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Ecological and Economic Benefits and Risks of Using Botanical Insecticides in Tanzanian Farms

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Abstract

Insect damage is a major concern for smallholder farmers in developing countries like Tanzania. Synthetic insecticides can tame infestations, however they can be expensive, inaccessible, and their misuse can threaten farmer health and ecological conditions. Botanical insecticides are cheap alternatives to treat infestations while preserving beneficial insects such as pollinators, predators, and parasitoids. This study assesses how both synthetic and botanical insecticides affect beneficial insects, crop yield and profit/costs. This study finds botanical insecticides slightly less harmful towards non-target insects. Botanical insecticides seldomly improve crop yields but usually result in a higher profit/lower cost. Due to high variation in ecological and economic results, I recommend implementing botanical insecticides as an alternative to synthetic insecticides or using synthetic insecticides as a supplement to botanical insecticides. These recommendations should be linked with improved insecticide training and regulation to ensure safety and efficacy.

Key words: *Agriculture, Tanzania, botanical insecticides, synthetic insecticides, beneficial insects, non-target insects, crop yield, cost, profit*

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1.0 Introduction

1.1 Background Information

Insect pests threaten the livelihoods of farmers by damaging crops in fields and storage. Insecticides are designed to control pest populations and are a management tool for farmers to increase their crop yield. Synthetic insecticides are substances containing one active ingredient produced in a laboratory. While effective, the misuse or overuse of synthetic insecticides can lead to ecological degradation and impact farmer health (Garming & Waibel, 2009; Maneepitak & Cochard, 2014; Loha, Lamoree, Weiss, & Boer, 2018). Botanical insecticides are complex mixtures of chemicals derived from plant material and provide an attractive alternative to synthetic insecticides.

Botanical insecticides have historically been used to protect stored food but were replaced by more effective synthetic methods (Panagiotakopulu, Buckland, & Day, 1995; Dougoud, Toepfer, Bateman, & Jenner, 2019; Anjarwalla, Belmain, Sola, & Jamnadass, 2016; Roy, et al., 2016). However, some synthetic insecticides contain persistent broad-spectrum formulas that can affect beneficial and/or non-target insects such as pollinators, predators, and parasitoids of common pests (Isenring, 2010; Mkenda, et al., 2015; Ndakidemi, Mtei, & Ndakidemi, 2016). Integrated pest management (IPM) is a farming method that relies on biological services and selective pesticides to improve crops and maintain a healthy environment. Botanical insecticides are commonly part of IPM strategies because they degrade quickly and do not affect beneficial insects that naturally predate on pests (Grzywacz, Stevenson, Mushobozi, Belmain, & Wilson, 2014) Thus, they are regarded as ecologically-friendly tools for farmers.

Currently, synthetic insecticides are most commonly used to treat crop fields, but access to reliable and safe synthetic tools is difficult in developing countries (Miglani & Bisht, 2019; Maneepitak & Cochard, 2014). Insecticide use exposes farmers to a variety of chemicals that can potentially cause acute or chronic poisoning (Garming & Waibel, 2009; Stevenson, Isman, & Belmain, 2017). Handling synthetic insecticides require personal protective gear, disposal methods, labels, and instructions, all of which are difficult to access (Loha, Lamoree, Weiss, & Boer, 2018). Moreover, synthetic insecticides are usually expensive for smallholder farmers to purchase (Grzywacz, Stevenson, Mushobozi, Belmain, & Wilson, 2014; Lian & Jin, 2017). High costs can be difficult to overcome, even if crop yields are high. Botanical insecticides are an affordable form of pest protection because they can be easily collected from plant material. Certain homemade botanical insecticides are relatively safer than many of the expensive, hazardous synthetic insecticides available in low-income countries (Dougoud, Toepfer, Bateman, & Jenner, 2019). If botanical insecticides provide a high crop yield and are less expensive, they may be economicaly better than convetional synthetic insecticides.

Tanzania is a developing country in East Africa with a large population of smallholder farmers. Botanical insecticides can be beneficial tools if effective, safe for both the environment and health, and affordable. Using data from both outside and inside Tanzania, this document specifically focuses assessing the ecological and economic implications of using botanical insecticides in Tanzanian farming.

1.2 Problem Statement

Synthetic insecticides are largely expensive and inaccessible for farmers in developing countries such as Tanzania. Botanical insecticides are an affordable alternative because they are accessible and less harmful to the environment (Biondi, Desneux, Siscaro, & Zappalà, 2012). Multiple studies compare ecological effects of botanical insecticides and synthetic insecticides by measuring their impact on non-target/beneficial insects (Ndakidemi, Mtei, & Ndakidemi, 2016; Zuhra, et al., 2018; Letourneau & Bothwell, 2008).

There is a growing movement to popularize botanical insecticides in Tanzania. However, it is important to determine the benefits of using botanical insecticides over current synthetic techniques. This document will compare the effect of synthetic and botanical insecticides on non-target/beneficial insects, and the costs and profits associated with either management tool.

2.0 Objectives and Justification

2.1 General Objective

To assess the ecological and economic implication of implementing botanical insecticides over synthetic insecticide in Tanzania.

2.2 Specific Objectives

1. Compare data on the effects of synthetic and botanical insecticides on beneficial/non-target insects (pollinators, predators, parasitoids)
2. Compare data on the cost of synthetic and botanical insecticides (crop yield, cost/profit)

2.3 Justification

Crop damage is detrimental for smallholder farmers, who make up a majority of Tanzania's population. This review can provide farmers in Tanzania information about which insecticide (botanical or synthetic) is most environmentally friendly and cost-effective.

3.0 Literature Review

Pest management is necessary to successfully plant and store crops for food and production. Insecticides can ensure higher quality crops, however there are some consequences to application. While a number of modern synthetic insecticides are designed to be more selective, a majority of the synthetic insecticides found in developing countries are broad-spectrum, highly toxic, and lack safety precautions (Amoabeng, Gurr, Gitau, & Stevenson, 2014; Loha, Lamoree, Weiss, & Boer, 2018). Threats to ecological health, economic costs, and farmer health have led to the development of botanical insecticides that can replace synthetic insecticides.

3.1 Review of Ecological Studies

Insects are important organisms that can determine the health of an environment; thus, they are a fundamental factor in integrated pest management systems. Complex biological interactions among insect species such as predations, mutualism, and parasitism are services that can keep pest load relatively low (Vandermeer, Perfecto, & Philpott, 2010). Thus, there is merit to preserve populations of pollinators, predators, and parasitoids in crop fields. Removing or changing predator and parasitoid populations increases the risk of secondary pest outbreaks in crop fields (Raupp, Holmes, Sadof, Shrewsbury, & Davidson, 2001; Crowder, Northfield, Strand, & Snyder, 2010). Pollinators are necessary for certain crops and can improve crop quality (Sawe, Nielsen, & Eldegard, 2020). One of the top criticism of using synthetic insecticides is their effects on non-target and beneficial insects (Mkenda, et al., 2015; Ndakidemi, Mtei, & Ndakidemi, 2016; El-Heneidy, Khadir, & Taman, 2015; Ricupero, Desneux, Zappala, & Biondi, 2020).

Botanical insecticides are considered ecologically safer to non-target insects because they are selective and degrade rapidly in field conditions (Lengai, Muthomi, & Mbega, 2020). However, botanical insecticides change behavior and reproduction of beneficial insects at sublethal levels (Fernandes, et al., 2016; Hikal, Baeshen, & Said-Al Ahl, 2017; Biondi, Desneux, Siscaro, & Zappalà, 2012; Ponsankar, et al., 2016; Mamduh, Hosseininaveh, Allahyari, & Talebi-Jahromi, 2017). Research has been conducted to measure the effects of botanical insecticides on a variety of insects, but do not always provide clear conclusions. For example, studies show Azadirachtin (Neem product) is harmful towards bees, while others conclude otherwise (Stevenson, Isman, & Belmain, 2017; Tschoeke, et al., 2019; Lengai, Muthomi, & Mbega, 2020). Certain modern synthetic insecticides are designed to be more selective and have similar effects on non-target insects as botanical insecticides (Lima, et al., 2015). However, selective synthetic insecticides are less accessible to developing countries such as Tanzania. Botanical insecticides may be the most viable option for ecologically friendly pest management.

3.2 Review of Economic Studies

Smallholder farmers in developing countries often produce low crop yields, and the decision to use insecticides is costly (Grzywacz, Stevenson, Mushobozi, Belmain, & Wilson, 2014; Laizer, Chacha, & Ndakidemi, 2019). Insecticides are economically beneficial if they result in a high crop yield while minimizing any cost inputs. Synthetic insecticides are regulated and developed uniformly, ensuring consistency. Botanical insecticides are sourced from plants and are difficult to formulate. Mixtures of secondary metabolites derived from one species of plants can vary between individuals exposed to different environmental conditions (Miresmaili & Isman, 2014; Lengai, Muthomi, & Mbega, 2020; Belmain, Amoah, Nyirenda, Kamanula, & Stevenson, 2012).

Since concentrations of active ingredients differ between botanical and synthetic insecticides, their efficacies can differ and determine a farmers seasonal harvest.

In various studies, synthetic insecticides provided optimal pest control and produced the high yield of crops (Mwatawala, Mziray, Malebo, & Meyer, 2015; Mkenda, et al., 2015; Opolot, Agona, Kyamanywa, Mbata, & Adipala, 2006; Jafarbeigi, Samih, Zarabi, & Esmaeily, 2014). Ideally, the income made by harvesting high quality crops offsets the cost of using insecticides. This can be a challenge for farmers in developing countries such as Tanzania, where high-quality synthetic insecticides are expensive. A few of studies found that botanical insecticides are more profitable due to their low cost and simple application (Mwatawala, Mziray, Malebo, & Meyer, 2015; Tembo, et al., 2018). However, not all botanical insecticides are accessible; it is likely farmers in Africa and Tanzania rely on crude plant materials rather than formulated botanical insecticides (Belmain & Stevenson, 2016).

Interestingly, two studies recommend combining synthetic and botanical insecticides to maximize crop yield and minimize pest damage (Khan, Afzal, Qureshi, Khan, & Raza, 2014; Opolot, Agona, Kyamanywa, Mbata, & Adipala, 2006). This can be a useful agricultural method because botanical insecticides degrade quickly and must be reapplied often (Isman, Botanical Insecticides in the Twenty-First Century—Fulfilling Their Promise?, 2020). Highly effective synthetic insecticides can be used occasionally, while botanical insecticides can maintain low pest levels. Integrating two pest management tools, however, would require regulations and education efforts across Tanzania.

3.3 Review of Agricultural Practice

A majority of Tanzanians are farmers, mostly working on a small parcel of land. Despite this, the agricultural sector is not well funded, and farmers receive little to no advice on pest management (Sawe, Nielsen, & Eldegard, 2020). Agricultural extension officers are available for farmers in Tanzania, however, current training in ecological services is underdeveloped. Many farmers do not recognize beneficial insects, which poses a challenge in implementing integrated pest management systems (Laizer, Chacha, & Ndakidemi, 2019; Stevenson, Isman, & Belmain, 2017; Sawe, Nielsen, & Eldegard, 2020). Training is necessary to raise environmental awareness among farmers and popularize botanical insecticides

Although farmers prefer synthetic insecticides despite health risks, botanical insecticides are used in Africa by farmers who cannot afford conventional pest protection (Laizer, Chacha, & Ndakidemi, 2019; Mkindi, Mtei, Njau, & Ndakidemi, 2015; Loha, Lamoree, Weiss, & Boer, 2018). For example, Tanzanian farmers utilize *Tephrosia vogelii (T. vogelii)* and snake bean trees (Grzywacz, Stevenson, Mushobozi, Belmain, & Wilson, 2014). Botanical insecticides are prepared from common weeds in simple ways, however some methods are suboptimal (Anjarwalla, Belmain, Sola, & Jamnadass, 2016; Mkindi, Mtei, Njau, & Ndakidemi, 2015; Dougoud, Toepfer, Bateman, & Jenner, 2019). Again, extension officers would have to provide training to choose and extract botanical insecticides efficiently and restore confidence in their protection.

4.0 Methodology

4.1 Study Area Description

Tanzania is located in Sub-Saharan Africa and covers a total area of about 945,087 km^2 It is bordered by the Indian Ocean to east, Kenya and Uganda on the north, Rwanda, Burundi and the Democratic Republic of the Congo on the west, and Zambia, Malawi and Mozambique on the south *(Fig.1).* The population is above fifty million people, with over 100 local tribes. Northeast Tanzania contains mountainous terrain and includes Mount Meru, Mount Kilimanjaro, and the Usambara and Pare mountain ranges. To the west is the Gregory Rift, and several salt lakes, including Natron, Manyara and Eyasi. Ol Doinyo Lengai is to the south of Lake Natron. The Crater Highlands include the Ngorongoro Conservation Area and the Ngorongoro Crater. Serengeti National Park is west of the Crater Highlands. Just to the southeast of the park is Olduvai Gorge.

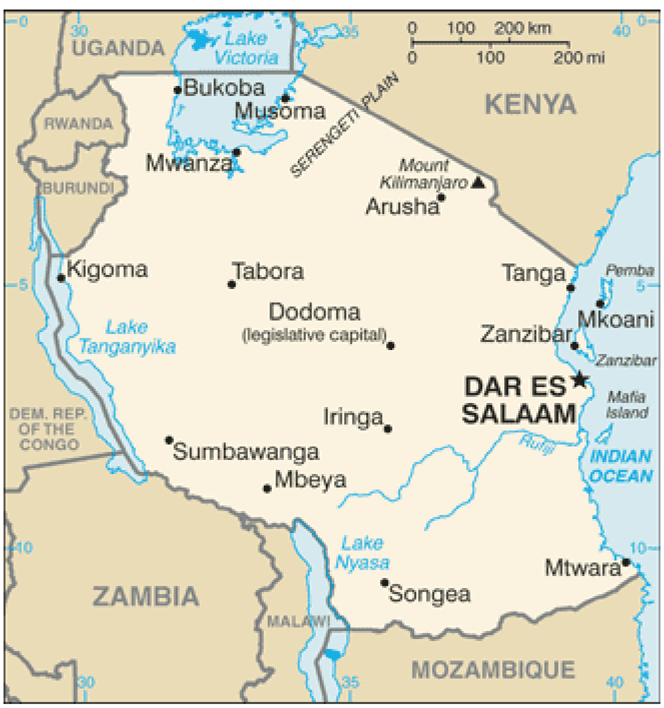

Figure 1: Map of Tanzania by CIA, 2006

4.2 Climate

Tanzania has an equatorial climate but has regional variations due to topography. In the highlands, temperatures range between 10 and 20 °C. In the rest of the country, the hottest period extends between November and February (25–31 °C) while the coldest period occurs between May and August (15–20 °C). There are two rainy seasons. The long rainy season begins from March to May and the short rainy season is from October to December. The climate favors several crops: maize, sorghum, millet, rice, wheat, beans, cassava, potatoes coffee, banana, cotton, sisal, sunflower, coconuts, ground nuts, tea, tobacco.

4.3 Data Collection

Data will be collected from secondary sources primarily from academic journals or books. Academic sources are collected using databases EBSCO, ProQuest, and Google Scholar. The key search words included are "agriculture", "botanical insecticides", "synthetic insecticides", "non-target insects", "beneficial insects", "cost-benefit", "Tanzania". The review of secondary sources will be done for ten days.

4.4 Data Analysis

Meta-analyses will be used for objectives 1 and 2 to show if there is a significant difference between synthetic and botanical insecticides across literature. Content analysis will be used for the current status of pest management in Tanzania, including information on agricultural extension practices. These methods aim to create a robust understanding of botanical insecticides in Tanzanian agricultural context.

5.0 Results

5.1 Synthetic and Botanical Insecticides on Non-target Organisms

A total of 12 academic articles provide data over non-target activity of synthetic and botanical insecticides. Out of 12 articles, only three measure the ecological impact of botanical insecticide and four only measure the ecological impact of synthetic insecticides. Five articles measure the ecological impact of both synthetic and botanical insecticides.

Experimental Results

Six articles are used in this section and displayed in Table 1. One article shows no significant difference between the effects of tested synthetic and botanical insecticide. Three articles find botanical insecticides to be less toxic or harmful towards non-target insects. Two articles find various results concluding botanical insecticides to be both less and equally as harmful to non-target insects as synthetic insecticides.

Table 1: Experimental results in six articles compare effects of synthetic and botanical insecticides on beneficial/non-target insects.

Source	Non-target Organism	Insecticides Tested (only botanical and synthetic)	Results
Biondi, et al., 2012	*O. laevigatus*	Azardirachtin, chlorantraniliprole, indoxacarb, metaflumizone	Synthetic and botanical both harmful
Tembo, et al., 2018	Lady beetle, spider, hoverfly	Karate, *L. javanica, T. diversifolia, T. vogelii, and V. amygdalina, L. cámara, B. pilosa*	Botanical less harmful
Ponsankar, et al., 2016	*S. litura*, earthworm	Cypermethrin, monocrotophos, *C. guianensis* flower extract	Botanical less harmful
Khan, et al., 2014	Psyllid, ladybeetles, syrphids, spiders, green lacewings	Neem, Tropane, Imidacloprid, spinetoram, spirotetramat	Botanical less harmful
Mkenda, et al., 2015	Lady beetle, spider	Karate, *L. javanica, V. amygdalina, T. vogelii, T. diversifolia*	Botanicals less harmful to only $^1/_2$ insects
Tschoeke, et al., 2019	*Plebeia spp., A. mellifera, Halictus sp.*	Neem, deltamethrin	Botanicals less harmful to only $^1/_3$ insects

5.2 Cost of Synthetic and Botanical Insecticides

Five articles were found to contain data and discussion regarding crop yield or profits related to botanical and synthetic insecticides. All five articles include information about crop yield. Three out of five articles analyze cost and benefit and/or profit from synthetic and botanical insecticide treatments.

Crop Yield

Two articles find synthetic treatment to significantly improve crop yield compared to botanical insecticides. One article finds a majority of tested botanical insecticides to provide highest yield compared to synthetic control. Two articles find crop yield results vary with experimental conditions and seasonally.

Table 2: Five articles compare crop yield after using botanical or synthetic insecticides

Source	Insecticides	Yield Result
Tschoeke, et al., 2019	Deltamethrin, fungicides, Neem	Synthetic and Synthetic + fungicide overall highest yield
Tembo, et al., 2018	Karate, *L. javanica*, *T. diversifolia*, *T. vogelii*, *V. amygdalina*, *L. camara*	Synthetic overall highest yield
Mkenda, et al., 2015	Karate, *L. javanica*, *V. amygdalina*, *T. vogelii*, *T. diversifolia*	Botanicals improve crop yield more than synthetic
Amoabeng, et al., 2014	Tobacco, Siam weed, goat weed, Cinderella weed, castor oil plant, Attack	Two botanicals improve crop yield in first season Synthetic improve crop yield in second season
Opolot, et al., 2006	Ambush (cypermethrin), tobacco	Synthetic and synthetic+botanical improve crop yield similarly

Cost-benefit or Marginal profit

One article shows that botanical insecticides have lower costs and result in higher profits compared to synthetic controls. Two articles show variable cost-benefit results according to experimental conditions.

Table 3: Three articles compare the cost and profit of using synthetic or botanical insecticides.

Source	Insecticides	Cost/Profit Result
Mkenda, et al., 2015	Karate, *L. javanica*, *V. amygdalina*, *T. vogelii*, *T. diversifolia*	*T. vogelii*, *V. amygdalina*, *T. diversifolia* less costly synthetic
Amoabeng, et al., 2014	Tobacco, Siam seed, goat weed, Cinderella weed, castor oil plant, Attack	Siam seed and tobacco more cost effective than Attack in major rainy season Attack marginally more cost effective than tobacco in minor rainy season
Opolot, et al., 2006	Ambush (cypermethrin), tobacco	Using combination of synthetic and tobacco (during podding stage) more cost effective than synthetic

6.0 Discussion

Pest management is an integral part of farming, especially for smallholder farmers in Tanzania. In order to understand how botanical insecticides may impact agriculture, it is important to asses ecological and economic effects and reference current challenges in agriculture. The data gathered from various sources show botanical insecticides to be a possible alternative for farmers in Tanzania, however the sample size of sources is low. A small sample size can skew data and likely reduces the chances that results are statistically valid. Nonetheless, the results show botanical insecticides may be a possible alternative, current agricultural practices in Tanzania pose challenges to widespread implementation.

The ecological effects of botanical insecticides are determined by their non-target activity compared to synthetic insecticides. A sample of 12 articles discuss the lethal and/or sublethal effects of botanical or synthetic insecticides. Among 12 articles, seven articles compare lethal or sublethal effects of only synthetic or botanical insecticides, which provides data on harmful and benign options among both insecticides. Six articles compare ecological effects between both synthetic and botanical insecticides. The findings show botanical insecticides to be slightly less harmful to non-target or beneficial insects.

Some botanical insecticides, however, do pose some threat to insects and must be carefully selected (Ndakidemi, Mtei, & Ndakidemi, 2016; Tschoeke, et al., 2019). Depending on the plant species, location, and chemical profile, specific botanical insecticides may be better suited to preserve ecological health of a particular crop field. Application methods may also impact beneficial insects; Ribeiro, et al., 2018 recommends applying certain botanical insecticides later in the day to minimize interaction between sensitive non-target insects. Likewise, there are certain synthetic insecticides that are known to significantly threaten non-target organisms, such as organophosphates and carbamates. Modern synthetic insecticides, such as neonicotinoids and chlorantraniliprole, are less harmful to some non-target insects compared to other, older synthetic insecticides (Goulson, 2013; Biondi, Desneux, Siscaro, & Zappalà, 2012; Ricupero, Desneux, Zappala, & Biondi, 2020; Fernandes, et al., 2016; Miglani & Bisht, 2019; Lima, et al., 2015). To further minimize interaction with non-target insects, synthetic insecticide application can be timed (Quesada & Sador, 2019). Thus, using carefully selected synthetic insecticides can still preserve some non-target insect populations.

All experiments are performed under laboratory or field conditions with exact concentrations of botanical extracts or synthetic insecticides. These conditions do not reflect a trend in current agricultural methods. A large amount of synthetic insecticides circulating in developing countries, including Tanzania, are expired, unlabeled, highly hazardous, and sometimes difficult for farmers to identify (Maneepitak & Cochard, 2014; Loha, Lamoree, Weiss, & Boer, 2018; Laizer, Chacha, & Ndakidemi, 2019; Stevenson, Isman, & Belmain, 2017). Misuse, such as overapplication or mixing with other household materials, also affect the toxicity of insecticides (Laizer, Chacha, & Ndakidemi, 2019; Sawe, Nielsen, & Eldegard, 2020). It is possible that botanical insecticides are significantly less harmful to non-target insects when compared to the synthetic insecticides farmers currently utilize.

While botanical insecticides are likely a safe ecological alternative for farmers in Tanzania, it will be difficult to overcome current attitudes and gaps in knowledge. Studies conducted by Laizer, et al., 2019 and Isman, 2017 found a majority of farmers believe synthetic insecticides are the only reliable form for pest control, even if they have knowledge of botanical alternatives. This may be because botanical insecticides usually affect insect behavior or physiology, rather than cause direct mortality. Moreover, many farmers in Tanzania do not differentiate between beneficial insects and pests, or may not recognize certain species of beneficial insects (Laizer, Chacha, & Ndakidemi, 2019; Sawe, Nielsen, & Eldegard, 2020; Elisante, et al., 2019). Training and education would be necessary to prioritize ecological health for farmers.

The economic impact of botanical insecticides is determined by crop yield and low cost/high profit. Overall, synthetic insecticides will yield the most crops because they are formulated to be highly effective and lethal to pests. Only one article finds botanical insecticides to improve crop yield compared to synthetic insecticides, and two articles find botanical insecticides to increase crop yield seasonally or when used with synthetic insecticides. It should be noted that two studies, Tembo, et al., 2018 and Mkenda, et al., 2015, use fertilizers on crop fields unlike other studies.

While crop yield does provide income for farmers, it is important to measure the cost of insecticides. A low cost will result in a higher profit for farmers. Although only one article finds botanical insecticides to be more cost effective than synthetic insecticdes, two other articles show a similar result in specific cases, such as seasonally or in combination with synthetic insecticides. Overall, synthetic insecticides are more costly than botanical insecticides, even though crop yields may be higher.

In Tanzania, a majority of synthetic insecticides are too expensive or difficult for farmers to access (Dougoud, Toepfer, Bateman, & Jenner, 2019; Laizer, Chacha, & Ndakidemi, 2019). Homemade botanical insecticides may be the most affordable method of pest management if extraction methods are refined and extracts are reapplied regularly (Dougoud, Toepfer, Bateman, & Jenner, 2019; Kestenholz, Stevenson, & Belmain, 2007). Moreover, farmers must know when and where to collect plant material for effective extracts. For example, *Tephrosia vogelii* produces multiple chemotypes, only one of which contains rotenone and possesses insecticidal properties (Belmain & Stevenson, 2016; Belmain, Amoah, Nyirenda, Kamanula, & Stevenson, 2012; Mkindi, Mtei, Njau, & Ndakidemi, 2015). Due to their variable nature, it is difficult to completely standardize botanical insecticides. Farmers may need training to know when to harvest specific plants and how often to reapply insecticides.

Farmer health is a factor that can over time cause some economic damage. Multiple studies found farmers in Tanzania and other developing countries experience high rates of acute poisoning from synthetic insecticides (Amoabeng, Gurr, Gitau, & Stevenson, 2014; Belmain & Stevenson, 2016; Kareru, Rotich, & Maina, 2013). This can be attributed to the use of hazardous insecticides and lack of safety gear. If a farmer is poisoned, they may not be able to tend their fields regularly. A study conducted by Garmin, et al., 2009 in Nicaragua finds farmers with little education and prior poisoning experience are willing to pay more for safer insecticides. Botanical insecticides can serve as a healthier option at a cheaper price. Botanical insecticides also include some hazardous compound, however the concentration may be lower (Hernández-Moreno, et al., 2013; Belmain, Amoah, Nyirenda, Kamanula, & Stevenson, 2012; Amoabeng, Gurr, Gitau, & Stevenson, 2014).

Protective gear and safety training are still recommended for the use of botanical insecticides to ensure farmer health.

There is little investment in creating markets, regulations, and robust research into botanical insecticides (Stevenson, Isman, & Belmain, 2017; Isman & Grieneisen, Botanical insecticide research: many publications, limited useful data, 2014). However, botanical insecticides are effective alternatives for farmers in Tanzania. Realistically, synthetic insecticides cannot be completely replaced by botanical insecticides. Two approaches can be taken to decrease the dependency on synthetic insecticide.

1. Farmers who cannot afford synthetic insecticides should rely on botanical insecticides. Effective extracts that preserve predators and beneficial insects can manage pests more effectively than using no treatment.
2. Pest management can integrate synthetic insecticides as a supplement for botanical insecticides. Using botanical and synthetic insecticides at different point within the crop season can be economically and ecologically beneficial. This can be especially helpful for farmers who have access to selective synthetic insecticides.

Any form of pest management will need extensive training to ensure safe handling and minimize ecological, health, and economic risks. More research, funding, and regulation over insecticides can help provide farmers quality tools to tend their land. Botanical insecticides and integration of botanical and synthetic insecticides can benefit the livelihoods of farmers in Tanzania.

7.0 Conclusion and Recommendation

Botanical insecticides provide an effective, low cost, and environmentally friendly pest management tool for farmers in Tanzania. With further efforts to improve farmer training and ecological knowledge, as well as agricultural regulations, botanical insecticides can be used by themselves or supplemented with synthetic insecticides. Future studies should increase the sample size of sources for ecological and economic comparisons of botanical and synthetic insecticides. This can be especially helpful to determine economic benefits of botanical insecticides, which are not widely researched. An experiment can be conducted to determine pest and non-target insect populations in fields with synthetic or botanical insecticides.

8.0 Bibliography

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.

Anjarwalla, P., Belmain, S. R., Sola, P., & Jamnadass, R. (2016). *Handbook on Pesticidal Plants.* Nairobi, Kenya: World Agroforestry Centre (ICRAF).

Bazie, S., Ebabuye, Y., Kim, S. W., & Lee, Y. S. (2019). Integrated Management of Haricot Bean Foliage Beetle in Northeast Ethiopia. *Psyche: A Journal of Entomology*.

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

Belmain, S., & Stevenson, P. C. (2016, October). PESTICIDAL PLANTS IN AFRICAN AGRICULTURE: LOCAL USES AND GLOBAL PERSPECTIVES. *Outlooks on Pest Management*, 226-230.

Biondi, A., Desneux, N., Siscaro, G., & Zappalà, L. (2012). Using organic-certified rather than synthetic pesticides may not be safer for biological control agents: Selectivity and side effects of 14 pesticides on the predator Orius laevigatus. *Chemosphere, 87*, 803-812.

Crowder, D. W., Northfield, T. D., Strand, M. R., & Snyder, W. E. (2010, July). Organic agriculture promotes evenness and natural pest control. *Nature, 466*, 109-112.

Dougoud, J., Toepfer, S., Bateman, M., & Jenner, W. H. (2019). Efficacy of homemade botanical insecticides based on traditional knowledge. A review. *Agronomy for Sustainable Development, 39*(37).

El-Heneidy, A. H., Khadir, A. A., & Taman, A. A. (2015). Side-effects on Insecticides on Non-target Organisms: 1- In Egyptian Cotton Fields. *Egyptian Journal of Biological Pest Control, 25*(3), 685-690.

Elisante, F., Ndakidemi, P. A., Arnold, S. E., Belmain, S. R., Gurr, G. M., Darbyshire, I., . . . Stevenson, P. C. (2019). Enhancing knowledge among smallholders on pollinators and supporting field margins for sustainable food security. *Journal of Rural Studies, 70*, 75-86.

Fernandes, M. E., Alves, F. M., Pereira, R. C., Aquino, L. A., Fernandes, F. L., & Zanuncio, J. C. (2016). Lethal and sublethal effects of seven insecticides on three beneficial insects in laboratory assays and field trials. *Chemosphere, 156*, 45-55.

Garming, H., & Waibel, H. (2009). Pesticides and farmer health in Nicaragua: a willingness-to-pay approach to evaluation. *The European Journal of Health Economics, 10*, 125-133.

Goulson, D. (2013). An overview of the environmental risks posed by neonicotinoid insecticides. *Journal of Applied Ecology, 50*(4), 977-987.

Grzywacz, D., Stevenson, P. C., Mushobozi, W. L., Belmain, S., & Wilson, K. (2014). The use of indigenous ecological resources for pest control in Africa. *Food Security, 6*, 71–86.

Hernández-Moreno, D., Soffers, A. E., Wiratno, Falke, H. E., Rietjens, I. M., & Murk, A. J. (2013). Consumer and farmer safety evaluation of application of botanical pesticides in black pepper crop protection. *Food and Chemical Toxicology, 56*, 483-490.

Hikal, W. M., Baeshen, R. S., & Said-Al Ahl, H. A. (2017). Botanical insecticide as simple extractives for pest control. *Cogent Biology, 3*.

Isenring, R. (2010). *Pesticides and the loss of biodiversity How intensive pesticide use affects wildlife populations and species diversity.* London: Pesticide Action Network Europe.

Isman, M. B. (2017). Bridging the gap: Moving botanical insecticides from the laboratory to the farm. *Industrial Crops and Products*, *110*, 10-14.

Isman, M. B. (2020). Botanical Insecticides in the Twenty-First Century—Fulfilling Their Promise? *Annual Review of Entomology, 65*, 233-249.

Isman, M. B., & Grieneisen, M. L. (2014). Botanical insecticide research: many publications, limited useful data. *Trends in Plant Science, 19*(3), 140-145.

Jafarbeigi, F., Samih, M. A., Zarabi, M., & Esmaeily, S. (2014). Sublethal effects of some botanical and chemical insecticides on the cotton whitefly, Bemisia tabaci (Hem: Aleyrodidae). *Arthropods, 3*(3), 127-137.

Kareru, P., Rotich, K. Z., & Maina, E. W. (2013). Use of Botanical and Safer Insecticides Designed in Controlling Insects: The African Case. *Insecticides - Development of Safer and More Effective Technologies*, 297-309.

Kestenholz, C., Stevenson, P. C., & Belmain, S. R. (2007). Comparative study of field and laboratory evaluations of the ethnobotanical Cassia sophera L. (Leguminosae) for bioactivity against the storage pests Callosobruchus maculatus (F.) (Coleoptera: Bruchidae) and Sitophilus oryzae (L.) (Coleoptera: Curculionid. *Journal of Stored Products Research, 43*, 79-86.

Khan, A. A., Afzal, M., Qureshi, J. A., Khan, A. M., & Raza, A. M. (2014). Botanicals, selective insecticides, and predators to control Diaphorina citri (Hemiptera: Liviidae) in citrus orchards. *Insect Science*, *21*, 717-726.

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

Lengai, G. M., Muthomi, J. W., & Mbega, E. R. (2020). Phytochemical activity and role of botanical pesticides in pest management for sustainable agricultural crop production. *Scientific African, 7*.

Letourneau, D. K., & Bothwell, S. G. (2008). Comparison of organic and conventional farms: challenging ecologists to make biodiversity functional. *Frontiers in Ecology and the Environment, 6*(8), 403-438.

Lian, W., & Jin, D. (2017). Development and Utilization of Botanical Pesticide Resources in Changbai Mountain. *Agricultural Economy and Management, 18*(9), 1760-1763.

Lima, D. B., Melo, J. W., Guedes, N. M., Gontijo, L. M., Guedes, R. N., & Gondim Jr., M. G. (2015). Bioinsecticide-Predator Interactions: Azadirachtin Behavioral and Reproductive Impairment of the Coconut Mite Predator Neoseiulus baraki. *PLOS ONE, 10*(2).

Loha, K. M., Lamoree, M., Weiss, J. M., & Boer, J. d. (2018). Import, disposal, and health impacts of pesticides in the East Africa Rift T (EAR) zone: A review on management and policy analysis. *Crop Protection, 1*(12), 322-331.

Mamduh, Z., Hosseininaveh, V., Allahyari, H., & Talebi-Jahromi, K. (2017). Side effects of garlic extract on the life history parameters of the predatory bug, Podisus maculiventris (Say) (Hemiptera: Pentatomidae). *Crop Protection, 100*, 65-71.

Maneepitak, S., & Cochard, R. (2014). Uses, toxicity levels, and environmental impacts of synthetic and natural pesticides in rice fields – a survey in Central Thailand. *Journal of Biodiversity Science, Ecosystem Services & Management, 10*(2), 144-156.

Miglani, R., & Bisht, S. S. (2019). World of eathworms with pesticides and insecticides. *Interdisciplinary Toxicology, 12*(2), 71-82.

Miresmaili, S., & Isman, M. B. (2014). Botanical insecticides inspired by plant–herbivore chemical interactions. *Trends in Plant Science*, *19*(1), 29-35.

Mkenda, P., Mwanauta, R., Stevenson, P. C., Ndakidemi, P., Mtei, K., & Belmain, S. R. (2015). Extracts from Field Margin Weeds Provide Economically Viable and Environmentally Benign Pest Control Compared to Synthetic Pesticides. *PLOS ONE, 10*, 1-14.

Mkindi, A. G., Mtei, K. M., Njau, K. N., & Ndakidemi, P. A. (2015). The Potential of Using Indigenous Pesticidal Plants for Insect Pest Control to Small Scale Farmers in Africa. *American Journal of Plant Sciences, 6,* 3164-3174.

Mwatawala, M. W., Mziray, H., Malebo, H., & Meyer, M. D. (2015). Guiding farmers' choice for an integrated pest management program against the invasive Bactrocera dorsalis Hendel (Diptera: Tephritidae) in mango orchards in Tanzania. *Crop Protection, 76*, 103-107.

Ndakidemi, B., Mtei, K., & Ndakidemi, P. A. (2016). Impacts of Synthetic and Botanical Pesticides on Beneficial Insects. *Agricultural Sciences, 7*, 364-372.

Onuminya, T. O., Agboola, O. O., & Ezeribe, S. R. (2018). INSECTICIDAL EVALUATION OF SOME BOTANICAL POWDERS AS STORED MAIZE GRAIN PROTECTANTS AGAINST SITOPHILUS ZEAMAIS (MOTSCHULSKY) (COLEOPTERA: CURCULIONIDEA); A CONCERN FOR POSTHARVEST LOSS. *Annals of West University of Timişoara: Series of Biology, 21*(2), 157-164.

Opolot, H. N., Agona, A., Kyamanywa, S., Mbata, G. N., & Adipala, E. (2006). Integrated field management of cowpea pests using selected synthetic and botanical pesticides. *Crop Protection, 25*, 1145-1152.

Panagiotakopulu, E., Buckland, P. C., & Day, P. M. (1995). Natural Insecticides and Insect Repellents in Antiquity: A Review of the Evidence. *Journal of Archaeological Science, 22*, 705-710.

Ponsankar, A., Vasantha-Srinivasan, P., Senthil-Nathan, S., Thanigaivel, A., Edwin, E.-S., Selin-Rani, S., . . . Dura. (2016). Target and non-target toxicity of botanical insecticide derived from Couroupita guianensis L. flower against generalist herbivore, Spodoptera litura Fab. and an earthworm, Eisenia foetida Savigny. *Ecotoxicology and Environmental Safety, 133*, 260-270.

Quesada, C., & Sador, C. (2019). Field evaluation of insecticides and application timing on natural enemies of selected armored and soft scales. *Biological Cotnrol*(133), 81-90.

Raupp, M. J., Holmes, J. J., Sadof, C., Shrewsbury, P., & Davidson, J. A. (2001). Effects of Cover Sprays and Residual Pesticides on Scale Insects and Natural Enemies in Urban Forests. *Journal of Arboriculture, 27*(4), 203-214.

Ribeiro, A. V., Farias, E. d., Santos, A. A., Filomeno, C. A., Santos, I. B., Barbosa, L. C., & Picanço, M. C. (2018). Selection of an essential oil from Corymbia and Eucalyptus plants against Ascia monuste and its selectivity to two non-target organisms. *Crop Protection, 110*, 207-213.

Ricupero, M., Desneux, N., Zappala, L., & Biondi, A. (2020). Target and non-target impact of systemic insecticides on a polyphagous aphid pest and its parasitoid Michele Ricupero a, Nicolas Desneux b, Lucia Zappal?a a, *. *Chemosphere, 247*.

Roy, S., Handique, G., Muraleedharan, N., Dashora, K., Roy, S. M., Mukhopadhyay, A., & Babu, A. (2016). Use of plant extracts for tea pest management in India. *Applied Microbiology and Biotechnology, 100*, 4831-4844.

Sawe, T., Nielsen, A., & Eldegard, K. (2020). Crop Pollination in Small-Scale Agriculture in Tanzania: Household Dependence, Awareness and Conservation. *Sustainability*, *12*(6).

Stevenson, P. C., Isman, M. B., & Belmain, S. R. (2017). Pesticidal plants in Africa: A global vision of new biological control products from local uses. *Industrial Crops and Products, 110*, 2-9.

Tembo, Y., Mkindi, A. G., Mkenda, P. A., Mpumi, N., Mwanauta, R., Stevenson, P. C., . . . Belmain, S. R. (2018). Pesticidal Plant Extracts Improve Yield and Reduce Insect Pests on Legume Crops Without Harming Beneficial Arthropods. *Frontiers in Plant Science, 9*.

Tschoeke, P. H., Oliveira, E. E., Dalcin, M. S., Silveira-Tschoeke, M. A., Sarmento, R. A., & Santos, G. R. (2019). Botanical and synthetic pesticides alter the flower visitation rates of pollinator bees in Neotropical melon field. *Environmental Pollution, 251*, 591-599.

Vandermeer, J., Perfecto, I., & Philpott, S. (2010). Ecological Complexity and Pest Control in Organic Coffee Production: Uncovering an Autonomous Ecosystem Service. *BioScience, 60*(7), 527-537.

Zuhra, B., Ahmad, K., Ali, S., Hussain, A., Nafees, M. A., Ali, S., . . . Ali, Z. (2018). Assessing the Toxic Potential of Insecticide and Indigenous Botanical Extract against the Stored Grain Pest Tribolium castaneum (Coleoptera: Tenebrionidae). *Polish Journal of Environmental Studies*, *27*(5), 2377-2383.