



**The insecticidal and repellent activities of extracts of three *Allium* spp.
(Amaryllidaceae) against grapevine mealybug (*Planococcus ficus* L.)**

by

Tokozani Mange

215253647

Master of Agriculture

Faculty of Applied Sciences

Cape Peninsula University of Technology

Supervisor: Prof Felix, Nchu

Co-supervisor: Prof Morris, Fanadzo

DECLARATION

I, Tokozani Mange, declare that the contents of this thesis represent my unaided work and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

T. Mange

07/10/25

Signed

Dated

DEDICATION

I dedicate this thesis to:

- Myself.
- My mom, I could not have done this without you.

ACKNOWLEDGEMENTS

- I thank God for the strength and drive to complete my work.
- I thank myself.
- I thank my mother, Miss W.P. Mange, for her love, support, and patience. Enkosi mama!
- A huge thank you to Pro Nchu for his supervision, guidance, and knowledge in the field of work.
- To Prof. Fanadzo for his supervision.
- This study was financially supported by Cape Peninsula University of Technology through the CPUT Bursary.
- To everyone involved in completing this thesis, I thank you.

Contents

DEDICATION	ii
ACKNOWLEDGEMENTS	iii
LIST OF FIGURES	vi
LIST OF TABLES.....	vii
LIST OF ACRONYMS.....	viii
ABSTRACT	ix
STRUCTURE OF THE THESIS	xi
CHAPTER ONE: INTRODUCTION	12
1.1 Background.....	12
1.2. Statement of the problem.....	13
1.3. Rationale of the study.	13
1.4. Significance of the study.	14
1.5. Aim and objectives of the study.	14
1.5.1. The specific objectives of the study were:.....	14
1.6. Hypothesis.....	15
References.....	16
CHAPTER TWO: LITERATURE REVIEW	21
2.2 Materials and methods	23
2.2.1 Data collection.....	23
2.4 Repellent plant extracts against mealybugs and other pest species	34
2.5 Registered botanical insecticides and their mode of action	38
2.5.1 <i>Pyrethrum</i>	40
2.5.2 Neem.....	40
2.5.3 Essential oils	41
2.5.4 Plant-based insecticides versus synthetic insecticides	41
2.6 The relationship between exposure time and concentration of plant-based insecticides.....	42
2.8 Suggestions for future research	43
2.9 Conclusion.....	43
References.....	45
CHAPTER THREE	55
3.1 Introduction	56
3.2 Materials and methods	58
3.2.1 Research Design	58
3.2.2 Insect culture	58

3.2.3 Plant material	59
3.2.4 Plant preparation	59
3.6 Choice repellence bioassay	62
3.7 Garlic-formulated soap against vine mealybugs at different concentrations	63
3.8 Statistical analysis	63
3.9 Results and Discussions.....	63
3.9.1 Toxic activity of <i>Allium spp.</i> against <i>P. ficus</i> at 25% concentration.....	63
3.9.2 Testing the toxic effect of different concentrations of DCM extract of garlic ...	64
3.9.3 Repellent activity of <i>Allium spp.</i> at 25% w/v concentration	65
3.9.4 Repellent activity at different concentration (25%, 12.5%, 6.25%, 3.125%)	66
Reference	70
CHAPTER FOUR: CONCLUSION AND RECOMMENDATIONS	75
4.1 General discussion, conclusion, and recommendations	75
4.1.1 General discussion	75
4.1.3 Recommendations.....	76

LIST OF FIGURES

Figure 3. 1: The wood ash-making process	60
Figure 3. 2: Packet filter paper with female grapevine mealybugs in a petri dish.....	62
Figure 3. 3: Organic bar soap	63

LIST OF TABLES

Table 2. 1: Toxic plants used against a range of pests.....	25
Table 2. 2: Selected plants tested for insecticidal activity against mealybug species.....	31
Table 2. 3: Repellent plants against mealybugs and other pests	35
Table 2. 4: Registered products of commercial use from plant-based pesticides	38
Table 3. 1: Extract yields of the three <i>Allium</i> species from four different solvents	59
Table 3. 2: Median insect number of mortalities of female grapevine mealybug (<i>Planococcus ficus</i>) at 10 minutes post-treatment	64
Table 3. 3: DCM extract of garlic on packet filter paper with female grapevine mealybug (<i>Planococcus ficus</i>) in toxicity bioassay	64
Table 3. 4: The median number of insects that stayed on the 25% w/v concentration sections (unrepelled female <i>P. ficus</i>) in the choice disc repellency bioassay	65
Table 3. 5: Percentage repellency of different concentrations of aqueous garlic against female grapevine mealybug on choice repellency bioassay	67

LIST OF ACRONYMS

BCAs – Biological control agents

EU – European Union

IPM – Integrated Pest Management

BAC – Biologically Active Compounds

OSC – Organosulfur Compound

GLRaV-3 – Grapevine leaf-roll-associated virus 3

GLD – Grapevine Leafroll Disease

DAPS – Diallyl polysulfides

EPNs – Entomopathogenic nematodes

IJs – Infective juveniles

DCM – Dichloromethane

RH – Relative humidity

EOs – Essential oils

nAChR – Nicotinic acetylcholine receptors

GABA – γ -aminobutyric acid

IPM – Integrated pest management

LC-MS - Liquid Chromatography – Mass Spectrometry

GC-MS - Gas Chromatography – Mass Spectrometry

ABSTRACT

Grapevines are susceptible to a wide variety of pests, including the grapevine mealybug. It is one of the most economically important pests of wine grapes. It causes sooty moulds on grape clusters and transmits the grapevine leafroll-associated virus. One of the primary methods for controlling this pest in the vineyard is the application of synthetic insecticides. However, these synthetic insecticides harm natural enemies, the environment, and human health. In modern agriculture, Plants are increasingly being recognised as an important source of insecticides. Many plant-based insecticides are used as alternatives to reduce the reliance on chemical insecticides. Hence, researchers have been developing new and safer pest control methods. Plant-based insecticides have been traditionally used worldwide, particularly by subsistence/smallholders. *Allium* species are among the most extensively researched plants for their sulphur compounds and other bioactive compounds.

The first part of this study, in Chapter One, begins with the background and rationale of the study, followed by a systematic literature review in Chapter Two, focusing on the use of plant-based products screened for pest repellence and insecticidal properties against the vine mealybug, which revealed that several plant species from different families have insecticidal properties against the vine mealybug pests. Chapter 3 is the experimental part of this study, consisting of two bioassays: toxicity and repellency, which evaluated the toxicity of *Allium* species (*A. sativum*, *A. cepa*, and *A. porrum*) against the vine mealybug. The three *Allium spp.* were store-bought, the garlic and onion were peeled, and the leek was rinsed and dried with a paper towel. The plants were crushed to a paste-like consistency and dissolved in various solvents (DCM, absolute ethanol, Acetone, and Distilled water) at room temperature (25 °C) for 24 hours. The extracts were filtered and allowed to dry at room temperature (25 °C). To perform the toxicity bioassay, the extracts were re-dissolved in extra-virgin olive oil to obtain a 25% w/v concentration, and this mixture was vortexed for 10 minutes. Fifty microlitres of each 25% w/v extract was applied to a 2x2 cm packet filter paper and allowed to dry for 5 minutes. A camel-hair brush was used to transfer the insect into the packet, and all sides were stapled. Five packets, each containing one insect, were placed in a petri dish and stored in a Perspex box containing saturated sodium solution in a 100 mL glass beaker, in a darkroom at room temperature and 60% RH. Data was collected after 10 minutes. The results showed a significant difference in insecticidal efficacy among the plant species (DF=2; $P < 0.05$). Garlic exhibited the highest potency against vine mealybug, particularly when extracted with DCM. The results showed that the DCM garlic extract was significantly more toxic (DF = 3; $\chi^2 = 23.09$;

$P < 0.05$), inducing 92% insect mortality at a concentration of 25% w/v. The DCM extract of garlic was further tested at different concentrations (25% w/v, 12.5% w/v, 6.25% w/v, 3.125% w/v) and at 0% (negative control) and compared to extra virgin olive oil. The highest corrected mortality rate was 92% of the vine mealybug, achieved at 25% w/v concentration. The mortality rate was concentration-dependent.

The choice repellence bioassay evaluated the repellent activity of *Allium spp.* (garlic, onion, and leek) against the vine mealybug. The same plant preparation method was followed as for the toxicity experiment, except that the extracts were redissolved in solvents (DCM, Acetone, absolute ethanol, and Distilled water) to achieve a 25% w/v concentration and tested in a choice repellence bioassay. The results showed a significant difference in repellent efficacy. The acetone garlic extract was significantly more repellent than the other treatments ($DF = 3$; $\chi^2 = 19.95$; $P < 0.05$). The distilled water extract of garlic and the organic soap exhibited 42% and 38% repellency, respectively, at 25% w/v. These findings demonstrated that garlic extracts have anti-grapevine mealybug activity and could be incorporated into integrated pest management.

STRUCTURE OF THE THESIS

This thesis is subdivided into the following chapters:

Chapter 1: Introduction provides a brief description of the vine mealybug and the use of herbal plants as insecticides. It also presents hypotheses, objectives, and the rationale of the study.

Chapter 2: Review paper on plant-based products used against vine mealybug.

Chapter 3: This chapter details the materials and methods of this study and the results of the experiments.

Chapter 4: General discussions, conclusion and recommendations.

CHAPTER ONE: INTRODUCTION

1.1 Background

Grapevines (*Vitis vinifera* L.) are among the most important fruit crops, which are cultivated globally for wine, raisin and fresh fruit production (Yadav et al., 2019). However, they are susceptible to various insect pest infestations that may significantly impact yield, fruit quality, and overall plant health, thus reducing production (Fermaud et al., 2016; Reineke and Thiéry, 2016; Mansour et al., 2018). In grapevine production, the economic cost of insect-related damages and disease transmissions is immeasurable (Niroumand et al., 2016). Mealybugs are pests that cause significant economic losses; most of which belong to the family Pseudococcidae, the second-largest family of scale insects (Mathulwe et al., 2021). The most important pests of this family are the vineyard mealybug (*Planococcus ficus* L.), obscure mealybug (*Pseudococcus viburni* L.), and long-tailed mealybug (*Pseudococcus longispinus* L.) (Ji et al., 2020). In South Africa, the grapevine mealybug is a key economic insect pest of grapevines. They are polyphagous insects that damage various commercially important crops, including fruits and vegetables. They feed on the plant sap by inserting their stylets into the epidermis of leaves, fruits, and stems. It excretes honeydew, which serves as a substrate for the sooty mould fungus. The honeydew also covers the leaves, fruits, and stems, preventing photosynthesis and gas exchange (Moniruzzaman et al., 2017).

To manage mealybug infestation, synthetic insecticides such as carbamates, pyrethroids, and organophosphates are commonly used. However, these synthetic insecticides have many setbacks, especially when used inappropriately and repeatedly. Many synthetic insecticide residues are toxic to their natural enemies and non-target organisms, the environment and human health, and have been linked to the resurgence of target insects and secondary pest outbreaks (Halder et al., 2013; Rotolo et al., 2018; Din et al., 2021; Arokiyaraj et al., 2022).

Therefore, it is important to seek alternative approaches for mealybug control that are economically effective, less toxic, and environmentally friendly. The use of biological control agents (BCAs) has emerged as a promising alternative to synthetic insecticides (Carrión et al., 2017; Rotolo et al., 2018; van Lenteren et al., 2018). The European Union (EU) and China have been advocating for BCAs for over a decade (van Lenteren et al., 2018). Among these BCAs are botanicals (BOTs, i.e. plant extracts), which produce secondary metabolites that are associated with insecticidal properties. For example, the *Allium* species of the Amaryllidaceae family have been recognised for their diverse medicinal impact, and insecticidal and repellent activities against different pests. Several studies have evaluated the effectiveness of the

Allium species against a wide range of pests (Aboelhadid et al., 2013; Douiri et al., 2013; Tembo et al., 2015; Baidoo and Mochiah, 2016; Salifu et al., 2019; Din et al., 2021). A variety of bioactive compounds, such as sulphur-containing compounds, phenolic acids, and flavonoids, are secondary metabolites found in these plants (Martins et al., 2016; Abdel-Gawad et al., 2018; Aydin and Mammadov, 2019; Elisovetcaia et al., 2018; Vuković et al., 2023). These bioactive compounds exhibit various activities, including insecticidal, repellent, antimicrobial, and antifungal properties against a wide range of agricultural pests (Aboelhadid et al., 2013; Mikaili et al., 2013; Batiha et al., 2020; Falcón-Piñeiro et al., 2023). Therefore, they are viable for sustainable and environmentally friendly strategies for pest management and reducing reliance on synthetic chemicals.

1.2. Statement of the problem.

The infestation of crops by various insect pests is the most limiting factor on crop yield, which is a worldwide concern in the agricultural industry (Banerjee et al., 2018). In vineyards, the grapevine mealybug (*Planococcus ficus* L.) is a major insect pest in many regions of the world, including South Africa (Ji et al., 2020). Grapevine mealybug has been reported to cause significant economic damage in many vineyards. It can transmit the grapevine leafroll virus (GRLaV-3) and produce a sooty mould on infested grape clusters, compromising the fruit quality (Moniruzzaman et al., 2017; Mansour et al., 2018; Cocco et al., 2021; Schulze-Sylvester et al., 2021). Farmers mostly depend on synthetic insecticides for effective control of insect pests, including the grapevine mealybug. However, the excessive or repeated use of these synthetic insecticides has been reported as a risk factor for human, environmental, and pest-resistant development (Ayilara et al., 2023). Therefore, the search for a safer alternative pest control measure is imperative. Thus, the use of natural products, such as plant-based ones, is compelling. Recent studies support the insecticidal and repellent activity of *Allium* spp. (Debra and Misheck, 2014; Elaziz et al., 2019; Michel et al., 2024; Hussein et al., 2025). These plants are medicinal and well-known for their bioactive compounds.

1.3. Rationale of the study.

As a result of the detrimental effects of synthetic insecticides on plant health and the environment. There is an increasing significance on the development and adoption of safer alternative control measures (Cocco et al., 2021; Khursheed et al., 2022). Screening of plant extracts could facilitate the development of new, plant-based insect repellents and insecticides, which could serve as an alternative to synthetic insecticides. Extracts of *Allium*

species, especially garlic, have been shown to have insecticidal and repellent effects on insect pests (Sarwar, 2013; Nchu et al., 2016; Hussein et al., 2025). Interestingly, some of these sulphur-based bioactive compounds also occur in other *Allium* spp., such as *Allium cepa* and *Allium porrum* (Plata-Rueda et al., 2017; Kale et al., 2021). We, therefore, hypothesise that extracts from *A. sativum*, *A. cepa*, and *A. porrum* will have insecticidal and repellent activities against the vine mealybug.

1.4. Significance of the study.

The findings of this study, if disseminated, will contribute to a broader understanding of reducing reliance on synthetic insecticides for controlling grapevine mealybugs in vineyards as a mitigative measure towards pest management, farmers' satisfaction, and compliance in the food safety industry. The contribution is beneficial in ensuring environmental sustainability and human health.

1.5. Aim and objectives of the study.

The study aimed to determine the insecticidal and repellent activities of dichloromethane, ethanol absolute, acetone, and aqueous extracts of *A. sativum*, *A. porrum*, and *A. cepa* on adult female vine mealybug (*Planococcus ficus* L.).

1.5.1. The specific objectives of the study were:

1. To reviewed literature on plant species and plant-based products that were screened for pest repellence and insecticidal properties with a view to exploiting their insect control properties to minimise agricultural losses due to vine mealybug infestation
2. To determine the toxicity effects of crude extracts of *A. sativum*, *A. porrum*, and *A. cepa* at five different concentrations of 25% w/v, 12.5%, 6.25%, 3.125% and 0% on the adult female insects of the grapevine mealybug in a packet filter paper test bioassay.
3. To evaluate the repellent activity of crude extracts of *A. sativum*, *A. porrum*, and *A. cepa* plants on the adult female insects of the grapevine mealybug in disc repellence bioassay.
4. To develop an organic soap that can potentially repel grapevine mealybug.

1.6. Hypothesis

1. The extracts of *A. sativum*, *A. porrum*, and *A. cepa* will have insecticidal and repellent activities against the adult female grapevine mealybug compared to corresponding controls.
2. The insecticidal and repellent activities of extracts of *A. cepa*, *A. porrum* and *A. sativum* on adult female grapevine mealybug will vary significantly among species.
3. The chemical constituents in extracts of *A. sativum*, *A. porrum*, and *A. cepa* will vary significantly among species and extracts.

References

- Abdel-Gawad, M., Abdel-Aziz, M., El-Sayed, M., El-Wakil, E., Abdel-Lateef, E. 2018. In vitro antioxidant, total phenolic and flavonoid contents of six *Allium* species growing in Egypt. *Journal of Microbiology, Biotechnology and Food Sciences*, 8: 343-346.
- Aboelhadid, S.M., Kamel, A.A., Arafa, W.M., Shokier, K.A. 2013. Effect of *Allium sativum* and *Allium cepa* oils on different stages of *Boophilus annulatus*. *Parasitol Res*, 112:1883-1890.
- Arokiyaraj, C., Bhattacharyya, K. and Reddy, S.G.E. 2022. Toxicity and synergistic activity of compounds from essential oils and their effect on detoxification enzymes against *Planococcus lilacinus*. *Frontiers in Plant Science*, 13:1016737.
- Aydin, Ç. and Mammadov, R. 2019. Phytochemical analysis, phenolic content, antioxidant, antibacterial, insecticidal and cytotoxic activities of *Allium reuterianum* Boiss. extracts. *Indian Journal of Traditional Knowledge*, 18(2): 290-298.
- Ayilara, M.S., Adeleke, B.S., Akinola, S.A., Fayose, C.A., Adeyemi, U.T., Gbadegesin, L.A., Omole, R.K., Johnson, R.M., Uthman, Q.O. and Babalola, O.O. 2023. Biopesticides as a promising alternative to synthetic pesticides: A case for microbial pesticides, phytopesticides, and nanobiopesticides. *Front Microbiology*, 14:1040901.
- Baidoo, P.K. and Mochiah, M.B. 2016. Comparing the effectiveness of garlic (*Allium sativum* L.) and hot pepper (*Capsicum frutescens* L.) in the management of the major pests of cabbage *Brassica oleracea* (L.). *Sustainable Agriculture Research*, 5(2).
- Banerjee, G., Sarkar, U., Bannerjee, G., Das, S. and Ghosh, I. 2018. Artificial Intelligence in Agriculture: A Literature Survey. *International Journal of Scientific Research in Computer Science Applications and Management Studies*, 7(3).
- Batiha, G.E.S., Beshbishy, A.M., Wasef, L.G., Elewa, Y.H.A., Al-Sagan, A.A., El-Hack, M.E.A., Taha, A.E., Abd-Elhakim, Y.M., Devkota, H.P. 2020. Chemical constituents and pharmacological activities of garlic (*Allium sativum* L.): A review. *Nutrients*, 12: 872.
- Carrión, J.M., Guerrero, I.C., Marrero, J.G., Alonso, M.M. and Osegueda, S. 2017. Herbal extracts as bioinsecticides for sustainable agriculture 'in' Méndez-Vilas, A. (ed), *Science within Food: Up-to-date Advances on Research and Educational Ideas*. Formatex Research Center, 132.

- Cocco, A., Pacheco da Silva, V.C., Benelli, G., Botton, M., Lucchi, A., Lentini, A. 2021. Sustainable management of the vine mealybug in organic vineyards. *Journal of Pest Science*, 94:153–185.
- Debra, K.R. and Misheck, D. 2014. Onion (*Allium cepa*) and garlic (*Allium sativum*) as pest control intercrops in cabbage based intercrop systems in Zimbabwe. *IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)*, 7(2): 13-17.
- Din, S. U.D., Azam, S., Rao, A.Q., Shad, M., Ahmed, M., Gul, A., Latif, A., Ali, M.A., Husnain, T., Shahid, A.A. 2021. Development of broad-spectrum and sustainable resistance in cotton against major insects through the combination of Bt and plant lectin genes. *Plant Cell Reports*, 40: 707–721.
- Douiri, L.F., Boughdad, A., Assobhei, O. and Moumni, M. 2013. Chemical composition and biological activity of *Allium sativum* essential oils against *Callosobruchus maculatus*. *IOSR Journal of Environmental Science*, 3(1):30-36.
- Elaziz, A., Ishag, S.A., Abdelbagi, A.O., Hammad, A.M.A., Abdurruhman, Abdullatief M, Mohammed, A., Hammad, A., Abdurruhman, Abdullatief Mohammed, Osman, M., Sir, M. and Khatim, E. 2019. Garlic (*Allium sativum*) Aqueous Extract as an Alternative Fumigant for the Control of Cowpea Seed Weevil *Callosobruchus maculatus* (F.). *American Journal of Biological Chemistry*, 7(1): 1-7.
- Elisovetcaia, D., Ivanova, R. and Brindza, J. 2018. Insecticidal and antifeedant activity of the ethanolic extracts from *Allium rotundum* L. *AGROFOR International Journal*, 3(2).
- Falcón-Piñero, A., García-López, D., Gil-Martínez, L., De la Torre, J.M., Carmona-Yañez, M.D., Katalayi-Muleli, A., Guillamón, E., Barrero-Domínguez, B., López-Feria, S., Garrido, D. and Baños, A. 2023. PTS and PTSO, two organosulfur compounds from onion by-products as a novel solution for plant disease and pest management. *Chemical and Biological Technologies in Agriculture*, 10: 76.
- Fermaud, M., Smits, N., Merot, A., Roudet, J., Thiéry, D., Wery, J. and Delbac, L. 2016. New multipest damage indicator to assess protection strategies in grapevine cropping systems. *Australian Journal of Grape and Wine Research*, 22: 450-461.

- Halder, J., Rai, A.B. and Kodandaram, M.H. 2013. Compatibility of neem oil and different entomopathogens for the management of major vegetable sucking pests. *National Academy Science Letters*, 36: 19-25.
- Hussein, H.S., Idriss, M.H., El-Gayar, F.H., Mousa, H.Y.S. and Salem, M.Z. 2025. Comparative efficacy of plant derived extracts with the insecticide mospilan on two whitefly species *Bemisia tabaci* biotype B and *Trialeurodes ricini*. *Scientific Reports*, 15: 1970.
- Ji, W., Han, K., Lu, Y. and Wei, J. 2020. Predicting the potential distribution of the vine mealybug, *Planococcus ficus* under climate change by MaxEnt. *Crop Protection* 137: 105268.
- Kale, R.B., Gadge, S.S., Jayaswall, K., Patole, A.O., Mahajan, V. and Singh, M. 2021. Validation of ethno-veterinary medicinal practices of onion (*Allium cepa* L.). *Indian Journal of Traditional Knowledge*, 20(3): 775-783.
- Khursheed, A., Rather, M.A., Jain, V., Wani, A.R., Rasool, S., Nazir, R., Malik, N.A. and Majid, S.A. 2022. Plant-based natural products as potential ecofriendly and safer biopesticides: A comprehensive overview of their advantages over conventional pesticides, limitations and regulatory aspects. *Microbial Pathogenesis*, 173:105854.
- Mansour, R., Belzunces, L.P., Suma, P., Zappalà, L., Mazzeo, G., Grissa-Lebdi, K., Russo, A. and Biondi, A. 2018. Vine and citrus mealybug pest control based on synthetic chemicals: A review. *Agronomy for Sustainable Development*, 38: 37.
- Martins, N., Petropoulos, S. and Ferreira, I.C. 2016. Chemical composition and bioactive compounds of garlic (*Allium sativum* L.) as affected by pre-and post-harvest conditions: A review. *Food chemistry*, 211: 41-50.
- Mathulwe, L.L., Malan, A.P. and Stokwe, N.F. 2021. A review of the biology and control of the obscure mealybug, *Pseudococcus viburni* (Hemiptera: Pseudococcidae), with special reference to biological control using entomopathogenic fungi and nematodes. *African Entomology*, 29(1): 1-16.
- Michel, M.R., Aguilar-Zárate, M., Perales-Rosas, D., Martínez-Ávila, G.C.G., Gómez-García, R., Tafolla-Arellano, J.C., Rojas, R. and Aguilar-Zárate, P. 2024. Enhancing the insecticidal efficacy of *Allium sativum* extracts through microencapsulation via complex coacervation. *Plant Science Today*, 11(4): 625-633.
- Mikaili, P., Maadirad, S., Moloudizargari, M., Aghajanshakeri, S. and Sarahroodi, S. 2013. Therapeutic uses and pharmacological properties of garlic, shallot, and their biologically active compounds. *Iranian journal of basic medical sciences*, 16(10): 1031-1048.

- Moniruzzaman, M., Yaakob, Z., Khatun, R. and Awang, N. 2017. Mealybug (Pseudococcidae) infestation and organic control in fig (*Ficus carica*) orchards of Malaysia. *Biology and Environment*, 117B (1), 25–32.
- Nchu, F., Magano, S.R. and Eloff, J.N. 2016. Repellent activities of dichloromethane extract of *Allium sativum* (garlic) (Liliaceae) against *Hyalomma rufipes* (Acari). *Journal of the South African Veterinary Association*, 87(1).
- Niroumand, M., Farzaei, M.H., Karimpour-Razkenari, E.E., Amin, G., Khanavi, M., Akbarzadeh, T. and Shams-Ardekani, M.R. 2016. An evidence-based review on medicinal plants used as insecticide and insect repellent in traditional Iranian medicine. *Iran Red Crescent Medical Journal*, 18(2): e22361.
- Plata-Rueda, A., Martínez, L.C., Santos, M.H. Dos, Fernandes, F.L., Wilcken, C.F., Soares, M.A., Serrão, J.E. and Zanuncio, J.C. 2017. Insecticidal activity of garlic essential oil and their constituents against the mealworm beetle, *Tenebrio molitor* Linnaeus (Coleoptera: Tenebrionidae). *Scientific Reports*, 7:46406.
- Reineke, A. and Thiéry, D. 2016. Grapevine insect pests and their natural enemies in the age of global warming. *Journal of Pest Science*, 89:313-328.
- Rotolo, C., De Miccolis Angelini, R.M., Dongiovanni, C., Pollastro, S., Fumarola, G., Di Carolo, M., Perrelli, D., Natale, P. and Faretra, F. 2018. Use of biocontrol agents and botanicals in integrated management of *Botrytis cinerea* in table grape vineyards. *Pest Management Science*, 74: 715–725.
- Salifu, B., Atongi, A.A. and Yeboah, S. 2019. Efficacy of spring onion (*Allium fistulosum*) leaf extract for controlling major field insect pests of cowpea (*Vigna unguiculata* L.) in the guinea savannah Agroecological zone of Ghana. *Journal of Entomology and Zoology Studies*, 7(1): 730–733.
- Sarwar, M., 2013. The Inhibitory Properties of Organic Pest Control Agents against Aphid (Aphididae: Homoptera) on Canola *Brassica napus* L. (Brassicaceae) Under Field Environment. *International Journal of Scientific Research in Environmental Sciences*, 1, 195–201.
- Schulze-Sylvester, M., Corronca, J.A. and Paris, C.I. 2021. Vine mealybugs disrupt biomass allocation in grapevine. *Oeno One*, 1:93-103

- Tembo, L., Fatima, K., Lovejoy, T. and Wisdom, K. 2015. Efficacy of Garlic (*Allium sativum*) and Red Chilli Pepper (*Capsicum annum*) Extracts in the Control of Red Spider Mite (*Tetranychus urticae*) in Tomatoes (*Lycopersicon esculentum*). *Asian Journal of Applied Sciences*, 3(1).
- van Lenteren, J.C., Bolckmans, K., Köhl, J., Ravensberg, W.J., Urbaneja, A. 2018. Biological control using invertebrates and microorganisms: plenty of new opportunities. *BioControl*, 63: 39–59.
- Yadav, A., Tyagi, S., Gupta, M. and Khanna, S. 2019. Current status of grapevine Leafroll disease on wine grape (*Vitis vinifera* L.) Cultivar in India. *International Journal of Chemical Studies*, 7(3): 911-918.

CHAPTER TWO: LITERATURE REVIEW

This chapter has been submitted for possible publication in the Journal of Medicinal Plants for Economic Development.

Planococcus ficus Ben-Dov (vine mealybug) is an economically important pest that causes significant damage to grapevines. The insect has evolved different strategies of escaping synthetic insecticides. However, the high diffusibility and cuticular penetration of plant-based insecticides have rendered these survival strategies ineffective, thereby predisposing insects to early mortality. This study reviewed the literature on plant-based products screened for pest-repellent and insecticidal properties, with a view to exploiting their biogenic principles to minimise agricultural losses from vine mealybug infestation. Related publications were sourced from Google Scholar, ScienceDirect and Web of Science databases using relevant keywords. Eligibility of the articles selected for review was based on titles and abstracts, methods and materials, language (English) and year of publication (2012 to 2025). A total of 103 scientific articles published in English in peer-reviewed journals, three conference papers, one book chapter and seven websites were used for the review. Articles with restricted access and incomplete information were excluded. The literature suggests that plant-based chemicals from *Azadirachta indica*, *Citrus aurantium*, *Eucalyptus camaldulensis*, *Calotropis procera*, *Cardamine hirsute*, and *Terminalia chebula*, which exhibit a wide range of proven insecticidal properties, could be exploited to control mealybug infestations. The development of new formulations from botanical ingredients with proven insecticidal properties will benefit grapevine farmers as they seek to overcome pest resistance and expand profit margins for small-scale and commercial farmers. Botanical pesticides are viable options for controlling the grapevine mealybug population to prevent depletion of agricultural production.

Keywords: Botanical insecticides; grapevine diseases; *Planococcus ficus*; pest management; synthetic insecticides

2.1 Introduction

Planococcus ficus Ben-Dov (vine mealybug), belonging to the family Pseudococcidae, is an economically important pest in global grape-growing regions, including South Africa, Australia and Argentina (Cocco et al., 2021). The significance of damage caused by the vine mealybug (VMB) to grapevines cannot be underestimated, as the pest sucks and pierces the phloem tissue of grapevines, causing diversion of nutrients otherwise required for flowering and fruit production (Timm and Reineke, 2014; Ahmed et al., 2023). While feeding on grapevines, the pest excretes honeydew on the leaves, which enhances the growth of sooty mould fungi on grape clusters, which compromises the fruit quality as the grape clusters become dehydrated (Mansour et al., 2018; Cocco et al., 2021). In addition, vine mealybug has been identified as a vector for grapevine leaf-roll-associated virus 3 (GLRaV-3), which reduces photosynthesis by at least 65%, leading to reduced girth of stems and root growth (Almeida et al., 2013; Bertin et al., 2016).

Several conventional strategies of controlling vine mealybug depend mainly on insecticidal chemicals, which kill the nymph and adult insects (Franco et al., 2009). Synthetic insecticides can either be applied directly to control VMB populations or used in conjunction with semiochemicals such as sex pheromones for purposes including monitoring, mass trapping, mating disruption, and kairomonal attraction to enhance the performance of natural parasitoids (Mansour et al., 2018). However, synthetic insecticides have adverse effects on human health, the environment, and other non-target organisms. These negative effects, along with the development of insect resistance, often resulting from the repeated or excessive use of insecticides from the same chemical family, have led to the search for safer and more sustainable alternative approaches (Pu and Chung, 2024).

The adverse effects attributed to the application of synthetic insecticides sparked the rising demand for sustainable pest management options for vine mealybug to minimise loss and optimise yield quality (Khan and Ahmad, 2019). These approaches may include chemical and biological control and other integrated pest management (IPM) techniques involving prophylactic and cultural practices, specialised encyrtid parasitoids, coccinellid predators, and the application of semi-chemicals in various pheromone-mediated pest management practices. Despite their proven insecticidal potential, entomopathogens and natural products are not yet widely adopted (Baker et al., 2020).

The use of crude extracts and essential oils from plants as botanical insecticides is a promising alternative for managing grapevine diseases. Several studies have profiled the toxicity of plant extracts against different pests to evaluate the insecticidal properties of the plant species and propagate their potential use as botanical insecticides (Arokiyaraj et al., 2022). This approach utilises secondary metabolites from plants such as phenolic acids, terpenoids, alkaloids, saponins, tannins and flavonoids. These plant-based biologically active chemicals have shown efficacy against VMB through repellence and other defence mechanisms, including inhibition of the insect's acetylcholinesterase and antifeedant activities (Peschiutta et al., 2018).

The effectiveness of botanical insecticides in controlling insect populations can vary depending on the physiological characteristics of the target pest, the type of plant materials used, the chemical properties of the plant materials and their modes of action (Grdiša et al., 2013). While the availability of effective commercial plant-based products remains limited amid increasing global demand, some botanical insecticides, such as neem and pyrethrins, are already registered and commercially available in the agricultural market (Acheuk et al., 2022). This article aimed to systematically review the published literature on plant extracts evaluated for insecticidal and repellent properties against a wide range of pests, with a view to exploiting their biogenic principles to minimise agricultural losses from vine mealybug infestation.

2.2 Materials and methods

2.2.1 Data collection

Google Scholar, ScienceDirect and Web of Science databases were used to identify related publications to the topic under review from 2012 to 2025. The following keywords and phrases were searched: “botanicals against *Planococcus ficus*”, “chemical insecticides for vineyard management”, “bioinsecticides”, “plant-based insecticides”, “bioinsecticides and their mode of action”, “plant-derived insecticides against *Planococcus ficus*”, “repellent activities of plant extracts”, “insecticidal plants”, “botanical insecticide”. A total of 103 scientific articles published in English in peer-reviewed journals, three conference papers, one book chapter and seven websites were used to gather data. Articles with restricted access and incomplete information were excluded. The articles eligible for this review were those published from 2012-2025, based on the title and abstract, and on the methods and materials used to determine the plant parts used and the type of extraction method. The review focused on the global scale of plant extracts used against pests and the commercial products developed from them.

2.3 Toxic plants against a range of pests

Plant materials have demonstrated toxicity against a range of pests when applied to reduce losses and damage before and post-harvest. Most targeted parts of the plant include leaves, roots, flower buds and stem bark (Costa et al., 2025; Isman, 2020). The crude extracts, pure compounds, and essential oils extracted from different plant parts largely constitute these plant-based chemicals, which exhibit different gradients of selective mortality and antifeedant effects on insects by disrupting their behaviour, causing larvicidal effects, or inhibiting gustatory responses. A list of plants tested against a wide range of pests is presented in Table 1, while Table 2 shows selected plants tested for insecticidal activity against mealybug species.

Aromatic plants such as *Mentha* spp., *Lavendula* spp., *Cedrus* spp., *Pinus* spp., *Eucalyptus* spp., *A. indica*, and *Citronella* spp. and many more are depots of repellent and insecticidal chemicals. The repellency and insecticidal properties of extracts from these plants may be attributed to the characteristic permeation of insect exoskeleton, crevices and other materials that may act as shields to synthetic insecticides (Chandi and Kaur, 2021). The insecticidal mechanisms of plant extracts, such as pyrethrum extracts, may include hyper-activating insect voltage-gated sodium channels, which could result in insect paralysis and death (Liu et al., 2021). In some cases, phytochemicals and essential oils from plants may act as chitin synthesis inhibitors by blocking the development of chitinous exoskeleton, making insects susceptible to early mortality due to indiscriminate interference with insect hormones during moulting (Chandi and Kaur, 2021). The insect repellent activities of volatile compounds from plants have been demonstrated to involve receptor proteins at several binding sites that enable the transformation of chemical signals into electrical signals, which are then picked up by electroantennographic recordings during receptor-repellent interactions (Portilla Pulido et al., 2022). Pulido et al. (2022) further demonstrated in proteomic and electrophysiological experiments that repellent exposure disrupts ionic channel activity and modifies neuronal synapses and energy production processes in mosquitoes. Repellents may interfere with or mask the perception of host-attractant signals by exciting repulsion receptors (Liu et al., 2021)

Table 2. 1: Toxic plants used against a range of pests

Plant	Family	Plant parts used	Extraction method	Solvent used	Pests	Reference
<i>Senegalia modesta</i>	Fabaceae	Whole plant (stem + bark, root, leaves and seeds)	Maceration	Water	<i>Tribolium castaneum</i>	(Nazeefullah et al., 2014)
<i>Glycyrrhiza glabra</i>	Fabaceae	Whole plants (rhizome, leaves and stem)	Maceration	Water	<i>Tribolium castaneum</i>	(Nazeefullah et al., 2014)
<i>Daphne mucronate</i>	Thymelaeaceae	No specified	Maceration	Methanol	<i>Acyrtosiphon pisum</i> <i>Drosophila melanogaster</i> <i>Tribolium castaneum</i> <i>Spodoptera exigua</i>	(Guru-Pirasanna-Pandi et al., 2018)
<i>Tagetes minuta</i>	Asteraceae	Not specified	Maceration	Methanol	<i>Acyrtosiphon pisum</i> <i>Drosophila melanogaster</i> <i>Tribolium castaneum</i> <i>Spodoptera exigua</i>	(Khan et al., 2017)
<i>Calotropis procera</i>	Apocynaceae	Not specified	Maceration	Methanol	<i>Acyrtosiphon pisum</i>	(Khan et al., 2017)

					<i>Drosophila melanogaster</i> <i>Tribolium castaneum</i> <i>Spodoptera exigua</i>	
<i>Boenninghausenia Albiflora</i>	Rutaceae	Not specified	Maceration	Methanol	<i>Acyrtosiphon pisum</i> <i>Drosophila melanogaster</i> <i>Tribolium castaneum</i> <i>Spodoptera exigua</i>	(Khan et al., 2017)
<i>Eucalyptus sideroxylon</i>	Myrtaceae	Not specified	Maceration	Methanol	<i>Acyrtosiphon pisum</i> <i>Drosophila melanogaster</i> <i>Tribolium castaneum</i> <i>Spodoptera exigua</i>	(Khan et al., 2017)
<i>Cinnamomum camphora</i>	Lauraceae	Not specified	Maceration	Methanol	<i>Acyrtosiphon pisum</i> <i>Drosophila melanogaster</i> <i>Tribolium castaneum</i> <i>Spodoptera exigua</i>	(Khan et al., 2017)
<i>Isodon rugosus</i>	Lamiaceae	Not specified	Maceration	Methanol	<i>Acyrtosiphon pisum</i> <i>Drosophila melanogaster</i> <i>Tribolium castaneum</i>	(Khan et al., 2017)

					<i>Spodoptera exigua</i>	
<i>Cleistanthus collinus</i>	Phyllanthaceae	Leaves	Soxhlet apparatus	Acetone	<i>Tribolium castaneum</i>	(Guru-Pirasanna-Pandi et al., 2018)
<i>Peganum harmala</i>	Zygophyllaceae	Seed	Maceration	Acetone	<i>Tribolium castaneum</i> , <i>Aphis fabae</i> , <i>Aphis gossypii</i> , <i>Aphis nerii</i> and <i>Myzus persicae</i>	(Salari et al., 2012)
<i>Urtica dioica</i>	Urticaceae	Aerial parts	Maceration	Methanol	<i>Aphis gossypii</i> <i>Phenacoccus solenopsis</i>	(Eldesouky et al., 2024)
<i>Pluchea dioscoridis</i>	Asteraceae	Aerial parts	Maceration	Methanol	<i>Aphis gossypii</i> <i>Phenacoccus solenopsis</i>	(Eldesouky et al., 2024)
<i>Xanthium strumarium</i>	Asteraceae	Aerial parts	Maceration	Methanol	<i>Aphis gossypii</i> <i>Phenacoccus Solenopsis</i>	(Eldesouky et al., 2024)
<i>Hyoscyamus albus</i>	Solanaceae	Aerial parts	Maceration	Methanol	<i>Aphis gossypii</i> , <i>Phenacoccus solenopsis</i>	(Eldesouky et al., 2024)
<i>Justicia adhatoda</i>	Acanthaceae	Leaves	Decoction	Distilled water	<i>Phenacoccus solenopsis</i>	(Madasamy et al., 2023)
<i>Ipomea carnea</i>	Convolvulaceae	Leaves	Decoction	Distilled water	<i>Phenacoccus solenopsis</i>	(Madasamy et al., 2023)

<i>Pongamia glabra</i>	Fabaceae	Leaves	Decoction	Distilled water	<i>Phenacoccus solenopsis</i>	(Madasamy et al., 2023)
<i>Annona squamosa</i>	Annonaceae	Leaves	Decoction	Distilled water	<i>Phenacoccus solenopsis</i>	(Madasamy et al., 2023)
<i>Tithonia diversifolia</i>	Asteraceae	Leaves	Maceration	Water	<i>Aphis fabae</i> , <i>Oothea mutabilis</i> , <i>Oothea bennigseni</i> , <i>Epicauta albobittata</i> , <i>Epicauta limbatipennis</i>	(Mkenda et al., 2015)
<i>Tephrosia vogelii</i>	Fabaceae	Leaves	Maceration	Water	<i>Aphis fabae</i> , <i>Oothea mutabilis</i> , <i>Oothea bennigseni</i> , <i>Epicauta albobittata</i> , <i>Epicauta limbatipennis</i>	(Mkenda et al., 2015)
<i>Vernonia amygdalina</i>	Asteraceae	Leaves	Maceration	Water	<i>Aphis fabae</i> <i>Oothea mutabilis</i> <i>Oothea bennigseni</i> <i>Epicauta albobittata</i> <i>Epicauta limbatipennis</i>	(Mkenda et al., 2015)
<i>Lippia javanica</i>	Verbenaceae	Leaves	Maceration	Water	<i>Aphis fabae</i> <i>Oothea mutabilis</i> <i>Oothea bennigseni</i>	(Mkenda et al., 2015)

					<i>Epicauta albovittata</i> , <i>Epicauta limbatipennis</i>	
<i>Nicotiana megalosiphon</i>	Solanaceae	Leaves	Maceration	Tap water	<i>Plutella xylostella</i> <i>Brevicoryne brassicae</i> <i>Myzus persicae</i>	(Amoabeng et al., 2018)
<i>Mentha satureioides</i>	Lamiaceae	Leaves	Maceration	Tap water	<i>Plutella xylostella</i> <i>Brevicoryne brassicae</i> <i>Myzus persicae</i>	(Amoabeng et al., 2018)
<i>Azadirachta indica</i>	Meliaceae	Leaves	Maceration	Water	<i>Spodoptera frugiperda</i>	(Phambala et al., 2020)
<i>Ocimum basilicum</i>	Lamiaceae	Leaves	Maceration	Water	<i>Spodoptera frugiperda</i>	(Phambala et al., 2020)
<i>Nicotiana tabacum</i>	Solanaceae	Leaves	Maceration	Water	<i>Spodoptera frugiperda</i>	(Phambala et al., 2020)
<i>Cymbopogon citratus</i>	Gramineae	Leaves	Maceration	Water	<i>Spodoptera frugiperda</i>	(Phambala et al., 2020)
<i>Tephrosia vogelii</i>	Fabaceae	Leaves	Maceration	Water	<i>Spodoptera frugiperda</i>	(Phambala et al., 2020)
<i>Aloe vera</i>	Asphodelaceae	Leaves	Maceration	Water	<i>Spodoptera frugiperda</i>	(Phambala et al., 2020)
<i>Lantana camara</i>	Verbenaceae	Leaves	Maceration	Water	<i>Spodoptera frugiperda</i>	(Phambala et al., 2020)

<i>Trichilia emetica</i>	Meliaceae	Leaves	Maceration	Water	<i>Spodoptera frugiperda</i>	(Phambala et al., 2020)
<i>Vernonia amygdalina</i>	Asteraceae	Leaves	Maceration	Water	<i>Spodoptera frugiperda</i>	(Phambala et al., 2020)
<i>Lippia javanica</i>	Verbenaceae	Leaves	Maceration	Water	<i>Spodoptera frugiperda</i>	(Phambala et al., 2020)
<i>Syzygium cumini</i>	Myrtaceae	Peel and seed	Maceration	Ethanol	<i>Tribolium confusum</i>	(Zaka et al., 2019)
<i>Citrus reticulata</i>	Rutaceae	Peel and seed	Maceration	Ethanol	<i>Tribolium confusum</i>	(Zaka et al., 2019)
<i>Lantana camara</i>	Verbenaceae	Leaves	Maceration	Water	<i>Spodoptera exigua</i>	(Asad et al., 2023)
<i>Aloe vera</i>	Asphodelaceae	Leaves	Maceration	Water	<i>Spodoptera exigua</i>	(Asad et al., 2023)
<i>Azadirachta Indica</i>	Meliaceae	Leaves	Maceration	Water	<i>Spodoptera exigua</i>	(Asad et al., 2023)
<i>Cymbopogon citratus</i>	Poaceae	Leaves	Maceration	Water	<i>Spodoptera exigua</i>	(Asad et al., 2023)
<i>Nicotiana tabacum</i>	Solanaceae	Leaves	Maceration	Water	<i>Spodoptera exigua</i>	(Asad et al., 2023)
<i>Ocimum basilicum</i>	Lamiaceae	Leaves	Maceration	Water	<i>Spodoptera exigua</i>	(Asad et al., 2023)
<i>Saponaria officinalis</i>	Caryophyllaceae	Roots	Maceration	Drinkable water	<i>Tetranychus urticae</i>	(Pavela, 2017)
<i>Azadirachta indica</i>	Meliaceae	Seed kernel	Maceration	Water	<i>Mythimna separate</i>	(Kumar et al., 2017)
<i>Artemisia annua</i>	Asteraceae	Leaves	Maceration	Water	<i>Mythimna separate</i>	(Kumar et al., 2017)
<i>Anthemis cotula</i>	Asteraceae	Leaves	Maceration	Water	<i>Mythimna separate</i>	(Kumar et al., 2017)
<i>Datura stramonium</i>	Solanaceae	Leaves	Maceration	Water	<i>Mythimna separate</i>	(Kumar et al., 2017)
<i>Zingiber officinale</i>	Zingiberaceae	Rhizome	Maceration	Water	<i>Mythimna separate</i>	(Kumar et al., 2017)

<i>Juglans regia</i>	Juglandaceae	Leaves	Maceration	Water	<i>Mythimna separate</i>	(Kumar et al., 2017)
<i>Allium sativum</i>	Amaryllidaceae	Bulb	Maceration	Distilled water	<i>Plutella xylostella</i> , <i>Brevicoryne brassicae</i> , <i>Hellula undalis</i> , <i>Trichoplusia ni</i>	(Baidoo and Mochiah, 2016)
<i>Capsicum frutescens</i>	Solanaceae	Fruit	Maceration	Distilled water	<i>Brevicoryne brassicae</i> , <i>Hellula undalis</i> , <i>Trichoplusia ni</i>	(Baidoo and Mochiah, 2016)
<i>Thevetia peruviana</i>	Apocynaceae	Seeds	Maceration	Aqueous	<i>Sahlbergella singularis</i>	(Mboussi et al., 2018)
<i>Azadirachta indica</i>	Meliaceae	Seeds	Maceration	Aqueous	<i>Sahlbergella singularis</i>	(Mboussi et al., 2018)

Table 2. 2: Selected plants tested for insecticidal activity against mealybug species

Scientific name	Botanical family	Solvent used	Mealybug species	Activity	Reference
<i>Azadirachta indica</i>	Meliaceae	Water, Ethanol, Acetone	<i>Drosicha mangiferae</i>	Mortality	(Majeed et al., 2018)
<i>Citrus aurantium</i>	Rutaceae	Water, Ethanol, Acetone	<i>Drosicha mangiferae</i>	Mortality	(Majeed et al., 2018)
<i>Citrus sinensis</i>	Rutaceae	Water, Ethanol, Acetone	<i>Drosicha mangiferae</i>	Mortality	(Majeed et al., 2018)
<i>Eucalyptus camaldulensis</i>	Myrtaceae	Water, Ethanol, Acetone	<i>Drosicha mangiferae</i>	Mortality	(Majeed et al., 2018)
<i>Azadirachta indica</i>	Meliaceae	n-Hexane, Acetone, Water	<i>Phenacoccus solenopsis</i>	Mortality	(Badshah et al., 2015)
<i>Azadirachta indica</i>	Meliaceae	Water	<i>Phenacoccus solenopsis</i>	Mortality	(Mamoon-Ur-Rashid et al., 2016)
<i>Azadirachta indica</i>	Meliaceae	Distilled water	<i>Phenacoccus solenopsis</i>	Mortality	(Sardar et al., 2018)

<i>Calotropis procera</i>	Asclepiadaceae	Distilled water	<i>Phenacoccus solenopsis</i>	Mortality	(Sardar et al., 2018)
<i>Cardamine hirsute</i>	Cardamine	Distilled water	<i>Phenacoccus solenopsis</i>	Mortality	(Sardar et al., 2018)
<i>Trachyspermum ammi</i>	Apiaceae	Distilled water	<i>Phenacoccus solenopsis</i>	Mortality	(Sardar et al., 2018)
<i>Terminalia chebula</i>	Terminalia	Distilled water	<i>Phenacoccus solenopsis</i>	Mortality	(Sardar et al., 2018)
<i>Allium sativum</i>	Amaryllidaceae	Distilled water	<i>Phenacoccus solenopsis</i>	Mortality	(Sardar et al., 2018)
<i>Azadirachta indica</i>	Meliaceae	Distilled water	<i>Drosicha mangiferae</i>	Mortality	(Rizwan et al., 2022)
<i>Eucalyptus camaldulensis</i>	Myrtaceae	Distilled water	<i>Drosicha mangiferae</i>	Mortality	(Rizwan et al., 2022)
<i>Datura stramonium</i>	Solanaceae	Distilled water	<i>Drosicha mangiferae</i>	Mortality	(Rizwan et al., 2022)
<i>Chenopodium album</i>	Amaranthaceae	Distilled water	<i>Drosicha mangiferae</i>	Mortality	(Rizwan et al., 2022)
<i>Cymbopogon citratus</i>	Poaceae	Distilled water	<i>Drosicha mangiferae</i>	Mortality	(Rizwan et al., 2022)
<i>Azadirachta indica</i>	Meliaceae	Distilled water	<i>Rastrococcus invadens</i>	Mortality	(Seye et al., 2022)
<i>Azadirachta indica</i>	Meliaceae	Ethanol	<i>Phenacoccus solenopsis</i>	Mortality	(Arif et al., 2015)
<i>Nicotiana tabacum</i>	Solanaceae	Ethanol	<i>Phenacoccus solenopsis</i>	Mortality	(Arif et al., 2015)
<i>Azadirachta indica</i>	Meliaceae	Methanol	<i>Dysmicoccus brevipes</i>	Mortality	(Talib et al., 2023)
<i>Phaleria macrocarpa</i>	Thymelaeaceae	Methanol	<i>Dysmicoccus brevipes</i>	Mortality	(Talib et al., 2023)
<i>Andrographis paniculata</i>	Acanthaceae	Methanol, Ethanol	<i>Phenacoccus solenopsis</i>	Mortality	(Bala et al., 2019b)
<i>Eucalyptus globulus</i>	Myrtaceae	Methanol, Ethanol	<i>Phenacoccus solenopsis</i>	Mortality	(Bala et al., 2019b)
<i>Calotropis gigantea</i>	Apocynaceae	Distilled water	<i>Maconellicoccus hirsutus</i>	Mortality	(Devi et al., 2018)
<i>Ocimum sanctum</i>	Lamiaceae	Distilled water	<i>Phenacoccus solenopsis</i> <i>Paracoccus marginatus</i>	Mortality	(Kadanakuppe Thammayya et al., 2024)
<i>Andrographis paniculata</i>	Acanthaceae	Distilled water	<i>Phenacoccus solenopsis</i>	Mortality	(Kadanakuppe Thammayya et al., 2024)

			<i>Paracoccus marginatus</i>		
<i>Annona squamosa</i>	Annonaceae	Distilled water	<i>Phenacoccus solenopsis</i> <i>Paracoccus marginatus</i>	Mortality	(Kadanakuppe Thammayya et al., 2024)
<i>Adathoda vasica</i>	Acanthaceae	Ethanol, Water	<i>Maconellicoccus hirsutus</i>	Mortality	(Mohamed et al., 2021)
<i>Trigonella foenum–Graecum</i>	Fabaceae	Ethanol Water	<i>Maconellicoccus hirsutus</i>	Mortality	(Mohamed et al., 2021)
<i>Eucalyptus Camaldulensis</i>	Myrtaceae	Ethanol	<i>Planococcus citri</i>	Mortality	(Bajwa et al., 2020)
<i>Azadirachta indica</i>	Meliaceae	Ethanol	<i>Planococcus citri</i>	Mortality	(Bajwa et al., 2020)
<i>Zingiber officinale</i>	Zingiberaceae	Ethanol	<i>Planococcus citri</i>	Mortality	(Bajwa et al., 2020)
<i>Allium sativum</i>	Amaryllidaceae	Ethanol	<i>Planococcus citri</i>	Mortality	(Bajwa et al., 2020)
<i>Tectona grandis</i>	Lamiaceae	Ethanol, Methanol	<i>Phenacoccus manihoti</i>		(Pumnuan et al., 2021)
<i>Allium sativum</i>	Amaryllidaceae	Methanol	<i>Pseudococcus viburni</i> Signoret	Mortality	(Ramzi et al., 2022)
<i>Gliricidia sp.</i>	Fabaceae	Ethanol	<i>Planococcus citrii</i>	Mortality	(Tintumol et al., 2022)
<i>Ocimum sanctum</i>	Lamiaceae	Ethanol	<i>Planococcus citrii</i>	Mortality	Tintumol et al., 2022)
<i>Capsicum frutescence</i>	Solanaceae	Ethanol	<i>Planococcus citrii</i>	Mortality	(Tintumol et al., 2022)
<i>Elaeagnus latifolia</i>	Elaeagnaceae	Water, Ethanol, Hexane	<i>Phenacoccus manihoti</i>	Mortality	(Pumnuan et al., 2019)
<i>Capsicum frutescens</i>	Solanaceae	Ethanol	<i>Ferrisia virgata</i>	Mortality	(Roddee et al., 2020)
<i>Allium sativum</i>	Amaryllidaceae	Ethanol	<i>Ferrisia virgata</i>	Mortality	(Roddee et al., 2020)
<i>Piper nigrum</i>	Piperaceae	Ethanol	<i>Ferrisia virgata</i>	Mortality	(Roddee et al., 2020)
<i>Azadirachta indica</i>	Meliaceae	Ethanol	<i>Ferrisia virgata</i>	Mortality	(Roddee et al., 2020)
<i>Ageratum conyzoides</i>	Asteraceae	Ethanol	<i>Rastrococcus invadens</i>	Mortality	(Mano et al., 2023)
<i>Hyptis suaveolens</i>	Lamiaceae	Ethanol	<i>Rastrococcus invadens</i>	Mortality	(Mano et al., 2023)

2.4 Repellent plant extracts against mealybugs and other pest species

Compared to studies on insect mortality, relatively few investigations have focused on the repellency of plant extracts (Peschiutta et al., 2018). The repellent activity of botanical extracts largely depends on the methods of extraction and the type of solvent used (Jaleel et al., 2020). Several plant species, their extraction methods, and solvent types have been tested against various plant species (Table 2.3). In a study by Singh (2012) methanolic leaf extract of *A. indica*, *Eucalyptus globulus* and *Ocimum basilicum* showed 97.0%, 93.0%, and 88.0% repellency, respectively, against cotton mealybug (*Phenacoccus solenopsis*) after 24 hours. The repellent effect was attributed to active compounds in these plants. For example, the bioactive alkaloid azadirachtin and other tetranortriterpenoids found in *A. indica* are responsible for its strong repellency (Guchhait et al., 2025). Similarly, Sombra et al. (2022) reported that compounds such as alkaloids, phenols, and esters may act at multiple sites within insect physiology, exhibiting biocidal, repellent, antifeedant, and developmental disruption activities.

Several plants, including *Azadirachta indica*, *Eucalyptus globulus*, *Prunus persica*, and *Polyalthia longifolia*, have been reported to exhibit significant repellency against mealybugs (Peschiutta et al., 2018). In another study, Baliyarsingh et al. (2021) reported high repellency of leaf extracts of *Andrographis paniculata* against *Tribolium castaneum* (red flour beetle). In addition, Roonjho et al. (2013) tested the toxicity and repellency of different solvent extracts (petroleum ether, ethanol and acetone) of *Prunus persica*, *Sonchus oleraceus*, *Silybum marianum*, *Polyalthia longifolia* and *Eucalyptus globulus* against cotton mealybug. Findings from the study indicated that the ethanol extract of *P. persica* exerted 72.5% repellency against the cotton pest while other plant extracts exhibited lower repellency compared to *P. persica*.

Table 2. 3: Repellent plants against mealybugs and other pests

Scientific name	Family	Plant parts	Extraction method	Solvents used	Pest species	Reference
<i>Psidium guajava</i>	Myrtaceae	Leaves	Maceration	Ethanol	<i>Sitophilus oryzae</i>	(Akhtar et al., 2013)
<i>Citrus reticulata</i>	Rutaceae	Fruit peel	Maceration	Ethanol	<i>Sitophilus oryzae</i>	(Akhtar et al., 2013)
<i>Citrus limon</i>	Rutaceae	Fruit peel	Maceration	Ethanol	<i>Sitophilus oryzae</i>	(Akhtar et al., 2013)
<i>Citrus sinensis</i>	Rutaceae	Fruit peel	Maceration	Ethanol	<i>Sitophilus oryzae</i>	(Akhtar et al., 2013)
<i>Azadirachta indica</i>	Meliaceae	Leaves	Maceration	Ethanol	<i>Sitophilus oryzae</i>	(Akhtar et al., 2013)
<i>Azadirachta indica</i>	Meliaceae	Seeds	Maceration	Water	Sugarcane mealybug	(Miah et al., 2018)
<i>Azadirachta indica</i>	Meliaceae	Seeds	Maceration	Acetone	<i>Bactrocera dorsalis</i> <i>Bactrocera correcta</i>	(Jaleel et al., 2020)
<i>Piper nigrum</i>	Piperaceae	Seeds	Maceration	Acetone	<i>Bactrocera dorsalis</i> <i>Bactrocera correcta</i>	(Jaleel et al., 2020)
<i>Seriphidium brevifolium</i>	Asteraceae	Seeds	Maceration	Acetone	<i>Bactrocera dorsalis</i> <i>Bactrocera correcta</i>	(Jaleel et al., 2020)
<i>Peganum harmala</i>	Meliaceae	Seeds	Maceration	Acetone	<i>Myzus persicae</i>	(Salari et al., 2012)
<i>Toona sureni</i>	Meliaceae	Seeds	Maceration	Methanol	<i>Tribolium castaneum</i>	(Parvin et al., 2012)
<i>Adathoda vassica</i>	Acanthaceae	Leaves	Soxhlet method	Ethyl acetate	<i>Spodoptera frugiperda</i>	(Henagamage et al., 2023)
<i>Datura metel</i>	Solanaceae	Leaves	Soxhlet method	Ethyl acetate	<i>Spodoptera frugiperda</i>	(Henagamage et al., 2023)
<i>Tagetes erecta</i>	Asteraceae	Leaves	Soxhlet method	Ethyl acetate	<i>Spodoptera frugiperda</i>	(Henagamage et al., 2023)
<i>Urtica dioica</i>	Urticaceae	Aerial parts	Maceration	Methanol	<i>Aphis gossypii</i> <i>Phenacoccus solenopsis</i>	(Eldesouky et al., 2024)

<i>Hyoscyamus albus</i>	Solanaceae	Aerial parts	Maceration	Methanol	<i>Aphis gossypii</i> <i>Phenacoccus solenopsis</i>	(Eldesouky et al., 2024)
<i>Pluchea dioscoridis</i>	Asteraceae	Aerial parts	Maceration	Methanol	<i>Aphis gossypii</i>	(Eldesouky et al., 2024)
<i>Xanthium strumarium</i>	Asteraceae	Aerial parts	Maceration	Methanol	<i>Phenacoccus solenopsis</i>	(Eldesouky et al., 2024)
<i>Andrographis paniculata</i>	Acanthaceae	Leaves	Soxhlet	Methanol, Ethanol	<i>Phenacoccus solenopsis</i>	(Bala et al., 2019b)
<i>Eucalyptus globulus</i>	Myrtaceae	Leaves	Soxhlet	Methanol, Ethanol	<i>Phenacoccus solenopsis</i>	(Bala et al., 2019b)
<i>Toddalia asiatica</i>	Rutaceae	Leaf and fruit	Maceration	Hexane, Diethyl ether, Methanol	<i>Callosobruchus maculatus</i> <i>Sitophilus oryzae</i> <i>Tribolium castaneum</i>	(Nattudurai et al., 2015)
<i>Eucalyptus globulus</i>	Myrtaceae	Leaves	Maceration	Acetone, Ethanol Petroleum ether	<i>Phenococcus solenopsis</i>	(Roonjho et al., 2013)
<i>Prunus persica</i>	Rosaceae	Leaves	Maceration	Acetone, Ethanol Petroleum ether	<i>Phenococcus solenopsis</i>	(Roonjho et al., 2013)
<i>Polyalthia longifolia</i>	Annonaceae	Leaves	Maceration	Acetone, Ethanol Petroleum ether	<i>Phenococcus solenopsis</i>	(Roonjho et al., 2013)
<i>Sonchus oleraceus</i>	Asteraceae	Leaves	Maceration	Acetone, Ethanol Petroleum ether	<i>Phenococcus solenopsis</i>	(Roonjho et al., 2013)
<i>Silybum marianum</i>	Asteraceae	Leaves	Maceration	Acetone, Ethanol Petroleum ether	<i>Phenococcus solenopsis</i>	(Roonjho et al., 2013)
<i>Nigella sativa</i>	Ranunculaceae	Seeds	Maceration	Acetone	<i>Tribolium castaneum</i>	(Sagheer et al., 2014)
<i>Syzygium aromaticum</i>	Myrtaceae	Flower buds	Maceration	Acetone	<i>Tribolium castaneum</i>	(Sagheer et al., 2014)
<i>Trachyspermum ammi</i>	Apiaceae	Seeds	Maceration	Acetone	<i>Tribolium castaneum</i>	(Sagheer et al., 2014)
<i>Caesalpinia bonducella</i>	Fabaceae	Leaves	Soxhlet	Methanol, Ethanol, Water	<i>Phenacoccus solenopsis</i>	(Bala et al., 2019a)

<i>Ocimum sanctum</i>	Lamiaceae	Leaves	Soxhlet	Methanol, Ethanol, Water	<i>Phenacoccus solenopsis</i>	(Bala et al., 2019a)
<i>Solanum torvum</i>	Solanaceae	Leaves	Soxhlet	Hexane, Ethyl acetate, Methanol	<i>Callosobruchus maculatus</i>	(Murugesan et al., 2021)
<i>Azadirachta indica</i>	Meliaceae	Not specified	Maceration	Acetone	<i>Tribolium castaneum</i>	(Khan et al., 2013)
<i>Eucalyptus globules</i>	Myrtaceae	Not specified	Maceration	Acetone	<i>Tribolium castaneum</i>	(Khan et al., 2013)
<i>Citrus limon</i>	Rutaceae	Not specified	Maceration	Acetone	<i>Tribolium castaneum</i>	(Khan et al., 2013)
<i>Allium sativum</i>	Amaryllidaceae	Not specified	Maceration	Acetone	<i>Tribolium castaneum</i>	(Khan et al., 2013)

2.5 Registered botanical insecticides and their mode of action

The main categories of botanical products include pyrethrum, rotenone, neem, and their essential oils (Sarwar, 2023). Among these, pyrethrum and neem are derived from plants that are widely used to produce some of the most commercially available botanical pesticides (Table 2.4). For example, rotenone is a flavonoid compound found in the roots of several plant species and is known for its insecticidal properties (Shivkumara et al., 2019). Nicotine, ryania and sabadilla are other plant-based insecticides with documented insecticidal potency; however, their mechanisms of action are not well understood (Campos et al., 2019; Peschiutta et al., 2019).

The potency of plant-derived insecticides is determined by different mechanisms which involve targeting biological systems, such as endocrine, nervous and respiratory systems, as well as homeostasis, including water regulation. In the nervous system, botanical insecticides target acetylcholinesterase, tyramine and octopamine receptors, sodium and γ -aminobutyric acid-gated chloride channels (Regnault-Roger et al., 2012). Unlike conventional insecticides, which typically rely on a single active ingredient, botanical insecticides leverage the synergistic effects of heterogeneous chemicals in plants, which influence both behavioural and physiological processes, providing a multifaceted mode of action. Their ability to interfere with insect physiology makes them a promising alternative that aligns with IPM (La Pergola et al., 2017).

Table 2. 4: Registered products of commercial use from plant-based pesticides

Trade name	Registration number	Active ingredient	Product description	Reference
NeemAzal	Reg. No. L7840 Act No. 36 of 1947	Azadirachtin	An azadirachtin-based botanical insecticide with antifeedant, repellent, and insect growth-regulating properties for controlling codling moth on apples and pears.	(Avima, 2025)
Bioneem	Reg. No. L6958 Act 36 of 1947	Azadirachtin	A growth regulator, anti-feedant, and insect repellent that disrupts the normal metabolic activity of insects.	(Biogrow https://biogrow.co.za/insecticide/)

Bio-neem	ACT / WET 36 / 1947 REG. No: L7039	Azadirachtin	Suitable for controlling leaf miners on potatoes and the snout beetle on apples and grapes	(Rovensa https://biogrow.co.za/insecticide/)
Biogrow Pyrol	Reg. No. L7062 Act 36 of 1947	Pyrethrin and canola oil	A broad-spectrum contact insecticide	(Biogrow https://biogrow.co.za/insecticide/)
Biogrow Vegol	Reg. No. L7061 Act No. 36 of 1947	Canola	Contact insecticide with ovicidal activity	(Green Houston, 2025)
Eco-neem	Not Applicable	Azadirachtin	Works in multiple ways, with the two main actions being suppression of insect appetite and restricting growth	(Eco organic garden, 2025)
Kannar KangroShield 100	Reg. No L7630 Act 36 of 1947	Canola Oil, garlic extract, Pyrethrin extract, and piperonyl butoxide	An organic broad-spectrum insecticide concentrated with contact and repellent action; used as a full cover spray for the control of insects	(Talborne Organic, 2022)
Kannar Kangar 931	Reg. L931 Act 36 of 1947	Canola Oil Garlic extract from Allium sativum	An organic broad-spectrum insecticide concentrate with contact and repellent action; used as a full cover spray for the control of insects	(Talborne Organic, 2022)
Kannar Pygar 932	Reg. No. L7146 Act 36 of 1947	Canola oil, garlic extract, and pyrethrin	An organic broad-spectrum insecticide concentrate with contact and repellent action; used as a full cover spray for the control of insects.	(Talborne Organic, 2022)
Bonide captain Jack's neem	EPA Reg. No. 70051-2- 4	Clarified Hydrophobic Extract of Neem oil	Neem Oil (3-in-1), insecticide, fungicide, miticide for organic gardening.	(Bonide, 2025)

oil concentrate				
-----------------	--	--	--	--

2.5.1 Pyrethrum

Pyrethrum, derived from the *Dalmatian pyrethrum* plant (*Tanacetum cinerariifolium* L.), contains six active ingredients known as pyrethrins, which are insecticidal esters. These are categorised into two groups, namely Pyrethrins I and Pyrethrins II. They are fast-acting and cause immediate “knockdown” paralysis in insects (Sarwar, 2023). Their neurotoxic mechanism of action involves blocking voltage-gated sodium channels in the insect nervous system, ultimately leading to paralysis and death upon contact, whether applied as a spray or powder (Chen et al., 2018; Sarwar, 2023). The insecticidal activity of the pyrethrins results from the synergistic action of the six ingredients. Pyrethrins are effective against a wide range of insect pests from various taxonomical orders. However, their moderate toxicity to mammals and non-target insect species limits their widespread application (Jeran et al., 2021).

2.5.2 Neem

Neem is the common name for *Azadirachta indica* Juss (Meliaceae), a tree native to the Indo-Pak subcontinent (Badshah et al., 2015). The tree contains several potent bioactive compounds, including azadirachtin, nimbin, meliantriol, desacetylnimbin, nimbidin, salannin, and desacetylsalannin. Over 100 chemical compounds have been identified from neem, with azadirachtin being the most effective among them. According to Jababu et al. (2016), Sarwar (2023), azadirachtin has two significant effects on insects. At the physiological level, it blocks the prothoracic gland from synthesising and discharging moulting hormones (ecdysteroids), which results in incomplete ecdysis in immature insects. In adult female insects, a similar mechanism results in sterility.

Neem exhibits multiple insecticidal properties, acting as an insect growth regulator, antifeedant, and sterilant. It also affects insect vigour, longevity, and fecundity. Neem has demonstrated effectiveness in controlling a wide range of agricultural insect pests. For example, a study reported by Majeed et al. (2018) that the neem extract was the most toxic against adult citrus mealybugs, whereas Ali et al. (2017) tested several plant extracts against sucking insect pests and found neem seed extract to be more effective compared to extracts from other plants.

2.5.3 Essential oils

Essential oils (EOs) are volatile hydrophobic compounds extracted from plants. These oils are highly concentrated heterogeneous mixtures of 20–60 compounds, though some contain over 300 different constituents (de Sousa et al., 2023). Typically, two or three compounds are generally available in significant proportions (20–70%), and these are primarily responsible for the biological activity (de Sousa et al., 2023). High variability and diverse complexity of aromatic mixtures of essential oils complicate the understanding of their mechanisms of action. This shifts attention to the study of individual compounds (Verdeguer et al., 2020). The toxicity and ability of the lipophilic compounds, essential oil, to penetrate the waxy cuticle of mealybugs and disrupt their physiological activities and morphological features make them more suitable than synthetic insecticides, which often encounter barriers when in contact with the waxy cuticle (Avila et al., 2023; Karamaouna et al., 2013).

2.5.4 Plant-based insecticides versus synthetic insecticides

Over the years, chemical insecticides have been used by farmers in controlling pest infestations to minimise pre- and post-harvest losses. These chemicals control pests but leave behind adverse effects such as food poisoning, environmental pollution, ozone layer depletion, pest resistance, mutations, and prolonged toxicity to non-target organisms and humans. In most cases, these chemicals cause severe injuries to critical human organs such as the liver, heart, kidneys, lungs and blood capillaries (Murugesan et al., 2021). For instance, pyrethroids, a prominent group of synthetic insecticides, have been classified as endocrine disruptors due to their antiprogestagenic properties, estrogenic activity and neurodevelopmental toxicity (Elser et al., 2022).

The persistence of chemical insecticides in the environment is of great concern to environmental biologists, as pest management has become a costly enterprise for organic farmers. The choice of plant-based biopesticides as alternatives to synthetic insecticides created a compelling need to screen the insecticidal properties of several plant materials (Seiber et al., 2014). Thus, it became necessary to invent efficient means of minimising the contamination of synthetic insecticides through microbial degradation, chemical oxidation and photooxidation (Gajendiran and Abraham, 2018). These approaches, coupled with the need to ensure human safety and safeguard the environment from chemical hazards, promoted the development and propagation of plant-based, eco-friendly chemicals that could be used as insecticides based on the pest management properties of novel compounds in the plants (Purkait et al., 2019).

The use of plant-based chemicals in pest management is supported by prominent epidemiological reports, including their biodegradability, reduced risk of toxicity to human and non-target organisms, and low resistance development by pests (Cantrell et al., 2012; Adetuyi et al., 2024). High diffusibility and cuticular penetration of phytochemical insecticides are enhanced by the polarity of solvents used for extraction and various antifeedant mechanisms, such as distortion of typical neurological function capable of perceiving chemical phagostimulants, interference of ribonucleic acid synthesis pathways or by stimulating specialised receptors for feeding inhibition ([Author/s in press] et al., 2023; Seiber et al., 2014).

2.6 The relationship between exposure time and concentration of plant-based insecticides

The exposure time and concentration of plant-based insecticides play a significant role in determining their efficacy. According to Peschiutta et al. (2018), exposure time plays a critical role in determining the effectiveness of botanical compounds. However, findings by Rajagopal et al. (2022) suggest that while the concentration of extracts significantly contributes to adult insect mortality, treatment duration may not always have a notable effect.

In contrast, several studies have reported that the efficacy of plant extracts generally increases with both higher concentrations and longer exposure periods (Badshah et al., 2015; Sardar et al., 2018; Ramzi et al., 2022). For instance, Badshah et al. (2015) found that after one-week exposure at 3% concentration, mortality rates were recorded at 100%, 97%, 88%, and 67% for neem seed n-hexane extract, neem seed acetone extract, neem oil, and neem seed water extract, respectively. At a lower concentration of 1%, the respective mortality rates decreased to 68%, 62%, 56% and 29%. Similarly, Sardar et al. (2018) observed that a 1% neem water extract resulted in a 21.66% mortality rate after 24 hours, which increased to 33.33% after 48 hours. These findings illustrate that both time and concentration can synergistically influence insect mortality. However, it is not always the case that an increase in the concentration of plant extracts increases the mortality rate.

The repellency and mortality rate increased proportionately with the concentration and time (Miah et al., 2018). According to Singh (2012), after 24 h of mealybug release, the methanolic extracts (*A. indica* leaf, *E. globules* leaf, and *O. basilicum* leaf extract) obtained the highest repellency of 97.0%, 93.0%, and 88.0%, respectively. However, Erdemir and Eler (2017)

reported that all the essential oils tested had a repellent activity in varying degrees, though the repellent activity was concentration and time-dependent.

2.7 Challenges of botanical pesticides

Despite a significant increase in academic publications recommending botanical insecticides as environment-friendly alternatives to synthetic pesticides, only a limited number of commercial products based on plant-derived pesticides are available. The preparation of these botanical formulations at the domestic level often requires basic technical skills, which may not be widely accessible (Ngegba et al., 2022; Tripathi, 2021). One major limitation to the commercialisation of botanical pesticides is the availability of plant materials in large and sustainable quantities. The cultivation of source plants is constrained by land-use competition with food crops, especially in regions experiencing increasing food production demands (Seiber et al., 2014).

2.8 Suggestions for future research

The study focuses only on a single insect species (vine mealybug) and a single exposure duration. Hence, future research could explore the long-term effects of these plant-based chemicals with extended exposure time on other insect species, especially close relatives of the vine mealybug. Additionally, it is imperative to investigate the mechanism of action of insecticidal properties of plant extracts to provide valuable insights for their application in integrated pest management strategies. Finally, it is crucial for researchers to continue innovating to promote the formulation of eco-friendly anti-insect chemicals. The studies reviewed used varied extraction and testing methods; however, very few focused on field experiments. Future research must develop stable and effective formulations for practical use.

2.9 Conclusion

Botanical pesticides are viable options for controlling the grapevine mealybug population to prevent depletion of agricultural production. The literature suggests that plant-based chemicals with a wide range of proven insecticidal properties could be exploited to control mealybug infestations. The benefits of botanical pesticides cannot be underestimated due to their high diffusibility and cuticular penetration, biodegradability, reduced risk of toxicity to humans and non-target organisms, and low resistance development by pests, which place phytochemical insecticides above synthetic chemicals. The development of new formulations

from botanical ingredients with proven insecticidal properties will be beneficial to grapevine farmers amidst the quest to overcome pest resistance, reduce pre- and post-harvest losses, and expand the profit margins in agricultural industries.

References

- Acheuk, F., Basiouni, S., Shehata, A.A., Dick, K., Hajri, H., Lasram, S., Yilmaz, M., Emekci, M., Tsiamis, G., Spona-Friedl, M., May-Simera, H., Eisenreich, W. and Ntougias, S. 2022. Status and prospects of botanical biopesticides in Europe and Mediterranean countries. *Biomolecules*, 12:311.
- Adetuyi, B.O., Olajide, P.A., Omowumi, O.S. and Adetunji, C.O. 2024. Application of Plant-Based Nanobiopesticides as Disinfectant. *Handbook of agricultural biotechnology*, 1:63-130.
- Ahmed, A.R., Apori, S.O. and Karim, A.A. 2023. Mealybug vectors: A review of their transmission of plant viruses and their management strategies. *AIMS Agriculture and Food*, 8(3): 736-761.
- Akhtar, M., Arshad, M., Raza, A.B.M., Chaudhary, M.I., Iram, N., Akhtar, N. and Mahmood, T. 2013. Repellent effects of certain plant extracts against rice weevil, *Sitophilus oryzae* L. (Coleoptera: Curculionidae). *International Journal of Agricultural Applied Science*, 5(1).
- Ali, S., Ullah, M.I., Arshad, M., Iftikhar, Y., Saqib, M. & Afzal, M. 2017. Effect of botanicals and synthetic insecticides on *Pieris brassicae* (L., 1758) (Lepidoptera: Pieridae). *Turkish Journal of Entomology*, 41(3): 275-284.
- Almeida, R.P.P., Daane, K.M., Bell, V.A., Blaisdell, G.K., Cooper, M.L., Herrbach, E. and Pietersen, G. 2013. Ecology and management of grapevine leafroll disease. *Frontiers in Microbiology*, 4(94).
- Amoabeng, B.W., Stevenson, P.C., Pandey, S., Mochiah, M.B. and Gurr, M.G. 2018. Insecticidal activity of a native Australian tobacco, *Nicotiana megalosiphon* Van Heurck & Muell. Arg. (Solanales: Solanaceae) against key insect pests of brassicas. *Crop Protection*, 106: 6-12.
- Arif, S., Rizvi, H., Ikhtlaq, M.N., Jaffar, S. and Hussain, S. 2015. Efficacy of some selected synthetic chemical insecticides and bio-pesticides against cotton mealybug, *Phenacoccus solenopsis* Tinsley (Sternorrhyncha: Pseudococcidae) under agroecological conditions of Peshawar, Pakistan. *Journal of Entomology and Zoology Studies*, 3(6): 223-231.
- Arokiyaraj, C., Bhattacharyya, K. and Reddy, S.G.E. 2022. Toxicity and synergistic activity of compounds from essential oils and their effect on detoxification enzymes against *Planococcus lilacinus*. *Frontiers in plant science*, 13: 1016737.
- Asad, M., Khan, R.R., Aljuboory, A.B., Rashid, M.H.U., Kumar, U., Haq, I.U., Hafeez, A., Noureldeen, A. and Alharbi, K. 2023. Toxic and antifeedant effects of different

- pesticidal plant extracts against beet. *Phyton-International Journal of Experimental Botany*, 92(4).
- Avila, M. del V., Achimón, F., Brito, V.D., Aguilar, R., Pizzolitto, R.P., Zunino, M.P. and Peschiutta, M.L. 2023. Insecticidal activity of essential oils against mealybug pests (Hemiptera: Pseudococcidae): A systematic review and meta-analysis, *Plants*, 12:109.
- Avima. 2025. Insecticides. <https://avima.co.za/products/> [17 April 2025].
- Badshah, H., Pakistan, P., Ullah, F., Farid, P. P.A., Crickmore, N., Farid, A. and Calatayud, P.A. 2015. Toxicity of neem seed *Azadirachta indica* Juss (Meliaceae) different solvent extracts against cotton mealybug *Phenacoccus solenopsis* Tinsley (Sternorrhyncha: Pseudococcidae) under laboratory conditions. *Journal of Entomology and Zoology Studies*, 3(4):45-49.
- Baidoo, P.K. and Mochiah, M.B. 2016. Comparing the effectiveness of garlic (*Allium sativum* L.) and hot pepper (*Capsicum frutescens* L.) in the management of the major pests of cabbage *Brassica oleracea* (L.). *Sustainable Agriculture Research*, 5(2).
- Bajwa, M.S., Tariq, M., Gulzar, A., Saeed, H. and Mashwani, Z. R. 2020. Toxicity of green silver nanoparticles of plant extracts against citrus mealybug *Planococcus citri*. *Plant Protection*, 4(1):1-10.
- Baker, B.P., Green, T.A. and Loker, A.J. 2020. Biological control and integrated pest management in organic and conventional systems. *Biological Control*, 140: 104095.
- Bala, K., Raja, A.G.B., Arivudainambi, S., and Aravinthraju, k. 2019a. Bio-efficacy of selected botanicals against cotton mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) in Okra. *The Pharma Innovation Journal*, 8(9):228-233.
- Bala, K., Raja, A.G.B., Arivudainambi, S., and Aravinthraju, k. 2019b. Efficacy of certain botanicals against cotton mealybug *Phenacoccus solenopsis* L. (Pseudococcidae: Hemiptera) on Okra. *Journal of Pharmacognosy and Phytochemistry*, 8(5): 1586-1591.
- Baliyarsingh, B., Mishra, A. and Rath, S. 2021. Evaluation of insecticidal and repellency activity of leaf extracts of *Andrographis paniculata* against *Tribolium castaneum* (red flour beetle). *International journal of tropical insect science*, 41: 765-773.
- Bertin, S., Pacifico, D., Cavalieri, V., Marzachi, C. and Bosco, D. 2016. Transmission of Grapevine virus A and Grapevine leafroll-associated viruses 1 and 3 by *Planococcus*

- ficus* and *Planococcus citri* fed on mixed-infected plants. *Annals of Applied Biology*, 169:53–63.
- Biogrow, n.d. Bioneem. <https://biogrow.co.za/product/bioneem/> [17 April 2025].
- Bonide, 2025. *Captain Jack's Neem Oil Concentrate*. <https://bonide.com/product/neem-oil-conc/> [17 April 2025].
- Campos, E.V.R., Proença, P.L.F., Oliveira, J.L., Bakshi, M., Abhilash, P.C. and Fraceto, L.F. 2019. Use of botanical insecticides for sustainable agriculture: future perspectives. *Ecological Indicators*, 105:483–495.
- Cantrell, C.L., Dayan, F.E. and Duke, S.O. 2012. Natural products as sources for new pesticides. *Journal of natural products*, 75(6): 1231-1242.
- Chandi, A.K. and Kaur, A. 2022. Hormone analogues and chitin synthesis inhibitors. In *Molecular Approaches for Sustainable Insect Pest Management*, 253-282).
- Chen, M., Du, Y., Zhu, G., Takamatsu, G., Ihara, M., Matsuda, K., Zhorov, B.S. and Dong, K. 2018. Action of six pyrethrins purified from the botanical insecticide pyrethrum on cockroach sodium channels expressed in *Xenopus* oocytes. *Pesticide Biochemistry and Physiology*, 151:82-89.
- Cocco, A., Pacheco da Silva, V.C., Benelli, G., Botton, M., Lucchi, A., Lentini, A. 2021. Sustainable management of the vine mealybug in organic vineyards. *Journal of Pest Science*, 94:153-185.
- Costa, L.T., Smaghe, G., Jumbo, L.O.V., Santos, G.R., Aguiar, R.W. and Oliveira, E.E. 2025. Selective actions of plant-based biorational insecticides: Molecular mechanisms and reduced risks to non-target organisms. *Current Opinion in Environmental Science & Health*, 44: 100601.
- de Sousa, D.P., Damasceno, R.O.S., Amorati, R., Elshabrawy, H.A., de Castro, R.D., Bezerra, D.P., Nunes, V.R.V., Gomes, R.C. and Lima, T.C. 2023. Essential oils: Chemistry and pharmacological activities. *Biomolecules*, 13(7):1144.
- Devi, N.I., Jeyarajan Nelson, S. and Kannan, M. 2018. Effect of *Calotropis gigantea* (L.) W.T. Aiton on pink mealybug, *Maconellicoccus hirsutus* (Green) (Hemiptera: Pseudococcidae). *Journal of Entomological Research*, 42(4):503–506.
- Eco Organic Garden, 2025. Eco-neem. <https://www.ecoorganicgarden.com.au/products/pest-disease/eco-neem/> [17 April 2025].

- Eldesouky, S.E., Tawfeek, M.E. and Salem, M.Z.M. 2024. The toxicity, repellent, and biochemical effects of four wild plant extracts against *Aphis gossypii* Glover and *Phenacoccus solenopsis* Tinsley: HPLC analysis of phenolic compounds. *Phytoparasitica*, 52:98.
- Elser, B.A., Hing, B. and Stevens, H.E. 2022. A narrative review of converging evidence addressing developmental toxicity of pyrethroid insecticides. *Critical reviews in toxicology*, 52(5):371-388.
- Erdemir, T. and Eler, F. 2017. Repellent, oviposition-deterrent and egg-hatching inhibitory effects of some plant essential oils against citrus mealybug, *Planococcus citri* Risso (Hemiptera: Pseudococcidae), *Journal of Plant Diseases and Protection*, 124:473-479.
- Franco, J.C., Zada, A. and Mendel, Z. 2009. Novel approaches for the management of mealybug pests. In *Biorational control of arthropod pests: application and resistance management*, 233-278). Dordrecht: Springer Netherlands.
- Gajendiran, A. and Abraham, J. 2018. An overview of pyrethroid insecticides. *Frontiers in Biology*, 13(2): 79-90.
- Grdiša, M., Babić, S., Periša, M., Carović-Stanko, K., Kolak, I., Liber, Z., Jug-Dujaković, M. and Satovic, Z. 2013. Chemical diversity of the natural populations of Dalmatian pyrethrum (*Tanacetum cinerariifolium* (Trevir.) Sch.Bip.) in Croatia. *Chemistry & Biodiversity*, 10(3):460–472.
- Green Houston, 2025. Product *Vegol*. <https://www.greenhouston.co.za/products/vegol-500ml> [17 April 2025].
- Guchhait, K.C., Dey, S., Das, A., Manna, T., Jana, D., Karmakar, M., Majumder, S., Panda, A.K. and Ghosh, C. 2025. Bioactive Alkaloids in *Azadirachta indica* Seed and Their Biological Activities. In *Natural Products: Phytochemistry, Botany, Metabolism of Alkaloids, Phenolics and Terpenes*, 1-25.
- Guru-Pirasanna-Pandi, G., Adak, T., Gowda, B., Patil, N., Annamalai, M. and Jena, M. 2018. Toxicological effect of underutilized plant, *Cleistanthus collinus* leaf extracts against two major stored grain pests, the rice weevil, *Sitophilus oryzae* and red flour beetle, *Tribolium castaneum*. *Ecotoxicology and Environmental Safety*, 154:92–99.
- Henagamage, A.P., Ranaweera, M.N., Peries, C.M. and Premetilake, M.M.S.N. 2023. Repellent, antifeedant and toxic effects of plants-extracts against *Spodoptera*

frugiperda larvae (fall armyworm). *Biocatalysis and agricultural biotechnology*, 48:102636.

- Isman, M.B. 2020. Botanical insecticides in the twenty-first century-fulfilling their promise?. *Annual Review of Entomology*, 65(1): 233-249.
- Jababu, N., Kopta, T. and Pokluda, R. 2016. Insecticidal activity of neem, pyrethrum and quassia extracts and their mixtures against diamondback moth larvae (*Plutella xylostella* L.). *Mendel net*. <https://mendelnet.cz/pdfs/mnt/2016/01/13.pdf> [15 January 2025].
- Jaleel, W., Wang, D., Lei, Y., Qi, G., Chen, T., Rizvi, S.A.H., Sethuraman, V., He, Y. and Lu, L. 2020. Evaluating the repellent effect of four botanicals against two *Bactrocera* species on mangoes. *PeerJ*, 8:e8537.
- Jeran, N., Grdiša, M., Varga, F., Šatović, Z., Liber, Z., Dabić, D. and Biošić, M. 2021. Pyrethrin from Dalmatian pyrethrum (*Tanacetum cinerariifolium* (Trevir.) Sch. Bip.): biosynthesis, biological activity, methods of extraction and determination. *Phytochemistry Reviews*, 20:875-905.
- Kadanakuppe Thammayya, S., Manikyanahalli Chandrashekara, K., Chinapolaiah, A., Ramesan Syamala, R., Kadukothanahalli Veerabhadraiah, S., Somanna Gotyal, B., Channappa, M., Casini, R., Mohamed Moussa, I., Elansary, H.O. and El-Sabrou, A.M. 2024. Comparative effectiveness of biorational pesticides for management of *Phenacoccus solenopsis* Tinsley and *Paracoccus marginatus* Williams & Granara de Willink in *Gymnema sylvestre* (Retz.) R.Br. ex Sm. *Heliyon*, 10:e23648
- Karamaouna, F., Kimbaris, A., Michaelakis, A., Papachristos, D., Polissiou, M., Papatsakona, P. and Tsora, E. 2013. Insecticidal activity of plant essential oils against the vine mealybug, *Planococcus ficus*. *Journal of Insect Science*, 13: 142.
- Khan, F.Z.A., Muhammad Sagheer, M.S., Mansoor-ul-Hasan, M.U.H., Shafqat Saeed, S.S., Kazam Ali, K.A., Gul, H.T., Bukhari, S.A. and Manzoor, S.A. 2013. Toxicological and repellent potential of some plant extracts against stored product insect pest, *Tribolium castaneum* (Herbst.) (Coleoptera: Tenebrionidae). *International Journal of Biosciences*, 3(9): 280-286.
- Khan, S., Taning, C.N.T., Bonneure, E., Mangelinckx, S., Smagghe, G. and Shah, M.M. 2017. Insecticidal activity of plant-derived extracts against different economically important pest insects. *Phytoparasitica*, 45:113-124.

- Khan, M.A. and Ahmad, W. 2019. Synthetic chemical insecticides: Environmental and agro contaminants. In *Microbes for Sustainable Insect Pest Management: An Eco-friendly Approach-Volume*, 1:1-22.
- Kumar, R., Ahad, I., Sheikh, A.A., Showkat, A., Arif, U. and Dorjey, S. 2017. Bioactive plant extracts an alternate to chemicals for management of armyworm infesting oats. *Int. J. Curr. Microbiol. App. Sci*, 6(12): 129-134.
- Liu, F., Wang, Q., Xu, P., Andrezza, F., Valbon, W.R., Bandason, E., Chen, M., Yan, R., Feng, B., Smith, L.B. and Scott, J.G. 2021. A dual-target molecular mechanism of pyrethrum repellency against mosquitoes. *Nature communications*, 12(1): 2553.
- La Pergola, A., Restuccia, C., Napoli, E., Bella, S., Brighina, S., Russo, A. and Suma, P. 2017. Commercial and wild Sicilian *Origanum vulgare* essential oils: chemical composition, antimicrobial activity and repellent effects. *Journal of Essential Oil Research*, 29(6):451–460.
- Madasamy, M., Sahayaraj, K., Sayed, S.M., Al-Shuraym, L.A., Selvaraj, P., El-Arnaouty, S.A. and Madasamy, K. 2023. Insecticidal mechanism of botanical crude extracts and their silver nanoliquids on *Phenacoccus solenopsis*. *Toxics*, 11:305.
- Majeed, M.Z., Nawaz, M.I., Khan, R.R., Farooq, U. and Ma, C.S. 2018. Insecticidal effects of acetone, ethanol and aqueous extracts of *Azadirachta indica* (A. Juss), *Citrus aurantium* (L.), *Citrus sinensis* (L.) and *Eucalyptus camaldulensis* (Dehnh.) against mealybugs (Hemiptera: Pseudococcidae). *Tropical and subtropical agroecosystems*, 21(3).
- Mamoon-Ur-Rashid, M., Jilani, M.S., Khan, Q., Hashim, M.M., Sayal, U., Khan, M.P., Latif, A., Waseem, K. and Nawaz, S. 2016. Evaluation of neem (*Azadirachta indica*) derivatives against jassids (*Emrasca devastans*) and cotton mealybug (*Phenacoccus solenopsis*), and side effects on the feeding potential of green lacewing (*Chrysoperla carnea*) on cotton aphid (*Aphis gossypii*), *Pakistan Journal of Zoology*, 48(6):1763-1768.
- Mansour, R., Belzunces, L.P., Suma, P., Zappalà, L., Mazzeo, G., Grissa-Lebdi, K., Russo, A. and Biondi, A. 2018. Vine and citrus mealybug pest control based on synthetic chemicals: A review. *Agronomy for Sustainable Development*, 38: 37.
- Mboussi, S.B., Ambang, Z., Kakam, S. and Bagny Beilhe, L. 2018. Control of cocoa mirids using aqueous extracts of *Thevetia peruviana* and *Azadirachta indica*. *Cogent Food & Agriculture*, 4(1): 1430470.

- Miah, M.N.A., Miah, M.R.U., Hossain, M.M. and Haque, M.E. 2018. Insecticidal effects of cattle urine and indigenous plant extracts against sugarcane mealybugs. *American Journal of Zoology*, 1(2): 35-39.
- Mkenda, P.A., Mwanauta, R.W., Stevenson, P.C., Ndakidemi, P.A., Mtei, K.M. and Belmain, S.R. 2015. Extracts from field margin weeds provide economically viable and environmentally benign pest control compared to synthetic pesticides. *PLoS ONE*, 10(11): e0143530.
- Murugesan, R., Vasuki, K., Kaleeswaran, B., Ramadevi, S. and Vasan, P.T. 2021. Environmentally benign *Solanum torvum* (Sw.) (Solanaceae) leaf extract in ecofriendly management of human disease vector, *Aedes aegypti* (Linn.). *Journal of Biological Control*, 35(2): 114-126.
- Mohamed, K.P.P., Sundaralingam, M., Sukumaran, A. and Christobher, S.C. 2021. Insecticidal effect of *Adathoda vasica* (leaf) and *Trigonella foenum-graecum* (seed) extracts against mealy bugs (*Maconellicoccus hirsutus*) on *Hibiscus rosa-sinensis* plant. *Asian Journal of Biological and Life Sciences*, 10(2).
- Nattudurai, G., Irudayaraj, S.S., Paulraj, M.G., Baskar, K. and Ignacimuthu, S. 2015. Insecticidal and repellent activities of *Toddalia asiatica* (L.) Lam. extracts against three major stored product pests. *Entomology, Ornithology & Herpetology*, 4(2):1.
- Nazeefullah, S., Dastagir, G. and Ahmad, B. 2014. Effect of cold water extracts of *Acacia modesta* Wall. and *Glycyrrhiza glabra* Linn. on *Tribolium castaneum* and *Lemna minor*. *Pakistan Journal of Pharmaceutical Sciences*, 27(2):217-222.
- Ngegba, P.M., Cui, G., Khalid, M.Z. and Zhong, G. 2022. Use of botanical pesticides in agriculture as an alternative to synthetic pesticides. *Agriculture*, 12(5): 600.
- Pavela, R. 2017. Extract from the roots of *Saponaria officinalis* as a potential acaricide against *Tetranychus urticae*. *Journal of Pest Science*, 90:683-692.
- Peschiutta, M.L., Brito, V.D., Ordano, M. and Zygadlo, J.A. 2019. Efficacy of selected volatile compounds for organic vine mealybug control. *Vitis – Journal of Grapevine Research*, 58(1):1–6.
- Peschiutta, M.L., Brito, V.D., Achimón, F., Dambolena, J.S., Zygadlo, J.A. and Ordano, M.A. 2018. Botanical compounds to combat vineyards mealybugs: An ideal alternative for organic vitiviculture. *Research & Reviews: Journal of Botanical Sciences*, 7(3).

- Phambala, K., Tembo, Y., Kasambala, T., Kabambe, V.H., Stevenson, P.C. and Belmain, S.R. 2020. Bioactivity of common pesticidal plants on fall armyworm larvae (*Spodoptera frugiperda*). *Plants*, 9:112.
- Portilla Pulido, J.S., Urbina Duitama, D.L., Velasquez-Martinez, M.C., Mendez-Sanchez, S.C. and Duque, J.E. 2022. Differentiation of action mechanisms between natural and synthetic repellents through neuronal electroantennogram and proteomic in *Aedes aegypti* (Diptera: Culicidae). *Scientific Reports*, 12(1): 20397.
- Pu, J. and Chung, H. 2024. New and emerging mechanisms of insecticide resistance. *Current Opinion in Insect Science*, 63: 101184.
- Pumnuan, J., Insung, A. and Montri, N. 2021. Insecticidal activity of teak (*Tectona grandis* L.f.) leaves extracts against diamondback moth (*Plutella xylostella* L.) and mealybug (*Phenacoccus manihoti* Matile-Ferrero). *Thai Journal of Agricultural Science*, 54(1):1-13.
- Pumnuan, J., Sannongmueang, T., Inyod, T. and Insung, A. 2019. Effectiveness of bastard oleaster (*Elaeagnus latifolia*) extracts against the nymph of mealybug (*Phenacoccus manihoti*). *Acta Horticulturae. International Society for Horticultural Science*, 1259.
- Purkait, A., Biswas, S., Saha, S., Hazra, D.K., Roy, K., Biswas, P.K., Ghosh, S.K. and Kole, R.K. 2019. Formulation of plant-based insecticides, their bio-efficacy evaluation and chemical characterization. *Crop Protection*, 125:104907.
- Rajagopal, R., Kuppusamy, P., Sathya, R., Nandhakumari, P., Bensa, A.D.V. and Biji, G.D. 2022. Antifungal phytochemicals from the methanol and aqueous extract of *Acacia concinna* and *Lantana camara* and synergistic biological control of the hibiscus mealybug (*Maconellicoccus hirsutus*). *Physiological and Molecular Plant Pathology*, 119:101813.
- Ramzi, S., Seraji, A., Azadi Gonbad, R. and Roofigari Haghghat, S. 2022. Effects of the extract and the essential oil of *Allium sativum* on tea mealybug, *Pseudococcus viburni* Sigornet (Hemiptera: Pseudococcidae). *Biocatalysis and Agricultural Biotechnology*, 42:102359.
- Regnault-Roger, C., Vincent, C. and Arnason, J.T. 2012. Essential oils in insect control: Low-risk products in a high-stakes world. *Annual Review of Entomology*, 57(1):405–424.
- Roonjho, R.A., Gillani, W.A., Rasool, A., Akhtar, N., Mahmood, T., Afzal, M., Khan, I., Asghar Ranjha, M., Irfan, M. and Khan, J. 2013. Repellency effects of different plant extracts

- to cotton mealybug, *Tinsley* (Hemiptera: Pseudococcidae) *Phenacoccus solenopsis*. *Pakistan Journal of Agricultural Research*, 26(3).
- Roddee, J., Nonkheang, N. and Klangjoho, S. 2020. Efficacy of botanical extracts against tomato mealybug *Ferrisia virgata* (Hemiptera: Pseudococcidae). *Khon kaen Agriculture Journal*, 48(6): 1434-1441.
- Rovensa Next, n.d. Integrated Disease Management. <https://www.rovensanext.co.za/en-za/biosolutions-by-grower-needs/integrated-disease-management/> [17 April 2025].
- Rizwan, M., Raza, A.B.M., Majeed, M.Z. and Arshad, M. 2022. Insecticidal potential of some selected phytoextracts against mealybug *Drosicha mangiferae* (Hemiptera: Pseudococcidae) infesting citrus plants in Sargodha. *Sarhad Journal of Agriculture*, 38(3):1098.
- Salari, E., Ahmadi, K., Dehyaghobi, R.Z., Purhematy, A. and Takaloozadeh, H.M. 2012. Toxic and repellent effect of harmal (*Peganum harmala* L.) acetonitrile extract on several aphids and *Tribolium castaneum* (Herbst). *Chilean Journal of Agricultural Research*, 72(1).
- Sarwar, M. 2023. Botanic plant resources as insect pests administrator of field crops. *Journal of Agriculture & Forestry Research*, 2(1):31–43.
- Seiber, J.N., Coats, J., Duke, S.O. and Gross, A.D. 2014. Biopesticides: state of the art and future opportunities. *Journal of agricultural and food chemistry*, 62(48): 11613-11619.
- Seye, F., Fall, A., Dia, C.A.K., Toure, M., Ndione, R.D. and Ndiaye, M. 2022. Effect of neem derivatives (*Azadirachta indica*) on the mango mealybug (*Rastrococcus invadens*) for biological control, *GSC Advanced Research and Reviews*, 10(3):025-031.
- Shivkumara, K.T., Manjesh, G.N., Satyajit, R. and Manivel, P. 2019. Botanical insecticides; prospects and way forward in India: A review. *Journal of Entomology and Zoology studies*, 7(3):206-211.
- Singh, A., Kataria, R. and Kumar, D. 2012. Repellence property of traditional plant leaf extracts against *Aphis gossypii* Glover and *Phenacoccus solenopsis* Tinsley. *African Journal of Agricultural Research*, 7(11):1623-1628.
- Sombra, K.E.S., Pastori, P.L., de Aguiar, C.V.S., André, T.P.P., de Oliveira, S.J., Barbosa, M.G. and Pratisoli, D. 2022. Selectivity of essential oils to the egg parasitoid *Trichogramma pretiosum* Riley (Hymenoptera: Trichogrammatidae). *Revista Ciencia Agronomica*, 53:e20207789.

- Talborne Organic, 2025. Pest & Disease Control. <https://talborne.co.za/pest-and-disease-control/> [17 April 2025].
- Talib, S., Mokhtar, A., Wan Abdul Ghani, W.M., Jamian, S. and Abdul Wahab, M. 2023. The insecticidal potential of *Azadirachta indica* and *Phaleria macrocarpa* plant extracts against pineapple mealybug, *Dysmicoccus brevipes* (Hemiptera: Pseudococcidae). *Egyptian Academic Journal of Biological Sciences, A, Entomology*, 16(1):149–154.
- Timm, A.E. and Reineke, A. 2014. First insights into grapevine transcriptional responses as a result of vine mealybug *Planococcus ficus* feeding. *Arthropod-Plant Interactions*, 8:495–505.
- Tintumol, K., Surendran, S., Chandrappa, K. and Seetharama, H.G. 2022. Insecticidal efficacy of plant extracts against *Planococcus citrii* (Risso) (Hemiptera: Pseudococcidae), in Coffee. *Quest Journals, Journal of Research in Agriculture and Animal Science*, 9(7):15-17.
- Tripathi, A. 2021. Eco-friendly management of harmful colonization of striped mealybug (*Ferrisia virgata*) over plants by using herbal pesticide. *International Journal of Biological Innovations*, 3(1):134-138.
- Sardar, M.U., Mamoon-ur-Rashid, M., Naeem, M. and Muhammad Umair Sardar, C. 2018. Entomocidal efficacy of different botanical extracts against cotton mealybug, *Phenacoccus solenopsis* Tinsley (Sternorrhyncha: Pseudococcidae). *Journal of Entomology and Zoology Studies*, 6(5):2078-2084.
- Verdeguer, M., Sánchez-Moreiras, A.M. and Araniti, F. 2020. Phytotoxic effects and mechanism of action of essential oils and terpenoids. *Plants*, 9:1571.
- Zaka, S.M., Iqbal, N., Saeed, Q., Akrem, A., Batool, M., Khan, A.A., Anwar, A., Bibi, M., Azeem, S., Rizvi, D.E.N. and Bibi, R. 2019. Toxic effects of some insecticides, herbicides, and plant essential oils against *Tribolium confusum* Jacquelin du val (Insecta: Coleoptera: Tenebrionidae). *Saudi journal of biological sciences*, 26(7): 1767-1771.

CHAPTER THREE

Abstract

Plant extracts with pesticidal properties are valuable alternatives for eco-friendly control of the highly destructive grapevine mealybug (*Planococcus ficus* L.). *Allium* species are well known for their medicinal, antimicrobial, and pesticidal properties, due to the presence of bioactive sulphur-containing compounds produced in their tissues. This study aimed to assess the insecticidal and repellent activities of extracts from three *Allium* species (*A. sativum*, *A. cepa*, and *A. porrum*) obtained using dichloromethane, distilled water, acetone, and ethanol, against adult *P. ficus* under laboratory conditions. Insecticidal and repellent activities of plant extracts were evaluated in packet test toxicity and choice repellency bioassays. In the toxicity bioassay, the extracts of the three plants were tested at a concentration of 25% w/v mixed with virgin olive oil. The most active extract was further evaluated at different concentrations of 12.5%, 6.25%, 3.25% w/v, with virgin olive oil as a negative control (0%) and Kemprin (Cypermethrin pyrethroid 200 g/L) as a positive control. The repellency of the three plant extracts was determined using a three-choice bioassay at a 25% w/v extract concentration. The results showed that the DCM garlic extract was significantly more toxic (DF=3; $\chi^2 = 23.09$; $P < 0.05$), inducing 92% insect mortality at 25% w/v. In the insect repellency bioassay, the acetone extract of garlic was significantly (DF=3; $\chi^2 = 19.95$; $P < 0.05$) more repellent than other treatments. Based on these results, an organic insect-repellent soap containing garlic was formulated and tested in a repellency bioassay. At a 25% w/v concentration, the aqueous garlic extract and its formulated organic soap exhibited percentage repellencies of 42% and 38%, respectively. These findings demonstrated that garlic extracts have anti-grapevine mealybug activity and could be incorporated into integrated pest management.

Keywords: Alliaceae, biopesticides, grapevine pests, pest management, vineyard management, viticulture

3.1 Introduction

The small, soft-bodied, phloem-sucking grapevine mealybug (Hemiptera: Pseudococcidae) is one of the destructive pests of grapevines. This mealybug is a polyphagous pest, with about 250 identified host families (Lopes et al., 2019). Infestations by this pest cause significant economic losses in vineyards. The grapevine mealybug is an invasive and problematic insect pest that delays the adoption of sustainable vineyard management practices worldwide (Daane et al., 2017). The grapevine mealybug is considered a major pest in grape-producing regions of the world, including South Africa (Daane et al., 2018). The adult female grapevine has a pink to slate-grey-coloured flesh, about 4mm in length, 2mm in width, and approximately 1.5mm thick (Le Vieux and Malan, 2013). They are also identified by their waxy hair-like extensions along the edge of their bodies, with a dark line running along their backs.

The grapevine mealybug (*Planococcus ficus*) causes more damage than other mealybug species, such as *Pseudococcus longispinus* (Targioni-Tozzetti), *Pseudococcus maritimus* (Ehrhorn), and *Pseudococcus viburni* (Signoret) (Le Vieux and Malan, 2013). This is due to the higher secretion of honeydew, which attracts ants and protects the mealybug against predation (Nyamukondiwa and Addison, 2011). Additionally, *P. ficus* has a high reproductive rate, with approximately 250 eggs per female, and a broader host range (Le Vieux and Malan, 2013). In a 2009 survey conducted by the American Vineyard Foundation, mealybugs and grapevine leafroll disease (GLD) were identified as significant threats to the sustainability of the wine industry (Sharma et al., 2018). The grapevine mealybug is a top-priority concern for grape growers and warrants high-priority research in its management (Almeida et al., 2013).

Conventionally, grapevine mealybug is controlled by the repeated application of chemical insecticides, which play a key role in plant protection and crop yield improvement (Sharma et al., 2019; Hogg et al., 2021). However, the misuse of these chemical insecticides, such as carbamates, pyrethroids, and organophosphates, has been proven to be harmful to human health and the environment, as well as non-target organisms (Khursheed et al., 2022; Mansour et al., 2018). Due to the aforementioned harmful effects of synthetic insecticides, safer alternatives to control the grapevine mealybug are urgently needed. According to Barzman et al. (2015), reduced pesticide use could be achieved by incorporating biorational tactics, including pheromones or natural enemies, in grapevine mealybug control programmes. Mansour et al. (2018) reported that it is expedient to develop new synthetic insecticides that are effective against grapevine mealybug yet safe for non-target beneficial arthropods such as bees.

Many well-known bioactive compounds have been isolated from plants, which are recognised as an important source of anti-insect compounds. These include pyrethrum obtained from

Asteraceae members, azadirachtin from neem seeds, and capsaicin from extracts of hot pepper (Divekar et al., 2022). For instance, plant extracts from *Jatropha* leaf and Neem leaf showed an inhibitory effect on *Phenacoccus solenopsis* Tinsley, *Pseudococcus longispinus* (Targioni Tozzetti), and *Planococcus ficus* (Signoret) (Moniruzzaman et al., 2017). Additionally, *Azadirachta indica* extracts showed higher mortality in both adults and the 3rd instar of cotton mealybugs (Sardar et al., 2018). These plant extracts are economically important in medicine and other industries. Many of these phytochemicals, which are also known as allelochemicals, are produced by plants as part of their defence mechanisms against environmental stress, including herbivory (Gajger and Dar, 2021). These compounds have been successfully extracted, synthesised, and formulated into plant-based anti-insect products for commercial use worldwide.

The anti-insect activities of botanical formulations, such as insecticidal activity, repellence, oviposition deterrence, adult emergence inhibition, ovicidal, larvicidal, pesticidal activity, and feeding deterrence as toxicants and fumigants, have been well-documented (Ludwaba et al., 2024; Sarwar, 2023). The specific compounds found in given species of plants make them effective against a given category of pests and dictate their mode of action on the target pests (Lengai et al., 2020). However, their formulation as botanical insecticides is challenging, as one plant can have multiple active compounds that differ in chemical properties and mixabilities (Kumar and Singh, 2015; Ngegba et al., 2022). The challenge in formulation and commercialisation is attributed to a lack of chemical data (Lengai et al., 2020; Ngegba et al., 2022). Pavela (2016) and Šunjka and Mechora (2022) suggested that improving the quality of botanical insecticide formulations would ensure sufficient persistence of their effect, quality, and stability of the products.

Among the well-reputed plant species with anti-insect compounds are *Allium* species. These species, including *A. sativum* (garlic), *A. cepa* (onion) and *A. porrum* (leek), possess antimicrobial and antifungal activities, and several anti-insect activities, including insecticidal, repellent, and acaricidal activities against a wide range of agricultural pests (Al-Shuraym et al., 2020; Mostafa et al., 2013; Wahyuni et al., 2019). Garlic and onion have been reported to control the aphid population (Qadir et al., 2018). The bioactivities of garlic have been ascribed to its many sulphur-based compounds, including diallyl polysulfides (DAPS) comprising diallyl monosulfide, diallyl disulfide (DADS), diallyl trisulfide, and diallyl tetrasulfide (Casella et al., 2013; Anwar et al., 2017). These sulphur-based active compounds also occur in other *Allium* spp., such as *Allium cepa* and *Allium porrum* (Kale et al., 2021; Plata-Rueda et al., 2017). The garlic demonstrated acaricidal activity *in vitro* and *in vivo* against cattle ticks, such as *Rhipicephalus (Boophilus) microplus* (Shyma et al., 2014; Nasreen et al., 2020) and repellent effect against *Aedes aegypti* (Adnani et al., 2013). These activities may be attributed to the

allicin compound in garlic, which can interfere with the synthesis of parasitic cell membranes (Wahyuni et al., 2019).

Allium species, including *A. sativum*, *A. cepa* and *A. porrum*, have been reported to exhibit fungicidal, repellent, toxic, and antimicrobial activities (Mostafa et al., 2013; Aydin and Mammadov, 2019; Wahyuni et al., 2019; Al-Shuraym et al., 2020; Hayat et al., 2022). According to Adnani et al. (2013), onion leaves are recognised for their flavonoids and essential oils that have been proven to contain health benefits, including insecticidal, repellent, anti-inflammatory, and antifungal activities. Identification of garlic-derived allicin has since proved the potential antimicrobial role of garlic against a myriad of microbes (Hayat et al., 2022). Blowfly larvae death was caused by the allicin compound contained in garlic extract (Wahyuni et al., 2019). The objectives of the study were to evaluate the toxicity and repellent activities of *A. sativum*, *A. porrum*, and *A. cepa* extracts on adult female grapevine mealybug and to develop an organic insecticide formulation based on *Allium* extracts against the grapevine mealybug.

3.2 Materials and methods

3.2.1 Research Design

The insecticidal and repellent activities of extracts of the three *Allium* species were carried out in the Research Laboratory at the Department of Horticultural Sciences, Cape Peninsula University of Technology, Bellville campus. The experiment was a complete randomised design to evaluate the insecticidal and repellent activities of *A. sativum*, *A. porrum*, and *A. cepa*. Each plant species was extracted with dichloromethane, ethanol absolute, acetone, and distilled water. Varied concentrations of extracts, obtained by extraction with the four solvents of the three species, were tested against the vine mealybug (*Planococcus ficus* L.) in ten replications in a toxicity packet filter paper test and choice repellence bioassay. The distilled water extract was selected for incorporation into an organic soap formulation and then tested in a grapevine mealybug choice-repellence bioassay at different concentrations.

3.2.2 Insect culture

The female vine mealybugs (*Planococcus ficus*) were obtained from the Agricultural Research Council (ARC) in Stellenbosch, Western Cape Province, South Africa. The vine mealybugs were reared on butternut squash in a darkroom at 25 °C with relative humidity (RH) of 60% in the Research Laboratory at the Department of Horticultural Sciences, Cape Peninsula University of Technology, Bellville campus. Eight-week-old vine mealybugs were used for insecticidal and repellent bioassays.

3.2.3 Plant material

Three *Allium* species, namely, *A. sativum*, *A. cepa*, and *A. porrum*, were used in this study. The *A. sativum* (garlic cloves) and *A. porrum* (leeks) were purchased at a local market, Bellville market (King of markets), Western Cape Province, and the *A. cepa* (onions) was purchased at Pick 'n Pay Pty Ltd., Wellington, Western Cape Province, South Africa.

3.2.4 Plant preparation

For this study, aerial parts of *A. porrum* (leek) and bulbs of *A. sativum* and *A. cepa* were used. The *A. sativum* and *A. cepa* bulbs were peeled, and the aerial part of the *A. porrum* (leek) was rinsed, dried using a paper towel, and allowed to dry for 10 minutes before crushing. The plant materials were manually crushed separately using a pestle and mortar for 20 minutes. Fifteen grams (15 g) of each crushed plant material was weighed and mixed with 30 mL of dichloromethane (DCM), acetone, absolute ethanol (99%), and distilled water separately for 24 hours. The undissolved portion was filtered out using a Whatman No. 1 filter paper, and the filtrate was transferred into a clean 250 mL beaker. The solvents, namely, DCM, acetone, ethanol (99%) and distilled water, were evaporated from the extracts under room conditions. After complete evaporation of the solvent, the crude extracts were weighed. The extract yields are shown in Table 3.1. The crude extracts were kept in the refrigerator at 4 °C until use.

Table 3. 1: Extract yields of the three *Allium* species from four different solvents

The dry weight of the crude extract was divided by the weight of the plant material and multiplied by 100 to obtain the percentage yield.

Plant	Distilled water %	Acetone %	Absolute Ethanol %	DCM %
Garlic	11.6	1.13	2.9	0.2
Leek	3.2	2.4	2.8	1.4
Onion	8.8	3.6	6.1	1.9

3.3 Procedure for soap formulation

3.3.1 Extraction of organic lye from wood ash

The initial wood weight used for this process was 127.8 kg. The wood was burned in a braai area for 5 days in unmeasured small portions for 4-6 hours each day. After the complete combustion, the resulting wood ash was collected, sieved, and weighed, yielding 2.14 kg. In a 20-litre bucket, 2.14 kg of wood ash and 5000 mL of water were added and stirred. After 24 hours, the mixture was filtered. The lye solution (Figure 3.1) is considered ready when it can float an egg with an area of a quarter above the surface. The lye water was poured into a beaker and kept until use.

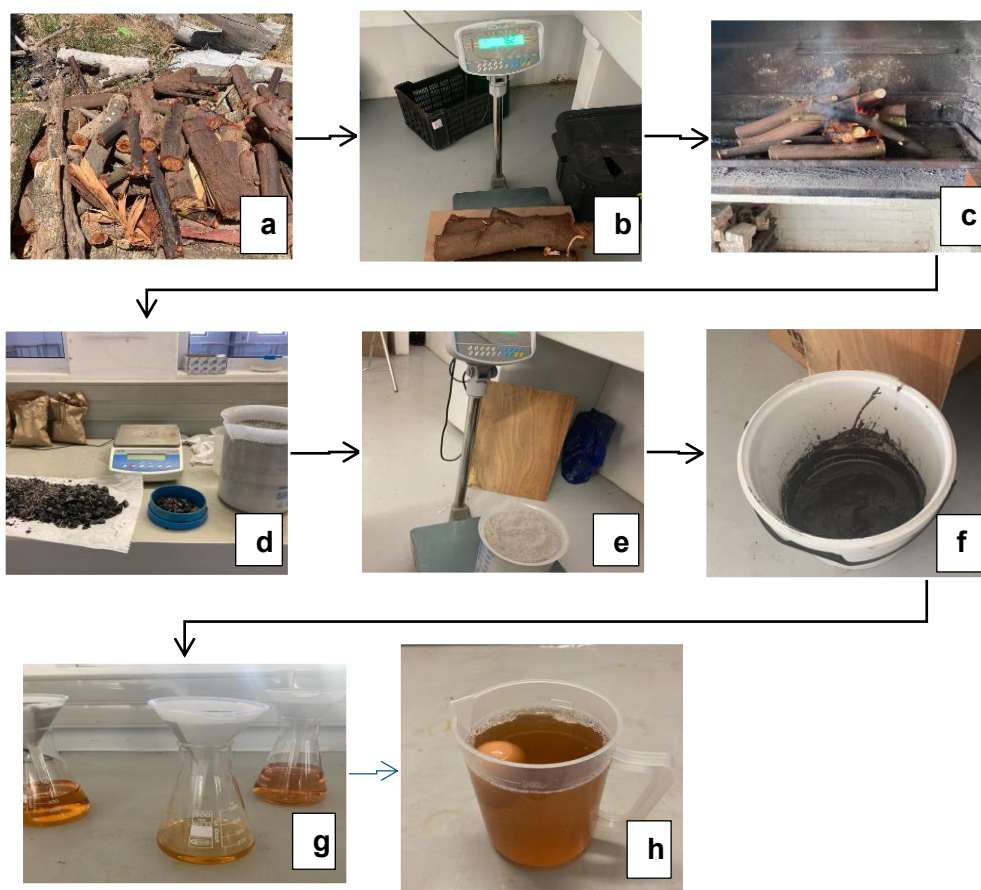


Figure 3. 1: The wood ash-making process.

This diagram illustrates the wood collection (a), weighing the wood (b), burning the wood in a fireplace until ash (c), the ash was collected and taken to the lab and sieved (d) and weighed (e). The ash is extracted with water (f) to obtain a lye solution (g), and the pH of the lye solution was tested using an egg (h).

3.3.2 Preparation of aqueous garlic extract for soap formulation

The garlic cloves were crushed manually in small quantities for 20 minutes. A total of 120 g of crushed garlic was weighed into a bottle beaker, and 140 mL of sterile distilled water was added. The mixture was then left to stand for 24 hours to fully extract the biologically active compounds. The solution was filtered into a beaker using a Whatman filter paper no.1. The garlic filtrate was left to dry at room temperature. The water solvent was selected for the soap formulation because aqueous extracts produced high tick repellency, and it dissolved and mixed well in the soap mixture.

3.3.3 Soap production

This process was adapted from Adjei et al. (2022) with slight modifications. Twenty-eight millimetres of the lye water, 60 mL of olive oil, and 60 mL of coconut oil were measured in clean, separate beakers. The lye was heated up for three minutes and poured into the blended

oils of 120 mL, which were also heated up for three minutes. The mixture was blended by continuous stirring for 3 hours to obtain a creamy mixture. The mixture was poured into a plastic container with parchment paper to reduce soap residue and left to dry for 7 days. The bar soap (Figure 3.3) weighed 112 g. To make the soap into a liquid to apply in the choice repellence bioassay, a mixture of distilled water (135 mL) and 120 mL of the garlic extract was heated up for 3 minutes, and the bar soap was cut into small pieces and added to the mixture until completely melted.

3.4 Experimental setup

The insect toxicity and insect repellence bioassays evaluated the toxic and repellent effects of the three *Allium* spp. against the female adult grapevine mealybugs. Plant extracts were obtained by dichloromethane, acetone, ethanol absolute, and distilled water extractions, and allowed to stand for 24 hours. The dried extracts were re-dissolved in extra virgin olive oil for the evaluation of toxicity tests, and with the solvents repellence tests to achieve a 25% w/v concentration. All treatments were homogenised using a vortex mixer for 10 minutes.

The toxic treatment tested at 25% w/v concentration was further tested at different concentrations: 25%, 12.5%, 6.25%, 3.125%, and 0%/negative control: extra virgin olive oil, and a commercial synthetic insecticide, Kemprin (Cypermethrin pyrethroid 200 g/L), was prepared and used as the positive control (PC). The toxicity bioassay was a modification of the larval packet filter bioassay used to evaluate the effect of acaricides on ticks (Aboelhadid et al., 2022). A larval packet was made from a folded filter paper strip of 2x2 cm². Fifty microlitres of each 25% w/v extract was applied to the packet filter paper and allowed to dry for 5 minutes. A camel-hair brush was used to transfer the insect into the packet, and all sides were stapled. Five packets, each containing one insect, were used per replicate for each treatment, placed in a petri dish (Figure 3.2), and kept in a darkroom at 60% RH. The bioassay was replicated ten times (5 insects × 10 replicates = 50) per treatment. Mortality was recorded after 10 minutes to evaluate the acute toxic effects of the plant extracts on vine mealybugs and observe immediate biological effects. The vine mealybugs that did not respond to tactile stimuli were considered dead.



Figure 3.2: Packet filter paper with female grapevine mealybugs in a petri dish.

3.5 Toxicity bioassay

The toxicity bioassay was performed as described in the Experimental setup section, using the modified larval packet filter method to evaluate the toxic effect of the three *Allium* spp. against the grapevine mealybug. Data were pooled from the replicates and summarised in Tables 3.2 and 3.3. For the most toxic treatment, different concentrations were tested, and percentage corrected mortality was calculated by following a formula used by Prishantithini and Vinobaba (2014):

$$\text{Corrected \% mortality} = \frac{\% \text{ mortality in treatment} - \% \text{ mortality in control}}{100 - \% \text{ mortality in control}} \times 100$$

3.6 Choice repellence bioassay

For the repellent bioassay, the choice-repellence bioassay was used to evaluate the repellent activities of the extracts against the grapevine mealybug. A Whatman no. 1 filter paper, of 125 mm diameter, was divided into three sections of similar dimensions by drawing diametric lines passing through the centre. A pencil was used to draw a 2 cm circle in the middle, which served as a neutral zone for the vine mealybug. Different treatments of 25 % w/v concentration were applied to the three sections. After application, the filter paper disk was air-dried for five minutes to remove the solvent, and 20 adult female vine mealybugs were released into the neutral zone. The positions of the grapevine mealybugs on the filter paper disk were recorded 10 minutes after their release. The sections with a low number of vine mealybugs were considered repellent. For the second part of the choice repellence bioassay, aqueous garlic extract and its soap formulation were each tested at different concentrations of 25%, 12.5%, 6.25%, 3.125%, and 0% (negative control or solvent), and PC (positive control: DEET insect repellent). The full repellence bioassay was repeated ten times.

The repellence bioassay was performed using a choice repellence bioassay as detailed in the Experimental setup section, evaluating the repellent effect of the three *Allium spp.* against the adult female grapevine mealybug. Data were pooled from the replicates and summarised in Tables 3.4 and 3.5. Percentage repellency was calculated for the distilled water extract and its organic soap formulation. Percentage repellency (PR) was calculated as follows: $PR = (C - T) / (C + T) \times 100$, where C is the number of insects on the untreated and T is the number of insects in the treated area (Mobki et al., 2014).



Figure 3.3: Organic bar soap

3.7 Garlic-formulated soap against vine mealybugs at different concentrations

The materials used for soap formulation were oil, lye (made from wood ash and water), distilled garlic water extract, extra-virgin olive oil, and coconut oil, a stove, a stainless pot, a wooden spoon, a plastic tub, parchment paper, a weighing balance, safety goggles, and a 500 mL beaker.

3.8 Statistical analysis

Data were recorded in Microsoft Excel, pooled from replicate assays, and summarised in tables. The data did not meet the assumptions of normality and homogeneity of variances; non-parametric tests were used. The Kruskal–Wallis test and Mann–Whitney test were used pairwise to separate the medians at a level of significance ($P < 0.05$). The Chi-square was used to compare differences among the various treatments. The statistical analyses were performed using PAST software version 4.11

3.9 Results and Discussions

3.9.1 Toxic activity of *Allium spp.* against *P. ficus* at 25% concentration.

The results showed a significant difference ($DF = 2$; $p < 0.05$) in insect mortalities induced by the different plant species at 25% w/v concentration. When comparing the three plant species, the DCM extract of garlic was significantly more toxic than all other treatments (Table 3.2). The garlic treatments were significantly ($DF = 3$; $\chi^2 = 23.09$; $P < 0.05$) higher compared to leek ($DF = 3$; $\chi^2 = 4.13$; $P > 0.05$) and onion treatments ($DF = 3$; $\chi^2 = 2.46$; $P > 0.05$); hence, it was

selected for further assessment by evaluating the effect of varying concentrations on insect repellence. This was followed by distilled water of garlic and leek extracted with DCM and ethanol. The garlic extracts obtained with acetone and distilled water were significantly different (DF=3; $\chi^2 = 19.95$; $P < 0.05$) from the garlic extracts obtained with ethanol absolute and DCM.

Table 3. 2: Median insect number of mortalities of adult female grapevine mealybug (*Planococcus ficus*) at 10 minutes post-treatment

Treatments	Ethanol absolute	Acetone	DCM	Distilled water	Statistics
Garlic	0.0 ^{bc}	1.0 ^{aB}	5.0 ^{aA}	1.0 ^{aB}	DF= 3; $\chi^2 = 23.09$; $P < 0.05$
Leek	1.5 ^{aA}	1.0 ^{aA}	1.0 ^{bA}	1.0 ^{aA}	DF= 3; $\chi^2 = 4.13$; $P > 0.05$
Onion	0.0 ^{bA}	0.0 ^{aA}	0.0 ^{bA}	0.0 ^{bA}	DF= 3; $\chi^2 = 2.46$; $P > 0.05$
Statistics	DF= 2; $\chi^2 = 8.58$; $P < 0.05$	DF= 2; $\chi^2 = 2.23$; $P > 0.05$	DF= 2; $\chi^2 = 20.29$; $P < 0.05$	DF= 2; $\chi^2 = 11.74$; $P < 0.05$	

Medians with the same lowercase letter in the same column (comparing plant species) and means with the same uppercase in the same row (comparing solvent extracts) are not significantly different at $P > 0.05$ following Mann-Whitney's test.

3.9.2 Testing the toxic effect of different concentrations of DCM extract of garlic

At 25% w/v concentration, the DCM garlic extract showed a higher significant difference ($p < 0.05$) compared to lower concentrations against the vine mealybug (Table 3.3). The mortality of vine mealybug increased significantly in the highest concentration of 25% w/v, achieving a mean percentage of 92%.

Table 3. 3: DCM extract of garlic on packet filter paper with female grapevine mealybug (*Planococcus ficus*) in toxicity bioassay

Conc. % w/v	Corrected mortality (%) of vine mealybug after 10 min
25	92
12.5	6

6.25	0
3.125	0
0 (neg control)	0
Positive control	96

3.9.3 Repellent activity of *Allium spp.* at 25% w/v concentration

The results showed a significant difference (DF = 2; $p < 0.05$) in repellent efficacy among the plant species at a 25% w/v concentration. The garlic extracted with acetone had the lowest median number of insects, indicating that the treatment was effective in repelling the grapevine mealybug, as shown in Table 3.4. This was followed by distilled water of garlic and leek extracted with DCM and ethanol. The garlic extracted with acetone and distilled water were significantly different (DF=3; $\chi^2 = 19.95$; $P < 0.05$) to the garlic extracts of ethanol absolute and DCM. In the Leek extracts, the leek extracted with DCM was significantly more repellent. Ethanol, Acetone, and DCM extracts of onion were significantly more repellent (DF=3; $\chi^2 = 8.09$; $P < 0.05$) than the distilled water extract of onion.

Table 3. 4: The median number of insects that stayed on the 25% w/v concentration sections (unrepelled female *P. ficus*) in the choice disc repellency bioassay

Treatments	Ethanol	Acetone	DCM	Distilled water	
Garlic	5.0 ^{aA}	1.0 ^{aB}	4.0 ^{aA}	1.5 ^{bB}	DF= 3; $\chi^2 = 19.95$; $P < 0.05$
Leek	2.0 ^{bB}	2.0 ^{aAB}	1.5 ^{bAB}	3.5 ^{aA}	DF= 3; $\chi^2 = 5.56$; $P > 0.05$
Onion	3.0 ^{abAB}	2.0 ^{aB}	2.0 ^{bB}	5.0 ^{aA}	DF= 3; $\chi^2 = 8.09$; $P < 0.05$
	DF=2; $\chi^2 = 10.3$; $P < 0.05$	DF= 2; $\chi^2 = 2.17$; $P > 0.05$	DF= 2; $\chi^2 = 9.07$; $P < 0.05$	DF= 2; $\chi^2 = 7.30$; $P < 0.05$	

Medians with the same lowercase letter in the same column (comparing plant species) and means with the same uppercase in the same row (comparing solvent extracts) are not significantly different at $P > 0.05$ following Mann-Whitney's test

3.9.4 Repellent activity at different concentration (25%, 12.5%, 6.25%, 3.125%)

The results of the repellent effects of garlic distilled water extracts tested at different concentrations (25% w/v; 12.5%; 6.25%; and 3.125%, 0% (negative control) and a positive control against adult *P. Ficus* using a choice disc bioassay at 10 minutes after treatment are presented in Table 3.5. The extract showed repellent activity against *P. ficus* at all the concentrations used except 0%. A percentage repellence (PR) value of 42% was noted at a 25% w/v concentration as the highest repellency percentage compared to lower concentrations. The repellent effect was concentration-dependent. The table also shows the results of the repellent effect of soap formulated with the garlic distilled water extract, following the same method above-mentioned. It was found that the concentrations 25% w/v, 12.5% w/v, and 6.25% w/v exhibited 38%, 28% and 6% respectively. The 3.125% w/v concentration did not produce any appreciable repellency. Based on the percentage repellency, the concentrations were categorised into different repellency classes; 25% w/v and 12.5% w/v concentrations are in class II.

Table 3. 5: Percentage repellency of different concentrations of aqueous garlic against female grapevine mealybug on choice repellency bioassay

Conc. % w/v	Aqueous extract (%)	Garlic soap
25	42	38
12.5	36	28
6.25	24	6
3.125	13	0
0 (negative control)	0	0
Positive control	79	63

Note: The choice of insects was recorded after 10 minutes of exposure to the treatments

3.10 Discussions

In this study, the three *Allium* species (garlic, onion, and leek) exhibited different insecticidal activities depending on the solvent and the plant species used for extraction. The garlic had the highest mortality rates, while the leek and onion showed variable reactions. Specifically, the dichloromethane (DCM) emerged as the most effective solvent, with higher mortality rates than acetone, ethanol and distilled water. These results are consistent with those of Nchu et al. (2005), who also found that DCM garlic extract was more effective in controlling *Hyalomma marginatum rufipes* and *Rhipicephalus pulchellus* ticks than acetone and ethanol. In a study by Munyore and Rioba (2020), DCM and methanolic extracts of both *A. sativum* and *A. cepa*

were larvicidal against the fall armyworm. Nwachukwu and Asawalam (2014) highlighted the potency of freshly prepared garlic against *Sitophilus zeamais*, while the insecticidal potency of its essential oil was also reported against overwintering *Cacopsylla chinensis* after 24 hours of treatment (Zhao et al., 2013). Earlier, Plata-Rueda et al. (2017) reported that different concentrations of garlic essential oil showed toxic effects on larva, pupa, and adult *Tenebrio molitor* 48 h after topical application. These insecticidal activities may be attributed to volatile and non-polar active constituents in garlic and the *Allium* species, which may have been extracted by the dichloromethane solvent used in this study. Some of the insecticidal compounds that have been widely studied include diallyl disulfide (Casella et al., 2013).

Notwithstanding, the onion extracts did not exhibit effective control against the vine mealybugs. This is in contrast with Qadir et al. (2018) who reported that aqueous extracts of onion and garlic, respectively, caused a mortality of 35 and 31% of aphids after six hours of application. Aboelhadid et al. (2013) reported that onion oil aqueous solution managed to kill 73% of ticks in a 20% concentration in 72 hours and concluded that onion extract took time to affect ticks as compared to garlic. This suggests that onion extracts need more exposure time to be active. Leek has been rarely tested for insecticidal properties, unlike garlic and onion. However, in this study, the leek demonstrated some insecticidal activity. In a study by Sadeghi et al. (2009), the mannose-binding lectin APA (*Allium porrum* agglutinin) exhibited lower acute toxicity compared to GNA (*Galanthus nivalis* agglutinin) and ASA (*A. sativum* agglutinin), of the pea aphid (*Acyrtosiphon pisum*), causing only 3% mortality after 800 µg/mL for 24 h. The three *Allium* spp. exhibited efficacy in varying degrees against the vine mealybug.

The results indicate that the toxicity activity of the non-polar (DCM) extract of garlic is greater than the mid-polar (acetone), polar (ethanol), and polar (distilled water) extracts. The DCM extract of garlic caused 92% of the mortality of the vine mealybug after 10 minutes of exposure time, at 25% w/v concentration. The result of the DCM extract of garlic from this study corroborates Nchu et al. (2005), who recorded 100% mortality of *Hyalomma marginatum rufipes* in less than 1 hour. At the highest concentration of the treatment, there is an observable increase in the mortality rate of the vine mealybug. This indicates that the efficacy of the treatment is directly proportional to its concentration.

The repellent activity of the three *Allium* spp. extracted with dichloromethane, acetone, distilled water and ethanol at 25% w/v concentration, were tested using the choice repellence bioassay, and results were recorded 10 minutes after treatment. The results showed that the highest repellent effect on the vine mealybug was induced by the acetone extract of garlic. This was closely followed by distilled water extract of garlic, and distilled water and acetone extracts of leek. In a study by Mobki et al. (2014), *Allium sativum* extracts were actively

repellent against *Tribolium castaneum*; this repellent activity is attributed to the concentrations applied and exposure time of the insect. Unlike in the toxicity bioassay, the DCM extracts performed poorly in the repellency bioassay. The compounds contained in the DCM extracts are volatile and might have quickly dissipated from the treated section of the repellency bioassay compared to the other extracts from the more polar solvents like water and acetone. According to Nchu et al. (2016), low concentrations of DCM garlic extract repelled ticks. Additionally, at a concentration of 0.2%, *A. sativum* essential oil successfully repelled adult *Sitophilus oryzae* (Chaubey, 2016). The DCM *A. porrum* extracts were significantly more repellent than the other solvents, producing a low median repellency of 1.5 insects. Bandara et al. (2009) reported on the repellency of aqueous extracts of *Allium porrum* against bean fly.

The experimental results of the repellent activity of the insecticidal soap formulated with garlic distilled water extract, and garlic distilled water extract were not significantly different across all concentrations used. The highest concentration of 25% w/v of the insecticidal soap induced a moderate female mealybug repellency of 38%. This could be due to several factors, such as the formulation, exposure time and the mode of action of this botanical insecticidal soap. According to Mukhtar et al. (2018) and Babendreier et al. (2020), the mode of action of soap is not fully understood. Furthermore, some of the active compounds of garlic, which are volatile and thermolabile, might have dissipated or degraded during the soap-making process, thus reducing the efficacy of the formulated soap. Prowse et al. (2006) reported that one of the main disadvantages of garlic extracts is their inconsistent chemical composition. The repellent activity of the garlic extract was significantly influenced by the concentration applied and, interestingly, the activity was also increased when insects were exposed for a longer time (Mobki et al., 2014). However, the results of this study may differ from those of other investigations, probably due to differences in the experimental insects, garlic cultivar, garlic culture conditions, formulation of insecticidal soap, and bioassay. Further formulation, development and testing of the insecticidal soap is advised.

The laboratory assay provided a controlled environment to evaluate the acute effects of plant extracts on vine mealybugs. However, these conditions do not fully reflect the real environmental complexities, including temperature fluctuations and humidity changes, and the insect may behave differently in the field. For example, the waxy coating and cryptic behaviour of mealybugs may reduce contact with treatments in the field. Therefore, future studies should include semi-field or field trials to validate the practical applicability and effectiveness of these extracts under natural conditions.

3.11 Conclusion

In conclusion, these results revealed that dichloromethane extracts of garlic induced high mortality in treated grapevine mealybug in a packet test assay, and that water and acetone extracts of garlic and DCM extract of leek bulb repel the problematic grapevine mealybug in a choice repellency bioassay. Furthermore, the study led to the successful development of an organic insecticidal soap that was formulated with garlic distilled water, tested in the choice repellency bioassay and yielded a moderate insect repellency. These findings demonstrated that garlic extracts have anti-grapevine mealybug activities and could be incorporated into the integrated pest management of grapevine mealybug.

Reference

- Aboelhadid, S.M., Kamel, A.A., Arafa, W.M., Shokier, K.A. 2013. Effect of *Allium sativum* and *Allium cepa* oils on different stages of *Boophilus annulatus*. *Parasitol Res*, 112:1883-1890.
- Aboelhadid, S.M., Abdel-Baki, A.A.S., Gadelhaq, S.M., Hassan, W.H., Mansour, L., Al-Quraishy, S., Kamimura, Y., Lee, C.Y. and Kamel, A.A. 2022. Potential of *Marava arachidis*, a newly recorded earwig species in Egypt as a biological control agent of *Rhipicephalus annulatus* tick in laboratory. *Insects*, 13(10): 934.
- Adjei, F., Amponsah, E., Ebo-Donkor, P., Smith, J.B. and Tulashie, S.K. 2022. Formulation of mosquito repellent soap using neem extract, and *Musa paradisiaca* covers as a substitute source of alkalis. *Case Studies in Chemical and Environmental Engineering*, 5: 100171.
- Adnani, B., Rahmah, Z., Fitriyaningsih, A.A., Setiawan, A.M. 2013. Potential test of ethanol extract from Onion (*Allium Cepa* L) leaves as a repellent to *Aedes Aegypti*. *Journal of Islamic Medicine* 4: 65–75.
- Almeida, R.P.P., Daane, K.M., Bell, V.A., Blaisdell, G.K., Cooper, M.L., Herrbach, E. and Pietersen, G. 2013. Ecology and management of grapevine leafroll disease. *Frontiers in Microbiology*, 4(94).
- Al-Shuraym, L.A.M., Al-Keridis, L.A., Al-Dakhil, A.A. and Al-Qahtani, W.S. 2020. The impact of onion-garlic mixture to control of *Rhynchophorus ferrugineus* in Saudi Arabia. *Journal of the Saudi Society of Agricultural Sciences*, 19: 521-527.
- Anwar, A., Gould, E., Tinson, R., Groom, M. and Hamilton, C.J. 2017. Think yellow and keep green—role of sulfanes from garlic in agriculture. *Antioxidants*, 6: 3.
- Aydin, Ç. and Mammadov, R. 2019. Phytochemical analysis, phenolic content, antioxidant, antibacterial, insecticidal and cytotoxic activities of *Allium reuterianum* Boiss. extracts. *Indian Journal of Traditional Knowledge*, 18(2): 290-298.
- Babendreier, D., Koku Agboyi, L., Beseh, P., Osaе, M., Nboyine, J., Ofori, S.E., Frimpong, J.O., Attuquaye Clottey, V. and Kenis, M. 2020. The efficacy of alternative, environmentally friendly plant protection measures for control of fall armyworm, *Spodoptera frugiperda*, in maize. *Insects*, 11:240.
- Bandara, K.A.N.P., Kumar, V., Ninkovic, V., Ahmed, E., Pettersson, J. and Glinwood, R. 2009. Can leek interfere with bean plant–bean fly interaction? Test of ecological pest management in mixed cropping. *Journal of Economic Entomology*, 102(3): 999-1008.
- Barzman, M., Bàrberi, P., Birch, A.N.E., Boonekamp, P., Dachbrodt-Saaydeh, S., Graf, B., Hommel, B., Jensen, J.E., Kiss, J., Kudsk, P. and Lamichhane, J.R. 2015. Eight principles of integrated pest management. *Agronomy for sustainable development*, 35(4): 1199-1215.

- Chaubey, M.K. 2016. Fumigant and contact toxicity of *Allium sativum* (Alliaceae) essential oil against *Sitophilus oryzae* L. (Coleoptera: Dryophthoridae). *Entomology and Applied Science Letters*, 3(2): 43-48.
- Daane, K.M., Vincent, C., Isaacs, R., Ioriatti, C. 2017. Entomological opportunities and challenges for sustainable viticulture in a global market. *Annual Review of Entomology*, 62:193–214.
- Daane, K.M., Middleton, M.C., Sforza, R.F.H., Kamps-Hughes, N., Watson, G.W., Almeida, R.P.P., Correa, M.C.G., Downie, D.A., Walton, V.M. 2018. Determining the geographic origin of invasive populations of the mealybug *Planococcus ficus* based on molecular genetic analysis. *PLOS ONE*, 13(3): e0193852.
- Divekar, P.A., Narayana, S., Divekar, B.A., Kumar, R., Gadratagi, B.G., Ray, A., Singh, Achuit Kumar, Rani, V., Singh, V., Singh, Akhilesh Kumar, Kumar, A., Singh, R.P., Meena, R.S. and Behera, T.K. 2022. Plant Secondary Metabolites as Defense Tools against Herbivores for Sustainable Crop Protection. *International Journal of Molecular Sciences*, 23: 2690.
- Gajger, I.T. and Dar, S.A. 2021. Plant Allelochemicals as Sources of Insecticides. *Insects*, 12: 189.
- 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: 111296.
- Hogg, B.N., Cooper, M.L. and Daane, K.M. 2021. Areawide mating disruption for vine mealybug in California vineyards. *Crop Protection*, 148: 105735.
- Kale, R.B., Gadge, S.S., Jayaswall, K., Patole, A.O., Mahajan, V. and Singh, M. 2021. Validation of ethno-veterinary medicinal practices of onion (*Allium cepa* L.). *Indian Journal of Traditional Knowledge*, 20(3): 775-783.
- Khursheed, A., Rather, M.A., Jain, V., Wani, A.R., Rasool, S., Nazir, R., Malik, N.A. and Majid, S.A. 2022. Plant-based natural products as potential ecofriendly and safer biopesticides: A comprehensive overview of their advantages over conventional pesticides, limitations and regulatory aspects. *Microbial Pathogenesis*, 173:105854.
- Kumar, S. and Singh, A. 2015. Biopesticides: present status and the future prospects. *Journal of Fertiizer & Pesticides*, 6(2):1-2.
- Le Vieux, P.D. and Malan, A.P. 2013. An overview of the vine mealybug (*Planococcus ficus*) in South African vineyards and the use of entomopathogenic nematodes as potential biocontrol agent. *South African Journal of Oenology and Viticulture*, 34(1): 108-118.
- 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:e00239.

- Lopes, F.S.C., Oliveira, J.V.D., Oliveira, J.E.D.M., Oliveira, M.D.D. and Souza, A.M.D. 2019. Host plants for mealybugs (Hemiptera: Pseudococcidae) in grapevine crops. *Pesquisa Agropecuária Tropical*, 49: e54421.
- Ludwaba, B., Jimoh, M. O., Laubscher, C. P., and Nchu, F. 2024. Insecticidal and antioxidant potential of volatile compounds and nanoparticles from *Tulbaghia violacea* Harv. inoculated with endophytic fungus *Beauveria bassiana* (Bals.-Criv.) Vuill. *South African Journal of Botany*, 165: 246–256.
- Mansour, R., Belzunces, L.P., Suma, P., Zappalà, L., Mazzeo, G., Grissa-Lebdi, K., Russo, A. and Biondi, A. 2018. Vine and citrus mealybug pest control based on synthetic chemicals: A review. *Agronomy for Sustainable Development*, 38: 37.
- Mobki, M., Safavi, S.A., Safaralizadeh, M.H. and Panahi, O. 2014. Toxicity and repellency of garlic (*Allium sativum* L.) extract grown in Iran against *Tribolium castaneum* (Herbst) larvae and adults. *Archives of Phytopathology and Plant Protection*, 47(1): 59-68.
- Moniruzzaman, M., Yaakob, Z., Khatun, R. and Awang, N. 2017. Mealybug (Pseudococcidae) infestation and organic control in fig (*Ficus carica*) orchards of Malaysia. *Biology and Environment*, 117B (1), 25–32.
- Mostafa, A.A., Al-Rahmah, A.N., Yakout, S.M. and Abd-Alrahman, S.H. 2013. Bioactivity of garlic bulb extract compared with fungicidal treatment against tomato phytopathogenic fungi. *Journal of Pure and Applied Microbiology*, 7(3): 1925-1932.
- Mukhtar, Y., Abdu, K., Abdulkadir, A.I., Galalain, A.M., Maigari, A.K. and Yunusa, U.M. 2018. Sustainable use of botanical products in plant protection as a promising panacea to integrated pests management and control: issues, challenges, benefits and future prospects. *International Journal of Advanced Academic Research*, 4(4).
- Munyore, M. and Rioba, N.B. 2020. Evaluation of garlic (*Allium sativum*) and onion (*Allium cepa*) extracts for the management of fall armyworm (*Spodoptera frugiperda*) on baby corn (*Zea Mays* L) under greenhouse conditions. *Science Heritage Journal (GWS)* 4(2): 64-69.
- Nasreen, N., Niaz, S., Khan, A., Zaman, M. A., Ayaz, S., Naeem, H. 2020. The potential of *Allium sativum* and *Cannabis sativa* extracts for anti-tick activities against *Rhipicephalus (Boophilus) microplus*. *Experimental and Applied Acarology*, 82(2): 281–294.
- Nchu, F., Magano, S.R. and Eloff, J.N. 2016. Repellent activities of dichloromethane extract of *Allium sativum* (garlic) (Liliaceae) against *Hyalomma rufipes* (Acari). *Journal of the South African Veterinary Association*, 87(1).
- Nchu, F., Magano, S.R. and Eloff, J.N. 2005. In vitro investigation of the toxic effects of extracts of *Allium sativum* bulbs on adults of *Hyalomma marginatum rufipes* and

- Rhipicephalus pulchellus*. *Journal of the South African Veterinary Association*, 76(2): 99-103.
- Ngegba, P.M., Cui, G., Khalid, M.Z. and Zhong, G. 2022. Use of botanical pesticides in agriculture as an alternative to synthetic pesticides. *Agriculture*, 12(5): 600.
- Nwachukwu, I.D. and Asawalam, E.F. 2014. Laboratory evaluation of freshly prepared juice from garlic (*Allium sativum* L.) Liliaceae as protectants against the maize weevil, *Sitophilus zeamais* (Motsch.) [Coleoptera: Curculionidae]. *African Journal of Biotechnology*, 13(10).
- Nyamukondiwa, C. and Addison, P. 2011. Preference of foraging ants (Hymenoptera: Formicidae) for bait toxicants in South African vineyards. *Crop Protection*, 30: 1034-1038.
- Pavela, R. 2016. History, presence and perspective of using plant extracts as commercial botanical insecticides and farm products for protection against insects: A review. *Plant Protection Science*, 54(4): 229–241.
- Plata-Rueda, A., Martínez, L.C., Santos, M.H. Dos, Fernandes, F.L., Wilcken, C.F., Soares, M.A., Serrão, J.E. and Zanuncio, J.C. 2017. Insecticidal activity of garlic essential oil and their constituents against the mealworm beetle, *Tenebrio molitor* Linnaeus (Coleoptera: Tenebrionidae). *Scientific Reports*, 7:46406.
- Prishanthini, M. and Vinobaba, M. 2014. Efficacy of some selected botanical extracts against the Cotton mealybug *Phenacoccus solenopsis* (Tinsley) (Hemiptera: Pseudococcidae). *International Journal of Scientific and Research Publications*, 4(3).
- Prowse, G.M., Galloway, T.S. and Foggo, A. 2006. Insecticidal activity of garlic juice in two dipteran pests. *Agricultural and Forest Entomology*, 8: 1-6.
- Qadir, R.A., M. Amin, H., J. Majeed, A. 2018. Effect of growing seasons, plant extracts with various rates on Black Bean Aphid, *Aphis fabae* (Aphididae: Homoptera). *Kurdistan Journal of Applied Research*, 3(1).
- Sadeghi, A., Damme, E.J.M.V., Michiels, K., Kabera, A. and Smagghe, G. 2009. Acute and chronic insecticidal activity of a new mannose-binding lectin from *Allium porrum* against *Acyrtosiphon pisum* via an artificial diet. *Canadian Entomologist*, 141: 95–101.
- Sarwar, M. 2023. Botanic plant resources as insect pests administrator off-field crops. *Journal Agriculture and Forestry Research*, 2:31-43.

- Sardar, M., Mamoon-ur-Rashid, M., Naeem, M. and Muhammad Umair Sardar, C. 2018. Entomocidal efficacy of different botanical extracts against cotton mealybug, *Phenacoccus solenopsis* Tinsley (Sternorrhyncha: Pseudococcidae). *Journal of Entomology and Zoology Studies*, 6(5):2078-2084.
- Sharma, L., Gonçalves, F., Oliveira, I., Torres, L. and Marques, G. 2018. Insect-associated fungi from naturally mycosed vine mealybug *Planococcus ficus* (Signoret) (Hemiptera: Pseudococcidae). *Biocontrol Science and Technology*, 28(2):122–141.
- Sharma, A., Kumar, V., Shahzad, B., Tanveer, M., Sidhu, G.P.S., Handa, N., Kohli, S.K., Yadav, P., Bali, A.S., Parihar, R.D., Dar, O.I., Singh, K., Jasrotia, S., Bakshi, P., Ramakrishnan, M., Kumar, S., Bhardwaj, R. and Thukral, A.K. 2019. Worldwide pesticide usage and its impacts on ecosystems. *SN Applied Sciences*, 1:1446.
- Shyama, K.P., Gupta, J.P., Ghosh, S., Patel, K.K. and Singh, V. 2014. Acaricidal effect of herbal extracts against cattle tick *Rhipicephalus (Boophilus) microplus* using in vitro studies. *Parasitol Res*, 113: 1919–1926.
- Šunjka, D. and Mechora, Š. 2022. An Alternative Source of Biopesticides and Improvement in Their Formulation—Recent Advances. *Plants*, 11: 3172.
- Wahyuni, D., Sari, N.P. and Hanjani, D.L. 2019. White Onion (*Allium sativum*) Extract as a Vegetable Larvicide in Blowfly (*Calliphoridae*) Control. *Jurnal Kesehatan Masyarakat* 15(2): 247–256.
- Zhao, N.N., Zhang, H., Zhang, X.C., Luan, X.B., Zhou, C., Liu, Q.Z., Shi, W.P. and Liu, Z.L. 2013. Evaluation of acute toxicity of essential oil of garlic (*Allium sativum*) and its selected major constituent compounds against overwintering *Cacopsylla chinensis* (Hemiptera: Psyllidae). *Journal of Economic Entomology*, 106: 1349–1354.

CHAPTER FOUR: CONCLUSION AND RECOMMENDATIONS

4.1 General discussion, conclusion, and recommendations

4.1.1 General discussion

Agricultural production has been infested by pests that cause economic damage for decades. Grapevines, which produce table grapes and are used for wine production, are among the crops that have been severely affected by pests, such as the vine mealybugs, in various regions of the world. This pest feeds on different parts of the crops, causing reduced crop yield, unsatisfactory fruit quality, and negatively affecting the overall plant health. Synthetic insecticides from various classes have been utilised to combat the effects of pest infestation. These chemicals had positive results in protecting the crops and contributing to food security. Therefore, there has been an increased reliance on them; however, over the years, research has reported their negative impact on the environment, including the killing of beneficial organisms and contamination of soil and water. Additionally, they negatively affect human health. This prompted a need for sustainable pest management practices that are effective and environmentally friendly, such as plant-based insecticides. The efficacy of plant-based products in pest management, both in the laboratory and in the field, has been reported by several studies. Neem, Pyrethrum, Garlic, Aloe vera, and some *Eucalyptus* species are among many plants extracted for compounds that are effective in pest management. Plants produce secondary metabolites with insecticidal properties and various mechanisms of action. These compounds form part of the plant's defence mechanism and offer significant advantages, including being biodegradable and environmentally safe, as well as being lower or non-toxic to non-target species.

This study reviewed studies that evaluated the insecticidal and repellent effects of plants from different families against the vine mealybug and other insect pests. This literature review proves the efficacy of the different plant extracts with different solvents and extraction methods being toxic and repellent against distinct stages of the insect pests. This represents a promising source for the vine mealybug control. The literature review also highlights the influence of the synergistic impact of longer exposure time and increased concentrations against the pest. There are commercially available plant-based pesticides derived from these plant extracts, which confirms their efficacy. However, they are not widely adopted and commercialised. This study also assessed the insecticidal and repellent effects of three *Allium* spp (*A. sativum*, *A. cepa* and *A. porrum*) against the vine mealybug. Dichloromethane, acetone, ethanol absolute, and water were used to extract each plant. The study demonstrated the toxic and repellent activities of the *Allium* spp. The effectiveness or ineffectiveness of these species could be due to their phytochemical composition, exposure time, and method of extraction. In both experiments, the efficacy of garlic was significantly stronger than onion and

leek at a 25% concentration in killing and repelling the adult female grapevine mealybugs. In the packet test toxicity bioassay, the dichloromethane extracts of garlic induced high mortality in treated grapevine mealybug, and water and acetone extract of garlic and DCM extracts of leek bulb repelled the problematic grapevine mealy in a choice repellency bioassay. Furthermore, the study led to the successful development of an organic insecticidal soap that was formulated with aqueous garlic, tested in the choice repellency bioassay and yielded a moderate insect repellency. While many plant species have been investigated for their anti-insect activities, few have been successfully formulated and developed into commercial products. Although the soap showed modest insect repellency, it provides a solid foundation for future improvements and development of low-cost, environmentally friendly, herbal-based anti-insect soaps. Specific areas to consider when developing anti-insect soap include enhancing adjuvants such as non-ionic surfactants from natural sources, synergistic use of natural bioactive agents and improving the repellence and toxicity bioassays.

4.1.2 Conclusion

In conclusion, utilising plant extracts with insecticidal and repellent secondary metabolites is a prominent biological control approach. The garlic exhibited significant control over the vine mealybug. Their efficacy could be influenced by the type of solvent used. The key findings of this study are that the DCM extract of garlic demonstrated the highest mortality, and the water and acetone extract of garlic showed some repellent activity against the vine mealybug. The results will contribute to the body of knowledge on the use of plant-based insecticides and repellents against the vine mealybug, as few studies have focused on plant extracts for controlling and repelling this pest. More research is needed on plant extracts that are both toxic and repellent to pests. Limited information is available on the insect-repellent activity of leeks and other *Allium* species; however, this study revealed that leek (*A. porrum*) exhibits promising activity against the vine mealybug. Therefore, further investigations are encouraged.

4.1.3 Recommendations

The study focuses solely on a single insect species and a specific exposure time. Future research could explore the long-term effects of these treatments with extended exposure times on the vine mealybug and other insect species. Furthermore, future studies should include bioassay-guided fractionation to identify bioactive fractions and compounds of *Allium* spp. extracts against the vine mealybug. Most research on plant-based insecticides consists of laboratory experiments; future research could assess the efficacy of DCM garlic extract,

particularly in the field and against different insect pests. To enhance garlic's potential, synergy with other botanicals is another avenue to explore. Additionally, investigating the mechanism of action underlying the insecticidal properties of these extracts could provide valuable insights for their application in integrated pest management strategies. Future research should prioritise the isolation and characterisation of bioactive compounds, such as organosulfur compounds and flavonoids, to identify the specific constituents responsible for their insecticidal activities. Advanced analytical techniques, including LC-MS, and GC-MS can be employed to accurately profile these compounds. Laboratory findings should be validated under field conditions to assess practical efficacy, safety, and ecological impacts.

Ultimately, it is essential for researchers to continue innovating with the goal of enhancing anti-insect formulation development. Instability, volatility, and rapid degradation are among the primary limitations of botanical insecticides. Recent advances in formulation strategies, such as microencapsulation, nano-emulsions, and controlled-release delivery systems and the use of entomopathogenic nematodes, address these limitations, offering physical and chemical stability of plant-based actives and increased shelf life. These innovative formulation technologies facilitate large-scale production and commercialisation of botanical products, such as garlic extracts, making plant-based insecticides more practical for farmers and supporting their integration into sustainable Integrated Pest Management (IPM) programs. Furthermore, these advances also reduce product costs and regulatory challenges, improving the commercial feasibility of botanical insecticides.