DETERMINING THE EFFICACY OF SYRINGA *(Melia azedarach* L.) EXTRACTS AND GARLIC (*Allium sativum* L.) EXTRACTS IN THE CONTROL OF TOBACCO SPIDER MITES (*Tetranychus evansi*) IN TOMATOES (*Lycopersicum esculentum)* UNDER FIELD CONDITIONS IN CHIREDZI DISTRICT, IN ZIMBABWE.

by

NYAMHUNGA SHOW (43556744)

Submitted in accordance with the
requirements for the degree

of

MASTER OF SCIENCE (MSc)

in

AGRICULTURE

at the

UNIVERSITY OF SOUTH AFRICA

SUPERVISOR : DR L.E NEMADODZI
CO-SUPERVISOR : DR G.M MANAGA

MARCH 2023

DECLARATION

I declare that this dissertation is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

18/03/2023

SIGNATURE DATE

ACKNOWLEDGMENTS

I would like to thank Dr L.E Nemadodzi, my supervisor and co-supervisor Dr G.M Managa for project development and closely monitoring and supervising this work. Dr Casper Kamutando from University of Zimbabwe is acknowledged for his technical support. I would also want to thank Chiredzi research station for sponsoring land to undertake this project. The University of South Africa's personnel and Faculty of Environmental Sciences and Agriculture (UNISA). I value the suggestions and constructive feedback I received from my coworkers. This initiative would not have been effective without all of the aforementioned coworkers and organizations. Last but not least, I would like to express my gratitude to my supervisors for the excellent work they carried out through numerous follow-ups, teams meetings, back-and-forth chapter reviews, and in general, your perseverance in ensuring the success of this write-up. May Almighty God richly bless the two of you in the field of research work.

DEDICATION

I dedicate this dissertation to my family for motivating me through this journey.

ABBREVIATIONS

Ca : Calcium

CO_2 : Carbon dioxide

Cu : Copper

DAS : Days after Spraying

FAO : Food and Agricultural Organization

FAOSTAT : Food and Agricultural Organization Statistics

DV : Daily Value

GDP : Gross Domestic Product

Ha :Hectares

IOBC : International organization of biological control

K : Potassium

N : Nitrogen

Mg : Magnesium

P : Phosphorus

RDA : Recommend Dietary Allowance

RSM : Red spider mites

SADC : Southern Africa Development Country

USA : United States of America

USDA : United States Department of Agriculture

UNICEF : International Childrens Emergency Fund

WFP : World Food Programme

WHO : World Health Organisation

Zn : Zinc

ABSTRACT

The production of tomatoes is hampered by a variety of pests and diseases despite the importance of tomatoes as a vegetable in everyday life and their economic significance in Zimbabwe. Tobacco spider mites (*Tetranychus evansi*), is the most troublesome parasite, have significantly reduced the marketable output, quality, and financial loss of tomatoes. The development and widespread use of synthetic pesticides as a quick and more efficient technique of controlling pests and diseases was prompted by the increased high demand for food to feed the expanding world population. Because of their negative impacts on human health, the environment, and the emergence of pest/pathogen strains with resistance, synthetic pesticides should not be used excessively. This, together with rising demand for food grown organically, sparked the development of alternative strategies and botanical insecticides as powerful tools for controlling tobacco spider mites. This sparked interest in research on syringa (a street lining tree) and garlic (grown in abundance for sale and for human consumption at household levels), which are locally available and easily accessible in Chiredzi district of Zimbabwe and led to the study. Botanical pesticides are effective in managing different crop pests, inexpensive easily biodegradable, have different modes of action and their sources are easily accessible and have low toxicity to non-target organisms.

A field experiment was conducted to ascertain the substantial differences in effectiveness between garlic and syringa in the control of tobacco spider mites. The concentrations of the two plants used were 5%, 25%, 50%, and 75% of each. The research showed that *Melia azedarach* and *Allium sativum* have pesticidal effects on tobacco spider mites. Allicin, an active component in minced garlic cloves, and limonoid, a triterpenoid that is an active component in syringa, could be responsible for the pesticidal actions of garlic.

Key words: Tomato, tobacco spider mites, botanical pesticides, efficacy, mortality rate

Table of Contents

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

1. INTRODUCTION

One of the most well-known and significant vegetable crops worldwide is the tomato (*Lycopersicum esculentum*), which is farmed by many smallholder farmers in Zimbabwe (Dube *et al.,* 2020). The crop was originally grown throughout Central and South America (FAOSTAT, 2017). Since the end of the nineteenth century, it has become more popular in the tropics and subtropics after being domesticated in Mexico (Saavendra *et al.,* 2016).

Tomatoes are produced for their fruits, which contain significant amounts of vitamins (particularly vitamin A and C), potassium, calcium, carbohydrates, dietary fiber, and proteins (Misheck *et al.,* 2015). Tomato fruit is known to be a rich source of carotenoids (lycopene and -carotene), phenolic acids, and flavonoids in addition to a huge variety of other crucial components. These mineral substances have anti-proliferative and anti-inflammatory characteristics, and they function as antioxidants to shield cells from reactive oxygen species (Silahle *et al.,* 2014). However, it is well known that tomatoes, whether cooked or raw, are the best source of these antioxidants. According to Dolinsky *et al.*, (2016), a 100 g tomato contains 20–40% of the daily required amount of vitamins A and C. Tomato fruits are eaten raw in salads and cooked as a seasoning in soups, sauces, and stews made with meat or fish (Indigenous knowledge).

While dried and canned tomatoes are known to be essential processed goods for the economy, they can also be made into juice, paste, purees, purse powder, chutneys, and ketchup (Naika *et al.,* 2019). This characteristic, according to Prado *et al.,* (2022), contributes to the crop's significance because it is required in almost every cuisine in the globe because of its flavorful abilities and ensuing economic value. Fresh tomato consumption and higher serum tomato levels have been linked to a number of positive health effects, including a lower risk of cardiovascular disease and cancer development in humans (including stomach, lung, and prostate *cancer).*

The tomato industry is one of the most advanced, creative, and internationally diversified, according to Amanda *et al.*, (2019). Over the past few decades, the Food and Agriculture Organization of the United Nations (FAO) estimated that at least 123 million tons of tomatoes were produced globally with a total production area of about 4.5 million yield per hectare (Gatahi, 2020). 88 million tons of the anticipated 123 million tons were intended for the fresh market, while 42 million tons were processed. The top four tomato-producing countries in the world—China, the European Union, the United States of America, and Turkey—account for 70% of the overall production (Gennari *et al.,* 2019).

The World Processing Tomato Council (WPTC) reported that Tunisia, Senegal, Algeria, Egypt, South Africa, and Morocco are among the African countries that produce tomatoes for the world market in accordance with data from the Food and Agriculture Organization (2019). Statistics show that region produces 3.7 kg/m2 of tomatoes on average. Contrasting sharply with this are the yields that farmers achieve in the US (9.03 kg/m2), Spain (8.62 kg/m2), and Morocco (8.08 kg/m2).

According to figures from the Food and Agriculture Organization (2019), the World Processing Tomato Council (WPTC) showed that Tunisia, Senegal, Algeria, Egypt, South Africa, and Morocco are among the African nations that produce tomatoes for the global market. According to the statistics, that area produces 3.7 kg/m2 on average of tomatoes. This contrasts sharply with the yields that growers achieve in: USA (9.03 kg/m^2), Spain (8.62 kg/m^2) and Morocco (8.08 kg/m^2).

Table 1: The top 10 tomato producing countries in the world for 2019

Rank Country	Production (tonnes)
China	62 674 671
India	19 007 000
Turkey	12 841 990
United states of America	10 858 990
Egypt	6 751 856
Italy	5 252 690
Iran Islamic Republic of	5 248 904
Spain	5 000 560
Mexico	4 271 914
Brazil	3,917

Source: FAOSTAT, (2019).

Previously reported statistics indicated that with an average of 50.7 kg/$m^{2,}$ the Dutch yield stands above the rest of the world, (FAOSTAT, 2017). Moreover, tomato production is expected to continue rising for both processed and fresh types globally.

Tomato Production in Zimbabwe

With an average yield per hectare of 71483 in 2018, Zimbabwe ranked 155 overall and fifth among the southern African development countries (SADC), behind South Africa, Malawi, Mozambique, and Angola (*see Table 1). In Zimbabwe, both the smallholder and commercial sectors' yields have remained well below the crop's genetic potential, according to research by FAOSTAT (2018). In addition, smallholder sector produce has continued to be very low, producing an average of 7–10 tons per hectare in contrast to commercial sector produce, which produces an average of 100–120 tons per hectare. This is because of a number of difficulties, including poor agronomic practices, high production costs, a lack of skills with poor management of pests and diseases, and inadequate irrigation facilities (Gatahi, 2020). Despite the difficulties, tomato cultivation in Zimbabwe has developed into a crucial, fast-growing source of income that significantly boosts the GDP of the nation (GDP). The fifth-highest agricultural export earner and a producer of horticulture, the tomato, contributes 6.5 percent of the agricultural domestic product. Due to successful business practices and stakeholder infrastructure developments, the majority of horticultural crop production—on both a large and small scale—is done close to major urban centers and along roads connecting urban settlements. Tomato production and selling creates jobs that eventually help the majority of rural Zimbabweans escape poverty and provide a source of income for the country's smallholder farmers (Misheck *et al*., 2015).

Diseases and pests affecting tomatoes in Zimbabwe

Different varieties of tomato vary in their resistance to pest and diseases (Gatahi, 2020). The major diseases of tomatoes include bacterial wilt caused by (*Ralstonia solanacearum),* bacterial canker caused by (*Clavibacter michiganensis)*, *Fusarium wilt,* yellow leaf curl disease caused by (*Taphrina deformans)*, early blight caused by (*Alternaria solani)* and late blight caused by (*Phytophthora infestans),* cabbage aphids (*Brevicoryne brassicae)*, tobacco spider mites (*Tetranychus envansi)*. Whiteflies (*Bemisia tabaci),* nematodes (*Meloidogyne javanica), (Tutor absoluta) Tomato leafminer and A*fricanbollworm (*Helicoverpa armigera Hubner*), are among the pests that attack tomatoes. There is a severe crisis in the production of tomatoes in other parts of Africa due in large part to these pests and diseases. Therefore, it is crucial to prevent pests and diseases from spreading during tomato production because they could reduce overall yield.

In Zimbabwe, using synthetic acaricides to control tobacco spider mites is growing in favor. However, because of side effects such environmental pollution and the emergence of resistance to chemical pesticides, utilizing them to manage tobacco spider mites is experiencing an increase in resistance. Contrary to synthetic pesticides, biological pesticides are known for leaving no harmful residues on crops. Additionally, it has been demonstrated that they are non-toxic, short-lived in the environment, and safe. According to Anjarwalla *et al*., (2016), ethnobotanical pesticides are naturally occurring pesticides derived from local plants and have proven to be highly effective in managing a variety of crop pests and human infections. For instance, sweet wormwood (*Astemisia annua*) and pyrethrum (*Tanacetum cinerariifolium*) flowers have been used as sources of safe insecticides for managing insect pest and malaria vectors, respectively (Sawar *et al.,* 2015), and have been credited for their effectiveness, biodegradability, varied modes of action, low toxicity, and availability of source of material. Globally, neem products from *Azadirachta indica,* rotenone from Derris, *Lonchocarpus capassa* and pyrethrum products from *Tanacetum cinerariifolium*, are the most common examplesof botanical pesticides developed and traded, (Smith *et al.,* 2021).

Tobacco spider mites are one of the principal pests influencing tomato quality and quantity, which in turn affects the market value of the crop, according to surveys conducted by Weinbulm *et al*., 2021. Tobacco spider mites (*Tetranychus evansi*) is reportedly most troublesome mite, hurting tomato production and quality (Ginette, 2015). The fundamental issue is the increased and ongoing use of comparable acaricides, which is leading to resistance while removing significant tobacco mite predators (Biezla *et al.,* 2020). It was estimated that the percentage yield losses caused by tobacco spider mites in Zimbabwe ranged according to predictions, between 2008 and 2017 are between 40 and 50 percent of Zimbabwe's output would have been lost owing to mite infestation (FAO, 2018). Therefore, it is imperative to find alternative solutions to the insect and disease problems that is damaging Zimbabwe's tomato production.

1.1 Problem statement

The same acaricides have been used to control tobacco spider mites for more than ten years, which has led to acaricide tolerance and/or resistance, which is gradually reducing the efficacy of acaricides on the market. Additionally, this has led to poor pest control, particularly with regard to tobacco spider mites, which has a negative impact on the viability of all the crops they attack, including tomatoes, on both a quality and quantity level. Smallholder farmers are most impacted by the availability, accessibility issues, and pricing of chemical pesticides because the majority of them are quite expensive. To battle insect pests in crops, botanical pesticides are usually regarded as an environmentally friendly, sustainable, and successful method. Tobacco spider mites are the most destructive and troublesome insect pests in tomatoes garlic and syringa may be effective biopesticides for managing them. However, this information is essential to recommending the use of botanical pesticides as distinctive substitutes for chemical pesticides in Zimbabwe's tomato industry**.**

1.2 Aim of the study

- ✓ The primary aim of the study was to investigate the efficacy of garlic and syringa worked in the field to suppress Tobacco spider mites (*Tetranychus evansi*) on tomatoes (*Lycopersicum esculentum*) in Chiredzi, Zimbabwe's southern east district.

1.3 Objectives of the study

- ✓ To assess the efficacy of *Melia azedarach* L*.* (syringa) and *Allium sativum* (garlic) extracts on red spider mites on tomatoes grown under field conditions.
- ✓ To determine the optimum concentration level between the two extracts to be used for the effective control of tobacco spider mites.

1.4 Hypothesis

- ✓ Different concentration levels of garlic and syringa extracts does not help in the control of red spider mites on tomato production

1.5 Significance of the study

Results of this study will assist farmers in the control of tobacco spider mites on tomato production, which will ultimately result in higher yields, high quality, and quantity in the irrigation schemes, which will significantly improve the livelihoods of rural communities in the Chiredzi district and generate income for smallholder farmers. The study's conclusions will provide additional opportunities for entomology experts to explore the usage of other botanical plant extracts in the management of tobacco spider mites. Other researchers working in the same field will also refer to the study's results as a starting point. Finally, the study will make a significant contribution to science and understanding.

1.6 Ethical consideration

Ethical approval was granted by Unisa Ethics Committee with REF: 2018/CAES/020 before the commencement of the study.

REFERENCES

Anjarwalla, P., Belmain, S., Ofori, D., Sola, P., Jamnadas, R. and Stevenson, P., 2016. Handbook on pesticidal plants Optimization of Pesticidal plants: Technology. *Innovation, Sensibilization, Research.(May), Nairobi, World Agroforestry Centre*.

Armanda, D.T., Guinée, J.B. and Tukker, A., 2019. The second green revolution: Innovative urban agriculture's contribution to food security and sustainability–A review. *Global Food Security*, *22*, pp.13-24.

Bielza, P., Balanza, V., Cifuentes, D. and Mendoza, J.E., 2020. Challenges facing arthropod biological control: identifying traits for genetic improvement of predators in protected crops. *Pest management science*, *76*(11), pp.3517-3526.

Borisade, O.A., Kolawole, A.O., Adebo, G.M. and Uwaidem, Y.I., 2017. The tomato leafminer (Tuta absoluta)(Lepidoptera: Gelechiidae) attack in Nigeria: effect of climate change on over-sighted pest or agro-bioterrorism?. *Journal of Agricultural Extension and Rural Development*, *9*(8), pp.163-171.

Dolinsky, M., Agostinho, C., Ribeiro, D., Rocha, G.D.S., Barroso, S.G., Ferreira, D., Polinati, R., Ciarelli, G. and Fialho, E., 2016. Effect of different cooking methods on the polyphenol concentration and antioxidant capacity of selected vegetables. *Journal of Culinary Science & Technology*, *14*(1), pp.1-12.

Dube, J., DDamulira, G. and Maphosa, M., 2020. Tomato breeding in Sub-Saharan Africa-Challenges and opportunities: A review. *African Crop Science Journal*, *28*(1), pp.131-140.

Dube, N., 2022. Climate Change Risks in Horticultural Value Chains: A Case Study from Zimbabwe. *Climate Change in Asia and Africa: Examining the Biophysical and Social Consequences, and Society's Responses*, p.119.

FAOSTAT of the United Nation. (2017) "Production of tomatoes, (2016) (from pick lists: Crops/World Regions/Production Quantity)"

Gatahi, D.M., 2020. Challenges and opportunities in tomato production chain and sustainable standards. *International Journal of Horticultural Science and Technology*, *7*(3), pp.235-262.

Gennari, P., Rosero-Moncayo, J. and Tubiello, F.N., 2019. The FAO contribution to monitoring SDGs for food and agriculture. *Nature plants*, *5*(12), pp.1196-1197.

Gwebu, J.Z. and Matthews, N., 2018. Metafrontier analysis of commercial and smallholder tomato production: A South African case. *South African Journal of Science*, *114*(7-8), pp.55-62.

Nayik, G.A. and Gull, A. eds., 2020. *Antioxidants in Vegetables and Nuts-Properties and Health Benefits*. Springer.

Neeraj, G.S., Kumar, A., Ram, S. and Kumar, V., 2017. Evaluation of nematicidal activity of ethanolic extracts of medicinal plants to Meloidogyne incognita (kofoid and white) chitwood under lab conditions. *Int. J. Pure Appl. Biosci*, *5*, pp.827-831.

Saavedra, T.M., Figueroa, G.A. and Cauih, J.G.D., 2016. Origin and evolution of tomato production Lycopersicon esculentum in México. *Ciência Rural*, *47*.

Sarwar, M., 2015. Microbial insecticides-an ecofriendly effective line of attack for insect pests management. *International Journal of Engineering and Advanced Research Technology*, *1*(2), pp.4-9.

Selahle, M.K., Sivakumar, D. and Soundy, P., 2014. Effect of photo-selective nettings on post-harvest quality and bioactive compounds in selected tomato cultivars. *Journal of the Science of Food and Agriculture*, *94*(11), pp.2187-2195.

Smith, H.H., Idris, O.A. and Maboeta, M.S., 2021. Global trends of green pesticide research from 1994 to 2019: A bibliometric analysis. *Journal of toxicology*, *2021*

CHAPTER TWO

LITERATURE REVIEW

2.1. Tomato *(Lycopersicum esculentum)*

Previously known as *Solanum lycopersicon* (Linnaeus, 1753), the tomato (*Lycopersircum esculentum*, Miller, 1768) belongs to the order Solanales and family Solanaceae. The family is one of the most diverse flowering plant families with between 1500 and 2000 members (Gatahi, 2020). It is one of the most well-known and significant vegetable crops worldwide, and many smallholder farmers in Zimbabwe cultivate it (Mafongoya *et al.,* 2019). The two most popular food crops in the Solanaceous family are the potato (*Solanum tubersosum*) and tomato (*Lycopersicum esculentum*). Nightshades (*Solanum retroflexum Dun),* eggplants (*Solanum melongena*), chillies and bell peppers *(Capsicum spp.),* tomatillos (*Physalis ixocarpa*), tobacco (*Nicotiana tabacum*), and various decorative flower and fruit plants are other notable members of the family (Motti *et al.,* 2021).

2.1.1 Origin, distribution and uses of tomatoes

The Andes of Central and South America, specifically in Peru, Bolivia, and Ecuador, are where the tomato is believed to have first cropped up (Larranaga *et al.,* 2021). Spanish conquistadors brought the domesticated tomato to Europe in the fifteenth century, according to Andrist (2021) the cultivated tomato was introduced to Europe by Spanish conquistadors in the sixteenth century and then expanded to southern and eastern Asia, Africa, and the Middle East. Recently, the wild tomato has been spread throughout Mexico and South America. According to reports, outside of the tomato's original region of origin, Mexico is where the use of tomatoes as food first began. There, a variety of fruit sizes and colors were chosen (Gatahi, 2020).

According to research by Gerszberg *et al.,* (2015), commercial tomato production did not begin until around 1860, when consumers began to accept tomatoes. Through tomato breeding, numerous tomato varieties have recently been created and established for consumption all over the world. One of the most important and widely used vegetables in the world, tomatoes are eaten both raw in salads and cooked as a condiment in soups, stews, and meat or fish dishes. While dried and canned tomatoes are known to be important processed goods for the economy, they can also be made into juice, paste, purees, purse powder, chutney, and ketchup.

One of the most advanced, inventive, and globally oriented industries is the tomato business (Gatahi, 2020). With a total production area of about 4.5 million ha, the annual production of tomatoes has increased steadily over the past few decades. According to the FAO (FAOSTAT, 2019), in 2018, the world produced about 123 million tons of tomatoes, of which 88 million were intended for the fresh market and 42 million were processed (Salhab *et al.,* 2020). China, the European Union, the United States of America, and Turkey are the top four tomato-producing nations in the world, accounting for 70% of total production. Statistics show that from that acreage, tomatoes are harvested at a rate of approximately 3.7 kilograms per square meter. This stands in stark contrast to the yields that farmers in the United States (9.03 kg/m2), Spain (8.62 kg/m2), and Morocco (8.08 kg/m2) manage to produce. Results from 2017 showed that, with an average yield of 50.7 kg/m2, the Netherlands outperforms the rest of the world (FAOSTAT, 2017). In terms of tomato output within SADC, Zimbabwe comes in fifth place behind South Africa, Malawi, Mozambique, and Angola (*see Table 2.1). Additionally, it is anticipated that tomato output would rise internationally for both fresh and processed varieties.

Table 2.1: Yield statistics, for SADC countries on tomato production from 2008 to 2017 (Hectogram per Hectare).

Year	Country											
	Zimbabwe		**Zambia**		**South Africa**		**Mozambique**		**Angola**		**Malawi**	
	Area	Yield hg/ha	Area	Yield hg/ha	Area	Yield hg/ha	Area	Yield hg/ha	Area	Yield hg/ha	Area	Yield hg/ha
2008	2866	69953	2200	97743	7800	692910	16000	85000	4363	33913	9603	96804
2009	3100	72455	2550	98039	7700	692422	20000	77500	4617	32570	10593	96922
2010	3200	78125	2700	96296	7958	696264	15000	123333	4969	31194	11543	97556
2011	3146	71524	2763	97732	6853	746438	9500	205263	5243	29820	12406	97215
2012	3300	71212	2850	100000	7755	728209	12240	204248	6150	26829	4500	90000
2013	3300	71212	2745	98628	7431	734538	15000	200000	6200	27419	20822	127293
2014	3462	69740	2631	97353	6929	740867	13953	215008	6132	26575	24516	214582
2015	3575	70220	2624	97880	7468	747196	16700	215569	5871	27439	24681	211921
2016	3699	70179	2624	97927	7800	753525	17000	220000	6003	27025	24621	196475
2017	3791	70214	2632	97655	8006	759855	17859	212775	6139	26616	24000	187500
Average	3344	71483	2395	97925	7540	729222	15325	175870	5569	28940	16729	141627

Source: (WHO. 2020).

2.1.2 Nutritional content and health benefits of tomatoes

Tomatoes are cultivated for their fruits, which contain significant amounts of vitamins (A, B, and C), potassium, calcium, iron, carbs, and proteins (Sarker *et al*., 2020). Additionally, tomatoes have nutritional fiber, carbohydrates, and vital amino acids, which are the most crucial components of the human diet (Ali *et al*., 2020). According to Petersen *et al.*, (2017) research, both vitamins and fiber can lower excessive cholesterol levels by scavenging dangerous free radicals. The recommended daily allowance (RDA) for vitamin C is 60 mg per day, but the vitamin content of tomatoes varies due to cultural approaches, cultivars, and postharvest handling practices.

According to Raiola *et al.,* (2015), a 100 g tomato contains 20–40% of the US recommended daily intake (DV) for vitamin C, 15% of the DV for vitamin A, 8% of the DV for potassium, 7% of the DV for iron, and 10% of the RDA for males. Fresh tomato consumption and increased tomato serum levels have been linked to a range of health benefits, including a decreased chance of acquiring various malignancies (including prostate, lung, and stomach cancers) and cardiovascular illnesses in people (Quinet *et al*., 2019; Collins *et al*., 2022).

Tomatoes are known to be an excellent source of carotenoids, particularly lycopene and -carotene, phenolic acids, and flavonoids, which act as a potent antioxidant to protect cells from reactive oxygen species and have anti-proliferative and anti-inflammatory properties, as shown in Table 2.2. Tomatoes also contain a variety of other essential nutrients (Collins *et al*., 2022). The best source of these antioxidants is thought to be raw or cooked tomatoes. As a result, a number of these components might help explain why tomatoes are good for your health. Tomato products make up a greater portion of human nutrition than other vegetables because they are readily available, reasonably priced, and used in so many different ways by people of all ages and cultures.

Table 2.2: Nutritional value of raw tomato per 100 g

Principle	Unit	Nutritional value per 100 g
Proximate		
Water	G	94.52
Energy	Kcal	18
Protein	G	0.88
Total lipid (fat)	G	0.2
Carbohydrates	G	3.89
Fiber, total dietary	G	1.2
Total sugars	G	2.63
Minerals		
Calcium, Ca	Mg	10
Iron, Fe	Mg	0.27
Magnesium, Mg	Mg	11
Phosphorus, P	Mg	24
Potassium, K	Mg	237
Sodium, Na	Mg	5
Zinc, Zn	Mg	0.17
Copper, Cu	Mg	0.059
Vitamins		
Vitamin c, total ascorbic acid	Mg	13.7
Thiamin	Mg	0.037
Riboflavin	Mg	0.019
Niacin	Mg	0.594
vitamin B-6	Mg	0.08
Total folate	µg	15
vitamin A, RAE	µg	42
Vitamin E (alpha-tocopherol)	Mg	0.54
Vitamin k (phylloquinone)	µg	7.9
Carotenoids		
Carotene, beta	µg	449
Carotene, alpha	µg	101
Lycopene	µg	2573
Lutein + zeaxanthin	µg	123

Source: USDA National Nutrient data base (2020)

2.1.3 Insect pests affecting tomatoes

There are numerous pests that are known to damage tomatoes, and their prevalence varies depending on the climate and other environmental conditions (Skendzic *et al.,* 2021). The tobacco spider mites and root knot nematodes are the most prevalent and troublesome pests. It is well recognized that aphids, thrips, and white flies have a negative impact on tomato yield. The main pest is the American bollworm (*Hemicorvepa armigera*), which lays creamy white eggs that, under normal circumstances, hatch at 3 to 5 days and develop within 2 to 3 weeks with a diameter of 40 mm long. If not regulated, the newly hatched larvae's feeding on the leaves and fruit could result in significant losses (Gupta *et al*., 2019). On either side of the fruit, mature larval colors range from pale yellow to greyish white. Although they are around all year, the population damage is minimal in the cooler months when temperatures are below 18°C.

Cutworms (*Agrotis spp.)* eat at night, sever the stems of young plants and spend the daytime close below the soil's surface. They are 35 mm in length and are a greasy-looking dark brown to grey color. Nocturnal moths, according to Muimba-Kankolongo (2018), are characterized by having light brown rear wings and brown or greyish-brown forewings. The light-green Plusia looper (*Chrysodeis alupa*) caterpillar attacks fruit by eating it shallowly and frequently leaves large cavities in the leaves. Young larvae feed on the underside of leaves, skeletonizing them (Chandel *et al.,* 2022). The bright yellow maggots known as American leaf miners (*Lyrioyza trifoli*) create small, winding tunnels that have an impact on fruit set (Amarasekere, 2019). They create thin, black streaks of faeces after damaging both the underside and upper surfaces of the leaves. Aphids are soft-bodied, slowly moving insects that range in size from 1.5 to 2 mm. They can have wings or are wingless (Barret, 2022). The common aphid with populations that rise in the summer is the green peach aphid (*Myzus pesicae*). The damage these sap-sucking parasites do is preferable to the virus transmission that they bring about.

Thrips (*Thrips tabaci*), which rasp the surface of flowers and early fruits to suck the sap from damaged cells, feed on them. They result in bloom loss, fruit scarring, and leaf deformation. The insect is the virus's most harmful carrier and can seriously harm tomatoes during cooler months when temperatures are below 18°C (Pano *et al.,* 2021).

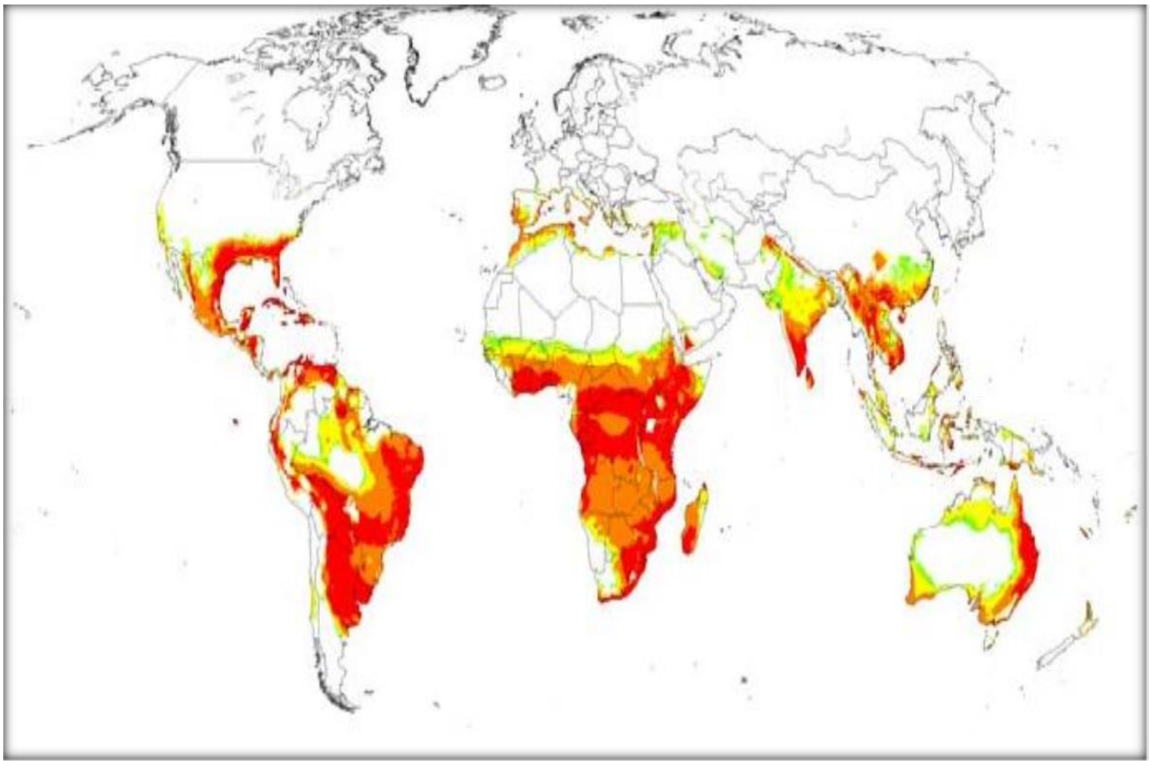
Erinose mite is a pest that affects primarily tropical and subtropical regions, where it causes dense patches of fine white hair on young leaves and stems (Yassen *et al.*, 2021).

Tobacco spider mites can cause harm to fruit, turning it rusty brown and breaking on the surface (Ghazy *et al.,* 2019). Tobacco spider mites are little approximately 0.02 mm long. As a result, the lowest leaves curl up, which is the first indication of damaged leaves, which have a silvery gloss on their lower surface. Later, the leaves turn bronze, eventually decompose, and the stem turns purplish brown. It is a well-known tomato pest that may give growers a lot of trouble and that requires rapid action to control. They have mouthparts for sucking and piercing. In close proximity to veins on the lower surfaces of leaves, you can find adults, nymphs, and eggs. The color of tobacco spider mites can range from orange to deep red. Tobacco spider (*Tetranychus evansi*) mites favours hot dry and dusty conditions (Unglesbee, 2020).

They are nasty pests that are difficult to eradicate, such as those that feed on the undersides of leaves and cause countless little yellow spots to emerge on the top surfaces (Zvereva *et al.*, 2010; Wari *et al.,* 2021). The undersides of the infected leaves appear to be covered in red brick dust, with a fine web encasing the mites' eggs. When severely attacked, plants lose their vigor and become stunted (Azandémè-Hounmalon *et al.,* 2014; Knegt *et al*., 2020), and their leaves turn brown and drop off*. Tobacco spider mites Tobacco spider mite (Tetranychus evansi)* is a spider mite that makes fine silk webbing that resembles spider web. It shields the mites from predators and adverse weather while also degrading the quality of the tomatoes (Akarawa *et al*., 2021). They can eat the contents of individual leaf cells thanks to their piercing mouthparts. Infested leaves display the typical yellow speckling of red spider mite symptoms as the mite population grows. If unmanaged, webbing may entirely envelop the plant (Azandémè-Hounmalon *et al*., 2014), becoming more and more obvious. Tobacco spider mite (*Tetranychus evansi)* can multiply tens of thousands of times in a short period of time on a single plant. The length of an adult is just approximately 0.6 mm, while younger stages are significantly tiny.

For pests with high invasive powers, it is especially crucial to anticipate the possible global dispersion of a species. Tobacco spider mite *Tetranychus evansi* (Chen *et al*., 2020), a spider mite pest of solanaceous crops, may be endemic to South America. In both Africa and Europe, this mite is regarded as an invasive species. The global distribution of the mites is depicted in Figure 2.5.

According to Djossou *et al*. (2021), tobacco spider mite (*Tetranychus evansi*) attack crops planted in greenhouses and fields, and they multiply quickly in warm and hot environments. Numerous issues were encountered when trying to control the mite population because *Tetranychus spp*. may live on both domesticated plants and wild species. In potatoes, soy beans, field beans, egg plants, green peppers, strawberries, tomatoes, tobacco, cotton, cucurbits, and a number of ornamental plants, tobacco spider mites (*Tetranychus evansi)* is a common pest. The aforementioned researchers also found that the issue has been made worse by yet another diverse range of wild plants that serve as the pest's reservoir and/or host. Among the wild host plants are apple of Peru (*Nicondra physalodes*), black nightshade (*Solarium nigrum*), bitter apple (*Datura stramonium*), wild gooseberry (*Physalis angulatio*), bobbin weeds (*Lences martinicensis*), upright starbur (*Acanthospernum hispidum*), pig weed (*Amaranthus hybridus*), and Sabi morning (*Ipomoea plebeion*). Resistance has emerged as a result of this propensity of switching between fields (Savi *et al*., 2022). This mite infestation is severe in the research region as a result of the mites' dispersion and encouraging factors. The red shaded areas show locations where mite populations are very abundant because of the local climate, the green shaded areas show marginal areas, and the areas with no shading show areas where mites are not a concern.



🟩 Mites thrive moderately they cause damage below economic levels

🟨 Mites are a minor pest

🟩 Marginal region

⬜ Mites are not a problem

Figure 2.1: Potential world distribution of tobacco spider (*Tetranychus evansi)* (Negm, 2014).

2.1.4 Biology and ecology of tobacco spider mites *(Tytranchus evansi)*

According to Ibrahim *et al.,* (2016), who presented information on the biology and ecology of tobacco spider mites (*Tytranchus evansi)*, activity peaks in the warmer months when temperatures range between 16 and 37 °C. After the eggs hatch, they can grow quickly during this period, reaching full size in as little as a week. Mature females may lay a dozen eggs every day for a few weeks after mating. Mite populations may rapidly grow as a result of the fast pace of development and high egg output. All spider mites thrive in dry environments, which is a key factor in their importance in the country's more arid regions. They consume more food when it is dry because the lower humidity makes it possible for them to expel excess water (Michereff-Filho *et al*., 2022).

The mites are more common following rains, according to Ghosh, (2019). When it comes to spider mite dissemination, wind is crucial. A spider mite's life cycle (*see Figure 2.2) can take ten to thirty days, depending on the temperature. It has four developmental phases: the egg, the larva (first instar), the two nymphal stages, and the adult. Over the course of her lifetime, a female may produce over one hundred eggs. Spider mites produce silk threads that they use to attach to plants, protecting them from predators and even pesticides as well as anchoring themselves and their eggs to the plant.

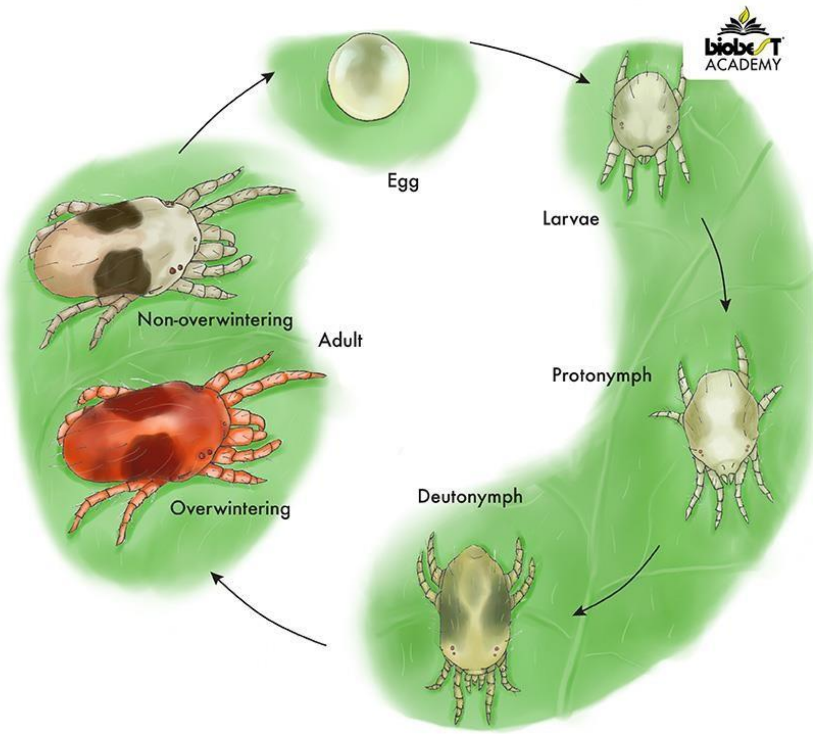


Figure 2.2: Life cycle of tobacco spider mite (*Tetranychus evansi)*, source Satish *et al*., (2018).

The tiny, pale-white, spherical eggs are placed below the surface of the leaves, frequently under the webbings. They cannot be seen without a magnifying lens; only with one can they be seen. The nymphs resemble the adults in appearance but are smaller in size, green or red in color, and have eight legs. The larvae are light green or pinkish, some larger than the eggs, and have six legs. The adults are oval, have eight legs, are extremely small (rarely more than 0.5 mm), and appear to the unaided eye to be tiny moving dots. When compared to the female, who has a more pointed abdomen, the male is often smaller in size. The spider mites come in a variety of colors. The color of the spider mites varies depending on the species. The term "spider mites" refers to several types of brilliant red spider mites. Others have colors that are rosy, greenish, yellowish, and orange. (*Tetranychus spp*) spider mites are polyphagous parenchyma cell-feeding pests that have a significant negative economic impact on numerous crops, particularly tomatoes (Knegt *et al.,* 2020).

2.1.5 Tobacco spider mite (*Tetranychus evansi)*

According to research done by Kungu *et al.,* (2020) on the tomato tobacco spider mite (*Tetranychus evansi*), it is the most harmful spider mite species in Southern and

Central Africa. The investigation also showed that this species was mistakenly introduced into Southern Africa in the 1980s from Brazil, South America. This spider mite has been gradually migrating north of Africa ever since. Tobacco spider mites (*Tetranychus evansi)* has recently been recognized as one of the primary pests in the production of tomatoes in nations including Kenya, Mozambique, Malawi, Namibia, Zambia, and Zimbabwe (Muimba-Kangolongo, 2018).

A cluster of yellow dots on the upper surface of leaves that may also seem chlorotic is typically tobacco spider mites *Tetranychus evansi's* first symptom (Knapp *et al.,* 2020). The result is a leaf that looks mottled or speckled. Certain plants, including okra, cotton, coffee, tea, and some ornamentals, may change in leaf color as a result of spider mite feeding, including some ornamentals. Additionally, leaves display symptoms such as lesions, discolorations, irregular leaf fall, and yellow or dead leaves. Additionally, inflorescences exhibit early fruit fall, an aberrant flavor fall, and a yellow or abnormal color. Each infestation causes the leaves to swell, wilt, and shed some spider mites.

Figure 2.3: Tobacco spider mites (*Tetranychus evansi)* and its corresponding symptoms upon infestation of tomato plants (Robeiro *et al.*, 2022).

2.1.6 General control of spider mites

Since the mites are widely dispersed at the beginning of the infestation, mitigating must begin quickly because it is difficult to eradicate the mites once they have become established. It is advised to use a "Damaged Leaf Index" ranking system to determine the extent of the mites' damage to three leaflets or plants, where 1 represents a few yellow spots and 5 represents a leaf completely covered with spots and dry patches.

Control measures should be put in place if the average damage level is higher than the first rank. Early diagnosis of the mites can occasionally be challenging for beginning farmers because the symptoms resemble a nutrient deficit or plant disease (Sinha *et al*., 2020). As a result, one method for figuring out when to spray is to carefully examine the underside of the affected leaves.

2.1.7 Chemical controls

Typically, pesticides created expressly for controlling spider mites (miticides or acaricides) are used in the chemical management of spider mites (WHO, 2010). Only a small number of synthetic pesticides have been shown to be successful in reducing spider mite infestations. Since most pesticides do not impact eggs, effective control usually requires repeated applications spaced roughly 10–14 days apart. Since pesticide resistance develops quickly as a result of frequent application (Sonhafouo-Chiana *et al*., 2022), it is necessary to have a wide variety of pesticides on hand to enable an efficient rotation. Tobacco spider mites are controlled by synthetic and chemical pesticides that are released into the atmosphere, where they eventually affect non-target species, have negative effects on wildlife, contaminate soil and water, and are typically very expensive and out of the reach of underprivileged African farmers.

2.1.8 Factors that influence pesticide efficacy

A variety of variables that affect the efficacy of pesticides are listed by Zinyemba *et al*., in 2018. The organization emphasized the following elements that influence pesticides' overall efficacy:

2.1.9 Use of appropriate spraying equipment

A spray needs to get through the foliage to the targeted insect within the plant in order to be effective. Commercial sprayers with high pressure can reach the targeted insect, but low pressure sprayers, especially those used by home owners, are poor at covering foliage since full cover sprays are rarely accomplished (Lou *et al*., 2018).

2.2 Effective pesticide application

Feeding on the underside of leaves are numerous insects and mites. Spider mites on broadleaf plants and cabbage worms on cabbage, broccoli, and cauliflower frequently present this challenge when pesticides are sprayed on top of the plants, where little to no pesticide reaches the pests (Roy *et al.,* 2018).

2.2.1 Stages of pest development

When insects mature, they are much more challenging to manage. As an illustration, Carbaryl is efficient against young, early instar grasshoppers but considerably less so against adults (Schowalter, 2018). The stage of the pest at the time of spraying is extremely important, according to a study of factors affecting the insecticidal efficacy of the Diatomaceous Earth Formulation SilicoSec against adults and larvae of the confused flour beetle, Tribolium confusum DuVal (*Coleoptera: Tenebrionidae*). The results demonstrated that mortality increased with exposure to interval and dose rate for both adults and larvae (Sudo *et al*., 2019).

Larvae were discovered to be more susceptible to pesticides than adults, and because adults could with stand exposure times and application rates that were fatal to larvae, mortality rates were higher in larvae. Adults' susceptibility to the pesticide decreased dramatically between the ages of 1 and 2 days and up to 7 days. The efficacy of a pesticide, however, significantly decreased as the relative humidity rose from 55% to 65%. When Saber *et al.,* (2018) stated that the age of the exposed mites had a significant impact on a pesticide's efficacy, it was in agreement with the findings above. The Apiaceae, Asteraceae, Lamiaceae, Myrtaceae, and taxonomies that are effective against phytophagous mites are some of the most researched botanical families for crop protection (Wanzala, 2017; Rincón *et al.,* 2019).

Due to their accessibility, availability, and low cost, there is currently a lot of interest in and use of botanical pesticides to determine their effectiveness in controlling tobacco spider mites.

2.2.2. Background of biopesticides

The demand for alternative bioactive botanical pesticides to control various crop pests is growing as a result of crops being exposed to and attacked by pests that may damage growth and quality. Sweet worm wood (*Artemisia annua*) and pyrethrum flowers (*Tanacetum cinerariifolium*) are two examples of plants that have been successfully used as natural insecticides to control pests and malaria vectors, respectively (Lengai *et al.,* 2020). Prior to the advent of synthetic pesticides, when technology took control, the usage of plant-based products was widespread (Mahmood *et al.,* 2016). Due to the popularity of synthetic pesticides and their success in managing numerous crop pests and diseases including rust and blights, the usage of botanical pesticides has been gradually declining. Currently the use of synthetic pesticides has been reported to pose a threat to human health and environmental safety (Pandey *et al*., 2018).

Current international efforts have demonstrated the importance of consuming food that is produced safely and organically. Some pesticides in the agriculture industry have been banned as a result of the discovery of toxic chemical pesticide residues in foods and increased consumer awareness of food safety and cleanliness. In addition, plant-based botanical pesticides are becoming more common in organic agriculture (Karaca *et al.,* 2017). The frequent use of synthetic chemicals has had a significant detrimental impact on the environment, health risks, and biodiversity loss, while the use of natural pesticides results in healthy surroundings and sustainable agriculture Riyaz *et al.,* 2022. Farmers in the export trade industry, such as the horticulture sector, have been adversely affected by synthetic produce (Fulano *et al.,* 2012).

In some developing nations, the discovery of banned pesticides with traces beyond regulatory residue limits has resulted in the loss of markets and money for exporters as well as growers (Lengai *et al.,* 2022). For example, the usage of emeton and alphadine (alpha-cypermethrin + dimethoate) on fresh vegetable export was prohibited (Handford *et al.,* 2015). The effectiveness, biodegradability, variety of modes of action, low toxicity, and accessibility of the material source are what give botanical pesticides their importance. The most common botanical pesticides are well known in organic farming, where products are produced naturally and sold for higher prices.

Currently, customers are prepared to pay more for organically produced food, which has made markets for botanical pesticides viable and safe for crops developed for human consumption (Das *et al.,* 2020). Numerous investigations utilizing well-known botanicals and undiscovered plant species with powerful botanical pesticidal activities have been conducted (Erenso *et al.,* 2016; Jawalkar *et al.,* 2016). Pyrethrum (*Tanacetum cinerariifolium*), neem (*Azadirachta indica*), sabadilla (*Schoenocaulon officinale*), tobacco (*Nicotiana tabacum*) and ryania (*Ryania speciose*) are among the plants that have botanical insecticides that are used commercially.

Farmers have historically utilized products with a botanical origin to save wheat. Plant-derived botanical insecticides deter and stop the growth of pests (Singh *et al.,* 2021). Botanical pesticide-producing plants contain chemicals that affect plant pathogens like bacteria, fungi, viruses, and nematodes.

2.2.3 Importance of botanical pesticides in crop production

Due to the rising demand for food to feed the expanding world population, synthetic pesticides have been used since they are an efficient way to manage agricultural pests (Nkechi *et al.,* 2018). Overuse of chemical pesticides was found to have negative health impacts on people, the environment and the emergence of pests resistant to chemical pesticides (Shabana *et al*., 2017). This led to the development of botanical pesticides, which are effective at controlling a variety of crop pests and are safe for the environment. Botanical pesticides are extremely affordable, biodegrade and have various modes of action that are related to the phytochemical makeup of various plants (Neeraj *et al*., 2017).

Integrating botanical pesticides into integrated pest management can help ensure sustainable agricultural productivity (Castillo-Sachez *et al*., 2015). However, because of difficulties in formulation and commercialization, botanical pesticides have not yet been widely used. In order to combat tobacco spider mites, which have been the main obstacle to tomato production in Zimbabwe's Chiredzi district, research into the use of syringa and garlic is necessary.

2.2.4 Sources of botanical pesticides

Botanical pesticides are made from plants from a variety of plant groups and are either used as plant extracts, essential oils, or both. The bark, leaves, roots, fruits, seeds, cloves, rhizomes, and stems of the plant can all be utilized as botanical insecticides (Hikal *et al.,* 2017). The plant component used frequently is influenced by the desired bioactive compounds and their accessibility in that particular area (Abubaka *et al.,* 2020).

There are bioactive substances found in several plant families, including the Myrtaceae, Lauraceae, Rutaceae, Lamiaceae, Asteraceae, Apiaceae, Cupressaceae, Poaceae, Zingiberaceae, Piperaceae, Liliaceae, Apocynaceae, Solanaceae, Caesalpinaceae, and Sapotaceae, that have activity against significant crop (Ahmad *et al*., 2017; Gakuubi *et al.,* 2016).

2.2.5 Botanical pesticides in agriculture production

It is not difficult to find plants in the environment that contain botanical pesticides and the majority of them have various uses, including as feed, spices, ornamentals, food and/or medicine (Weinzierl *et al*., 2020). They may be simply included into agricultural production systems because they are readily available and affordable (Castillo-Sanchez *et al*., 2015). Because they are harmful to non-target creatures like pollinators and fish, commercialized botanical pesticides from plant extracts like pyrethrum, neem, and sabadilla are effective, reliable, and acceptable in sustainable crop protection (Dantas *et al*., 2021).

Natural pesticides ensure good environmental conservation and consumer safety because they don't leave residues on crops, produce, or the environment. Pests and botanical insecticides interact biochemically naturally, making it unlikely that pests will acquire resistance (Nawaz *et al*., 2016). The allelopathic impact of botanical insecticides on crops varies depending on the source plant and dosage utilized (Arafat *et al*., 2015). Botanical pesticides have a variety of modes of action on the target pest, including repellence, toxicity, growth regulation and structural modification, making them a suitable alternative in crop pest management. Their efficacy depends on the species of the plant source, whether dry or fresh, the extraction solvents used and the extraction methods.

The behavior, physiological functions, biochemical reactions, morphology and metabolic pathways of insects are all disrupted by botanical pesticides. Terpenes, for example, inhibit glucose on chemosensory receptor cells in the mouth of Lepidoptera larvae, while other plant essential oils exhibit chemosterilant activity. The activity of metabolites is particular in how they affect the pest (Dubey *et al.,* 2010).

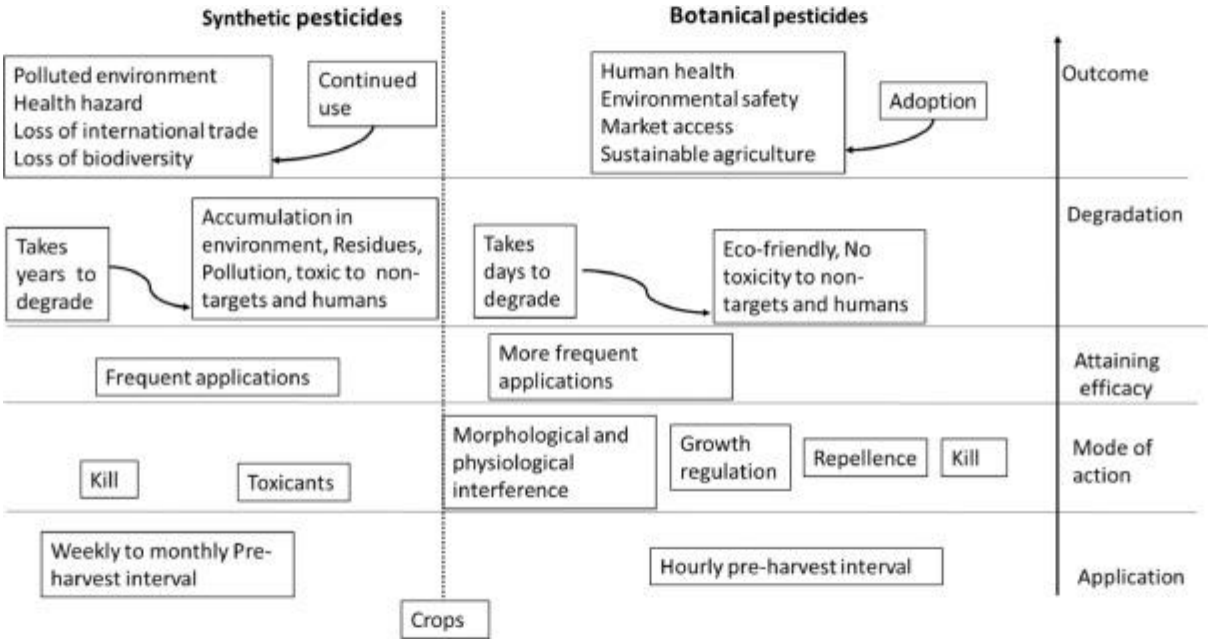


Figure 2.4: Examples of plants with pesticidal activity, their chemical composition and target organisms (Dubey *et al*., 2010).

2.2.6 Differences between synthetic pesticides and bio-pesticides.

According to the above model, there are differences between synthetic and natural pesticides in terms of their mechanism of action, persistence, and environmental impact. Several scientists have studied the use of botanical pesticides, but additional data on the chemistry and effectiveness of these pesticides is needed before they can be authorized for use in commerce (Chougule *et al.,* 2016). The aforementioned involves synthesis, deterioration, persistence, and toxicity. If used in agricultural production systems, bio-pesticides have a number of benefits, including improved produce quality that fetches higher prices and a guaranteed market access because consumers are willing to pay more for foods produced organically. The incorporation of botanical pesticides leads in the creation of a significant market opportunity for produce and decreases the need for wasteful use of synthetic pesticides (Damalas, 2016).

2.2.7 Phytochemical composition of botanical pesticides

Research on the makeup of chemicals in diverse plant families has been prompted by the demand for botanical pesticides products in the medical, agricultural and food industries (Garay *et al.,* 2020). Secondary metabolites with antifungal, antibacterial, antioxidant, or insecticidal characteristics, such as steroids, alkaloids, terpenes, phenols, flavonoids and resins make up the majority of the bioactive chemicals in botanical pesticides (Amad *et al.,* 2017). Examples include the high concentrations of phenolics, esters and flavonoids found in the seed kernels of Jatropha carcus (Oskoueian *et al.,* 2011). The main bioactive components of Mentha piperita leaves are tannins and flavonoids (Chandrasekara *et al.,* 2012). In other words the specific compounds found in a given species of plants makes them effective against a given category of pest.

2.2.8 Mechanisms of action of bio-pesticides.

Various pest insects, fungus, bacteria, nematodes and plant host cells that have been infected by viral viruses are each targeted by different bioactive components in botanical pesticides. Repulsion, inhibition, denaturing of proteins and other actions based on the botanical insecticides chemical and pest are some of the modes of action. A good example is the fact that pyrethrum-based botanical pesticides target insects' nerve cells, causing paralysis and ultimately death, while neem-based pesticides have anti-feedant and repellent properties, cause abnormal moulting, obstruct oviposition, and mess with their endocrine systems. Synthetic pesticides have similar goals to those of botanical pesticides but are more focused on their intended pests and are typically neurotoxicants. Understanding the physical, biological and chemical interactions between pests and pesticides is crucial for pest management because it informs the appropriate treatment approach (Ziska *et al*., 2016).

2.2.9 Mode of action on insects

Several extracts can deter insects, reduce the harmful effects of feeding and oviposition, have deadly effects and interfere with physiological processes (Thakur *et al*., 2017). A great example of how bio-pesticides are becoming more popular on the market is the commercialization of products made from plants like pyrethrum, which has been proven to have neurotoxic effects on insects pests that cause paralysis and knockdown, and ultimately mortality (Isman, 2014). Botanical pesticides prevent the synthesis of vital enzymes, such as those involved in molting, which prevents growth and development.

Red flour beetle (*Tribolium castaneum*) extracts from garlic (*Allium sativum*) and turmeric *(Curcuma longa*) cause death, repulsiveness, toxicity, and inhibition of progeny emergence. Plant extracts also affect oviposition, egg hatching and the general life cycle of the insect pest (Saxena *et al*., 2018). Other natural pesticides are linked to toxicity, immobility and inhibition of electron transport in insects' respiratory systems, as well as paralysis (Ali *et al*., 2014). Insecticides are the most prevalent type of botanical pesticide on the market today in every country.

2.3.4 Natural biodegradation of botanical pesticides

Since they are exposed to air, sunlight, moisture, and high temperatures are enough to breakdown their constituents, for example, thymol, a component found in *Thymus vulgaris, Satureja hortensis, Zataria multiflora*, and *Piper nigrum*, takes about 28 hours to degrade under sunlight and does not accumulate in environments such as water and soil, thereby eliminating chances of pollution. Additionally, since they are biological in nature, botanical pesticides result in degradation, swiftly (Chen *et al.,* 2017).

In soil and plants, azadirachtin's half-life of neem (*Azadirachta indica*) is between one and two days. Neem extracts, for example, lose their efficiency as pesticides when stored in sunlight, proving that they lose their potency shortly after use and that pyrethrum-based insecticides only remain effective for a short time in the field after application. The hydrolysis of ester bonds via carboxy lesterases enzymes produced by microorganisms like *Bacillus cereus* and *Aspergillus niger* is another common biodegradation pathway. The complexity of the pesticide and the enzymatic capability of the soil's microbial community are factors that affect biodegradation. According to Narwal *et al.,* (2017), pesticides both entirely biodegrade in water, gases or salts and their byproducts are either absorbed by soil or further degraded, which contributes to bio-magnification.

The nature of the microorganisms, their interactions with the pesticides and the environment all play a role in effective microbial degradation of pesticides, and swift degradation is a great attribute in relation to environmental conservation.

2.3.5 Role of Botanical pesticide management in intergrated pest management.

A variety of tactics are combined in integrated pest management (IPM) in order to achieve sustainable pest management. The goal is to get a high and profitable output while reducing pest in a sustainable manner. Natural products known as botanical pesticides are efficient against bacteria, fungi, nematodes, viruses and insect pests. Botanical pesticides are readily available, non-polluting, less toxic to humans and have a variety of modes of action.

As a result, they play a crucial role in integrated pest management, along with other crop protection strategies like host tolerance or resistance, good agricultural practices, the use of natural enemies like predators, parasitoids, microbial pesticides and sparingly the use of safe synthetic pesticides. With this strategy, early pest monitoring and detection using cutting-edge technologies like the internet of things and geographic information systems, crop pest management would be timely, efficient and sustainable.

2.3.6 Challenges with adoption of botanical pesticides

Despite ample proof of botanical pesticides' effectiveness against pests, they are currently underrepresented in the market for commercial products (Dougoud *et al.,* 2019). The availability of source plants in large quantities and the capacity to easily cultivate the plants are requirements for the commercialization of botanical insecticides. The source plants can be grown for food, medicine, shade, ornamental purposes or for natural growth in forests and other untamed areas (Chang *et al*., 2021).

Large-scale plant cultivation is required for production, potentially competing with food production in highly arable agricultural lands. In some cases, certain plant sources would be employed as food supplies and farmers would choose to engage in the more lucrative venture, risking the security of their supply of food (Lengai *et al.,* 2020). Large-scale investments in warehouse preservation technologies and machinery would be needed to store and handle the massive amounts of plant material needed to make botanical pesticides (Manandhar *et al.,* 2018).

Synthetic pesticides that are readily created, have a long shelf life, are simple to use and have established production facilities compete with botanical pesticides as well (Mazid *et al.,* 2015). It can be difficult to create botanical pesticides because a single plant may have a number of active chemicals with different chemical characteristics (Ikbal *et al.,* 2019). The registration process is exceedingly expensive and fraught with difficulties, which limits the availability of botanical pesticides on the market. Since they are easily destroyed, especially if used in their raw form, botanical pesticides are used less frequently by smallholder farmers and their application is weather-dependent (Sales *et al.,* 2016). The shelf life of botanical pesticides is also shortened by their biodegradability. The nature of the plants used to make the extracts, the solvents system, the temperature range, and the storage medium all affect the quality, efficacy and stability of these botanical pesticides (Bubalo *et al.,* 2018).

REFERENCES

Abubakar, A.R. and Haque, M., 2020. Preparation of medicinal plants: Basic extraction and fractionation procedures for experimental purposes. *Journal of pharmacy & bioallied sciences*, *12*(1), p.1.

Ali, M.Y., Sina, A.A.I., Khandker, S.S., Neesa, L., Tanvir, E.M., Kabir, A., Khalil, M.I. and Gan, S.H., 2020. Nutritional composition and bioactive compounds in tomatoes and their impact on human health and disease: A review. *Foods*, *10*(1), p.45.

Amarasekare, K. (2019). Pepper Pest Management (Extension Curriculum).

Andrist, D.D. ed., 2021. *Sustenance for the Body & Soul: Food & Drink in Amerindian, Spanish and Latin American Worlds*. Liverpool University Press.

Arafat, Y., Shahida, K., Lin, W., Fang, C., Sadia, S., Ali, N. and Azeem, S., 2015. Allelopathic evaluation of selected plants extract against broad and narrow leaves weeds and their associated crops. *Academia Journal of Agricultural Research*, *3*(10), pp.226-234.

Arakawa, K., Mori, M., Kono, N., Suzuki, T., Gotoh, T. and Shimano, S., 2021. Proteomic evidence for the silk fibroin genes of spider mites (Order Trombidiformes: Family Tetranychidae). *Journal of Proteomics*, *239*, p.104195.

Arora, N.K., Fatima, T., Mishra, I., Verma, M., Mishra, J. and Mishra, V., 2018. Environmental sustainability: challenges and viable solutions. *Environmental Sustainability*, *1*(4), pp.309-340.

Ashrith, K.N. and Hegde, J.N., 2020. Insect Pests of Jasmine and Their Management. In *Advances in Pest Management in Commercial Flowers* (pp. 103-118). Apple Academic Press.

Asirvatham, J. and Bell, K., 2022. Organic Produce Retail Premiums Vary Across Regions and by Attributes. *Agricultural Economics*, *7*(4), pp.175-185.

Azandeme-Hounmalon, G.Y., Fellous, S., Kreiter, S., Fiaboe, K.K., Subramanian, S., Kungu, M. and Martin, T., 2014. Dispersal behavior of Tetranychus evansi and T. urticae on tomato at several spatial scales and densities: implications for integrated pest management. *PloS one*, *9*(4), p.e95071.

Azouz, H.A., 2016. The effect of Intercropping Tomato with Garlic Plants on the Corresponding infestation with some Pests at Beni-Suif Governorate. *Egyptian Academic Journal of Biological Sciences. A, Entomology*, *9*(3), pp.1-6.

Barrett, B.A., 2022. Least-toxic control methods to manage indoor plant pests.

Bubalo, M.C., Vidović, S., Redovniković, I.R. and Jokić, S., 2018. New perspective in extraction of plant biologically active compounds by green solvents. *Food and Bioproducts Processing*, *109*, pp.52-73.

Chandel, R.S., Chandla, V.K., Verma, K.S. and Pathania, M., 2022. Insect pests of potato in India: biology and management. In *Insect pests of potato* (pp. 371-400). Academic Press.

Chandrasekara, A. and Shahidi, F., 2018. Herbal beverages: Bioactive compounds and their role in disease risk reduction-A review. *Journal of traditional and complementary medicine*, *8*(4), pp.451-458.

Chang, C.R., Chen, M.C. and Su, M.H., 2021. Natural versus human drivers of plant diversity in urban parks and the anthropogenic species-area hypotheses. *Landscape and Urban Planning*, *208*, p.104023.

Chen, L., Sun, J.T., Jin, P.Y., Hoffmann, A.A., Bing, X.L., Zhao, D.S., Xue, X.F. and Hong, X.Y., 2020. Population genomic data in spider mites point to a role for local adaptation in shaping range shifts. *Evolutionary applications*, *13*(10), pp.2821-2835.

Collins, E.J., Bowyer, C., Tsouza, A. and Chopra, M., 2022. Tomatoes: an extensive review of the associated health impacts of tomatoes and factors that can affect their cultivation. *Biology*, *11*(2), p.239.

Chougule, P.M. and Andoji, Y.S., 2016. Antifungal activity of some common medicinal plant extracts against soil borne phytopathogenic fungi Fusarium oxysporum causing wilt of tomato. *International Journal of Development Research*, *3*, pp.7030-7033.

Damalas, C.A., 2016. Safe food production with minimum and judicious use of pesticides. In *Food Safety* (pp. 43-55). Springer, Cham.

Dantas, J., Motta, I.O., Vidal, L.A., Nascimento, E.F., Bilio, J., Pupe, J.M., Veiga, A., Carvalho, C., Lopes, R.B., Rocha, T.L. and Silva, L.P., 2021. A comprehensive review of the coffee leaf miner leucoptera coffeella (Lepidoptera: Lyonetiidae)—a major pest for the coffee crop in Brazil and others neotropical countries. *Insects*, *12*(12), p.1130.

Das, S., Chatterjee, A. and Pal, T.K., 2020. Organic far ming in India: a vision towards a healthy nation. *Food Quality and Safety*, *4*(2), pp.69-76.

David, B.V., Chandrasehar, G. and Selvam, P.N., 2018. Pseudomonas fluorescens: a plant-growth-promoting rhizobacterium (PGPR) with potential role in biocontrol of pests of crops. In *Crop improvement through microbial biotechnology* (pp. 221-243). Elsevier.

Djossou, R., Azandémè-Hounmalon, G.Y., Onzo, A., Gnanvossou, D., Assogba-Komlan, F. and Tamò, M., 2021. Susceptibility of ten tomato cultivars to attack by Tetranychus evansi Baker & Pritchard (Acari: Tetranychidae) under laboratory conditions. *International Journal of Tropical Insect Science*, *41*(1), pp.425-431.

Dougoud, J., Toepfer, S., Bateman, M. and Jenner, W.H., 2019. Efficacy of homemade botanical insecticides based on traditional knowledge. A review. *Agronomy for sustainable development*, *39*(4), pp.1-22.

Dubey, N.K., Shukla, R., Kumar, A., Singh, P. and Prakash, B., 2010. Prospects of botanical pesticides in sustainable agriculture. *Current Science*, *98*(4), pp.479-480.

Erenso, T.F. and Berhe, D.H., 2016. Effect of neem leaf and seed powders against adult maize weevil (Sitophilus zeamais Motschulsky) mortality. *Int. J. Agric. Res*, *11*, pp.90-94.

Fulano, A.M., Lengai, G.M. and Muthomi, J.W., 2021. Phytosanitary and Technical Quality Challenges in Export Fresh Vegetables and Strategies to Compliance with

Market Requirements: Case of Smallholder Snap Beans in Kenya. *Sustainability*, *13*(3), p.1546

Garay, J., Brennan, T. and Bon, D., 2020. Essential oils a viable pest control alternative. *Int J Ecotoxicol Ecobiol*, *5*(2), pp.13-22.

Gerszberg, A., Hnatuszko-Konka, K., Kowalczyk, T. and Kononowicz, A.K., 2015. Tomato (Solanum lycopersicum L.) in the service of biotechnology. *Plant Cell, Tissue and Organ Culture (PCTOC)*, *120*(3), pp.881-902.

Ghazy, N.A., Gotoh, T. and Suzuki, T., 2019. Impact of global warming scenarios on life-history traits of Tetranychus evansi (Acari: Tetranychidae). *BMC ecology*, *19*(1), pp.1-12.

Ghosh, S.K., 2019. Climate impact on red spider mite (Tetranychus sp. Koch) infesting eggplant (Solanum melongena L.) and their management using plant extracts. *Journal of Entomological Research*, *43*(3), pp.345-350.

Gupta, N., Verma, S.C., Sharma, P.L., Thakur, M., Sharma, P. and Devi, D., 2019. Status of invasive insect pests of India and their natural enemies. *Journal of Entomology and Zoology Studies*, *7*(1), pp.482-489.

Handford, C.E., Elliott, C.T. and Campbell, K., 2015. A review of the global pesticide legislation and the scale of challenge in reaching the global harmonization of food safety standards. *Integrated environmental assessment and management*, *11*(4), pp.525-536.

Hikal, W.M., Baeshen, R.S. and Said-Al Ahl, H.A., 2017. Botanical insecticide as simple extractives for pest control. *Cogent Biology*, *3*(1), p.1404274.

Ibrahim, M.M., El-Esnawy, B.A. and El-Adawy, A.M., 2016. Biological and Ecological Fitness of the Two-Spotted Spider Mite, Tetranychus urticae Koch (Acari: Tetmnychidae) on Certain Host Plants. *Acarines: Journal of the Egyptian Society of Acarology*, *10*(1), pp.31-35.

Ikbal, C. and Pavela, R., 2019. Essential oils as active ingredients of botanical insecticides against aphids. *Journal of pest science*, *92*(3), pp.971-986.

Isman, M.B., 2017. Bridging the gap: Moving botanical insecticides from the laboratory to the farm. *Industrial crops and products*, *110*, pp.10-14.

Jawalkar, N., Zambare, S. and Zanke, S., 2016. Insecticidal property of Datura stramonium L. seed extracts against Sitophilus oryzae L.(Coleoptera: Curculionidae) in stored wheat grains. *Journal of Entomology and Zoology Studies*, *4*(6), pp.92-96.

Junior, S.S., Casagrande, J.G., de Lima Toledo, C.A., da Silva Ponce, F., da Silva Ferreira, F., Zanuzo, M.R., Diamante, M.S. and Lima, G.P.P., 2022. Selection of thermotolerant Italian tomato cultivars with high fruit yield and nutritional quality for the consumer taste grown under protected cultivation. *Scientia Horticulturae*, *291*, p.110559.

Karaca, G., Bilginturan, M. and Olgunsoy, P., 2017. Effects of some plant essential oils against fungi on wheat seeds. *Indian Journal of Pharmaceutical Education and Research*, *51*(3), pp.S385-S388.

Knapp, M., Palevsky, E. and Rapisarda, C., 2020. Insect and mite pests. In *Integrated pest and disease management in greenhouse crops* (pp. 101-146). Springer, Cham.

Knegt, B., Meijer, T.T., Kant, M.R., Kiers, E.T. and Egas, M., 2020. Tetranychus evansi spider mite populations suppress tomato defenses to varying degrees. *Ecology and evolution*, *10*(10), pp.4375-4390.

Kungu, M., Subramanian, S., Salifu, D., Fiaboe, K.K., Azandémè-Hounmalon, G.Y., Gitonga, L., Onyambu, G.K., Deletre, E. and Martin, T., 2020. Influence of Predatory Mites, Phytoseiulus longipes Evans. on the Within-Plant Diurnal Migration and Distribution of the Red Spider Mite, Tetranychus evansi, Baker and Pritchard on African Nightshade, Solanum scabrum. In *Sustainable Management of Invasive Pests in Africa* (pp. 267-282). Springer, Cham.

Kushram, T., Yadu, Y.K., Sahu, M.K., Kulmitra, A.K. and Kumar, R., 2017. Bio efficacy of botanical insecticides against defoliators pests on soybean. *International Journal of Current Microbiology and Applied Sciences*, *3*(3), pp.2196-2204.

Larranaga, N., van Zonneveld, M. and Hormaza, J.I., 2021. Holocene land and sea-trade routes explain complex patterns of pre-Columbian crop dispersion. *New Phytologist*, *229*(3), pp.1768-1781.

Lengai, G.M., Muthomi, J.W. and Mbega, E.R., 2020. Phytochemical activity and role of botanical pesticides in pest management for sustainable agricultural crop production. *Scientific African*, *7*, p.e00239.

Lengai, G.M., Fulano, A.M. and Muthomi, J.W., 2022. Improving Access to Export Market for Fresh Vegetables through Reduction of Phytosanitary and Pesticide Residue Constraints. *Sustainability*, *14*(13), p.8183.

Lou, Z., Xin, F., Han, X., Lan, Y., Duan, T. and Fu, W., 2018. Effect of unmanned aerial vehicle flight height on droplet distribution, drift and control of cotton aphids and spider mites. *Agronomy*, *8*(9), p.187.

Mafongoya, P., Gubba, A., Moodley, V., Chapoto, D., Kisten, L. and Phophi, M., 2019. Climate change and rapidly evolving pests and diseases in Southern Africa. In *New frontiers in natural resources management in Africa* (pp. 41-57). Springer, Cham.

Mahmood,I.,Imadi,S.R,.Shazadi,K,.Gul,A. and Hakeem,K.R.(2016).Effects of pesticides on environment.Plant ,Soil and Microbes,Springer,Cham ,pp 253-269.

Manandhar, A., Milindi, P. and Shah, A., 2018. An overview of the post-harvest grain storage practices of smallholder farmers in developing countries. *Agriculture*, *8*(4), p.57.

Michereff-Filho, M., Navia, D., Quevedo, I.A., de Almeida Magalhães, M., da Silva Melo, J.W. and Lopes, R.B., 2022. The effect of spider mite-pathogenic strains of Beauveria bassiana and humidity on the survival and feeding behavior of Neoseiulus predatory mite species. *Biological Control*, p.105083.

Motti, R., 2021. The Solanaceae Family: Botanical Features and Diversity. In *The wild solanums genomes* (pp. 1-9). Springer, Cham.

Muimba-Kankolongo, A., 2018. Food Crop Production by Smallholder Farmers in Southern Africa: Challenges and Opportunities for Improvement.

Narwal, S.K. and Gupta, R., 2017. Biodegradation of xenobiotic compounds: an overview. *Handbook of research on inventive bioremediation techniques*, pp.186-212.

Nawaz, M., Mabubu, J.I. and Hua, H., 2016. Current status and advancement of biopesticides: microbial and botanical pesticides. *J Entomol Zool Stud*, *4*(2), pp.241-246.

Neeraj, G.S., Kumar, A., Ram, S. and Kumar, V., 2017. Evaluation of nematicidal activity of ethanolic extracts of medicinal plants to Meloidogyne incognita (kofoid and white) chitwood under lab conditions. *Int. J. Pure Appl. Biosci*, *5*, pp.827-831.

Nefzi, A., 2016. Aydi Ben Abdallah R. *Jabnoun-Khiareddine H, Medimagh-Saïdana S, Haouala R, et al*, pp.144-150.

Negm, M.W., 2014. Increasing knowledge of the mite fauna of the United Arab Emirates: new records and a checklist. *Acarologia*, *54*(1), pp.113-120.

Nkechi, E.F., Ejike, O.G., Ihuoma, N.J., Maria-goretti, O.C., Francis, U., Godwin, N. and Njokuocha, R., 2018. Effects of aqueous and oil leaf extracts of Pterocarpus santalinoides on the maize weevil, Sitophilus zeamais pest of stored maize grains. *African Journal of Agricultural Research*, *13*(13), pp.617-626.

Thakur, S. and Sood, A.K., 2019. Lethal and inhibitory activities of natural products and biopesticide formulations against Tetranychus urticae Koch (Acarina: Tetranychidae). *International Journal of Acarology*, *45*(6-7), pp.381-390.

Oskoueian, E., Abdullah, N., Ahmad, S., Saad, W.Z., Omar, A.R. and Ho, Y.W., 2011. Bioactive compounds and biological activities of Jatropha curcas L. kernel meal extract. *International journal of molecular sciences*, *12*(9), pp.5955-5970.

Panno, S., Davino, S., Caruso, A.G., Bertacca, S., Crnogorac, A., Mandić, A., Noris, E. and Matić, S., 2021. A review of the most common and economically important diseases that undermine the cultivation of tomato crop in the mediterranean basin. *Agronomy*, *11*(11), p.2188.

Pandey, S., Giri, K., Kumar, R., Mishra, G. and Raja Rishi, R., 2018. Nanopesticides: opportunities in crop protection and associated environmental risks. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences*, *88*(4), pp.1287-1308.

Raiola, A., Tenore, G.C., Barone, A., Frusciante, L. and Rigano, M.M., 2015. Vitamin E content and composition in tomato fruits: Beneficial roles and bio-fortification. *International journal of molecular sciences*, *16*(12), pp.29250-29264.

Rincón, R.A., Rodríguez, D. and Coy-Barrera, E., 2019. Botanicals against Tetranychus urticae Koch under laboratory conditions: A survey of alternatives for controlling pest mites. *Plants*, *8*(8), p.272.

Riyaz, M., Mathew, P., Zuber, S.M. and Rather, G.A., 2022. Botanical Pesticides for an Eco-Friendly and Sustainable Agriculture: New Challenges and Prospects. *Sustainable Agriculture*, pp.69-96.

Rodrigues, L.R., Zélé, F., Santos, I. and Magalhães, S., 2022. No evidence for the evolution of mating behavior in spider mites due to Wolbachia-induced cytoplasmic incompatibility. *Evolution*, *76*(3), pp.623-635.

Roy, S., Handique, G., Bora, F.R. and Rahman, A., 2018. Evaluation of certain non-conventional plant based oils against red spider mite of tea. *Journal of Environmental Biology*, *39*(1), pp.1-4.

Saber, M., Ahmadi, Z. and Mahdavinia, G., 2018. Sublethal effects of spirodiclofen, abamectin and pyridaben on life-history traits and life-table parameters of two-spotted spider mite, Tetranychus urticae (Acari: Tetranychidae). *Experimental and Applied Acarology*, *75*(1), pp.55-67.

Sales, M.D.C., Costa, H.B., Fernandes, P.M.B., Ventura, J.A. and Meira, D.D., 2016. Antifungal activity of plant extracts with potential to control plant pathogens in pineapple. *Asian Pacific Journal of Tropical Biomedicine*, *6*(1), pp.26-31.

Salhab, J., Weber, M., Paganini, T., Khamassi, F., Bellagha, S., Hadj, H.B. and Laabidi, F., 2020. Olive oil, medicinal and aromatic plants, and tomatoes in North-West Tunisia.

Saravanan, A., Kumar, P.S., Vo, D.V.N., Jeevanantham, S., Karishma, S. and Yaashikaa, P.R., 2021. A review on catalytic-enzyme degradation of toxic environmental pollutants: Microbial enzymes. *Journal of Hazardous Materials*, *419*, p.126451.

Sarkar, M. and Kshirsagar, R., 2014. Botanical pesticides: current challenges and reverse pharmacological approach for future discoveries. *Journal of Biofertilizers & Biopesticides*, *5*(2), p.1.

Sarker, U., Oba, S. and Daramy, M.A., 2020. Nutrients, minerals, antioxidant pigments and phytochemicals, and antioxidant capacity of the leaves of stem amaranth. *Scientific reports*, *10*(1), pp.1-9.

Satish, S.B., 2018. Biology of Tobacco Spider Mite, Tetranychus macfarlanei Baker and Pritchard on Soybean. *International Journal of Microbiology Research, ISSN*, pp.0975-5276.

Sato, S., Tabata, S., Hirakawa, H., Asamizu, E., Shirasawa, K., Isobe, S., Kaneko, T., Nakamura, Y., Shibata, D., Aoki, K. and Egholm, M., 2012. The tomato genome sequence provides insights into fleshy fruit evolution. *Nature*, *485*(7400), pp.635-641.

Sato, Y., Tsuda, Y., Sakamoto, H., Egas, M., Gotoh, T., Saito, Y., Zhang, Y.X., Lin, J.Z., Chao, J.T. and Mochizuki, A., 2019. Phylogeography of lethal male fighting in a social spider mite. *Ecology and evolution*, *9*(4), pp.1590-1602.

Savi, P.J., de Moraes, G.J., Carvalho, R.F. and de Andrade, D.J., 2022. Bottom-up effects of breeding tomato genotypes on behavioural responses and performance of Tetranychus evansi population. *Journal of Pest Science*, *95*(3), pp.1287-1301.

Saxena, B. and Sayyed, R.Z., 2018. Botanical insecticides effectively control chickpea weevil, Callosobruchus maculatus. *Environmental Sustainability*, *1*(3), pp.295-301.

Schowalter, T.D., 2018. Biology and management of the eastern lubber grasshopper (Orthoptera: Acrididae). *Journal of Integrated Pest Management*, *9*(1), p.10.

Shabana, Y.M., Abdalla, M.E., Shahin, A.A., El-Sawy, M.M., Draz, I.S. and Youssif, A.W., 2017. Efficacy of plant extracts in controlling wheat leaf rust disease caused by Puccinia triticina. *Egyptian Journal of Basic and Applied Sciences*, *4*(1), pp.67-73.

Singh, K.D., Mobolade, A.J., Bharali, R., Sahoo, D. and Rajashekar, Y., 2021. Main plant volatiles as stored grain pest management approach: A review. *Journal of Agriculture and Food Research*, *4*, p.100127.

Skendžić, S., Zovko, M., Živković, I.P., Lešić, V. and Lemić, D., 2021. The impact of climate change on agricultural insect pests. *Insects*, *12*(5), p.440.

Sonhafouo-Chiana, N., Nkahe, L.D., Kopya, E., Awono-Ambene, P.H., Wanji, S., Wondji, C.S. and Antonio-Nkondjio, C., 2022. Rapid evolution of insecticide resistance and patterns of pesticides usage in agriculture in the city of Yaoundé, Cameroon. *Parasites & Vectors*, *15*(1), pp.1-15.

Sowmya, V., Behera, L., Mounika, A. and Thera, U.K., 2020. Chapter-1 Phytochemical Activities of Botanical Pesticides in Plant Pest Management. *Recent Trends in*, *1*, p.1.

Sudo, M., Yamanaka, T. and Miyai, S.I., 2019. Quantifying pesticide efficacy from multiple field trials. *Population Ecology*, *61*(4), pp.450-456.

Wanzala, W., Wagacha, J.M., Dossaji, S.F. and Gakuubi, M.M., 2016. Bioactive properties of Tagetes minuta L.(Asteraceae) essential oils: A review

Wanzala, W., 2017. Potential of traditional knowledge of plants in the management of arthropods in livestock industry with focus on (Acari) ticks. *Evidence-Based Complementary and Alternative Medicine*, *2017*.

World Health Organization, 2020. *The state of food security and nutrition in the world 2020: transforming food systems for affordable healthy diets* (Vol. 2020). Food & Agriculture Org.

Wari, D., Kuramitsu, K. and Kavallieratos, N.G., 2021. Sap-Sucking Pests; They Do Matter. *Insects*, *12*(4), p.363.

Weinzierl, R. and Henn, T., 2020. Botanical insecticides and insecticidal soaps. In *Handbook of integrated pest management for turf and ornamentals* (pp. 541-555). CRC Press

WHO, G., 2010. The WHO recommended classification of pesticides by hazard and guidelines to classification 2009.

Yaseen, M., Bhat, B.A., Bora, J., Jan, Y., Malik, M. and Azad, Z.R.A.A., 2021. Insect Pest Infestation During Storage of Fruits and Vegetables. In *Packaging and Storage of Fruits and Vegetables* (pp. 235-268). Apple Academic Press.

Yegrem, L. and Ababele, L., 2022. Pretreatments, Dehydration Methods and Packaging Materials: Effects on the Nutritional Quality of Tomato Powder. *Austin J Nutri Food Sci*, *10*(2), p.1167.

Zaller, J.G. and Brühl, C.A., 2019. Non-target effects of pesticides on organisms inhabiting agroecosystems. *Frontiers in Environmental Science*, *7*, p.75.

Zinyemba, C., Archer, E. and Rother, H.A., 2018. Climate variability, perceptions and political ecology: factors influencing changes in pesticide use over 30 years by Zimbabwean smallholder cotton producers. *PloS one*, *13*(5), p.e0196901.

Ziska, L.H. and McConnell, L.L., 2016. Climate change, carbon dioxide, and pest biology: monitor, mitigate, manage. *Journal of Agricultural and Food Chemistry*, *64*(1), pp.6-12.

Zvereva, E.L., Lanta, V. and Kozlov, M.V., 2010. Effects of sap-feeding insect herbivores on growth and reproduction of woody plants: a meta-analysis of experimental studies. *Oecologia*, *163*(4), pp.949-960.

CHAPTER THREE

3.1 MATERIALS AND METHODS

3.1.1 Study site

The Chiredzi Research Station in Zimbabwe (Figure 3.1), which is 10 km off the Ngundu-Tanganda highway, is where the experiment was carried out in the open fields. On the southern edge of the Lowveld, in Masvingo Province, sits the Chiredzi district. The district, located at coordinates S21°00' 0" and 31° 30' 0'E, lies in agro-ecological region five, which is characterized by aridity and erratic rainfall patterns. The region's average annual rainfall is between 450 and 800 mm (Defe *et al.,* 2021). The region's typical summer temperatures vary from 26 to 40 °C, and its typical winter temperatures are between 15 and 25 °C. Heavy clays make up the majority of the district's soil (Soropa *et al.*, 2015).

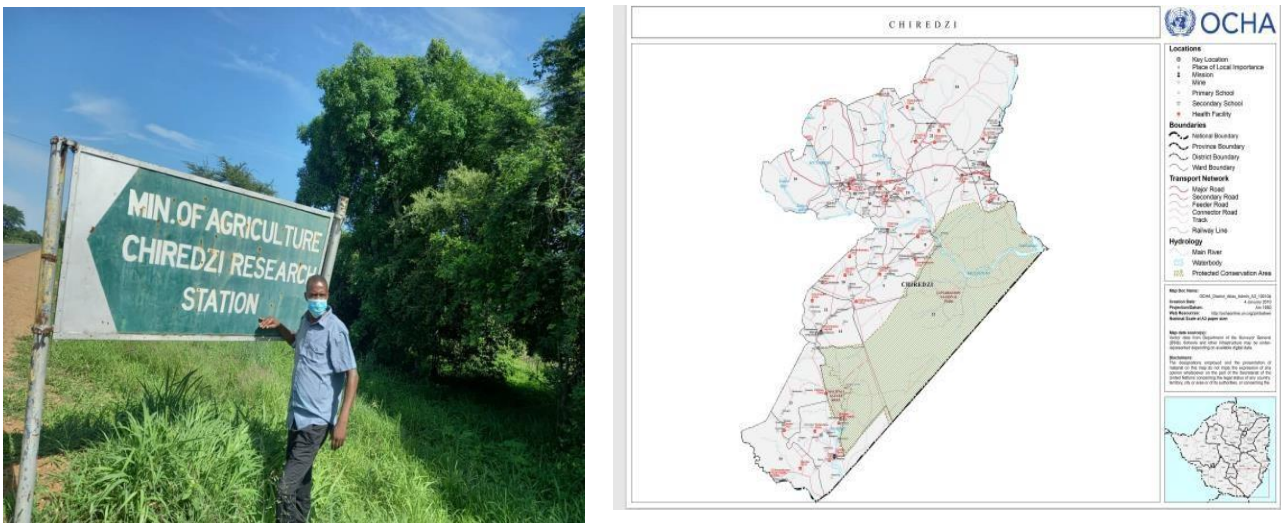


Figure 3.1 a) Photo taken outside the Research station figure, b) Chiredzi District map (Matarira *et al*., 2021).

3.1.2 Experimental design and treatments

Table 3.1: Treatment table showing a total of 9 treatments were prepared and details are below:

Treatment code	**Treatment description**
1	Control with distilled water only 0%
2	Garlic extracts concentration at 5%
3	Garlic extracts concentration at 25%
4	Garlic extracts concentration at 50%
5	Garlic extracts concentration at 75%
6	Syringa extracts concentration at 5%
7	Syringa extracts concentration at 25%
8	Syringa extracts concentration at 50%
9	Syringa extracts concentration at 75%

The trial was carried out during the summer season of the year 2021/2022. The 9 treatments described above were laid out in the field using the split-plot block design, replicated five times with the total number of 50 plants used for the experiment (*see Figure 3.2).

Figure 3.2 Trial site at Chiredzi Research Station

3.1.3 Land preparation

In December 2021, the land was prepared by broadcasting 25 tons of cattle dung per hectare, followed by a horse pipe irrigation system. Because it has a wealth of nutrients and is good for plant growth, cattle dung was used. Because it contains 3% nitrogen, 2% phosphorus, and 1% potassium, it is the ideal fertiliser for all crops and restores the organic nutrient balance to the field (Zhu *et al.,* 2021). Hand hoes were used to prepare the field using the traditional tillage technique. As recommended by Masud *et al*., 2020.Lime was administered at a rate of 450 kg per hectare to condition the soil and control soil acidity by reducing the acidic effects of nitrogen (N) fertiliser, slurry and excessive rainfall. The plots were prepared by creating dividing strips or plot ridges after the soil had been leveled and was in good condition. Since flood irrigation was used to water the tomato plants, irrigation furrows were built on both sides of the ridge.

Figure 3.3: Photographs illustrating land preparations on the research site a) Weeding of the grass on the research plot and b) making ridges ready for planting.

3.1. 4 Planting material

On November 30, 2021, five-week-old tomato seedlings of the cultivar “Rodade” were transplanted. On December 15, 2021, 50 seedlings from Triangle Nurseries, a reputable seedlings provider in Chiredzi. Seedlings were planted into the field with an intrarow spacing of 30 cm and an inter row of 90 cm after being hardened for a week. Compound S (6:17:6), a base fertilizer, was given at a rate of 0.264 kg per plot prior to planting in order to replenish the nutrients that plants used during their growth cycle and keep the fertility of the soil constant. Before irrigating each plot with 24 L of water, the fertilizer was covered with soil. In order to prevent fungal infection, seedlings were planted in the planting station so that the stem above the roots would not come into touch with damp soil or be exposed to the light. To protect tomato seedlings from waterborne infections, they were planted on top of the ridge, away from any moving water.

3.1.5 Irrigation, fertilizer application and weeding of tomato plants

Every two days, irrigation was applied to tomato crops. Ammonium nitrate was used as a top dressing 3 weeks after transplanting at a rate of 100 kg/ha (* see table 3.2), as it is not often subject to volatilization (Powlson *et al.,* 2022). A week after transplanting and then every three weeks after that, the crop was top dressed. Weeding was done routinely every two weeks using a hand hoe just before top dressing to keep the crop clear of weeds at all times. Tomatoes were constructed on a vertical hanging trellis (*see Figure 3.4).Trimming of lower old leaves which included removing leaves that were in contact with the soil was done every week to prevent plants from falling over and to prevent fungal disease infection.

Table 3.2: Fertilizers applied during production of tomato.

Fertilizer applied	**Planting/Per Plot**	**Vegetative growth per plot**	**Flowering per Plot**
Compound D	0.264kg	0.264kg	0
Compound S	0.264kg	0	0
Ammonium Nitrate ($NH4^+$)	0	0	0.264kg

Figure 3.4: Signage showing date planted.


Figure 3.5: Fertilizer Application

3.1.6 Syringa and garlic seeds collection

Syringa trees growing along the side of the road in Chiredzi's low-density suburbs provided five kilograms of syringa seeds, while small-scale farmers in Nyangambe's irrigation project provided five kilograms of garlic cloves. Farmers donated garlic after hearing about a study employing garlic extracts to combat tobacco spider mites *(Tetranychus evansi),*which is a very difficult problem to solve during the seasonal production of tomatoes.

Figure 3.6: Collection of syringa seeds ready to remove green fruits for pounding in the mortar and garlic cloves ready for pounding.

3.1.7 Preparation of extracts

Plant parts were dried and grounded into fine powder and then extracted with solvents to maximize extraction of the target and compounds as prescribed by Sivakumar *et al*., (2020). Compounds were then concentrated, formulated and evaluated for efficacy under laboratory, controlled or field condition as prescribed by Lengai *et al., (*2020).

In brief, botanical extracts of both syringa and garlic were separately crushed using a mortar and pestle until thoroughly crushed into fine particles. To separate the juice from the resultant cake of the extracts, a new mutton cloth was used and filled with crushed syringa seeds and garlic cloves, wrapped and squeezed to separate the liquid extracts from the resultant cake. The extracts were then collected into clean bottles respectively which resulted into 100% liquid extracts solution of *Melia azedarach* and *Allium sativum.* A 100ml measuring cylinder was used during preparation of syringa and garlic formulations. From the concentrated syringa and garlic extracts, four different concentrations were prepared namely 5%, 25%, 50%

and 75% for the treatments. To obtain 5% concentration,100% syringa liquid extract was diluted by 95ml of distilled water that resulted in 100ml,25% concentration of 100% syringa liquid extract was diluted by 75ml of distilled water that resulted in 100ml, 50% concentration of 100% syringa liquid extract was diluted by 50ml of distilled water that resulted in 100ml, 75% concentration of 100% syringa extract solution was diluted by 25ml of distilled water that resulted in 100ml (* see Figure 3.7).A 1.5L hand pressure sprayer was used to spray syringa and garlic extracts following specific concentration levels, in the morning every seven day over 21 days.

Figure 3.7: Preparation of extract in progress using a pounding mortar and pestle for both syringa and garlic extracts.

A 2L concentrate reservoir for each extract (garlic and syringa) dilution was done per each spray, for instance, 5ml concentrate to 95ml of distilled water, 25ml concentrate to 75ml of distilled water, 50ml of concentrate to 50ml of distilled water and 75ml of concentrate to 25ml of distilled water respectively.

Figure 3.8: Pictures show casing how extraction of syringa and garlic took place and ready for spraying.

3.1.8 Collection and inoculation of tobacco spider mite

To introduce adult tobacco spider mites (Tetranychus evansi) into the experimental plots, tobacco spider mites were collected from infested leaves of tomato plants that were grown in other plots away from the experimental plot. At 5 weeks after transplanting with the use of a pencil brush as prescribed by Keno et al., 2022, ten adult mites were transferred and inoculated into the non-affected tomato plant leaves of each trial plot and left to feed on the leaves. Data on the following parameters: plant height (cm), stem diameter (cm), leaf chlorophyll content (nm) was documented at three-week intervals (Week 1, 2 and 3) after application. Furthermore, the efficacy of Melia azedarach and Allium sativum extracts was recorded and/or measured by counting live and dead mites using hand lens at 10× magnifications for three consecutive weeks.

Figure 3.9: Inoculation of tobacco spider mites *(Tetranychus evansi)* on a healthy tomato plant.

3.2 Data collection

Data collection was done in the field, the effectiveness of garlic (*Allium sativum*) and syringa (*Melia azedarach*.L*)* extracts were tested on tobacco spider mites.

Figure 3.10: scouting for natural infestation of disinfected tomato plant

3.2.1 Agronomic parameters and mortality rate measured.

Plant height

With the aid of a measuring tape, plant height was recorded in centimeters (cm). Data collecting started one month following planting, and it took place once a week for 21 days.

Stem diameter

A tape measure was used to measure the stem's diameter in millimeters (mm).

Leaf chlorophyll content

Measuring of leaf chlorophyll content was done using a chlorophyll SPAD meter (nm) as shown on the figure below.

Mortality rate of tobacco spider mites

The mortality rate of tobacco spider mites *(Tetranychus evansi)* was conducted using hand lens which was used to visualize and count the dead/live mites.

Figure 3.11: Measuring of leaf chlorophyll content on tomato plants.

3.3 Data analysis

Statistical analysis of the collected data was performed using the statistical analysis system software version of 9.2 (SAS 2012), using one-way analysis of variance (ANOVA) following the general linear model (GLM). Where there is significance, means were separated using Tukey's test.

REFERENCES

Defe, R. and Matsa, M., 2021. The contribution of climate smart interventions to enhance sustainable livelihoods in Chiredzi District. *Climate Risk Management*, *33*, p.100338.

Keno, G., Habtegebriel, B. and Azerefegne, F., 2022. Evaluation of Ethiopian Entomopathogenic Fungi Isolates Against the Two-Spotted Spider Mite, Tetranychus urticae Koch on Tomato, Solanum lycopersicum L. *American Journal of Zoology*, *5*(2), pp.11-19.

Lengai, G.M., Muthomi, J.W. and Mbega, E.R., 2020. Phytochemical activity and role of botanical pesticides in pest management for sustainable agricultural crop production. *Scientific African*, *7*, p.e00239.

Matarira, D., Mutanga, O. and Dube, T., 2021. Landscape scale land degradation mapping in the semi-arid areas of the save catchment, Zimbabwe. *South African Geographical Journal*, *103*(2), pp.183-203.

Sivakumar, A., Mishra, M., Dagar, V.S. and Kumar, S., 2020. Reduced physiological and reproductive fitness induced by Nerium oleander leaf extracts in the cotton bollworm, Helicoverpa armigera (Lepidoptera: Noctuidae). *Acta Ecologica Sinica*.

Soropa, G., Gwatibaya, S., Musiyiwa, K., Rusere, F., Mavima, G.A. and Kasasa, P., 2015. Indigenous knowledge system weather forecasts as a climate change adaptation strategy in smallholder farming systems of Zimbabwe: Case study of Murehwa, Tsholotsho and Chiredzi districts. *African Journal of Agricultural Research*, *10*(10), pp.1067-1075.

Masud, M.M., Abdulaha-Al Baquy, M., Akhter, S., Sen, R., Barman, A. and Khatun, M.R., 2020. Liming effects of poultry litter derived biochar on soil acidity amelioration and maize growth. *Ecotoxicology and Environmental Safety*, *202*, p.110865.

Zhu, N., Zhu, Y., Kan, Z., Li, B., Cao, Y. and Jin, H., 2021. Effects of two-stage microbial inoculation on organic carbon turnover and fungal community succession during co-composting of cattle manure and rice straw. *Bioresource Technology*, *341*, p.125842.

CHAPTER FOUR

RESULTS

After application of *Allium sativum* extracts at different concentration levels (5%, 25%, 50% and 75%) data was recorded at week 1, 2 and 3 (table 1) and the findings revealed that there was a significant different ($p<0.001$) during time of exposure and concentration levels. At week 1, 75% concentrations level attained the highest significant difference plant height of (39.8 cm) and leaf chlorophyll content (52.70 nm) whilst 50% concentration showed a thicker and higher stem diameter of (0.58 cm) as compared to other concentration levels. It was interesting to note that amongst the concentration levels, 5% attained the least plant height (30.8 cm) and leaf chlorophyll content whilst 25% concentration level had the least significant difference ($p<0.001$) stem diameter. The plant height and leaf chlorophyll content of the infested leaf plant under distilled water was significantly ($p<0.001$) lower in comparison to the plants that were treated with *Allium sativum* extracts.

In week 2 (table 1), the results showed a significance ($p<0.001$) greater plant height and leaf chlorophyll content was observed on tomato plants treated with extracts of *Allium sativum* at 75% concentration level, however amongst other concentrations levels of *Allium sativum,* 5% and 25% had the least plant height and leaf chlorophyll content although there was no significant difference ($p<0.001$) observed. 5%, 50% and 75% concentration levels performed similarly and showed a thicker and higher stem diameter. The findings also revealed that tomato plants treated with distilled water exhibited lower measurements with shorter plant height of (42.95 cm), thinner stem diameter (0. 66 cm) and leaf chlorophyll content of (26.65 nm).

An increase in growth parameter on the tomato plants was noted as the time exposure increases in weeks, it is evident from table 1 that in week 3, plants treated with *Allium sativum* *extracts* at 75% concentration level to control tobacco spider mites had the significant greater plant height (93.20 cm) followed by both 5%, 25% and 50% concentrations levels which performed similar to each other at (82.2, 84 and 85.60 cm) respectively with no significant differences observed. On a contrary, higher stem diameter was recorded within all the concentrations (5, 25, 50 and 75%) however, there was no significant difference ($p<0.001$) amongst the concentration level of *Allium sativum* extracts. A significant difference in the leaf chlorophyll content was recorded between the concentration levels used, 75% had the highest leaf chlorophyll content whilst the least leaf chlorophyll content was measured at 5% concentration respectively. Tomato plants treated with distilled water (control) were significantly ($p<0.001$) lower in Plant height, stem diameter and leaf chlorophyll content when compared to the tomato plants that were treated with *Allium sativum extracts*. The same concentrations, 5%, 25, 50 and 75% of *Allium sativum* extracts were also used on *Melia azedarach* against tobacco spider mites to determine the significant differences in effectiveness at time exposure (after extracts application) at week 1, week 2 and week 3).

Table 1: Efficacy of different concentration of *Allium sativum* (garlic) extracts on tomato growth parameters measured at week 1, 2 and 3 after treatment.

Duration	Week 1			Week 2			Week 3		
Concentration	Parameters								
%	Plant height	Stem diameter	Leaf chlorophyll	Plant height	Stem diameter	Leaf chlorophyll	Plant height	Stem diameter	Leaf chlorophyll
0-control	24.90^{e}	0.52^{ab}	31.75^{d}	42.95^{d}	0.66^{b}	36.65^{d}	64.50^{c}	0.89^{b}	50.60^{e}
5	30.80^{d}	0.54^{ab}	38.10^{c}	61.20^{c}	0.76^{a}	41.50^{c}	82.20^{b}	1.10^{a}	69.90^{d}
25	34.20^{c}	0.48^{b}	42.70^{b}	63.80^{c}	0.74^{ab}	45.10^{c}	84.00^{b}	1.10^{a}	79.50^{c}
50	37.60^{b}	0.58^{a}	44.10^{b}	69.60^{b}	0.78^{a}	57.70^{b}	85.60^{b}	1.10^{a}	85.70^{b}
75	39.80^{a}	0.52^{ab}	52.70^{a}	74.00^{a}	0.78^{a}	66.90^{a}	93.20^{a}	1.10^{a}	88.50^{a}
SEM	0.7828	0.0025	6.1985	3.6500	0.0025	4.9186	5.9942	0.0002	2.4971
F probability	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

SEM is the standard error of the mean. Note* cell sizes are not equal, means within the columns followed by same lower-case letters did not differ significantly.

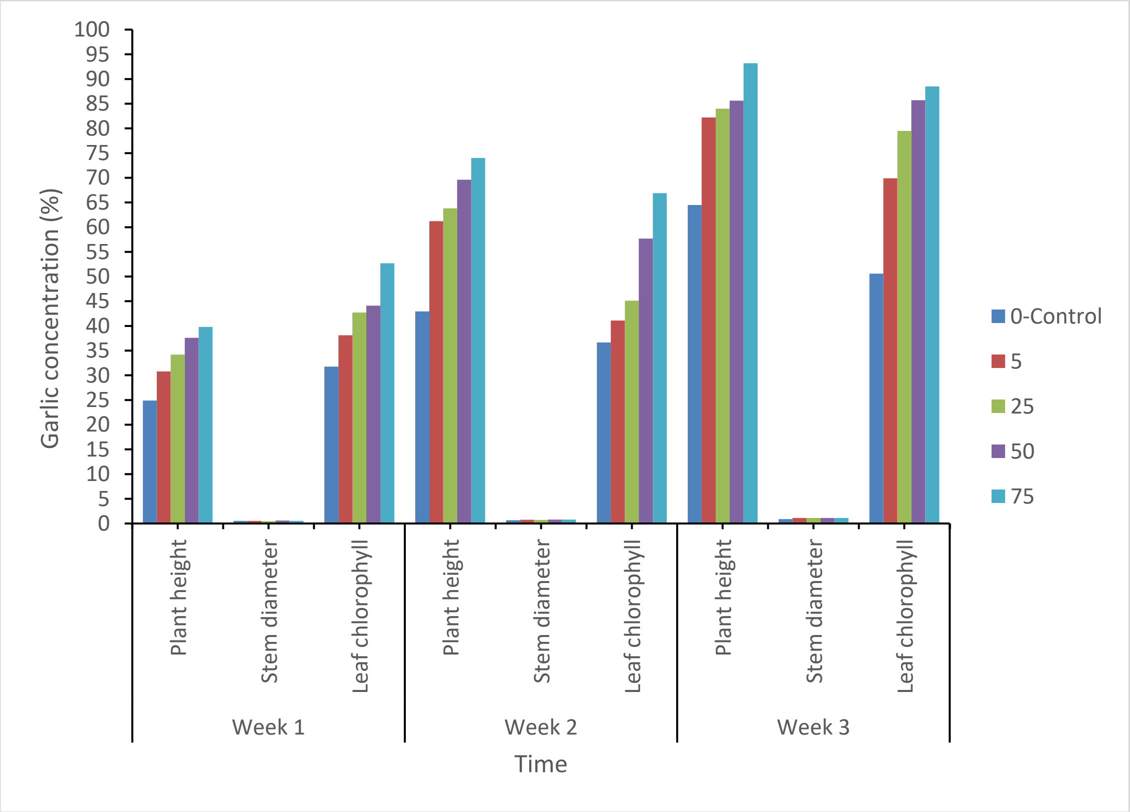


Figure 4.1: A summary of agronomic parameter's response to garlic concentration on a weekly basis.

	Plant height		
	Week 1	Week 2	Week 3
0	24.9	42.95	64.5
5	30.8	61.2	82.2
25	34.2	63.8	84
50	37.6	69.6	85.6
75	39.8	74	93.2

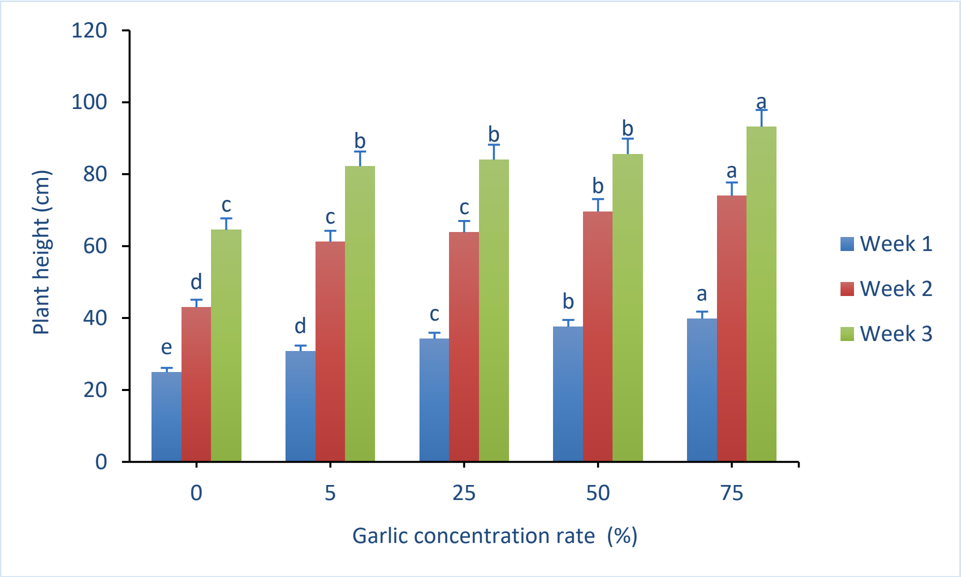


Figure 4.2: Plant height response to different garlic concentrations (weekly basis).

	Stem diameter		
	Week 1	Week 2	Week 3
0	0.52	0.66	0.89
5	0.54	0.76	1.1
25	0.48	0.74	1.1
50	0.58	0.78	1.1
75	0.52	0.78	1.1

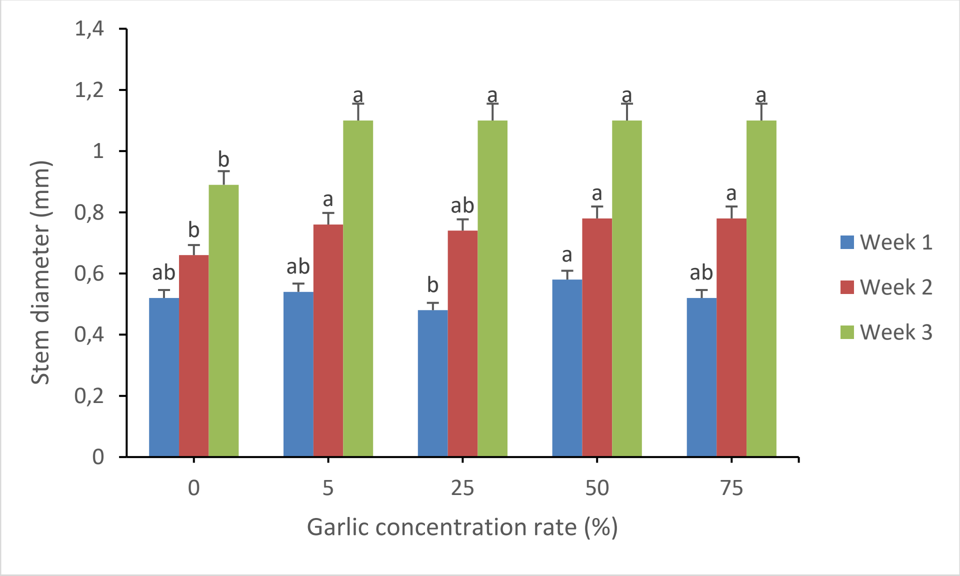


Figure 4.3: Stem diameter response to different garlic concentrations (weekly basis).

	Leaf chlorophyll		
	Week 1	Week 2	Week 3
0	31.75	36.65	50.6
5	38.1	41.1	69.9
25	42.7	45.1	79.5
50	44.1	57.7	85.7
75	52.7	66.9	88.5

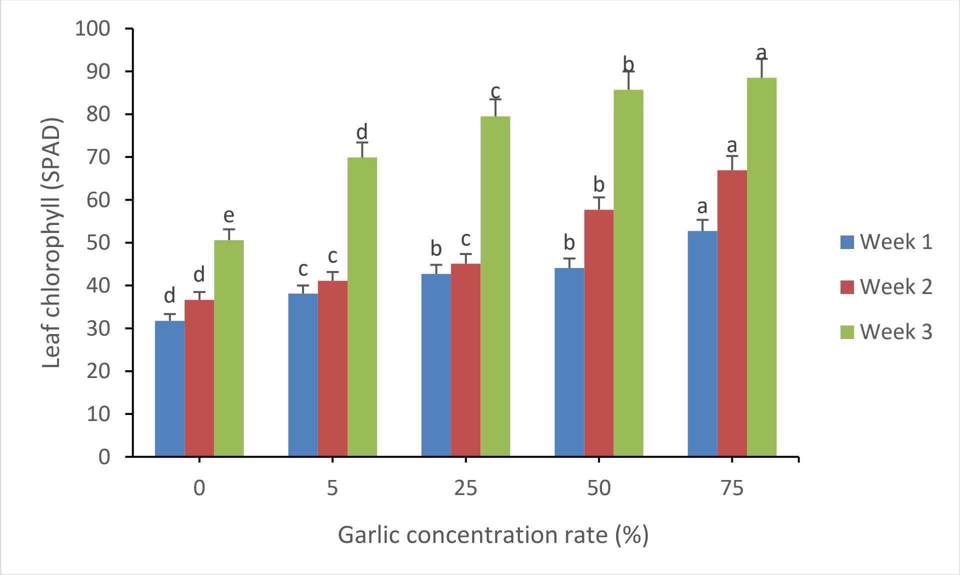


Figure 4.4: Leaf chlorophyl content response to different garlic concentrations (weekly basis).

In week 1 (table 2), a greater plant height and leaf chlorophyll content was significantly (p<0.001) higher on tomato plants treated with *Melia azedarach* at 75% concentration when compared to other concentrations levels. Amongst the concentration's levels of *Melia azedarach,* 5% concentration had a shorter plant height (32.80 cm), and low leaf chlorophyll content was recorded at 5% and 25% concentrations, however there was no significant difference (p<0.001). It was interesting to note that no significant difference (p<0.001) was observed in the stem diameter; either amongst the extract's concentration levels or control in week 1. The findings also revealed that, plant height and leaf chlorophyll content of tomato plants treated with distilled water (control) at week 1 was significantly lower when compared to those treated with different concentrations levels of *Melia azedarach* extracts (table 2). In week 2, after application of *Melia azedarach* extracts Similar trend of results was observed where plant height and leaf chlorophyll content were significantly (p<0.001) higher at 75% concentration level whilst 5% and 25% exhibited shorter plant height of (67 and 70 cm) respectively but there was no significant difference amongst the two concentrations, whereas the least leaf chlorophyll content (51.10 nm) was recorded at 5% concentration level. There was no significant difference (p<0.001) observed in the stem diameter of the tomato plant treated with both the concentration (5%, 25%, 50% and 75%) levels of *Melia azedarach* extracts in week 2 and week 3 (table 2). The parameters of the plants treated with distilled water (control) was significantly (p<0.001) lower when compared to the parameters of the plants treated with different concentrations levels of *Melia azedarach* extracts after week 2 and week 3 of the treatment application. It is evident from table 2 that at week 3, plants treated with *Melia azedarach* at 75% concentration to control tobacco spider mites had the significant greater plant height (101,20 cm) and higher leaf chlorophyll content (94.10 nm). On the contrary to all the concentration levels, 5% continues to perform least in all the parameters recorded after application of the treatment.

Table 2: Efficacy of different concentration of *Melia azedarach* (syringa) seeds extracts on tomato growth parameters measured at week 1, 2 and 3 after treatment.

Duration		**Week 1**			**Week 2**			**Week 3**	
Concentration					**Parameters**				
%	**Plant height**	**Stem diameter**	**Leaf chlorophyll**	**Plant height**	**Stem diameter**	**Leaf chlorophyll**	**Plant height**	**Stem diameter**	**Leaf chlorophyll**
0-control	24.90^{e}	0.52^{a}	31.75^{d}	42.95^{d}	0.66^{b}	36.65^{e}	64.50^{e}	0.89^{b}	50.60^{e}
5	32.80^{d}	0.54^{a}	42.10^{c}	67.00^{c}	0.80^{a}	51.10^{d}	85.20^{d}	1.20^{a}	74.70^{d}
25	37.00^{c}	0.52^{a}	45.30^{c}	70.00^{c}	0.80^{a}	55.70^{c}	90.40^{c}	1.20^{a}	84.70^{c}
50	39.80^{b}	0.54^{a}	57.72^{b}	74.00^{b}	0.86^{a}	60.50^{b}	94.00^{b}	1.22^{a}	89.10^{b}
75	47.20^{a}	0.54^{a}	65.30^{a}	80.40^{a}	0.86^{a}	78.30^{a}	101.20^{a}	1.24^{a}	94.10^{a}
SEM	1.4914	4.0614	8.8068	3.9700	0.0020	5.6042	3.9942	0.0008	5.2400
F probability	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

SEM is the standard error of the mean. Note* cell sizes are not equal, means within the columns followed by same lower-case letters did not differ significantly.

	Plant height (cm)		
	Week 1	Week 2	Week 3
0	24.9	42.95	64.5
5	32.8	67	85.2
25	37	70	90.4
50	39.8	74	94
75	47.2	80.4	101.2

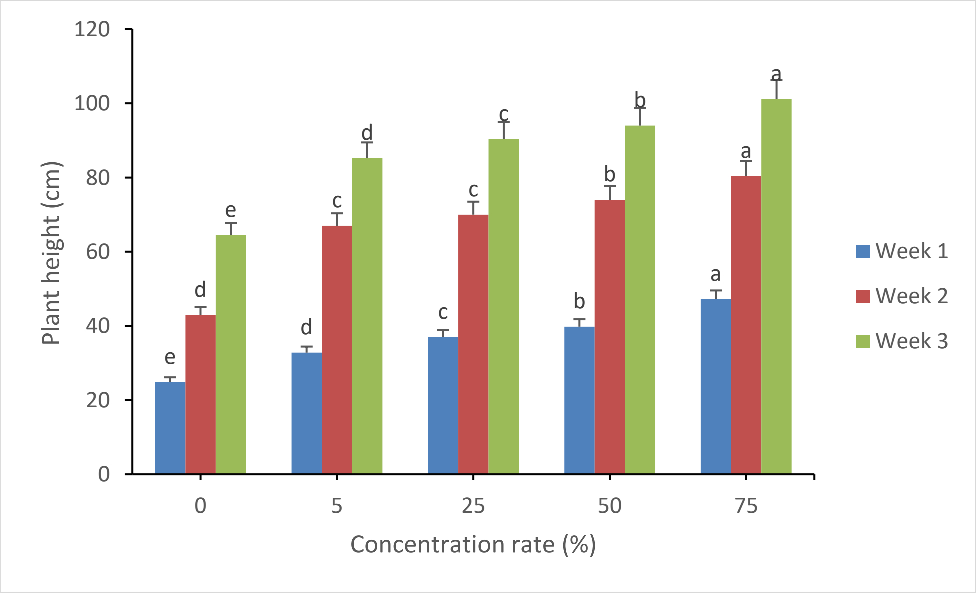


Figure 4.5: Plant height response to different syringa concentrations (weekly basis).

	Stem diameter (mm)		
	Week 1	Week 2	Week 3
0	0.52	0.66	0.89
5	0.54	0.8	1.2
25	0.52	0.8	1.2
50	0.54	0.86	1.22
75	0.54	0.86	1.24

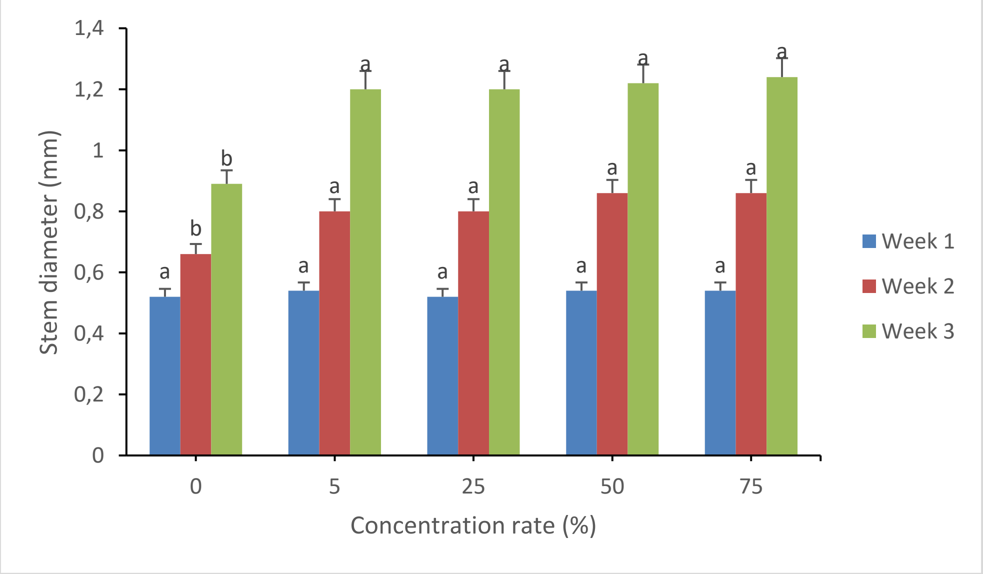


Figure 4.6: Stem diameter response to different syringa concentrations (weekly basis).

	Leaf chlorophyll (SPAD)		
	Week 1	Week 2	Week 3
0	31.75	36.65	50.6
5	42.1	51.1	74.7
25	45.3	55.7	84.7
50	57.72	60.5	89.1
75	65.3	78.3	94.1

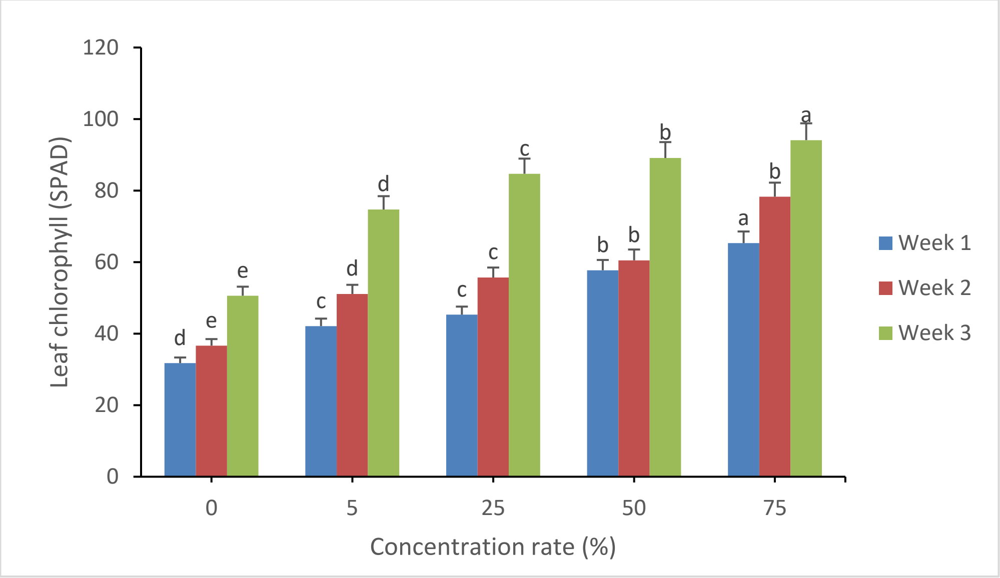


Figure 4.7: Leaf Chlorophyl response to different syringa concentrations (weekly basis).

All the concentrations of the extracts showed to be effective in causing mortality of tobacco spider mites and significantly reduce mite population. The significant differences in live and dead tobacco spider mites amongst the different concentrations of the plant extracts (*Allium sativum and Melia azedarach)* are shown in table 3 and table 4 at different time exposure (week 1, 2 and 3) respectively. The findings in table 3 after week 1 of exposure revealed that there was no significant difference ($p<0.001$) in the mean count of live mites amongst the concentration extracts of *Allium sativum.* However, control exhibited the highest mean count of live mites after week 1 of exposure. The results also showed that there was a significant difference ($p<0.001$) in mortality rate at week 1 of exposure, 75% concentration had the highest mean mortality of 7.40 while the least mortality of mites was recorded in 5% concentration (3.40). On the contrary, no dead mites were recorded on the mites’ infested leaves treated with distilled water (control) at week 1 of exposure.

The similar trend of results was also noted at week 2 of exposure (table 3), after application of different *Allium sativum* extracts, there was no significant difference between the different concentration levels on the mean count of live mites, yet the lowest number of live mites were recorded on the plants leaf treated with *Allium sativum* extracts. At week 2 of exposure (table 3) the highest mortality rate of the mites was observed at the concentration levels of 50 % and 75% killing 12.60 and 13.00 mites respectively whilst 5% concentration persisted, causing the least mortality rate of 7.20 when compared to other concentration levels of *Allium sativum.* The mites continued to survive and multiply under control treatment (untreated) as there was no dead mites recorded as shown in table 3. Results in table 3 also show that there was a significant difference ($p<0.001$) between control and tomato plants treated with different concentration of *Allium sativum* at week 3.

There was no significant difference($p<0.001$) observed amongst the concentration levels of *Allium sativum* extracts used (5%, 25%, 50% and 75%) which had the lowest mean count of live mites at week 3 of exposure. On a contrary, control had the highest mean count of live mites which was (51.00). It is evident that that a longer period of exposure (week 3), the mortality rate of the mites increased as compared to (week 1 and 2) 50% and 75% concentration had the highest mortality of the mites yet, table 3 at week 3 of exposure also shows that lower concentrations extract of *Allium sativum* (5%) caused significantly ($p<0.001$) lower mortality of red spider. The mites that were inoculated onto the leaves of tomato plants and treated with distilled water survived and continued to multiply; this was evident through the higher mean count of live mites and 0.00 count of mortality at week 3 (table 3).

Table 3: Live and dead red spider mites caused by different concentrations of *Allium sativum* (garlic) extracts at week 1, 2 and 3 after treatment.

Concentration	***Week 1***		***Week 2***		***Week 3***	
%	**Live mites**	**Dead mites**	**Live mites**	**Dead mites**	**Live mites**	**Dead mites**
0-control	20.25^{a}	0.00^{d}	26.85^{a}	0.00^{d}	51.00^{a}	0.00^{d}
5	10.60^{b}	3.40^{c}	15.00^{b}	7.20^{c}	30.20^{b}	16.40^{c}
25	10.80^{b}	5.40^{b}	15.20^{b}	9.60^{b}	30.80^{b}	22.20^{b}
50	10.80^{b}	6.00^{b}	14.60^{b}	12.60^{a}	30.40^{b}	27.40^{a}
75	10.80^{b}	7.40^{a}	15.20^{b}	13.00^{a}	29.40^{b}	29.00^{a}
SEM	4.2100	0.1600	1.8100	0.4914	1.4285	1.2914
F probability	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

SEM is the standard error of the mean. Note* cell sizes are not equal, means within the columns followed by same lower-case letters did not differ significantly.

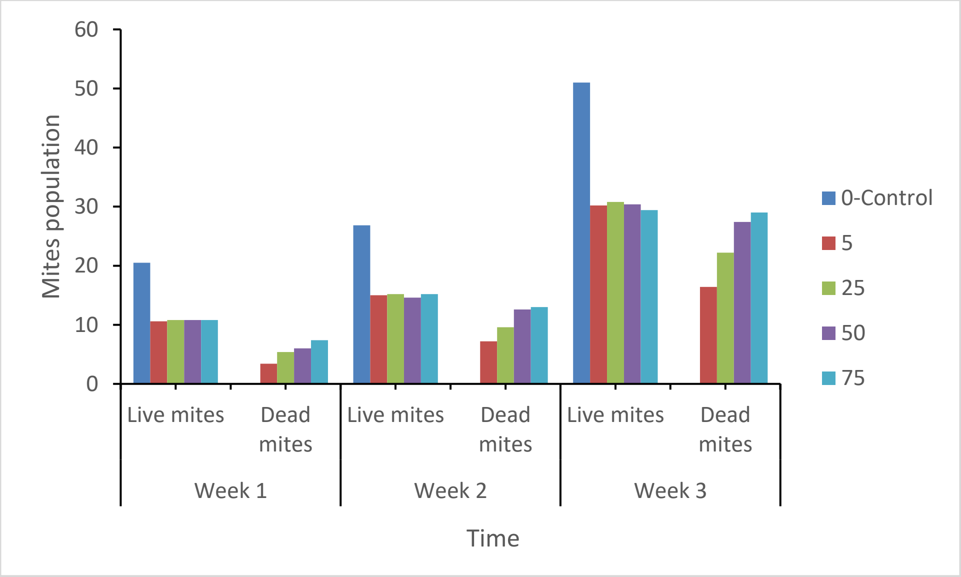


Figure 4.8: Response of tobacco spider mites' response to different garlic concentrations (weekly basis).

Week1		
	Live mites	Dead mites
Control	21	0
5	11	3
25	11	5
50	11	6
75	11	7

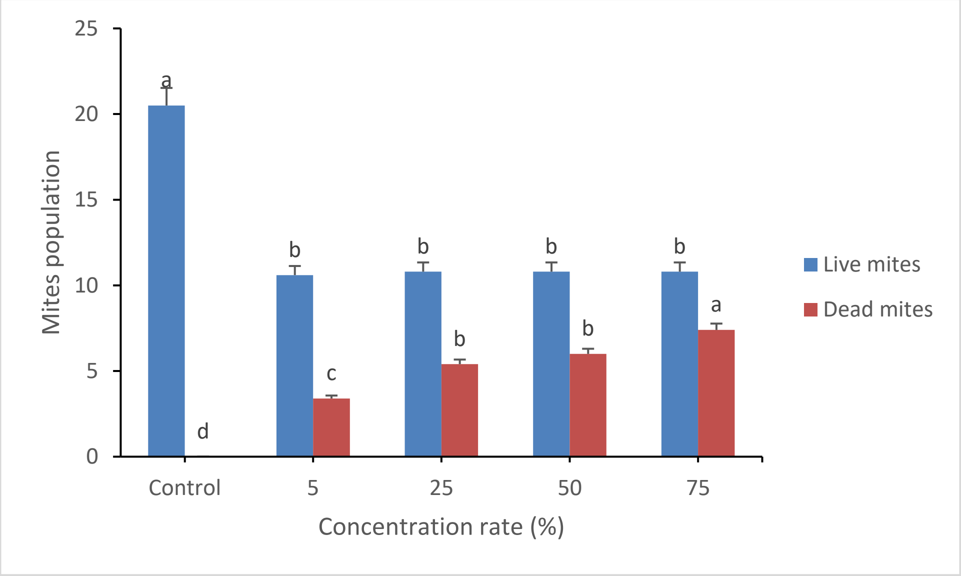


Figure 4.9: Response of tobacco spider mites' response to different garlic concentration recorded at week one after application.

Week 2		
	Live mites	Dead mites
Control	27	0
5	15	7
25	15	10
50	14	13
75	15	13

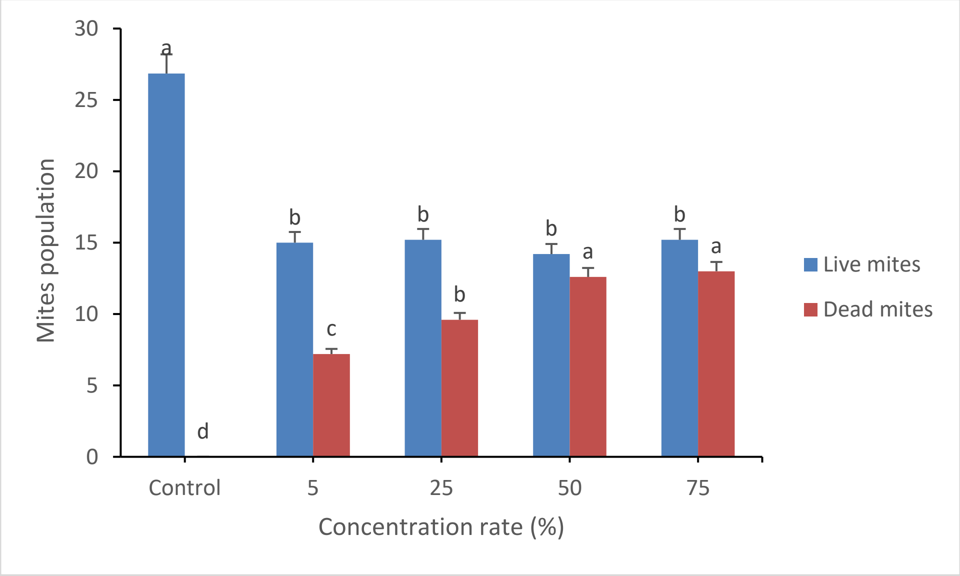


Figure 4.10: Response of tobacco spider mites' response to different garlic concentration recorded at week two after application.

Week 3		
	Live mites	Dead mites
Control	51	0
5	30.2	16.4
25	30.8	22.2
50	30.4	27.4
75	29.4	29

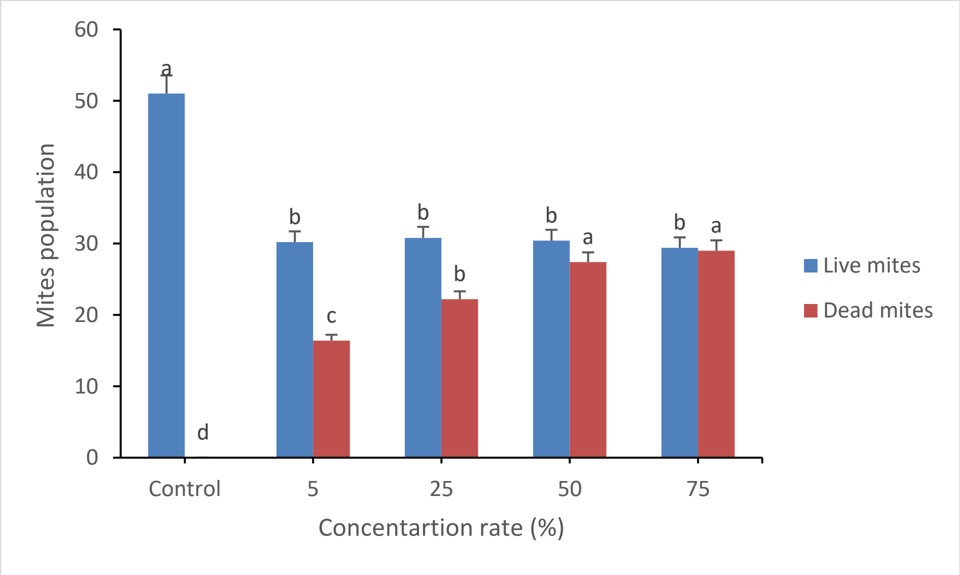


Figure 4.11: Response of tobacco spider mites' response to different garlic concentration recorded at week three after application.

Results in table 4 at week 1 and 2 of exposure showed that there was significant difference (p<0.001) in the mean count of live mites between tomato plants treated with *Melia azedarach* extracts and untreated (control). Although (5, 25, 50 and 75%) concentration levels had the lowest mean count of live mites after both week 1 and 2, there was no significant difference amongst the concentrations. Table 4 indicates that control (untreated) had the highest number of live mites after both week 1 and 2 exposure. There were significant differences (p<0.001) in mortality rate amongst the different concentrations of *Melia azedarach* extracts as shown in table 4, after week 1 and 2 of exposure the highest mortality rate was recorded on both 50% and 75% concentrations. It is worth noting, that 5% concentration at weeks 1 and 2 had the least

mortalities of 8.80 respectively, whilst for all the periods (week 1 and 2) there were no dead mites recorded on the mites’ infested leaves treated with distilled water (control).

After week 3 of exposure, control had the highest mean count of live mites which was (51.00), the results also showed that there was a significant difference ($p<0.001$) amongst the concentration level with 5% exhibited the highest mean count of live mites while 50% concentration had the least number of live mites after week 3 of exposure. It is evident from table 1 that after week 3, the mortality rate of the mites increased as compared to (week 1 and 2), 75% concentration of *Melia azedarach* extracts had the highest mortality rate, while there were no significant differences ($p<0.001$) amongst (5, 25 and 50%) concentrations in the number of dead mites. The concentration levels of *Melia azedarach* extracts on tomato plant leaves showed to be effective against tobacco spider mites’ population as time of exposure increased. Similar trend of results was noted after week 1, 2 and 3 of exposure that mites that were inoculated onto the leaves of tomato plants and treated with distilled water survived and as a result there was no dead mites recorded.

Table 4: Live and dead red spider mites caused by different concentrations *of Melis azedarach* (syringa) seeds extracts at week 1, 2 and 3 after treatment.

Concentration	***Week 1***		***Week 2***		***Week 3***	
%	**Live mites**	**Dead mites**	**Live mites**	**Dead mites**	**Live mites**	**Dead mites**
0-control	20.25^{a}	0.00^{d}	26.85^{a}	0.00^{d}	51.00^{a}	0.00^{c}
5	10.60^{b}	8.80^{c}	15.00^{b}	8.80^{c}	24.40^{b}	16.00^{b}
25	10.80^{b}	11.06^{b}	15.20^{b}	11.00^{b}	19.20^{cd}	16.60^{b}
50	10.60^{b}	13.80^{a}	14.80^{b}	13.80^{a}	16.80^{d}	15.00^{b}
75	10.40^{b}	14.60^{a}	15.20^{b}	14.60^{a}	20.20^{c}	20.00^{a}
SEM	4.0614	0.2514	1.6842	0.2514	3.1314	2.5485
F probability	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

SEM is the standard error of the mean. Note* cell sizes are not equal, means within the columns followed by same lower-case letters did not differ significantly.

Week1		
	Live mites	Dead mites
Control	20	0
5	11	9
25	11	11
50	11	14
75	10	15

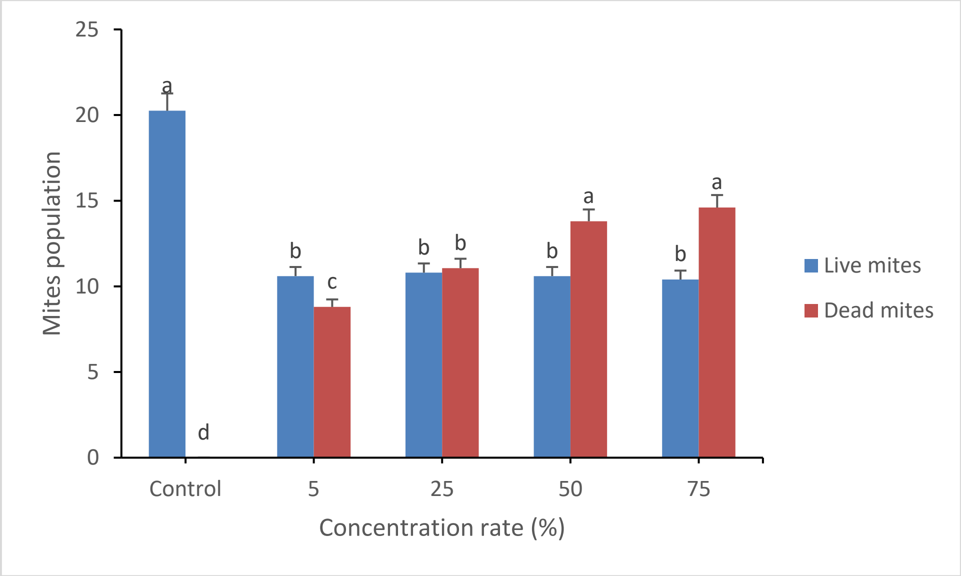


Figure 4.12: Response of tobacco spider mites' response to different syringa concentration recorded at week one after application.

Week 2

	Live mites	Dead mites
Control	27	0
5	15	9
25	15	11
50	15	14
75	15	15

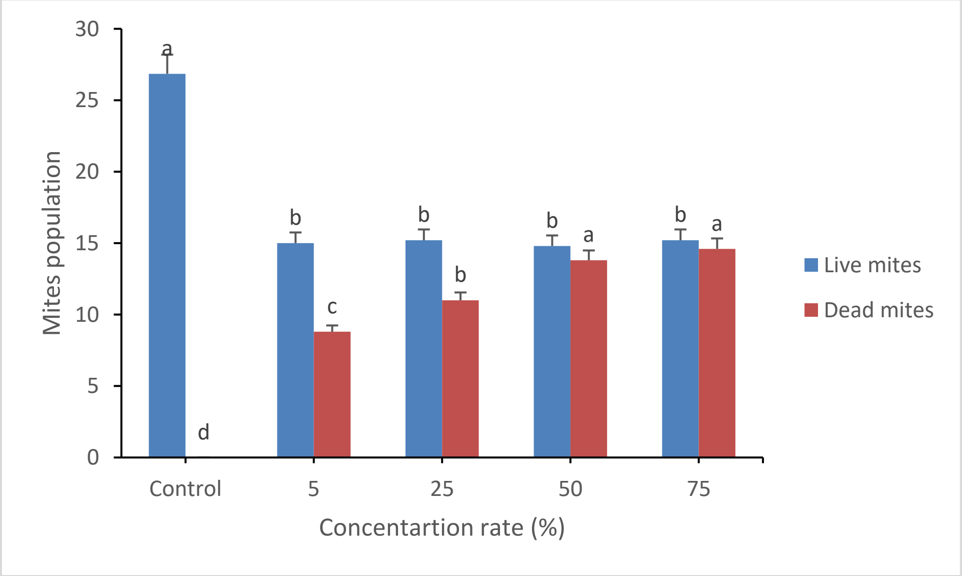


Figure 4.13: Response of tobacco spider mites’ response to different syringa concentration recorded at week two after application.

Week 3		
	Live mites	Dead mites
Control	51	0
5	24	16
25	19	17
50	17	15
75	20	20

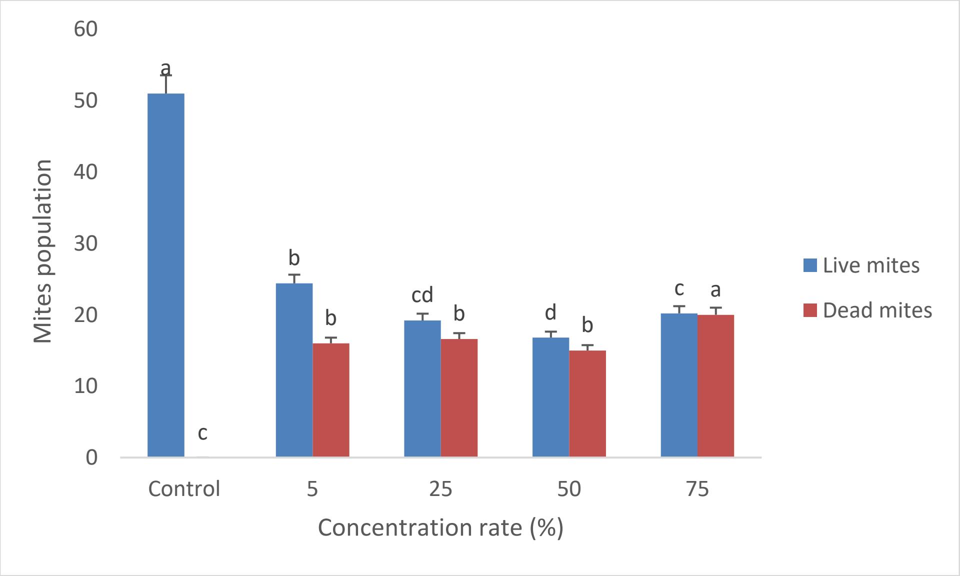


Figure 4.14: Response of tobacco spider mites’ response to different syringa concentration recorded at week three after application.

CHAPTER FIVE

DISCUSSION

The substantial variation in plant height, stem diameter, and chlorophyll content may have resulted from the tomato plants' physiological growth brought on by the potency of the botanical extracts (garlic and syringa) (Chen *et al.,* 2018; Mamarabadi *et al.,* 2018). According to a study by Hayat *et al.,* (2018), applying treatments of aqueous garlic extract to tomato plants significantly increased plant height, leaf area, stem diameter, and plant fresh/dry weight. Garlic acts as a biostimulator and has a priming effect on tomato plant growth, regardless of the concentration levels used (Hayat *et al*, 2022). Additionally, Ali *et al.,* (2019) found that pre-transplanting spraying of a single aqueous garlic foliage on eggplant increased plant shape, photosynthesis, and chlorophyll content. Ascorbic acid and nicotinamide, two biochemical substances found in aqueous garlic extract, are known as growth-regulating substances that have an impact on a variety of physiological and biochemical processes in plants, including cell elongation and expansion and metabolic processes like photosynthesis (Mohamed *et al*., 2020).

Tomato plants showed low mite populations as a result of the pesticidal action of the *M*elia *azedarach* extracts employed in the current investigation, which also had a positive impact on agronomic parameters since the plants were less stressed. The results by Thakur *et al*., (2022), which showed that high death rate and little feeding damage leads to good growth in tomatoes, are consistent with the aforementioned findings. Contrarily, there was no mortality of the mites observed on tomato plants treated with distilled water (control) after weeks 1, 2, and 3. This result could have been explained by the distilled water's lack of lethal properties, which may have allowed the mites to feed and multiply (Ahmed *et al*., 2021). The study's findings suggest that the low chlorophyll content in the control could have been caused by a heavy infestation of tobacco spider mites on tomato plant leaves, which caused the leaves to turn from green to yellow-white to bronze as a result of the web the mites built to protect themselves from natural predators.

The study's findings also revealed that *Allium sativum and Melia azedarach* significantly reduced the number of tobacco spider mites that live on tomato leaves. The active component allicin, which is present in crushed or chopped garlic cloves, may be responsible for the pesticidal properties of garlic. According to Bazaraliyeva *et al.,* (2022), the enzyme alliinase is transformed into allicin when garlic is crushed or diced, which adds to the herb's insecticidal capabilities. On the other hand, syringa's active components, limonoid and triterpenoid, may have contributed to its effectiveness in reducing tobacco spider mites on tomato leaves (Lin *et al*., 2022). According to the study's findings, all concentrations other than control had an effect on the tobacco spider mites' mortality.

According to tables 3 and 4 in chapter 4, the number of mite deaths increased as pesticide concentration levels and exposure times increased. The high mortality rate brought on by the concentration of garlic and syringa extracts after weeks 1, 2, and 3 was also most likely caused by other modes of action, such as antifeedant or repellent action, (Mwandila, 2013). rather than antagonistic action against the moulting hormone, ecdysone, because adult mites do not moult, according to Huang *et al*., (2022).

Tobacco spider mite mortality was low at weeks one and two following exposure to plant pesticides for mites, but at week three after exposure, as shown in tables three and four in chapter four, the mortality rate slightly increases. This might be the result of water dilution reducing the concentration of allicin, an active component of garlic, and limonoid, triterpenoid, an active component of syringa. The result of the study is in agreement with those of Sarmah *et al*., (2009) where similar research was conducted at Tocklai Experimental station in India, the results of low concentration (2.5%) of *Acorus calamus* (L), *Xanthium strumarium* (L), *Polygonum hydropiper* (L) and *Clerodendron infortunatum* (Gaertn) aqueous extracts in controlling tobacco spider mite showed lowest mortality.

Tobacco spider mite mortality increased by 50% and 75% as syringa and garlic concentrations rose from 5% to 25%. The fact that the mites kept dying after being exposed to pesticides is probably because the concentration of the active components in the extracts increased when they were diluted with water. There was an increase in the number of mites dying at week 2 following the application of the extracts, especially those exposed to concentration levels of 50% and 75%. However, the findings showed that during the third week of data collection, there was an increase in the number of tobacco spider mites dying at a 75% garlic concentration.

This showed that the level of efficacy against tobacco spider mites rose with the duration of exposure to garlic extracts, which may be related to the combination of an increase in allicin, an active element. According to Nxumalo *et al.,* (2021), who concurred with our findings, the highest concentration of garlic extracts used in the study—50%—killed about 95% of the mites. As a result, higher concentrations of botanical pesticides and prolonged exposure times may be used because the pesticides' increasing lethality is killing off mites more frequently. Additionally, it has been suggested that garlic produces polysulfides or organosulfur compounds, which, when used in greater quantities, may be the deadly substances responsible for the mites' demise (Subroto *et al*., 2021).

However, it is intriguing to note that the study's results showed that, at week 2, syringa extracts were superior to garlic extracts in their ability to combat tobacco spider mites. About 14.60 mean counts of the mites were killed by 75% syringa concentration at week 2, whereas 13.00 of the mortality was noted for garlic extracts at week 2. This might be caused by active substances like limonoid and triterpenoid, which, according to Chadhary *et al.,* (2017) have an effect that inhibits growth while also functioning as an insect repellent and an antifeedant. In addition, the meliantriol, azadirachtin, and salannin chemicals present in syringa could have killed the mites infested on the leaves treated with syringa extracts (Ascher *et al*., 2018).

By finding that the active ingredient, azadirachtin, is present in syringa in low concentrations (Sharma *et al.,* 2019), it may be possible to further explain why lengthier treatments (2 weeks) resulted at a higher mortality rate for tobacco spider mites. The effectiveness of neem and syringa extracts on eggs, nymphs, and adult mites died with an increase of 50% in syringa concentration, according to Masoud *et al.,* (2018)'s research. Tobacco spider mite mortality on diseased plant leaves treated with distilled water at weeks 1, 2, and 3 was undetectable because neither botanical extract nor insecticides were applied. Tobacco spider mites were assessed/observed on a hand lens a week after infestation and treatment with distilled water, and it was discovered that they were highly active, moving over the leaf surface. Additionally, little white eggs and spider webs were also noticed.

REFERENCES

Ali, M., CHENG, Z.H., Hayat, S., Ahmad, H., Ghani, M.I. and Tao, L.I.U., 2019. Foliar spraying of aqueous garlic bulb extract stimulates growth and antioxidant enzyme activity in eggplant (Solanum melongena L.). *Journal of Integrative Agriculture*, *18*(5), pp.1001-

1013.

Ahmed, M.M., Abdel-Rahman, H.R. and Abdelwines, M.A., 2021. Application of demographic analysis for assessing effects of pesticides on the predatory mite, Phytoseiulus persimilis (Acari: Phytoseiidae). *Persian Journal of Acarology*, *10*(3), pp.281-298.

Ascher, K.R.S. and Meisner, J., 2018. The effects of neem on insects affecting man and animal. In *1988 Focus on Phytochemical Pesticides* (pp. 113-132). CRC Press

Bazaraliyeva, A., Moldashov, D., Turgumbayeva, A., Kartbayeva, E., Kalykova, A., Sarsenova, L. and Issayeva, R., 2022. Chemical and biological properties of bio-active compounds from garlic (Allium sativum). *Pharmacia*, *69*(4), pp.955-964.

Chen, C., Liu, C.H., Cai, J., Zhang, W., Qi, W.L., Wang, Z., Liu, Z.B. and Yang, Y., 2018. Broad-spectrum antimicrobial activity, chemical composition and mechanism of action of garlic (Allium sativum) extracts. *Food Control*, *86*, pp.117-125.

Chaudhary, S., Kanwar, R.K., Sehgal, A., Cahill, D.M., Barrow, C.J., Sehgal, R. and Kanwar, J.R., 2017. Progress on Azadirachta indica based biopesticides in replacing synthetic toxic pesticides. *Frontiers in plant science*, *8*, p.610.

Hayat, S., Ahmad, H., Ali, M., Ren, K. and Cheng, Z., 2018. Aqueous garlic extract stimulates growth and antioxidant enzymes activity of tomato (Solanum lycopersicum). *Scientia Horticulturae*, *240*, pp.139-146.

Hayat, S., Ahmad, A., Ahmad, H., Hayat, K., Khan, M.A. and Runan, T., 2022. Garlic, from medicinal herb to possible plant bioprotectant: A review. *Scientia Horticulturae*, *304*, p.111296.

Huang, S., Huang, H., Xie, J., Wang, F., Fan, S., Yang, M., Zheng, C., Han, L. and Zhang, D., 2022. The latest research progress on the prevention of storage pests by natural products: Species, mechanisms, and sources of inspiration. *Arabian Journal of Chemistry*, p.104189

Lin, M., Bi, X., Zhou, L. and Huang, J., 2022. Insecticidal Triterpenes in Meliaceae: Plant Species, Molecules, and Activities: Part II (Cipadessa, Melia). *International Journal of*

Molecular Sciences, *23*(10), p.5329.

Mohamed, M.H., Badr, E.A., Sadak, M.S. and Khedr, H.H., 2020. Effect of garlic extract, ascorbic acid and nicotinamide on growth, some biochemical aspects, yield and its components of three faba bean (Vicia faba L.) cultivars under sandy soil conditions. *Bulletin of the National Research Centre*, *44*(1), pp.1-8.

Mamarabadi, M., Tanhaeian, A. and Ramezany, Y., 2018. Antifungal activity of recombinant thanatin in comparison with two plant extracts and a chemical mixture to control fungal plant pathogens. *AMB Express*, *8*(1), pp.1-12

Mwandila, N.K., 2013. Efficacy of Syringa (Melia Azedarach L.) extracts on eggs, nymphs and adult red spider mites, Tetranychus spp.(Acari: Tetranychidae) on tomatoes. *African Journal of Agricultural Research*, *8*(8), pp.695-700.

Sarmah, M., Rahman, A., Phukan, A.K. and Gurusubramanian, G., 2009. Effect of aqueous plant extracts on tea red spider mite, Oligonychus coffeae, Nietner (Tetranychidae: Acarina) and Stethorus gilvifrons Mulsant. *African Journal of Biotechnology*, *8*(3)

Subroto, E., Cahyana, Y., Tensiska, M., Filianty, F., Lembong, E., Wulandari, E., Kurniati, D., Saputra, R.A. and Faturachman, F., 2021. Bioactive compounds in garlic (Allium sativum L.) as a source of antioxidants and its potential to improve the immune system: a review. *Food Research*, *5*(6), pp.1-11.

Thakur, S. and Sood, A.K., 2022. Foliar application of natural products reduces population of two-spotted spider mite, Tetranychus urticae Koch on parthenocarpic cucumber (Cucumis sativus L.) under protected environment. *Crop Protection*, p.106036

CHAPTER SIX

CONCLUSION

The tobacco spider mite *(Tetranychus evansi)* infestation on tomato production has been a major problem and has resulted in a large loss in tomato yield for Zimbabwean farmers and producers. Since tomatoes are a dietary source of the antioxidant lycopene, which has been linked to many health benefits, including reduced risk of heart disease and cancer, great source of vitamin C, and will also improve on health by easing malnutrition to families, encouraging the use of botanical pesticides could reduce costs and limit the importation of expensive chemical synthetic pesticides.

The results of the current investigation showed that treatment concentration and exposure time boosted the efficacy of *Allium sativum* and *Melia azedarach* extracts. At week 2, 50% and 75% syringa concentrations were more effective at reducing tobacco spider mite mortality, with 75% concentration having a highly significant impact. However, the concentration of garlic extracts at 75% was much greater and more efficient against tobacco spider mites by week 3. It is not advised to use lower quantities of these plant extracts to prevent and/or control mites on tomato plants, despite the fact that they had little mortality effect against the mites. Therefore, it is concluded that the most effective pesticides to use on tomato plants cultivated in the field by resource-poor farmers are extracts of both garlic and syringa botanicals at concentrations of 50% and 75%. Garlic and syringa extracts had a beneficial influence on the agronomical parameters of the tomato plants in addition to their botanical pesticidal action.

FUTURE RECOMMENDATION ON RESEARCH STUDIES

To ascertain the effectiveness of syringa leaves and bark, garlic leaves, and stem extracts against tobacco spider mites and to investigate their impact on beneficial organisms' predatory mites, more research is necessary. Additionally, it is advised that the production of botanical pesticides be made publicly available for sale as this will encourage more tomato producers and growers and generate cash that will support the livelihoods of communities in Zimbabwe's Chiredzi District.

Further investigation is needed into domestic and wild plants that contain bioactive substances relevant to crop protection that can be used as efficient insecticides. Increased usage of organic pest control products in integrated pest management techniques will boost agricultural products' acceptance in niche markets, promoting improved global trade, food safety, biodiversity preservation, environmental protection, and human health.