EFFICACY OF INDIGENOUS PESTICIDAL PLANTS FOR TOMATO AND BRASSICA PEST MANAGEMENT IN MALAWI.

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DECLARATION

I certify that this work has not been accepted in substance for any degree, and is not concurrently being submitted for any degree other than that of Doctor of Philosophy (PhD) being studied at the University of Greenwich.

I also declare that this work is the result of my own investigations except where otherwise identified by references and that I have not plagiarised the work of others.

Candidate:

Stephen P.M. Nyirenda Date 28th April, 2016

Supervisors

Prof. Steven R. Belmain Date

Prof Philip C. Stevenson Date

DEDICATION

To

My Beloved wife Joyce Ngalonde Nhlane

My late father Pearson Maxon Nyirenda; May your soul rest in peace.

Mum Minaless Phelire Sakala, be soothed now, after living under little care

My Dear Sisters; Yizaso Stella Nyirenda and Violet Nyirenda

My Brothers; Brave Kadoko, Allan Msochi and Isaiah ‘Esaya’ Nyirenda; Good luck.

and

My Dear Sons Daniel and David AKA **NJADADA**,

ABSTRACT

The cultivated tomato, *Lycopersicon esculentum,* and rape (*Brassica napus*) are the most important horticultural vegetable crops grown in southern Africa. However, their production is highly constrained by insect pests including red spider mites *Tetranychus evansi* and the aphids (*Brevicoryne brassicae* and *Myzus persicae*). The results on field surveys revealed that majority of smallholder farmers have considerable knowledge about pesticidal plants and reported *Tephrosia vogelii, Vernonia amygdalina*, *Tithonia diversifolia* and *Azadirachta indica* as particularly important. *T. vogelii* was the most popular species in Zambia (60.7%) and Malawi (53.4%) while brassicas constituted 34% and 44% of all vegetables grown in Malawi and Zambia respectively. Although insect pest infestation during the field trials was low but nonetheless, significant differences were observed between pesticidal plant extracts treated plots and the control. Use of pesticidal plants resulted in significantly lower damage to vegetables. The results further revealed that pesticidal plant products as compared to untreated control decreased the incidence of red mites, aphids and diamond back moth significantly. Although synthetic insecticides were most effective against these pests, the pesticidal plant extracts examined offered valuable contribution to pest management efforts. *T. diversifolia* was the most effective at reducing numbers of both red spider mites and aphids followed by *T. vogelii*. Crude extracts applied at a concentration of 10% w/v reduced effect on the abundance of red spider mites and aphids significantly ($P<0.001$) when compared to control treatment. All the plant extracts tested had some level of toxic effect at 4% w/v. Yields of tomato treated with pesticidal plants ranged from 24,414 to 38,320 Kg ha^{-1} compared to control plots (21,590 $Kgha^{-1}$). Vegetable damage due to levels of insect pest (aphids, red mites and diamondback moth) infestation varied from 6 to 45%. *T. vogelii* was a promising species in field and laboratory trials and analysis of the extracts identified several rotenoids as the biologically active components. Laboratory studies showed for this first time that the rotenoids tephrosin and deguelin were toxic against red mite and aphids. However, field experimentation with *T vogelii* showed that compounds were not present on the leaf surface when applied on bean leaves indicating total degradation of the compounds under the sun after three days. The study has also shown that there is substantial temporal and spatial variation in the occurrence of these rotenoids, which might affect harvesting protocols. Pesticidal plant extracts can improve vegetable production for resource poor farmers at controlling vegetable pests at much reduced

costs as claimed by farmers since most plant materials are found locally or can easily be cultivated.

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CHAPTER 1 INTRODUCTION AND BACKGROUND

1.1 AGRICULTURE IN MALAWI

Agriculture generates 90% of Malawi's foreign exchange earnings of which 70% come from tobacco alone. Over 80% of Malawian livelihoods depend on agriculture with 5.3 million hectares of arable land cultivated that is increasing the pressure on natural resources. Malawi's vegetation is a reflection of its diverse climate and terrain with various forest and woodland vegetation (White et al. 2001). Evergreen forests are found in places where ground water is plentiful, such as the river valleys and mountains. Grasslands are mainly found on the high plateau regions. Dry lowland areas are largely made up of savanna, while Miombo (mostly dominated by *Brachystegia spp*.) woodland stretches out along barren slopes and plateaus. Miombo is a vernacular word that has been adopted by ecologists to describe the dry deciduous woodland ecosystem dominated by trees of the genera *Brachystegia Julberardia* and their associates (Kayambazinthu, 1988; Lowore, 1993). The climate varies from hot and dry to moist and cool, depending on the elevation. This enables farmers in different areas to grow a variety of vegetable crops. Vegetables are an important source of mineral salts and vitamins which are vital for good health and also provide income to most smallholder farmers in Malawi. Despite being so important, they are mostly available in the rainy season. As a result, supplies are not adequate throughout the year.

Smallholder farmers contribute in excess of 80% of the total horticultural production, mainly exotic and indigenous leafy vegetables. Popular leafy vegetables in the country include; rape *Brassica napus*, mustard *Brassica carinata*, and Chinese cabbage *Brassica chinensis*. The cultivated tomatoes *Lycopersicon esculentum* are also widely grown throughout the country.

However, its production is low, scattered, and highly seasonal, with most taking place in winter along dambo areas, ranging from narrow belts along small streams to broad flood-plains of major rivers, and also as extensive areas on level grounds. The potential yield for tomato ranges from 18,000 to 50,000 kg per hectare depending on variety and leafy vegetables like rape yields between 15,000 to 25,000 kg per hectare (Anonymous 2004; Tindall, 1983). Insect pests and diseases attack these vegetables with red spider mites and aphids contributing significantly to low yields in tomato and rape production (Muzemu et. al., 2011). It is therefore important that farmers must use some control measures in order to improve both yields and quality.

1.1.1 Significance of vegetables

Vegetables represent important and rich sources of essential vitamins, minerals and dietary fiber. Therefore, they are valuable and nutritious food commodities that can contribute substantially to improved social welfare and the health status of the rural as well as urban populations. However, vegetable crops are often overlooked in research prioritisation (Dinham, 2003). In order to improve production of vegetables, there is need to undertake appropriate research to meet domestic demand and thereby improve the nutritional status of resource poor farmers. Farmers should also be advised to continuously produce and preserve vegetables so that they may have food in times of scarcity.

Tomatoes and brassicas are among the most important and popular cultivated vegetables throughout the country and are an integral part of the Malawian diet. In a typical dry season production, tomatoes constitute 10% of the cultivated land (Mapemba, et al., 2013) but their availability and supply continue to be key hurdles to optimizing the nutrition of Malawians. Tomatoes are versatile as they can be eaten raw or cooked. Large quantities of ripe tomatoes are used to make soups and sauces. Leafy vegetables like rape form the major vegetable dish in Malawi. They are widely used at household level, educational institutions and hospitals as a source of vitamins and minerals (Mazuma, 2003). Vegetables provide a valuable source of nutrition and income for many poor farmers in southern Africa (Dobson, et al., 2002). Vegetables are also an important complement to the staple food of Malawi, maize. According to a survey on urban residents' consumption and purchasing habits, the most commonly bought vegetable in Malawi is mustard (35%), followed by rape (31%), tomato (13%), Chinese cabbage (8%), pumpkin leaves (7%) and cabbage (6%) (Chadha et al., 2008). Therefore, farmers must ensure continued production of vegetables in order to have secure supply and maximise consumption of quality vegetables at all times.

Figure 1.1: Field of brassica (rape) produced under small scale farming system in Malawi

Figure 1.2: Tomato production under resource poor farming system in Malawi

1.1.2 Insect pests and their control

Insect pests represent a serious threat particularly in the tropics and sub-tropics where a warm and humid climate provides optimal conditions for their development and occurrence. It has been estimated that worldwide more than 60% of agricultural commodities are lost to insect pests and diseases in production and post-harvest, despite the annual application of 2.5 million tonnes of pesticides (Paoletti and Pimentel, 2000). Pests are among the most important factors that affect vegetable and other food crop production.

Tomatoes and brassicas succumb severely to red spider mites *Tetranychus evansi* Baker and Pritchard (Acari: Tetranychidae) and aphids *Brevicoryne brassicae* L. and *Myzus persicae* Sulz (Aphididae) respectively. Red spider mites kill cells in the photosynthetically active leaves thereby causing plant growth and fruit development losses (Munthali et al., 1992). Diamond back moth was introduced in this study on request from farmers that experienced serious damage of their crop from a strange pest, which was later identified as diamond back moth. Diamondback moth (DBM), *Plutella xylostella* (Lepidoptera: Plutellidae), is also a serious pest of crucifer crops worldwide (You and Wei, 2007). Hooks and Johnson, 2003) observed that biological control can be effective and increased abundance of DBM natural enemies was reported in diversity habitats. Generally, insect pests become a major problem with increased use of synthetic pesticides as beneficial organisms are also killed but cannot re-establish as rapidly the pests. In developing countries, the problem of competition from insect pests is even more severe because of the rapid annual growth in human population (2.5-3%) and consequently an increasing demand for food (Runge et al., 2003; Rabbinge, 1993). Furthermore, pest problems tend to be mostly experienced in developing countries like Africa due to the high importation costs of pesticides (FAO, 2006).

1.1.2.1 Aphids

Aphids are widely distributed, and aphids attack a number of crops in Africa and many parts of the world (Arancon et al., 2006; Mochiah et al., 2011; Hill, 1983). Outbreaks are common on young plants especially in the dry spells which later clear up with onset of the rains. They can colonise plants around the stems, growing points and leaves, where they feed by sucking sap. Due to sucking the sap, they are known to reduce the vigour of plants. Aphids usually cluster on the tips of the plant shoots where they feed on young shoots and the foliage of both tomatoes and rape, primarily targeting the phloem sap hence affecting yield, quality of produce and being major vectors of viral diseases. Plants may sometimes wilt in a form of dieback. Aphid infestations may build up very quickly, producing a new generation every seven days.

Many authors (Lu *et al.*, 2008; Farag and Gesraha, 2007; Mathews *et al*., 1974) have indicated that aphids are often green, black or red in colour and might sometimes covered in whitish waxy powder. Aphids may be winged or wingless depending on the colony biology being established and are usually slow moving; small to medium sized, about 1-2 mm long with their antennae only about half the length of the body. With this considerable morphological polymorphism, wingless aphids can easily get in contact with a treated surface or vapour whereas winged ones can escape ingesting treated product through migration. Wingless adults are around 2 mm long and 1 mm wide, tapering at each end. The wingless females are somewhat larger, more globular and generally paler in colour. The adults may live for 2-3 weeks and produce 2 to 20 offspring each day.

Aphids retard plant growth and deform leaves, reducing both photosynthetic area and yields. They are also vectors of virus diseases, which can severely reduce yields and quality (Grzywacz et al., 2010; Gray and Gildow, 2003; Liu and Yue, 2001; Kennedy et al., 1962). Heavily infested brassica crops may become unpalatable, further increasing losses. Aphids secrete sticky substance (honeydew) on which certain sooty moulds grow and block the leaf pores thereby cutting out light falling on the leaves. Aphids also attract other vector pests like whiteflies and results in fungal growth, which affects photosynthesis and further reduces crop yields.

The appropriate management of aphids will depend mainly on a number of factors, such as the extent of the infestation, the presence of other pests and predators in the crop. Hence advising farmers to monitor aphid infestation on a weekly basis and record the data becomes paramount. Frequent monitoring enables spotting aphid infestations while they are still light, and thus easier and cheaper to manage. However, control measures for aphids are not usually required on most crops due to numerous natural enemies that occur such as spiders, ladybirds, lacewings and parasitoids. Both, the larvae and adults of predators belonging to the family Coccinellidae (ladybird beetles) feed on aphids. Cultural control can be effective through early planting and close spacing (Nabirye et al., 2003). There are also aphid tolerant cultivars available, which offer resistance against aphid attack (McCarville et al., 2011). The resistant plants will not be aphid free, but they will have fewer aphids than susceptible plants. Removal of alternate hosts such as wild turnip *Arisaema triphyllum* can also limit the multiplication of the aphids.

If chemical control becomes necessary, then dimethoate and pesticidal plant extracts are applied. For instance, neem has been used for controlling insect infestation in rural communities for over 20 years (Schmutterer, 1990). Neem seed extracts are rich in azadirachtin and act as potent antifeedants as well as insect growth regulators (Morgan 2009). Azadirachtin has been reported to cause marked effects on adult aphids when used as systemic insecticides to mature and immature stages of bean aphid (Ahmed et al 2007).

Figure 1.3: Aphids on brassica and beans

1.1.2.2 Red spider mites

Spider mites are major pests of commercial crops requiring costly control measures particularly because of the development of resistance to synthetic pesticides (Zhang, 2003; Cranham and Helle, 1985). The red spider mite *Tetranychus evansi* is a pest of tomato in East and Southern Africa. This species is currently the most important dry season pest of tomatoes in Southern Africa (Knapp et al., 2003a). It is probably native to South America but has become a persistent problem in Southern Africa especially in Malawi, Zambia and Zimbabwe (Dobson et al., 2002). Mites are oligophagous pest of solanaceous species (Moraes et al., 1987; Knapp et al., 2003b) including pepper, eggplants, European potato and tomato, although they do feed on other crops such as beans, citrus, cotton, castor bean and ornamental plants (Moraes et al., 1987).

Red spider mites often occur in vast numbers on the underside of the leaves making them hidden from harsh environmental condition such as direct sunlight allowing them to readily establish and multiply rapidly. The underside of the affected leaves usually have fine webs with hundreds of small green to red mites and pearly eggs. Webbing also protects the mites against climatic factors such as wind and rain; as well as from natural enemies and exposure to chemicals. When spraying, some spray droplets are caught up in the webbing and fail to contact the mites. Capinera (2001) indicated that wide distribution of red spider mites is also largely due to their small size and the ease with which they are transported by wind.

The life cycle of red spider mite comprises five stages between egg and adult. Females will begin laying eggs from one to three days after emerging as adults, and mating is not required. One female is capable of laying over 100 eggs during her lifetime. Eggs hatch after 5-8 days into two nymphal stages; starting with protonymph which later moults into a deutonymph stage followed by the adult stage with eight legs. Each of these active immature stages feed on the host plant normally separated by a resting stage before a final moult to the adult (Klubertanz et al., 1991). Bonato (1999) showed that the optimal temperature for population growth of mites considerably varies. The shortest developmental time (6.3 days) occurs at 36°C and its life cycle may take as long as 13.5 days at 25°C thus this pest is likely to become increasingly important as temperatures globally rise during the 21st century. All the larval stages are very destructive to crop production.

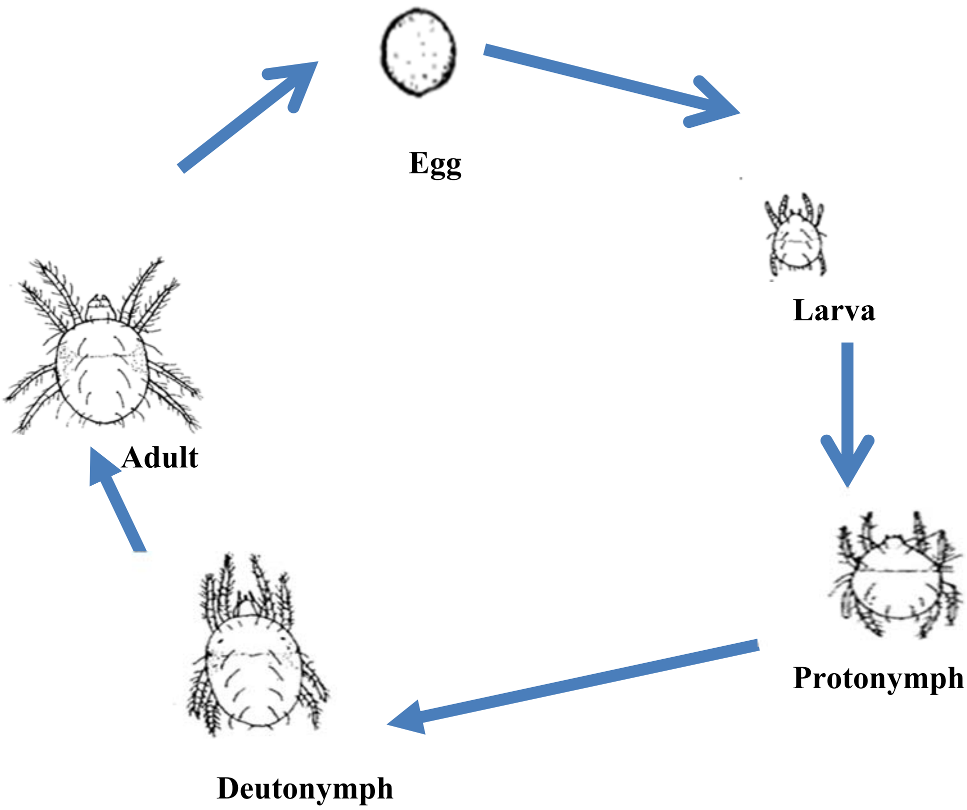


Figure 1.4: Red spider mite life cycle (Adapted from Mwandila, 2009)

Red spider mites cause leaf browning and dropping, bronzing of fruits and sometimes foliage has a silvery appearance (Park and Lee 2002; Hill and Waller, 1978). Red spider mites are a menace due to intensive webbing that acts to shield the blanket like colony, and it provides a series of ladders or netting that allow the mites to crawl from stem to stem. Both nymphs and adults produce webbing that can cause cosmetic damage to the crop. If large numbers of red mites are present, plants may be completely covered with webs. Mansour *et al*., 1987) observed that generally older plants succumb to red spider mites' infestation more than younger plants. Nyirenda (2000) reported that red spider mite infestation increases towards flowering and fruiting stages thus affecting yield and quality of tomato fruits. This drastically reduces the crop yield and market value of fruits (Bok *et al*., 2006). Pandey and Verma (1982) reported that nymphs and adults inflict most of the damage. Red spider mites can also significantly affect the accumulation and partitioning of shoot nitrogen in plants such as cotton (Sadras and Wilson, (1997).

Figure 1.5: Red spider mite and its damage on tomato plants

1.1.2.3 Diamond back moth

Diamond back moth *Plutella xylostella* (Lepidoptera: Plutellidae) is an important insect pest of Brassicas (Isman, 2008; Ogendo et al., 2008; You et al., 2013). The adult is a medium-sized grey moth (usually 10 mm in length) which is preceded by four larval instars and a non-feeding pre-pupal stage, all of which occur on the plant. The adult lives for about 10-15 days. The female moth lays eggs singly along the veins on the underside of leaves; about 300 eggs per moth throughout its reproductive period. The eggs hatch within 2-4 days and larvae feed on the underside of green leaves during their larval period, which ranges from 10-15 days depending upon the temperature (Gujar, 1999). The life cycle from egg to adult can be as short as 21 days or as long as 51 days. The average is 32 days, and will depend on climatic conditions and quality of food. The adult moth displays triangular markings on forewings at rest that meet together to form a diamond shape, which gives the moth its name. The wings are usually folded over the abdomen, in a tent-like manner. Usually when the wings are folded along the body a line of yellow diamond-shaped spots are visible (Sandur, 2004).

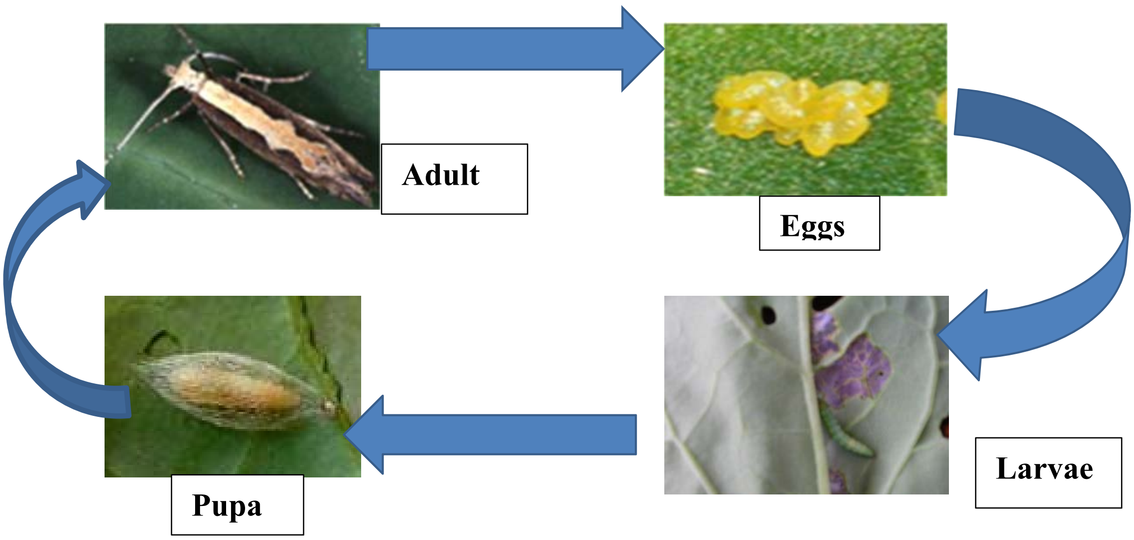


Figure 1.6: Life cycle of diamondback moth (Adapted from Faithpraise et al., 2014)

Diamond back moth can be so damaging and destroy crops. The most destructive stage of diamond back moth is the older larvae that feed on the underside of vegetable leaves between the veins making holes right through them (Hill, 1983). The larvae cause extensive defoliation of leaves (Gujar, 1999). Young larvae bore into the leaf and feed on the internal leaf tissue, tunneling through the leaf and leaving white markings. At the slightest disturbance, the larvae wriggle actively and drop down from the leaf, suspending themselves by silken threads. Weinberger and Srinivasan, (2009) reported up to 100% yield losses on crucifers which has been estimated to cost between US$ 4 and 5 billion per annum (Zalucki et al., 2012). Apart from yield losses, diamondback moth also causes cosmetic damage to the crop resulting in poor quality leaves.

Figure 1.7: Diamond back moth larva and its damage on brassica

lthough diamond back moth is a weak flier, it acquires local importance depending upon cropping systems and agro-ecological conditions (Gujar, 1999; Mohan and Gujar, 2002). It breeds continuously in the tropical countries like Malawi giving as many as fifteen generations in a year (Mazuma, 2003). Crop damage is usually first evident on plants growing on ridges and knolls in the field. Larvae will remove the surface tissue from the stems and seedpods. Seeds within a damaged pod may not fill completely and pods shatter easily. Larvae may occasionally chew into seed pods and eat a few developing seeds. The most critical stage in cabbage cultivation is head initiation usually 25-35 days after transplanting. The economic injury threshold of diamondback moth on cabbage has been estimated at seven larvae per plant. Damage can only be prevented by early field monitoring and timely application of insecticides. Application of pesticides is recommended when the pest population exceeds this economic threshold level.

However, diamond back moth is notorious for developing resistance very easily and has developed resistance to nearly most of the available classes of insecticides used against it all over the world (Kianmatee and Ranamukhaarachchi, 2007; Hema, 1988), A high degree of resistance has been reported to pyrethroids, cypermethrin, fenvalerate, deltamethrin and organophosphate in this pest (You et al., 2013; Saxena et al., 1989). Diamond back moth have also developed resistance to even microbial insecticides (Zago et al., 2014; Shelton et al., 2007; James et al., 2007; Shelton et al., 1993). Factors that influence the development of resistance in the pest include high reproductive potential, rapid turnover of generations, long growing season and frequent insecticide applications.

1.1.3 Overview of pesticidal plant use

Over the last 70 years, insect pest management has mainly relied on synthetic pesticides. However, there are difficulties associated with insecticide applications such as insect pest resurgence, secondary pest outbreaks and development of insecticide resistance (Iftner & Hall, 1984; Wilson et al., 1991; Dimetry & Merei, 1992; Kakahel et al., 1998; Zhao et al., 2006). Plants are an important source of biologically active substances and have been used for medicinal purposes since ancient times (Holt and Chandra, 2002; Cragg and Newman, 2001). According to Holt and Chandra, (2002), the use of herbaceous plants by the Chinese dates back to 2000 BC. They were also first recorded being used against biting insects by the ancient Greeks and are still used by many people today as biopesticides (Holt and Chandra, 2002).

Traditional agricultural practices have also utilized natural products for centuries (Roy et al. 2005). Plants have evolved a wide spectrum of strategies to defend themselves against herbivores. The chemical defense mechanism of plants against herbivores are often more subtle in action which has been shaped in the evolutionary process of 300 million years (Isman, 1996). Most of these botanical pesticides are non-selective poisons that target a broad range of pests and this may not be good if we are to conserve natural enemies (Rosell et al., 2008).

According to Isman (1997), botanical insecticides were important products for pest management in industrialised countries before the Second World War (early 1940s). However, synthetic pesticides have since dominated the market. Governments are slowly introducing favourable policies to replace chemicals that pose risks to human health and the environment. High costs of pesticides and their negative side effects calls for a paradigm shift towards the development of non-chemical technologies which may eliminate the use of insecticides, bringing economic and health benefits to the applicators, consumers and the environment (Murdock *et al*., 1997).

Most smallholder farmers in developing countries do not have the resources to buy and apply chemical pesticides (Palikhe, 2002). Botanical pesticides are more affordable to low-income farmers, having the potential for use in agriculture, especially with the dramatic increase towards the consumption of organically produced plants (Moyo et al., 2006). In recent years it has become evident, as a result of public opinion and environmental laws, that new safer alternatives to conventional synthetic pesticides are both desirable and mandated (Locke, 2008).

Many published reports have described the significance of natural crop protection where botanical insecticides feature highly, providing evidence that they are not only effective but also commercially or economically viable (Berger, 1994, Stoll, 2000; Amoabeng et al., 2013 and 2014), hence, many plant species have been used for the control of insect pests (Schutterer, 1990b, Dales, 1996; Berger, 1994; Harve and Kamath, 2004; Sileshi et al., 2009; Dubey et al, 2010). Studies in Uganda and Ghana have also established that farmers use botanical pesticides widely and that they are perceived to be as effective as the synthetic pesticides (Belmain and Stevenson, 2001; Mugisha-Kamatenesi et al., 2008) and are even less harmful to beneficial insects (Amoabeng et al., 2013).

Plants play significant role as pesticides in smallholder farming, but only a few plants are used commercially for insect pest control (Isman, et al., 2011) which include the use of nicotine from *Nicotiana tabacum*, rotenone from *Lonchocarpus* spp. and *Derris elliptica*, and pyrethrum dating back to the 1850s (Dales, 1996). However, according to Isman, (2006), the use of plants in pest control has been in decline since the discovery of inexpensive and highly efficacious synthetic pesticides.

Although biopesticides are generally perceived to be safer than the synthetics (Charleston et al., 2006), plant products have been underutilized in pest control (Isman, 2011). In fact, other studies have further shown that botanical pesticides have delivered little as viable alternative to synthetics (Isman and Grieneisen, 2014; Sola et al., 2014). However, synthetic pesticides get accumulated into the food chain and bring negative impacts on humans and the environment (Kuntashula, et al., 2006). High levels of applications have also been reported to induce pest resistance. Synthetic pesticides may also affect non-target organisms (Isman, 2008; Pandey et al., 1982) whereas pesticidal plants have been shown in field trials to be less toxic to beneficial insects such as natural enemies (Amoabeng et al., 2013).

Stevenson et al., (2012) highlighted the potential of plants as alternatives to synthetic pesticides and provided a wider perspective on the pesticidal plants for plant protection improvement programmes within the Southern African Development Community (SADC). Mugisha-

Kamatenesi et al., (2008) reported that subsistence farmers prefer using botanical pesticides to synthetic pesticides mainly because of cost and availability. This preference of pesticidal plant products by subsistence farmers clearly shows their potential use for pest control by small holders in developing countries (Isman, 2008; 2011).

1.2 PROBLEM STATEMENT

Tomatoes and brassicas are among the most important and popular cultivated vegetables throughout the world. In southern Africa they provide a valuable source of nutrition and income for many poor farmers (Dobson, et al., 2002). However, tomatoes and brassicas succumb severely to red spider mites, *Tetranychus spp* and aphids, *Brevicoryne brassicae, Plutella xylostella* and *Myzus persicae*, respectively, causing both direct and indirect qualitative and quantitative damage and losses (Munthali et al., 1992). The pests become a major problem with increased use of synthetic pesticides as beneficial organisms are also killed such that insects cannot re-establish as rapidly as possible. For instance, farmers in Malawi apply fourteen different pesticides in their fields per season with three of them being considered highly toxic to humans and non-target organisms (Orr et al., 1999). These chemical pesticides are a threat to the environment and the health of those applying them (Kuntashula, et al., 2006). High levels of applications have also been reported to induce pest resistance. The pesticides may also leave toxic residues for considerable periods, thereby contaminating crops and could have detrimental effects against beneficial organisms and pollinators. Generally, continued search for alternatives to synthetic pesticides would easily avoid the problem of obsolete pesticide stocks. It is against this background that safer products are sought for vegetable pest management.

Although there has been a surge in interest on pesticidal plants, particularly in emerging economies, much of the work is considered to be of little value in practical terms because very few plant products are commercialized and used by farmers (Isman and Grieneisen, 2014). The present study aims to take an adaptive approach to research in order to identify ways to optimize the use of pesticidal plants in Malawi and the region as a whole.

1.3 RESEARCH OBJECTIVES

The main aim of the research reported in this thesis was to find ways to optimise use of indigenous pesticidal plants on smallholder farms in Malawi. Much as there is evidence of the efficacy of pesticidal plants, they are not without their drawbacks. For example, extreme variation in the chemistry of plant materials has shown some effects on the biological activity in pesticidal plants (Stevenson et al., 2014). The later part of this thesis discusses the spatial and temporal variation in the commonly used plant species in Malawi. Findings from this study later geared at determining efficacy of some of the compounds present in *T. vogelii* against key insect pests of vegetable crops in Malawi.

1.3.1 Specific research objectives

I. Determine farmers' knowledge and perception of pests and pesticidal plants could be useful in controlling pests of tomato and rape. This objective was established to provide a foundation for the subsequent research activities after understanding farmers' comprehension of pest management and was necessary to guide the research.

II. Validate the potential biological activity of pesticidal plants against red spider mites aphids and diamond back moth under field conditions.

III. Evaluate the efficacy of some selected pesticidal plant extracts and determine their effects against red spider mites and aphids under laboratory conditions.

IV. Determine the spatial-temporal variability of efficacy and chemistry and test crude extracts of *T. vogelii* for acaricidal activity.

V. Understand the biological factors that cause variable efficacy in pesticidal plants through optimizing application techniques

The evaluation of potential pesticidal plants for pest control in tomato and brassicas used participatory approaches where appropriate. Through this, the research aimed at assisting the resource poor farmers' at decision making in pest and crop management to improve their sustainable livelihoods. Decision making in pest management, like all other economic problems, involves allocating scarce resources to meet needs (Byerlee, 2009; Mumford and Norton, 1984). Hence, involvement of farmers in participatory research evaluation accelerates quick uptake of cost effective technologies and save them from costs.

1.4 HYPOTHESES

In this study, it was hypothesized that:

1. Pesticidal plants are effective in controlling major crop pests of tomato and brassicas in Malawi.
2. Pesticidal plants can be cost effective compared to synthetic pesticides commonly used for vegetable pest control.
3. Improved application techniques can be developed in the use of the pesticidal plants.
4. Spatial and temporal variation in efficacy of control occurs and can be identified in the pesticidal plants to inform and optimize use of plant materials such as *T. vogelii*.

1.5 Thesis Plan

Six chapters address the issue of pesticidal plants used for agricultural pest management in Malawi. Chapter 1 has introduced the study and covered background information on agriculture in Malawi. A general description of the importance of agriculture in Malawi has been presented with special emphasis on vegetable production and their main pests and management. Chapter 1 also provides an overview of pesticidal plant use and reviews some literature related to insect pest control. Chapter 2 gives an overview of pesticidal plants used in vegetable pest management through an intensive resource farmer and extension survey. It deals with an ethnobotanical survey of pesticidal plants, to establish an overview of tomato and brassica pests and pesticidal plants used among vegetable farmers in Zambia and Malawi.

In the next chapters 3, 4 and 5 selected pesticidal plants are analyzed for their effects on and efficacy against aphids and red spider mites. Chapter 3 presents the validation of some selected pesticidal plant materials against aphids spider mites and diamond back moth through participatory field evaluation with local farmers in Malawi. The findings in this chapter necessitated further laboratory work that evaluated the efficacy of some selected pesticidal plants that could be used for pest control. Chapter 4 therefore reports the results of the laboratory efficacy of selected pesticidal plants by analyzing the toxicity and repellent effect of some selected pesticidal plants. Chapter 5 describes the spatial and temporal variation of *T. vogelii* and evaluation of its biological activity against aphids and red spider mites. Finally, chapter 6 provides a general discussion and critical analysis of the research findings, discussing the validation of selected pesticidal plants and ending with final conclusions and summarizing some suggestions for further research on pesticidal plants for vegetable pests under rural farming set up.

CHAPTER 2 FARMERS' ETHNO-ECOLOGICAL KNOWLEDGE ON VEGETABLE PESTS AND THEIR MANAGEMENT

2.1 INTRODUCTION

Smallholder farmers produce vegetables all year-round in many parts of Malawi and Zambia and typically grow brassicas, tomatoes and onions in both countries. The main brassicas grown are cabbage, (*Brassica oleracea* L.), rape (*Brassica carinata* A. Br. and *Brassica napus* L.), kale *(Brassica oleracea* L. var. *acephala*), Chinese cabbage *(Brassica chinensis* L.) and cauliflower (*Brassica oleracea* L. var. *botrytis*) (Nkhungulu and Msikita, 1985; Theu, 2008). The vegetables are grown during both the wet and dry season. They are grown largely in upland areas during the wet season and in the wetlands locally known as *dambo*s during the dry season in Zambia, Malawi (Kuntashula et al., 2006; Mwandira, 2003) and most southern African countries. Vegetables are valuable as a relish, providing necessary dietary vitamins and minerals in the largely maize-based diet, as well as a source of cash. There is a high level of vegetable consumption among Malawians and Zambians because, traditionally, the population eats *nsima*, a staple dish made of maize flour, which goes with a side dish of either vegetables or meat. According to Mwandira, (2003), the most commonly bought vegetables in Malawi include mustard (35%), rape (31%), tomato (13%), Chinese cabbage (8%), pumpkin leaves (7%), and cabbage (6%). Vegetables fetch attractive prices at the local market and generate income throughout the year (Jackson, 1997; Kuntashula et al., 2006). A wide variety of brassica crops are grown in Africa although rape is an especially important vegetable in the diets of urban Zambians and Malawians, and the per capita consumption has been estimated at 15 kg per person annually (Nkhungulu and Msikita, 1985; Sibanda et al., 2000). The potential yield production of vegetables such as tomatoes and rape has been estimated to range from 18-50 and 15-25 tonnes per hectare respectively (Anonymous 2004; Tindall, 1983). However, this production is often constrained by damage caused by a range of pests during the rainy season. Hence, production is restricted to the cooler wetlands during the dry season (Kuntashula et al., 2006; Grzywacz et al., 2010). The wetlands are extremely vulnerable to poor agricultural practices such as intensive use of pesticide and fertilizer (Kuntashula et al, 2004). Therefore, the growing application of pesticides poses serious challenges to the ecological sustainability of the wetlands. The continued use of chemical pesticides to achieve higher vegetable yields can also lead to disruption of natural control (Kannan, et al., 2004; Laetemia and Isman, 2004; Kuntashula et al., 2006).

Understanding and applying traditional farming knowledge is important to solving agricultural problems. Ethno-ecology or traditional ecological knowledge is important for the formulation of sustainable pest management (Sileshi et al., 2009) and natural ecosystems are potentially important sources of natural pest control materials – both biological and plant based pesticides (Grzywacz et al., 2014). Traditional ecological knowledge is defined as "a cumulative body of knowledge, practice and belief evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings with one another and with their environment" (Berkes et al. 2008; Guimarães and Mourão, 2006; Toledo, 1992).

For decades, smallholder farmers across Africa have struggled to maintain food security for their families. There are diverse and mixed views about the causes of food shortages within different communities in Africa (Mapfumo et al., 2008). Many pests and diseases easily attack vegetables. It is, therefore, important that farmers use recommended measures to protect their vegetables from pest damage. A growing body of literature suggests that farming communities have a thorough knowledge of the history, biology and bionomics of pests that affect their crops (Price, 2001; Price and Björnsen Gurung, 2006; Sileshi et al., 2008). However, some farmers' fail to identify common pests affecting their crops and rank the degree of damage they cause to crops is also quite common (Altieri, 1993; Björnsen Gurung, 2003; Sileshi et al., 2008). Hence, frequent observation of crops during the growing season assists farmers identify and understand what happens within their field. The survey mainly focused on interviewing vegetable growers in order to understand the knowledge, perception, and pest management practices used in pest control.

The overarching aim of the survey was to investigate farmers' knowledge and perception about pests and pesticidal plant use in tomato and brassicas in Malawi and Zambia. Understanding the potentials and drawbacks of farmers' indigenous pest management knowledge may form the basis for constructive collaboration between farmers, scientists and extension staff. The specific objectives were:

(i) To identify the pest problems that farmers perceive as most important in brassicas and tomatoes;

(ii) To evaluate farmers' knowledge and practices in vegetable pest management including use of pesticidal plants used and

(iii) To identify training and extension gaps amongst smallholder farmers' in northern Malawi and eastern Zambia.

It was hypothesized that farmer's awareness and their use of pesticidal plants is a function of farmer-specific explanatory variables such as age, sex, education level and years of experience in growing vegetable crops.

2.2 MATERIALS AND METHODS

2.2.1 The study areas

The study was conducted in two districts of northern Malawi (Mzimba and Rumphi) and three districts (Chadiza, Chipata and Katete) of eastern Zambia (Fig 2.1). The majority of the people in the study area in northern Malawi belonged to the Tumbuka and Ngoni ethnic groups, while those in eastern Zambia belonged to the Ngoni and Chewa (Nyanja) ethnic groups. Ethnic groups are important because they know and analyze the way local people view and define specific issues in their area (Price, 2001). Mzimba and Rumphi districts are located in the Northern part of the country's highlands of Viphya and Nyika at an altitude of 1300 and 1700m respectively. Mzimba is one of the largest districts (10,382 sq km) with a population of 724,873 mostly comprising descendants of Tumbuka and Ngoni tribes. Rumphi is slightly smaller (4,769 sq km.) Tumbuka dominated district with a population of 169,112 (NSO, 2008).

2.2.2 Data collection

The survey was conducted just before the onset of the rainfall season in northern Malawi and eastern Zambia. The study was conducted among randomly selected horticultural household farmers producing either brassicas or tomatoes in the targeted districts in Malawi and Zambia using semi-structured questionnaires (Appendix 2.3). A total of 91 farmers were interviewed in the eastern Zambia while 168 farmers were interviewed in the northern Malawi.

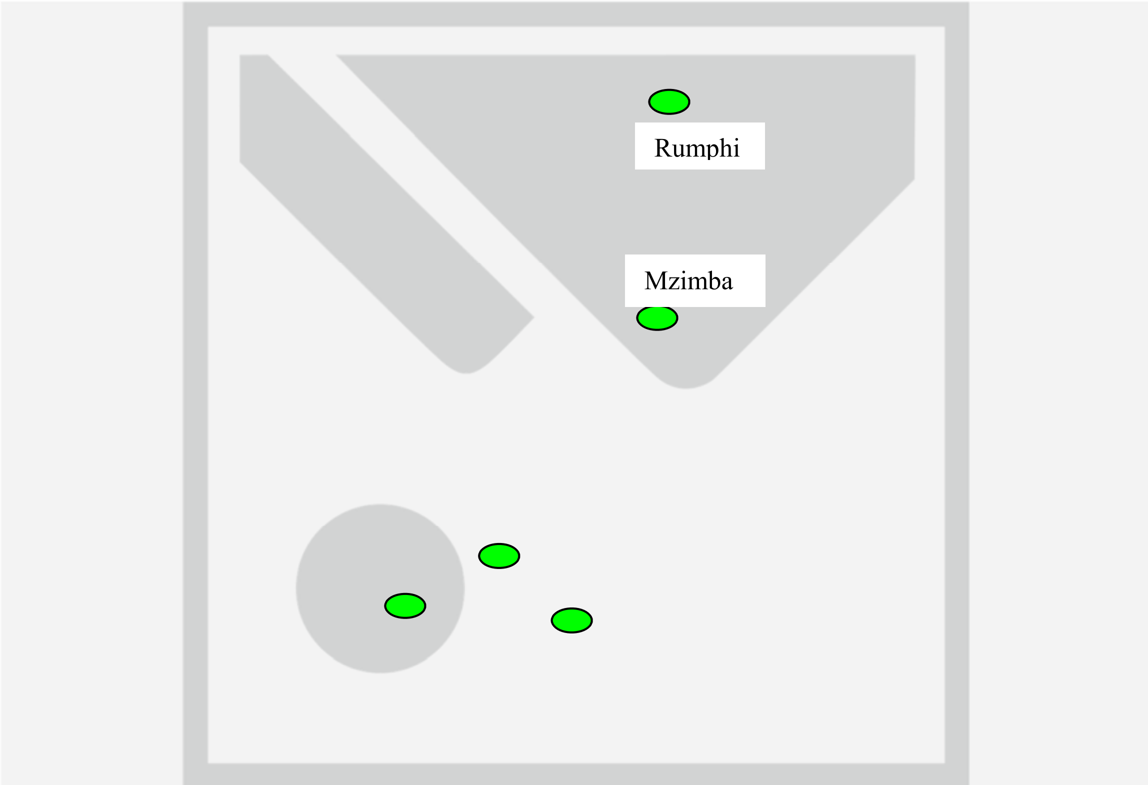


Figure 2.1 Map showing areas surveyed in Malawi and Zambia denoted with

(Map Source: http://upload.wikimedia.org/wikimedia/commons/a/a5/katete_town_location.PNG)

2.2.3 Data analysis

The qualitative and quantitative information gathered in the survey were summarized and a contingency table was drawn. The chi-square statistic was used to analyze the contingency table data in order to investigate whether any association existed on the information given by male and female based on sex, education, age and experience in vegetable production. The test also determines if a conspicuous discrepancy exists between the observed and the expected counts. A generalized linear model assuming binomial/multinomial error distribution of farmer responses was used to characterize respondents' awareness of pesticidal plants and their use of these plans for pest control. Parameters of the logit linear model were estimated using the LOGISTIC procedure of SAS (SAS, 2001).

2.3 RESULTS

2.3.1 Characteristics of respondents

Demographic characteristics of the respondents was dominated by men (>74%) in both northern Malawi and eastern Zambia (Table 2.1). The majority (>80%) of the respondents in both northern Malawi and eastern Zambia were older than 25 years of age. Over 75 % of the respondents in northern Malawi and eastern Zambia had undergone formal schooling (Table 2.1). The majority (>83%) of respondents were married, while single, widows and divorcees constituted less than 10% each in both countries (Table 2.1). Out of all the respondents in Malawi, 39.9% were the small households with less than four family members, 42.2% were of medium size with 4-6 family members and 17.9% had large family members of over six people in a family. Of the 83.6% respondents of the households in Zambia, 30.8% were medium size and 52.8% comprised of large households while the small household family only comprised of 16.4% from the total respondents. From the list, it shows that in Zambia there were larger family members per household than in Malawi (Table 2.1).

Table 2.1: Percentage of respondents according to sex, age, education and household size in northern Malawi and eastern Zambia.

Variable	**Category**	Malawi (n=168)	Zambia (n=91)
Gender	Female	25.6	16.5
	Male	74.4	83.5
Age	Young (<25 years)	17.9	12.0
	Middle (25-40 years)	48.2	44.0
	Old (>40 years)	33.9	44.0
Education	None	0.1	24.2
	Primary (up to Std 8)	64.1	57.1
	Secondary (>Std 8)	35.3	18.7
Marital	Divorce/Widow	10.1	2.2
	Married	83.3	96.7
	Single	6.6	1.1
Households	Small (<4 people)	39.9	16.4
	Medium (4-6 people)	42.2	30.8
	Large (>6 people)	17.9	52.8

A large proportion (>54%) of all respondents from Malawi had more than 5 years' experience in farming. On the other hand, the number of respondents with more than 5 years' experience was greater than those with little experience from Zambia (Table 2.2). Most of the respondents in Zambia (77.8%) owned more than 1.0 ha of land compared to those in Malawi (5.4%). Over 65% of the respondents from Malawi had less than 0.4 ha. Majority (76%) of the respondents in Malawi and Zambia had inherited land, while less than 10% had purchased or leased/rented the land (Table 2.2). Most of respondents also preferred customary land tenure in Malawi

(85%) and Zambia (60%) to renting or leasing. The data indicated that respondents were satisfied with their landholding size. About 52% (51.8%) of the respondents in Malawi appraised their landholding size as adequate for farming compared to 49.4% of the respondents in Zambia (Table 2.2).

Table 2.2: Percentage of respondents according to their experience in farming, landholding size, land tenure and preference for tenure and appraisal of their land holding size in northern Malawi and eastern Zambia

Variable	**Category**	Malawi (n=168)	Zambia (n=91)
Farming experience	Short (<10 years)	45.8	30.0
	Long (> 10 years)	54.2	70.0
Size	Small (<0.4 ha)	65.5	0
	Medium (0.4-1 ha)	29.1	22.2
	Large (>1 ha)	5.4	77.8
Land ownership	Chief	4.9	17.6
	Borrow	4.9	0
	Inherit	80.8	76.9
	Rent	7.9	2.2
	Private	0.6	3.3
Preferred tenure	Customary land (Inherited)	85.0	60.4
	Private/purchase	11.4	38.5
	Rent/lease	3.6	1.1
Landholding appraisal	Very small	20.2	18.7
	Small	28.0	31.9
	Perfect	51.8	49.4

2.3.2 Production of vegetables

Brassicas, tomatoes, onions, cucurbits and potatoes were the most commonly grown vegetables in northern Malawi and eastern Zambia (Figure 2.2). Among the brassicas, cabbage, rape and Chinese cabbage were most frequently mentioned by respondents in the study areas. Brassicas were grown by 75% of the respondents in Malawi and 85.7% of the respondents in Zambia. Brassicas constituted 34 and 44% of all vegetables grown by respondents from Malawi and Zambia (Figure 2.2). Malawian respondents reported seven varieties of cabbage, while Zambian respondents reported three varieties (Table 2.3). Out of the seven varieties of cabbage, Florida, Maracanta and Drumhead were the most frequently reported varieties in Malawi. Giant Essex was the most frequently mentioned variety of rape in both Malawi and Zambia (Table 2.3). Tomatoes were grown by 94% of the respondents in Malawi and 83% of the respondents in Zambia. The most frequently mentioned tomato varieties were Rodade and Money Maker in both Malawi and Zambia.

Table 2.3: Percentage of respondents growing different Brassica and tomato varieties in northern Malawi and eastern Zambia

Country	Brassica variety	Respondents (%)	Tomato variety	Respondents (%)
Northern Malawi (n=168)	Cabbage (Florida)	37.5	Rodade	74.3
	Cabbage (Maracanta)	21.2	Money maker	25.7
	Rape (Giant Essex)	10.6	-	-
	Cabbage (Drum head)	9.6	-	-
	Cabbage (Gloria)	8.7	-	-
	Cabbage (Mayford)	2.9	-	-
	Cabbage (Sugar loaf)	1.0	-	-
	Cabbage (Inkuqueen)	1.0	-	-
	Mustard	4.8	-	-
Eastern Zambia (n=91)	Rape (Giant Essex)	62.9	Money maker	37.5
	Rape (Hobson)	17.1	Rodade	23.2
	Rape (Choumolier)	2.9	Tengelo	17.9
	Cabbage (Drum head)	2.9	Floridade	7.2
	Cabbage (Glory)	2.9	Heinz	3.6
	Cabbage (White rob)	2.9	Recycled	3.6
			Mkushi	3.6
			Monpale	1.8

Brassicas and tomatoes were produced up to three times in a year. The majority of Malawian respondents (90.5%) while about 66% of the Zambian respondents produced brassicas twice in a year. About 51% of the Malawian and 40% of the Zambian respondents said that they produce two crops of tomatoes in a year. Over 42% of the Malawian and 24% of the Zambian respondents said that they produce three crops of tomatoes a year.

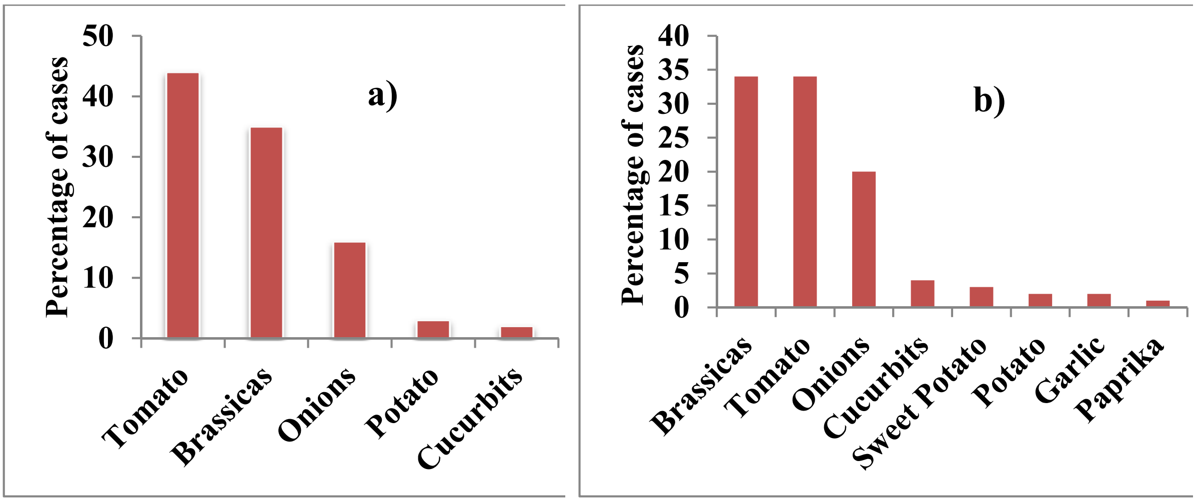


Figure 2.2: *Major vegetable crops reported by respondents in a) northern Malawi and b) eastern Zambia. Values were calculated as the percentages of all vegetable crop species reported*

2.3.3 Experience of pest damage to brassicas and tomatoes

All of the respondents in Malawi and Zambia reported that they experienced pest damage on brassicas and tomatoes. The major pests of brassicas reported by respondents were aphids *Brevicorynae brassicae*, the diamond back moth *Plutella xylostella*, cutworms *Agrotis ipsilon*, webworms *Hellula undalis*, grasshoppers and beetles in Malawi and Zambia (Figure 2.3). Red spider mites *Tetranychus evansi*, aphids *Brevicorynae brassicae*, bollworms *Heliothis armigera* and cutworms *Agrotis ipsilon* were commonly associated pest problems of tomato (Figure 2.3). The other minor pests in tomato production included striped blister beetles *Epicauta albovittata*, leafminers *Liriomyza bryoniae* and variegated grasshopper *Zonocerus variegatus*.

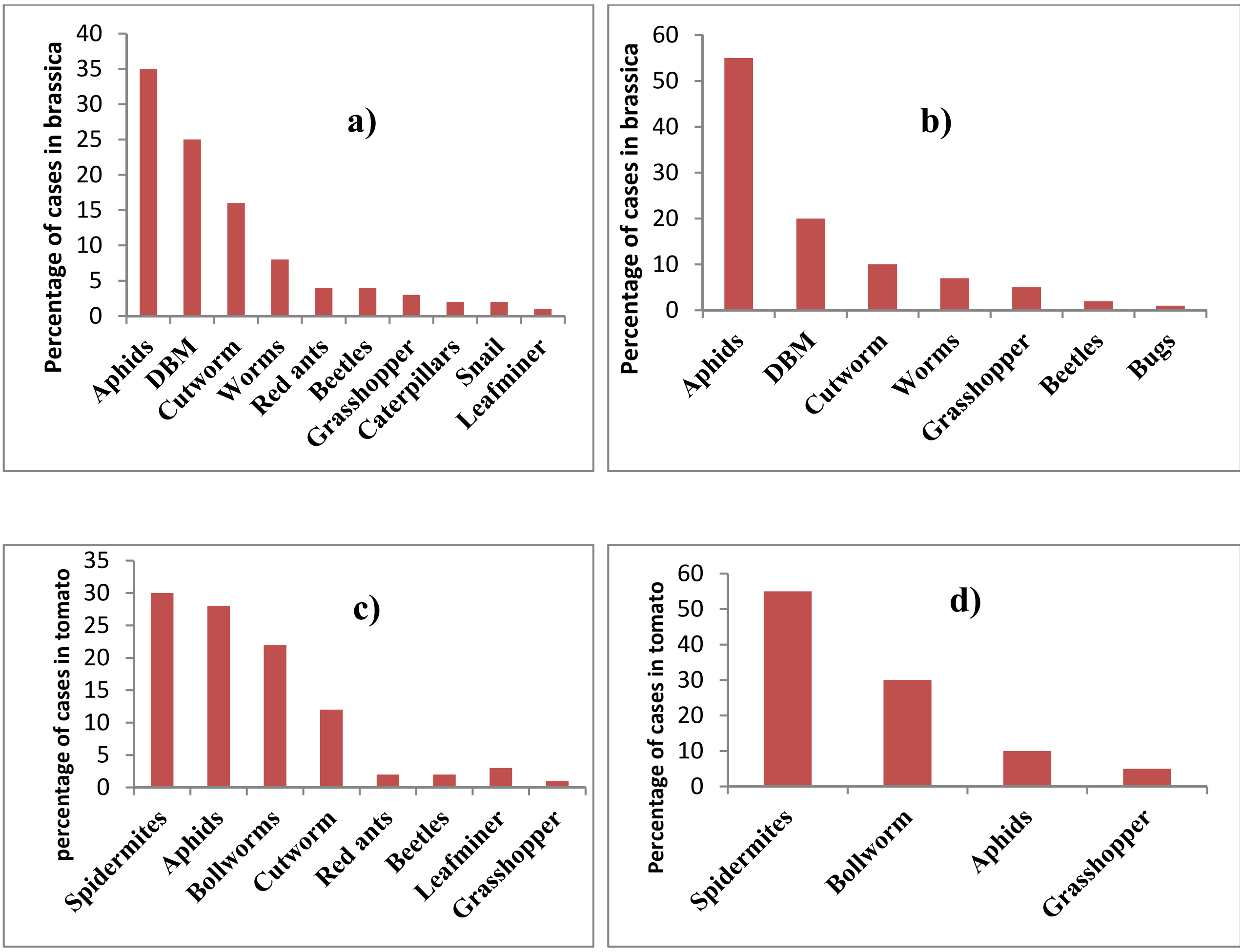
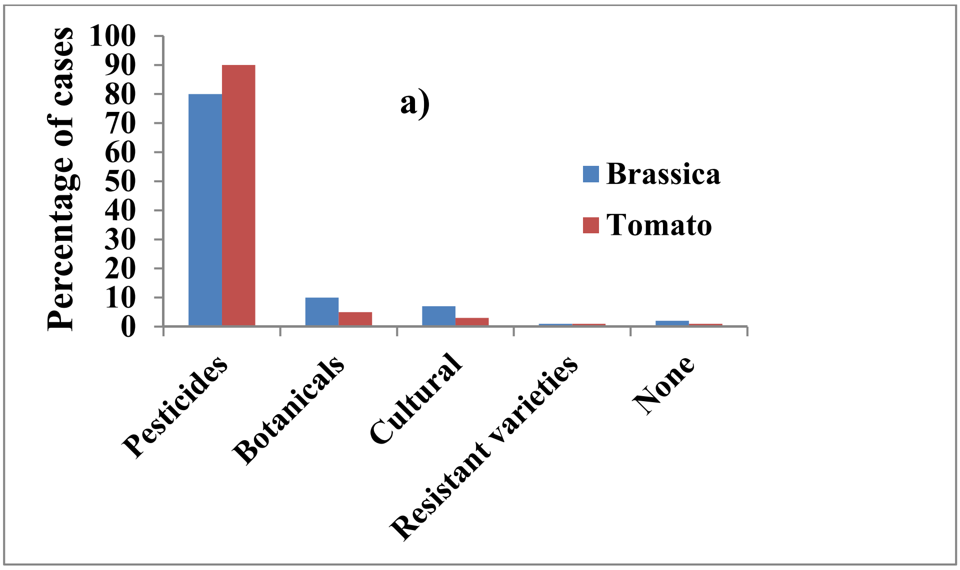


Figure 2.3: *Major pests of brassicas and tomato reported by survey respondents in Malawi (a & c) and Zambia (b & d). Values were calculated as the percentages of all insect pest species mentioned by the respondents*

2.3.4 Farmers' pest management practices and knowledge of pesticidal plants

Majority of farmers take control measures for the vegetables they cultivate. Over 75% of the respondents in Zambia and Malawi had used pesticides to control pests of brassicas and tomatoes (Figure 2.4). Many farmers applied insecticides recommended for control of cotton pests. The most hazardous pesticides were being sold in difficult and less commonly used trade names to the farmers (Appendix 2.1, 2.2 and 2.3). This was common in Zambia where one product could be named differently from farmer to farmer. Cultural practices, use of botanicals (pesticidal plants) and resistant varieties constituted a smaller portion of the pest control in both brassicas and tomato crops. Cultural practices mainly involved hand picking and destroying visible insects.



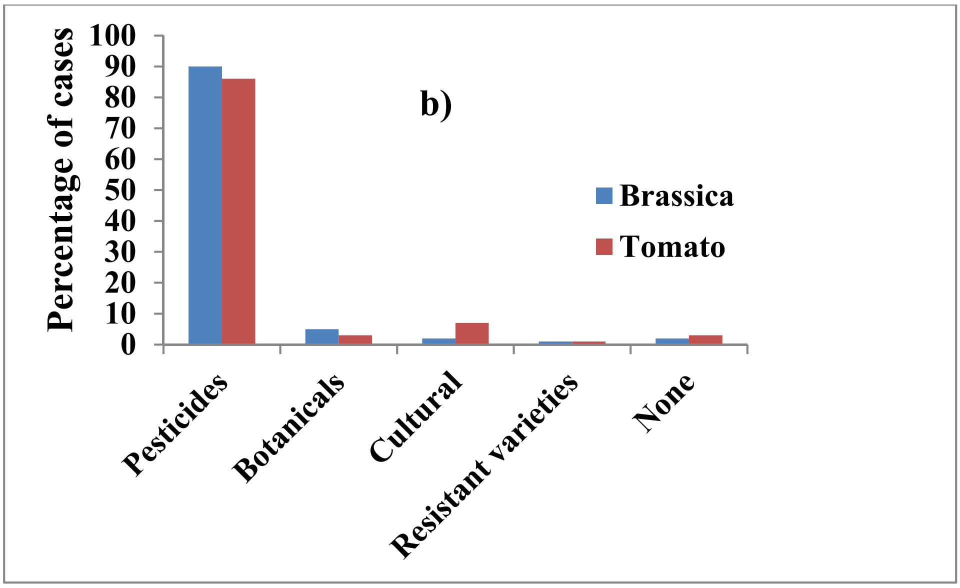
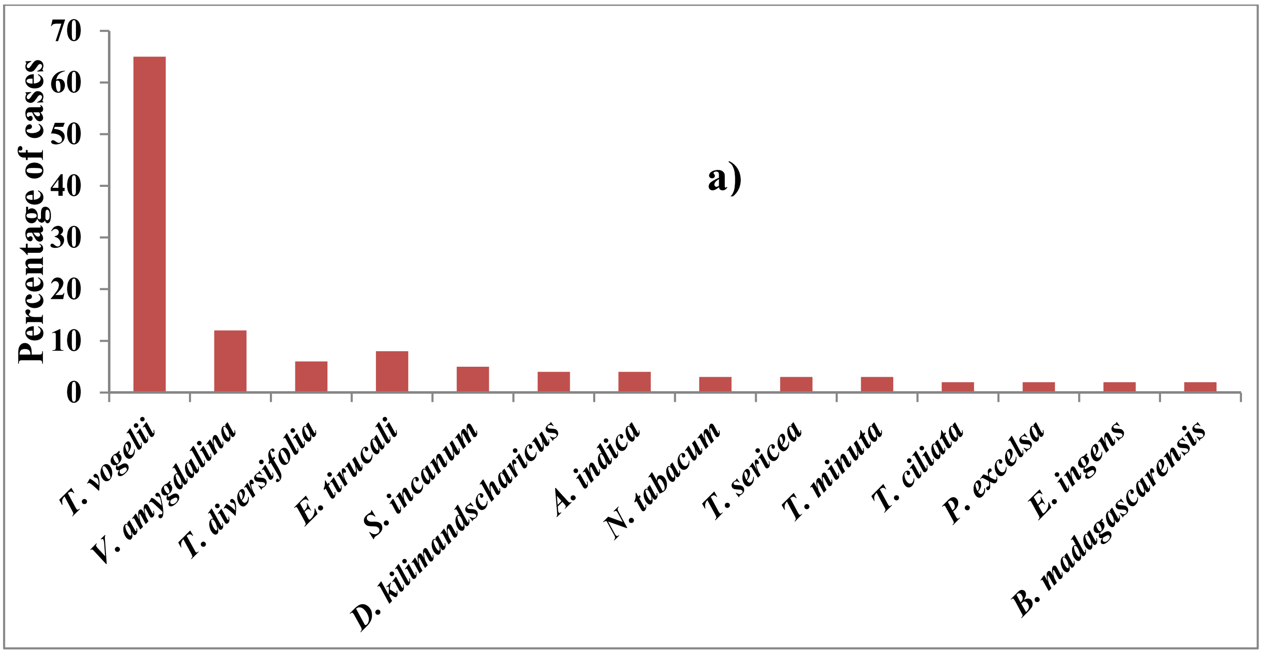


Figure 2.4: Control measures reported by respondents in a) Malawi and b) Zambia. Values were calculated as the percentages of all control measures reported by the respondents

In order to determine farmers' knowledge of pesticidal plants, farmers were asked about the pesticidal plant species they were aware of. Respondents in Malawi reported fourteen different pesticidal plants while Zambia respondents reported four pesticidal plants (Fig. 2.5). Results of the survey indicated that pesticidal plants are playing a significant role in vegetable pest management in the two study countries. Many pesticidal plants could be documented if the study was continued to cover a wider vegetable farming areas. The pesticidal plants reported included *Tephrosia vogelii* Hook f., Neem (*Azadirachta indica* A. Juss), *Mucuna pruriens* L, *Bobgunnia madagascariensis* (syn. *Swartzia madagascariensis*) Dev, *Euphorbia tirucali* L, *Vernonia amygdalina* Del, *Tithonia diversifolia* A. Grey, *Solanum panduriforme* L and tobacco *Nicotiana tabacum* L (Table 2.4) where the values were calculated as the percentages of all species reported by the respondents. This was done to enable listing of priority species for further studies. The fact that most of the pesticidal plants reported in the two study areas were common is a clear indication of their common use and abundance amongst vegetable farmers in the study areas.



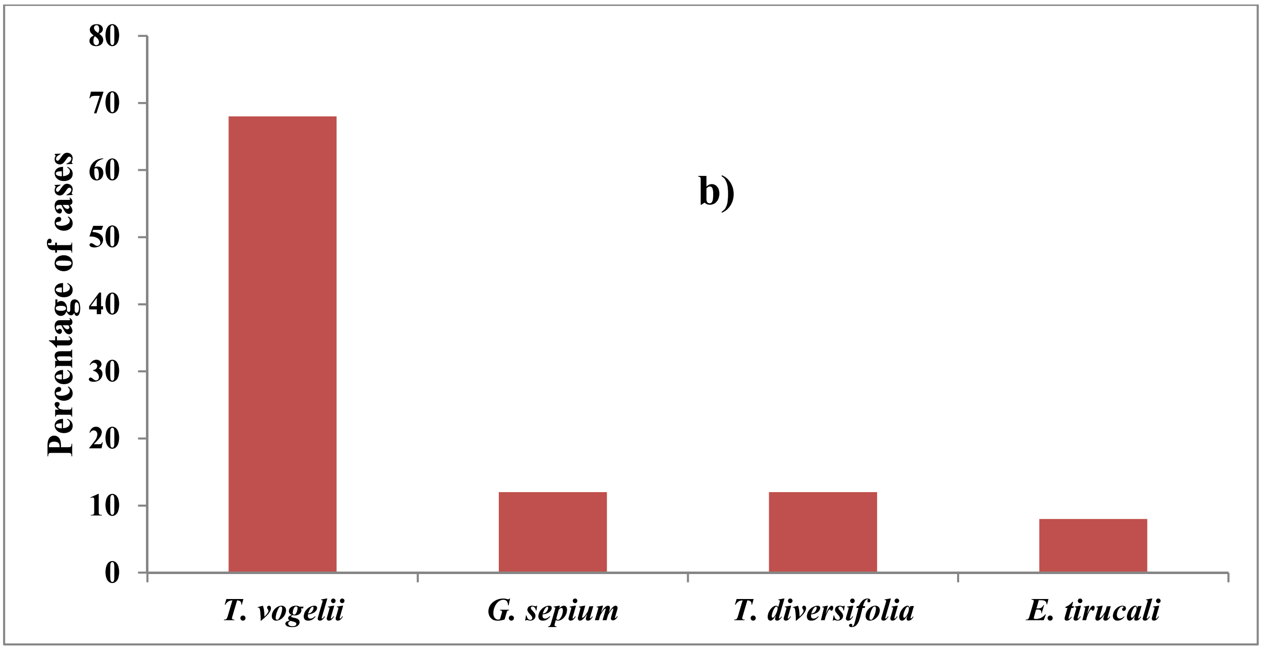


Figure 2.5: Pesticidal plants used by respondents in a) Malawi and b) Zambia. Values were calculated as the percentages of all species reported by the respondents.

Accordingly, *T. vogelii* accounted for 60.7% in Malawi and 53.4% of the species known to the respondents as pesticidal plants (Table 2.4). Some 87.6% of the respondents in Zambia have heard about *T. vogelii*. However, only 13.2% of the respondents had actually used it for pest control. In Malawi, 79.3% of the respondents have heard about *T. vogelii*, and 67.5% had used it for pest control. The species used by respondents in Zambia and Malawi are presented in Figure 4 according to the frequency of mention by respondents. The values were calculated as the percentages of all species used by the respondents. *T. vogelii i* accounted for 66.7% of the species used in Zambia and 63.3% in Malawi (Figure 2.5) was the number one species followed by *Tithonia diversifolia*, *Vernonia amagdalyna*, *Euphorbia tirucali*, *Azadirachta indica* and numerous other species that are yet to be identified.

Table 2.4: Proportion of Zambian and Malawian respondents that know or have heard about specific pesticidal plant use.

Botanical name	**Local name** (s)	**Zambia** (%)	**Malawi** (%)
Tephrosia vogelii Hook f.	Ububa, Mtetezga, Gulinga,	60.7	53.40
Vernonia amygdalina Del.	Soyo, Mluluzga, Futsa	NM	10.20
Tithonia diversifolia A. Grey	Belibeli, Heji	3.3	7.14
Euphorbia tirucali L.	Nkadze, Nkhadzi, Mduzi	3.3	6.80
Solanum incanum L.	Nthula, Nthuma	NM	4.76
Azadirachta indica A. Juss	Neem, Nimu	5.0	2.72
Bobgunnia madagascarensis Dev	Mulundu, Ndale, Kasokosoko	3.3	2.72
Mucuna pruriens L	Chitedze	5.0	NM
Sesbania sesban (L.) Merr	Jerejere	3.3	NM
Euphorbia ingens E.Mey	Mlangale	NM	2.04
Terminalia sericea Wight & Arn.	Mjoyi	NM	2.04
Dolichos kilimandscharicus Taub	Dema, Dindya	NM	1.70
Nicotiana tabacum L.	Tobacco, Fodya, Hona	1.7	1.70
Toona ciliata M. Roem	Senderera	1.0	1.36
Allium cepa L	Onion, Anyezi, Hanyezi	1.7	NM
Capsicum annuum L	Pepper, Sabola, Tsobola	1.7	NM
Aloe vera L.	Chinthembwe	NM	0.34
Cassia abbreviata Oliv.	Mubabani	NM	0.34
Cussonia paniculata Eckl & Zeyh	Chibwabwa	NM	0.34
Allium sativum L	Garlic, Adyo	NM	0.34
Lantana camara L	Maluwa	NM	0.34
Parinari excelsa	Mwambula, Mbula, Muula	NM	0.34
Erythrophleum suaveolens Brenan	Mwayi, Mwavi	NM	0.34
Agave sisaliana Perrine	Sisal, Kholokoto, Khonje	NM	0.34
Tagetes minuta L	Welensky, Marigold	NM	0.34

NM= Not Mentioned

Awareness of pesticidal plants varied significantly only with the educational level of respondents (Table 2.5). The majority of respondents with secondary education (88.0%) and primary education (77.4%) said they heard about pesticidal plants. On the other hand 48% of those without education said they heard about pesticidal plants. The significant determinants of use of pesticidal plants were gender ($\chi^2 = 6.0$, P = 0.014), education ($\chi^2 = 10.3$, P = 0.006) and land holding size ($\chi^2 = 15.9$, P = 0.004) (Table 2.5).

Table 2.5: Logit-linear model results on determinants of farmers' knowledge and use of pesticidal plants in northern Malawi and eastern Zambia

	Parameter	Category	Estimate	Standard error	Wald Chi-Square	Probability
Northern Malawi	Gender	Male	-1.12	0.23	24.82	<0.0001
		Female	0.02	0.19	0.01	0.9341
	Education	None	1.08	0.31	11.84	0.0006
		Primary	-0.19	0.22	0.69	0.4057
	Experience	Long	0.29	0.17	2.95	0.0857
Eastern Zambia	Gender	Male	0.16	0.39	0.16	0.6854
		Female	-0.57	0.23	5.96	0.0146
	Education	None	2.00	0.75	7.08	0.0078
		Primary	-0.65	0.40	2.60	0.1068
	Experience	Long	0.07	0.18	0.17	0.6805
	Household size	Large	0.10	0.25	0.15	0.6985
		Medium	-0.05	0.23	0.04	0.8355
	Landholding size	Large	0.84	0.26	10.05	0.0015
		Medium	0.03	0.23	0.01	0.9049

Farmers with small landholdings were more inclined to use pesticidal plants than those with medium and large holdings. About 88% of respondents with small landholdings had used pesticidal plants while 78% of those with large landholdings said they have not used pesticidal plants suggesting their use is largely the practice of the poorest and least well-resourced farmers. Table 2.5 shows the significant predictors in the logit-linear model relating knowledge and use of pesticidal plants. Respondent's knowledge was described by models with gender, education level and farming experience Respondent's use of pesticidal plants was adequately described by a model with gender, education level, farming experience, household size and landholding size that gave 76.8% correct classification (20% discordant). Significant use of the pesticidal plants for vegetable pest management in the study areas also shows that most farmers' could easily source the plant materials in the study areas.

Relatively higher numbers of plants were reported in the two countries, which still is predominantly small-scale farming community with abundant source of labour. Almost half of the respondents have heard of pesticidal plants used for vegetable pest management. *Tephrosia vogelii* has been used by 30% and many of the farmers are willing to cultivate some of the pesticidal plants. The fact that nearly half of the farmers use pesticidal plants becomes more applicable indicating that small land owners could afford cheap farm labour to effectively make them self-sufficient in supplying adequate labour. Pesticidal plant use could be labour intensive during collection, processing and application in the field.

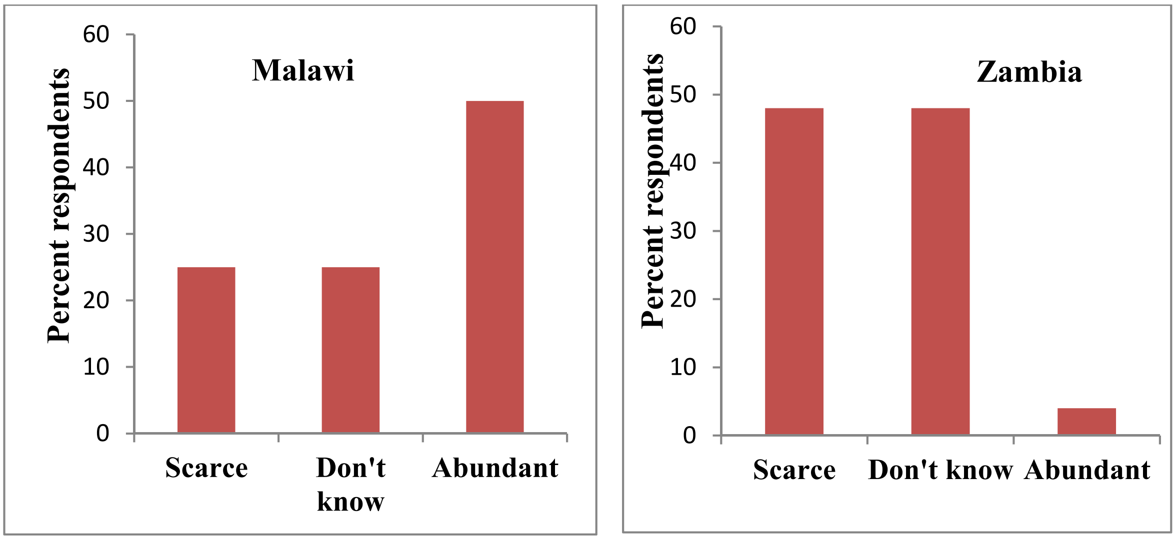


Figure 2.6: Perception of availability of pesticidal plants among Malawian and Zambian respondents

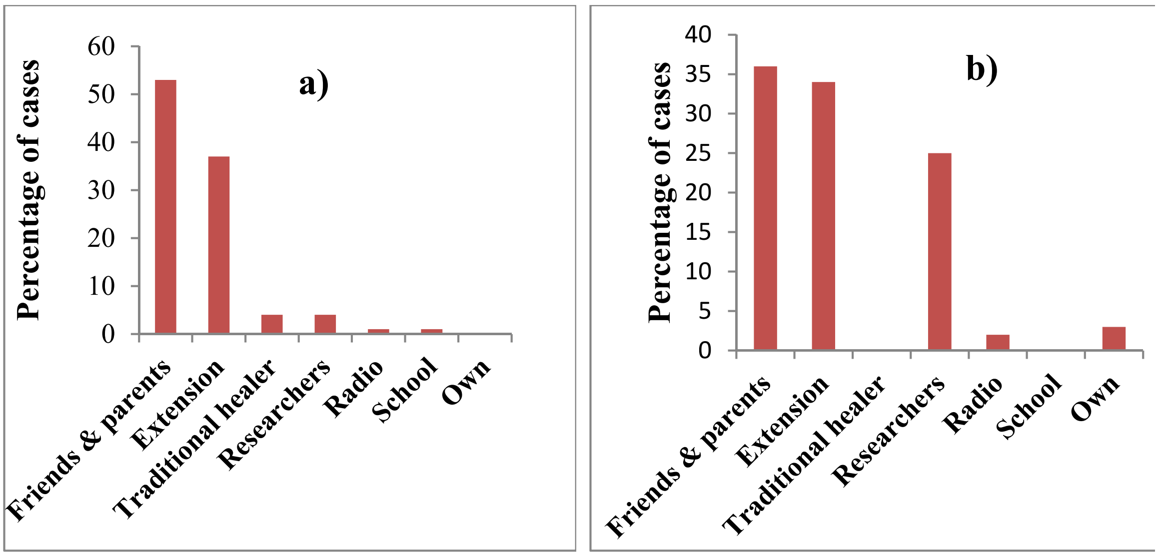
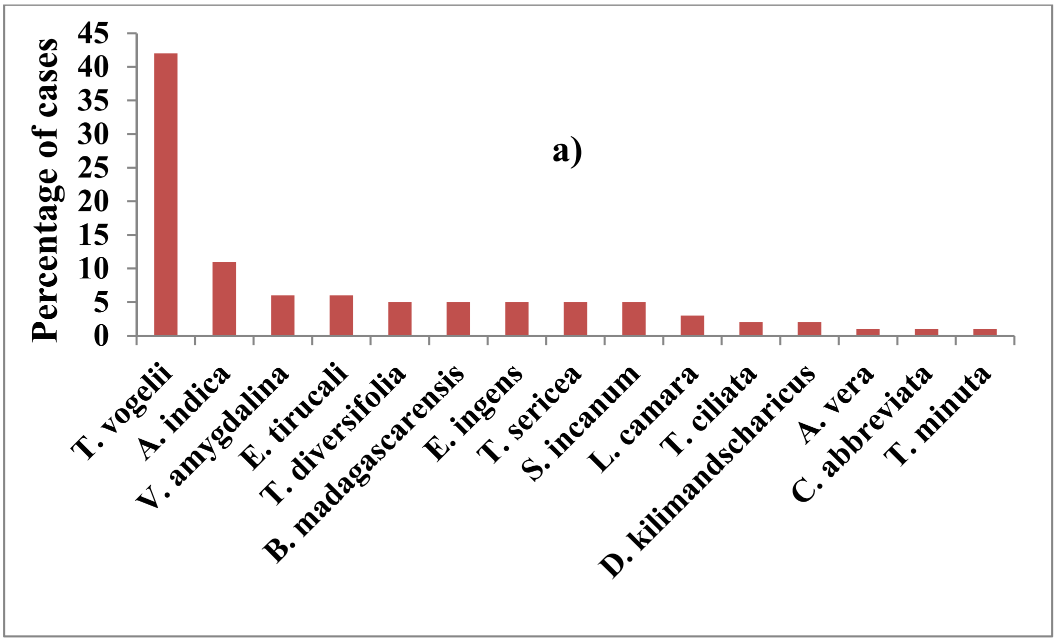


Figure 2.7: Source of information on pesticidal plants in a) Malawi and b) Zambia. Values were calculated as the percentages of all information sources reported by the respondents

2.3.5 Farmers' perception of Pesticidal Plants, their availability and conservation

About 51% of respondents in Malawi believed that pesticidal plants were abundant, while 47% in Zambia thought pesticidal plants were scarce (Figure 2.6). In both Zambia and Malawi, friends and parents were the major sources of information on pesticidal plants (Figure 2.7). The second major sources were researchers and extension staff, in Zambia and Malawi, respectively. Education and radio contributed least to farmers' knowledge in both countries. This suggests that probably pesticidal plants are not in the primary syllabi and that either most farmers did not own radio or those that had the radio were not listening from agricultural programmes. Some respondents from eastern Zambia were willing to plant *T. vogelii, A. indica, E. tirucali, B. madagascarensis, T. diversifolia* or any other pesticidal plant; while Malawian respondents more frequently said they were willing to plant some plant species such as *T. vogelii*, *A. indica, V. amygdalina, E. tirucali, B. madagascarensis, E. ingens, T. sericea and* others (Figure 2.8). Farmers' perception of pesticidal plants is very relevant for the development of the research project. It provides the basis for validating the commonly used plant materials for pest management. Farmers' perceptions of insect pests and their control are important in quickly adopting pesticidal plants for insect pest management. Generally, farmers easily believe and adopt use of pesticidal plants because the technology has been passed on from their ancestral parents.



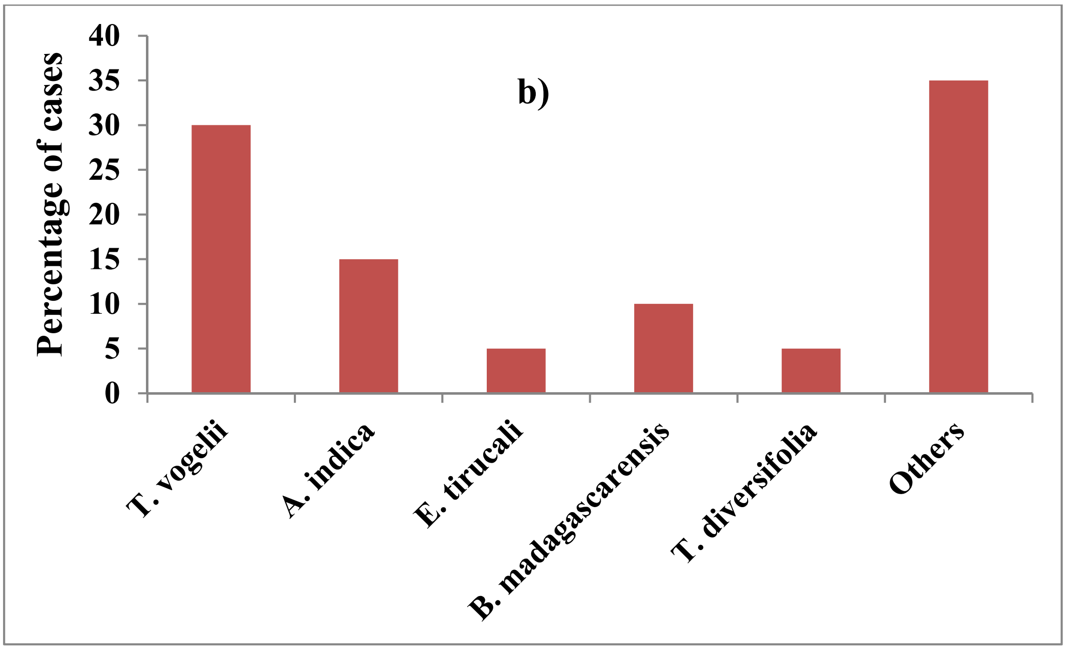


Figure 2.8: Pesticidal plants that respondents are willing to plant in a) Malawi and b) Zambia. Values were calculated as percentages of all pesticidal plant species reported by the respondents

2.4 DISCUSSION

2.4.1 Major vegetables and their pests

This study has established that brassicas and tomatoes are the most important and abundantly grown vegetables in northern Malawi and eastern Zambia. It has also established that invertebrate pests, mainly the red spider mite (RSM) and the diamond back moth (DBM) and aphids are the major constraints to production of tomatoes and brassicas, respectively. Likewise other authors (Mingochi et al., 1995; Kibata 1996) have identified that DBM and aphids (*Brevicoryne brassicae* L, *Lipaphis erysimi* Davis and *Myzus persicae* Sulzer) as the most damaging in most parts of eastern and southern Africa on brassica crops. If young seedlings are damaged they branch profusely and later fail to develop into normal sized heads thereby reducing the marketable yield (Kuntashula et al., 2006).

2.4.2 Pesticide use

The study has shown that the majority of the farmers in the two regions depend on the use of insecticides to control vegetable pests. Most of these pesticides are potent nerve poisons to humans and animals and intensive usage poses potential hazards to the environment and human health (Chambers et al., 2001). However, DBM, *Plutella xylostella* has developed resistance to most of the available synthetic insecticides (Isman, 2008; Ogendo et al., 2008). Furthermore, Palikhe, (2002) outlined some of these detrimental effects to human health, environment and natural enemies especially those in classes I and II. As such, their recommendation should be limited for occupational exposure which has mostly been adopted by national authorities. This is in agreement with reports from elsewhere in Malawi and Zambia. For example, farmers in southern Malawi applied up to 19 sprays to tomato and 14 to cabbage in the wetlands (Orr and Ritchie 2004). The fact that farmers applied insecticides not recommended for vegetable pest control indicates their desperation and indiscriminate use of pesticides and perhaps points to poor information provision by commercial stakeholders. Besides their environmental and health effects, insecticides are becoming increasingly uneconomical to achieve effective control where adulterated products are used particularly where used incorrectly (Rates, 2001).

Table 2.6: Some of the frequently used synthetic pesticides for pest management recorded from agrodealer shops in Malawi

Common Name/Trade Name	Active ingredient	Formulation	Pests
Karate	cyhalothrin	EC	Bollworms, Aphids
Malathion	malathion	EC	Armyworms
Decitab		EC	Aphids, Bollworms
Cymbush/Ripcord	cypermethrin	EC	Cutworms, Aphids
Phoskil/Azodrin	monocrotophos	EC	Mites
Dursban	chlorpyrifos	EC	Termites
Rogor	dimethoate	EC and WP	aphids
Deltamethrin	deltamethrin	EC	Aphids
Abamectin-plus	abamectin	EC	Aphids
Fenthion	fenthion	EC	Armyworms
Seven	carbaryl	EC and WP	Aphids
Regent	fipronil	EC	Beetles
Ambush	permethrin	EC	Grasshoppers
Mitac/Amitraz	amitraz	EC	Mites, Ticks
Pyrethrin	pyrethrin	EC	Aphids, Bollworms
Super Shumba	pirimyphos methyl	EC	Larger grain borer
Actellic Super	pirimyphos methyl	WP and EC	Weevils
Furadan/Carbofuran	carbofuran	GR	Termites, Cutworms
Thiodan	endosulfan	EC	Mites, Termites, Aphids

2.4.3 Commonly used Pesticidal plants in study area

Most of the plant species reported in the study area have also been known to be used by farmers elsewhere (Mugisha-Kamatenesi et al., 2008). Among the plants commonly used by Malawian and Zambian farmers were *Tephrosia vogelii*, *Tithonia diversifolia*, *Vernonia amygdalina* and *Euphorbia tirucali*. Farmers apply leaf concoctions of *Tephrosia vogelii*, *Tithonia diversifolia*, *Vernonia amygdalina*, *Euphorbia tirucalii* and neem to control field pests in various crops. As for *B. madagascariensis* farmers mostly used crushed dried pods/fruits. *T. vogelii* was most used and farmers seemed to know about it in both regions. This is also consistent with findings from other studies in Zambia (Karlsson, 1995; Kuntashula et al., 2006) and other parts of Africa (Mugisha-Kamatenesi et al., 2008; Sileshi et al., 2008). Therefore, promotion of this species as a pesticidal plant may require less additional investment in terms of farmer training compared to less familiar species. This also suggests that much effort has already been exerted to popularize the use of *T. vogelii*. Earlier studies have also revealed that the scope for improving soil fertility include hedge row intercropping and relay intercropping of legumes such as *T. vogelii* to improve maize production (Snapp et al. 2002; Sileshi and Katanga, 2002).

2.4.4 Limitations for farmer adoption of pesticidal plants

Despite the importance of pesticidal plants, the study indicated that majority of respondents inherited customary land. This is probably because the existing land user-rights of customary land were within a private property regime, and provided smallholder farmers much freedom in land utilization. Initial appropriation of customary land both in Malawi and Zambia is often undertaken through treaties with local chiefs who allocate land as per customary law. According to Adams *et al*. (2000), land tenure is defined as terms and conditions under which land is held, used and transacted. Shackleton, (1996) argues that one of the most important components of any land use need to be carefully considered if improved incomes and local economic development are desired. Farming system can influence what crops a farmer can grow, how long a particular piece of land can be tilled, the rights over the fruits of his labour and his ability to undertake long-term improvements on the land. Land tenure may be essential to manage land resources, invest in the land and use it sustainably. If land tenure is responsibly followed, land owners (in this case farmers) may be encouraged to invest on their pieces of land and eventually be inspired to economically develop (Matchaya, 2009). Therefore, how land is owned has been cited as one of the factors that could affect planting of trees even if farmers may be willing to grow pesticidal plants. Some of limiting factors in replanting trees or shrubs on farmers' fields that could be used in managing pests' include:

- Collecting seed material for establishment of new orchards can be labour intensive.
- No deliberate policies to promote and regulate use of pesticidal plants
- Limited commercial seed production and distribution amongst communities.
- Limitation in managing or cultivating perennial crops amongst poor resource farmers.
- Limited registration procedures for indigenous pest management technologies such as use of pesticidal plants

Commercial seed production and distribution can be limiting in most societies. These factors can only be minimized by formalizing production, marketing and use of the pesticidal plants. Thus, there is need to have friendly registration procedures, sustainable forest management, propagation and cultivation of pesticidal plants that could traditionally facilitate their regular use and regulate marketing to ensure long term conservation and sustainable use of pesticidal plants. Hence greater emphasis is needed on promoting community-based seed collection, production and distribution through a range of partners: farmer groups, individual seed producers and private nurseries. However, collection of plant materials can be encouraged from the already naturally occurring plants for pest control in preference to promoting its cultivation.

For instance, *Tithonia diversifolia* has been widely used for soil fertility improvement and it is easily accessible to most farmers as it is aggressively invasive and found in most parts of eastern and southern Africa. At present it has been declared as a Category I weed in South Africa, and its planting is restricted (Henderson, 2001). *Tithonia* can colonize farmlands quickly and if uncontrolled it can become a weed in crop fields and thereby increase labour for weeding. Its ecological impacts include, competing with indigenous species, obstructing access to riverbanks and dense stands along road verges obstruct motorists' vision. This plant species also threatens natural biodiversity and often out-competes the indigenous vegetation. Similarly, in Malawi it invades savanna, grassland, roadsides, and riverbanks mainly at low altitudes. Invasions of non-indigenous species into natural communities are currently rated as one of the most important threats to biodiversity. Invasive species may also have impacts on pollinators, particularly if the compounds that exert invertebrate toxicity also occur in the floral food resource i.e. pollen and nectar (Adler, 2000). Therefore, planting of this species on farm land is not recommended.

2.5 CONCLUSION

The survey has revealed that smallholder farmers have a substantial knowledge of pesticidal plants used in vegetable pest control, notably *T. vogelii, V. amygdalina*, *T. diversifolia* and *A. indica.* It indicates that there is a growing interest in the use of pesticidal plants for vegetable pest control. The study has shown that *T. vogelii* ranks highly amongst Zambian and Malawian farmers.

Overall, this study has highlighted the need to support specific research in pesticidal plants for pest control. Although pesticidal plants are talked about highly for pest management among small holder farmers, there is no clear validation of their efficacy against the claimed pests. The study forms the basis for selecting commonly used and widely familiar pesticidal plants for evaluation in order to validate their efficacy on farmers' fields and in the laboratory. Thus there is need to thoroughly study these plant materials before advocating large scale propagation and commercialisation. Resource poor farmers would also need some modern knowledge in cultivation, naming of plant materials and propagation of the pesticidal plants in order to facilitate long-term use in pest control. Furthermore, research is required for comparing pesticidal plant establishment in various localities before advocating for producing and distributing materials as location may affect their efficacy. Training of farmers and extension advisors on pesticidal plant use could ensure that farmers carefully use plant materials for pest control. Proper use of land may assist farmers produce more pesticidal plants on their pieces of land that may be used for pest control. Thus, further analysis is needed to treat each case individually, before these pesticidal plants are promoted for pest management in other areas.

CHAPTER 3 PARTICIPATORY FIELD EVALUATION OF SELECTED PESTICIDAL PLANTS FOR MANAGEMENT OF VEGETABLE PESTS IN MALAWI

3.1 INTRODUCTION

Tomato and rape are widely used as food for human consumption in various forms. However, their production has been constrained by various insect pest attacks (Mathews et al., 1974; Anonymous, 2004; Kuntashula et al., 2006; Valantin-Morisona et al., 2007). Main pest attack in tomato includes red mites that cause serious damage and reduction in yield. Red mites are most serious during dry season in eastern and southern Africa (Knapp et al., 2003). Generally, several synthetic pesticides are used against red mites even though most of them have limitations. They are expensive, present a high risk for worker exposure, environment and are detrimental to natural enemies (Macharia et al., 2005; Ntow et al., 2006).

Results from chapter 2 showed that pesticidal plants are known among vegetable producers as alternative pest management options to synthetic pesticides. However, the effects of these plant species have not been validated for any meaningful and practical application by the smallholder farmers on the invertebrate species they identified as their key vegetable pests. The survey was carried out to establish the utility of pesticidal plants in eastern Zambia and northern Malawi. The study established that more than 20 plant species such as *Tephrosia vogelii, Azadirachta indica, Tagetes minuta*, *Tithonia diversifolia* and others are used as pesticidal plants in this region. In view of this, it was considered appropriate to evaluate and validate the biological efficacy of five pesticidal plants against tomato red mites (*T. evansi*) and aphids (*B. brevicoryne*) under field conditions. The study was specifically carried out in order to (i) determine the effect of pesticidal plant extracts on tomato red mites, aphids and diamond back moth counts in tomatoes and rape (ii) assess the relative efficacy of some selected pesticidal plants on tomato and rape yield based on amount of fruits and leaves (iii) screen and rank the relative effectiveness of pesticidal plants for vegetable pest control.

3.2 MATERIALS AND METHODS

3.2.1 Experimental Field Sites

Participatory farmer field experiments were conducted for two seasons from August to November during 2008/09 and 2009/2010 at Jenda and Nchenachena in Malawi. These two Extension Planning Areas in Mzimba and Rumphi districts were selected based on their high vegetable production including tomato and rape under the Mzuzu Agricultural Development Division. Jenda lies at 1404 m above sea level on southing and easting 12º 22.19', and 33 º 87', respectively, and mostly dry with rainfall ranging from 600-1000mm annually. Nchenachena falls at an altitude of 1213 m above sea level on southing 10º 45' and easting 34º 02' mostly cool with high rainfall (1000-1200mm). Nchenachena is rich in rivers that flow all year round and contribute greatly to irrigate crops in the area. Furthermore, Rumphi district is small with the lowest population density of 35 people per square kilometre, while Mzimba district, which is considered the largest district, has more farming area. This makes it possible for Mzimba farmers to own and cultivate slightly larger farms than in Rumphi.

3.2.2 Preparation of plant extracts

Preparation of botanical extracts: *Vernonia amygdalina*, *Tephrosia vogelii, Tithonia diversifolia* leaves, and *Solanum panduriforme* fruits were collected from within the study area except for *Azadirachta indica*, which is restricted to southern part of the country. The plant materials were then shade dried (Fig.3.1) coarsely ground and soaked in water at room temperature and a 4% plant extract formulation was prepared. The formulation was arrived at through calculation of the amount of materials that farmers used to prepare the extracts for use in their fields. Hence, in all cases, 200 grams of dried plant material (*Vernonia amygdalina*, *Tephrosia vogelii, Azadirachta indica, Tithonia diversifolia* leaves, and dried *Solanum panduriforme* fruits) were ground, sieved and mixed separately in 5 litres of water with the addition of sunlight dishwashing liquid (Product of Unilever, South African Private Limited) as a sticker. The aqueous plant material was then vigorously stirred and allowed to stand for 12 hours. The plant extract samples were then filtered through a cotton cloth and the filtrate was later sprayed to plants using a knapsack sprayer (Sileshi, 2006) during the experimental period. Knapsack sprayers were chosen since they are relatively easy to use and are used effectively for spraying synthetic pesticides at small holder level (Matthews, 1992) so are a familiar tool for farmers. Monocrotophos (Phoskil) and dimethoate an organophosphate insecticide with 10ml dissolved in the ten litres of water and sprayed as positive control for tomatoes and rape, respectively.

Figure 3.1: Pesticidal plant materials (Neem) being dried under shade at Kasinthula Research Station

3.2.3 Experimental design

The field trials to evaluate the toxicity level were conducted on tomato and rape vegetable crops under smallholder farmers at Jenda and Nchenachena in Malawi. The experimental trial was laid out in a complete randomized block design with seven treatments, each replicated four times. The treatments included *Vernonia amygdalina*, *Azadirachta indica*, *Tephrosia vogelii*, *Tithonia diversifolia*, *Solanum panduriforme*, Monocrotophos (Phoskil) and an untreated control. These plant materials were selected based on their known ethnobotanical use in vegetable pest management and on easy availability (chapter 2). Each plot measured 5 x 2 m with a one metre path separating the plots. Tomato (cv. Rodade) and Rape (cv Giant Essex) were transplanted into the raised beds at 0.6 m and 0.5 m between plants, respectively. Plants were irrigated using buckets and water canes. Agronomic practices were kept constant on all farms with close monitoring from the research team.

3.2.4 Insect pests sampling and damage assessment

Ten plants were randomly selected and tagged from each plot for the assessment of insect pest abundance using actual insect counts on each plant on a fortnightly basis just before spraying. At harvest, tomato fruit and rape leaf damage were determined for insect pest damage using a three score category where 1= no damage, 2= moderate damage and 3= severe damage (Adapted from Sutherland et al., 1996 and Wosula et al., 2005). Farmers were asked to rank the most preferred treatment during the vegetative growing season of the crop and at harvest in order of effectiveness. All farmers then scored each treatment on selected criteria that were determined by a group of six farmers in each area.

Figure 3.2: Observation of pests in rape vegetable at Nchenachena on 15th September, 2009

3.2.5 Statistical data analysis

The number of insect pests (mites, aphids and diamond back moths), plant damage and yield were subjected to a one way analysis of variance (ANOVA) after checking the validity of assumptions underlying this analysis, using Genstat 12th edition statistical computer package. Following any significant differences between treatments, all means were then separated accepting least significant difference (LSD) at $P<0.05$. All graphic presentations were carried out using Microsoft office Excel windows 7.

3.3 RESULTS

Mean red spider mite and aphid counts varied between the two sites of Jenda and Nchenachena with Jenda displaying higher pest infestation. The botanical treatments of *T. vogelii, V. amygdalina*, *T. diversifolia, S. panduriforme* and *A. indica* showed significant effects (*P*<0.001) on the abundance of red spider mites and aphids at Jenda (Table 3.1) compared to the control. However, the lowest number of red spider mites and aphids were recorded on the plot sprayed with the conventional pesticide, phoskil.

Table 3.1: Mean numbers of red spider mites and aphids in tomatoes for Season 1 trials at Jenda, Malawi

Treatments	Red spider mites	Aphids
Tithonia diversifolia	31.0± 3.58b	6.75±1.03 b
Azadirachta indica	31.2±6.37b	7.00±1.08b
Tephrosia vogelii	35.8±3.97bc	8.75± 0.48b
Solanum panduriforme	37.0± 2.86bc	8.25±1.55b
Vernonia amygdalina	31.5± 4.34b	7.00±0.71b
Phoskil	11.8±3.84a	1.5±0.29a
Unsprayed	51.0± 8.07c	12.5 ±2.53c
Mean	**32.7**	**7.39**
Sed	**6.33**	**1.649**
CV (%)	**27.4**	**31.5**
Significance	***	***

Means within the same column followed by the same letter are not significantly different from control (*P*< 0.05)

The pesticidal plants were less effective at reducing the population of red spider mites and a similar outcome followed with aphids in season 2 (Table 3.2). However, the results indicated that all the plots treated with pesticidal plants recorded reduced numbers of red mites and aphids compared to the unsprayed plots throughout the spraying periods of study. Overall, the number of red spider mites and aphids was lower in the phoskil treated plots. It was also observed that none of the plant materials exhibited any phytotoxic effect on the sprayed plants throughout the spraying period.

Table 3.2: Mean numbers of tomato red mites and aphids in tomatoes for Season 2 at Jenda, Malawi

Treatments	Red spider mites	Aphids
T. diversifolia	186±42bc	4.33± 0.84b
A. indica	200±40bc	6.04±1.22c
T. vogelii	176±33b	4.89 ±1.15bc
S. panduriforme	181±39b	4.29±1.13b
V. amygdalina	190±42bc	4.77±1.06bc
Phoskil	83±16a	1.14±0.33a
Unsprayed	204±42c	5.82 ±1.42bc
Mean	**174**	**4.46**
Significance	*	*

Means within the same column followed by the same letter are not significantly different from control ($P \leq 0.05$)

The effect of all five pesticidal plant extracts varied significantly ($P \leq 0.05$) against mite population over the fortnightly counts (Figure 3. 3). The observed total tomato mite numbers was higher during the first and second fortnight unlike towards the fifth fortnight. Among the phoskil treated plots, lower than 200 mites were observed.

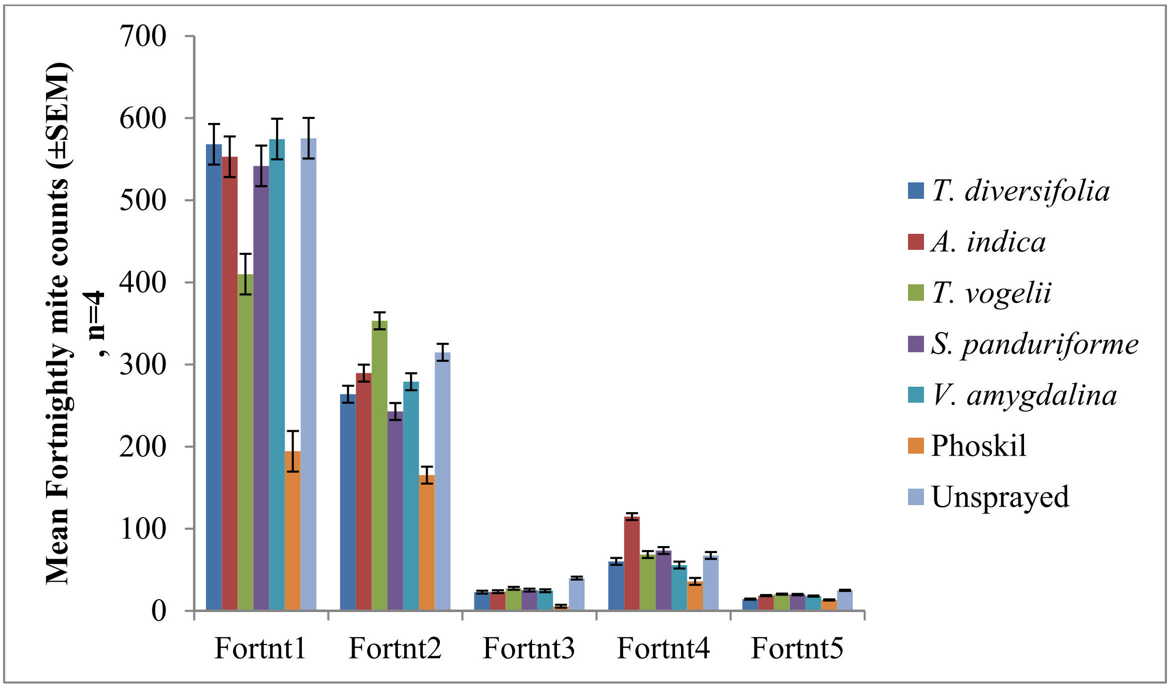


Figure 3.3: *Effect of pesticidal plants on fortnightly red spider mite counts (±SEM) at Jenda*

Results on yields of tomatoes (Table 3.3) ranged from 16477 to 36406 $Kgha^{-1}$ compared to control (15176 $Kgha^{-1}$). Phoskil gave the highest yields (36406 $Kgha^{-1}$) while *T. diversifolia* gave the highest yield amongst the pesticidal plant extracts (30883 $Kgha^{-1}$). This indicates that *T. diversifolia* leaf extracts were as effective as the synthetic pesticide at controlling pests and had sufficiently reduced yield losses. However, the other treatments except *T vogelii* were also significantly different ($P \leq 0.05$) in yield of tomato fruits than unsprayed control.

Table 3.3: Yield and growth of tomatoes for Season 1 at Jenda, Malawi.

Treatments	Marketable Fruits (Kg ha^{-1})	Plant height (cm)
T. diversifolia	30883±4337a	42.5±3.52a
A. indica	23469±3541b	43.0±3.03a
T. vogelii	16477±2559c	40.5±2.67a
S. panduriforme	20055±3231b	41.5±2.06a
V. amygdalina	26352±4054b	43.5±2.9a
Phoskil	36406±3817a	42.75±3.43a
Unsprayed	15176±2454c	36.25±3.09a
Mean	24117	41.43
Sed	5793.2	2.695
CV (%)	34.0	9.2
Significance	*	ns

Means within the same column followed by the same letter are not significantly different from control ($P \leq 0.05$)

Tables 3.4 shows the effects of pesticidal plant extracts and synthetic pesticide tested against aphids and diamond back moth on rape at Jenda and Nchenachena respectively. Yields at Nchenachena were generally higher than at Jenda which could be attributed to the differences in the levels of aphids and diamondback moth. However, the analysis of variance showed no significant effect ($P \leq 0.05$) in fresh leaf yield at both sites.

Table 3.4: Effect of pesticidal plant extracts on aphids, DBM and yield (Mean ± SEM) on rape for Season 1 at Jenda and Nchenachena, Malawi

	Jenda			**Nchenachena**		
Treatments	Total Yield (Kg ha^{-1})	Aphids	DBM	Total Yield (Kg ha^{-1})	Aphids	DBM
T. diversifolia	24686±2904a	57.3±6.33b	4.67 ±0.67bc	32725±6835a	7.75±1.65b	1.0±0.00a
A. indica	23002±4644a	51.7 ±15.3ab	3.67±0.33a	32475±1983a	9.0±1.47bc	1.0±0.00a
T. vogelii	25039±4362a	40.3±6.94ab	3.33±0.33a	32775±5532a	9.0±1.29bc	1.0±0.00a
S. panduriforme	25946±2750a	44.0± 9.4ab	4.33± 0.33b	27525±5505a	6.5±1.50b	0.75±0.25a
V. amygdalina	25705±4301a	53.7±13.37ab	4.33± 0.88b	28275±5663a	7.25±2.98b	0.75±0.25a
Dimethoate	21113±1389a	10.3 ±5.03a	5.0 ±0.58bc	26050±2247a	2.5±0.29a	1.0±0.00a
Unsprayed	20710±1872a	103.7± 24.06c	6.67 ±0.88c	24800±1765a	14.25±1.93c	1.0±0.00a
Mean	23743	51.6	4.57	29232	7.35	0.929
CV (%)	12.6	42.4	23.6	26.5	48.0	29.6
Significance	ns	**	*	ns	**	ns

Means (n=4) within the same column followed by the same letter are not significantly different from control ($P \leq 0.05$)

The results of the second season field trials showed that the pesticidal plant extracts significantly suppressed infestation by aphids in tomato although the effect was not as profound as the phoskil treatment (Fig.3.4). Aphid infestations mostly peaked up from second and third fortnights after transplanting (Fig. 3.4) during the second season at Nchenachena. The numbers of aphids was not significantly different among the extracts sprayed plots but were lower than in the unsprayed plots. However, phoskil sprayed plots had significantly fewer ($P \leq 0.05$) aphids than pesticidal plant extracts only during the fourth and fifth fortnights of spraying and were superior to all the extracts. This indicates that pesticidal plant extracts had reduced aphid population compared to untreated (Fig. 3.4).

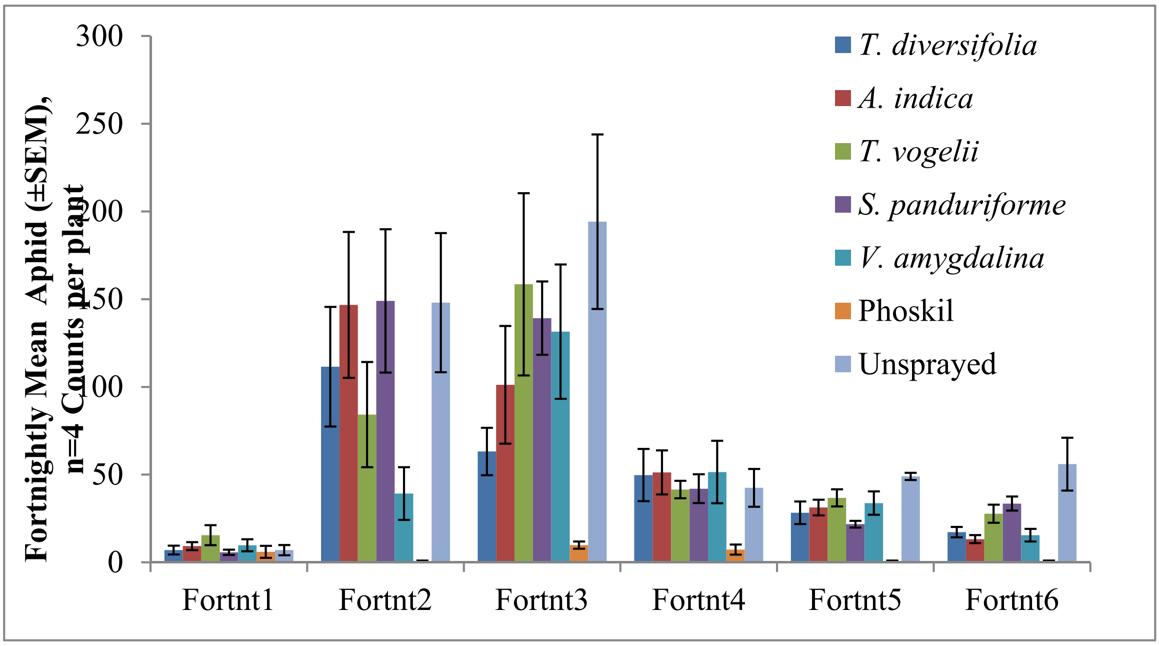


Figure 3.4: Fortnightly (Fortnt) mean tomato aphid counts per plant at Nchenachena during season 2

The difference in the yield of tomato was significant between the treated and untreated plots ($P \leq 0.05$). During the second season field trial, the fresh marketable tomato fruits from protected plots significantly out yielded the untreated (Table 3.5). However, the yield in the positive control was slightly higher than the pesticidal plant treated plots. Generally, yields were lower at Nchenachena compared to Jenda. The percentage yield loss due to insect pest infestation ranged from 6% to 45% (Fig., 3.5).

Table 3.5: Effect of pesticidal plants on yield (Mean ± SEM) of tomato for season 2 at Nchenachena and Jenda

Treatments	**Nchenachena**		**Jenda**	
	Marketable yield (Kg ha^{-1})	**Non marketable yield** (Kg ha^{-1})	**Marketable yield** (Kg ha^{-1})	**Non marketable yield** (Kg ha^{-1})
T. diversifolia	15758±1053a	1104±483b	36289±4907a	5406±1828bc
A. indica	10938±338bc	1797±532c	28617±3215b	6148±239c
T. vogelii	10234±2803bc	782±90a	20414±2756c	3938±739b
S. panduriforme	11055±1804b	1211±390b	24414±3322b	3844±1239b
V. amygdalina	13516±1584b	1250±403b	32742±5182b	6391±3415c
Phoskil	11487±1594b	1016±322a	38320±3837a	1914±726a
Unsprayed	8555±1349c	1992±475c	21590±2903c	6414±1417c
Mean	11649	1307	28912	4865
CV %	25.2	58.2	32.6	54.8

Means (n=4) within the same column followed by the same letter are not significantly different from control ($P \leq 0.05$)

Tomato fruits were harvested when matured. Healthy and damaged tomato fruits due to red spider mites were recorded and weighed separately during each picking. All five pesticidal plant extracts had lower levels of damaged tomato fruits than control at both sites Jenda and Nchenachena (Fig., 3.5; Table 3.6). For example, at Jenda *V. amygdalina* recorded the least tomato fruit pest damage followed by *T. diversifolia* while at Nchenachena all five pesticidal plant extracts had relatively same damage.

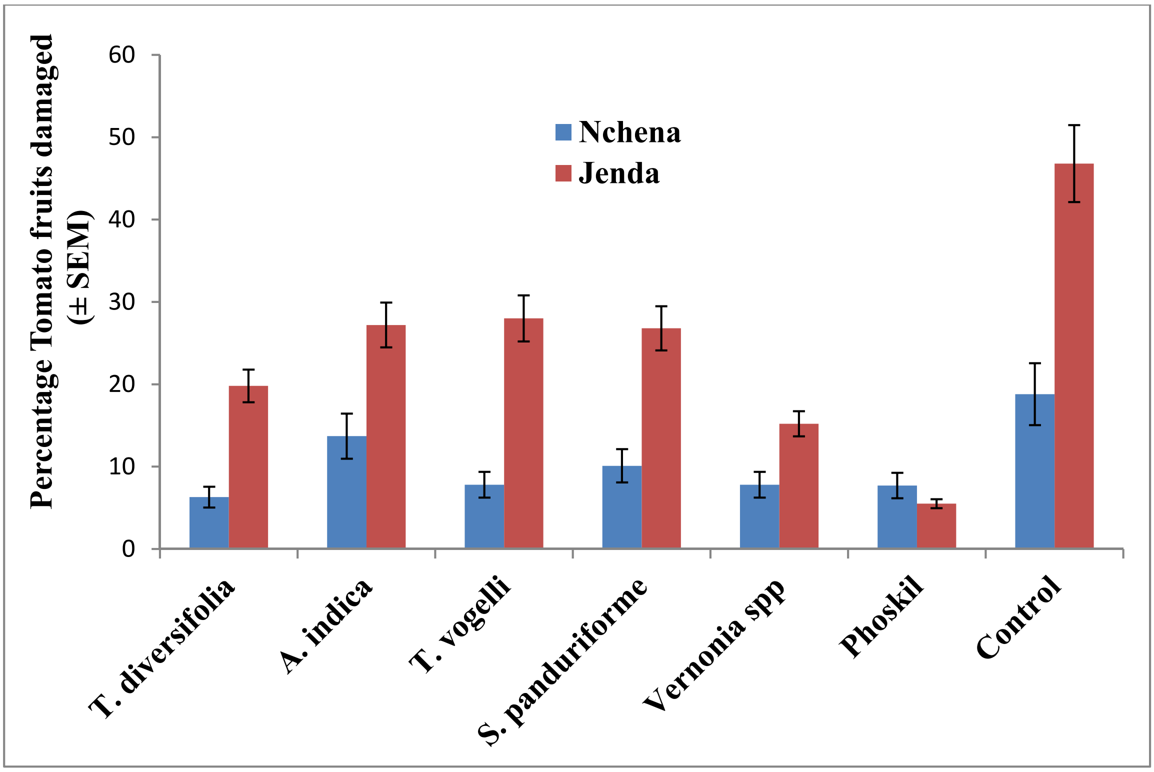


Figure 3.5: Pesticidal plant extracts effect on tomato fruits damaged for season 2 at Jenda and Nchenachena (Nchena)

Table 3.6: Pesticidal plant effect on rape yield (Mean ± SEM) for season 2 at Nchenachena and Jenda

Treatments	Nchenachena		Jenda	
	Marketable yield Kg ha^{-1}	Non marketable yield Kg ha^{-1}	Marketable yield Kg ha^{-1}	Non marketable yield Kg ha^{-1}
T. diversifolia	29000±6030 a	3725±927a	21097±3667bc	7465±969b
A. indica	29250±6120 a	3225±2104 a	18132±2236c	10660±1411c
T. vogelli	28575±4914 a	4200±2368 a	23028±5313b	6771±1027b
S. panduriforme	26225±5276 a	1300±238a	22050±3293bc	8858±744bc
V. amygdalina	26850±5093 a	1375±851a	18285±1273c	10452±374bc
Dimethoate	24800±1601 a	1250±732a	37535±2822a	3263±1217a
Unsprayed	20275±2354 a	4400±1787a	22847±2526bc	9757±1767bc
Mean	26425	2782	23282	8175
CV %	29.2	94.9	24.9	28.3
Sign. Level	ns	ns	***	***

Means (n=4) within the same column followed by the same letter are not significantly different from control ($P \leq 0.05$)

Yield data (Fig., 3.6) indicated that the synthetic insecticide treated rape plots had significantly lower leaf damaged in comparison to unsprayed plots. Minimum of 12% and 7% to rape leaf damage were recorded in dimethoate (the standard check). Among pesticidal plant treatments evaluated, *T diversifolia* and *T. vogelii* equally recorded lower rape leaf damage than untreated control at both sites. The other pesticidal plant treatments proved relatively inferior in managing rape vegetable pests.

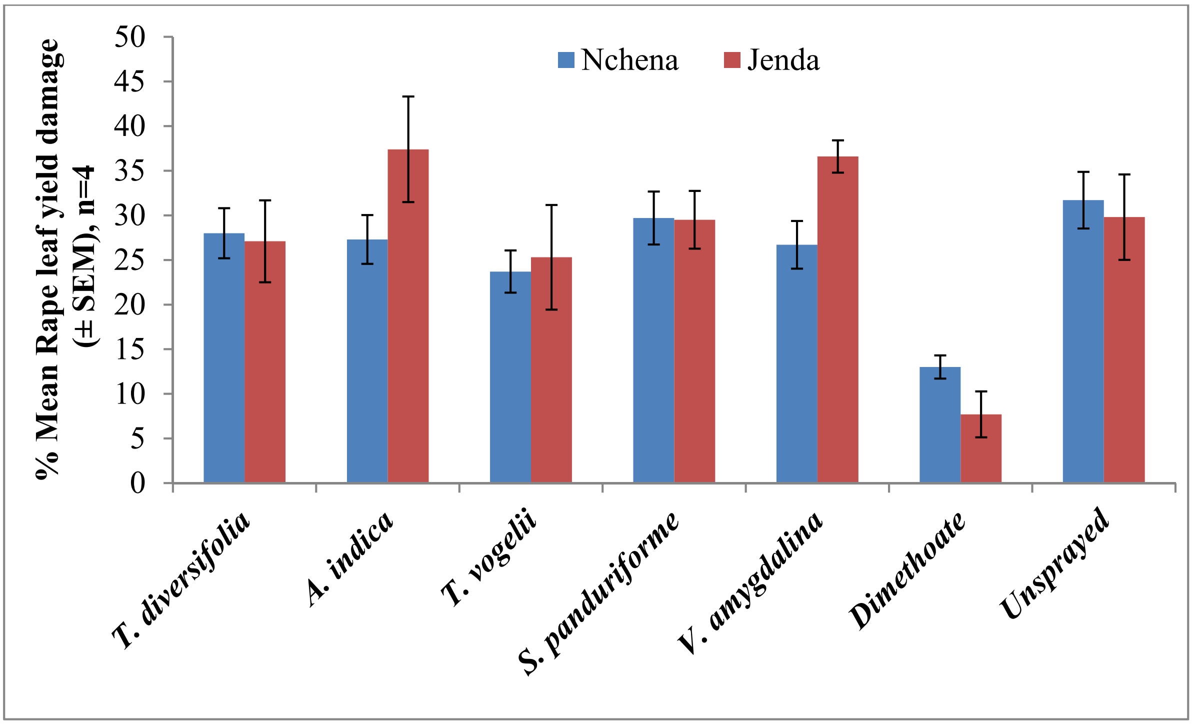


Figure 3.6: Pesticidal plant extract effect on rape leaf yield damaged for season 2 at Jenda and Nchenachena (Nchena)

The effect of these pesticidal plant extracts was demonstrated to farmers during agricultural field days in the area where farmers were given an opportunity to choose the most effective treatments. Farmers' preferences for the different pesticidal plant treatments varied considerably (Fig. 3.7). Generally, farmers preferred *T. diversifolia* and *V. amygdalina* treatments more than other pesticidal plant treatments. During the growing season of tomato and rape, 80% of the farmers preferred *T. diversifolia* due to low pest severity and high yields in terms of tomato fruits and vigorous rape growth in the treatment. Other treatments were not favoured since they displayed high pest pressure and low yield making them non impressive according farmers.

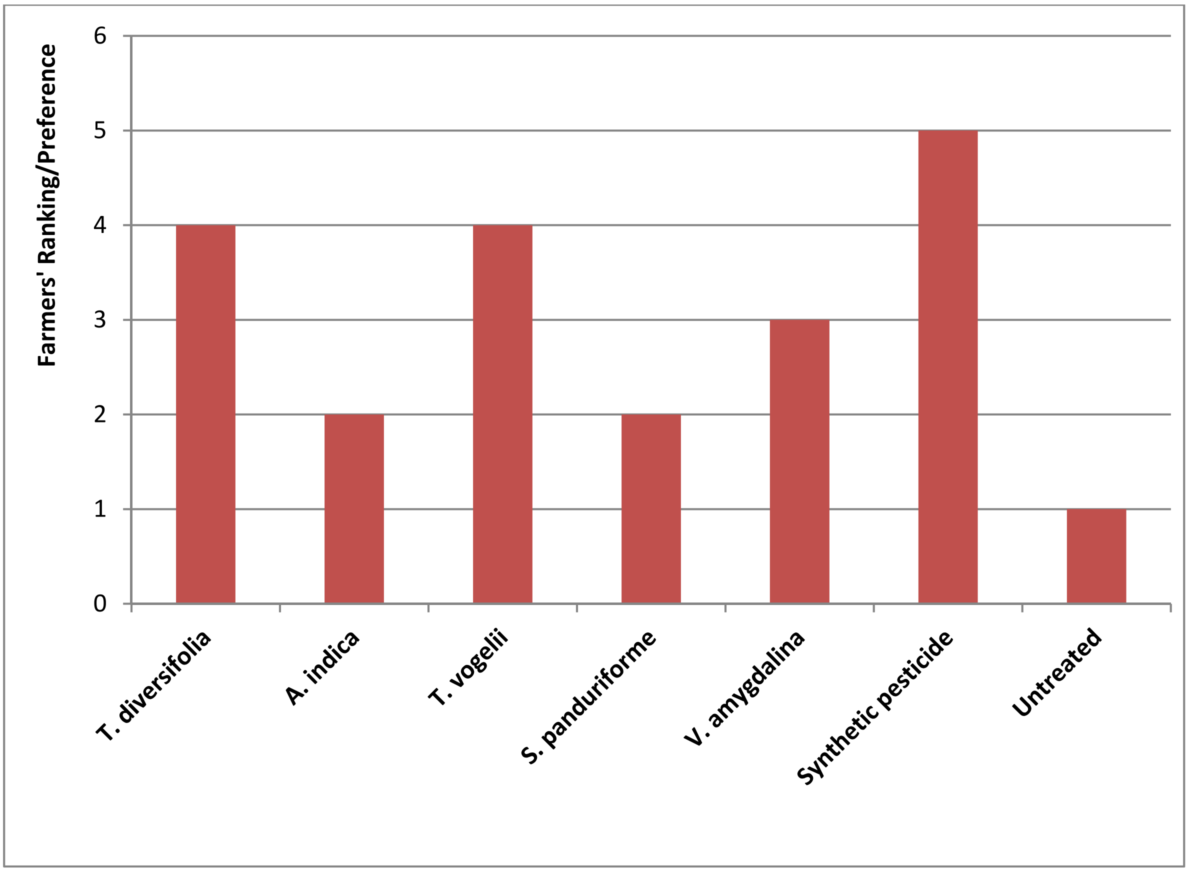


Figure 3.7: Farmers' preference to the different treatments evaluated at the two sites

3.4 DISCUSSION

The study provides the information on biological efficacy of five pesticidal plants against important vegetable pests such as red spider mite, aphids and diamond back moth. All the tested pesticidal plants showed varied efficacy on the mortality of the study insects. However, *T. diversifolia* and *T. vogelii* demonstrated significant insecticidal and acaricidal activity against aphids, mites and diamond back moth indicating that indeed some plant materials have potential to be utilized for pest control. This justifies further evaluation of plant materials for pest management in a wider range of pests under different cropping systems. Hence, it would be necessary to repeat this research over several seasons in order to understand the effects of locality. For instance, Nchenachena is much wetter than Jenda in most parts of the year, which could influence soil fertility, as well as general performance of the vegetables growth. In order to encourage the farmers to use more of pesticidal plants in these areas, they should be given proper knowledge on the types of pests associated with such conditions and should be trained properly on using locally available plants, which have biological properties. Therefore, further research work would facilitate identification of more pesticidal plants that may be used for more efficient and effective ways to vegetable pest control in their areas.

The promising effect of pesticidal plants against vegetable pests in this study agrees with earlier findings of Isman (2006) and Pavela, (2007) that some plants have biological activity against insects. The advantage of using pesticidal plants is that they have been used traditionally by human communities in many parts of the world against insect pest species. According to Charleston et al., 2005, pesticidal plant extracts can be applied to insect pests in the same way as conventional insecticides. Furthermore, Pavela, (2007) reported that spraying pesticidal plants proved most effective in reducing insect pests for resource poor farmers. Adedire and Akinneye, (2004) reported the biological activity of tree marigold, *Tithonia diversifolia*, on three cowpea seed bruchid. Similarly, a study in Uganda revealed that crude aqueous extracts of locally available plants such as tobacco and *Tephrosia vogelii* could be efficacious as conventional synthetic insecticides in reducing damage caused by insect pests (Kawuki et al., 2005). Hence, the results of this study contribute relevant information and supports farmers' claims on the use of pesticidal plants. In Kenya, *T. diversifolia* has also been traditionally reported to be widely used for reduction in the build-up of termite colonies (Stoll, 2000). Farmers pour the extracted leaf material into the opening of each termite nest and consider it to be very effective. The plant has also been reported to have antimalarial and repellent effect on mosquitoes (Oyewole et al., 2008).

Moreover, continuous foliar pesticide applications to crops are also known to greatly reduce predators and induce rapid multiplication of pests within a very short period (Mitchell, 1973; Helle and Sabelis, 1985; Devine et al., 2001; Wright, 2001; Macharia et al., 2005; El-Sharabasy, 2010). In addition, the cost benefit of some pesticidal plants could be comparable to conventional insecticide use whilst extracts are produced easily from locally available plant materials and are likely to be safer to use for smallholder farmers (Amoabeng et al., 2014). According to Rutunga et al., (1999), *T. diversifolia* and *T. vogelii* are also well known for their fast growth as such it will be much easier for farmers to collect adequate leaf materials within a very short period of growth that would frequently be used as pesticidal materials.

The current study has therefore demonstrated that some locally available plant materials could be used for pest control on Malawi farms and serve as an alternative to synthetic. Pesticidal plants contain compounds that show repellent, antifeedant and toxic effects in insects (Isman, 2000; Isman, 2006; Bakkali et al., 2008). These results corroborate previous studies that have reported the importance of using pesticidal plants as control products for pests and pathogens (Isman, 2000; Wekesa et al., 2011; Ogendo et al., 2004; Belmain et al., 2001, Matovu and Olila, 2007). *T. vogelii* plant extracts have been used against ticks (Matovu and Olila, 2007), lice, and flies and rats. *T. vogelii* has also been shown to be active against *Callosobruchus maculatus* with mortality attributed to the presence of certain rotenoids which were toxic to *C. maculatus* (Belmain et al., 2012). Plant based acaricides have also long been recommended as alternatives to synthetic chemicals since they pose little threat to the environment and human health (Isman, 2006). Furthermore, various plant species have been used for centuries as medicinal products which suggest that plant materials are safe (Baker et al., 1995; Ijeh and Ejike, 2011). Similarly, these results agree in general with those of other researchers (Delobel and Malonga, 1987; Koona and Dorn, 2005) who showed that Tephrosia species have some promise for on-farm application to protect stored legume seeds against *A. obtectus*, *C. maculatus* and *C. chinensis.*

Plant materials have excellent potential to provide naturally occurring agents that may be utilised for pest control. A wealth of literature has been published based on the effects of plant secondary chemicals on insects (Asawalam and Hassanali, 2006; Antonious et al, 2006; Roobakkumar et al., 2010; Kamanula et al., 2011; Muzemu et al 2011) and indicate that certain plant extracts are more effective against insect pests. For instance, Asawalam and Hassanali, 2006 reported the effect of the main constituent compounds isolated from *V. amygdalina* leaves against maize weevil. About seventeen constituent compounds of *V. amygdalina* essential oils were confirmed and their relative proportion determined. Eucalyptol (1,8-cineole) was the most abundant compound. Thus, the toxic effects of plant materials might be attributed to their essential oil composition. For pest control, (Asawalam and Hassanali, 2006) reported that all the essential oil treatments isolated from *V. amygdalina* had a toxic effect against the maize weevil (*Sitophilus zeamais*) suggesting that the plant is suitable for possible exploitation in insect pest control. The results presented here are the first to demonstrate the acaricidal activity of *V. amygdalina* against red spider mites and its insecticidal effect against aphids. Similarly, toxicity of *V. amygdalina* in the present study might be attributed to some essential oil constituents in the plant. Hence, plant materials deserve further investigation to help researchers in identifying cheap and readily available pest control agents.

Intensive use of synthetic insecticides to control insect pests can lead to many problems such as pest resistance and resurgence, negative effects on non-target organisms and the environment. For instance, Diamond back moth (DBM) was reported to develop resistance to many insecticides (Zhao *et al.,* 2006; Shelton *et al.,* 2008; Zago et al., 2014). However, pesticidal plant products are less likely to cause resistance in pests since they are known to be relatively slow in action, have variable efficacy and do not cause any harm (Charleston et al., 2006). As such plant pesticides have been recommended as a suitable alternative of plant protection with minimum negative risks (Isman, 2006; Schmutterer, 1990b). Major human poisoning from pesticides has been reported in developing countries in some cases even causing death (Ecobichon, 2001). Farmers frequently use highly toxic pesticides with very little knowledge of the dangers of such chemical products. In this case it can be argued that pesticidal plants might be beneficial in many developing countries, where human pesticide poisonings are most prevalent. Isman, (2008) reported that crude botanical products pose no greater risk to human health than conventional insecticides. Moreover, recent studies in Africa suggest that plant extracts can be effective as crop protectants. Current studies could therefore contribute valuable information to be used in crop production.

Substantial use of chemical pesticides induces problems of health and environmental hazards in agricultural system. Plant products are best biorational alternatives and as such studies on alternative control methods to ensure environmental and food safety have become an important task amongst researchers (Mazuma and Mtambo, 2003; Isman 2006). They are known to contain thousands of constituents, which are valuable sources of new and biologically active molecules. The secondary metabolites present in plants inhibit reproduction and other processes (Rattan, 2010). Botanical insecticides have especially been the subject of research in an effort to develop alternatives to conventional insecticides since they find favour in organic food production. Thus, the common traditional practice of using pesticidal plants can make valuable contributions to domestic food production amongst resource poor farmers. Results in this study showed that pesticidal plants had significant effect against vegetable pests. These results are also in agreement with the ones obtained by other researchers that botanical pesticides are effective against crop pests (Ogendo et al., 2004, Belmain et al., 2001, Isman 2006). Botanical pesticides have been shown to exhibit various bioactivities, such as antifeedant, antimicrobial, insecticidal, acaricidal, antiviral and growth inhibiting activities (Sinha et al., 1982; Koul et al., 1990; Parekh and Chanda, 2007; Sileshi et al., 2009; Muzemu et al., 2011; Belmain et al., 2012) such that the botanical compounds have gained attention especially to investigators who intend to discover the alternative for synthetic pesticides. The pesticidal plants used in these experiments are also readily available amongst the resource poor farmers and farmers have extensively used the plant materials for medical, nutritional and cosmetic purposes (Liu et al., 2007) and pose a minimal threat to humans and the environment. Hence, plant materials could add value if they can be cultivated, conserved and commercialized for pest control.

Pesticidal plants are an effective alternative to manage insect pests and would have enormous impact on resource poor farmers in improved vegetable production. Farmers are familiar with the concept of pesticidal plant use in pest management and farmers have generally used plant materials as pesticides. A number of studies have been conducted in different countries to prove such efficiency (Nascimento *et al*., 2000; Belmain et al., 2001; Isman 2006; Orwa et al., 2009, Kamanula et al., 2011)**.** Stoll (2000) provides a comprehensive list of plant materials used for tropical insect pest control which are considered to be easy in preparation. Adeyemi, 2010 reported that use of plant derived products is well known and has long been used for pest management amongst small scale farmers. Normally, these plant materials are used for pest control at concentrations that are too low to pose significant threat (Isman, 2008). This potentially shows that the use of plant extracts could be of great significance in pest management amongst small holder farmers.

Finally, it should be emphasized that pesticidal plant extracts are considered as safe both for the environment and health, and they can be recommended for use in pest control. This claim stems from known use of these plants as food and medicine (Erasto et al., 2006; Ijeh and Ejike, 2011). The study has therefore provided reasonable evidence to suggest that there is great potential for pesticidal plant use to control red spider mites, aphids and other pests in vegetables. Sole reliance on synthetic pesticides could also lead to problems such as destruction of natural enemies, pesticide residues and more costly to farmers. According to Amoabeng et al., 2014 the use of pesticidal plants could also be less expensive and give financial benefits that are higher or comparable to synthetic pesticides. Under such circumstances, the use of pesticidal plants in pest management is considered ecologically viable in order to overcome some of these problems. This study therefore justifies further evaluation of plant materials that small holder farmers collect and use for pest control.

3.5 CONCLUSION

In conclusion, results revealed that *T. diversifolia* and *T. vogelii* significantly reduced the population of aphids, mites and diamond back moth. *T. diversifolia* showed the strongest pest controlling effects compared to other plant materials. This suggests that not all pesticidal plants identified by farmers as potentially useful materials for pest control were effective against vegetable pests in comparison to standard synthetic pesticides but proved superior to untreated controls. Based on these results, *T diversifolia* and *T vogelii* can be recommended for pest control against vegetable pests such as red spider mites, aphids and diamond back moth.

Advanced studies may identify other pesticidal plant materials that may not only be useful in the control of aphids and red spider mites but also address most unanswered questions in the management of some pests in other crops such as white grubs and other caterpillars. Moreover some of the plants evaluated in these trials have uses as herbal medicines amongst many farmers so may have heritage capital to be more easily accepted and promoted for new uses (Rungeler et al., 1998; Wedge et al., 2000; Erasto et al., 2006). For instance, Wedge et al., 2000 reported that the leaf extracts of *V. amygdalina* had antifungal activity. The farmers also identified pesticidal plants that best suited their needs which allowed them to be part of the validation process. However, attention has to be focused on human safety issues, as well as the best formulation to improve insecticidal potency and stability in order to reduce cost. The farmers said that there is need of additional field studies in order to further evaluate and validate other plant materials for various other pests. Interest in the use of locally available, cheap and environmentally benign plant species is a step ahead in coming up with appropriate alternative control measures for pests of importance in vegetable production.

Given that the efficacy of these pesticidal plant treatments have shown potential to controlling vegetable pests owing to lower damaged rape and increased tomato yield they may ultimately be used for pest control. Considering their eco-friendly and non-toxic nature, some of these pesticidal plants may therefore be recommended for the suppression of vegetable pests such as mites and aphids in tomato and rape. In general, pesticidal plant treatments produced significantly lower damaged yield than unsprayed control treatment that may result into higher incomes. Furthermore, many resource poor farmers do not have the financial capacity to purchase synthetic pesticides but have ability to freely collect and prepare plant materials for use in pest control. Hence, this research justifies further evaluation of more plant materials whether under laboratory as well as field conditions in order to identify other plant materials that can favourably act against aphids and red spider mites.

CHAPTER 4 LABORATORY EVALUATION OF SELECTED PESTICIDAL PLANTS FOR BIOACTIVITY AGAINST RED SPIDER MITES *Tetranychus evansi* AND BRASSICA APHIDS *Brevicoryne brassicae*

4.1 INTRODUCTION

Red spider mites *Tetranychus evansi* and aphids *Brevicoryne brassicae; Myzus persicae* still pose as serious threat to horticultural crops (Hill, 1983; Andow, 1991; Asare-Bediako et al., 2010; Grzywacz et al., 2010). Furthermore, a detailed study of farmers in Kenya indicated that aphids and diamond back moth are the major insect pests (Kibata, 1996; Oruku and Ndun'gu, 2001; Ayalew, 2006). As indicated in Chapter 1, little work on the biological activity of the pesticidal plant materials against vegetable pests has been done. Thus, protection of plants from agricultural pests and pathogens remains a primary preoccupation of agricultural scientists.

Chapter 3 showed that the efficacy of pesticidal plant materials against vegetable pests such as aphids, mites and diamond back moth varied considerably. Understanding the variability in the efficacy of plant materials require more detailed laboratory studies to determine the sources of variation and whether the efficacy of the plant materials could be predicted. This chapter describes work on the comparative laboratory evaluation of some selected pesticidal plants and determine their efficacy against red spider mites (RSM) and aphids. In this context, resource poor farmers may be assisted in identifying pesticidal plants that can be utilised to control pests without continuously relying on synthetic pesticides.

4.2 MATERIALS AND METHODS

4.2.1 Plant materials

Plants were collected from different sites in Mzuzu Agricultural Development Division (MZADD) and other areas in Malawi. These plant samples were coded for use in laboratory experimentation and crude extract were prepared with methanol (Table 4.1) in order to extract more compounds from the plant materials. The plant materials were selected based on traditional knowledge concerning their application in vegetable pest control and easy availability as reported in chapter two. All plant materials were dried under shade at ambient temperatures (23–27 $^{\circ}$C) for one week and stored under cool conditions in the laboratory. The dried plants were ground to a fine powder using either a blender or mortar and pestle. If a mortar was used, ground materials were sieved in a 2 mm mesh and kept in a sealed plastic container until needed.

4.2.2 Preparation of the crude extract

Sample preparation is the most important step for extraction of components from pesticidal plant material. Some of the basic operations include shade drying of plant materials, freeze drying and grinding in order to obtain a homogenous sample. In this study, shade dried samples of pesticidal plants were ground and extracted with methanol. The plant materials were separately prepared by adding 2 g dried powdered plant material in 20 ml solvent (Steenkamp et al., 2007) to give a 10% stock solution (W/V) for all bioassays. The extraction proceeded up to 12 hours at room temperature and filtered under vacuum pump.

Table 4.1: List of selected plant materials used in the laboratory experiments for biological activities

Botanical name/ Family	**Collection Site**	**Plant part**	**Code**
Cassia abbreviata **Caesalpinioideae**	Ekwendeni	Stem bark	BI 17737
Securidaca longepedunculata **Polygalaceae**	Luhomero	Stem bark	BI 17684
Euphorbia tirucalli **Euphorbiaceae**	Ekwenden	Leaf twigs	BI 17691
Vernonia amygdalina **Compositae**	Mganthira	Leaves	BI 16960
Bobgunnia madagascariensis **Leguminosae**	Luhomero	Dried pods	NRI 1
Tephrosia vogelii **Leguminosae**	Luhomero	Leaves	NRI 2
Tagetes minuta **Compositae**	Gulliver	Leaves & stems	NRI 5
Agauria salicifolia **Ericaceae**	Kasasire	Leaves	NRI 7
Dolichos kilimandscharicus **Fabaceae**	Kasasire	Root/Bulb	NRI 8
Tithonia diversifolia **Asteraceae**	Mganthira	Leaves	BI 16965
Azadirachta indica **Meliaceae**	Kasinthula	Leaves	BI 16962
Solanum panduriforme **Solanaceae**	Tropha Estate	Leaves	BI 16961

4.2.3 Insects

Two agricultural pests were tested in this study, red spider mites *Tetranychus evansi* and aphids *Myzus persicae*. Red spider mites were reared on susceptible tomato *Lycopersicon esculentum* cultivar Money maker and locally grown common beans *Phaseolus vulgaris* while the aphids were reared on brassica plants - rape *Brassica napus* under greenhouse conditions at 27±3°C.

4.2.4 Toxicity of selected pesticidal plants against mites

Toxicity tests of ten pesticidal plant extracts against red spider mites were conducted in the laboratory. Mites were collected from the tomato fields of Lunyangwa Experimental Farm, Mzuzu, Malawi and were immediately transferred onto four week old potted tomato plants kept in a green house at 27 ± 3°C and 65 ± 5% RH and used as stock culture. Red spider mites were collected from laboratory culture to ensure use of a homogenous culture from tomato plants. Matured tomato leaves were then collected from separate uninfested tomato plants from the stock culture, and leaf discs of 2 cm diameter cut from whole leaves. Leaf discs were treated with a constant amount spray solutions for 5 seconds using a glass atomizer on both leaf surfaces. Treating both surfaces of leaf disc was necessary to ensure exposure of adult mites because mites have the tendency to feed from the underside of the leaf. The treated leaf discs were left for about 5 minutes to let the extracts dry up then five mites were separately introduced into each bioassay well. Acetone was sprayed to the untreated leaf disc in the control to allow quick evaporation of the chemical in order not to have any effect to mites. The experiments were conducted at room temperature 27±3°C and 65±5 % RH in our laboratory. The mortality of the mites and aphids was observed and recorded at 1, 12 and 24 hours after treatment.

4.2.5 Toxicity of selected pesticidal plants against aphids

Aphid populations were reared on bean and brought to laboratory for bioassays. The plant materials were dried under shade and later ground to dry powder. Pesticidal plant extracts were prepared in methanol and used for experiments. About 2 g of the powdered pesticidal plant materials were extracted with 20 ml of methanol for 24 h in order to prepare the stock solution. All pesticidal plant extracts were replicated four times. The aphids were exposed to surface coated glass vials with pesticidal plant extract solution. Each vial was coated with pesticidal plant extracts by dispensing 2 ml of the pesticidal plant extract solution. The vials were rolled manually until the whole surface was coated with the solution and air-dried at room temperature for 30 to 60 minutes or until they were completely dry. Control vials were treated with 2 ml of distilled water containing 5% and 10% methanol. Methanol was allowed to evaporate completely from the vials before the aphids could be placed into the vials. Then aphids were placed individually in the surface coated vials.

Preliminary bioassays demonstrated that 2 ml of plant residue suspensions produced reproducible results; therefore, 2 ml of each plant extract was spread into the vial and left to dry for about 5 minutes before introducing aphids. The plant extracts were assayed at 5 % and 10% w/v in order to determine if the treatments were dose dependent. Mortality of aphids was assessed at 1, 12 and 24h after treatment application. Aphids were considered dead if they did not move when prodded with fine brush. A total of eleven treatments comprising ten pesticidal plant extracts and control were used. In the experiment, treatments were laid in a randomized block design and all bioassays were replicated four times.

4.2.6 Choice Test against red spider mites

The antifeedant/repellency activity of crude extracts of different plant material was conducted using leaf disc choice test (Sadek, 2003). The plant materials were dried under shade and later ground to dry powder. About 2 g of the powdered pesticidal plant materials were extracted with 20 ml of methanol for 24 h in order to prepare the stock solution that was used to treat tomato leaves. Two alternate leaves of similar size were excised from a tomato plant and placed in a three-way 9 cm in diameter plastic Petri dishes from Fisher, UK and parafilmed to contain the pests in the Petri dishes. The treated leaf was priorly dipped in each prepared plant extract for at least ten seconds and left to dry under room temperature before being placed on the 9 cm plastic Petri dish. Water was sprayed to all the untreated leaf in the control batch. Five unsexed mites were then introduced on the front part of the three-way Petri dish (Plate 4.1). Four replicates were prepared for each treatment. The number of mites present on each treated leaf and non-treated leaf was counted at various time intervals between 1, 12 and 24 hr. The percentage repellency/ repellency index (RI) was calculated from the formula:

RI = [(C-T)/(C+T)]*100 (Campbell, 1983)

Where C is the number of mites found on the control leaf disc and T is the number of mites found on treated leaf disc.

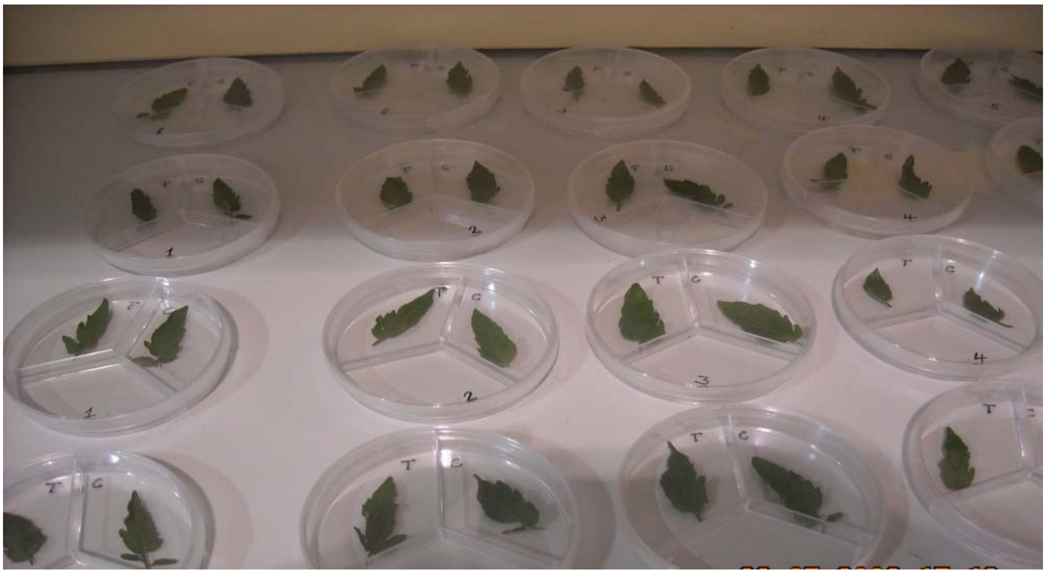


Plate 4.1: Three-way petri dishes used for choice test trial

4.2.7 Data analysis

The test was performed by placing one control and one treated leaf disc in a three way plastic Petri dish arena (9 cm in diameter). All experiments were repeated using mites collected from the same generation of stock culture. The observations on these cultures were largely consistent after 24 h. The corrected mean spider mite mortality (%) data was calculated using Abbott's formula (Abbott, 1925). Treatments were randomly assigned and the repellency index for each treatment was compared using an analysis of variance (ANOVA) followed by Students Newman Keuls test at P< 0.05 level for multiple-comparison where significant differences were observed. Statistical Package for the Social Sciences (SPSS) was used to calculate analysis of variance.

4.3 RESULTS

4.3.1 Toxicity of pesticidal plants against mites

The results showed that plant extracts of all species caused a significant increase in mortality of *T. evansi* after 24h (Fig. 4.1) compared to control. After one hour, only leaves treated with *T. vogelii* extracts caused significantly greater mite mortality than the control. *D. kilimandscarichus*, *T. vogelii*, *A. indica* and *B. madagascarensis* had significantly greater mite mortality than the control 12 h after crude extract application (Fig 4.1). The other treatments were not significantly different regarding red mite mortality after 1 hour. This suggests that the effect of plant extracts varies or more time is required for plant extracts to display their effects on mites. All plant extracts displayed significantly (P<0.0001) higher mortality than the control at 24 h after application. *T. diversifolia* recorded over 50% mite mortality followed by *A. indica* and *B. madagascarensis*.

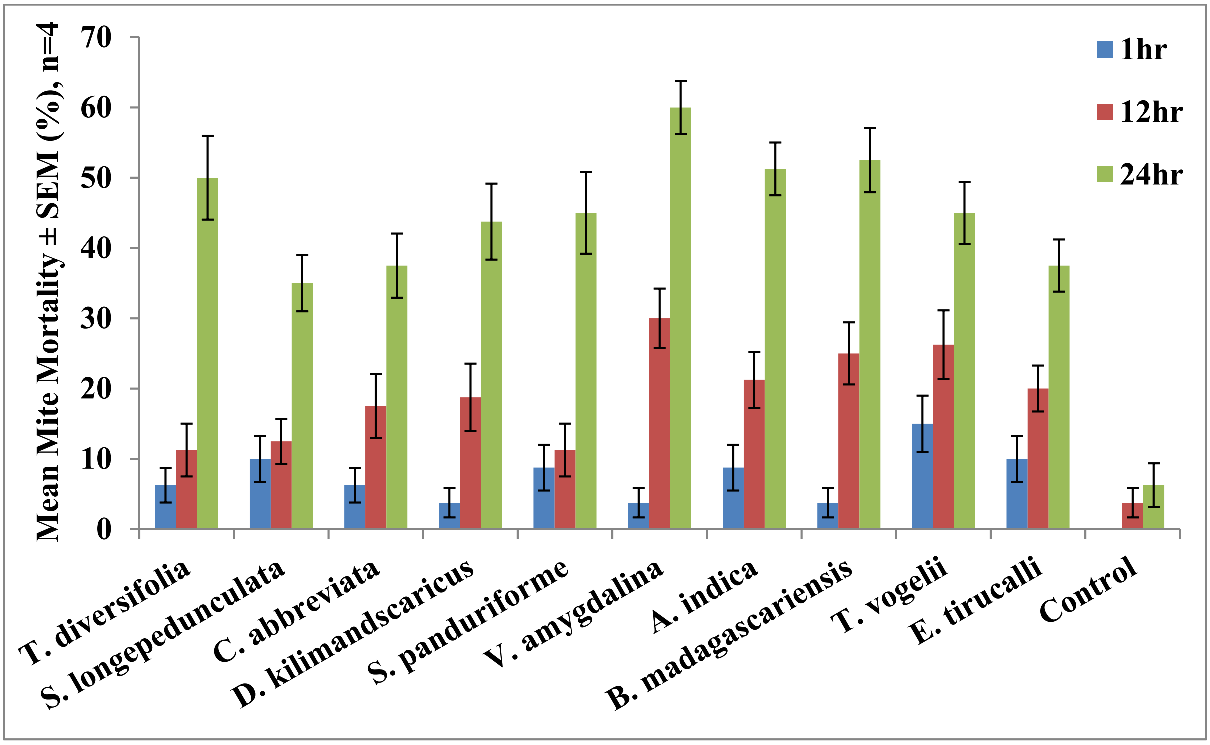


Figure 4.1: Toxicity of methanol plant extracts (10% W/V) against T. evansi at 1, 12 and 24hr after application

Plant extracts were further assayed at 4% (w/v) to determine their dose-dependent effects (Fig 4.2). At 4% (w/v), all plant extracts had the same trend but with significantly lower mortality effect against mites (Fig 4.2). However, after 12 h only *E. tirucalli, S. longepedunculata, A. indica, B. madagascarensis* and *D. kilimandscarichus* caused significantly ($P<0.01$) greater mite mortality than the control.

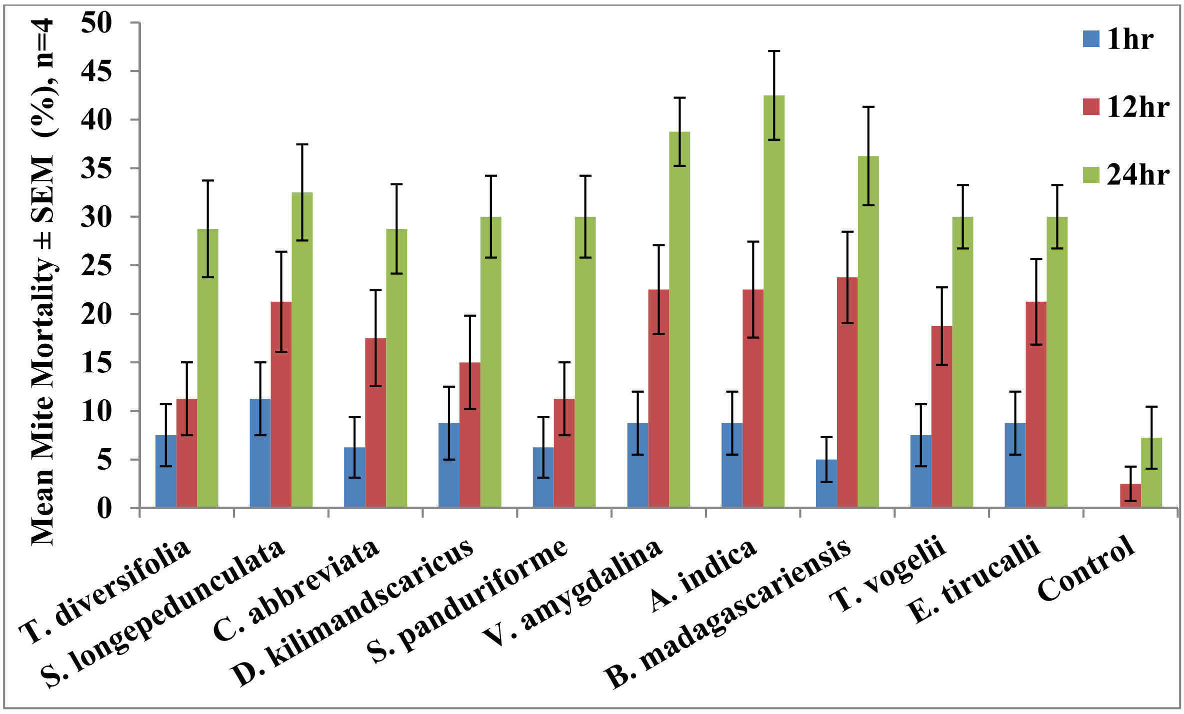


Figure 4.2: Toxicity of methanol plant extracts (4% W/V) against T. evansi at 1, 12 and 24hr after application

4.3.2 Toxicity of pesticidal plants against aphids

The results in Figures 4.3 and 4.4 show that aphid mortality on the methanol plant extracts were higher than controls indicating that plant extracts were significantly (P<0.0001) toxic against aphids at both 2% and 4% w/v. The most dramatic aphicidal activity (16.25 - 40.0%) was recorded after 24 h where *E. tirucalli*, *B. madagascarensis* and *C. abbreviata* extracts resulted in 40%, 32.2% and 40 % mortality respectively after 24 h of application. However, only less than 15% aphid mortality was recorded from *S. panduriforme* and *A. indica*. All other plant extracts, caused greater than 15% aphid mortality after 24h compared to less than 5% aphid mortality observed from control treatment (Fig 4.3 and 4.4). This fact suggests that most plant extracts may have insecticidal activity against aphids.

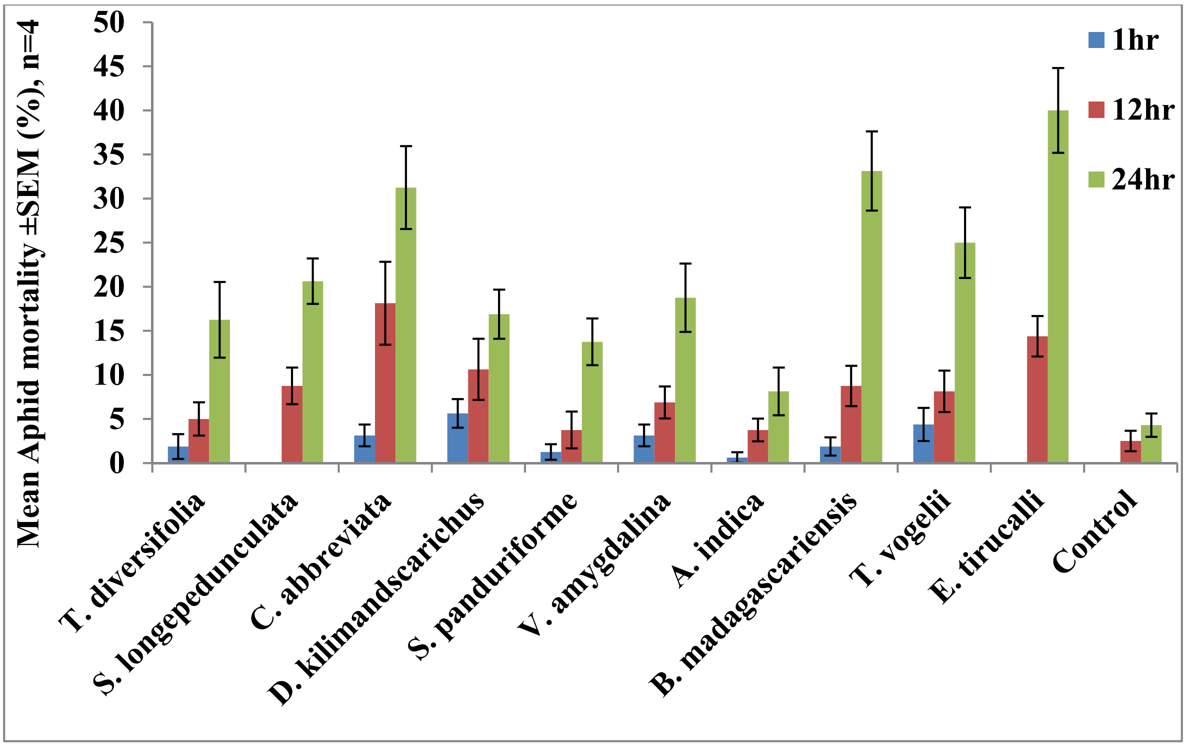


Figure 4.3: Aphid mortality for the 4% methanol plant extracts at 1, 12 and 24hr after application

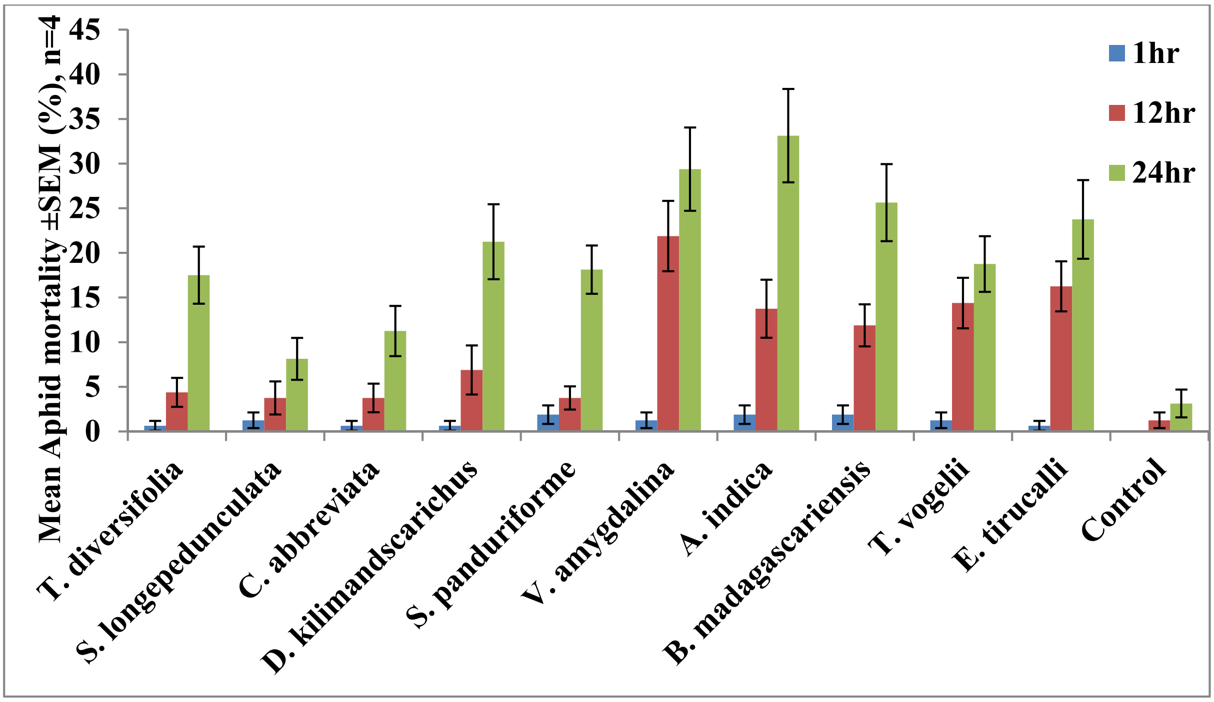


Figure 4.4: Aphid mortality for the 2% methanol plant extracts at 1, 12 and 24hr after application

4.3.3 Choice Tests against red mites

The results of the choice test bioassay reveal that repellent activity of the plant extracts was time dependent (Table 4.2). More mites were attracted towards the control treatment suggesting that plant extracts repelled the mites after application. *Tephrosia vogelii* (83.2%) crude extracts significantly (P < 0.001) repelled mites more strongly followed by *Bobgunnia madagascariensis* (77.5%)*, Azadirachta indica* (75%) and *Tithonia diversifolia* (67.5%) 48 h after application of plant extracts. *Solanum panduriforme* showed an attractive effect of 25% and 45% at 24h and 48h after application, respectively. However, *Euphorbia tirucalli* and *Tagetes minuta* slowly lost their repellency effect with time. These two plant extracts displayed 100% effect within the first 24h period. The fact that these plant materials showed some effect suggests some plant extracts may act as repellent materials to mites.

Table 4.2: Repellency (%) of methanol plant extracts on mites 24 h and 48 h after application.

	Repellency (%)	
Plant extract	24h	48h
S. panduriforme	-25	-45b
C. abbreviata	0	5ab
V. amygdalina	0	65ab
T. diversifolia	8.4	67.5a
D. kilimandscarichus	16.7	22.5ab
S. longepedunculata	25.8	50ab
T. vogelii	41.7	83.2a
B. madagascarensis	50	77.5a
A. salicifolia	50	63.3ab
A. indica	58.3	75a
E. tirucalli	100	57.5ab
T. minuta	100	62.5ab
F value	1.94	5.466
Sig.	.066	0.001

Means with same letters in the column indicate no significant difference Tukey honestly significant difference (HSD) P= 0.05

4.4 DISCUSSION

The present study indicated that different pesticidal plants screened can be used in the control of vegetable pests. Previous studies have demonstrated that pesticidal plants have insecticidal properties against agricultural pests. Many authors have undertaken the screening of plant species for pesticidal activity (Miguel *et al.*, 1994; Zang *et al.*, 1997; Dyer *et al*., 2003). Generally leaf extracts are widely used for screening plant extracts against chewing insects such as lepidopteran larvae and sucking insects such as aphids (Wolfson and Murdock, 1987; Xie *et al.*, 1996). Extracts from the neem tree have shown various potential as antifeedant, antioviposition, repellent and growth-regulating (Rembold and Sieber, 1981; Schmutterrer, 1995). The advantage of using pesticidal plants is that they are easily available and they have been used extensively for medicinal purposes, implying that they have low or no toxicity to humans. In addition, they can be applied to insect pests in the same way as conventional insecticides (Charleston et al., 2005; Liu et al., 2007). Liu et al., 2007 reported that plant extracts are promising candidates as botanical insecticides against agricultural pests. The present study shows that among the pesticidal plants tested, *T. vogelii and B. madagascarensis* extracts significantly repelled mites at the rate of 83.2% and 77.5% 48h after treatment. Similarly, *D. kilimandscarichus*, *T. vogelii*, *A. indica* and *B. madagascarensis* had significantly greater mite mortality than the control 12h after treatment application. This indicates that these pesticidal plants were either toxic to red spider mites or aphids feeding on the treated discs and directly reduced the population of mites and aphids. Therefore, these pesticidal plants may also be of use in the control of insect pests such as aphids and red spider mites. Mulla and Su (1999) also showed that neem has minimal contact toxicity and requires ingestion to be fully effective. In this study, mortality of mites due to treatment of pesticidal plants was directly related to the dosages used and the exposure time of the pest to the treatment. This indicated that higher dosage and longer exposure periods of pests to pesticidal plants are needed to achieve appreciable management of aphids and mites.

These results indicate the importance of traditional knowledge for pest control in science. In related studies, dried pesticidal plants or their extracts have been used by farmers in many developing countries to protect food and fibre from insects (Jacobson 1986; Belmain et al, 2001). Many authors have studied the effect of different plant extracts on insect pests and were reported to be toxic to insects and mites (Isman, 2006, Akhtar and Isman, 2004, Antonious and Snyder, 2006). For instance, Antonious et al, 2006 found out that there is potential in using fruit extracts of hot pepper as alternatives to synthetic acaricides for controlling the two-spotted spider mite, *Tetranychus urticae* Koch. Twenty-four Capsicum accessions (Solanaceae) were screened for their toxicity and repellency to the red spider mites. Crude extracts from fruits of *Capsicum chinense*, *C. frutescens*, *C. baccatum, C. annuum*, and *C. pubescens* were prepared in methanol and tested for their acaricidal properties. Miresmaili and Isman (2006) assessed the efficacy of rosemary oil against two spotted spider mite, *Tetranychus urticae* Koch as fumigants. They found out that rosemary oil was toxic to spider mites as a contact toxicant, which also might have fumigant toxic effect due to its chemical composition. Laboratory bioassay results indicated that pure rosemary oil and EcoTrol (a rosemary oil-based pesticide) caused complete mortality of spider mites. EcoTrol was also safe to tomato (Clarance) even when applied at double the recommended label rate. Similarly, in this study, a wide range of plant extracts proved to be toxic resulting in the death of pests as exhibited with red spider mite (RSM) using the leaf discs method with mortality ranging from 7.5 to 38.75% with 5% leaf extracts, and 6.25-60% at the highest concentration of 10% leaf extract (Fig., 4.1 and 4.2).

There was a strong repellent effect of the pesticidal plants during the initial 24h after application of the extracts on the pests. The results suggest that there are compounds in some of the plant extracts that are toxic or repellent to the target pest species. This shows that pesticidal plants also present many farmers with large number of options for the control of insect pests that attack their vegetable crops as they are cheap and based on local plant materials. Methanol extracts of *A. indica, T. diversifolia, T. vogelii, B. madagascarensis, S. panduriforme,* and *V. amagdylina* showed significant toxicity and repellency to mites and aphids and have the potential for crop protection against the two target species.

Other laboratory studies have also shown that pesticidal plant extracts have significant lethal effects on red spider mites in general. Roobakkumar et al., (2010) evaluated bioefficacy, ovicidal action and ovipositional deterrence of a few selected bio-pesticides such as neem kernel aqueous extract (NKAE), pongam kernel aqueous extract (PKAE) and garlic aqueous extract (GAE) against the tea red spider mite (RSM). Muzemu et al., (2011) also evaluated extracts of *Lippia javanica* leaf powder and *Solanum delagoense* ripe fruit pulp for pesticidal effects under on-station conditions against rape aphids and tomato red spider mites as alternatives to conventional pesticides. They reported that plant extracts significantly reduced pest numbers in their experiments. The similarity of the results in this thesis with other studies on arthropod pests indicate that the impact of pesticidal plant extracts on the existing pest complex must be taken into consideration. It is therefore possible that some plant materials will be incorporated in pest management in order to reduce on costs from purchasing synthetic pesticides.

However, efficacy of products may vary with cultivars and families of the plant materials. According to farmers in Malawi, local cultivars of tephrosia are more effective compared to the improved cultivar introduced mainly for soil improvement (Mviha et al 2004). These results also showed that the toxicity of plants increased according with concentration of plant extract and time the pest were exposed to the materials. Similarly, Ahmed et al. (2007) stated that toxicity and biological activity of methanolic extracts of neem products against bean aphids increased with increasing concentration and time exposure of aphids to the products.

The results presented in this chapter demonstrated that two of the plant extracts evaluated (*T. vogelii* and *T. diversifolia*) exhibited contact toxicity to red mites and aphids (Fig 4.1). The results further showed that toxicity existed for 24 hrs and then toxic effects disappeared. Significantly, higher repellency was recorded from *T. diversifolia, B. madagariensis and T. vogelii* (Table 4.2) with 68%, 77% and 83% respectively. One of the samples of *S. panduriforme* was clearly attractive to mites, whereas the others were less so or not at all. No or less significant preference was found with *C. abbreviata* and *D. kilimandscarichus* while *A. indica*, *E. tirucalli*, *T. minuta* and *A. salicifolia* recorded 50% to 63% repellency. Generally neem causes mortality of many arthropod pests by toxic and some antifeedent (starvation) effects. This difference probably indicates that these plants vary in the content of the active components responsible for the insecticidal properties. These results are in agreement with a previous study showing contact toxicity of *T. diversifolia and T. vogelii* (Ramondo 1997; Boeke et al., 2004). Hence the bioassay effect of the pesticidal plants to these insects needs further study. However, the results from these current laboratory studies imply that the plant materials could practically be used for pest management.

The use of repellents as crop protectants is likely to be useful under limited circumstances. Plant extracts could only control insect pests if it is applied in such a way that it reaches its intended target insect at the correct life stage. When aphids were subjected to 7 ml vials, it was observed that they had their bodies fully elevated from the edge of the vials signifying total dislike of the treated surface. Such behaviour was very unusual for aphids and was therefore typically related to unfavourable condition on the vial. This may indicate that aphids start detecting the presence of repellent compounds in the treatments. If the aphids abandon the treated surface, feeding or sucking of such plants may not occur. This is important since both aphids and red spider mites feed by sucking sap from mature leaves as reported by Lu and Wang (2005).

Behavioural observations are crucial in determining the antifeedant effects (Wright, 1963; Koul et al., 1990; Lowery et al., 1993; Soulé et al., 2000). For instance, Koul et al., 1990 reported the biological activities of extracts from neem, which include feeding and ovipositional deterrence, repellence, growth disruption, reduced fitness and sterility. Since aphids usually like to feed on succulent tissues such as the new shoot tips, leaves, buds and flowers, the prospects of antifeedants in pest management can have more successful practical application when insect behavioural effect leads to less damage to plants (Ahmad 2007). Through such behaviour, it would be easier to repel aphids upon spraying in order to effectively keep aphids out of the crops. It may show that aphids could have been detecting the odour of the pesticidal plants, which may deter feeding. Therefore, it is possible that vegetable pests such as aphids and mites could leave treated plants because of antifeedant effects of the pesticidal plant extracts. It will be necessary to observe this in other assays and assess the effect of the plant materials especially through residual effects where extracts would be sprayed directly on the plant with aphids present. In another study, Simmonds *et al* (1990a) reported high antifeedancy with low median effective dose (ED_{50}) for pure compounds isolated from different plants against the larvae of *H. armigera.* The median effective dose is the dose that produces a quantal effect (all or nothing) in 50% of the population that takes the drug or chemical (median referring to the 50% population base).

Some studies have indicated the potential ecological damage due to the widespread use of synthetic pesticides (Antonious et al., 1998). It is therefore important to encourage effective birational control measures that are not detrimental to humans or the environment. If botanical pesticides are promoted to resource poor farmers; it may be possible to satisfy the growing needs of farmers for pest control measures without resorting to the use of synthetic pesticides for crop protection (Mansour et al., 2004; Schmutterer and Ascher, 1987) without negative effects on environment and mankind. Crude plant extracts often consist of complex mixtures of active compounds that act synergistically, and may show greater overall biological activity compared to the individual constituents (Chen et al., 1995). This study indicates that cheap, sustainable protection of vegetables against pests may be feasible using locally available pesticidal plant products.

4.5 CONCLUSION

In this study, a number of pesticidal plants proved effective against aphids and mites. The results also showed that some pesticidal plant materials were more effective than others. In some cases, pesticidal plant extracts displayed significant effect when used at higher concentration. As such, it may not be practical for small-scale farmers since they might require relatively more materials to effectively manage pests. Eventually, this may render farmers to over collect plant materials and facilitate the extinction of available plant species within their vicinity. Plant materials might also be time consuming to collect thereby making it more expensive.

The relatively long period of pesticidal plant repellent effects indicates that these pesticidal plants are sensitive. Thus, pesticidal plant extracts may act as repellent, stomach and contact poisons (Law-Ogbomo and Enobakhare, 2007). It also clearly showed that pesticidal plants can be effective against red spider mites causing complete mortality in the laboratory at 5 and 10% concentrations. Nevertheless, the 10% dosage is too high from the economic point of view, and may not be used very much in practical application. According to Isman, (2008), harmful effects associated with plant compounds can largely be alleviated by crude plant preparations that must range from 1% to 5% w/v.

There are a number of pesticidal plants known for their insecticidal activity, but there has been less progress in validating them for their efficacy. Insecticidal activities of pesticidal plants can be broad and variable depending on different factors like the presence of bioactive chemicals which need to be identified for use in pest management. It would also be important to test for the toxicity of these pesticidal plant extracts on natural enemies.

The study has also demonstrated the efficacy of crude extracts from several plant species with known toxicity to insect pests as reported by small holder farmers from chapter two. However, *D. kilimandscarichus*, *T. vogelii*, *A. indica* and *B. madagascarensis* had significantly greater mite mortality than control suggesting that they may easily be used for pest control. It would be essential that further work be conducted in order to investigate more plant materials and improve their efficacy.

The current findings demonstrated that most of the pesticidal plants tested possess repellent and toxicity properties that can be used in the control of aphids and mites in vegetable production. The repellent activity of the pesticidal plants also revealed that the activity of plant extracts was time dependent. Such studies could also be extended to cover management of other vegetable pest species. Therefore, there is a rationale for the incorporation of these plant materials into vegetable pest protection practice amongst the resource poor farmers. The availability of these pesticidal plants within the farm yard vicinity is another additional value for which pesticidal plants could be preferred than other control methods, particularly the use of insecticides. However, the study has also demonstrated variations in bioassay mortality that can arise from many causes such as insect age, plant material and temperature. These promising plant species should also be investigated further for their effect on natural organisms. Hence, the variability in the efficacy of plant materials required more detailed laboratory studies to determine the sources of variation.

CHAPTER 5 :BIOLOGICAL ACTIVITIES AND VARIATION OF ROTENOIDS WITHIN *Tephrosia vogelii* HOOK. f. (Fabaceae) FROM MALAWI

5.1 INTRODUCTION

Research in Chapters 3 and 4 demonstrated that the effect of pesticidal plants varied significantly indicating that there could be variation of compounds within the pesticidal plants. Such factors were considered as critical issues because farmers think that all plant materials could have same effect on pests. Consequently it was decided to explore the effect of location on compound variation of rotenoids within *T. vogelii* which is popularly used for pest control in vegetables among small holder farmers. Fang and Casida, (1999) reported some variation in the rotenoid content of leaves that could also influence the pesticidal efficacy of this species. Some authors perceive that the insecticidal activity of *T. vogelii* is largely derived from rotenoids of which tephrosin and deguelin are the most abundant (Marston et al., 1984; Stevenson et al., 2012).

This study was therefore conducted in order to understand how the spatial and temporal chemical variations might affect use of *T. vogelii* against red spider mites and aphids in tomato and brassicas. In addition the study examined whether the *T. vogelii* leaf extracts easily degraded after spraying on crops by determining the rate of compound breakdown on bean plants. Finally, the implications of using pesticidal plants in pest control were considered. It was hypothesised that compounds from *T. vogelii* would vary at different times of the year and if such plant materials were used against red spider mites and aphids, would adversely affect and ultimately have significant effect for pest control.

5.2 MATERIALS AND METHODS

5.2.1 Test invertebrates

A mite colony was established from mites collected in tomato gardens within Lunyangwa Agricultural Research Station and reared in the insectory of the research laboratories. Five mites were introduced per plant to raise a homogenous culture and were later reared on three to four week old bean plants (*Phaseolus vulgaris*). A separate culture was reared on four week old tomato plants raised at the station greenhouses. At Natural Resources Institute (NRI), a subculture of about fifty mites was brought from the Lunyangwa Research Station to UK laboratories. These mites were initially reared on tomato (Money maker) free from pesticides and were left to develop and reproduce for about two weeks before setting up the experiment. The experiment was conducted with temperature set at 27 ± 3°C.

5.2.2 Plant materials

Fresh leaves of *T. vogelii* plant materials were collected from Lunyangwa Agricultural Research Station fields and prepared as described in section 4.2.2. Lunyangwa is the regional agricultural research centre in the northern part of Malawi. The station is located some 7 kilometres northeast of Mzuzu, on latitude 11^0 25’ South and longitude 34^0 03’ East. It is on the Viphya plateau, at 1,356 meters above sea level (m.a.s.l.), representing the high altitude ecological zone. *T. vogelii* plant species was identified and authenticated by Dr Gudeta Sileshi from the World Agroforestry Research Centre (ICRAF) and also based on herbarium vouchers reported earlier (Stevenson et al., 2012). The leaves were air dried under shade over a period of one week and ground into powder.

Figure 5.1: T. vogelii field at Lunyangwa Research Station (11°25’39” S, 34°2’45”E, 1356 masl)

Table 5.1: Localities of *T. vogelii* plant samples collected in Malawi for determining chemical constituents.

Village	Flower colour	Location		Elevation
		Latitude South	Longitude East	
Chawaye	white	10°46’5.76”	34°1’35.76”	1212
Choma	white	11°17’48.66”	34°0’33.54”	1322
Kakoko	white	11°28’6.24”	33°58’4.86”	1306
Lumbwezi	purple	10°43’49.8”	34°2’12.54”	1304
Lunyangwa 1	white	11°25’39”	34°2’45”	1356
Lunyangwa 2	purple	11°25’39”	34°2’45”	1356
Luweni	white	10°44’5.1”	34°2’27.84”	1279
Malepula 1	white	11°27’14.28”	33°57’9.66”	1302
Malepula 2	white	11°27’16.14”	33°57’20.4”	1282
Maloto 1	white	10°45’39.24”	34°2’18.78”	1229
Maloto 2	purple	10°45’42.84”	34°2’19.56”	1221
Mkombezi	white	10°56’27.84”	33°58’42.06”	1031
Phwezi	white	10°54’7.02”	34°2’14.16”	1023

5.2.3 Isolation of Tephrosin and Deguelin

T. vogelii leaf samples were air dried for a week at room temperature and ground using a coffee mill and 2 g of the plant materials were extracted in 20 ml of MeOH for 24 h at room temperature as described in section 4.2.2. Each extract was first filtered through Whatman grade 1 paper and an aliquot of the filtrate passed through a 0.45 µm nylon acrodisc filter. From this filtrate, 10 µl of the stock solution was subjected to High Performance Liquid Chromatography (HPLC) analysis. High performance liquid chromatograph (HPLC) is a multipurpose instrument used in pharmaceutical, agrochemical and biochemical industries for analytical and preparative purposes. Normally in the HPLC, a sample is carried by a mobile phase and sample components separated according to their differential affinity for the solid phase packing and the mobile or solvent phase. The extract was eluted and isolation of tephrosin and deguelin were conducted on a waters system (600E pump and 996 PDA detector) using a LichroCART 250-4, RP 18 column, with 5µm pore size; 254nm DAD; 50µL; 1ml/min; 25 to 100% MeOH 20min operating under gradient conditions, with A = MeOH, B = H2O, C = 1% HCO2H in MeCN; A = 0%, B = 90% at t = 0 min; A = 90%, B = 0% at t = 20 min; A = 90%, B = 0% at t = 30 min; A = 0%, B = 90% at t = 31 min; column temperature 30°C and the pressure of the system was 1800 psi at 35 min run time. The vacuum pump was connected to a waters ^{Tm} 717 plus autosampler and through this process, the peak of tephrosin and deguelin eluted at 24.60 and 25.55 min which were separately collected into 7ml vials. It was possible to operate several injections provided that the column was prewashed in MeCN for 5-10 min in order to isolate sufficient quantities of deguelin and tephrosin which was then reserved for further use in experiments. The standard rotenone was purchased from Sigma–Aldrich (Gillingham, Dorset, UK).

5.2.4 Invertebrate Bioassay 1: Biological activity testing of rotenoids against mites in leaf disc bioassays.

Bioassays were conducted at the Natural Resources Institute and Lunyangwa Research Station Entomology laboratories. In order to investigate the activity of compounds isolated from *T. vogelii* against aphids and red spider mites, bioassay described in section 4.2.3 were used. Briefly, leaf discs were prepared using a cork borer and placed bottom side up in bioassay wells then treated with 30 ul of each compound dissolved in acetone to come up with solutions of 0, 50, 100, 500 and 1000 ppm. Acetone was used to solubilise compounds for application to leaf discs because it evaporates rapidly. Acetone is less toxic to mites compared to methanol, which is less volatile and may be absorbed into the leaf more readily and present an effect against mites. The leaf discs were air dried for 30 minutes before being placed in bioassay well and after drying, five adult mites were placed on each disc. Each treatment was replicated four times within a trial. The number of dead mites was recorded 24 hours after treatment. Mites were considered dead if they did not move when probed with a pencil brush.

5.2.5 Invertebrate Bioassay 2: Biological activity testing the efficacy of *T. vogelii* against aphids in whole bean plant bioassays.

Bean plants (Fig 5.2) were grown in a glasshouse at Lunyangwa Research Station. Two bean seeds of the variety Kholopete were sown in pots containing soil mixed with cattle manure (pot sizes were 7 cm diameter and a height of 17 cm). One part of cattle manure was added to three parts of soil to provide adequate fertility for plant growth. When plants reached a height of five to six centimetres some bamboo sticks were inserted into individual pots as staking material for bean plants. The pots were arranged in two rows. The rows were 80 cm apart and the pots 10-15 cm from each other in each row.

The experiment was laid down in a completely randomized design with nine treatments in order to determine the efficacy of *T. vogelii* leaf extracts collected from seven different localities against aphids. *T. vogelii* leaf extracts from the seven different localities (Mkombezi, Luweni, Maloto, Lumbwezi, Malepula, Lunyangwa and Phwezi) were compared to dimethoate and untreated control. These crude extracts represented both the more and less active materials of *T. vogelii*. Each treatment was replicated four times.

A two litre bottled sprayer was used in this experiment. Each treatment used a different two litre bottled sprayer to ensure no treatment effect overlap. The untreated control was sprayed with tap water to simulate the spray wash down of aphids in the other treatments. One round of foliar spray was given to each treatment plot soon after the aphid counts were recorded from ten randomly selected plants on each of the two set rows of pots. Aphid counts were conducted just before each spray period in order to simulate the normal practice with field trials. This experiment was run once in an effort to validate the efficacy of *T. vogelii* leaf extracts from the different localities against aphids.

Figure 5.2: The potted bean experimental trial on the effect of T. vogelii from different localities under the screen house

5.2.6 Determination of rotenoid breakdown under field conditions.

T. vogelii plant materials were collected from one location at Lunyangwa Research Station because these materials are known to be of chemotype 1 which is effective (Stevenson et al 2012). Bean plants were sprayed with *T. vogelii* aqueous extracts (1 plant per treatment) to the point of run off (approx. 50 ml per. plant) using a knapsack sprayer under field conditions and was repeatedly sprayed five consecutive days. The spraying regime followed one day interval using uniform rate of *T. vogelii* leaf extracts on bean plants for five respective days. Thus, each treatment consisted of five uniform doses of *T. vogelii* leaf extracts sprayed on bean plants during early hours of each day. Following the respective applications, bean leaves were harvested, packed bags for determining the rate of rotenoid breakdown under field condition. Under the laboratory, dried bean leaves were crushed soaked and ground to fine powder with a coffee mill. The ground dried bean leaves (2g) were extracted with methanol (20 m l) for 24 h at room temperature. The bean leaf extracts were then filtered through a 0.45 μm nylon acrodisc membrane filter and then 10 ul of the stock solution was subjected to HPLC analysis in order to determine the rotenoid content on the samples. The effluents were monitored with UV detector at 254-280 nm by a 996 photo detector array (PDA) to perform the UV absorbance measurement. The compounds were identified by comparison of UV mass spectra with authenticated standards (Stevenson et al., 2012).

5.2.7 Data analysis

The acaricidal activity under laboratory conditions was subjected to statistical analysis to evaluate the efficacy of tephrosin and deguelin compared to rotenone against red spider mites. All treatments were subjected to complete block design, and four treatments were applied to each concentration block and one control block. Five mites were used for each replication at different concentrations. The percent mortality data was determined 24 hours after treatment application. Thereafter, mortality data was collected and subjected to one way statistical analysis of variance accepting significant differences at $P<0.05$. The LC50 values and estimation of slopes were calculated by probit analysis using SPSS V13 computer software. These values were used to compare toxicities of the different compounds. Acaricidal activity was considered to be significantly different when 95% confidence limits of the LC50 values failed to overlap.

All *T. vogelii* leaf samples were categorised into altitude and geographic references in order to determine the spatial and temporal variation on the collected materials. The altitude ranges were <1200 m, 1200−1300 m and >1300 m) within three geographical spatial clusters of North, Central and South before carrying out an analysis of variance (ANOVA) in order to quantify whether the abundance of any of the rotenoids were affected by their physical location or collection time.

5.3 RESULTS

5.3.1 Contact Toxicity tests

Three compounds isolated from *T. vogelii* (deguelin, rotenone and tephrosin) were toxic to mites although these compounds differed in the level of effect with Tephrosin having significantly greater toxicity compared to deguelin and rotenone. Increased concentration and exposure period increased mortality of mites when exposed to the isolated compounds. At 1000 ppm, tephrosin was highly toxic to mites after 24 h, causing 60% mortality seconded by rotenone that exhibited 50% mortality of mites.

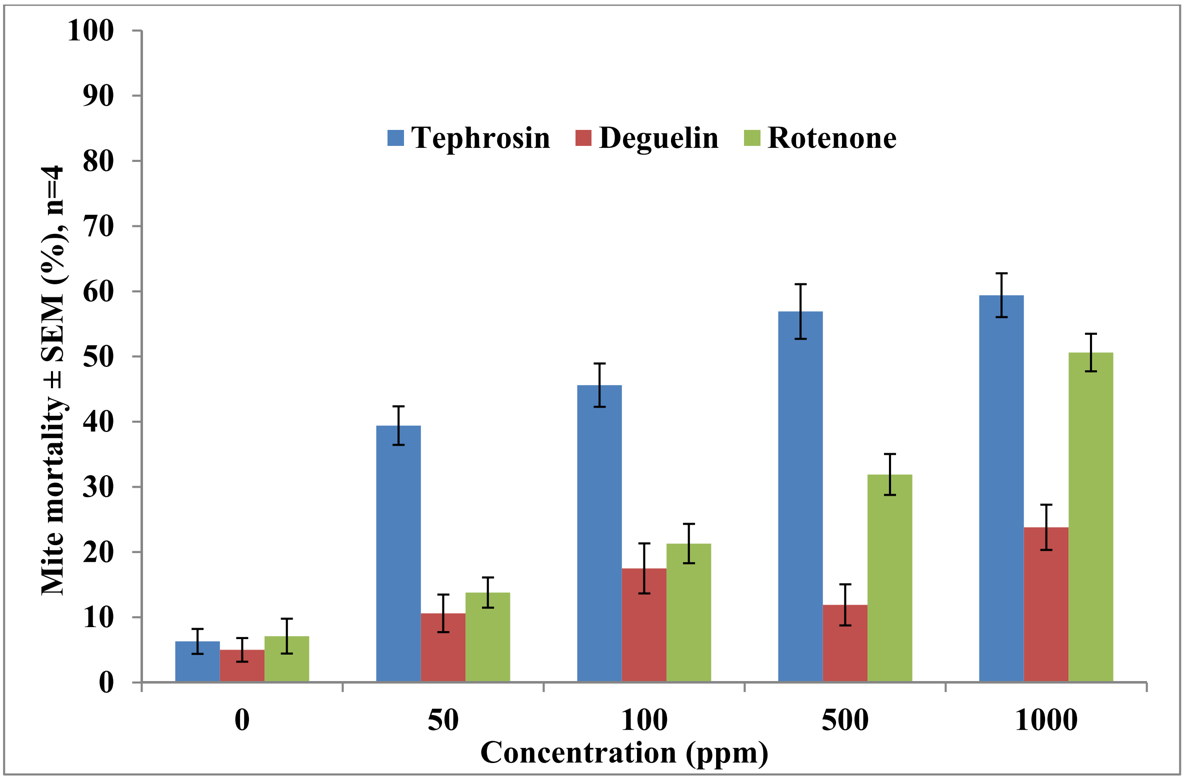


Figure 5.3: Percentage mortality activity (±SEM) of tephrosin, rotenone and deguelin against red spider after 24hr treatment application

While all three rotenoid compounds caused mortality, tephrosin was the most effective causing 40% red spider mortality at 50 ppm, whereas rotenone and deguelin recorded less than 15% mortality (Fig. 5.3) at this low concentration. Toxicity was dose dependent and increased with increasing concentration of all compounds. In this experiment, the toxicity of the rotenoids was considered to be mostly through contact when mites were walking over the treated disc. However, stomach toxicity could not be ruled out completely though it is common with chewing insects such as lepidopterans.

The LC50, 95% confidence limits and chi-square values are presented in Table 5.2. Comparisons of the LC50 values of the compounds against mites indicate that rotenone was the least effective while tephrosin and deguelin were more toxic. After 24hrs the highest mortality (59.4%) was recorded for tephrosin as compared to 50.6% in rotenone with deguelin recording 23.8% mite mortality. The LC_{50} of tephrosin was significantly higher (276 ppm; χ^2 =0.138, 2 df, P=0.933) than that of rotenone (622 ppm; χ^2 =1.581, 2 df, P=0.454). Mite mortality appeared to increase in a dosage dependent manner (Fig. 5.3). Mite mortality significantly varied from the lowest to highest concentration for tephrosin (P<0.006) and rotenone (P<0.0001) respectively. At highest concentration tested (1000 ppm) tephrosin had greater effect on mite mortality than rotenone. Thus, increasing compound concentration caused increased mortality of mites in the bioassay.

Table 5.2: The relative toxicity (LC50, 95% confidence limits, chi square values) of rotenoids tested against mites in the laboratory after 24 Hrs

Compound	Concentration (ppm)	% Mortality	R^2	LC_{50} (95% Fiducial limits)	Sig	χ^2	SE
	0	6.3±1.92					
	50	39.4±2.95 (40.4)					
Tephrosin	100	45.6±3.32 (44.7)	0.983	276 (80 – 471)	0.006	0.138, 2 df; 0.933	0.100
	500	56.9±4.19 (55.6)					
	1000	59.6±3.35 (60.6)					
	0	7.1±2.68					
	50	13.8±2.31 (14.1)					
Rotenone	100	21.3±3.02 (19.5)	0.954	622 (394 – 850)	0.0001	1.581, 2 df; 0.454	0.116
	500	31.9±3.14 (37.2)					
	1000	50.6±2.88 (46.9)					
	0	5±1.82					
	50	10.6±2.88					
Deguelin	100	17.5±3.84	0.35	95 (38-474)	-	-	-
	500	11.9±3.14					
	1000	23.8±3.47					

Figures in brackets show the corrected mortality rate. LC = Lethal Concentration (ppm), R^2 values represent Coefficient of determination, χ^2 represent Chi square SE=Standard Error

5.3.2 Determination of T vogelii leaf extract breakdown

Field experiments were done in the field where environmental effects such as high precipitation rates and ultraviolet radiation occur that may cause degradation of biologically active substances on the sprayed plants. Investigation of rotenoids on the bean leaf extracts of sprayed plants with *T vogelii* leaf extracts over several days was determined using LC/MS. The results revealed that from day two none of the rotenoids (Fig 5.4) were detected on the treated bean leaf extracts. Generally, if a product persists under field condition for at least several days becomes more desirable. However, the results on the residual activity of *T. vogelii* extracts on beans showed that the effect could not persist longer than three days in the field (Fig., 5.4). Such activity was therefore assumed that exposure of the plant extracts to conditions like light and excessive day temperatures and precipitation might have consequences of the rotenoid breakdown. Based on these results, there is high probability that significant reduction of efficacy of the products could be compromised in the field.

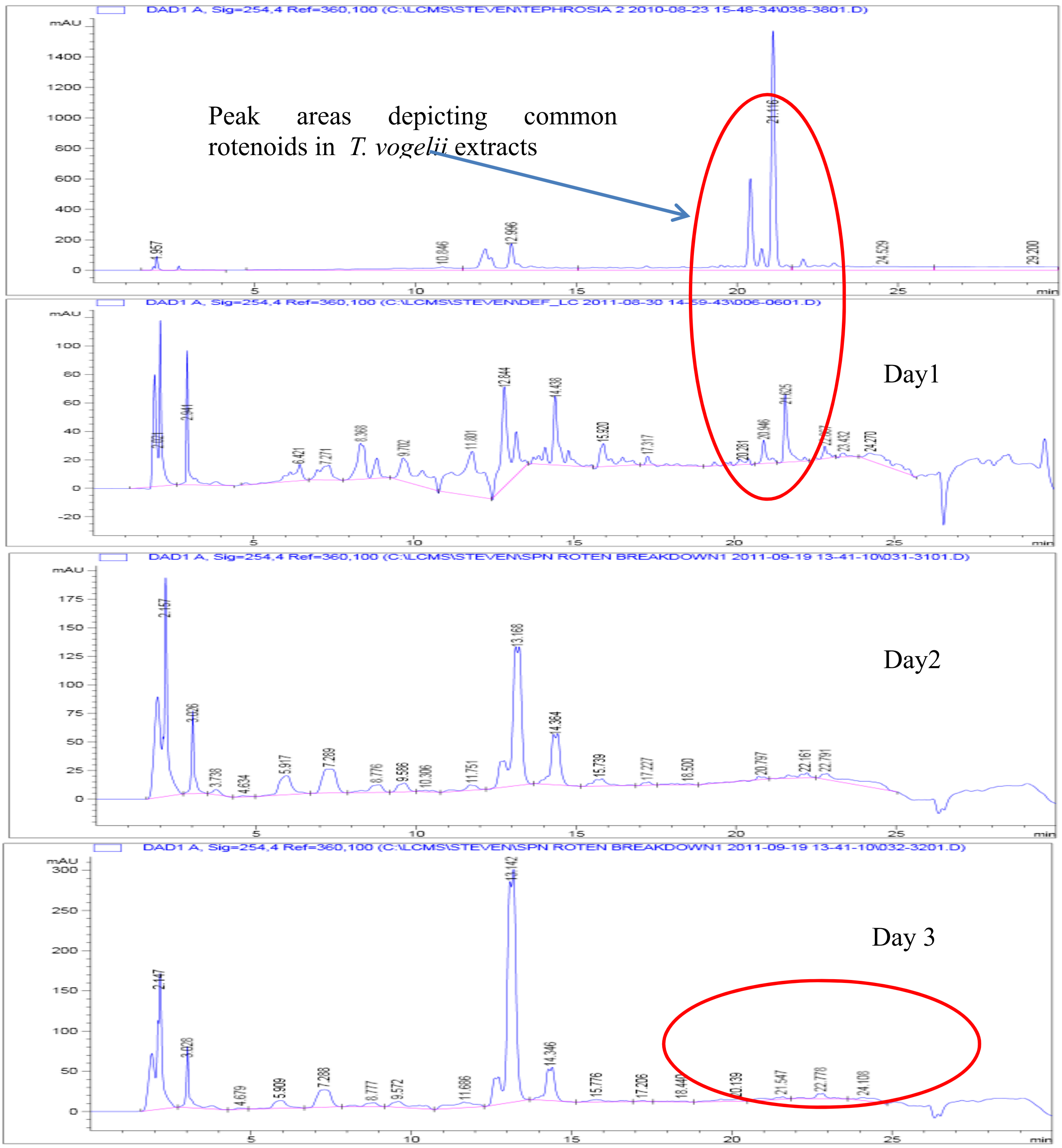


Figure 5.4: LC-MS chromatograms of the typical methanol extract of bean leaf extracts after spraying of T. vogelii extract showing some of the rotenoids variation

In this study, the mass spectrometry of bean plant extracts that were sprayed with *T. vogelii* leaf extracts showed that the corresponding molecular mass of the common rotenoids in *T. vogelii* were not present based on the occurrence of the respective molecular ion in the LC-MS which were *m/z*, 395.4 $[M + H]^+$ (rotenone), m/*z*, 433.4 $[M + Na]^+$ (tephrosin) and *m/z*, 395.4 $[M + H]^+$; and (deguelin). Thus, since rotenoid constituents from *T. vogelii* could not be detected on the sprayed bean leaves, this suggests that the compounds from *T. vogelii* might have degraded over the five day period. It is possible that the compounds in *T. vogelii* had broken down rapidly after being exposed to sunlight. Since use of pesticidal plants depends primarily on knowing their chemical constituents, thus, it is important to undertake preliminary phytochemical screening of the plants in order to understand common variation that may affect their bioactivity. It might be inappropriate to assume that all *T. vogelii* have significant effect on pests when applied to crops. This prompted the study of the spatial and temporal variation of *T. vogelii* plants collected from various localities of northern Malawi. The study showed that major variation occurred in *T. vogelii* plants collected from different localities as discussed below.

5.3.3 Spatio-temporal Variation of Rotenoids within T. vogelii.

The chemical analysis of *T. vogelii* samples collected at three different times of year (Jan, Mar, Jun) from thirteen (13) different farms in Malawi (Table 5.1) showed significant ($P < 0.05$) differences in seasonal occurrence of rotenoids (Fig., 5.5, Table 5.3) and in the relative abundance of tephrosin, deguelin and rotenone. However, there were no significant effects regarding the location (distance and altitude) of the samples, nor any significant interactions between season and location (ANOVA $F = 0.32$, $df = 2$, $P > 0.05$).

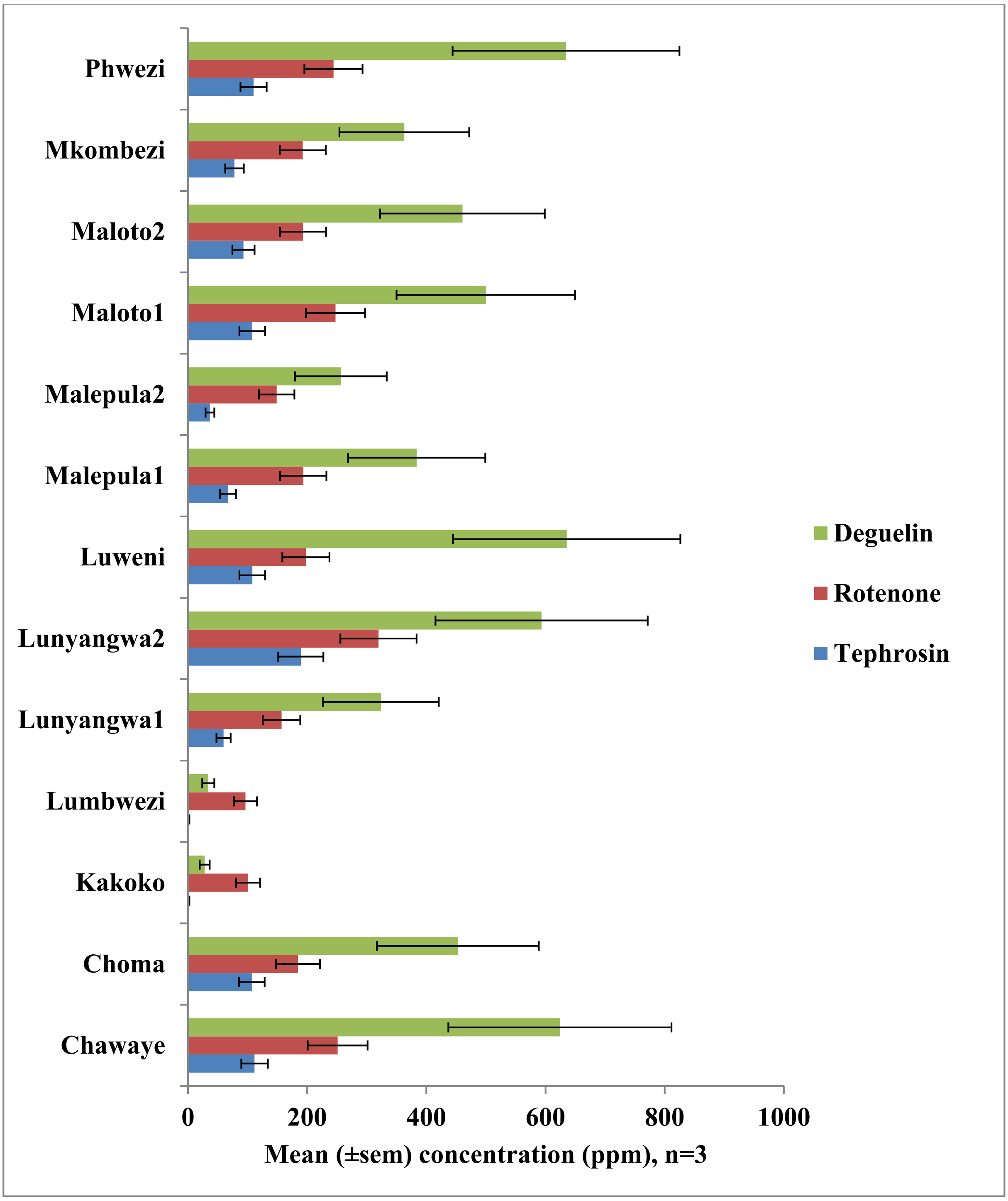


Figure 5.5: Occurrence of rotenoids on T. vogelii plants from the thirteen locations in Malawi

Deguelin and tephrosin production varied across seasons, with deguelin being highest in January and tephrosin highest in June. In contrast, the trend in tephrosin production was highest in June and lowest in January. This inverse relationship in production was statistically significant as verified by linear regression (r 356 2 = 0.14, F = 6.13, df = 1, P = 0.018). However, production for rotenone did not vary significantly across seasons (Table 5.3). The overall efficacy of *T. vogelii* is diminished by its relatively low abundance and efficacy vs the much higher abundance and efficacy of deguelin. Neither altitude nor distance was able to explain any of the chemical variability among sites or seasons (ANOVA F = 0.32, df = 2, P > 0.05). This supports the findings regarding the relative activity of these compounds against tested pest organisms.

Table 5.3: The Effect of Season on the Production of Rotenoids in *T. vogelii* Leaves

Collection time	Mean (±sem) concentration (ppm) from thirteen locations		
	Tephrosin	Rotenone	Deguelin
January 2010	48.3±8.16 b	235.5±26.36 a	665.4±115.91a
March 2010	75.0±21.74 b	158.6±36.37 a	267.2±75.64 b
June 2010	124.2±28.03 a	189.2±26.53 a	288.1±58.99 b

5.3.4 Biological activity of T. vogelii against aphids in whole bean plant bioassays.

Based on the results of the biological activity of *T vogelii* (Figure 5.6), it clearly shows that there is considerable variation on the effect of this plant species from the seven sites against aphids. Aphids were observed on weekly basis to determine the effect of *T. vogelii* that was collected from the seven different localities in this potted bean experiment. The effect of *T. vogelii* against aphids on bean plants under screen house showed that plant materials varied in suppressing aphids (Figure 5.6). The treatments significantly (*P* > 0.05) reduce the population of aphids when compared to control. All the treatments significantly (P <0.05) reduced the damage to bean by aphids. However, the positive control treatment was more effective in suppressing the aphid population than the other treatments. This demonstrates the importance of conducting chemical analysis of the plant species and validating their efficacy before they can be promoted for pest control.

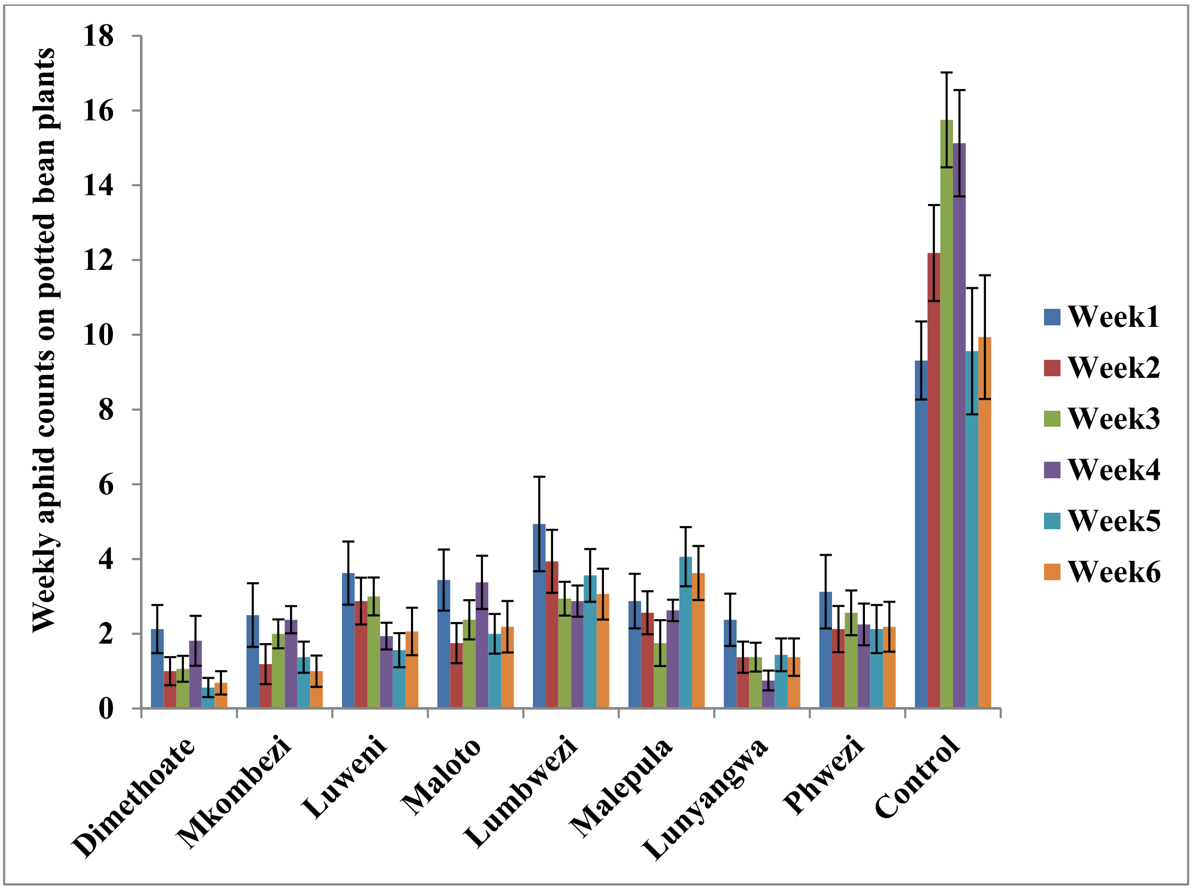


Figure 5.6: Effect of T. vogelii leaf extracts from seven different localities against aphids

5.4 DISCUSSION

Plants produce an enormous diversity of secondary metabolites that are effective against a broad range of insects (Adeyemi. 2010). For example, *Tephrosia* is known to be good source of a number of rotenoids that include rotenone, tephrosin, and deguelin with toxic and deterrent activity toward insects (Simmonds et al. 1990b; Lambert et al., 1993; Machocho et al. 1995; Lapointe et al., 2003; Chen et al., 2014). According to Lambert et al., 1993, the plant has been traditionally used for its ichthyotoxic, insecticidal and food parasiticidal activities in West Africa. . *Tephrosia vogelii* is used as a source of contact insecticides, fish and arrow poisons to several aquatic animals such as snails (Marston et al., 1984; Lambert et al., 1993). The chemical constituents from the genus *Tephrosia* have also been shown to exhibit various bioactivities (Belmain et al., 2012; Chen et al., 2014). Despite this well reported bioactivity, there is surprisingly limited information on the activity of these rotenoids against mites with the exception of rotenone only. Some studies concerning the effect of *T. vogelii* against mites and aphids have not been extensively been conducted but the preliminary acaricidal and aphicidal activity observed here, suggest good indication that this plant could well be used to control these pests. Thus this paper reports important and new findings about the bioactivity of rotenoids against mites and aphids

Chen et al., 2014 provide various traditional use of the genus *Tephrosia* and have outlined its chemistry and biological activities of the plant from different parts of the world. The use of *Tephrosia vogelii* Hook f. (family Leguminosae) extracts is not new to most small holder farmers in Africa (Belmain et al., 2012; Kamanula et al., 2011). It is used to control insect pests in maize, beans, cotton and vegetable crops. In Zambia, *T. vogelii* leaf extracts proved to be highly effective to termites, citrus aphids and red spider mites with mortality rate of 90 to 100% within 24 hours in the laboratory and in the field (Mcdavid and Lesseps, 1995). According to Mbozi, 1996, experiences from Tanzania suggest that *Tephrosia* sprays can also effectively control maize stemborer, *Busseola fusca*. Stoll, 2000 also reported that farmers use *T. vogelii* leaf extracts against some aphids in onion, pepper and beans. He reported that farmers extract leaves using 100-150g per litre of water and add soap as sticker to control flea beetles, cabbage worm and spider mites. This shows that *T. vogelii* has a great promise as source of an effective, safe, inexpensive and easily available botanical pesticide. However, the leaf extracts from *T. vogelii* have been used to stupefy fish in order to easily harvest them for consumption, which also demonstrates the potential risk of some plant materials on the environment.

Rotenone is especially well known for its toxic properties against various invertebrates (Castagnoli et al, 2005, Isman, 2006). Castagnoli et al, (2005) reported toxic effects of rotenone to eggs rather than to females of *T. urticae*. In this study the uptake of rotenoids by the mites must have been simply through contact with toxin when moving over the leaf disc or by consumption if mites fed on the leaf discs that had been treated. The toxic effect increased in a dose dependent manner and according to duration of exposure to the treatments.

It is therefore important to understand these differences since presently much of the grey literature implies that the presence of rotenoids indicates certain biological effects. In this chapter the spatial and temporal variation in some rotenoids is apparent and could affect the efficacy of plant materials when used as a pesticide. Amongst the three *T. vogelii* rotenoids, tephrosin was the most active against red spider mites compared to deguelin and rotenone (Fig., 5.2). These results corroborate with earlier findings that major constituents in *T. vogelii* show insecticidal and repellent effects (Delobel and Malonga, 1987). Levinson (1976) also reported the presence of alkaloids in most of the pesticidal plants that prevent insect pest infestation. He cited that *Tephrosia* contain rotenoids, and that rotenone is the main component of the active ingredients.

However, botanicals are considered to be safer than synthetic pesticides (Belmain et al., 2001) particularly those that are also used for medicinal purposes. Plant-derived products are increasingly being used to combat crop pests because they are natural and are often assumed to be safe for the environment and there is strong evidence that this is the case (Amoabeng et al., 2013). According to Isman, (2008), crude botanical preparations pose no greater risk to human health than conventional insecticides and are probably of substantially lower risk. He suggested that the harmful effects associated with plant compounds to users are largely alleviated by virtue that crude plant extracts are used within a range of 1% to 5% in concentrations. Grainge and Ahmad, 1998 considered phytochemical pesticides could be environmentally benign, biodegradable and safer to higher animals. Belmain et al., 2012 suggest that a fully grown man would need to consume between 2 and 20kg of dried *T. vogelii* leaf at a sitting to suffer a lethal dose. Hence it is clear that the level of risk associated with the use of plant extracts to human health poses less risk to users than conventional insecticides (Isman, 2008).

Some side effects have been reported when using *T. vogelii,* notably amongst fishermen that gather stunned fish. Nwude (1982) recorded an anaesthetic effect on limbs and roughness of skin of people who wade into streams to collect fish poisoned with *T. vogelii*. It was assumed that this effect might have been caused by its principle toxic rotenoids. However, botanicals have been reported to generally degrade (Devlin and Zettel, 1999) more rapidly than most conventional pesticides, and are therefore considered relatively environmentally safe. Fukami and Nakajima (1971) reported that rotenoids are considerably less toxic to mammals than to insects.

Despite earlier reports on the variation in the relative abundance of rotenoids in *T. vogelii* (Irvine and Freyre, 1959; Lambert et al., 1993), there are no previous reports describing the importance of chemical variability in *T. vogelii* with respect to efficacy. Delfel et al., (1970) only reported about some variation in the occurrence of rotenoids in *T. vogelii*. Results presented in this chapter have revealed that rotenoids varied considerably in *T. vogelii* and easily degraded within two to five days once sprayed on plants. This might explain why these plants are of lower risk to beneficial insects because they are less persistent. Other authors have reported that *T vogelii* also contain significant amount of rotenoids (Fukami and Nakajima, 1971; Belmain et al 2012) that break down and behave as toxins and deterrents, particularly for insects (Matovu and Olila, 2007).

There can be great variability in the quality and composition of toxic compounds extracted from plant materials. According to Turek and Stintzing, (2013), botanical insecticides are relatively unstable and easily breakdown when exposed to elements, such as light, temperature, and air. The active compounds from pesticidal plants may also vary with season, growing conditions, age at harvest, differences in extraction methods and storage conditions which may affect their biological efficacy (Clegg and Mackean, 1994; Cabizza et al., 2004). According to Clegg and Mackean, 1994, solar radiation accelerates decomposition and subsequent breakdown of compounds. The composition of compounds in plants can also actively change due to minute changes in their microclimate. It is therefore imperative that the potency of compounds from pesticidal plants be well studied since most of these compounds act as pesticide agents (Stevenson et al., 2012, Belmain et al 2012). Stevenson et al. (2012) studied the rotenoid composition of *T. vogelii* from thirteen localities in Malawi and showed that rotenoids of chemotype 1 were common in 25% of the localities. The chemical analysis of *T. vogelii*, showed various rotenoids, flavonoids, and phenolic compounds (Stevenson et al., 2012). Belmain et al., (2012) studied the biological activity of these compounds and effectively determined that deguelin and rotenone were the principle active substances in the *T. vogelii* against bruchids. Hence, the nature of the active compounds from

T. vogelii responsible for its biological activity should be the subject of further investigation within the southern Africa.

Most importantly the study has shown that the biological activity of tephrosin and deguelin differed significantly. Seasonal variation of rotenoids becomes relevant if farmers are to collect plant materials for pest control. On the basis of these bioassay results, it can be argued that farmers should be harvesting *T. vogelii* leaves in January, when compounds are highest in content. Although it was not significant, the data showed a decline in rotenoid abundance with every 100 m increase in altitude. Other factors such as soil type and rainfall were not measured but may help explain some of the variation. This data can also not exclude the prospect of inherent variation in the production of rotenoids within chemotype 1 or, indeed, the presence of other distinct chemotypes. These current findings on the temporal and spatial variation of *T. vogelii*, become relevant that adequate scientific research so far must be done in order to verify farmers' experiences with pesticidal plants. Due to unknown active ingredients from plant species, it can be difficult to recommend proper rates of application. Therefore, the selection of elite material should be based on the relative occurrence of selecting provenances that produce most active compounds which are particularly important for pest control.

5.5 CONCLUSION

The study has considerably contributed to validation of plant materials but further work is required to study factors that lead to major spatial and temporal variation of the plant materials. The use of *T. vogelii* in pest management needs to be promoted by well-informed messages. It would be advisable to promote the most effective plant material that should be grown on farm in order to use them for pest management based on their chemical composition. The study on spatial and temporal variation of *T. vogelii* has provided some important information whether time and location has a significant effect on performance of plant materials. It presents rather difficult explanation, judging from the fact that this was the first kind of study in Malawi. It is therefore appropriate to develop accurate extension messages on proper use of *T. vogelii*. Further studies need to be conducted before messages are developed for extension workers. Therefore, it is important that thorough research must be conducted before advising farmers about the significance of some pesticidal plants. Further investigations need to be done to determine the limitations on the efficacy of some plant materials.

In the current study, components from *T. vogelii* under laboratory displayed significant effect against aphids and mites. However, it was noted that the source of plant material also plays an important factor on the effect of the plant material. It remains to be seen whether more pesticidal plants can just be used as alternatives to control insect pests or if it will be possible to first carry out similar studies as demonstrated in this study. If plant materials are just collected without confirming the presence of effective compounds, it would affect the ability of such plants to efficiently control pests in the field. This is of paramount importance where resource poor farmers entirely rely on use of plant materials with little capacity to purchase effective synthetic pesticides that may be considered safe. In light of these results, testing of bioactive compounds is the best tool in discovering the most important components in plants against pests that could lead to development of new safe pesticides (Hossain et al 2006).

This study has also revealed that there are differences between *T. vogelii* species from different ecological zones. The biological activity of rotenoids are concentration dependent at naturally occurring levels thus low amounts of these compounds would have implications on the pest control efficacy of the material. In summary, the study has revealed that there could be significant spatial and temporal changes in the chemistry of *T. vogelii* in the samples examined from different locations in Malawi. Naturally, there might also be more significant seasonal changes in most the chemistry of commonly promoted pesticidal plants. This research has therefore enlightened for more focused study on other pesticidal plants before they could be promoted for use in pest control. Importantly, most pesticidal plants grow at different times during the year which may very likely affect the chemistry of the plants. It is therefore imperative that biological studies be conducted on pesticidal plants in order to disclose their efficacy and potential for pest management. Hence more studies are required to better understand how potentially dynamic changes in pesticidal plants affect the composition of compounds in a plant. Consequently, products that easily break down could have practical implications for pest management and recommended field rate is essential to achieve acceptable population reduction. However, if we are to conserve natural enemies, the present results should be considered for the management of pest populations. Such products may be relatively harmless to natural enemies and their use may increase the effectiveness of biological control within the agro ecological system.

CHAPTER 6 GENERAL DISCUSSION

6.1 INTRODUCTION

The most common method of pest control followed at present by many resource poor farmers is the application of synthetic chemicals. Though, these chemicals offer efficient protection against pests, they also cause certain undesirable side effects like residual toxicity, application hazards and environmental pollution (Ntow et al., 2006). Continuous foliar pesticide applications to crops are also known to greatly reduce predators and induce rapid multiplication of pests within a very short period (Mitchell, 1973; Helle and Sabelis, 1985; Devine et al., 2001; Wright, 2001; Macharia et al., 2005; El-Sharabasy, 2010).

Literature shows that resource poor farmers have used pesticidal plant materials to provide effective control of pests and diseases (Belmain and Stevenson, 2001; Kamanula et al., 2011; Ogendo et al 2006; Isman, 2008). The key species in this study, *T. vogelii* and *T. diversifolia*, were previously reported to control arthropod pests, including red spider mites although this was not previously shown to be very effective (Nyirenda, 2000). Sileshi et al., (2008) had also earlier reported that *T. vogelii* was widely used in southern Africa for soil improvement and pesticidal insect control. The discussion in this chapter re-evaluates the results from this thesis that became apparent in the course of study and deduces recommendations and suggests future research that might be worth undertaking.

6.2 FIELD SURVEYS TO DOCUMENT FARMERS KNOWLEDGE REGARDING THE USE OF PESTICIDAL PLANTS FOR PEST MANAGEMENT

Collection of realistic data from vegetable growers on pesticidal plant use for pest management became the main goal. Translating the information collected from the survey also raised questions like what percentage of the resource rural farmers did have the knowledge of pesticidal plant use and if any does the proportion vary from place to place. Field surveys of pesticidal plants could be conducted for different reasons. Some of the reasons include assessment of functions of plant species (Kamatenesi-Mugisha et al., 2007). They help to obtain a record of pesticidal plants from the farmers especially those who are elderly before the knowledge is lost. Since people largely rely on experience collected and passed on over generations then virtually none of this knowledge could be published or documented. Concurrent with the modern trend of increasing urbanization, it is important to protect the biodiversity of local ecosystems. Generally the older generation know which plants are endangered and compiling this information might help to prevent over collecting of these species by indicating other, more common and widespread species with similar uses. Hence surveys are also set up to contribute to documentation of pesticidal plants used in agricultural production and record new plant species used in specific societies which might not have been extensively studied. However Cox (2000), cautioned that if traditional knowledge of the plant species is not well documented, they will soon face extinction depending on the management and conservation of available plant materials.

The purposes of field surveys could be three or fourfold: to gather information on the use of plant species in vegetable pest control, to document valuable knowledge concerning pesticidal plant use which is becoming endangered of being lost and to compare the utilization of pesticidal plants among different societies and in turn transfer pesticidal plant knowledge to succeeding generations. However, promotion of plant materials should be based on thorough scientific studies so that effective plant species should be promoted for pest control. The relative concentration of compounds from pesticidal plants seems very variable. It has been observed that the variation of *T. vogelii* compounds could be related to both time and the geographical location where the plant materials are collected (Stevenson et al 2012). Hence, not all materials could be effective if used for pest control based on time and location where they have been collected. Farmers might be collecting plant materials at a time and location that could not provide required compounds for pest control. Variability in the chemistry might affect the promotion and minimise adoption of relevant pesticidal plants for pest control. As such, promotion of plant species should be based on thorough scientific studies. Thorough chemistry of plant materials must be studied in order to optimise the efficacy of plant materials.

Other reasons include determination of species conservation status (Schemske et al., 1994; van Jaarsveld et al., 1998). This could then stimulate further research on management and conservation of the plant species. Farmers mostly collect plant leaves that they normally pound and soak in water. According to Bonet et al., (1999) the easiest accessibility to leaves is the reason why they are used in most of the preparations. Gerken et al., (2001) reported that about 14% to 25% of farmers in Ghana use traditional plant products for crop protection. Current study has also shown that most commonly reported pesticidal plants included *Tephrosia vogelii, Vernonia amygdalina*, *Tithonia diversifolia, Solanum panduriforme* and *Azadirachta indica*. Plant species should be harvested sustainably focusing on timing of harvesting, material to be harvested and harvesting techniques. It can therefore be concluded that there is potential in using pesticidal plant species in order to reduce adverse use of synthetic pesticides.

Most of plant species were harvested from wild sources suggesting that the majority of plants were not yet cultivated and this reflects the pattern of use of plants in other parts of the world (Yineger and Yewhalaw, 2007; Bussman and Sharon, 2006). Therefore, there is need for cultivation of plant materials in order to increase their economic viability. Amoabeng et al., 2014 argues that cultivation of plant materials is likely to increase their economic viability showing that if pesticidal plants are cultivated, farmers can easily collect plants from within and the wild.

Cultivation of the most important plant species could also reduce from implications of plant extinction of commonly used species as people may over collect due to increased population. Preferences for particular pesticidal plants may be determined by their availability. Hence, plant species such as *T. vogelii* that can be cultivated easily (Mafongoya and Kuntashula, 2005) could prove to be important for wide use. In light of this, consideration to conserve or domesticate potential species should be made as quickly as possible before they disappear completely.

6.3 FIELD VALIDATION ON BIOLOGICAL ACTIVITY OF SOME PESTICIDAL PLANTS

Controlling pests is a major challenge that resource poor farmers face. Crop losses caused by insect pests can have a serious negative impact on livelihoods of farmers in developing countries (Oerke, 1994). Farmers must therefore fight these insect pests in order to obtain tangible outputs from fields. In order to save infested plants from various insect pests, pest-control is almost always necessary. According to Helle and Sabelis (1985), the outbreak of spider mites is often a result of repeated application of non-selective pesticides which might kill natural enemies. This is one, but not the only reason why the alternative means of plant protection should look for alternative option. It is a difficult decision for any farmer to choose to abandon the use of synthetic pesticides for the simple reason that his production yield may decrease. The fact that pesticides are still used by many farmers emphasizes the need to ensure that non persistent pesticides must be promoted. For instance, use of selective pesticides is a major consideration in developing an integrated control program. Even though, the effectiveness of botanicals is not superior to chemicals, they are moderate in their efficacy in reducing pest population. Utilizing pesticides that are relatively harmless to natural enemies could increase the effectiveness of natural predation. Pesticidal plant extracts are also considered safer for beneficial organisms that make them preferable to the synthetic insecticides (Charleston et al., 2006; Amoabeng et al., 2013). Many plant species show potential as alternatives to synthetic pesticides especially in the developing countries. They potentially act as repellents, feeding deterrents or toxins against insect pests (Nawrot and Harmatha, 1994; Hadacel, 2002; Isman, 2006). Many farmers favour pesticidal plants since they are considered to be cost effective, relatively stable and easily degrade. Farmers can also easily collect them within their localities and are easy to prepare. This makes pesticidal plants to have several advantages compared with synthetic insecticides.

Insect pests are traditionally controlled with pesticidal plants (Chimbe and Galley, 1996; Nyirenda, 2000; Mazuma and Mtambo, 2003; Mviha et al., 2004) in some parts of Malawi. Use of some locally available pesticidal plants has often been restricted to defined geographical areas. As such the traditional knowledge has not often spread as a consequence of geographical, social and political reasons. However, this study was conducted in different geographical regions which makes it feasible to let the traditional knowledge spread across regions since the indigenous knowledge is mostly unwritten and much of it remains unrecorded. It is therefore imperative that it gets passed on to younger generation in different societies. According to Schultes and von Reis (1995) it is proper that the scientific community should record and publish this knowledge. This study has taken a step further in introducing use of local pesticidal plants to other areas in Malawi where vegetables are commonly produced.

There are about 300 species of *Tephrosia* in the tropical and subtropical regions of the world, several of which have important uses (Prakash, 1952; Barnes and Freyre, 1967, Gaskins 1972; Lambert et al., 1993). One of such local pesticidal plant used in Malawi crop production is *T. vogelii*. *T. vogelii* leaves are a source of biologically active compounds for pest control and their use is increasingly popular in Malawi and most southern African countries (Kamanula et al., 2011). Extracts of *T. vogelii* have been reported to be effective against bruchids (Boeke et al., 2004; Kawuki et al., 2005). It also enriches soil quality through nitrogen fixation and as well as green mulch (Mafongoya and Kuntashula, 2005; Sileshi et al., 2005; Sileshi et al., 2008). In this context, *T. vogelii* is cultivated extensively on fallow lands and intercropped with maize such that it has remained as popular and rated as most useful plant species in most parts of southern Africa (Kamanula et al., 2011; Stevenson et al., 2012).

6.4 CRUDE USE OF PESTICIDAL PLANTS AGAINST INSECT PESTS

Pesticidal plant materials have some advantages over the synthetic pesticides, especially in developing countries. The reasons for this are that plants can be found locally and can be used to control insect pests (Duraipandiyan et al., 2006). Pesticidal plant extracts for spraying onto crops can be made easily and many of them are readily available for use. Similarly, Amoabeng et al., 2014 suggests that locally available plant species are likely to be safer to use for smallholder farmers and consumers in developing countries. They are also known to easily degrade hence could generally be regarded as safer to users, consumers, animals and the environment due to their non-persistent nature (Buss and Park-Brown, 2002; Isman, 2006). Photodegradation of azadirachtin has previously been reported under field conditions (Ladd et al., 1978; Stokes and Redfern, 1982). For example, Stokes and Redfern, 1982 reported that azadirachtin content was reduced by nearly 50% following 7 days exposure to sunlight. In the present study the degradation of retonone was shown to be similarly rapid suggesting the active components would have lower impacts on non-target species. In some circumstances rapid degradation could be considered a problem as the effect is not persistent and the plant material requires more frequent application but the benefits of lower non target impacts may outweigh the reduced persistence. According to Devlin and Zettel, 1999, phytochemical pesticides are considered environmentally benign, biodegradable and maintain biological diversity of predators (Grainge and Ahmad, 1998). It can be concluded that there is potential in using pesticidal plant extracts in order to reduce adverse use of synthetic pesticides. Finally, it could be emphasized that pesticidal plants used herein are considered as safe both for the environment and health, and they can be recommended for use in plant protection.

This thesis provides the information on efficacy of some pesticidal plants against important insect pests of tomato and rape. Generally the pesticidal plants showed good efficacy on the mortality of red mites and aphids under laboratory and field conditions. Nevertheless, differences in their efficacy were found. In view of this study, it seems appropriate to conclude that some knowledge on the use of pesticidal plants has been validated and may contribute in vegetable pest control amongst resource poor farmers in developing countries. Some of the plant extracts tested in the study may be useful for the development of new botanical insecticides. Remarkably, *T vogelii* and *T diversifolia* have potential as contact toxicity. This observation coincides with the mortality reported by Boeke et al., (2004) and Ramondo, (1997). If pesticidal plants are promoted, they could easily be adopted for continued use as pesticides amongst wider communities (Ngowi et al., 2007).

However, the cost of pesticidal plants is associated with collection and preparation of the plant materials. It is labour intensive that farmers may feel overburdened with the associated activities of plant material processing. This may well be reduced due to communal labour which is usually practiced amongst many farmers in the developing countries. Furthermore, pesticidal plants contain natural insecticides, deterrents/repellents that belong to various groups of chemicals such as alkaloids, rotenoids and pyrethrins (Adeyemi, 2010) which are important in insect pest control. The use of locally available plant materials could be necessary for resource poor farmers and be of potential economic value. Considering their eco- friendly and non-toxic nature, pesticidal plants may be recommended for the suppression of pests in vegetables. As such, use of pesticidal plant extracts becomes more feasible than purchasing and using the synthetic insecticides. This stems from known practical use of pesticidal plants and their effects on non-target organisms and the environment (Isman, 2000; Charleston *et al.,* 2005).

6.5 SPATIAL AND GEOGRAPHICAL VARIATION OF T. VOGELII

T. vogelii is known for its high rotenoid content (Lapointe et al., 2003) with impressive insecticidal potential in southern Africa. Koona and Dorn, (2005) also reported that dried leaves of *T. vogelii* are used for their potential to protect stored legume seeds from damage by the bruchids and as a fish poison (Neuwinger, 2004) in Africa. Due to its popularity, *T. vogelii* has been the subject of many scientific investigations in an attempt to understand a rational scientific basis for its mechanisms of action (Stevenson et al., 2012). However, the typical variation on its activity has not been well understood. The genus Tephrosia is represented in Malawi by two major species; *T vogelii* and *T candida*. Analysis of *T. vogelii* leaves has resulted in the identification of various rotenoids such as deguelin, tephrosin and rotenone (Stevenson et al., 2012). Several other authors (Neuwinger, 1994; Neuwinger, 1996; Lapointe et al., 2003; Neuwinger, 2004; Isman and Akhtar, 2007; Stevenson et al., 2012) have reported that *T. vogelii* is a good source of rotenoids, and these compounds could be responsible for the plant's cited biological effects as a pesticide against different pests (Belmain et al., 2012; Koona and Dorn, 2005). Knowledge of responsible compounds from any plant species becomes necessary to determine the safety and economics of their use in agriculture.

Stevenson et al. (2012) examined and characterised two chemotypes (Chemotype 1 and 2) present in *T. vogelii* dried leaves which are reported across southern Africa. This suggests that some effects of plant materials against insect pests might be from such variability and consequently affect the efficacy of plant materials. Possibly this study has provided initial background to extensively undertake more studies on other plant materials. It is also possible that large number of plants vary due to the varieties of the plant materials from different localities.

According to Adeyemi (2010), plant species produce a diverse group of chemicals that contain natural insecticides. A mixture of compounds with different physical properties becomes important for insect pest control. Völlinger, (1987) suggested that extracts from plants, which contain numerous compounds, are more complex in comparison to synthetic pesticides and may therefore delay the build up of resistance. He compared the development of resistance to neem seed kernel (NSKE) and deltamethrin in the strains of *P xylostella* and expected that the diamond back moth to develop resistance to a single toxicant like deltamethrin. However, the combination of behavioural and physiological actions of pesticidal plant products such as neem deters the development of resistance (Rice, 1993). Most successful plant materials typically synthesize a wide range of moderately toxic defense compounds that could be highly toxic to insect pests and can play a significant role, as part of an integrated pest management. The knowledge of chemical properties of such compounds is necessary to determine the safety and economic use of plant materials in agriculture.

It is noteworthy that the leaves of *T. vogelii* have both insecticidal and acaricidal effect in this thesis. The leaf extracts of this plant have previously shown some promise for application to protect stored legume seeds against bruchid species (Koona and Dorn, 2005; Belmain et al., 2012). The results in chapter 5 of this thesis, however, showed that rotenoids, the major compounds found in *T. vogelii*, varied from location to location which could influence the activity of this pesticidal plant against pests. Further research by Belmain et al (2012) indicated that temporal and spatial variation of compounds in *T. vogelii* affected the insecticidal activity against bruchids hence the need for more research before it can be promoted. The spatial and temporal variation may have occurred due to differences in soil composition, management practices and altitude where *T vogelii* was cultivated. Similarly, studies must be done on this plant within southern Africa to ensure sustainable use and optimize the application of *T. vogelii* for pest management.

6.6 CRITIQUE OF RESEARCH METHODS

There has been a growing interest in the use of pesticidal plants for the protection of agricultural insect pests due to their relative biosafety, inexpensiveness, low mammalian toxicity and eco-friendliness compared to the synthetic chemicals (Nyirenda, 2000; Belmain, 2001; Talukder, 2006; Ogendo et al., 2006; Sileshi, 2006). Earlier studies by Golob et al (1982) also showed that locally available materials have significance in protecting insect pests. In this thesis, field studies have provided relevant information on significance of some plant materials that farmers generally use in vegetable pest control. However, the research required comprehensive studies on the effect of pesticidal plants against natural enemies and quick identification of pesticidal plants. More studies must be conducted to understand the effect of these plant materials against commonly available natural enemies. It is also proposed that studies of this nature require strong teamwork especially during field surveys when collective action may be required in order to have prompt identification and naming of plant species. This therefore requires major involvement of diverse research team to quickly come up with the scientific naming of plants through involvement of plant taxonomists, extension staff and relevant research staff.

Data from participatory on-farm trials take many forms, from insect pest populations, diseases and crop yields measured on individual plots. It therefore calls for appropriate choice of analysis methods depending on the set objectives, the experimental design and type of measurements to be taken. Generating information for participating farmers, for other members of the same community or for wider application require different designs. If such experiments need to be repeated with farmer involvement, one should consider the set differences before making any conclusions. It is very important that farmers understand the purpose of the study and what is being assessed which may require some training before setting up the trials. Lack of understanding may lead to the generation of inaccurate or unimportant information. It is important to critically examine each step and make sure that the involved partners are well trained in every step of experimentation. Worse still, it may lead to inappropriate actions by farmers if they are not well trained in conducting field experiments that may in turn invalidate the experiment. Coe and Franzel (2000) summarize the research design principles that must still be followed if the research is to lead to valid predictions/inferences. It is also valuable to know the farm to farm variability so that your desired results should reflect directly to the set objectives based on the research design you are to consider. However, the findings in this study would enable to assess preliminary information on plants used for pest control in order to reduce insect crop losses.

Tephrosia vogelii contain mixtures of rotenoids such as rotenone, tephrosin, deguelin and other flavonoids (Stevenson et al., 2012). In Chapter 5, studies on *T. vogelii* have revealed that due to the presence and absence of specific compounds account to biological activity against red spider mites. This is in agreement with earlier findings that rotenoids were responsible for the biological activity of *T. vogelii* against insect pests (Simmonds et al., 1990b; Machocho et al., 1995). *T. vogelii* has also been reported to be effective against bruchids (Boeke *et al*., 2004). However, the use of *T. vogelii* for pest management needs to be provided with intensively well-informed extension services. Belmain et al., 2012 argues that there is substantial seasonal variation in occurrence of rotenoids that may affect the biological activity of *T. vogelii* against pests. The results from chapter 5 of this study agree that chemical composition of *T. vogelii* varies over seasons and locations. It was clear that deguelin was highest in January while more tephrosin occurred in June. Hence, farmers must be advised on the most opportune time to collect plant material for cultivation in order to maximize on production of necessary rotenoids. There is need to support such service with appropriate provision of quality seed materials to be distributed to interested resource poor farmers. Thus, improvement in pesticidal plant products requires further studies in order to improve product efficacy.

Additionally, there is some evidence that pesticidal plant products easily biodegrade and may thus be short lived under field conditions. Numerous researchers have documented that plant materials easily degrade if exposed to sunlight under field conditions (Stokes and Redfern, 1982; Salie et al., 1996; Buss and Park-Brown, 2002). Buss and Park-Brown (2002) noted that rotenone degrades rapidly in air and sunlight thus it provides an excellent biodegradable insecticide. Similarly, results in chapter 5 show the absence of rotenoids from bean leaves sprayed with *T. vogelii* leaf extracts under field condition in short period of time indicating that compounds appear to have easily degraded. Residual spray of *T. vogelii* leaf extracts on beans revealed the possibility of compounds to have easily degraded. The addition of soap could also assist to act as spreaders or wetting agents. Additives act as natural surfactants and could therefore increase plant material activity. This is in agreement with Shaalan *et al.* (2005) who stated that most botanicals have low human toxicity with low half-life and can easily disappear from the environment in a short time. It is therefore more appropriate to apply the pesticidal plant extracts during the late hours of the afternoon in order to enhance the activity of the plant constituents.

Plant species are complex with variable chemical constituents therefore caution should be taken that mammalian toxicity and residual effects still require extensive research studies. This calls for more research in developing countries where crude extracts are mainly used (Isman, 2008). Traditional knowledge concerning the application is of paramount importance, so that the correct concoction is formulated and applied in order to control pests on any crop. Advance information about pest population is also needed for decision-making in pest management. However, obtaining accurate density estimates using local personnel; be it farmer or extension workers can be largely impractical. Information may be exaggerated in order for them to get the support that they may desire to improve cultivation of specific crop.

6.7 COMMERCIALIZATION AND PROPAGATION OF PESTICIDAL PLANTS

Whilst the results of this study may be useful for assessing locally available pesticidal plants, it could be less applicable if extension personnel are not well informed of the findings to inform rural farmers. The achievements of the results could only be considerable if the findings are well informed to policy makers as well as extension staff in order to make the results as robust as possible. Isman 2006 points out that only a handful of successful commercial pesticidal plant products have been put in use. Foerster et al., 2001 alludes to the fact that there is limited information available on application, efficacy and safety issues. However, this information is mostly limited to a few global players. First and foremost it is important to understand how the synthetic pesticide industry operates before pesticidal plants could fully be developed. Pesticidal plant product commercialization remains small and undeveloped because in most cases few initiatives have remained as pilot and demonstration projects without forcefully supporting them to grow. Most companies are reluctant to invest in pesticidal plant production and distribution because pesticidal plant products are considered to be of low cost and efficiency compared to synthetic pesticides. Sola et al., 2014 lobbies that regulations and protocols for production, marketing and trade of pesticidal plants must be reviewed in order to facilitate the development of this industry in Africa.

If plant materials are to be promoted, their propagation must be paramount among resource poor farmers. Mbuya et al., 1994 also reported that natural plants have low seed germination rates. Other than use of seeds, shoot multiplication and rooting of such plant materials could therefore be improved through appropriate propagation methods. However, this is not common and mostly limits availability of most plant materials. Farmers must therefore adopt the planting of pesticidal plants along their farm lands in order to reduce pressure on the natural stands of the plant materials. Similarly, the harvesting of species from the wild is not sustainable because some species face numerous threats through unsustainable harvesting practices and intensities (Hamilton, 2004). Furthermore, natural stands are compromised due to considerable pressure from harvesting of roots for numerous uses (Ouedraogo et al., 2003). Hence initiatives should be worked out to cultivate some of these species for their protection and availability. Zulu et al., 2011 noted that propagation methods are limited for most of African medicinal and pesticidal plants. Hence simply having information on use of plant materials for pest management may not be sufficient than raise awareness and motivate farmers to propagate them. Sola et al., 2014 recommends that friendly procedures such as sustainable forest management, propagation and cultivation of pesticidal plant materials on farms should be promoted.

6.8 CONCLUSION OF THE STUDY

Resource poor farmers are highly constrained and often cannot afford the expensive chemical pesticides. They often rely on producing crops under much compromised input support. Results from this thesis could help farmers by providing suitable control measures for their various pest problems. Most farmers are aware of at least one of the various pesticidal plants evaluated in this thesis. However, farmers were not knowledgeable of the most efficient extraction and application methods. Farmers relied on water for extraction of compounds and did not always appreciate the importance of spraying crops in the evening to extend duration of activity. Clear dissemination of knowledge such as incorporating soap during extraction to improve extraction of compounds should be advocated amongst extension staff as well as farmers.

Good compilation of messages must therefore be done to aid development of appropriate extension materials which could be used during training of extension personnel. If more extension staff members are made aware, then they would act as main liaison officers between researchers and farmers as it is the case with dissemination of other crop production technologies in Malawi. Although policy makers have not taken up the promotion and use of pesticidal materials, they should be well sensitised in order to easily let the information be passed to various government institutions.

The present study established that several plant species are used as pesticidal plants in Malawi. Many species had previous scientific documented use, such as *Tephrosia vogelii, Tagetes minuta*, *Azadirachta indica* and *Vernonia amygdalina*. However, some species such as *Euphorbia tirucalli, Solanum panduriforme* and *Bobgunnia madagascariensis* were associated with pest management in this region in the absence of much scientific literature on their use in crop protection. It was concluded that for such pesticidal plants to be put to extensive use, efficacy studies should be carried out in order to validate farmers' claims.

In conclusion, the use of pesticidal plants could provide alternative tool for the control of vegetable pests like aphids, red mites and diamond back. In addition, pesticidal plants are desirable alternative to synthetic pesticides because they can locally be collected and tend to have little environmental effect. They are also known to be nontoxic to mammal and readily degrade on plants and soil (Isman, 2006). These results suggest that pesticidal plants have the potential for use in the control of aphids and mites. Some of the pesticidal plants tested in this study have shown significant effect and could be potential alternatives for synthetic pesticides.

6.9 RECOMMENDATIONS FOR FUTURE WORK

This study demonstrates the potential of pesticidal plants for use against vegetable pests. The pesticidal plants deserve further investigation to help scientists in identifying cheap and readily available environmentally friendly pest control agents. It has become clear that so many pesticidal plants exist which could be used for pest management to assist the poor resource farmers. However not all plant materials could be studied within this thesis, and therefore further work would assist in understanding the mechanism of activity for some of the plants. This is especially important as pesticidal plants are increasingly being adopted for pest management not only in Malawi, but also in many other tropical countries whose population is predominantly composed of resource poor farmers. Therefore additional information is required for understanding of the mode of action of the various pesticidal plants which would then alleviate farmers' problems in pest management.

Despite the fact that some pesticidal plant materials are well known to farmers, it is important to conduct proper research in order to validate the claims and provide appropriate information on how they can effectively be used. Reliable information is also important if such materials can be advocated for promotion to extension personnel and be accepted by policy makers. Recommendations should include information about the best harvesting period, the most effective application and extraction method and whether the plant material is most appropriate to effectively be used as an alternative to synthetic pesticides. Thus promotion of pesticidal material should be those that are in a position to increase insect mortality.

Although the thesis has successfully validated some selected pesticidal plants against diamond back moth, aphids and red spider mites in Malawi, it only addresses very few vegetable pests. It is recommended that more work focus on identifying active ingredients and mechanism of action in plant species that have not been extensively studied and reported in the literature, namely *Augaria salicifolia* and *Terminalia sericea*. The findings in this thesis clearly suggest that efficacy of plant materials could be affected by spatiotemporal conditions and appropriate chemotype species that grow alongside which could have effect on production of bioactive constituents. This suggests that pesticidal plants need to be studied in different localities before they are promoted widely wherever the plant naturally grows. The specific chemotype, correct material, elite material, time period and localities in order to collect effective plant materials have to be established before the wholesale promotion of pesticidal plant use in pest management.

6.10 SUMMARY FOR FUTURE STUDY

While farmers may claim good activity of any particular plant materials (Chapter 2), in depth studies should be conducted to validate and quantify the effectiveness of such plant materials in order to optimize extraction and application as well as understand potential limitations in their use. Since ecological and geographic conditions can affect pesticidal plants in terms of phytochemical production, researchers can help validate farmers' information on pesticidal plant use in their areas and the potential constraints to more widespread promotion. Farmers should be aware of the growing condition where plant materials are collected. Such factors include altitude, temperature and rainfall pattern.

Based on the results presented in this thesis, the study showed that some selected pesticidal plants can be used for vegetable pest control (Chapters 3 and 4). Simultaneously it was shown that collection location and time of collection of plant materials can affect the level of efficacy (chapter 5). This implies that they could not immediately be recommended for use in other areas with 100% guarantees of efficacy of the plant material. Nevertheless small holder farmers could use them as alternative pest control measures. Generally synthetic insecticides are perceived as expensive while locally available pesticidal plants have got several advantages that outweigh their disadvantages. It is believed that use of pesticidal plants will minimize the undesirable side effects of synthetic insecticides and help to preserve the environment for future generations. They are also easily available and easy to use and perceived as cheap amongst resource poor peasant farmers. However, farmers need to be trained in handling of pesticidal plant materials considering that they can sometimes be unsafe.

Hence research on pesticidal plants needs to continue to increase their reliability, safety and cost effectiveness for environmentally safe vegetable pest control.

Although suggestions for future work have been presented throughout each discussion sections, it should also be noted that timing of application of plant materials is crucial. Further studies are therefore needed to determine the efficacy of pesticidal plants. Some of the materials have also not been studied in this thesis. Based on studies from chapter 2, more work has to be conducted in order to effectively control pests at less expensive cost than synthetic pesticides. Validation of farmers claim would help in coming up with effective alternatives to synthetic chemical pesticides. This justifies further evaluation of plant materials at a larger scale and over several years so that more information is collected.

The study also sought farmers' knowledge and perceptions on effective pesticidal plants against pests on vegetables in Malawi and eastern part of Zambia only. This has possibly given an insight for further research on other crops that would determine pesticidal plants of importance in controlling pests and diseases on other crops. It is worth noticing that more robust screening of pesticidal plants and particularly on other significant crops should be conducted. Such studies should also include the propagation techniques of potential pesticidal plants in order to avoid over destruction of such plant species that would eventually read to extinction of commonly used plants for various pest control and ailments amongst smallholder resource poor farmers.

Future research should be conducted to identify specific ways through which communities and policy makers could be involved in conserving and sustaining habitants where plant species are found and collected. Deliberate initiatives should be advocated amongst farming community to come up with cooperatives that should conserve important plant species in their respective communities once specific technologies can be developed for propagation of locally available plant species.

Protocols could be developed for disseminating the findings from this thesis to end users. Farmers should be informed in selecting most recommended plant materials that could be used for the control of red mites and aphids providing them with proper protocols. Further research on potential residue levels of bioactive constituents on crops under field conditions would help validate the conclusions found under laboratory conditions. Such studies could also help understand the effect of plant materials on natural enemies.

Although pesticidal plants are eco-friendly, the chemistry of plant species is so variable from different locations that is a cause of concern calling for more scientific studies. Greater emphasis is needed before promoting pesticidal plants based on full scientific research. Finally, more research is needed to compare the effectiveness of different pesticidal plants that have not been studied in this thesis. Therefore, future work is required to investigate time of collection, geographic location and timing of application in order to increase adoption rate of plant materials.

7.0 REFERENCES

Abbott W.S. (1925). A Method of computing the effectiveness of an insecticide. Journal of Economic Entomology 18: 265-267.

Adams M., Cousins B. and Manona S. (2000). Land Tenure and Economic Development in Rural South Africa: Constraints and Opportunities. In: B. Cousins (ed) At the Crossroads: Land and Agrarian Reform in South Africa Into the 21st Century Cape Town Programme for Land and Agrarian Studies, University of Western Cape and National Land Committee.

Adedire C.O. and Akinneye J.O. (2004). Biological activity of tree marigold, *Tithonia diversifolia*, on cowpea seed bruchid, *Callosobruchus maculatus* (Coleoptera: Bruchidae). *Annals of Applied Biology, **144**, 185–189*.

Adeyemi M. M. H., (2010). The potential of secondary metabolites in plant material as deterrents against insect pests: A review. *African Journal of Pure and Applied Chemistry* **4(11)**: 243-246.

Adler , L.S. (2000). The ecological significance of toxic nectar. *Oikos* **91**: 409 – 420.

Ahmad M. (2007). Insecticide resistance mechanisms and their Management in *Helicoverpa armigera* (Hübner) *– A review J Agric Res **45**:319-335.*

Ahmed A.A.I., Gesraha M.A. and Zebitz C.P.W., (2007). Bioactivity of two neem products on *Aphis fabae*. *Journal of Applied Sciences Research **3**: 392-398.*

Akhtar Y. and Isman M.B., (2004). Comparative growth inhibitory and antifeedant effects of plant extracts and pure allelochemicals on four phytophagous insect species. *J Appl Entomol*; 128: 32-38.

Altieri M.A. (1993). Ethnoscience and biodiversity: key elements in the design of sustainable pest management systems for small farmers in developing countries. *Agr Ecosyst Environ **46**, 257-272.*

Amoabeng, B. W., Gurr, G. M. Gitau, C. W., Nicol, H.I., Munyakazi, L. Stevenson, P. C. (**2013**). Tri-trophic insecticidal effects of African plants against cabbage pests. *PLoS One*. 8(10): e78651.

Amoabeng, B. W., Gurr, G. M. Gitau, C. W., Stevenson, P. C. (2014). Cost: benefit analysis of botanical insecticide use in cabbage: implications for smallholder farmers in developing countries. *Crop Protection*. **57**, 71-76.

Andow D.A., (1991). Vegetational diversity and arthropod population response. *Annu. Rev. Entomol., **36**: 561-586.*

Anonymous, (2004). A guide to Agricultural production and natural resources management. Ministry of Agriculture and Food Security, Lilongwe, Malawi.

Antonious G.F., Meyer J. E. and Snyder J.C., (2006). Toxicity and repellency of hot pepper extracts to spider mite, Tetranychus urticae Koch. *Journal of environmental science and health **41**:1383-1391.*

Antonious, G.F. and Snyder, J.C. (2006). Natural products: Repellency and toxicity of wild tomato leaf extracts to the two-spotted spider mite, *Tetranychus urticae* Koch. *J. Environ. Sci. Health **41**, 43–55.*

Antonious, G.F.; Byers, M.E. and Snyder, J.C. (1998). Residues and fate of endosulfan on field grown pepper and tomato. *Pesticide Sci., **54**, 61–67.*

Arancon, N.Q., Edwards, C.A., Yardim, E.N., Oliver, T.J., Byrne, R.J., Keeney, G., (2006). Suppression of two-spotted spider mite (*Tetranychus urticae*), mealy bug (*Pseudococcus sp*.), and aphids (*Myzus persicae*) populations and damage by vermicomposts. *Crop Prot.* **26**, 29–39.

Asare-Bediako E., Addo-Quaye A.A. and Mohammed A., (2010). Control of diamondback moth (*Plutella xylostella)* on cabbage *(Brassica oleracea* var *capitata*) using intercropping with non-host crops. Am. J. Food Technol., **5**(4): 269-274.

Asawalam E.F. and Hassanali A. (2006). Constituents of the essential oil of *Vernonia amygdalina* as maize weevil protectants. *Tropical and Subtropical Agroecosystems* **6**: 95-102.

Ayalew, G., (2006). Comparison of yield loss on cabbage from Diamondback moth, *Plutella xylostella* L. (Lepidoptera: Plutellidae) using two insecticides. *Crop Prot.* ***25****, 915–919.*

Baker J.T., Borris R.R., Carte B., Cordell G.A., Soejarto D.D., Cragg G.M., Gupta M.P., Iwu M.M., Ladulid D.R., Tyler V.E. (1995). Natural product drug discovery and development: New perspective on international collaboration. *J. Nat. Prod.,* **58**: 1325-1357.

Bakkali, F., Averbeck, S., Averbeck, D., Waomar, M., (2008). Biological effects of essential oils-a review. *Food Chem. Toxicol.* **46**, 446–475.

Barnes D.K. and Freyre R.H. (1967). Recovery of natural insecticides from *Tephrosia vogelii.* III. An improved procedure for sampling and assaying rotenoid content in leaves. *Economic Botany* ***21****:93-98.*

Belmain SR, Neal GE, Ray D, Golob, P (2001). Insecticidal and vertebrate toxicity associated with ethnobotanicals used as postharvest protectants in Ghana. *Food Chem. Toxicol.* **39**: 287-291.

Belmain, S.R., B. A. Amoah, S. P. Nyirenda, J. F. Kamanula, and P.C. Stevenson, **(2012).** Highly Variable Insect Control Efficacy of *Tephrosia vogelii* Chemotypes. *Journal of Agricultural and Food Chemistry* **60**: 10055−10063.

Belmain, S.R., Haggar, J., Holt, J. and Stevenson, P.C. (2013). Managing legume pests in sub-Saharan Africa: Challenges and prospects for improving food security and nutrition through agroecological intensification. Chatham Maritime (United Kingdom): Natural Resources Institute, University of Greenwich. 34p.

Berger A. (1994). Using natural pesticides: Current and future perspectives. A report for the plant protection improvement programme in Botswana, Zambia and Tanzania. http://www.blackherbals.com/using_natural_pesticides.htm. Last accessed August, 2014.

Berkes, F. (2008). *Sacred Ecology:* Traditional ecological knowledge and resources management, 2nd edition, Routledge, New York, 336 pp.

Björnsen Gurung A. (2003). Insects–a mistake in God's creation? Tharu farmers' perception and knowledge of insects: A case study of Gobardiha Village Development Committee, Dang-Deukhuri, Nepal. *Agriculture and Human Values* ***20****, 337–370.*

Boeke, S.J., Baumgart, I.R., van Loon, J.J.A., van Huis, A., Dicke, M. and Kossou, D.K. (2004). Toxicity and repellence of African plants traditionally used for the protection of stored cowpea against *Callosobruchus maculatus*. *Journal of Stored Products Research*, **40**: 423-438.

Bok, I., Madisa M., Machacha, D, Moamongwe M. and More, K. (2006). Manual for Vegetable Production in Botswana. Ministry of Agriculture, Botswana.

Bonato O. (1999). The effect of temperature on life history parameters of *Tetranychus evansi* (Acari: Tetranychidae). *Experimental and Applied Acarology* **23** (1), 11-19.

Bonet, M.A., Parada, M., Selga, A., and Valles, J., (1999). Studies on pharmaceutical ethnobotany in the regions of L'Alt Emporda and Les Guilleries (Catalonia, Iberian Peninsula). *Journal of Ethnopharmacology* **68**: 145–168.

Buss, E.A. and Park-Brown, S.G., (2002). Natural Products for Insect Pest Management. UF/IFAS Publication ENY-350 URL. http://edis ifas ufl edu/IN197. Last accessed 24/12/2012.

Bussman, R.W. and Sharon, D., (2006). Traditional medicinal plant use in Northern Peru: tracking two thousand years of healing culture. *Journal of Ethnobiology and Ethnomedicine* **2**: 47–64.

Byerlee D., De Janvry A. and Sa doulet E., (2009). Agriculture for development: Toward a new paradigm. *Annual Review of Resource Economics*, **1**:15-31.

Cabizza, M.; Angioni, A.; Melis, M.; Cabras, M.; Tuberoso, C.V.; Cabras, P. (2004). Rotenone and rotenoids in cubé resins, formulations, and residues on olives. J. Agric. Food Chem. **52**, 288−293.

Campbell, M.M. (1983). A test for repellency to non – biting flies and a comparison of repellents using *Musca domestica* L. *Pesticides Sci. **14**: 199-212.*

Capinera, J. L., (2001). Handbook of vegetable Pests. University of Florida, Academic Press, New York, USA.

Castagnoli M., Liguori M., Simoni S. and Duso C., (2005). Toxicity of some insecticides to *Tetranychus urticae*, *Neoseiulus californicus* and *Tyldeus californicus. Biocontrol **50**: 611-622.*

Chadha M.L., Oluoch M.O., Saka A.R., Mtukuso A.P., Daudi A.T., editors. (2008). Vegetable Research and Development in Malawi, Review and Planning Workshop Proceedings, September 23-24, 2003, Lilongwe, Malawi. AVRDC-The World Vegetable Center, Shanhua, Taiwan. AVRDC Publication No. 08-705. 116 pp.

Chambers, H.W., Boone, Z.S., Carr, R.L., Chanbers, J.E., (2001). Chemistry of organophosphorus insecticides. In: Robert, I.K. (Ed.), Handbook of Pesticide Toxicology, second ed. Academic Press, CA, USA, pp. 913–917.

Charleston, D. S., Kfir, R., Dicke, M. and Vet, L. E. M. (2005). Impact of botanical pesticide derived from *Melia azedarach* and *Azadirachta indica* on the biology of two parasitoid species of the diamondback Moth. *Biological Control,* **33**: 131–142.

Charleston, D.S., Kfir, R., Dicke, M., Vet, L.E., (2006). Impact of botanical extracts derived from *Melia azedarach* and *Azadirachta indica* on populations of *Plutella xylostella* and its natural enemies: a field test of laboratory findings. *Biol. Control* **39**, 105-114.

Chen Y., Yan T., Gao C., Cao w. **and Huang R., (2014).** Natural Products from the Genus *Tephrosia. Molecules* **19**:1432-1458.

Chen, W., Isman, M. B. and Chiu, S. F. (1995). Antifeedant and growth inhibitory effects of the limonoid toosendanin and *Melia toosendan* extracts on the variegated cutworm, *Peridroma saucia*. *Journal Applied Entomology,* **119:** 367–370.

Chimbe, C.M. and Galley, D.J. (1996). Evaluation of material from plants of medicinal importance in Malawi as protectants of stored grain against insects. *Crop protection **15**: 289-294.*

Clegg P. and Mackean D.G. (1994). Farming for sustainable Agriculture. John Wiley and sons, New York.

Coe, R., and S. Franzel. (2000). Keeping research in participatory research. Presented at the 3rd International PRGA Conference, 6-11 November 2000, Nairobi, Kenya.

Cox P.A., (2000). Will tribal knowledge survive the millennium? *Sci.,* 287(5450): 44-45.

Cragg, G. M. and Newman, D. J. (2001). Natural product drug discovery in the next millennium. *Pharmaceut. Biol.*, **39**: 8–17.

Cranham, J.E. and Helle, W., (1985). Pesticide resistance in Tetranychidae. In: Helle, W., Sabelis, M.W. (Eds), Spider Mites, their Ecology, Natural enemies and control, vol 1B. Elsevier Science Publishing, Amsterdam, The Netherlands, pp405-419.

Dales M.J., (1996). A Review of Plant Materials used for Controlling Insect Pests of Stored Products. NRI Bulletin 65, Natural Resources Institute, Chatham, UK.

Delfel, E. N.; Tallent, W. H.; Carlson, D. G.; Wolff, I. A. (1970). Distribution of rotenone and deguelin in *Tephrosia vogelii* and separation of rotenoid-rich fractions. *J. Agric. Food Chem. 18, 385−390.*

Delobel, A. and Malonga, P. (1987). Insecticidal properties of six plant materials against *Caryedon serratus* (Ol.) (Coleoptera: Bruchidae). *Journal of Stored Products Research*, **23** (3): 173-176.

Delvin J.F. and Zettel, T. (1999). Ecoagriculture : Initiatives in Eastern and Southern Africa. Weaver Press, Harare.

Devine, G.J., M. Barber and P.S. Denholm, (2001). Incidence and inheritance of resistance to METIacaricides in European strains of the two-spotted spider mite (*Tetranychus urticae*) (Acari: Tetranychidae). *Pest Manag. Sci.,* 57: 443-448.

Dimetry, N.Z. and S.S. Merei, (1992). Laboratory evaluation of some pesticides on the cabbage aphid, *Brevicoryne brassicae* L. and their side effects on some important natural enemies. *Anz. Schaedlingskund. Pfl.,* ***56****: 16-19.*

Dinham, B., (2003). Growing vegetables in developing countries for local urban populations and export markets: problems confronting small-scale producers. *Pest Manag. Sci.* **59**, 575-582.

Dobson, H., Cooper, J., Manyangarirwa, W., Karuma, J. and Chiimba, W. (2002). Integrated Vegetable Pest Management. NRI, Chatham Maritime, UK.

Dubey, N.K., Shukla, R., Kumar, A., Singh, P., Prakash, B., (2010). Prospects of botanical pesticides in sustainable agriculture. *Curr. Sci.* 98, 479–480.

Duraipandiyan V, Ayyanar M, Ignacimuthu S. (2006). Antimicrobial activity of some ethnomedicinal plants used by Paliyar tribe from Tamil Nadu, India. *Complementary Altern Med.* 6:35–41.

Dyer, L.A., Dodson, C.D. and Gentry, G. (2003). A bioassay for insect deterrent compounds found in plant and animal tissues. *Phytochem. Anal.*, **14**, 381-388.

Ecobichon D.J., (2001). Pesticide use in developing countries. *Toxicol* **160**:27–33.

El-Sharabasy, H. M., (2010). Acaricidal activities of *Artemisia judaica* L. extracts against *Tetranychus urticae* Koch and its predator *Phytoseiulus persimilis* Athias Henriot (Tetranychidae : Phytoseiidae). *Journal of Biopesticides,* 3: 514 – 519.

Erasto P, Grierson D.S., Afolayan A.J. (2006). Bioactive sesquiterpene lactones from the leaves of *Vernonia amygdalina*. *J. Ethnopharmacol*., **106**: 117-120.

Faithpraise F. O., J. Idung, C. R. Chatwin, R. C. D. Young and P. Birch, (2014). Targeting the Life Cycle Stages of the Diamond Back Moth (Plutella xylostella) with Three Different Parasitoid Wasps. International Journal of Biological, Food, Veterinary and Agricultural Engineering **8**: 520-528.

Fang, N.B. and Casida, J.E., (1999). Cubé resin insecticide: identification and biological activity of 29 rotenoid constituents. *J. Agric. Food Chem.* **47**, 2130–2136.

FAO. (2006), FAO Production year book, Rome: Food and Agriculture Organisation of the United Nations.

Farag, N. A. and Gesraha, M. A. (2007). Impact of four Insecticides on the parasitoid wasp, *Diaertiella rapae* and its host aphid, *Brevicoryne brassicae* under laboratory conditions. *Res. J. Agric. Biol. Sci.*, **3**: 529-533.

Foerster, P., Varela, A., and Roth, J., (2001). Best practices for the Introduction of Non-Synthetic Pesticides in Selected Cropping Systems: Experiences gained from selected crops in Developing Countries, GTZ, Eschborn, 152 pp. http://www2.gtz.de/dokumente/bib/02-0007.pdf. Last accessed 20 Feb., 2015.

Fukami, H. and Nakajima, M., (1971). Rotenone and rotenoids. In: Jacobson, M., Crosby, D.G. (Eds.), Naturally Occurring insecticides. Marcel Dekker, New York, p. 71.

Gaskins M.H., White G.A and Martin F.W. (1972). *Tephrosia vogelii*; A source of rotenoids for insecticidal and pesticidal use. *US Dept Agricultural Technol Bull 1445*.

Gerken A, Suglo J.V. and Braun M., (2001). Pesticides use and policies in Ghana. Pesticide Policy Project, Publication series 10: 90.

Golob P., Mwambula J., Mhango V. and Ngulube F. (1982). The use of locally available materials as protectants of maize grain against insect infestation during storage in Malawi. *J. stored Prod. Res.* 18, 67-74.

Grainge, M. and Ahmed, S. (1998). Handbook of plants with pest-control properties. Wiley, New York, pp. 470.

Gray, S. M. and Gildow, F. (2003). Luteovirus-Aphid Interactions. *Annu. Rev. Phytopathol*., **41**: 539-566.

Grzywacz D, Rossbach A, Rauf A, Russell D, Srinivasan R. and Shelton A.M., (2010). Current control methods for diamondback moth and other Brassica insect pests and the prospects for improved management with lepidopteran-resistant Bt vegetable brassicas in Asia and Africa. *Crop Protect* **29**: 68-79.

Grzywacz, D., Stevenson, P.C., Belmain, S.R. and Wilson, K. (2014). The use of indigenous ecological resources for pest control in Africa, *Food Security,* **6**, 71-86.

Guimarães A.S. and Mourão J. S. (2006). Management of plant species for controlling pests, by peasant farmers at Lagoa Seca, Paraíba state, Brazil: an ethnoecological approach. *Journal of Ethnomedicine* 2: 42.46

Gujar, G.T., (1999). Farmers' fight against diamondback moth, *Pesticides World*, 64-65.

Hadacel F (2002). Secondary Metabolites as Plant Traits: Current Assessment and Future Perspectives**.** *Critical Reviews in Plant Sciences,* **21**(4), 273-322.

Hamilton, A.C., (2004). Medicinal plants, conservation and livelihoods. *Biodiversity and Conservation* **13**: 1477–1517.

Harve, G. and Kamath, V., (2004). Larvicidal activity of plant extracts used alone and in combination with known synthetic larvicidal agents against *Aedes aegypti*. *Indian J. Exp. Biol.* **42**, 1216–1219.

Helle, W. and M.W. Sabelis, (1985). Spider Mites. Their Biology, Natural Enemies and Control. Vol. 1A. Elsevier, Amsterdam, Oxford, New York, Tokio.

Hema, H. (1988). Development of pyrethroid resistance in the diamond back moth. *Appl. Ent. Zool*. 21(2): 166-175.

Henderson, L. (2001). Alien weeds and Invasive plants: A complete guide to declared weeds and invaders in South Africa. Paarl printers, Cape Town, South Africa. Pg 140.

Hill, D.S. and Waller, J.M. (1978). Pests and Diseases of Tropical Crops. Vol. 2. Longman, New York, USA.

Hill, D.S., (1983). Agricultural insect pests of the tropics and their control. Cambridge University press, New York, USA.

Holt, G. A. and Chandra, A. (2002). Herbs in the modern healthcare environment—An overview of uses, legalities, and the role of the healthcare professional. *Clin.Res. Regulatory Affairs (USA)*, *19*, 83–107

Hooks C.R.R. and Johnson M.W. (2003). Impact of agricultural diversification on the insect community of cruciferous crops. *Crop Prot*., 22: 223-238.

Hossain, S., Haque M. M. and Naher, N. (2006). Control of two–spotted spider mite *Tetranychus urticae* Koch (Acari:Tetranychidae) by some selected chemicals. *Univ. j. zool. Rajshahi Univ.* 25:15-18.

Iftner, D.C. and Hall, F.R. (1984). The effects of fenvalerate and permethrin residues on *Tetranychus urticae* Koch fecundity and rate of development. *J. Agric. Entomol*. **1**:191-200.

Ijeh I.I. and Ejike C.E.C.C., (2011). Current perspectives on the medicinal potentials of *Vernonia amygdalina* Del. *Journal of Medicinal Plants Research* **7**: 1051-1061.

Irvine, J. E. and Freyre, R. H., (1959). Source materials for rotenone occurrence of rotenoids in some species of the genus Tephrosia. *J.Agric. Food Chem.* **7**, 106−107.

Isman M. B. (2008). Botanical insecticides: for richer, for poorer. *Pest Management Science* 64:8-11.

Isman M.B. and Grieneisen M.L., (2014). Botanical insecticide research: many publications, limited useful data. *Trends in plant sci* (In Press).

Isman M.B., (2000). Plant essential oils for pest and disease management. *Crop Protection* **19**: 603-608.

Isman, M. B. (2006). Botanical insecticides, deterrents, and repellents in modern agriculture and an increasingly regulated world. *Annual Review of Entomology* 51: 45-66.

Isman, M.B. (1997). Neem and other botanical insecticides: barriers to commercialization. *Phytoparasitica* 25: 339-344.

Isman, M.B. and Akhtar, Y., (2007). Plant natural products as a source for developing environmentally acceptable insecticides. In: Ishaaya, I., Nauen, R., Horowitz, A.R. (Eds.), Insecticides Design Using Advanced Technologies. Springer-Verlag, Berlin/Heidelberg, pp. 235–248.

Isman, M.B., 1996. Some target and non-target effects of neem insecticides. International Neem Conference, Queensland, Australia. The University of Queensland Gatton College, Gatton, Australia, 4-9 February 1996.

Isman, M.B., Miresmailli, S. and Machial C., (2011). Commercial opportunities for pesticides based on plant essential oils in agriculture, industry and consumer products. *Phytochem. Rev.* 10, 197–204.

Jackson, J.E. (1997). Vegetable crop production in communal areas in Mashonaland: Results of a survey in 1988. In *Smallholder Horticulture in Zimbabwe*. 207. (Eds J.E. Jackson, A. Turner & M. Matanda). Harare: University of Zimbabwe.

Jacobson, M. (1986). The neem tree: natural resistance par excellence. In *Natural resistance of plants to pests*; Green, M.B. and Hedin, P.A. Eds. American Chemical Society: Washington, D.C., pg 220-232.

James, B., Godonou, I., Atcha-Ahowe, C., Glitho, I., Vodouhe, S., Ahanchede, A., Kooyman, C., Goergen, G., (2007). Extending integrated pest management to indigenous vegetables. *Acta. Hortic*. **752**, 89–93.

Kakahel, S.A., K. Ahad, M. Amjad and S.A. Hassan, (1998). The side effects of pesticides on *D. rapae*, a parasitoid of the turnip aphid (*Lipaphis erysmi*). *Anz. Schaedlingskund. Pfl.,* 71: 61-63.

Kamanula, J., Sileshi, G.W., Belmain, S.R., Sola, P., Mvumi, B.M., Nyirenda, G.K.C., Nyirenda, S.P.. and Stevenson, P.C. (2011). Farmers' insect pest management practices and pesticidal plant use for protection of stored maize and beans in Southern Africa. *International Journal of Pest Management* **57**: 41-49.

Kamatenesi-Mugisha M, Oryem-Origa H. and Olwa O., (2007). Medicinal plants used in some gynaecological morbidity ailments in western Uganda. *Afr. J. Ecol.,* 45: 34-40.

Kannan, M., Uthamasamy, S. and Mohan, S. (2004). Impact of insecticides on sucking pests and natural enemy complex of transgenic cotton. *Curr Sci* **86**:726–729.

Karlsson T. (1995). Plant derived pesticides - field trials and farmers experience in Laupula province. In: Proceedings from the first National Symposium in Zambia held in Lusaka, 2nd-5th August of 1994.

Kawuki, R.S., Agona, A., Nampala, P. and Adipala, E. (2005). A comparison of effectiveness of plant-based and synthetic insecticides in the field management of pod and storage pests of cowpea. *Crop Protection*, **24**: 473-478.

Kayambazinthu, D. (1988). Indigenous forest resources conservation in Malawi. Forest Research Institute of Malawi Report No. 88007, Zomba.

Kennedy, J.S., Day, M.F. and Eastop, V.F., (1962). A conspectus of aphids as vectors of plant viruses. Commonwealth Institute of Entomology, London, SW7, 1–114.

Kianmatee S. and Ranamukhaarachchi S.L., (2007). Combining Pest Repellent Plants and Biopesticides for Sustainable Pest S. and Combining Pest Repellent Plants and

Biopesticides for Sustainable Pest Management in Chinese Kale. *J. Asia-Pac. Entomol.,* **10**: 69- 74.

Kibata G.N. (1996). The diamondback moth: a problem pest of brassica crops in Kenya. In: *The management of diamondback moth and other crucifer pests* (eds A Sivapragasam, WH Loke, AK Hussan & GS Lim). Proceedings of the Third International Workshop, 29 October - 1 November 1996, Kuala Lumpur, Malaysia, Malaysian Agricultural Research and Development Institute (MARDI), pp. 47–53.

Klubertanz, T.H., Pedigo, L.P. & Carlson, R.E. (1991). Impact of fungal epizootics on the biology and management of the two spotted spider mite *Tetranychus urticae* in soyabean. *Environ. Entomology*. 20: 731-735.

Knapp, M., Mugada, D. A. and Agong, S. G. (2003b). Screening tomato (*Lycopersicon esculentum*) accessions for resistance to the two-spotted mite (*Tetranychus urticae* Koch):Population growth studies. *Insect Sci. Applic.* ***23**:15-19*.

Knapp, M., Wagener, B., and Navajas, M., (2003a). Molecular discrimination between the spider mite *Tetranychus evansi* Baker; Prichard, an important pest of tomatoes in southern Africa, and the closely related species *T. urticae* Koch (Acarina: Tetranychidae). *African Entomology* 11: 300–304.

Koona, P. and Dorn, S. (2005). Extracts from *Tephrosia vogelii* for the protection of stored legume seeds against damage by three bruchid species. *Annals of Applied Biology*, **147**: 43-48.

Koul, O., Isman M.B. and Ketkar C.M., (1990). Properties and uses of neem, *Azadirachta indica*. *Can. J. Bot*. 68: 1-11.

Kuntashula, E., Mafongoya, P. L., Sileshi, G., and Lungu, S. (2004). Potential of biomass transfer technologies in sustaining vegetable production in the wetlands (dambos) of eastern Zambia. *Experimental Agriculture,* **40**: 37–51.

Kuntashula, E., Sileshi, G., Mafongoya P.L. and Banda, J. (2006). Farmer Participatory Evaluation of the Potential for Organic Vegetable production in the Wetlands of Zambia. *Outlook on Agriculture* 35 (4):299-305.

Ladd, T.L. Jr, Jacobson, M. and Buriff, C.R., (1978). Japanese beetles: extracts from neem tree seeds as feeding deterrents. *J. econ. Ent.* **71**: 810-813.

Laetemia, J.A. and Isman, M.B., (2004). Toxicity and antifeedant activity of crude seed extracts of Annona squamosal (Annonaceae) against lepidopteran pests and natural enemies. *International Journal of Tropical Insect Science* **24**: 150–158.

Lambert N., Trouslot M.F., Nef-Campa C. and Chrestin H. (1993). Production of rotenoids by heterotrophic and photomixotrophic cell cultures of Tephrosia vogelii. *Phytochem* 34 (6): 1515-20.

Lapointe S.L., McKenzie C.L., and Hunter W.B. (2003). Toxicity and repellency of Tephrosia candida to larva and adult Diaprepes root weevil (Coleoptera: Curculionidae). *Journal of Economic Entomology,* **96**, 811–816.

Law-Ogbomo K.E., and Enobakhare D.A., (2007). The use of leaf powders of *Ocimum gratissimum* and *Vernonia amygdalina* for the management of *Sitophilus oryzae* (L.) in stored rice. J. Entomol. 4: 253-257.

Levinson, H.Z. (1976). The defensive role of alkaloids in insects and plants**.**

Liu, T. & Yue, B. 2001. Comparison of some life history parameters between alate and apterous forms of turnip aphid (Homoptera: Aphididae) on cabbage under constant temperatures. *Fla. Entomol*. **84**: 239–242.

Liu, Z.L., Goh S.H., and Ho S.H., (2007). Screening of Chinese medicinal herbs for bioactivity against *Sitophilus zeamais* Motschulsky and *Tribolium castaneuam* (Herbst). *Journal of Stored Product Research* **43:** 290-296.

Locke, J.C. (2008). Identification and Development of Biological Control Agents and Natural Plant Products as BioPesticides. www.usda.gov/research/~jcl.html. Last accessed 08/08/12.

Lowery, D.T., Isman M.B. and Brard, (1993). Laboratory and field evaluation of neem for the control of aphids. J. Econ. Entomol. 886: 864-870

Lowore, J. (1993). Problems with management of natural forests in Malawi. Forest Research Institute of Malawi, Zomba.

Lu, C.T. & Wang, C.L. (2005). An investigation of spider mites on papaya and reevaluation of some acaricides. *Plant Protection Bulletin Taipei,* **47**: 273 – 279.

Lu, W. N., Wu, Y. T. and Kuo, M. H. (2008). Development of species-specific primers for the identification of aphids in Taiwan. *Appl. Entomol. Zool.* **43** (1): 91–96.

Macharia, I., Lohr, B. and De Groote H., (2005). Assessing the potential impact of biological control of *Plutella xylostella* (diamondback moth) in cabbage production in Kenya. *Crop Protection* 24: 981–989.

Machocho, A. K., W. Lwande, J. I. Jondiko, L.V.C. Moreka, and A. Hassanali. (1995). Three new flavonoids from the root of *Tephrosia emoroides* and their antifeedant activity against the larvae of the spotted stalk borer *Chilo partellus* Swinhoe. *Int. J. Pharmacognosy* **33**: 222-227.

Mafongoya, P. L. and Kuntashula, E. (2005). Participatory evaluation of Tephrosia species and provenances for soil fertility improvement and other uses using farmer criteria in eastern Zambia. *Exp. Agric.* 41: 69−80.

Mansour F., Azaizeh H., Saad B., Tadmor Y., Abo-Moch F. and Said O., (2004). The potential of Middle Eastern flora as a source of new safe bio-acaricides to control *Tetranychus cinnabarinus*, the carmine spider mite. *Phytoparasitica **32(1)**: 66-72.*

Mansour, F., Ascher, K.R.S., and Omari, N. (1987). Effect of Neem seed kernel extracts from different solvents on predacious mite *Phytoseiulus persinilis* and phytophagous mite *Tetranychus cinnabarinus*. Proceedings, 3rd International Neem Conference, Nairobi, Kenya.

Mapemba Lawrence D., Maganga M. Assa and Nelson Mango, (2013). Farm Household Production Efficiency in Southern Malawi: An Efficiency Decomposition Approach. *Journal of Economics and Sustainable Development (Online) Vol.4 No.3, 2013.*

Mapfumo P., Chikowo R., Mtambanengwe F., Adjei-Nsiah S., Baijukya F., Maria R., Mvula A. and Giller K., (2008). Farmers' perceptions lead to experimentation and learning. LEISA Magazine 24.4, December 2008, pg 30-31.

Marston, A.; Msonthi, J. D. and Hostettmann, K. (1984). On the reported molluscicidal activity from *Tephrosia vogelii* leaves. *Phytochemistry* 23: 1824−1825.

Matchaya G. (2009). Land ownership security in Malawi. *African Journal of Agricultural Research* **4**: 1-13.

Mathews, G. A., Whellan, J.A. and Mkamanga, G.Y. (1974). Malawi Crop Protection Handbook. Extension Aids Branch, Lilongwe, Malawi.

Matovu, H. and Olila, D. (2007). Larvicidal activity of *Tephrosia vogelii* crude extracts on mosquito larval stages. *Research Journal of Biological Sciences* **2**: 612-616.

Matthews, G.A., (1992). Pesticide Application Methods, 2nd Edition. Longman Scientific and Technical, New York, 405pp.

Mazuma, C.D.L. and Mtambo, C. (2003). Management of Diamondback moth (*Plutella xylostella*). Malawi-Germany plant protection project, Lilongwe, Malawi.

Mbozi, A.D.P., (1996). Fish poison bean shows great promise in IPM. Foes of Famine, 3 (1): 14-15, Kenya.

Mbuya L.P., Msanga C.K., Ruffo C.K., Birnie A. and Tengas B. (1994). Useful trees and shrubs for Tanzania: identification, propagation and management for agricultural and pastoral communities. Regional Soil Conservation Unit (RSCU), Swedish International Development Authority (SIDA).

McCarville M., Oneal M. and Hodgson E. (2011). Field crop insects and soybean aphid management- resistant soybean varieties for Iowa. Department of Entomology, Extension and Outreach, Iowa State University, USA. www.soybeanaphid.info/.

Mcdavid A. and Lesseps R.S.J., (1995). Effects of Tephrosia vogelii leaf extracts on several crop pests. In: Berger A. and Mugoya C.F. (1995). Natural products as pesticides. Proceedings from the first National symposium in Zambia held in Lusaka, 2nd – 5th August of 1994. Swedish University of Agricultural sciences, department of Plant Protection Sciences Report 4, Alnarp 1995.

Miguel, E.A., Avila, J.L., Otero, L.D., Mora, F. and Wolff, B. (1994). A new bioassay for testing plant extracts and pure compounds using red flour beetle *Tribolium castaneum* Herbst. *J. Chem. Ecol*., **20**, 1161-1177.

Mingochi D.S., Luchen S.W. and Kembo J. (1995). Biological control of vegetable pests in Zambia. In: Integrating biological control and host plant resistance. Proceedings of a CTA/IAR/IIBC seminar, Addis Ababa, Ethiopia, 9–14 October 1995. pp. 107–112.

Mitchell, R. (1973). Growth and population dynamics of a spider mite *(Tetranychus urticae Koch,* (Acarina: Tetranychidae). *Ecology* **54**: 1349-1355.

Mochiah M, Banful B, Fening K, Amoabeng B. and Offei Bonsu K., (2011). Botanicals for the management of insect pests in organic vegetable production. *Journal Entomol Nematol* 3: 85-97.

Mohan, M., and Gujar, G.T., 2002. Local variation in susceptibility of the diamondback moth, *Plutella xylostella* (Linnaeus) to insecticides and role of detoxification enzymes. *Crop Prot.* 22, 495–504.

Moraes, G.J. de, McMurtry, J.A. and Baker, E.W., (1987). Redescription and distribution of the spider mites *Tetranychus evansi* and *T. marianae*. *Acarologia* 28 (4): 333–343.

Morgan E.D. (2009): Azadirachtin, a scientific gold mine. *Bioorganic and Medicinal Chemistry*, **17**: 4096-4105.

Moyo M., Nyakudya I.W., Katsvanga C.A.T. and Tafirei R. (2006). Efficacy of the Botanical Pesticides, *Derris elliptica*, *Capsicum frutescens* and *Tagetes minuta* for the Control of *Brevicoryne brassicae* in Vegetables. www.jsd-africa.com/Jsda/Spring2006PDF/ARC_Efficacy/. Last Accessed 6th August, 2011.

Mugisha-Kamatenesi M., Deng A. L., Ogendo J.O., Omolo E. O., Mihale M. J., Otim M., Buyungo J. P. and Bett P. K. (2008). Indigenous Knowledge of Field Insect Pests And Their Management Around Lake Victoria Basin In Uganda. *African Journal of Environmental Science and Technology* 2:342-348.

Mulla, M.S. and Su, Y. (1999). Activity and biological effects of neem products against arthropods of medical and veterinary importance. *J. Am. Mosq. Control. Assoc*., **15**, 133-152.

Mumford, J. D. and Norton, G. A. (1984). Economics of decision making in pest management. *Ann. Rev. Entomol.* 29: 157-174.

Munthali, D.C., Kaunda C.E. and Nyirenda C.B. (1992). The major insect pests, plant diseases and weeds affecting subsistence farmers' crops in the Southern Region of Malawi. Report No. 2, Soil pest project, Chancellor College, Zomba, Malawi.

Murdock L.L, Shade R.E, Kitch L.W, Noar W, Chambliss O.L, Endondo C and Wolfson J.L (1997). Postharvest storage of Cowpea in sub-Saharan Africa. In: Singh BB, Mohan Raj DR, Dashiell KE and Jackai LEN (Eds.*) Advances in Cowpea Research.* Publication of International Institute of Tropical Agriculture (IITA) and Japan International Centre of Agricultural Sciences (JIRCAS), IITA, Ibadan, Nigeria, 302-312

Muzemu S., Mvumi B.M., Nyirenda S.P.M., Sileshi G.W., Sola, P., Kamanula J.F., Belmain S. R. and Stevenson P.C. (2011). Pesticidal effects of indigenous plants extracts against rape aphids and tomato red spider mites. *African Crop Science Conference Proceedings* 10: 169 – 171.

Mviha P., N. Sangole, L. Soko, H. Chidaya and H. Mlenga, (2004). Farmer group activity reports for the DFID Crop Protection Programme (CPP) Bean IPDM Promotion Project in eastern and southern Africa. www.ciat.cgiar.org/africa/pdf/ffd_booklet_April04.pdf/. Last accessed 12th October, 2011.

Mwandila N.J.K., (2009). The control of red spider mites on tomatoes using neem and syringa extracts. PhD Thesis, University of South Africa.

Mwandira C. (2008). The status of the vegetable industry in Malawi: current and future prospects. In: Chadha ML, Oluoch MO, Saka AR, Mtukuso AP, Daudi AT (editors). Vegetable Research and Development in Malawi, Review and Planning Workshop Proceedings, September 23-24, 2003, Lilongwe, Malawi. AVRDC-The World Vegetable Center, Shanhua, Taiwan. AVRDC Publication No. 08-705. 11-27 pp.

Nabirye, J., Nampala, P., Ogenga-Latigo, M.W., Kyamanywa, S., Wilson, H., Odeke, V., Iceduna, C., Adipala, E. (2003). Farmer-participatory evaluation of cowpea integrated pest management (IPM) technologies in Eastern Uganda. *Crop Protection*, 22, 31-38.

Nascimento G. G. F., Locatelli J., Freitas P. C. and Silva, G. L. (2000). Antibacterial Activity Of Plant Extracts and phytochemicals on Antibiotic resistant bacteria. *Brazilian Journal of Microbiology* **31**:247-256.

Nawrot J. and Harmatha J., (1994). Natural products as antifeedants against stored products insects. *Post Harvest News and Information* **5**(2), 17-21.

Neuwinger H.D., (1994). Fish poisoning plants in Africa. *Botanica Acta* **107**, 263-270.

Neuwinger H.D., (1996). African Ethnobotany, Poisons and Drugs Chemistry, Pharmocology, Toxicology Chapman and Hall, London, UK, 743-753.

Neuwinger H.D., (2004). Plants used for poison fishing in tropical Africa. *Toxicon* **44**: 417–430.

Ngowi, A.V.F., Mbise T.J., Ijani, A.S.M., London L. and Ajayi, O.C. (2007). Smallholder vegetable farmers in Northern Tanzania: Pesticides use practices, perceptions, cost and health effects. *Crop Protection* **26**:1617–1624.

Nkhungulu, I.C. and W. Msikita (1985). Importance and development of rape (*Brassica napus* L.) as a vegetable in Zambia. *Acta Horticulturae 153*

NSO, (2008). Population and Housing Census Preliminary Report. National Statistical Office, Zomba, Malawi, September, 2008.

Ntow, W.J., Gijzen, H.J., Kelderman, P. and Drechsel, P. (2006). Farmer perceptions and pesticide use practices in vegetable production in Ghana. *Pest Manag. Sci.* ***62****:356-365*.

Nwude, N., (1982). Plants poisonous to Man in Nigeria. Vet. Hum. Toxicol. 24: 101–106.

Nyirenda, S.P.M., (2000). The effect of different natural pest control products on spider mites *Tetranychus evansi* BARKER & PRITCHARD (Tetranychidae) in tomatoes at Bunda. Bunda College, Lilongwe, Malawi.

Oerke E.C., (1994). Estimated crop losses due to pathogens, animal pests and weeds, in E.C. Oerke, H.W. Dehne, F. Schönbeck, and A. Weber (eds), Crop Production and Crop Protection - Estimated Losses In Major Food and Cash Crops: Amsterdam, Elsevier.

Ogendo, J. O. Deng A. L., Belmain S.R., Walker D.J. and Musandu, A. A. O, (2004). Effect of Insecticidal Plant Materials, *Lantana camara* L. and *Tephrosia vogelii* Hook, on the Quality Parameters of Stored Maize Grains. *The Journal of Food Technology in Africa* **9**: 29-36.

Ogendo, J.O., Kostyukovsky, M., Ravid, U., Matasyoh, J.C., Deng, A.L., Omolo, E.O., Shaaya, E., 2008. Bioactivity of *Ocimum gratissimum* L. oil and two of its constituents against five insect pests attacking stored food products. *J. Stored Prod. Res*. 44, 328-334.

Ogendo, J.O., Omolo, E.O., Deng, A.L., Matasyoh, J.C. and Tabu, I.M. (2006). Field grain losses and insect pest management practices in subsistence agriculture: Farmers' perceptions and practices in Western Kenya. *Journal of Agriculture, Science and Technology*, **8(1)**: 24-42.

Orr A., Mwale B. and Saiti D. (1999). The economic potential of IPM for dimba crops. In Ritchie, J.M. and Muyaso F. (Compilers): Farming systems integrated pest management project: Selected Reports 1996-2000 Vol 2. *Farming systems Research continued. 536 pp.*

Orr, A. and Ritchie J. M. (2004). Learning from failure: smallholder farming systems and IPM in Malawi. *Agricultural Systems* 79: 31-54.

Oruku, L. and Ndun'gu, B., (2001). Final socio-economic report for the peri-urban vegetable IPM thematic cluster. CABI Africa Regional Centre Report, Nairobi, 49 pp.

Orwa C, Mutua A., Kindt R., Jamnadass R, Simons A. (2009). Agroforestree Database: a tree reference and selection guide version 4.0. http://www.worldagroforestry.org/af/treedb/.

Ouedraogo A, Thombiano A, Hahn-Hadjali K. Guinko S (2003). Regeneration of threatened woody species in Eastern Burkina Faso, University of Ouagadougou, BIOLOG, BIOTA W11.

Oyewole I. O., Ibidapo, C. A., Moronkola, D. O., Oduola, A. O., Adeoye G. O., Anyasor G.N. and Obansa J. A., (2008). Anti-malarial and repellent activities of *Tithonia diversifolia* (Hemsl.) leaf extracts. *Journal of Medicinal Plants Research* **8**:171-175.

Palikhe, B.R. (2002). Challenges and options of pesticide use: In the context of Nepal. *Landschaftsökologie und Umweltforschung* **38**:130-141

Pandey, U.K. and Verma, G.S., (1982). Effectiveness of some indigenous plant products against insect- pests of cruciferous vegetables. Department of Zoology, DRS College, India.

Pandey, U.K., Srivastava, A.K., Singh, A.K. and Panday, M., (1982). Evaluation of some plant origin insecticides against Gram Caterpillar, Heliothis armigera, Hubn. Short Notes, Department Of Zoology, D.B.S. College, Kanpur, India.

Paoletti, M. G. and Pimental, D. (2000). Environmental risks of pesticides versus genetic engineering for agricultural pest control. *Journal of Agricultural and Environmental Ethics,* 12: 279-303.

Parekh, J. and Chanda, V.S., (2007). In vitro antimicrobial activity and phytochemical analysis of some Indian medicinal plants. *Turk. J. Biol.* **31**: 53–58.

Park, Y.L. and Lee, J.H. (2002). Leaf cell and tissue damage of cucumber caused by twospotted spider mite (Acari: Tetranychidae). *J. Econ. Entomol*. **95**: 952-957.

Pavela R. (2007): Possibilities of botanical insecticide exploitation in plant protection. *Pest Technology*, **1**: 47–52.

Price L.L. (2001). Demystifying farmers' entomological and pest management knowledge: A methodology for assessing the impacts on knowledge from IPM-FFS and NES interventions. *Agriculture and Human Values* **18**: 153-176.

Price L.L. and Björnsen Gurung A.B. (2006). Describing and measuring ethno-entomological knowledge of rice pests: tradition and change among Asian farmers. *Environment, Development and Sustainability* 8: 507-517.

Rabbinge R., (1993). The ecological background of food production. In: *Crop Protection and Sustainable Agriculture. Ciba Foundation Symposium 177. Wiley & Sons,* 2-29.

Rates S.M.K., (2001). Plants as source of drugs. Toxicon **39**: 603–613.

Rattan R.S., (2010). Mechanism of Action of Insecticidal Secondary Metabolites of Plant Origin. Crop Protect., **29**: 913-920.

Rembold, H. and Sieber, K.P. (1981): Inhibition of oogenesis and ovarian ecdysteroid synthesis by azadirachtin in *Locusta migratoria migratorioides.* Z. Naturf., 36:466-469.

Rice, M., (1993). Built-in Resistance Prevention (BIRP): a Valuable Property of Azadirachtin. In: World Neem Conference, India, Bangalore, pp. 13-14.

Roobakkumar A., Subramaniam M.S.R., Babu A. and Muraleedharan N., (2010). Bioefficacy Of Certain Pant Extracts Against The Red Spider Mite, *Oligonichus coffeae*

(NIETNER) (Acarina: Tetranychidae) Infesting Tea In Tamil Nadu, India. *International Journal of Acarology* **36:** 255–258.

Rosell, G., Quero C., Coll J. and Guerrero A., (2008). Biorational insecticides in pest management. *J. Pest sci* **33**: 103-121.

Roy B., Amin R., Uddin M.N., Islam A.T.M.S., Islam M.J. and Halder B.C. (2005). Leaf extracts of Shiyalmutra (Blumea lacera Dc.) as botanical pesticides against lesser grain borer and rice weevil. *Journal of Biological Sciences* **5** (**2**): 201 – 204.

Runge C. F, Senauer B., Pardey P.G., and Rosegrant M.W., (2003). Ending Hunger by 2050**:** Crucial Investments and Policies. www.ifpri.org. Last accessed June 2013.

Rungeler, P., Lyss, G., Castro, V., Mora, G., Pahl, H.L., Merfort, I., (1998). Study of three sesquiterpene lactones from *Thitonia diversifolia* on their anti-inflammatory activity using the transcription factor MF-Kappa B and enzymes of the arachidonic acid pathway as a target. *Planta Medica* **64**, 588–593.

Rutunga V., N. K. Karanja, C.K.K. Gachene and C. Palm. (1999). Biomass production and nutrient accumulation by *Tephrosia vogelii* (Hemsley) A. Gray and *Tithonia diversifolia* Hook F. fallows during the six-month growth period at Maseno, Western Kenya. *Biotechnol. Agron. Soc. Environ.* **3:** 237–246.

Sadek, M. M. (2003). Antifeedant and toxic activity of *Adhatoda vasica* leaf extract against *Spodoptera littoralis* (Lepidoptera: Noctuidae). *Journal Applied Entomology,* **27:** 396-404.

Sadras, V. O., and Wilson, L. J., (1997). Nitrogen accumulation and nitrogen partitioning in shoots of cotton plants infested with two spotted spider mites. *Aust. J. Agric Res.* **48**, 525-533.

Salie F., Eagles P.F.K., Lens H.M.J. (1996). Preliminary antimicrobial screening of four South African *Asteraceae* species. *J. Ethnopharmacol.* **52**: 27-33.

Sandur, S., (2004). Implications of Diamondback moth control for Indian cabbage farmers.

A consultant report produced for the Centre for Environmental Stress and Adaptation Research, La Trobe University, Victoria 3086, Australia, 31 pp.

SAS Institute, (2001). The SAS System for Windows, release 8.1. Cary, NC.

Saxena, J.D., S. Rai, K.M. Srivastava & S.R. Sinha. (1989). Resistance in the field population of the diamondback moth to some commonly used synthetic pyrethroids. *Indian J. Entomol*. **51**: 265-268.

Schemske D.W., Husband B.C., Ruckelshaus M.H., Goodwillie C., Parker I.M. and Bishop J.G., (1994). Evaluating Approaches to the Conservation of Rare and Endangered Plants. *Ecol.,* **75**: 584-606.

Schmutterer H. and Ascher K.R.S., (1987). Natural pesticides from the neem tree (Azadirachta indica A. Juss) and other tropical plants. Proceedings of the third International Neem Conference Nairobi Kenya, 10-15 July, 1986. GTZ, Eschborn, Germany.

Schmutterer H (1990)a. Properties and potential of natural pesticides from neem tree, Azadirachta indica. *Ann. Rev.Entomol.* **35**: 271-297.

Schmutterer, H. (1990)b. Control of Diamondback moth by application of Neem extracts: in diamondback moth and other crucifer pests. Proceedings of the Second International Workshop, Asian Vegetable Research and Development Center. Tainan, Taiwan.

Schmutterer, H., (1995). The Neem Tree Azadirachta indica A. Juss. And Other Meliaceous Plants: Source of Unique Natural Products for Integrated Pest Management, Medicine, Industry and Other Purposes. VCH, Weinheim, Germany.

Schultes RE, von ReisV (1995). Ethnobotany Evolution of A discipline. Portland; Timber Press.

Shaalan E., Canyon D., Younes M., Abdel-Wahab H. and Mansour A. (2005). A review of botanical phytochemicals with mosquitocidal potential. Environment International **31**:1149-1166.

Shackleton, C. M. (1996). Potential substitution of local rural economies by harvesting secondary products: A case of the central low veld of the Central Transvaal. *Ambio* 25 (1).

Shelton, A.M., Hatch, S.L., Zhao, J.Z., Chen, M., Earle, E.D. and Cao, J. (2008). Suppression of diamondback moth using Bt-transfergenic plants as a trap crop. *Crop Protection*, **27**: 403–409.

Shelton, A.M., Robertson, J.L., Tang, J.D., Perez, C., Eigenbrode, S.D., Preisler, H.K., Wilsey, W.T. and Cooley, R.J. (1993). Resistance of diamondback moth (Lepidoptera: Plutellidae) to *Bacillus thuringiensis* subspecies in the field. *J. Econ. Ent*. **86**(3): 687-705.

Shelton, A.M., Roush, R.T., Wang, P. and Zhao, J.Z., (2007). Resistance to insect pathogens and strategies to manage resistance: An update. In: Lacey, L., Kaya, H.K. (Eds.), Field Manual of Techniques in Invertebrate Pathology, second ed. Kluwer Academic Press, pp. 793–811.

Sibanda, T., Dobson, H.M., Cooper, J.F., Wanyangarirwa, W. and Chiimba,W. (2000). Pest management challenges for smallholder vegetable farmers in Zimbabwe. *Crop Protection* **19**: 807-815.

Sileshi G and Katanga R., (2002). The many uses of *Tephrosia*, Africa's wonder species. *Ground UP* **1**: 14-17.

Sileshi, G., Kuntashula, E., Matakala, P. and Nkunika, P.O. (2008). Farmers' perceptions of pests and pest management practices in agroforestry in Malawi, Mozambique and Zambia. *Agroforestry Systems 72: 87-101*.

Sileshi, G.; Mafongoya, P. L.; Kwesiga, F. and Nkunika, P. (2005). Termite damage to maize grown in agroforestry systems, traditional fallows and monoculture on nitrogen-limited soils in eastern Zambia. *Agric. For. Entomol.* **7**: 61−69.

Sileshi, G.W., Nyeko, P., Nkunika, P.O.Y., Sekamatte, B.M., Akinnifesi, F.K. and Ajayi, O,C. (2009). Integrating ethno-ecological and scientific knowledge of termites for sustainable termite management and human welfare in Africa. *Ecology and Society* **14**(1): 48.

Simmonds M.S.J., Blaney W.M. and Fellows F.E., (1990a). Behavioral and electro-physiological study of antifeedant mechanisms associated with polyhydroxy alkaloids. *J Chem Ecol* **16**:3167-3196.

Simmonds, M.S.J., W. M. Blaney, R. Delle Monache, and G. B. Marini Bettolo. (1990b). Insect antifeedant activity associated with compounds isolated from species of *Lonchocarpus* and *Tephrosia. J. Chem. Ecol.* **16**: 365-380.

Sinha, B., Natu, A.A. and Nanavati, D.D. (1982). Prenylated flavonoids from *Tephrosia purpurea* seeds. *Phytochemistry*, **21**: 1468–1470.

Snapp S.S., Rohrbach D.D., Simtowe F., Freeman H.A., (2002). Sustainable soil management options for Malawi: Can smallholder farmers grow more legumes? *Agriculture, Ecosystems and Environment **91**: 159–174.*

Sola, P., Mvumi, B.M., Nyirenda, S.P.M., Ogendo, J.O., Mponda, O., Andan, F.P.H., Kamanula, J.F., Belmain S.R. and Stevenson. P.C. (2014). Botanical pesticide production, trade and regulatory mechanisms in sub-Saharan Africa: making a case for plant-based pesticidal products. *Food Security DOI 10.1007/s12571-014-0343-7*

Soulé, S., Güntner, C., Väzquez, A., Argando˜na, V., Moyna, P. and Ferreira, F., (2000). An aphid repellent glycoside from *Solanum laxum*. *Phytochemistry* **55**, 217–222.

Stevenson, P.C., Arnold, S.E.J. and Belmain, S.R. (2014). Pesticidal Plants for stored product pest in small holder farming in Africa. In "Advances in Plant Biopesticides" Ed. D. Singh. Springer Verlag. Pp. 149-172.

Stevenson, P.C., Kite, G.C., Lewis, G.P., Forest, F., Nyirenda, S.P., Belmain, S.R., Sileshi, G.W. and Veitch, N.C., (2012). Distinct chemotypes of Tephrosia vogelii and implications for their use in pest control and soil enrichment. *Phytochemistry* **78**: 135-146.

Stokes, J.B. and Redfern, R.E. (1982). Effect of sunlight on azadirachtin: antifeeding potency. *J. envir. Sci. Hlth* A **17**: 57-65.

Stoll G., (2000). Natural crop protection in the Tropics; letting information come to life. Margraf GmbH 2005. Germany. pg 210.

Sutherland, J. A. Kibata, G. N. and Farrel, G. (1996). Field Sampling Methods for Crops and Diseases in Kenya, Nairobi: Kenya Agricultural Research Institute/ODA.

Talukder, F.A. (2006). Plant products as potential stored-product insect management agents-A mini review. *Emirates Journal of Agricultural Sciences* **18:**17-32. [http://www.cfa.uaeu.ac.ae/research/ejas.htm]. Last accessed 17/10/2012.

Theu M.P.K.J. (2008). Diseases and nematodes as vegetable problems. In: Chadha ML, Oluoch MO, Saka AR, Mtukuso AP, Daudi AT (editors). Vegetable Research and Development in Malawi, Review and Planning Workshop Proceedings, September 23-24, 2003, Lilongwe, Malawi. AVRDC-The World Vegetable Center, Shanhua, Taiwan. AVRDC Publication No. 08-705. 57-60 pp.

Tindall, (1983). Vegetable crops in the tropics. Mc Millan, Hong Kong.

Toledo V.M. (1992). What is ethnoecology? Origins, scope and implications of a rising discipline. *Etnoecológica* **1**: 5-27.

Turek, C. and Stintzing, F.C. (2013). Stability of essential oils: a review. *Compr. Rev. Food Sci. Food Safety* **12**, 40–53.

Valantin-Morisona, M., Meynard J.M. and Dore T., (2007). Effects of crop management and surrounding field environment on insect incidence in organic winter oilseed rape (*Brassica napus* L.). *Crop Protection* **26**:1108–1120.

Van Jaarsveld A.S., Freitag S., Chown S.L., Muller C., Koch S., Hull H., Bellamy C., Krüger M., Endrödy-Younga S. and Mansell M.W., (1998). Biodiversity Assessment and Conservation strategies. *Science* **279**: 2106-2108.

Völlinger, M., (1987). The possible development of resistance against neem seed kernel extract and deltamethrin in *Plutella xylostella*. In: Schmutterer, H. and Ascher, K.R.S. (Eds.), Natural Pesticides from the Neem Tree (Azadirachta indica A. Juss) and Other Tropical Plants. Proceedings of Third International Neem Conference. German Agency for Technical Cooperation (GTZ), Eschborn, Germany, pp. 543-554.

Wedge D.E., Galindo J.C.G. and Macias F.A. (2000). Fungicidal activity of natural and synthetic sesquiterpene lactone analogs. *Phytochem*., **53**: 747-757.

Weinberger K. and Srinivasan R., (2009). Farmers' management of cabbage and cauliflower pests in India and their approaches to crop protection. *J Asia Pac Entomol* **12**: 253-259.

Wekesa V.W., S. Vital, R.A. Silva, E.M.M. Ortega, I. Klingen and I. Delalibera Jr. (2011). The effect of host plants on *Tetranychus evansi*, *Tetranychus urticae* (Acari: Tetranychdae) and on their fungal pathogen *Neozygites floridana* (Entomophthorales: Neozygitaceae). *Journal of invertebrate pathology* **107**: 139-145.

White, F., Dowsett-Lemaire, F and Chapman, J.D. (2001). Evergreen forest flora of Malawi. Royal Botanic Gardens, Kew. 697 pp.

Wilson, D. (1991). Spider mites (Acari: Tetranychidae) affect yield and fiber quality of cotton. *J. Econ. Entomol.* **86**: 566-585.

Wolfson, J.L., and Murdock, L.L. (1987). Method for applying chemicals to leaf surfaces for bioassay with herbivorous insects. *J. Econ. Entomol*: **80**, 1334-1336.

Wosula, E.N., Agong, S.G. and Knapp, M. (2005). Development of Tomato Hybrids (*Lycopersicon esculentum* X *L. hirsutum*) Resistant to Tobacco Spider Mite (*Tetranychus* evansi). In Isutsa et al. (Eds.). 2006. Proceedings of the Fifth Workshop on Sustainable Horticultural Production in the Tropics, held from 23rd to 26th

November 2005 at the Agricultural Resources Centre of Egerton University, Njoro, Kenya.

Wright, B. (2001). Know Your Friends: Minute. Pirate Bugs. http:///www.entomology.wige.edu/mbcn/kyf101.html/. . Last accessed 07/09/2011

Wright, D. P. Jr. (1963). Antifeeding compound for insect control. *Adv. Chem. Ser.* **34**: 24-39.

Xie, Y.S., Bodnaryk, R.P. and Fields, P.G. (1996). A rapid and simple flour-disk bioassay for testing substances active against stored-product insects. *Can. Entomol.* **128**, 865-875.

Yineger, H. and Yewhalaw, D., (2007). Traditional medicinal plant knowledge and use by local healers in Sekoru District, Jimma Zone, Southwestern Ethiopia. *Journal of Ethnobiology and Ethnomedicine* **3**: 24–30.

You M.S. and Wei H., (2007). The research of diamondback moth. China Agriculture Press. China.

You, M., Yue, Z., He, W., Yang, X., Yang, G., Xie, M., Zhan, D., Baxter, S.W., Vasseur, L., Gurr, G.M., Douglas, C.J., Bai, J.,Wang, P., Cui, K., Huang, S., Li, X., Zhou, Q.,Wu, Z., Chen, Q., Liu, C., Wang, B., Li, X., Xu, X., Lu, C., Hu, M., Davey, J.W., Smith, S.M., Chen, M., Xia, X., Tang, W., Ke, F., Zheng, D., Hu, Y., Song, F., You, Y., Ma, X., Peng, L., Zheng, Y., Liang, Y., Chen, Y., Yu, L., Zhang, Y., Liu, Y., Li, G., Fang, L., Li, J., Zhou, X., Luo, Y., Gou, C., Wang, J., Wang, J., Yang, H., Wang, J., 2013. A heterozygous moth genome provides insights into herbivory and detoxification. *Nat. Genet*. 45, 220-225.

Zago, H.B., Siqueira, H.A.A., Pereira, E.J.G., Picanço, M.C. and Barros, R. (2014). Resistance and behavioural response of *Plutella xylostella* (Lepidoptera: Plutellidae) populations to *Bacillus thuringiensis* formulations. *Pest management Science* **70**: 488-495.

Zalucki M.P., Shabbir A., Silva R., Adamson D. and Shu-Sheng L., (2012). Estimating the economic cost of one of the world's major insect pests, *Plutella xylostella* (Lepidoptera: Plutellidae): Just how long is a piece of string? *J Econ Entomol* **105:** 1115-1129.

Zang, X., Fukuda, E.K. and Rosen, J.D. (1997). Method for the determination of veratridine and cevadine, major compounds of the natural insecticide sabadilla, in lettuce and cucumbers. *J. Agric. Food Chem*., **45**, 1758-1761.

Zhang, Z.Q., (2003). Mites of Greenhouses: Identification, Biology and control.CABI Publishing, Wallingford, UK. 244 pp.

Zhao, J. Z., Collins, H. L., Li, Y. X., Mau, R. F., Thompson, G. D., Hertlein, M. S., Andaloro, J. T., Boyken, R. and Shelton, A. M. (2006). Monitoring of diamond back moth resistance to spinosad, indoxacarb and enamectin benzoate. *Journal of Economic Entomology*, **99**: 176–181.

Zulu, D., Thokozani, B. L. K., Sileshi, G. W., Teklehaimanot, Z., Gondwe, D. S. B., Sarasan, V. and Stevenson P.C., (2011). Propagation of the African medicinal and pesticidal plant, *Securidaca longepedunculata*. *African Journal of Biotechnology*, **10**, 5988–5992.

APPENDICES

APPENDIX I: Some of the appendix from Chapter two

2.1: Percentage respondents using specific synthetic pesticides in northern Malawi

Pesticide	WHO class	Respondents (%)
Phoskil/Parathion/Protein C	I	25.2
Cypermethrin/Ripcord	II	22.7
Azodrin	I	13.6
Karate/Lambda cyhalothrin/ Fenthion	II	10.9
Carbaryl	II	6.2
Dithane	Basic(o)	5.6
Copper oxychloride	o	4.4
Bravo/Daconil/Chlorothalonil	o	3.9
Dimethoate	II	2.9
Actellic	I	1.4
Dursban/Chlorpyrifos	II	1.1
Funguran/Copper hydroxide	III	0.7
Novachlorvos	I	0.6
Acephate/Orthene	III	0.6
Metaphos/Methamidophos	I	0.1

2.2: Percentage respondents using specific synthetic pesticides in eastern Zambia

Name	WHO class	Respondents (%)
Phoskil/Monocrotophos	I	41.4
Copper oxychloride	o	9.1
Fenkil	I	4.5
Karate	II	3.5
Kanoma/Canon/Yakanona/Lakanona(Milky)	-	8.0
Cotton pesticide	-	2.8
Diefen/Dithane	o	4.2
Spear	-	2.1
Doom	-	1.7
Malathione/Marazone	III	2.4
Soluba	II	2.4
Decitab	I	1.4
Delta-x 100EC	II	1.4
Fortis k	-	1.4
Sailax	II	1.4
Acetan	III	1.0
Batha	II	1.0
Mathioruz	III	1.0
Surf	-	1.0
Twatonge	-	1.0
Cypermethrin/ Sepermefin/Fastac	II	2.4
Nicotine sulphate		0.7
Red spider killer	I	0.7
Spur acetamirids		0.7
Vagila	-	0.7
Dikof	II	0.3
Dursban	II	0.3
Logo/Dimethoate/Rogor	II	0.3
Sylesc	-	0.3
Tetex	-	0.3

2.3: Questionnaire for Farmer Field Survey on indigenous pesticidal plant use for tomato and brassicas pest management

Section A: Personal Details

Name of Farmer……………………..………………… Farmer ID…………..…………

EPA……………………. ADD…………………GPS Reading ………………..…

Date……………….…………….. Field Type……………………………………….

Village……………………… TA……….…………. Recorder …………...………….

1. Farmer's Gender

Gender	Code	Tick
Male	1	
Female	2	

2. Farmer's Age (Years)

Age	Code	Tick
15-25	1	
25-40	2	
41-60	3	
>60	4	

3. Farmer's education

Education	code	Tick
None	1	
Primary School	2	
Secondary school	3	
University	4	
Other Profession: specify	5	

4. Marital Status

Status	Code	Tick
Single	1	
Married	2	
Widowed	3	
Divorced	4	

5. Family size

Members	Code	Male	Female	Tick
Alone	1			
1-3	2			
4-6	3			
>6	4			

6. Land Holding capacity (Ha)

Plot size	Code	Tick
<0.4	1	
0.4-1.0	2	
1.0	3	
>1.0	4	
Do not Know	5	

7. How did you acquire the land?

Ownership	Code	Tick
Inherited	1	
Through village chief	2	
Leasing/Renting	3	
Purchased	4	

8. Which type do you prefer to?

Ownership	Code	Tick
Inherited/Customary	1	
Through village chief	2	
Leasing/Renting	3	
Purchased /Private	4	

9. Are you satisfied with the land size?

Appreciation	Code	Tick
Do not think so	1	
Very small	2	
Small	3	
Perfect	4	

10. Farmer's experience in Farming

Experience	Code	Tick
First year	1	
<5 years	2	
6-10 years	3	
10 years	4	

Section B: Horticultural production

11. Which horticultural crop do you grow?

Type of crop	Code	Tick	Varieties
Tomato	1		
Brassicas	2		
Onions	3		
All three above	4		
Cucumber/Pumpkins	5		
Others: specify	6		

12. Apart from the crops, which are in the field now, what other crops do you grow in your garden/Dimba?

Type of crop	Code	Tick
Peas	1	
Beans	2	
Maize	3	
Melons	4	
Other: specify	5	

13. Where do you get the seed for your horticultural crops?

Source	Code	Tick	Shop /Kind
Reserve	1		
Shops	2		
Friends/Family	3		
Other: specify	4		

14. How do you perceive the terrain of your field?

	Code	Tick
Flat	1	
Slight Slope	2	
Steep slope	3	
Do not know	4	

15. What is the most prevalent soil type on your field?

Soil type	Code	Tick
Light soil	1	
Medium	2	
Heavy	3	
Do not know	4	

16. How do you grow/cultivate your crops?

Planting method	Code	Tick
Ridges	1	
Beds	2	
Flat	3	
Any method	4	

17. How often do you grow the crop per year?

Cycles	Code	Tick	Cropping System
Once	1		
Twice	2		
Thrice	3		
>Thrice	4		

18. Why are you growing horticultural crops?

Reason	Code	Tick
Additional income	1	
Food/Nutrition	2	
Both above	3	
Very profitable	4	
No other better crop	5	
Low pest pressure	6	
Other: specify	7	

19. Are you satisfied with the income you get from sales? (Recall Past Three years)

Satisfaction	Code	Tick
Not at all	1	
Very satisfied	2	
Fairly sufficient	3	
Other: specify	4	

20. How do you use the income from sales? (Recall Past Three years)

Reason	Code	Tick
House improvement	1	
Health care	2	
Education	3	
Clothing	4	
All above	5	
Other: specify	6	

21. What is the main activity that spends most of your income?

Consideration	Code	Tick
Land preparation	1	
Planting	2	
Weeding	3	
Harvesting	4	
Pest control	5	
Fertiliser Application	6	

22. Do you apply anything to your crop?

Response	Code	Tick
Yes	1	
No	2	

23. If yes, what do you apply in your crop?

	Code	Tick
Nothing	1	
Manure	2	
Fertiliser	3	
Fert and manure	4	

24. Where do you sell you sell the produce?

Mode	Code	Tick
Open markets	1	
Local wholesale	2	
Local people	3	
Local retailers/middlemen	4	
Other: Specify	5	

25. Who helps you in the production of your crops?

Labour source	Code	Tick
Family members	1	
Hired	2	
Communal labour	3	
Other:specify	4	

Section C: Pest Control

26. Do you experience pests in your field?

Response	**Code**	**Tick**
Yes	1	
No	2	

27. What are the major pests in your field? (Rank all)

Major pests	**Code**	**Tick**	**Rank**	**Most Affected crop**
Diamond back moth	1			
Aphids	2			
Red spider mites	3			
Blister beetles	4			
Bollworms	5			
Cutworms	6			
Others:specify	7			

28. How do you rate pest infestation in your field?

Rate	**Code**	DBM	Aphid	RSM	BB	BW	CW	Others
None	1							
Slight	2							
Moderate	3							
Severe	4							
Do not know	5							

29. At what stage is the damage so prevalent /severe?

Period	**Code**	DBM	Aphid	RSM	BB	BW	CW	Others
Transplanting time	1							
First month	2							
Vegetative stage	3							
Flowering Stage	4							
Fruiting stage	5							
Do not know	6							

30. During which season is the damage severe?

Period	**Code**	DBM	Aphid	RSM	BB	BW	CW	Others
Dry season	1							
Rainy season	2							
No difference	3							
Do not know	4							

31. Which part of the plant is severely damaged?

Plant part	**Code**	DBM	Aphid	RSM	BB	BW	CW	Others
Leaves	1							
Stem	2							
Roots	3							
Leaves and stems	4							
Roots,stem and leaves	5							
Do not know	6							

32. Do you take any control measures?

Response	**Code**	DBM	Aphid	RSM	BB	BW	CW	Others
Yes	1							
No	2							

33. If yes, what measures do/did you take?

Method	**Code**	DBM	Aphid	RSM	BB	BW	CW	Others
Nothing	1							
Hand picking	2							
Synthetic pesticides	3							
Pesticidal plants	4							
Resistant varieties	5							
Cultural practices	6							

34. Name the pesticides that you usually apply?

List of pesticides	**Rank**	DBM	Aphid	RSM	BB	BW	CW	Others

35. How do you rate the method used to control pests on your field?

Response	**Code**	**Tick**	**Comment**
Cheap	1		
Affordable	2		
Expensive	3		
Cannot tell	5		

Section D: Farmers Experience with pesticidal plants

36. Have you ever heard of pesticidal plants use for pest control?

Response	Code	Tick
Yes	1	
No	2	

37. How did you hear about it?

Source	Code	Tick
Friend	1	
Traditional healer	2	
Extension	3	
Research	4	
Other: specify	5	

38. Name any of the pesticidal plants you have heard about?

List	Rank	Effective on which Pest
Tephrosia (Gulinga, Mtetezga, Muthuthu)		
Neem		
Tithonia (Belibeli)		
Vernonia (Soyo,		
Bobgunnia (Mulundu)		
Nkhadze (Milk Weed/Plant)		
Lantana camara		
Terminalia (Mjoyi)		
Solanum (Nthuma)		
Euphorbia ingens (Mlangale)		
Others: Specify		

39. Have you ever used any one of them?

Response	Code	Tick
Yes	1	
No	2	

40. If yes, which ones? (Any three)

Pesticidal Plant	**Rank**	**For what?**	**Efficacy**		
			Slight	Moderate	Effective

41. Are these pesticidal plants readily available in the area?

Response	**Code**	**Tick**	**1**	**2**	**3**
Rare/scarce	1				
Abundant	2				
Not available at all	3				

42. Would you be willing to work with researchers on any of these?

Response	**Code**	**Tick**
Yes	1	
No	2	

43. If yes, which ones would you happily cultivate? Any three

Pesticidal Plant	**Rank**

44. Any final comment

…………………………………………………………………………………………….

…………………………………………………………………………………………….

Thank you for sparing your time

APPENDIX II Results of Analysis of variance for comparing participatory field evaluation of pesticidal plants as described in Chapter 3 of this thesis.

3.1: Analysis of variance on tomato at Nchenachena

Variate: week1					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	234.39	78.13	2.01	
Rep._units_ stratum					
chemicals	6	277.43	46.24	1.19	0.357
Residual	18	700.86	38.94		
Total	27	1212.68			
Variate: week2					
Rep stratum	3	24237.	8079.	2.31	
Rep._units_ stratum					
chemicals	6	83008.	13835.	3.96	0.011
Residual	18	62863.	3492.		
Total	27	170108.			
Variate: week3					
Rep stratum	3	6609.	2203.	0.42	
Rep._units_ stratum					
chemicals	6	91881.	15314.	2.93	0.036
Residual	18	94101.	5228.		
Total	27	192591.			
Variate: week4					
Rep stratum	3	1803.8	601.3	1.19	
Rep._units_ stratum					
chemicals	6	5736.9	956.1	1.89	0.138
Residual	18	9121.4	506.7		
Total	27	16662.1			
Variate: week5					
Rep stratum	3	362.71	120.90	1.69	
Rep._units_ stratum					
chemicals	6	5354.21	892.37	12.49	<.001
Residual	18	1285.79	71.43		
Total	27	7002.71			
Variate: week6					
Rep stratum	3	305.4	101.8	0.56	
Rep._units_ stratum					
chemicals	6	7599.9	1266.6	7.01	<.001
Residual	18	3253.6	180.8		
Total	27	11158.9			

3.2: Analysis of variance on tomato at Jenda

Variate: week1					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	3	1675.	558.	0.40	
block._units_ stratum					
chemicals	6	722403.	120400.	85.82	<.001
Residual	18	25253.	1403.		
Total	27	749331.			
Variate: week2					
block stratum	3	1704.7	568.2	0.78	
block._units_ stratum					
chemicals	6	3296.9	549.5	0.75	0.616
Residual	18	13152.8	730.7		
Total	27	18154.4			
Variate: week3					
block stratum	3	4204.9	1401.6	2.30	
block._units_ stratum					
chemicals	6	43170.9	7195.1	11.83	<.001
Residual	18	10951.1	608.4		
Total	27	58326.9			
Variate: week4					
block stratum	3	793.9	264.6	1.74	
block._units_ stratum					
chemicals	6	3078.9	513.1	3.37	0.021
Residual	18	2741.1	152.3		
Total	27	6613.9			
Variate: week5					
block stratum	3	442.7	147.6	1.07	
block._units_ stratum					
chemicals	6	1775.4	295.9	2.14	0.099
Residual	18	2487.8	138.2		
Total	27	4705.9			
Variate: week6					
block stratum	3	34.571	11.524	1.55	
block._units_ stratum					
chemicals	6	100.857	16.810	2.27	0.083
Residual	18	133.429	7.413		
Total	27	268.857			
Variate: week7					
block stratum	3	60.14	20.05	1.23	
block._units_ stratum					
chemicals	6	151.71	25.29	1.55	0.218
Residual	18	292.86	16.27		
Total	27	504.71			

APPENDIX III: Results of Analysis of variance for comparing repellent of plant extracts at 24 and 48hr after treatment/application as described in Chapter 4 of this thesis.

	Source of variation	DF	SS	MS	VR	F pr
24hr AT	Replicate	3	15703	5234	1.79	
	Treatment	11	66664	6060	2.07	0.053
	Residual error	33	96737	2931		
	Total	47	179104			
48hr AT	Replicate	3	563	188	0.17	
	Treatment	11	60794	5527	5.09	<0.001
	Residual error	33	35835	1086		
	Total	47	97192			

AT- After Treatment

APPENDIX IV **Results of the analysis of variance on the effect of *T vogelii* against aphids collected from different localities described in Chapter 5 of this thesis**.

Source of variation	d.f.	s.s.	m.s	v.r.	F pr.
Rep stratum	3	84.764	28.255	3.22	
Treatment	8	8427.884	1053.486	120.21	<.001
Date	5	117.176	23.435	2.67	0.021
Treatment.Date	40	835.574	20.889	2.38	<.001
Residual	807	7072.486	8.764		
Total	863	6537.884			

APPENDIX V: Some Publication abstracts and Presentaions

Full Length Research Paper: African Journal of Agricultural Research Vol. 6(2)

Farmers' ethno-ecological knowledge of vegetable pests and pesticidal plant use in Northern Malawi and Eastern Zambia

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Accepted 25 August, 2010

ABSTRACT While pests are a major constraint in vegetable production in many parts of Southern Africa, little is known about farmers' knowledge and management practices. A survey was conducted among 168 and 91 vegetable farmers in Northern Malawi and Eastern Zambia, respectively, to evaluate their knowledge, attitudes and traditional management practices in tomato and crucifers (brassica). All respondents in Malawi and Zambia reported experiencing pest damage on tomato and crucifers, and 75% had used synthetic pesticides. The use of pesticidal plants, cultural practices and resistant varieties constituted a smaller portion of the pest control options in both crucifers and tomato. Over 70% of the respondents were aware of pesticidal plants, and more female (75%) than male (55%) respondents reported using them. While over 20 different plant species were mentioned by respondents, *Tephrosia vogelii* accounted for 61 and 53% of the pesticidal species known to respondents in Malawi and Zambia, respectively. Farmers with small landholdings were more inclined to use pesticidal plants than those with medium and large landholding highlighting the importance of this management alternative for poor farmers. Most respondents were willing to cultivate pesticidal plants, which indicate that farmers understand the potential value of these plants in pest management.

Key words: *Azadirachta*, brassica, *Tephrosia*, *Tithonia*, tomato, *Vernonia*

International Journal of Pest Management Vol. 57, No. 1, January-March 2011, 41–49
Farmers' insect pest management practices and pesticidal plant use in the protection of stored maize and beans in Southern Africa.

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ABSTRACT Storage losses due to pests threaten livelihoods of farmers across Africa. Synthetic pesticides provide effective control when used correctly but resource-poor farmers cannot afford them. A survey of farmer ethno-ecological knowledge of pests of stored maize and bean, and their pest management practices including pesticidal plant use, was conducted in eastern Zambia and northern Malawi. Almost all respondents reported serious pest damage, with bruchids (Callosobruchus maculatus) and grain weevils (Sitophilus spp.) being major pests in beans and maize, respectively. The larger grain borer (Prostephanus truncatus) was reported more widely in Malawi. In Zambia, 50% of farmers used synthetic pesticides during storage, while nearly all did so in Malawi. Despite differences in storage methods between Malawi and Zambia, farmers in both countries were familiar with pesticidal plants, where Tephrosia vogelii was the most frequently reported. Surprisingly few farmers actually used pesticidal plants, highlighting a promotion opportunity. Our results provide a foundation for optimizing the use of pesticidal plants and enhancing their value to resource-poor farmers, across Africa.

Keywords: Callosobruchus; ethno-ecology; pesticidal plants; Prostephanus; Sitophilus;

Tephrosia

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Pesticidal effects of indigenous plant extracts against rape aphids and tomato red spider mites

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ABSTRACT Aphids, *Brevicoryne brassicae* and Red spider mites, *Tetranychus evansi* are the most damaging pests of rape, *Brassica napus* and tomato, *Solanum lycopersicum*, respectively. Farmers respond by using synthetic pesticides which pose environmental challenges. Extracts of *Lippia javanica* leaf powder and *Solanum delagoense* ripe fruit pulp were evaluated for pesticidal effects under on-station conditions against rape aphids and tomato red spider mites as alternatives to conventional pesticides and in comparison to Neem, *Azadirachta indica* leaf powder. The extracts of *A. indica, L. javanica and S. delagoense* were mixed with water at 8, 12.5 and 25 % w/v respectively. Amitraz and dimethoate were applied on tomato and rape respectively at label rate. Extracts were kept for 24 h at room temperature and then sieved. A liquid soap surfactant was added at 0.1 % v/v, prior to spraying. Sprays were applied weekly once pest infestations had established within the crop. Pests were counted 24 h after spraying for six weeks. Plant extracts significantly reduced pest numbers ($P < 0.05$) in both experiments. Dimethoate reduced aphid by 96 % while amitraz reduced red spider mite by 72%. *L. javanica* and *S. delagoense* at 12.5 and 25 % reduced aphids by 63 % and 57.9 % and mites by 66.5 % and 55 %, respectively. Both extracts were more effective on aphids than mites while *L .javanica* was more effective than *S. delagoense* on both crop pests. *L. javanica* and *S. delagoense* had some pesticidal effects against the vegetable pests.

Key words: *Lippia javanica,* pesticidal effect, rape aphids, *Solanum delagoense,* tomato red spider mites

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Highly Variable Insect Control Efficacy of *Tephrosia vogelii* Chemotypes

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ABSTRACT: Tephrosia vogelii has been used for generations as a pest control material in Africa. Recently, two chemotypes have been reported based on the occurrence (chemotype 1) or absence (chemotype 2) of rotenoids. This could have an impact on the efficacy and reliability of this material for pest control. We report that chemotype 2 has no pesticidal activity against Callosobruchus maculatus Fabricius (family Chrysomelidae) and that this is associated with the absence of rotenoids. We present a first report of the comparative biological activity of deguelin, tephrosin, α-toxicarol, and sarcolobine and show that not all rotenoids are equally effective. Tephrosin was less toxic than deguelin which was less active than rotenone, while obovatin 5-methyl ether, the major flavonoid in chemotype 2 was inactive. We also report that in chemotype 1 the occurrence of rotenoids shows substantial seasonal variation.

KEYWORDS: *Tephrosia candida*, *Callosobruchus maculatus*, flavanones, rotenoids, deguelin, pesticidal plants, bruchids, cowpea weevil

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Distinct chemotypes of Tephrosia vogelii and implications for their use in pest control and soil enrichment

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ABSTRACT: *Tephrosia vogelii* Hook. f. (Leguminosae) is being promoted as a pest control and soil enrichment agent for poorly-resourced small-scale farmers in southern and eastern Africa. This study examined plants being cultivated by farmers and found two chemotypes. Chemotype 1 (C1) contained rotenoids, including deguelin, rotenone, sarcolobine, tephrosin and α-toxicarol, required for pest control efficacy. Rotenoids were absent from chemotype 2 (C2), which was characterised by prenylated flavanones, including the previously unrecorded examples (2S)-5,7-dimethoxy-8-(3-hydroxy-3-methylbut-1Z-enyl) flavanone, (2S)-5,7-dimethoxy-8-(3-methylbut-1,3-dienyl)flavanone, (2S)-4′-hydroxy-5-methoxy-6″,6″-dimethylpyran[2″,3″:7,8]flavanone,(2S)-5-methoxy-6″,6″-dimethyl-4″,5″-dihydrocyclopropa [4″,5″]furano[2″,3″:7,8]flavanone, (2S)-7-hydroxy-5-methoxy-8-prenylflavanone, and (2R,3R)-3-hydroxy-5-methoxy-6″,6″-dimethylpyrano[2″,3″:7,8] flavanone. The known compounds (2S)-5-methoxy-6″,6″-dimethylpyrano [2″,3″:7,8] flavanone (obovatin 5-methyl ether) and 5,7-dimethoxy-8-(3-hydroxy-3-methylbut-1Z-enyl)flavone (Z-tephrostachin) were also found in C2. This chemotype, although designated *Tephrosia candida* DC in collections originating from the World Agroforestry Centre (ICRAF), was confirmed to be *T. vogelii* on the basis of morphological comparison with verified herbarium specimens and DNA sequence analysis. Sampling from 13 locations in Malawi where farmers cultivate Tephrosia species for insecticidal use indicated that almost 1 in 4 plants were *T. vogelii* C2, and so were unsuitable for this application. Leaf material sourced from a herbarium specimen of T. candida contained most of the flavanones found in *T. vogelii* C2, but no rotenoids. However, the profile of flavonol glycosides was different to that of T. vogelii C1 and C2, with 6-hydroxykaempferol 6-methyl ether as the predominant aglycone rather than kaempferol and quercetin. The structures of four unrecorded flavonol glycosides present in *T. candida* were determined using cryoprobe NMR spectroscopy and MS as the 3-*O*-α-rhamnopyranosyl(1→6)-β-galactopyranoside-7-*O*-α-rhamnopyranoside, 3-*O*-a-rhamnopyranosyl(1→2)[α-rhamnopyranosyl(1→6)]-β-galactopyranoside, 3-*O*-α-rhamnopyranosyl-(1→2)[α-rhamnopyranosyl(1→6)]-β-galactopyranoside-7-*O*-α-rhamnopyranoside, and 3-*O*-α-rhamnopyranosyl (1→2)[(3-*O*-E-feruloyl)-α-hamnopyranosyl(1→6)]-β-galactopyranosides of 6-hydroxykaempferol 6-methyl ether. Tentative structures for a further 37 flavonol glycosides of *T. candida* were assigned by LC–MS/MS. The correct chemotype of *T. vogelii* (i.e. C1) needs to be promoted for use by farmers in pest control applications.

Keywords: *Tephrosia vogelii*, *Tephrosia candida*, Leguminosae, Flavanones, Dihydroflavonol, Flavonol glycosides, Rotenoids, Pesticidal plants

Available on http://projects.nri.org/adappt/docs/ICPPabstracts&timetable.pdf

Participatory field evaluation of selected pesticidal plants for management of vegetable pests in Malawi

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ABSTRACT Tomato (*Lycopersicon esculentum*) and rape (*Brassica napus*) are probably the most important horticultural vegetable crops grown in Malawi and the southern African region. However their production is highly constrained by insect pests. Farmers rely primarily on the use of synthetic pesticides to manage insect pests such as red spider mites (*Tetranychus evansi*) and aphids (*Brevicoryne brassicae* and *Myzus persicae*) in their fields. In this study, five dried pesticidal plant aqueous solutions; *Tithonia diversifolia, Azadirachta indica, Tephrosia vogelii, Solanum panduriforme* and *Vernonia amygdalina* were evaluated at the rate of 5% in comparison to Phoskil, Dimethoate and untreated control through participatory farmer field trials for the management of red spider mites, aphids and other pests on tomato and brassicas in Malawi. The results suggest that pesticidal plant extracts had significantly higher effect on controlling red spider mites and aphids. Amongst the plant extracts, *T. diversifolia* recorded the lowest mean number of red spider mites (31) and aphids (7) compared to untreated control (51 and 103). Lower mean tomato fruit damage were recorded on *T. diversifolia* (20%) and *Vernonia amygdalina* (15%) compared to control (47% and 32%) at Jenda and Nchenachena in 2008 season. Highest mean tomato yields (30,883; 16,862 Kg ha-1) were obtained at Jenda compared to control (15, 176 and 15, 117 Kg ha-1) for seasons one and two respectively. Moreover, these pesticidal plant materials had no effect on vegetative growth of tomato and rape plants. The results obtained indicate that the use of the pesticidal plant materials can play a significant role in improving vegetable production for the resource-poor farmers without relying on conventional pesticides.