* has an ability to overcome and suppress crop plants in a wide range over a short period of time (Ivens, 1989). However, the secondary metabolites involved are largely unknown and weather they can be applied in managing other weeds and controlling insect pests is yet to be determined. Understanding this could considerably justify the practical application of botanical-based weeds and insect pests management techniques for most smallholder farmers in areas where *S. suaveolens* is growing.

This review article therefore highlights the allelopathic, insecticidal and repellent potential of an invasive plant *S. suaveolens* with a focus on its application in controlling insect pests and managing weeds by smallholder farmers.

Overview of S. suaveolens and its spatial distribution in Tanzania

S. suaveolens is an aromatic annual spreading herb from the family Asteraceae with broad sessile leaves covered with glandular hairs (Osman, 2011). The lower stem often trails along the ground and roots at the nodes with thread-like root, flowers are purple, in compound heads ovoid in shape and borne on solitary glandular peduncles with toothed wings (Fayed & Mohamed, 1991).

The head as a whole is surrounded by several rows of bracts, of which only the tips are visible when flowers are fully open, and propagated by seeds which takes about 10-12 days to germinate, and the seedlings attain the height of 5.0 - 6.0cm within 30 days in a favorable environment (Beentje, 2002).

S. suaveolens is widespread in Africa over a range of altitudes from Rwanda, Burundi, Sudan, Ethiopia, Zambia, Malawi, Mozambique, Egypt, Uganda, Kenya to Tanzania (Everard *et al.*, 2002; Fahmy, 1997). It is mostly found growing in wet areas and thrives well in medium clayey soils, but also common in and around irrigation ditches and rice fields and considered as a major weed in most farms (Ivens, 1989). In Tanzania, the plant was first reported in Songea (Brenan, 1960), then Mpwapwa (Launert, 2003), Mkata and Mandela in Wami River Ecosystem (Mligo, 2017). The spatial distribution of *S. suaveolens* in Northern Tanzania particularly Arusha and Kilimanjaro regions however, have not been mapped despite being reported as a weed to most agricultural fields.

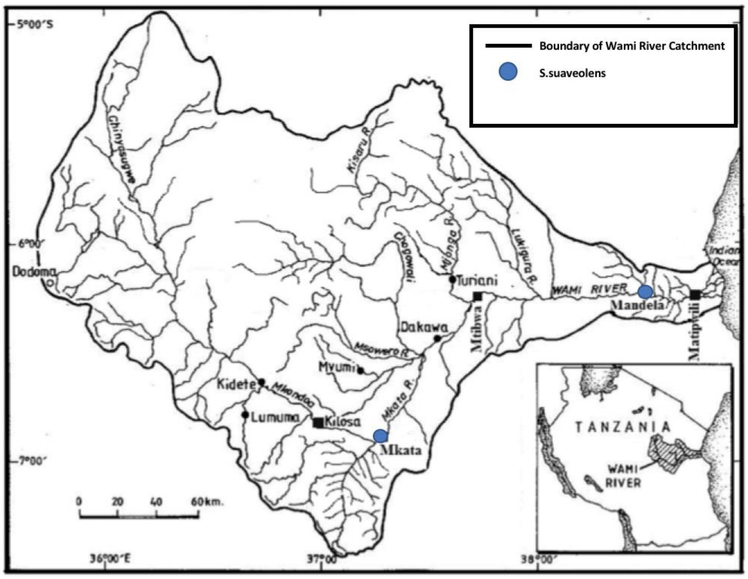

Fig. 1. Distribution of *S. suaveolens* in Wami River Ecosystem in Tanzania.

Allelopathic effects of S. suaveolens on crops

Allelopathy is a phenomenon, whereby one plant influences the growth of another one, including microorganisms by the release of chemical compounds into the environment (Keeley, 2010; Rice, 1983; Whittaker & Feeny, 1971). The allelopathic effects are the result of chemical compounds known as allelochemicals, which are usually plants' secondary metabolites or byproducts of the principal metabolic pathways in plants (Chancellor, 1987; Dayan *et al.*, 2009; Macías *et al.*, 2007). In recent years, allelopathy has become a research hotspot for making comprehensive analysis about the mechanism of weeds and identification of specific chemical compounds responsible for allelopathic effects (Azirak & Karaman, 2008; Bais *et al.*, 2003; Einhellig & Leather, 1988).

Most allelopathic plants have been observed to significantly affect the growth, productivity and yield of other crops by causing soil sickness and nutrient imbalance (Kohli *et al.*, 2008), as well as affecting the microbial population (Batish *et al.*, 2001). Several studies have indicated that, most weeds possess allelopathic effects which play a significant roles in their invasion success (Macías *et al.*, 2014; Qasem & Foy, 2001; Zhou *et al.*, 2013). Numerous weeds from the Asteraceae family have been reported to possess allelopathy and can significantly inhibit crop productivity in agricultural land (Ilori *et al.*, 2010; Kong *et al.*, 2007). The invasive weed, *Sphaeranthus indicus* has been reported to inhibit seed germination and growth of wheat (*Triticum aestivum),* rice (*Oryza* *sativa*) and mung bean (*Vigna radiata*) in different farming systems (Lodha, 2004).

Recently, Mahajan *et al.* (2015) reviewed the allelopathic potential of *S. indicus* and found that the germination and seedling growth of various crops were significantly decreased with increase in concentration of its extract.

Despite of the negative effects on cultivated crops, allelochemicals from allelopathic plants can be manipulated and used to control weeds of various crops. For example, Khanh *et al.* (2006) noted that the allelochemicals contained in tissues of *Passiflora edulis* can significantly suppress the two noxious paddy rice weeds (*Echinochloa crusgalli* and *Monochoria vaginalis*). Other studies have also reported the use of allelochemicals for weed control in the laboratory as well as application under field conditions (Jabran *et al.*, 2015; Ngondya *et al.*, 2016). Jamil *et al.* (2009) described the utilization of allelopathic water extract as an important and useful way of exploiting the allelopathic potential to manage wild oat and canary grass in wheat fields.

The emergence and root length of most rice weeds was inhibited by allelochemical (Lycorine) from the dead leaves of spider lily (Iqbal *et al.*, 2006). The allelopathic crops when used as cover crop, mulch, smother crops, green manures, or grown in rotational sequences maybe helpful in reducing noxious weeds and plant pathogen, improve soil quality and crop yield (Khanh *et al.*, 2005).

Furthermore, the application of allelopathic extracts may give an efficient alternative control over weeds similar to that offered by synthetic herbicides (Xuan *et al.*, 2004). Interactions among potential allelopathic plants, target pests and other non- target organisms in a cropping system also need to be considered and fully realized to avoid detrimental effects to desired crops and non-target species (Farooq *et al.*, 2013).

The allelochemicals involved in weed suppression can serve as basic templates for developing new generation of biopesticides with low or no toxic effects to the environment and human health (Ferguson *et al.*, 2009).

The allelopathic potential of *S. suaveolens*, therefore need to be realized and selectively used to suppress density of other weeds and insect pests population particularly in small farming agricultural systems.

Insecticidal and repellent activities of S. suaveolens to insect pests

Insecticides, weather natural or synthetic are developed to either kill, repel, or interfere with the damaging behavior of insect pests (EPA, 2009). Due to intensity of plant-insect interactions, plants have well developed defense mechanisms against insect pests by producing natural compounds which acts as natural pesticides (Després *et al.*, 2007). The most exciting concept is to isolate and identify such compounds and use them as candidates in making safer pesticides (Maia & Moore, 2011). Plant extracts with pesticidal properties can be active against specific target insects, biodegradable, have low to non-toxic effects, cheap and easy to prepare (Kim *et al.*, 2003; Mkindi *et al.*, 2017). Due to this facts, these plant extracts could lead to the development of new classes of safer pesticides (Céspedes *et al.*, 2014; Tembo *et al.*, 2018).

The Asteraceae family in which *S. suaveolens* belongs, have been reported to contain plants with insecticidal activities (Dhale, 2013; Green *et al.*, 2017; Sosa *et al.*, 2018). These insecticidal activities are mostly linked to presence of secondary metabolites such as terpenes, which can act as larvicides, insect growth regulators and feeding and oviposition deterrents (Miresmailli & Isman, 2014). Terpene is among the most diverse class of plant secondary metabolites found in essential oils of most plants, *S. suaveolens* included (Ahmed *et al.*, 2017; Pagare *et al.*, 2015). This secondary metabolite has been reported to play an important role in plant protection against pathogens (Neerman, 2003), insects (Wu *et al.*, 2016) and toxic to mammals as well (Gurib-Fakim, 2006). Recently, Sosa *et al.* (2018) reported insecticidal activities of the terpene isolated from *Vernonanthura nebularum* against fall army warm (*Spodoptera* *frugiperda)* and fruit fly (*Ceratitis capitate*).

Moreover, two other terpenes from *Inula helenium* were examined by Kaur *et al.* (2017) and reported to significantly inhibit the growth of tobacco leafworm (*Spodoptera litura*).

Other techniques such as use of water extracts from *S. indicus* was also reported to demonstrated toxic effects against insect pests such as rice weevil (Patole *et al.*, 2008), cowpea weevil (Singh & Shrivastava, 2012) and red flour beetle (Pugazhvendan *et al.*, 2012). Furthermore, the extracts from *S. indicus* have been showing larvicidal activities and repellent activities to most of the insect pests (Arivoli *et al.*, 2016; Baby, 1994; Singh & Shrivastava, 2012).

The presence of secondary metabolites with pesticidal properties such as terpene in the essential oil of *S. suaveolens* may give positive insecticidal and repellent activities to most insect pests, hence used for as protective agents against insect pests, but this needs further scientific investigation.

Key allelochemicals from the leaf, stem and root extracts of S. suaveolens

Allelochemicals are secondary metabolites produced by living organisms such as plants that have stimulatory or inhibitory effects upon the growth, health, behavior and distribution of neighboring organisms being another plants, insects or microbes (Haig, 2008). The role played by secondary metabolites is mostly ecological, linked to plant defense against other plants, pests, or diseases (Ramakrishna & Ravishankar, 2011). Allelochemicals undoubtedly pose problems in agriculture, but if well manipulated they can be beneficial and offer great opportunities such as insect pests and weeds control (Einhellig, 1987). Despite the efforts in allelopathic researches, little is known on the potential to exploit the key allelochemicals in agricultural systems and use them as templates in making safer and affordable herbicides and/or pesticides (Kremer & Ben-Hammouda, 2009). Much of the work to date has focused on weather extracts from *S. suaveolens* show biological activities such as antimicrobial, immune stimulating, anticancer, antitumor, anthelmintic, repellency, insecticidal and allelopathy (Ahmed & Mahmoud, 1997; Kleinowski *et al.*, 2016). However, very few literatures have reported the identified compounds found in *S. suaveolens* extracts, none of it has a list of allelochemicals found in *S. suaveolens* despite being the weed of economic importance in many rice and common bean farms in Africa.

Allelochemicals belong to various chemical groups, and can be classified based on their structures and properties into: water-soluble organic acids, straight-chain alcohols, aliphatic aldehydes, and ketones, lactones, long-chain fatty acids and polyacetylenes, quinines (benzoquinone, anthraquinone and complex quinines), phenolics, cinnamic acid and its derivatives, coumarins, flavonoids, tannins, steroids and terpenoids (Li *et al.*, 2010).

Most of these biochemicals are synthesized during the shikimate pathway (Hussain & Reigosa, 2011) or, in the case of essential oils, from the isoprenoid pathway (Rehman *et al.*, 2016). The extract of the aerial parts of *S. suavealens* was reported by Jakupovic *et al.* (1990) to contain eight eudesman-12. 6 β abides, carvotacetone derivatives and a thymohydroquinone glucopyranoside. Later on, Pooter *et al.* (1991) reported extract of the same plant comprise of thymohydroquinone dimethylether, a diacetylene thiophene, inositol and myoinositol esters, and several carvotanacetone derivatives, he went further to examine the essential oil of *S. suaveolens* and noted methyl chavicol, α-ionon,e, dcadinene and p-methoxycinnamadehyde as major constituents, and a-terpinene, citral, geraniol, geranyl acetate, βionone, shaerene, indicusene and sphaeranthol as minor constituents. Ahmed and Mahmoud (1997) examine the extract of aerial parts of *S. suaveolens* and reported three carvotacetone derivatives, together with four monoteroene compounds. Later on, Hassanali *et al.* (1998) reported cis-pinocamphone as the major constituents (63.5%) of the leaf oil of *S. sauveolens*.

The details of these identified compounds are stated in Table 1, however, identifying alone isn't sufficient enough, rather gaining an understanding on which among these compounds are allelochemicals and how to use them in improving crop production though managing weeds and controlling insect pests in sustainable agriculture will be a big advantage.

Table 1. Identified compounds from leaf oil of *S. suaveolens*.

Compound	Ip on RSL-150	Content
α- Thujene	921	0.1
α- Pinene	931	10.6
Camphene	941	0.1
Sabinene	964	1.5
Oct-1-en-3-ol	967	0.3
Myrcene	981	0.6
α- Phellandrene	995	4.1
α- Terpinene	1007	tr
p- Cymene	1011	6.3
1,8- Cineole	1019	6.6
γ- Terpinene	1049	1.1
trans- Pinene hydrate (?)	1131	0.3
Pinocamphone	1139	1.0
Isopinocamphone	1155	33.5
Terpinen-4-ol	1164	0.7
p- Cymen-8-ol	1170	0.4
α-Terpineol	1173	0.6
Methyl thymol ether (?)	1222	0.1
Cuminaldehyde	1228	tr
Thymol	1267	0.2
Carvacrol	1274	0.3
α- Terpinyl acetate	1329	1.2
Eugenol	1330	tr
α- Ylangene	1369	tr
β- Elemene	1382	tr
Thymohydroquinone	1400	16.1
dimethylether	1418	0.9
β- Caryophyllene	1447	0.1
α- Humulene	1449	0.1
β-Farnesene	1461	tr
allo- Aromadendrene	1515	1.2
δ- Cadinene	1547	0.1
Nerolidol	1564	0.7
Spathulenol	1570	0.4
Caryophyllene oxide		

tr = trace (<0.05%); (?) = identification based on the MS and RT

Source: Pooter *et al.* (1991)

Farmers knowledge and perception towards use of S. suaveolens in insect pests and weeds management

The diversity of insect pests and weeds in most agricultural lands need a multi-control strategies to produce satisfactory results in a sustainable manner (Parker *et al.*, 2013). The goals and values of long-term sustainability must be reflected in combinations of practices and methods consistent with an individual farmer's resources, including knowledge and farming practices (Ikerd, 1993). Unfortunately, most smallholder farmers in developing countries have limited knowledge and are resource-constrained. This limits their capacity to manage weeds and insect pests (Whitbread *et al.*, 2010).

Pest management practices by most smallholder farmers are mainly based on use of chemical pesticides, though this alone does not give the desired results (Toda & Morishita, 2009). Few of these farmers have combined such method with some cultural practices such as intercropping and crop rotation (Ajeigbe *et al.*, 2010; Ngowi *et al.*, 2007). Other studies reported that limited technical knowledge among small holder famers and shortage of extension services are among the limiting factors that hinder the adoption of suitable pest management practices (Midega *et al.*, 2012; Mkenda *et al.*, 2020). Most farmers still relying on past experience and farming practices despite the fact that they have not attained fruitful results over the years (Khan & Damalas, 2015). Integrating different pest management practices has long been proposed as the long term solution and future for sustainable agriculture (Pretty & Bharucha, 2015).

For any pest management approach to work and eventually adopted by farmers, their knowledge, perceptions and practices has to be fully realized (Chitere & Omolo, 2008; Hashemi & Damalas, 2010; Huis, 2014). Khan *et al.* reported that some farmers are aware of the role played by companion crops with repellent or toxic characteristics in pests control, as well as harboring natural enemies and in this regard, *S. suaveolens* may have considerable potential (Khan *et al.*, 2010). Isman and Grieneisen (2014) pointed out several plant species from the Asteraceae and other families with pesticidal properties that may be used to control and manage insect pests and weeds, however, very few of these plants are known and used by smallholder farmers despite the increasingly focus in research on plant species with pesticidal potential in Africa.

Conclusion

S. suaveolens is a weed which possesses diverse group of biological activities both in medicine as well as in agriculture.

However, the importance of such activities on the later have been ignored despite its potential in managing insect pests in the field, storage and suppressing other weeds. The wide geographical distribution of *S. suaveolens* give an added advantage and opportunities to small holder farmers as a cheap alternative in managing weeds and controlling pests since they cannot afford the synthetic pesticide. Additionally, the combination of small dosage of synthetic pesticides with botanical extracts may be more effective and environmental friendly compared with standard dose of synthetic pesticides (Isman, 2006b; Joseph *et al*., 2008). The allelochemicals from the plant extracts may be isolated and identified and eventually serves as templates for developing new generation of pesticides with less toxic effect to environment and human health. Extension services and trainings are very important in enhancing the performance and promoting adoption of new strategies and practices to smallholder farmers such as use of botanical extracts particularly from invasive weeds in managing and controlling pests, other weeds and diseases.

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Research Article 1

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Article

Farmers' Knowledge, Perceptions and Practices in Managing Weeds and Insect Pests of Common Bean in Northern Tanzania

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Abstract: Weeds and insect pests are among the serious constraints in common bean production in most rural communities. A survey of 169 smallholder farmers was conducted in two common bean-growing districts in northern Tanzania. The aim was to assess farmers' knowledge, perceptions, current management practices and challenges in order to develop sustainable weed and insect pest management strategies. The results revealed that 83% of farmers perceived insect pests as the major constraint in common bean production, while 73% reported weeds as the main drawback. Insect pest management was mainly achieved through the use of synthetic pesticides, however, only 24% of farmers were able to apply, the rest could not afford due to high cost, limited access and lack of knowledge. Only 6.5% of farmers were aware of non-chemical methods and 2.1% did not practice any method in managing insect pests, both in the field and during storage. Moreover, farmers generally relied on experience in managing insect pests and weeds, and about 43% did not see the need to consult extension officers. These findings indicate that there is a need to sensitize and train farmers on the sustainable methods for pest and weed management in common bean farming systems in northern Tanzania.

Keywords: smallholder farmer; *Phaseolus vulgaris*; crop protection; sustainable agriculture; integrated pest and weed management

1. Introduction

Grain legumes are very important crops in rural livelihoods in East Africa, with common bean, *Phaseolus vulgaris* L., being the most essential and major source of protein for most smallholder farmers [1,2]. Common bean also plays an important role in crop rotation and intercropping in most agricultural fields due to its ability to fix nitrogen [3]. In Tanzania, common bean is cultivated in many regions. However, the main areas of production have been the mid to high altitude zones, which experience more reliable rainfall and cooler temperatures since the crop does not tolerate prolonged periods without rainfall [4,5].

Northern Tanzania, particularly the Arusha and Kilimanjaro regions, represent one of the key and most suitable areas for common bean production. This can be attributed to their favorable agro-climatic conditions [1]. Most of the common bean production is carried out by smallholders farmers [6], cultivating less than 2 ha [7] and generally without using fertilizers [8]. The yields obtained are primarily for home consumption [9,10] and only the surplus of around 20% is being marketed [4]. Despite the favorable climatic conditions for common bean production and easy access to international markets, yields in the two regions are generally low ranging, from 500 to 700 kg/ha [7,8]. This is contrary to potential yields under favorable conditions, which range from 1500 to 3000 kg/ha [11].

Insect pests and weeds are a major drawback of common bean production in northern Tanzania, particularly in smallholder farming systems. Insect pests have been reported to attack common bean both in the field and during storage [12]. The most important insect pests in the field are the bean stem maggots (*Ophiomyia phaseoli)* [13], while during storage the bean bruchids (*Acanthoscelides obtectus*) are the most common [14]. Weeds, on the other hand, have been reported to negatively affect common bean production as well. They compete for resources [15], releasing allelochemicals [16] and harboring insect pests [17,18]. The diversity of pests and weeds have made it very difficult for resource-constraint farmers to manage and control them in a sustainable manner [19,20].

The use of synthetic pesticides and herbicides have been reported as the main and preferred method by most farmers in managing and controlling insect pests and weeds [5,21]. However, there are growing concerns on the safety of such chemicals to consumers and the environment at large [22,23]. Moreover, most smallholder farmers cannot afford a wide spectrum of these herbicides and pesticides [24]. Cultural practices such as intercropping, crop rotation have also been practiced by farmers in trying to control pests and weeds [25]. Nevertheless, no fruitful results have been attained and common bean yields are still below standard under favorable conditions [4].

In spite of these pest and weed management challenges, very little information is available on farmers' perceptions, knowledge, and practices in controlling insect pests and weeds in common bean farms particularly in northern Tanzania [26]. In order to develop an appropriate pest and weed management approach that will eventually be adopted by farmers, their knowledge, perceptions, and practices have to be fully realized and incorporated in the process [27–29]. Therefore, this study highlights farmers' knowledge and perception of weeds and insect pests in common bean farming by examining their current management practices and challenges with a view to develop an effective weed and pest management strategy for smallholder farming systems in northern Tanzania.

2. Materials and Methods

2.1. Study Site

The household surveys (HHS) were conducted from October 2018 to February 2019 in 13 villages from the two districts (Arumeru 3°08′ S, 36°52′ E and Moshi rural 3°21′43.2″ S, 37°27′32.4″ E) in northern Tanzania covering the key common bean growing areas in the region (Figure 1). The villages covered were Nambala, Lekitatu, Ndato, Kikatiti, Malula, Maroroni, King'ori, Boro, Kirima Kati, Umbwe Sinde, Maua, Uchau Kusini, and Sambarai. These areas experience a bi-modal rainfall pattern, with the main cropping season running from March to May and the short cropping season from November to January. The zone is also considered high potential for agriculture, with both high and medium elevation (1035 to 1724 m above sea level). The main farming systems comprise of crops such as banana, coffee, and cereals such as maize intercropped with legumes such as common beans.

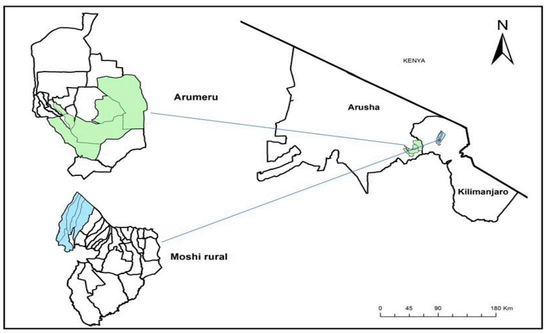

Figure 1. Location of the study area i.e., Arumeru and Moshi rural districts.

2.2. Data Collection

Data on common beans farming and its constraints, particularly insect pests and weeds in northern Tanzania were collected through household surveys and focused group discussions using methodologies described by Midega et al. [30]. In each of the 13 villages visited, the respondents for the interviews were randomly selected using sampling lists provided by the village leaders in both districts. A total of 169 common bean farmers were interviewed, 87 farmers from Arumeru and 82 farmers from the Moshi rural district. The semi-structured questionnaire used comprised of questions on households' demographic characteristics, economic profile, farm characteristics, yields, percentage of yields damaged by pests and weeds, knowledge and perceptions of common bean pests and weeds, pest control methods and practices (Table 1). The questionnaire was pre-tested in a pilot study before being used in the targeted districts. Before starting an interview, a consent form was provided to a respondent, which introduced and explained the aim of the research and asked for approval to continue with the interview. The household data were supplemented by information obtained from the key informant interviews and focus group discussions, which were conducted through organized community meetings in all villages where guiding questions were asked to provoke a discussion on the key aspects of common bean farming and its constraints, particularly weeds and pests, their management and challenges most farmers face.

Table 1. Overview of the questions included in the questionnaire used.

Data Group	Description
Personal data, economic profile and farms characteristics	Gender; Age; Education; Household size; Yields; Land ownership
Knowledge of common bean pests and weeds	Most common and dangerous insect pests and weeds
	Local, common and scientific names of each species
	Perceptions of impact on common bean yields
Pest and weed management practices	Common methods of pest and weed control
	Criteria for the selection of weed and pest control strategy
	Decisions on which methods should be used and for what periods
	Pros and cons of different control methods
	Pesticide use; pesticide products; pesticide rates applied in the field
	Perceptions of the effects of pesticide use (synthetic vs. botanical)
	Levels of knowledge about pesticide safety (synthetic vs. botanical)

2.3. Data Analysis

Survey data were summarized and descriptive statistics (means, standard deviation, and percentages) were calculated using the Statistical Package for Social Sciences (SPSS) version 25. For multiple answered questions, the percentages were calculated for each group of similar responses. The percentages of farmers in the two districts (Arumeru and Moshi rural) who gave similar responses to a question were calculated based on the total number of farmers who responded to each question. Comparative statistical tools, such as Chi-square and one-way analysis of variance (ANOVA), were conducted to assess differences regarding socio-demographic, farm characteristics, knowledge, perceptions and management practices of common bean pests and weeds. The level of significance was set at 0.05 and means were separated by Tukey's HSD (honestly significant difference) test.

3. Results

3.1. Socio-Economic Characteristics of the Farmers

Most of the farmers (70.9%) surveyed in the two districts were male. The average age of the farmers did not vary ($p < 0.18$) across the surveyed districts, ranging from a mean of 48.95 years in Arumeru to 51.29 years in Moshi rural. The mean age for all districts combined was 50.12 years, which is in the middle age category (Table 2). The majority of the respondents (78.15%) had primary education, while 8.35% had non-formal education but were able to read and write. There was only a paltry of 1.15% with tertiary education (college and university) (Table 2). The average household size of farmers comprised of five individuals ranging from 2–11 individuals in the Arumeru and Moshi rural districts, respectively. The respondents in both districts were smallholder farmers who owned an average land size of 0.44 ha. Additionally, the average area allocated to common bean by most farmers was less than 0.2 ha. Common bean was grown both for home consumption and sale by the majority of the farmers (70%), whereas 20% of the farmers reported that the produce was used solely for home consumption and 10% of the farmers reported selling all their produce. Yields of common bean varied significantly (p = 0.001) across districts, with a mean yield of 242 kg/ha for all districts (Table 2).

Table 2. Socio-economic characteristics of the respondents, their common bean yields.

Variable		Districts			
		Arumeru	Moshi Rural	Mean (SD)	Chi Square
Gender (%)	Male	74.7	67.1	70.9 (5.37)	x^2 = 1.197; df = 1; p = 0.27
	Female	25.3	32.9	29.1 (5.37)	
Education level (%)	None	5.7	11	8.35 (3.75)	
	Primary	77	79.3	78.15 (1.63)	
	Secondary	14.9	9.8	12.35 (3.61)	
	College	2.3	0	1.15 (1.63)	
Education (years)	Mean (SD)	7.07 (2.55)	6.29 (2.74)	6.68 (2.65)	x^2 = 8.73; df = 7; p = 0.27
Age (%)	18–45	44.8	36.6	40.7 (3.54)	
	45–60	35.6	41.5	39 (0.71)	
	>60	19.5	22	20.75 (2.83)	
Age (years)	Mean (SD)	48.95 (12.51)	51.29 (10.13)	50.12 (11.32)	x^2 = 50.27; df = 42; p = 0.18
Household size (%)	1–5	65.5	56.1	60.8 (4.24)	
	6–10	34.5	42.7	38.6 (2.83)	
	>10	0	1.2	0.6 (1.41)	
Household size	Mean (SD)	4.94(1.57)	5.52(1.74)	5.23 (1.66)	x^2 = 14.36; df = 8; p = 0.07
Land owned per household (%)	0–1	92	100	96 (5.65)	
	2–3	8	0	4 (5.65)	
Land owned per household (ha)	Mean (SD)	0.5 (0.53)	0.38 (0.18)	0.44 (0.2)	x^2 = 18.95; df = 9; p = 0.02
Yields (kg/ha)	Common bean	306 (188.11)	178 (81.98)	242 (135)	x^2 = 79.88; df = 15; p = 0.001

3.2. Common Bean Cultivation Practices

On average, common bean was grown on 0.44 ha per household in both districts visited. This ranged from 0.34 ha to 0.63 ha in the Moshi rural and Arumeru districts, respectively. Intercropping was the most common practice reported by almost all respondents in the two districts. On average, 98% of farmers in both districts reported intercropping common bean with maize as a traditional practice. Crop rotation, on the other hand, was only practiced by few farmers (16%) in the Arumeru district, with common bean being rotated mostly with indigenous vegetables, such as African eggplant (*Solanum aethiopicum*). The majority of the respondents (96%) had experience in common bean cultivation, with an average of 17 years, but the period varied significantly across districts, ranging from nine to 25 years in the Moshi rural and Arumeru districts, respectively (Table 2). However, despite years of experience in common bean farming, yields remained low and varied significantly across districts, with Moshi rural recording the lowest yields (178 kg/ha) and Arumeru with the highest yields (306 kg/ha) in the year 2019 (Table 2). Most of the farmers (89%) in the two districts indicated that they check and sort seeds that are not damaged by insect pests before planting.

3.3. Farmers' Knowledge of Weed and Pest Problems in Common Bean

In this study, 88% of the respondents reported that insect pests were the major constraint to effective production of common bean, followed by weeds (73%) and diseases (14%) (Table 3). Amongst the three most common insect pests, bean aphid (*Aphis fabae*) was mentioned by 86% (x^2 = 0.1; df = 1; p = 0.752) of the farmers as the main insect pest of common bean, followed by bean weevil (*Acanthoscelides obtectus*) (49%) (x^2 = 4.043; df = 1; p = 0.044) and ootheca (*Ootheca bennigseni*) (44%) (x^2 = 4.975; df = 1; p = 0.026) (Figure 2). On the other hand, the three most common weeds mentioned by respondents were *Cyperus rotundus* reported by 79.8% (x^2 = 0.276; df = 1; p = 0.599), followed by *Bidens pilosa* (45.3%) (x^2 = 57.703; df = 1; p = 0.001) and *Sphaeranthus suaveolens* (37.5%) (x^2 = 0.638; df = 1; p = 0.424) (Figure 3). The majority of farmers (92%) were able to identify and describe common bean weeds and insect pests by their local names. Only 2% were able to identify the insect pests and weeds upon seeing the pictures. A significant proportion of farmers (77%) mentioned beneficial insects such as ladybird beetle and honey bees as insect pests. Additionally, most of the farmers (84%) reported insect pest occurrence in the field, while 72% of farmers experienced insect pest attacks during storage. A huge proportion of farmers (98%) perceived that insect pests, particularly bean weevils, were causing significant loss of income, shortage of food (77%) and damage of seeds (62%) for planting in the subsequent season. On the other hand, 56% of the farmers described insect pest and weed challenge as being worse at present compared with the past 10–20 years.

Table 3. Perception of farmers on insect pest and weed control strategies in common bean farming.

Variable	District			
	Arumeru	**Moshi Rural**	**Mean**	**Statistics**
Insect Pest Control Methods				
Chemical sprays (pesticides)	85.5	72.2	78.9	x^2 = 2.87; df = 1; p = 0.09
Cultural	7.3	5.6	6.45	x^2 = 0.13; df = 1; p = 0.72
Do nothing	3	1.2	2.1	x^2 = 3.72; df = 1; p = 0.05
Weed Control Methods				
Chemical sprays (herbicides)	67.3	25.9	46.6	x^2 = 18.71; df = 1; p = 0.00
Mechanical (weeding)	84.5	87.1	85.8	x^2 = 3.52; df = 1; p = 0.03
Cultural	6.5	0	3.3	x^2 = 2.00; df = 1; p = 0.16

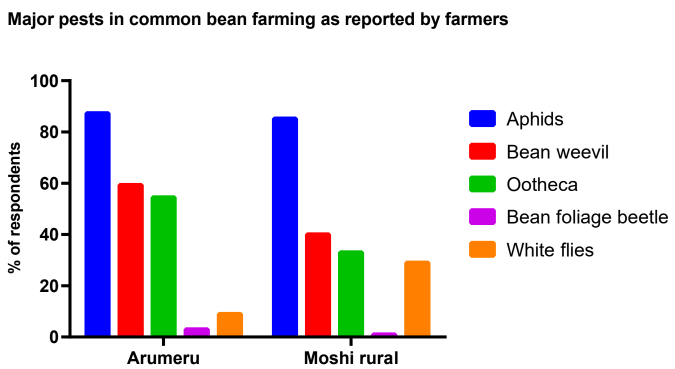

Figure 2. Major pests in common bean farming as reported by farmers in Arumeru and Moshi rural districts.

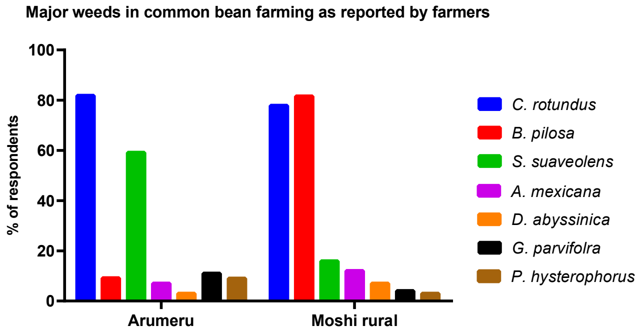

Figure 3. Major weeds in common bean farming as reported by farmers in Arumeru and Moshi rural districts.

3.4. Insect Pests and Weeds Management Practices

In this study, it was found that farmers in both Arumeru and Moshi rural districts apply chemical, mechanical and cultural methods to eradicate the damage caused to common beans as summarized in Figure 4. The use of chemical sprays was perceived by 78.9% of farmers as the main insect pest control method. Additionally, mechanical (weeding) was reported by 85.8% farmers as the main weed control method (Table 3). The cultural methods, such as intercropping and crop rotation, were practiced by most farmers in the surveyed districts. However, only 6.45% regarded them as insect pest and weed control strategies. In both surveyed districts, Profenofos was the most commonly used synthetic pesticide, reported by 33% of farmers, while Glyphosate was reported by 17% of farmers as the most commonly utilized synthetic herbicide. Furthermore, farmers described the use of other different insect pest management techniques such as an increase in dosage of application (22%), rate of application (14%), and mixing synthetic pesticide/herbicide with detergents and/or kerosene (3%). On the shortcomings of chemical sprays, most of the respondents (88%) mentioned harmful effects to human health, while 21% reported that most pesticides are non-selective and kill all insects including harmless ones such as butterflies. On the other hand, only 24% of the farmers were able to afford pesticides and herbicides. Others (67%) complained about the high price, and 60% reported availability and accessibility as the major challenge. Despite the effectiveness of different pest and weed management practices, 3% of the farmers in Arumeru and a paltry 1.2% in the Moshi rural districts did not apply any control methods against insect pests both in the field and during storage (Table 3).

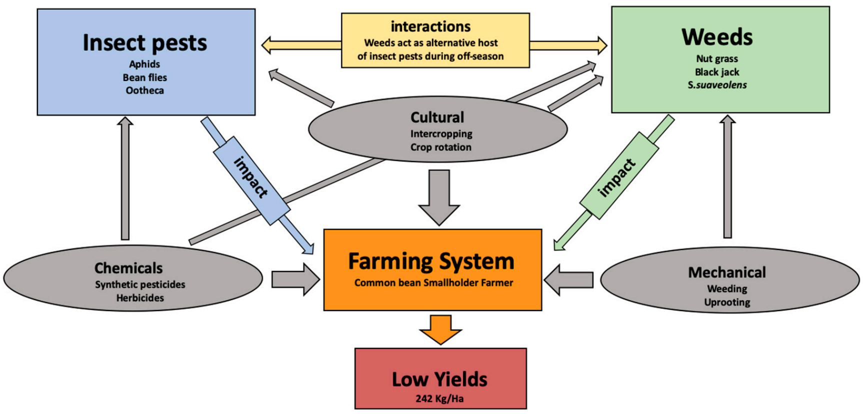

Figure 4. Summary of impact and management strategies for insect pests and weeds in common bean smallholder farming system in northern Tanzania.

4. Discussion

The majority of farmers in this study mentioned insect pests as a serious constraint to effective production of common bean in their farms. The insect pests were alleged to cause an average to major loss on yields, with the responses varying among the pest groups. Similar results were previously reported in common bean and pea smallholder farming systems in Ethiopia, Kenya, and South Africa [19,31,32]. Moreover, smallholder farmers of common bean have been linking the loss of common bean production with insect pest attack. Karungi et al. [33] suggested that, if no serious measures were taken to manage the insect pests yield losses can reach up to 100%. This could have a serious impact on food security of the smallholder farmers.

The perception of farmers that insects are the most dangerous pests in common bean production may be related to the great number of destructive insect species such as aphids, ootheca, and bean stem maggot (Table 3). This corroborates with a study by Ochilo and Nyamasyo [13] that bean aphids and stem maggots can account for yield losses of up to 100%. These insect pests have a high chance of damaging crops and reducing yields, thus causing visible and economical losses that can greatly affect smallholder farmers [34,35]. During the focus group discussions, farmers explained that the major loss of their common bean is caused by insect pests. This confirms further that insect pests are the major constraint in common bean production.

On the other hand, weeds were considered to cause a moderate to low effect on common bean production by competing for nutrients, water, space, and sunlight among others. Additionally, most farmers were aware of the importance of managing weeds in their farms. Pannacci et al. [36] stressed on the importance of combining different weed management strategies for smallholder farmers. The proper weed management strategies enhance crop yields by increasing sprouting of desired crops as well as reducing insect pest population [37]. However, in the absence of proper management practice, weeds may interfere with the normal growth of the desired crops and cause a significant loss in yields [38,39]. This emphasis on the need to train farmers on the different strategies for sustainable weed management.

Furthermore, farmers in the study area were able to identify some few weeds, such as black-jack (B. pilosa) as an alternative host to common bean insect pests during the offseason. Similar observations were also noted by Capinera [18] who pointed out that weeds are potential alternative hosts for insect pests. Weeds may also distract beneficial insects such as pollinators during the flowering stage. This subsequently reduces chances of desired crops to be pollinated thereby decreasing yields at large [40]. Takim [41] reported that weeding in and around the farm greatly reduced the population densities of legume pests such as pod borer (M. vitrata). Therefore, knowledge of weed and insect pest interactions is very important in developing sustainable and cost-effective pest management strategies for smallholder farmers.

The most common method that was frequently used to control insect pests and perceived as effective by most farmers in the two districts is the use of synthetic pesticide. However, this study discovered a knowledge gap in pesticide use. For example, of the farmers visited, most did not remember the name of the pesticides they applied. Farmers also get recommendations on pesticide use from fellow farmers and local agro-input dealers. It was also found that 43% of these dealers have only attained primary education and have had no formal training on pesticide use and safety. The current results are similar to those reported by [5,19,22]. In addition, some farmers reported the mixing pesticide kerosene, detergent soap, and other pesticides to increase their efficiency. Such strategies of improving the effectiveness of pesticides were also reported by Matthews et al. [42] and Oparaeke et al. [43]. However, the effects that these cocktail pesticides may pose to human health and the environment are largely unknown and need further investigation.

Additionally, the majority of farmers (43%) did not see the need to consult extension officers despite the challenges they face on pesticide use and safety. This could be attributed to improper application, the use of non-recommended pesticides, lack of personal protective equipment, and use of a mixture of pesticides with other compounds. These practices may lead to economic loss to farmers, adverse effects on the environment and health-related problems associated with pesticide use to smallholder farmers particularly in developing countries [5,22,44–47]. It is, therefore, important for farmers to consult extension officers on issues related to pesticide application and safety.

On the contrary, mechanical methods (weeding) were perceived by the majority of farmers as the most effective weed control strategy in the two districts visited. Similarly, Pannacci and Tei [48] showed that a mechanical method can be an effective and fast non-chemical method of controlling weeds in different agro-ecosystems. Furthermore, most farmers in the study area perceived mechanical weeding as a traditional and the only method for weed control in maize and common bean farms over the years. Additionally, they were not aware of any other weed control methods such as the use of herbicides. Moreover, Bilalis et al. [49] highlighted the use of saline water and organic fertilizers as alternative strategies in managing weeds in common beans farming. These weed control practices should be encouraged to smallholder legume farmers, as they are cost-effective and safe compared with the use of chemicals.

Cultural practices such as intercropping and crop rotation were also practiced by most farmers in the study area; common bean being intercropped mostly with maize, and for crop rotation, maize and common bean were rotated with vegetables such as African eggplant. The main reasons for practicing intercropping and crop rotation reported, were for increasing productivity of farmland, enhanced soil fertility and risk minimization in case one crop fails. Correspondingly, legume farmers in Ethiopia gave similar reasons for practicing intercropping and were not aware of the other benefits such as pest and weed control [31,50]. Nevertheless, only a handful of farmers were aware that intercropping and crop rotation can be used as pest and weed management practices.

The knowledge gap identified in this study warrants for capacity building of farmers on the integrated weed and pest management strategies for controlling damage caused by weeds and insect pests in common bean production in Northern Tanzania. Furthermore, this study has proposed a framework (Figure 5), which stresses the importance of integrating extension services in managing insect pests and weeds by translating research findings into sustainable farming practices such as Integrated Pest Management and Integrated Weed Management that can easily be adopted by smallholder farmers in developing countries.

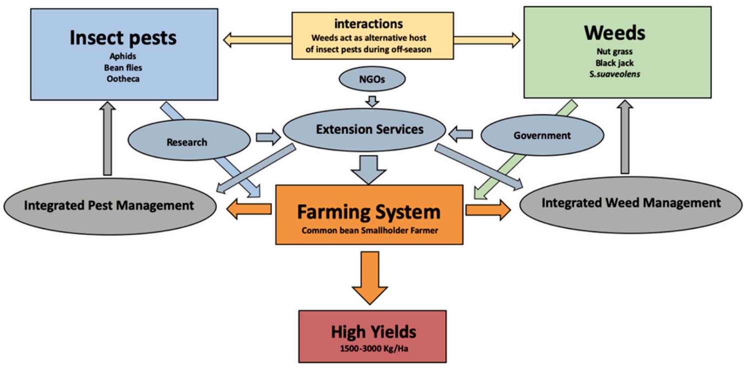

Figure 5. Proposed framework for the management of insect pests and weeds in common bean smallholder farming system in northern Tanzania.

5. Conclusions

The current study has confirmed that insect pests and weeds are perceived by common bean farmers in northern Tanzania as the major setback in the effective production of crops. Synthetic pesticides were reported as the main method for insect pest control. However, most farmers were not able to apply them due to reasons such as accessibility and affordability. There exists a knowledge gap in the area of integrated weed and pest management among most farmers in the surveyed districts.

This can be addressed through different capacity building training to farmers. The findings from this study urge the need to consider extension officers as key players in linking farmers with government programs, non-governmental organizations (NGOs) and agricultural research findings, as proposed in Figure 5. This will contribute to the development of an efficient, low-cost and environmentally friendly pest and weed management strategy that can be easily adopted by resource-constraint farmers. By implementing such measures, we aspire to see sustainable common bean production.

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Research Article

Allelopathic Effects of *Sphaeranthus suaveolens* on Seed Germination and Seedling Growth of *Phaseolus vulgaris* and *Oryza sativa*

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Weeds with allelopathic effect have been reported to cause significant damage in agriculture particularly in smallholder farming systems. This study assessed the allelopathic effects of different concentrations of crude extract of a noxious weed *Sphaeranthus suaveolens* on seed germination and seedling growth of *Phaseolus vulgaris* and *Oryza sativa* by examining germination, seedling height, and total chlorophyll content after seven and fourteen days of crude extract treatment, respectively. Results showed that seed germination and seedling growth were significantly ($p < 0.001$) decreased with increase in concentration of crude extract, signifying concentration dependency. Highest concentration (100%) of *S. suaveolens* crude extracts resulted in 90% and 100% inhibition of *P. vulgaris* and *O. sativa* seed germination, respectively. Chlorophyll content, fresh weight, and root and shoot length of both *P. vulgaris* and *O. sativa* were also significantly ($p < 0.001$) affected by highest concentration (100%) of *S. suaveolens* crude extracts. Results from this study suggest that the extract of *S. suaveolens* contains water-soluble allelochemicals which significantly reduce growth and productivity of *P. vulgaris* and *O. sativa*.

1. Introduction

Weed invasion is becoming a major challenge in agricultural sector worldwide particularly in smallholder farming systems [1, 2]. Weeds have been reported to significantly affect crop production by competing for light, water, nutrients, and space thereby threatening the economic growth and food security of smallholder farmers [3–6]. Additionally, these unwanted plants have been observed to host insect pests and diseases [7–9] as well as disrupting and interfering with natural interactions by displacing native species, distracting pollinators, and other insects that are beneficial in the smallholder farming systems [10–12].

Most weeds have been alleged to possess allelopathic effects which play an important role in their invasion success [13–15]. Allelopathy is a phenomenon, whereby one plant influences the growth of biological systems, including microorganisms, by the release of chemical compounds into the environment [16–18]. The allelopathic effects are the result of plant's secondary metabolites known as allelochemicals, which are usually byproducts of the principal metabolic pathways in plants [19–21]. These allelochemicals can be found in the leaves, stem, flowers, fruits, and roots [22].

Plants with allelopathic properties have been observed to significantly affect the growth and development of other neighboring plants by inhibiting seed germination, causing soil infertility and nutrient imbalance as well as limiting the microbial population in the soil [23–25]. Due to these effects, allelopathy has become a research hotspot for making comprehensive analysis about the mechanism of weed invasions and possibilities of utilizing these naturally occurring phytochemicals in managing weeds and insect pests in agricultural ecosystems [26, 27].

Common bean (*Phaseolus vulgaris*) and rice (*Oryza sativa*) are among important food and income generating crops globally [28]. The two crops have been reported as the principal source of protein and main calorie supply to a significant portion of the households in Africa and globally at large [29–31]. Despite the importance of the two crops in the agricultural sector and livelihood of most smallholder farmers, yields are generally low with the average revolving around 990 kg/ha for *P. vulgaris* and 2400 kg/ha for *O. sativa* [32]. The potential yields under favorable conditions are estimated to be around 1500–3000 kg/ha for *P. vulgaris* and 2500–4000 kg/ha for *O. sativa* [33]. Among the reasons behind this low yields are heavy infestation from weeds, insect pest attacks, and poor crop management skills such as late weeding [7, 34, 35].

Sphaeranthus suaveolens is a spreading weed from the family Asteraceae, commonly found in swampy and cultivated farmlands [36, 37]. A heavy infestation of this weed results in adverse effects on the growth of adjacent plants [38]. It has also been observed that *S. suaveolens* has an ability to suppress crops in a wide range over a short period of time [39]. Additionally, significant portion of common bean and rice smallholder farmers reported major yield loss due to *S. suaveolens* infestations [7]. Despite of these tragic losses, the allelopathic effects of *S. suaveolens* to *P. vulgaris* and *O. sativa* have not yet been studied or reported. Understanding these effects could considerably improve the *S. suaveolens* management in farmlands and significantly reduce its effects on crop productivity. The present study was carried out to evaluate the allelopathic effects of *S. suaveolens* using different aqueous extract concentrations on germination and seedling growth of *P. vulgaris* and *O. sativa* crops under laboratory and screen house conditions.

2. Materials and Methods

2.1. Seed Preparation and Treatment. Seeds of *P. vulgaris* and *O. sativa* were collected from Selian Agricultural Research Institute (SARI) in Arusha, Tanzania, in June of 2019. Before the experiment, the seeds were air dried and stored in plastic bags. Seed viability of both plants was determined by the germination test [40], in which all the 20 seeds (100%) for each crop (10 *P. vulgaris* and 10 *O. sativa* seeds) that were selected randomly from a seed stock and planted in a Petri dish lined with cotton wool in early September 2019 germinated. Seeds were later washed using tap water and sterilized with 5 % NaOCl for 2 min and then rinsed with distilled water before planting.

2.2. Crude Extract Preparation. Freshly matured plants of *S. suaveolens* were collected from Arumeru and Moshi rural districts, Tanzania, between June and July 2019. The plants were shade dried under room temperature for 14 days, grounded into powder using a grinder, and stored in plastic containers before the experiments. Extracts were prepared according to Ngondya et al. [41] with few modifications as follows: 100 g of *S. suaveolens* powder was soaked separately in 1 liter of distilled water and left for 72 h. Afterwards, crude extracts were filtered using Whatman filter paper no. 1 to obtain a final volume of 1 liter each. Both crude extracts (ml) were diluted with distilled water (ml) in the ratio of 25 : 75, 50 : 50, 75 : 25, and 100 : 0 (extract : distilled water) to obtain different concentrations of 25%, 50%, 75%, and 100%. The diluted extracts were kept in the refrigerator at 4°C.

2.3. Laboratory Experiment. The effects of *S. suaveolens* crude extracts on the seed germination, seedling height, and leaf chlorophyll content of *P. vulgaris* and *O. sativa* were studied using a completely randomized design (CRD) from October to November 2019. Ten seeds of each crop (*P. vulgaris* and *O. sativa*) were placed in each of the five Petri dishes (each with the surface area of 70.8 cm^2) lined with cotton wool. Each Petri dish was moistened once a day with 10 ml of different concentration treatments, i.e., 0% (for control) and 25%, 50%, 75%, and 100% (for S. suaveolens crude extracts). Each treatment was replicated three times. Seeds were observed every day under the 12 h dark and 12 h light conditions. Number of germinated seeds was recorded and counted for 7 days for *P. vulgaris* and 14 days for *O. sativa*. Seedlings were harvested and fresh weight, seedling height, and leaf total chlorophyll content were determined for each germinated seedling. The entire experiment was repeated three times.

2.4. Screen House Experiment. The effects of crude extracts of *S. suaveolens* on the seed germination, seedling height, leaf total chlorophyll content, and fresh and dry weight of *P. vulgaris* and *O. sativa* crops were studied using a completely randomized design in a screen house from October to November 2019. Six seeds for each crop (*P. vulgaris* and *O. sativa*) were placed each in five pots with the surface area of 763.8 cm^2. The pots were then moistened on daily basis with 100 ml of different concentration treatments (25%, 50%, 75%, and 100%) of *S. suaveolens* crude extracts and distilled water for the control. Each treatment was replicated three times. Seeds were observed every day and the number of germinated seeds were recorded and counted for 7 days for *P. vulgaris* and 14 days for *O. sativa*. Thereafter, seedlings were harvested and fresh weight, seedling height, and leaf total chlorophyll content were determined for each germinated seedling. Similar to the laboratory experiment, this experiment was also repeated three times.

2.5. Chlorophyll Content Determination. Leaf chlorophyll of the *P. vulgaris* and *O. sativa* seedlings was extracted according to Hiscox and Israelstam (1978) with some modifications: 50 mg of each crop (*O. sativa* and *P. vulgaris*) fresh leaves of 2.25 cm^2 surface area were immersed in 4 ml of dimethyl sulfoxide (DMSO) and incubated at 65°C for 12 h. The extract was transferred to glass cuvettes for absorbance determination. The absorbance of blank liquid (DMSO) and samples were determined under 2000 UV/VIS spectrophotometer (UNICO®) at 645 and 663 nm (Hiscox and Israelstam, 1978), and the leaf total chlorophyll content (Chl) was calculated according to Arnon (1949) using the following equation:

$$\text{total Chl} = 0.0202A_{663} + 0.00802A_{645}, \quad (1)$$

where A_{663} and A_{645} are absorbance readings at 663 and 645 nm, respectively.

2.6. Data Analysis. Data on allelopathic effects of *S. suaveolens* on seed germination and seedling growth (shoot length, root length, fresh weight of shoot, and fresh weight of root and chlorophyll content) of *P. vulgaris* and *O. sativa* were compared using one-way ANOVA. The normality and homogeneity of variance were verified using Shapiro–Wilk test and Levene's test, respectively. Fishers LSD test was used to compare the significance differences between the group means. The statistical software used for all tests was Origin (version 2018b) at a significance level of 5%.

3. Results

3.1. Seed Germination. Generally, higher concentrations (75% and 100%) of *S. suaveolens* in both laboratory and screen house experiments were effective in suppressing both *P. vulgaris* and *O. sativa* seeds germination. The germination of *P. vulgaris* and *O. sativa* seeds was delayed at higher concentrations (75% and 100%) compared with the negative control (0%) and lower concentrations (25%) of the *S. suaveolens* crude extract. The mean percentage germination under 0% concentration (negative control) was 100% for *P. vulgaris* and 90% for *O. sativa* in the laboratory, as compared with 100% for both *P. vulgaris* and *O. sativa* in the screen house experiment. Additionally, under higher concentration (100%), the mean percentage germination for *P. vulgaris* was 10% and 0% in laboratory and screen house experiments, respectively, while for *O. sativa,* it was 0% in both experiments (Table 1). In general, the seed germination for both *P. vulgaris* and *O. sativa* decreased significantly ($p < 0.001$) with the increase in the concentration of *S. suaveolens* crude extract (Table 1).

3.2. Shoot Length. Shoot length of *P. vulgaris* and *O. sativa* seedlings sprayed with *S. suaveolens* concentrations differed significantly in the laboratory ($F_{(4,\ 15)} = 56.64$, $p < 0.0001$, and $F_{(4,\ 15)} = 52.65$, $p < 0.0001$) and screen house ($F_{(4,\ 15)} =$, $p < 0.0001$, and $F_{(4,\ 15)} = 52.65$, $p < 0.0001$) experiments, respectively (Figures 1 and 2). Mean (±SE) seedling lengths of *P. vulgaris* and *O. sativa* in 0% treatments (16 ± 1 cm and 8 ± 1 cm) were 5 and 8 times longer than the ones in 100% treatments (3 ± 0 cm and 0 ± 0 cm) in both laboratory and screen house experiments. In general, the shoot length for *P. vulgaris* and *O. sativa* seedlings decreased significantly ($p < 0.001$) with the increase in concentration of *S. suaveolens* crude extract in both the laboratory and screen house experiments.

3.3. Root Length. The root length of *P. vulgaris* and *O. sativa* seedlings sprayed with *S. suaveolens* crude extract concentrations differed significantly in both laboratory ($F_{(4,\ 15)} = 165.89$, $p < 0.001$, and $F_{(4,\ 15)} = 34.66$, $p = 0.001$) and screen house ($F_{(4,\ 15)} = 10.37$, $p < 0.001$, and $F_{(4,\ 15)} = 47.55$, $p < 0.001$) experiments (Figures 3 and 4). At higher concentration (100%) of *S. suaveolens* crude extract, the mean root length (±SE) in *P. vulgaris* (0 ± 0.1 cm and 2 ± 0.3 cm) and *O. sativa* (0 ± 0 cm) seeds was significantly reduced ($p < 0.001$) as compared with lower (0%) concentrations (8 ± 0.4 cm and 7 ± 0.9 cm) for *P. vulgaris* and (3 ± 0.5 cm and 4 ± 0.5 cm) *O. sativa* in both laboratory and screen house experiments, respectively (Figures 3 and 4). The root length for *P. vulgaris* and *O. sativa* seedlings in both laboratory and screen house experiments was significantly reduced ($p < 0.001$) as the concentration of *S. suaveolens* crude extract increased.

3.4. Fresh Weight of Roots and Shoots. The average fresh weight of roots (FWR) for *P. vulgaris* and *O. sativa* differed significantly with *S. suaveolens* treatment in both laboratory ($F_{(4,15)} = 284.23$, $p < 0.001$, and $F_{(4,15)} = 30.88$, $p < 0.0009$) and screen house ($F_{(4,15)} = 435.35$, $p < 0.001$, and $F_{(4,15)} = 92.71$, $p < 0.001$) experiments. The fresh weight of shoots (FWS) also differed significantly among tested crops in both laboratory ($F_{(4,15)} = 399.39$, $p < 0.001$, and $F_{(4,15)} = 59.12$, $p < 0.0003$) and screen house ($F_{(4,15)} = 504.51$, $p < 0.001$, and $F_{(4,15)} = 301.13$, $p < 0.001$) experiments. Seedlings treated with higher concentrations in both tested crops were observed to have lower fresh weights than those treated with lower concentrations in both laboratory and screen house experimentations (Figures 5–8).

3.5. Total Chlorophyll Content. Total leaf chlorophyll content of *P. vulgaris* and *O. sativa* seedlings differed significantly in both laboratory ($F_{(4,15)} = 21.53$, $p < 0.00004$, and $F_{(4,15)} = 3.81$, $p < 0.002$) and screen house ($F_{(4,15)} = 18.38$, $p < 0.00001$, and $F_{(4,15)} = 71.96$, $p < 0.00001$) experiments under *S. suaveolens* crude extract treatments (Figures 5 and 6). In general, the seedlings of both tested plants (*P. vulgaris* and *O. sativa*) treated with higher (100%) concentration of *S. suaveolens* crude extracts had lower total chlorophyll content than those sprayed with lower (0%) concentrations in both laboratory and screen house experiments (Figures 9 and 10).

4. Discussion

This study revealed that the crude extract of *S. suaveolens* significantly reduced seed germination of *P. vulgaris* and *O. sativa*. This suggests that *S. suaveolens* possess water-soluble allelochemicals which showed inhibitory effects on the two tested crops. Moreover, at higher concentrations (75% and 100%), the *S. suaveolens* extracts showed maximum inhibition in the germination of *P. vulgaris* and *O. sativa*. These results are in agreement with the study conducted by [42, 43] on the allelopathic effects of various weeds on seed germination of rice and beans where germination was reduced to 20% and 6%, respectively. The

Table 1: Mean percentage germination (±SE) of *P. vulgaris* and *O. sativa* seeds (after 7 and 14 days, respectively) per treatment of *S. suaveolens* extracts of treatment in a laboratory and screen house experiments.

Concentration (%)	Laboratory experiment		Screen house experiment	
	P. vulgaris	*O. sativa*	*P. vulgaris*	*O. sativa*
0	100 ± 0.2^{a}	90 ± 0.3^{a}	100 ± 0.1^{a}	100 ± 0^{a}
25	80 ± 0.4^{b}	90 ± 0.2^{a}	83 ± 0.4^{b}	83 ± 0.3^{a}
50	70 ± 0.4^{c}	50 ± 0.6^{b}	50 ± 0.4^{c}	33 ± 0.4^{b}
75	20 ± 0.4^{d}	10 ± 0.3^{c}	17 ± 0.2^{d}	17 ± 0.3^{c}
100	10 ± 0.2^{e}	0 ± 0.2^{c}	0 ± 0.2^{e}	0 ± 0^{c}
F-statistics	$F_{(4, 15)} = 142^{*}$	$F_{(4, 15)} = 140^{*}$	$F_{(4, 15)} = 53^{*}$	$F_{(4, 15)} = 144^{*}$

Values with different superscript letter(s) in the same column are significantly different by Fisher LSD at $p = 0.05$. $^{*}P < 0.001$.

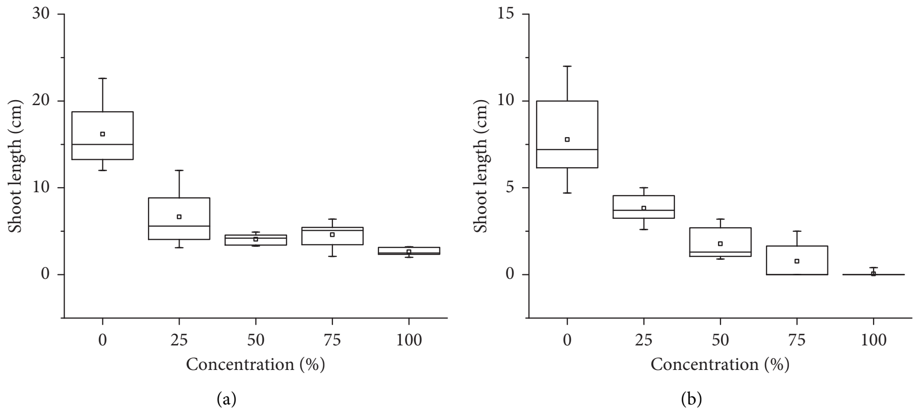


Figure 1: Shoot length of germinated *P. vulgaris* (a) and *O. sativa* (b) seedlings in laboratory experiment after 7 and 14 days of treatment with *S. suaveolens* extracts, respectively.

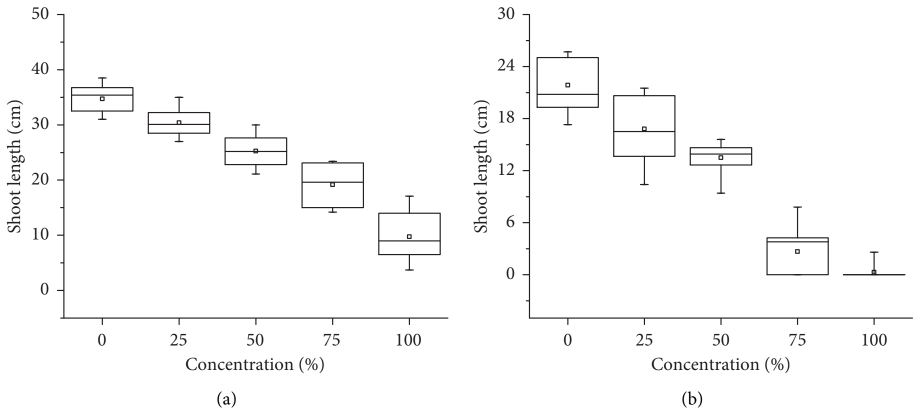
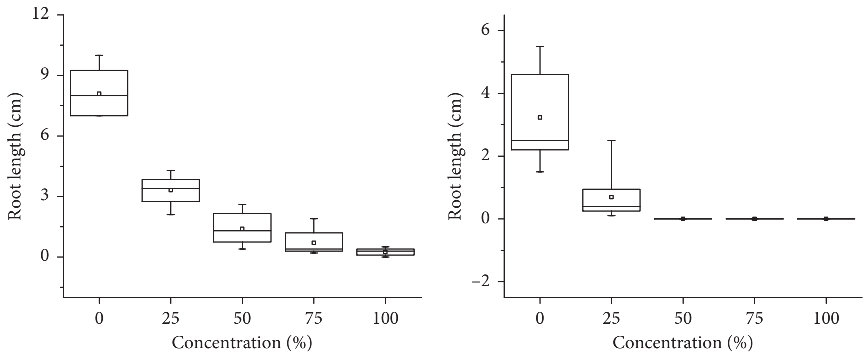


Figure 2: Shoot length of germinated *P. vulgaris* (a) and *O. sativa* (b) seedlings in screen house experiment after 7 and 14 days of treatment with *S. suaveolens* extracts, respectively.

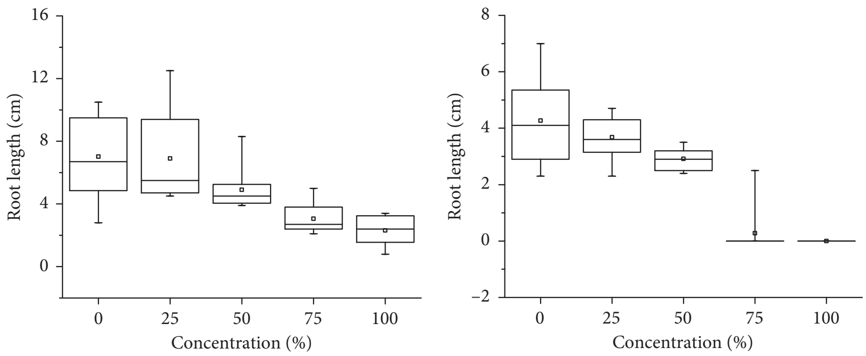
reduced seed germination in *P. vulgaris* and *O. sativa* might be caused by the allelopathic stress of different extract concentrations resulting from different abnormalities in metabolic activities and cell division due to the effect of allelochemicals [44]. This is reported to affect the productivity of *P. vulgaris* and *O. sativa* in different farming systems, thereby lowering yields.

The findings in this study also indicate that root and shoot lengths of *P. vulgaris* and *O. sativa* were significantly reduced by the *S. suaveolens* crude extracts. However, the



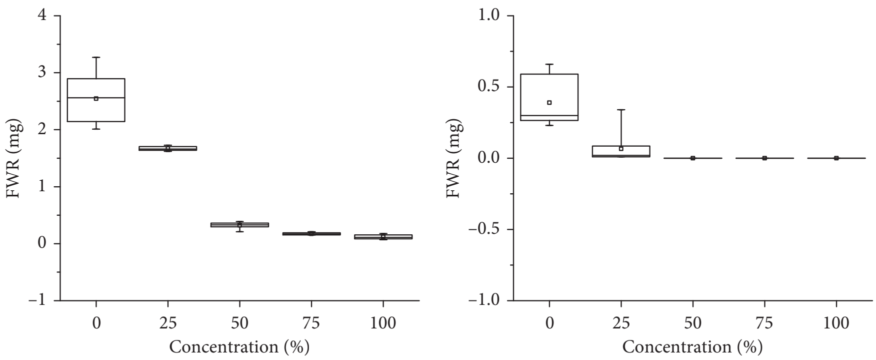
(a) (b)

Figure 3: Root length of germinated *P. vulgaris* (a) and *O. sativa* (b) seedlings in a laboratory experiment after 7 and 14 days of treatment with *S. suaveolens* extracts, respectively.



(a) (b)

Figure 4: Root length of germinated *P. vulgaris* (a) and *O. sativa* (b) seedlings in screen house experiment after 7 and 14 days of treatment with *S. suaveolens* extracts, respectively.



(a) (b)

Figure 5: Fresh weight of root (FWR) of germinated *P. vulgaris* (a) and *O. sativa* (b) seedlings in laboratory experiment after 7 and 14 days of treatment with *S. suaveolens* extracts, respectively.

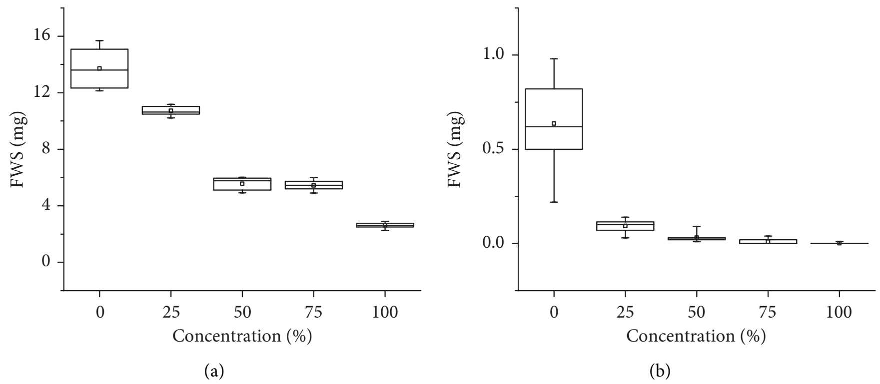


Figure 6: Fresh weight of shoot (FWS) of germinated *P. vulgaris* (a) and *O. sativa* (b) seedlings in laboratory experiment after 7 and 14 days of treatment with *S. suaveolens* extracts, respectively.

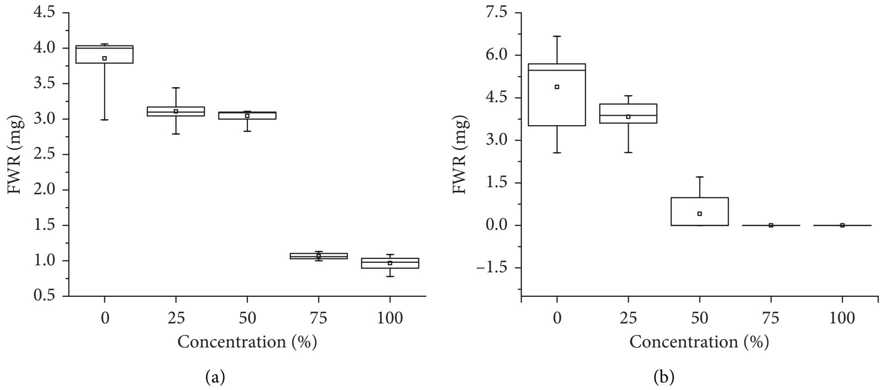


Figure 7: Fresh weight of root (FWR) of germinated *P. vulgaris* (a) and *O. sativa* (b) seedlings in screen house experiment after 7 and 14 days of treatment with *S. suaveolens* extracts, respectively.

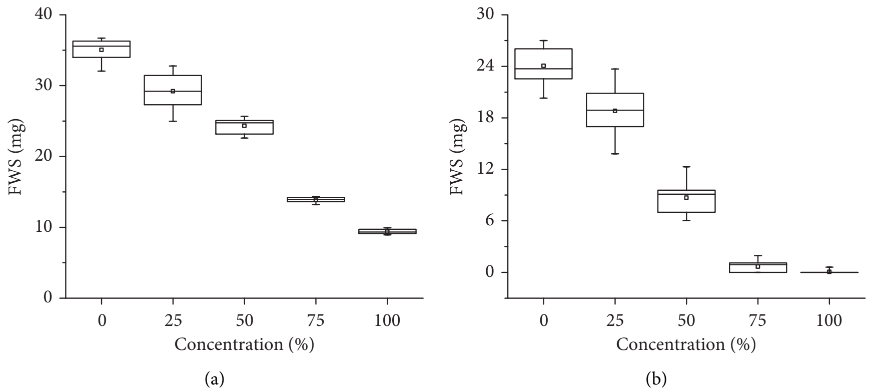


Figure 8: Fresh weight of shoot (FWS) of germinated *P. vulgaris* (a) and *O. sativa* (b) seedlings in screen house experiment after 7 and 14 days of treatment with *S. suaveolens* extracts, respectively.

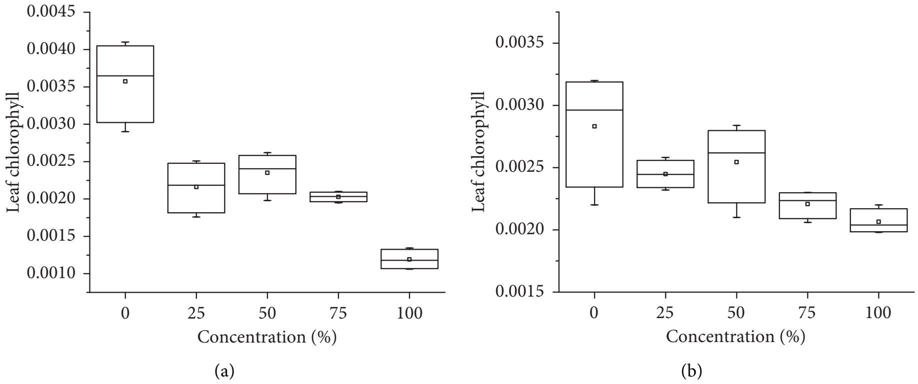


Figure 9: Leaf chlorophyll content of *P. vulgaris* (a) and *O. sativa* (b) seedlings in laboratory experiment after 7 and 14 days of treatment with *S. suaveolens* extracts, respectively.

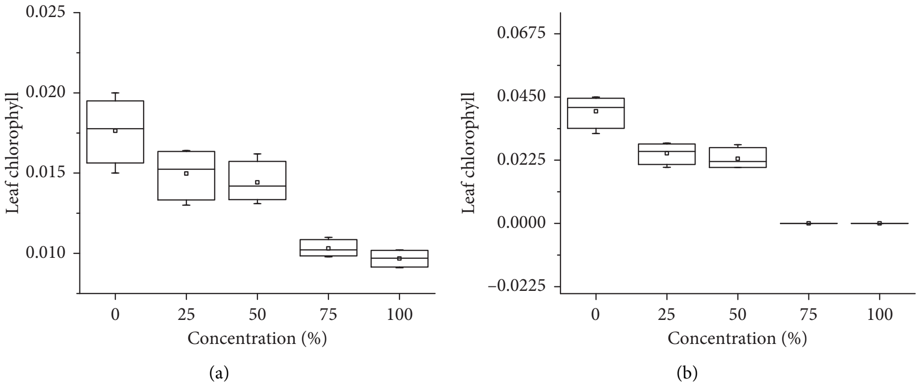


Figure 10: Leaf chlorophyll content of *P. vulgaris* (a) and *O. sativa* (b) seedlings in screen house experiment after 7 and 14 days of treatment with *S. suaveolens* extracts, respectively.

effects were concentration dependent and differed between the two tested crops (*P. vulgaris* and *O. sativa*). The roots and shoots of *O. sativa* were found to be more sensitive to the applied allelopathic stress than *P. vulgaris*, whereby at high concentration (100%) of crude *S. suaveolens* extract, root and shoot length was reduced considerably as compared with those of *P. vulgaris* at lower concentrations and in control treatments. These results corroborate with findings from Lodha [42] who revealed that extracts of different plant parts of *S. indicus* weed had strong inhibitory effects and reduced seed germination by 80% and root length and stem length by 94.4% and 83.3%, respectively, of *O. sativa*. Root and shoot lengths are very important parameters which determine plants' growth and health due to their importance in nutrients uptakes and physical support of the plant.

The reduced root and shoot lengths observed in this study may in one way or the other negatively affect crop production particularly in smallholder farming systems. The association between shorter roots and failure of plants to compete and search for water and minerals from the ground has been well reported by Sofi et al. [45], Subudhi et al. [46], and Yamane et al. [48]. On the other hand, shorter shoots have been associated with plants' inability to withstand environmental stresses such as drought [48]. Also, shorter shoots hinder plants' ability to compete for space, light, and air which are important parameters during photosynthesis and their shortage may result into poor plant growth [49]. Additionally, Laizer et al. [7] and Lodha [42] reported lower *P. vulgaris* and *O. sativa* yields, respectively, in farms that were invaded with *S. suaveolens*. The low yields may have been attributed to the allelopathic effects of *S. suaveolens* which negatively affect root and shoot lengths.

Furthermore, results from this study show that, fresh weights of shoots and roots for *P. vulgaris* and *O. sativa* were significantly affected by the higher concentrations of *S. suaveolens* in both laboratory and screen house experiments. The seedling fresh weight is an important factor for a plant to withstand physical stresses from the environment [49]. Therefore, affecting the fresh weight of the *P. vulgaris* and *O. sativa* may affect their ability to withstand harsh environmental conditions. The chlorophyll content of both *P. vulgaris* and *O. sativa* was also negatively affected by the *S. suaveolens* crude extract. The lower chlorophyll content observed in this study was due to the presence of allelochemicals found in the *S. suaveolens*. These findings were also reported by Frabboni et al. [50], Ngondya et al. (41), Ojija et al. (51), Rawat et al. [52], and Siyar et al. [44]. Reduced chlorophyll content may negatively affect plant's ability to perform photosynthetic functions, hence lowers the chance to survive or compete with other neighboring plants [53].

5. Conclusion

The findings from this study are among the first to demonstrate effects of *S. suaveolens* crude extracts to seed germination and growth of *P. vulgaris* and *O. sativa*. The results further show that *O. sativa* is more sensitive to the applied allelopathic stress than *P. vulgaris*. This might be due to its genomic characteristics which influence tolerance levels to chemical and other environmental stresses. At higher concentrations (75% and 100%), the *S. suaveolens* crude extract exerted deleterious effect on seed germination and seedling growth for both *P. vulgaris* and *O. sativa* compared with lower concentrations (25%) and the control (0%). These effects might be caused by the presence of the water-soluble allelochemicals in *S. suaveolens* crude extracts which are largely unknown and need to be isolated, identified, and characterized for profound understanding and further investigations on their applications in agriculture and other fields.

Data Availability

The germination and seedling growth data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Research article 3: Under Review

International Journal of Pest Management

Bio-pesticidal potential of Sphaeranthus suaveolens in the management of storage insect pest of common bean (Acanthoscelides obtectus) in Northern Tanzania

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Keywords:	Storage insect pest, Bean bruchid, Postharvest loss, Botanical pesticide, Sustainable agriculture

Bio-pesticidal potential of *Sphaeranthus suaveolens* in the management of storage insect pest of common bean (*Acanthoscelides obtectus*) in Northern Tanzania

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Abstract

Storage insect pests have been reported to cause significant post-harvest loss particularly in grains and legumes thereby threatening food security. This study assessed the potential and effectiveness of *Sphaeranthus suaveolens* in the management of bean bruchids in three commonly cultivated bean varieties; Jesca, Lyamungu 90 and Selian 97 in northern Tanzania. The experiment was carried out using complete randomized design from six treatments; (a) four (3.75 g, 7.5 g, 11.25 g and 15 g) from *Sphaeranthus suaveolens* powder; (b) one (0.25 g) from an actellic super dust and (c) one (0 g) from a control (check). The aim was to assess the effects of bean bruchids on stored common bean seeds by examining the number of live and dead insects, number of seeds with holes, number of holes per seed and weight loss after ninety days of treatments. Results showed that seed damage was significantly lower in seeds treated with actellic super dust (0.25 g) and *S. suaveolens* powder (11.25 g and 15 g) and did not differ significantly ($p > 0.05$) across the three bean varieties. Weight loss on the other hand differed significantly across the treatments and bean varieties ($p < 0.001$). Highest mean percentage weight loss was observed under control treatment (9 %) and Jesca bean variety (4 %) while the lowest (1 %) was recorded in seeds treated with 0.25 g of actellic super dust, 11.25 g and 15 g of *S. suaveolens* powder and in the Selian 97 bean variety (2 %). These results suggest that *S. suaveolens* contains naturally occurring chemicals with insecticidal properties and has a potential to significantly reduce post-harvest loss of common beans particularly among small holder farmers who cannot afford a wide spectrum of pesticides.

Keywords: Bean bruchid; Storage insect pest; botanical pesticides; insecticidal properties; post-harvest loss; sustainable agriculture

1. Introduction

Common bean (*Phaseolus vulgaris*) is among the most important grain legumes globally (FAOSTAT, 2019). In Africa, the crop is largely grown for food consumption and income generation by most smallholder famers (Diana *et al.*, 2019; Kansiime *et al.*, 2018). Common bean also plays a significant role in soil health improvement through biological nitrogen fixation (Latati *et al.*, 2017; Reinprecht *et al.*, 2020). Despite its importance in food security and the economy, the production of common bean in most African countries is done in small plots with the average production of 799 kg/ha (Hummel *et al.*, 2018; Ndakidemi *et al.*, 2006). This is lower when compared with potential yields of 1500 - 3000 kg/ha under favorable conditions (FAOSTAT, 2017; Farrow, 2009).

In Tanzania, common bean is grown mostly in northern and southern highlands particularly Arusha, Kilimanjaro and Mbeya regions with an average yield of 700 kg/ha (Crop *et al.*, 2015; Hillocks *et al.*, 2006). The low yield is mostly contributed by weeds, diseases, insect pests, use of unimproved seed varieties among other factors (Laizer *et al.*, 2019; Ngadze *et al.*, 2018). The low yields obtained are also not safe in storage facilities due to storage insect pest attacks which cause significant loss of food and seeds for subsequent season (Loko *et al.*, 2018; Nukenine, 2010).

Bean bruchid (*Acanthoscelides obtectus*) is among major pests of stored legumes particularly for common bean (Alemayehu and Getu, 2017). The pest originates from America but currently, it is widely distributed in several countries in Asia and Africa (Abate and Ampofo, 1996). Bean bruchid has a life cycle of 100 to 110 days, with an adult female capable of laying an average of 45 eggs on to the seed pods or cracks/holes (Nchimbi-Msolla and Misangu, 2014). The hatching of eggs to larvae takes place after anywhere from 3 to 15 days and the larva are internal feeders which bore and develop inside the seed until it reaches adulthood, where it emerges from the seed and disperse (Alemayehu and Getu, 2017). The pest is vastly favored by warm climate with a succession of 2 to 3 generations annually. This makes it a very destructive pest in storage facilities in sub-Saharan Africa

(Soares *et al.*, 2015). The pest has been reported to attack common beans in the fields and during storage and the estimated losses due to bean bruchid are from mild (20 %) to total loss (100 %). This is particularly evident where the post-harvest management is poor (Alemayehu and Getu, 2017; Kamanula *et al.*, 2011; Mishili *et al.*, 2011).

The control of bean bruchid both in the field and during storage is mostly done using synthetic pesticides (Karani *et al.*, 2017; Nukenine, 2010). Farmers have been reported to frequently use chemical pesticides regardless of the safety concerns and threats they pose to people and the environment at large (Dhineshkumar *et al.*, 2017; Gianessi and Reigner, 2007). Additionally, there has been increasing pressure from regulatory authorities on the reduction and control of chemical pesticides in stored food crops due to their carcinogenicity, toxicity and other adverse effects (Jallow *et al.*, 2017). Furthermore, most of these pesticides are often not accessible and affordable to a larger proportion of smallholder farmers in developing countries due to limited supply and the economic status (Laizer *et al.*, 2019; Mulungu *et al.*, 2007). Therefore, there is a need to develop insect pest management strategies in storage facilities that are affordable, easily accessible and safe so as to enhance the food security to small holder farmers.

On the other hand, plant species from *Asteraceae, Fabaceae, Verbenaceae* among other families have been reported to possess insecticidal, repellant and antifeedant activities (Amoabeng *et al.*, 2014; Fouad *et al.*, 2014; Laizer *et al.*, 2020). Different studies have further documented the effectiveness of extracts from these plant species in the management of insect pests both in the field and during storage (Alemayehu and Getu, 2017; Mkindi *et al.*, 2020). The use of techniques such as mixing of seeds with powders from the locally known pesticidal plants has proved to significantly reduce insect pest attacks in the storage facilities and more importantly the practicability and affordability to most small holder farmers (Hikal *et al.*, 2017; Soujanya *et al.*, 2016). Despite these advantages, only few studies have explored the potential of different plant species in the management of insect pests particularly in the storage facilities (Dimetry, 2012; Kedia *et al.*, 2015). Therefore, this study specifically aimed at determining the insecticidal potential of *Sphaeranthus suaveolens* in the management of bean bruchid in storage facilities so as to reduce post-harvest loss and improve food security for smallholder farmers especially in developing countries such as Tanzania.

2. Materials and methods

2.1 Plant materials

Freshly matured plants of *S. suaveolens* were collected from Arumeru and Moshi rural districts, in Arusha and Kilimanjaro regions of northern Tanzania between May and June 2020. The plants were shade dried under room temperature for 14 days, grounded into powder and stored in plastic containers prior to the experiments. Then 1000 g of *S. suaveolens* powder was sieved with 0.2 mm sieve until fine powder was obtained to serve as a stock sample for treatment preparation. Four different treatments were then prepared from the *S. suaveolens* powder i.e. 3.75 g, 7.5 g, 11.25 g and 15 g. Additionally, 0.25 g of actellic super dust was prepared and container with nothing (0 g) served as control treatment.

2.2 Bean samples

Seeds from the three commonly grown bean varieties in northern Tanzania (Jesca, Lyamungu 90 and Selian 97) were collected from Selian Agricultural Research Institute (SARI) in Arusha, Tanzania in June 2020. Prior to the experiment, the seeds were checked for any signs of damage, followed by sorting and later dried at 12 % moisture content. The seeds were subsequently placed in plastic bags and stored in a cold room for 14 days. One hundred and fifty grams (150 g) of common bean seeds for each variety was measured and placed in the plastic containers with different treatments.

2.3 Insects

Adult bean bruchids were collected from infested common bean seeds purchased from local market and brought to the laboratory. The insects were reared with common bean seeds and kept at a temperature ranging from 28 to 30 °C and relative humidity of 70 % and continuously maintained throughout the study period. Adult bean bruchids were separated from the culture and used in the experiment.

2.4 Layout of the experiment

The experiment was set in 54 (6 treatments x 3 replicates x 3 bean varieties) plastic containers (16 cm long x 20 cm wide) arranged in a completely randomized design each containing 150 g of common bean seeds. Then different treatments i.e. 0 g (control), 3.75 g, 7.5 g, 11.25 g and 15 g of *S. suaveolens* and 0.25 g of actellic super dust were added in the containers with common bean seeds and mixed thoroughly. Afterwards, 15 unsexed adult bean bruchids were introduced into each of the container. Data on effects of bean bruchids as influenced by different treatments in each common bean variety were recorded every 30 days for a period of 90 days. Data collected included number of live and dead insects, number of holes per seed, number of damaged seeds and weight.

2.5 Data analysis

The mean values from the experiment with regard to the effects of different treatments and the correlation coefficients for the investigated variables were calculated. Results were statistically analyzed by two-way analysis of variance (ANOVA). Significant differences between treatments and bean varieties were determined using Fishers LSD test. The statistical software employed for all tests was Origin Pro 9.0 (version 2018b) at a significance level of 5 %.

3. Results

3.1 Mortality of bean bruchid

Highest mean percentage mortality (100 %) for bean bruchids was observed in the bean varieties treated with 0.25 g of actellic super dust followed by bean varieties treated with 15 g of *S. suaveolens* powder (90 %) (Table 1). Lowest mortality (21 %) was observed in the control (0 g) treatment followed by bean varieties treated with 3.75 g of *S. suaveolens* powder (44 %). The mean percentage mortality of bean bruchids did not differ significantly across the three bean varieties (Jesca, Lyamungu 90 and Selian 97) ($p > 0.05$) (Tables 2 and 3). In general, the mean percentage mortality of bean bruchids in all three bean varieties increased significantly ($P < 0.001$) with the increase in *S. suaveolens* powder amount and in seeds treated with the 0.25 g actellic super dust (Table 1).

Table 1. Effects of treatments (Mean percentage ± SE) on variables investigated

Treatments	Variables				
	Damaged seeds (%)	Dead insects (%)	Seeds with eggs (%)	Holes per seed	Weight loss (%)
0g	$18^{a} \pm 2$	$21^{a} \pm 3$	$42^{a} \pm 4$	$4^{a} \pm 1$	$9^{a} \pm 2$
3.75g	$8^{b} \pm 1$	$44^{b} \pm 4$	$13^{b} \pm 2$	$2^{b} \pm 1$	$5^{b} \pm 1$
7.5g	$1^{c} \pm 0$	$66^{c} \pm 5$	$2^{c} \pm 1$	$0^{c} \pm 0$	$2^{c} \pm 0$
11.25g	$1^{c} \pm 1$	$90^{d} \pm 3$	$1^{c} \pm 0$	$0^{c} \pm 0$	$1^{c} \pm 0$
15g	$0^{c} \pm 0$	$90^{d} \pm 3$	$0^{c} \pm 0$	$0^{c} \pm 0$	$1^{c} \pm 0$
Actellic (0.25g)	$0^{c} \pm 0$	$100^{d} \pm 0$	$0^{c} \pm 0$	$0^{c} \pm 0$	$1^{c} \pm 0$

Values with different superscript letter(s) are significantly different by Fisher LSD at $p = 0.05$

3.2 Damaged seeds, seeds with eggs and holes per seed

The mean percentages for damaged seeds were higher in the control (0 g) and in common bean seeds treated with 3.75 g of *S. suaveolens* powder (Table 1). The percentage mean (±SE) for damaged seeds in the three common bean varieties differed significantly ($p < 0.001$). Jesca bean variety had the highest seed damage (6 ± 1) followed by Lyamungu 90 (4 ± 1) while Selian 97 had the lowest seed damage (3 ± 1) (Table 2). Similarly, means (± SE) for seeds with eggs and holes per seed were higher in the control experiment (42 ± 4 and 4 ± 1). However, this was observed to decrease significantly in the common bean seeds treated with actellic super dust (0 ± 0) and in seeds treated with 11.25 g and 15 g of *S. suaveolens* powder (Table 1). Generally, seed damaged, number of holes per seed and seeds with eggs did not differ significantly across the bean varieties (Tables 2 and 3), and were higher in seeds with control (0 g) and in 3.75 g of *S. suaveolens* treatments respectively.

Table 2. Effects of bean varieties (Mean percentage ± SE) on variables investigated

Common bean varieties	Variables				
	Damaged seeds (%)	Dead insects (%)	Seeds with eggs (%)	Holes per seed	Weight loss (%)
Jesca	$6^{a} \pm 1$	$68^{a} \pm 3$	$10^{a} \pm 1$	$1^{a} \pm 0$	$4^{a} \pm 1$
Lyamungu 90	$4^{ab} \pm 1$	$67^{a} \pm 3$	$9^{a} \pm 1$	$1^{a} \pm 0$	$3^{ab} \pm 1$
Selian 97	$3^{b} \pm 1$	$70^{a} \pm 3$	$9^{a} \pm 1$	$1^{a} \pm 0$	$2^{b} \pm 1$

Values with different superscript letter(s) are significantly different by Fisher LSD at $p = 0.05$

3.3 Weight loss

The percentage weight loss for common bean seed varieties tested in this study differ significantly across the treatments (p < 0.001) and was higher (9 %) in the control treatment (0 g) followed by seed varieties treated with 3.75 g of *S. suaveolens* powder (5 %). On the contrary, common bean seeds treated with actellic super dust, 11.25 g and 15 g of *S. suaveolens* recorded lowest percentage weight loss (1 %) in all the experiments (Table 1). The weight loss among the three bean varieties differed significantly (p < 0.001) (Table 3) with Jesca recording the highest weight loss of 4 % whereas Selian 97 had the lowest weight loss of 2 % among the three varieties tested (Table 2).

Table 3. ANOVA summary (Mean squares) on variables investigated

		Mean Square				
Source of variation	d.f.	Damaged seeds	Dead insects	Seeds with eggs	Holes per seed	Weight loss
Replication	2	1.906	79.9	54.36	0.963	0.863
Treatments	5	454.219***	8610.9***	2463.38***	29.63***	88.566***
Varieties	2	36.628	24.7	6.3	0.685	14.057***
Treat. x Var.	10	15.258	143.8	8.24	0.752	13.311***
Error	34	7.686	108.8	44.2	1.041	1.285
Total	53					

*** Significant at p < 0.001

Furthermore, results from this study indicate that there were significant (p < 0.001) and positive correlations among the variables investigated i.e. live insects, percentage damaged seeds, holes per seed, seeds with eggs and weight loss as shown in the Table 4.

Table 4. Correlation coefficient among variables investigated

Variables	1	2	3	4	5
1. Live insect	1	0.77***	0.82***	0.94***	0.69***
2. Damaged seeds		1	0.85***	0.85***	0.85***
3. Holes per seed			1	0.79***	0.76***
4. Seeds with eggs				1	0.75***
5. Weight loss					1

*** Significant at p < 0.001

4. Discussion

The findings from this study show that dry powder of *S. suaveolens* significantly reduced effects of bean bruchids on common bean seeds. This suggests that *S. suaveolens* may possess natural chemicals with insecticidal properties which killed bean bruchids. Additionally, maximum insecticidal activities were seen in the common bean seeds treated with large amount (11.25g and 15g) of the *S. suaveolens* powder and with 0.25g of actellic super dust. These results are in agreement with the study conducted by Pugazhvendan *et al.* (2012) and Badgujar *et al.*(2011) with regard to the insecticidal effects of *Sphaeranthus indicus* on the management of stored insect pest of grains. The reduced seed damage in common bean seeds treated with *S. suaveolens* might be caused by the toxic and antifeedant reactions of different chemicals present in the *S. suaveolens*. Most of the botanical pesticides affect insect pest by either deterring them from eating the stored crops or causing direct toxic effects that lead to their death (Hikal *et al.*, 2017; Rodríguez-González *et al.*, 2019). The death of adult insects is very important in the management of post-harvest loss since it significantly reduce the egg-laying capabilities and progeny development.

The results in this study also show that the number of seeds with eggs and holes per seed were significantly reduced by the *S. suaveolens* and actellic super dust pesticide as compared with the seeds in control treatment. However, the effects were treatment dependent and did not differ between the three tested common bean varieties (Jesca, Lyamungu 90 and Selian 97). These results are similar to what Koona and Dorn (2005) reported on reduced number of eggs for adult females in bean bruchid due to the effects of botanicals.

Weight loss on the other hand differed significantly among treatments and bean varieties as well. The Jesca variety was found to be more damaged by bean bruchids and its seeds had less weight compare with Lyamungu 90 and Selian 97 varieties. These results corroborates with findings of Mulungu *et al.* (2007) who revealed that Jesca bean variety was highly affected by insect pest compared with other varieties tested. This might be due to soft seed coat of Jesca and less secondary metabolites particularly flavonoids which acts as protectant against insect pests hence made it easy for bean bruchids' larva to penetrate inside the seed. Similar results were reported by Togola *et al.* (2017) in their study that assessed the cowpea resistance to insect pests such as *Acanthoscelides obtectus*, and found out that secondary metabolites such as flavonoids act as protectant of seeds against pest damage. However, due to its fast cooking and good taste, most people prefer Jesca bean variety compared with Lyamungu 90 and Selian 97 varieties.

Furthermore, results from this study show that, synthetic pesticide actellic super dust was effective and fast acting in controlling bean bruchids whereby all insects were killed within the first 24 hours. Despite the effectiveness of this synthetic pesticide, farmers should be cautious when using it due to possibly health risks it may pose during and after application (Mulungu *et al.*, 2007). On the contrary, botanical pesticide tested in this study was also effective in controlling bean bruchids at the rate of 11.25 g/150 g and 15 g/150 g, but showed the insecticidal effects from the fourth day of its application onwards. The slow mode of action of botanical pesticide noted in our experiment has been previously reported by Nattudurai *et al.* (2014) during the assessment of insecticidal and repellent activities of *Toddalia asiatica* (L.) extracts against stored product pests. Furthermore, Alemayehu and Getu (2017) in their study involving management of bean bruchids using botanicals noted that, the effectiveness of the botanical pesticides took four days to kill adult bruchids. However, due to the fact that botanical pesticides are affordable, easily accessible and do not pose threat to human health and the environment, farmers can be encouraged to use them as a possible alternative to synthetic insecticides.

The effectiveness of *S. suaveolens* powder in killing bean bruchids observed in this study might be due to the presence of volatile compounds with toxic, antifeeding and larvicidal effects. These naturally occurring compounds includes alkaloids, glycosides, flavonoids and others have been screened in several plants from genus *Sphaeranthus* and found to be toxic to the stored grain pests such as *Callosobruchus chinensis* (Patole *et al.*, 2008), *Sitophilus oryzae* (Pugazhvendan *et al.*, 2012). Furthermore, plants from the genus *Sphaeranthus* have been reported to contain aromatic essential oils with insecticidal and larvicidal properties and has been reported to be popular among organic farmers and environmentally conscious customers (Badgujar *et al.*, 2011). The larvicidal property of *Sphaeranthus sp* is very important in the management of bean bruchids since the larval stage is the most destructive due to the fact that the larvae bore a hole into the seeds to hide and feed.

5. Conclusion

This study has demonstrated the bio-pesticidal potential of *Sphaeranthus suaveolens* in post-harvest management of *Acanthoscelides obtectus*. The findings show that, at higher doses the *S. suaveolens* powder significantly reduce the seed damage caused by bean bruchids. The effective utilization of *S. suaveolens* as a botanical pesticide could minimize the use of hazardous chemicals in stored product pest control. Furthermore, resource poor farmers in developing countries in Africa and elsewhere and particularly from areas where *S. suaveolens* is in situ could easily prepare the powder and use it in managing bean bruchids. Additionally, our findings warrant for further research that could explore plants with insecticidal properties for the identification, isolation and discovery of the bioactive compounds suitable for plant products development.

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Conflict of interests

The authors declare no conflict of interest regarding the publication of this paper.

Data availability

Data used in this study will be provided upon request to the corresponding author.

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Leaflet for Common Bean Farmers in Arumeru and Moshi Rural Districts

Poster

Farmers' Knowledge, Perceptions and Practices in Managing Weeds and Insect Pests of Common Bean in Northern Tanzania

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Introduction

Weeds and insect pests are among the serious constraints in common bean production in most rural communities. A survey of 169 smallholder farmers was conducted in two common bean-growing districts (Arumeru and Moshi rural) in northern Tanzania. The aim was to assess farmers' knowledge, perceptions, management practices and challenges in order to develop sustainable weed and insect pest management strategies.

Methods

Focus Group Discussion

Household Interview

Key Informant Interview

Results

Variable	District			
	Arumeru	Moshi Rural	Mean	Statistics
Insect Pest Control Methods				
Chemical sprays (pesticides)	85.5	72.2	78.9	$x^2 = 2.87$; df = 1; $p = 0.09$
Cultural	7.3	5.6	6.45	$x^2 = 0.13$; df = 1; $p = 0.72$
Do nothing	3	1.2	2.1	$x^2 = 3.72$; df = 1; $p = 0.05$
Weed Control Methods				
Chemical sprays (herbicides)	67.3	25.9	46.6	$x^2 = 18.71$; df = 1; $p = 0.00$
Mechanical (weeding)	84.5	87.1	85.8	$x^2 = 3.52$; df = 1; $p = 0.03$
Cultural	6.5	0	3.3	$x^2 = 2.00$; df = 1; $p = 0.16$

Insect pest and weed control strategies in common bean farming

Major insect pest and weed in common bean farming

Conclusion

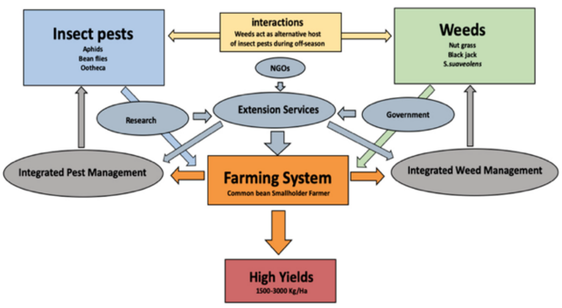
- This study confirmed that pests and weeds are the most serious constraints in common bean production in the two districts surveyed.

- Use of chemicals such as synthetic pesticides and herbicides was the main method of pest and weed control.

- Most farmers are not aware of other non-chemical methods for managing weeds and insect pests.

- Training to farmers on other methods for managing pests and weeds is urgently needed.

- There is a need to develop an effective and appropriate weed and pest management approach.



Proposed management strategies for insect pests and weeds

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