

**STUDIES ON WHITEFLY (*Bemisia tabaci* G.)
MANAGEMENT STRATEGIES FOR SUSTAINABLE
PRODUCTION OF EGGPLANT (*Solanum melongena* L.)**

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2024

**Dedicated
to
Beloved Parents and Entire
Family**

DECLARATION

I, hereby declared that the presented work in the thesis entitled “**Whitefly (*Bemisia tabaci* G) Management Strategies for Sustainable production of Eggplant (*Solanum melongena* L.)**” in fulfilment of degree of **Doctor of Philosophy (Ph. D.)** is outcome of research work carried out by me under the supervision of **Dr. Bhupendra Koul**, working as **Associate professor**, in the Department of Botany, School of Bioengineering and Biosciences, Lovely Professional University, Punjab, India. In keeping with general practice of reporting scientific observations, due acknowledgements have been made whenever work described here has been based on findings of another investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.



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CERTIFICATE

This is to certify that the work reported in the Ph. D. thesis entitled “**Whitefly (*Bemisia tabaci* G.) Management Strategies for Sustainable production of Eggplant (*Solanum melongena* L.)**” submitted in fulfillment of the requirement for the award of degree of **Doctor of Philosophy (Ph.D.)** in Botany, School of Bioengineering and Biosciences, is a research work carried out by Mustapha **Abubakar**, reg. no.: 11919605, is bonafide record of his original work carried out under my supervision and that no part of thesis has been submitted for any other degree, diploma or equivalent course.



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Mustapha Abubakar

ABSTRACT

The eggplant (*Solanum melongena* L.) is among the most cultivated vegetables in family solanaceae. It's known as a valuable source of nutrients and bioactive substances that are required for human health and nutrition (Agregan et al. 2021; Sharma and Kaushik 2021). Despite the various benefits, eggplant production has been constrained by various, sap-sucking pests' infestations (Lee and Zhang, 2018). Whiteflies (*Bemisia tabaci* Genn.) are aggressive, small, hemipteran sugar-robbing species that depend primarily on plant leaf tissue for their nourishment causing direct and indirect infestation effects on their host (Sani et al. 2020). Uncontrolled infestation by whiteflies can cause up to 100% yield losses in eggplant (Srinivasan 2009; Taher et al. 2020). These destructive agricultural pests are commonly managed through the use of synthetic insecticides. However, they are associated with various negative consequences on human health and the ecosystem (Muhannadali et al. 2019; Sani et al. 2020; Abubakar et al. 2022). Considering the benefits of eggplant and susceptibility of solanaceous crops to sap-sucking pests' attacks, researches were carried out to analyze the effect of whitefly infestations on the green round eggplant cultivar and the potential of different management measures against the whiteflies for improved production of eggplant in Nigeria, during the 2022 and 2023 cropping periods.

The effect of whitefly infestation on eggplant (*Solanum melongena* L.) was evaluated under the field and indoor conditions using standard experimental methods. The results showed the level of damage and susceptibility of eggplant to whitefly infestation. The infestation led to the emergence of multiple symptoms, such as leaf discoloration, deformation, reduced plant growth, the presence of holes, the deposition of honeydew, and the formation of sooty mold. These symptoms collectively resulted in substantial leaf damage. Plants in T₃ were most affected under field trial with 85.8 and 88.0% leaf damage, while those in T₁ were least affected with 69.23 and 66.60%, 12 weeks after infestation during the 2022 and 2023 experiments. The effects were higher under pot experiments, causing 90.10 and 93.18% leaf damage with plants in T₃ while the least (70.00 and 68.00%) were found in T₁, 12 weeks after infestation during the 2022 and

2023 experiments. All the eggplant growth parameters assessed were negatively affected by whitefly infestation. In the field trial, net assimilation rate was most affected (100% reduction) in T₃, while the number of leaves was least affected (18.1%) in T₁, 12 weeks after infestation during the 2022 trial. In 2023, relative growth rate recorded the highest reduction (99.2%) in T₂ with the number of leaves being the least reduced (9.4%) in T₁, 12 weeks after infestation. In the pot trial, relative growth rate was also most reduced (94.9%) in T₃ with the plant height being least affected (22.3%) in T₁ during the 2022 experiment. In 2023, net assimilation rate has the highest reduction (93.8%) in T₁ and T₂ respectively, while the leaf area recorded the least reduction (19.6%) in T₁, 12 weeks after infestation. The highest (92.1 and 90.1%) reduction in yield were recorded in T₃ in 2022 and 2023 trials under field experiments. In the pot trial, plants in T₃ were the most reduced (89.4 and 90.0%) with those in T₁ being the least affected (82.0 and 78.4%), 12 weeks after infestation during the 2022 and 2023 cropping seasons. These showed the level of susceptibility of the variety examined to whitefly feeding effect, demonstrating the urgent need for development and deployment of safe and sustainable whitefly management measures so as to protect the crop and increase its productivity.

In an attempt to protect this crop against the whitefly infestation, efficacy of traditional treatments was evaluated using randomized block design (RBD) consisting of seventeen (17) treatments replicated three times for 45 days. The results revealed that the treatments examined were statistically different ($P < 0.05$), with neem leaf extract (60 mL/L) being highly effective with 1.6 and 1.3 whiteflies/leaf while, cow dung (50 mL/L) had the least effect with 10.6 and 10.8 whiteflies/leaf) as compared to the control (26.2 and 33.4 whiteflies/leaf), 45 days after the 3rd spray during the 2022 and 2023 experiments. The least average nymph population (1.0 and 1.3 nymphs/leaf) were recorded in cow urine (75 mL/L) and neem leaf extract (60 mL/L) while butter milk (50 mL/L) has the highest (13.3 and 8.8 nymphs/leaf) 45 days after the 3rd spray. The highest reduction (%) in were found in neem leaf extract (93.2 and 94%) and cow urine (91.2 and 94%) with cow dung recording the least overall average (57.5 and 63.7%), 45 days after the 3rd spray during the 2022 and 2023 experiments. The result remained

similar with nymphs' population having highest reduction recorded in neem leaf extract (93.2 and 93.9%) and cow urine (92.5 and 94.4%) while the least were recorded with cow dung (60.9 and 64.2%) in 2022 and 2023 experiments. Neem leaf extracts (60 mL/L) and cow urine (75 mL/L) were most effective and thus, recommended to be used in whitefly management (WFM) for sustainable eggplant cultivation.

Furthermore, *Citrus aurantifolia* Christm and *Eucalyptus camaldulensis* Dehnh extracts were examined under field conditions during the 2022 and 2023 cropping seasons. This was done in an effort to determine more robust strategies for sustainable whitefly control. Eucalyptus oil (30 mL/L) had the highest effect (1.8 and 1.5 whiteflies /leaf) while citrus essential oil (10 mL/L) and eucalyptus aqueous extracts (100 mL/L) were the least effective (12.2 and 11.3 whiteflies/leaf) 45 days after the 3rd spray during 2022 and 2023 experiments. The lowest nymphs' population (0.7 and 1.0 nymphs/leaf) were recorded with Eucalyptus oil (30 mL/L) while the highest (9.1 and 9.8 nymphs/leaf) were recorded with citrus aqueous extracts (100 mL/L) 45 days after the 3rd spray during 2022 and 2023 experiments. The highest reductions (%) in adult density were recorded in eucalyptus fermented extract (92.8%) and its essential oil (95.5%) while the least were recorded with citrus oil (10 mL/L) (62.5%) and eucalyptus aqueous extract (100 mL/L) (61.3%) during the respective years. Nymph population were most affected in eucalyptus oil (30 mL/L) (90.0 and 96.1%) with the least reduction (54.5 and 58.5%) found with citrus aqueous and eucalyptus fermented extracts (100 mL/L) 45 days after 3rd spray during 2022 and 2023 experiments. The phytochemicals analyzed in this research demonstrated high efficacy and are therefore recommended as eco-friendly alternatives to synthetic chemicals in the management of whiteflies for sustainable vegetable cultivation

An integrated pest management module was then developed using T-test design to evaluate the combined effect of the two best treatments from the traditional and plant phytochemicals strategies along with the yellow sticky traps and limited use of chemical as compared to chlorpyrifos 20% EC under field conditions. The results revealed that the bio pesticide and synthetic chemical differed significantly ($p < 0.05$) and were effective against the whiteflies. The highest (7.63 and 5.31 adult/leaf) and lowest (2.02 and 1.73

adult/leaf) population were recorded with the bio pesticide and synthetic chemical on the 15th and 45th days after the 1st and 3rd sprays during the 2022 experiment. During the 2023 trial, the least whitefly number (1.05 and 0.48 adults/leaf) were recorded for the bio pesticide and synthetic chemical, 45 days after the 3rd spray. The least (0.20 and 0.78 nymphs/leaf) and highest (3.77 and 4.12 nymphs/leaf) nymphs count were recorded for the synthetic chemical and bio pesticide respectively during the 2022 and 2023 experiments. The IPM strategy was effective in maintaining the whitefly population below the economic threshold level and thus, recommended to be used as substitute to synthetic chemical against the whiteflies for improved vegetable production in the area.

TABLE OF CONTENTS

DEDICATION	iii
DECLARATION	iv
CERTIFICATE	v
ACKNOWLEDGEMENTS	vi
ABSTRACT	vii
LIST OF TABLES	xvii
LIST OF FIGURES	xx
LIST OF ABBREVIATIONS	xxii
CHAPTER ONE	1
1.0. INTRODUCTION	1
1.1. Background of the study	1
1.2. Research problem	3
1.3. Justification/research rationale	4
1.4. Scope of the study	6
1.5. Aim and objectives of the research	7
CHAPTER TWO	8
2.0. LITERATURE REVIEW	8
2.1. Botanical description of eggplant (<i>Solanum melongena</i> L.)	8
2.1.1. Eggplant botanical features	8
2.2. Global production of eggplant	10
2.2.1. Climate and soil requirements in eggplant production	14
2.2.2. Agronomic practices in eggplant farming	16
2.2.2.1. Cultivar selection	16
2.2.2.2. Field preparation	17
2.2.2.3. Sowing and transplanting	17
2.2.2.4. Cropping patterns	19
2.2.2.6. Manure and fertilizer application	20
2.2.2.7. Weed management	20
2.2.2.8. Harvesting and yield	21
2.3. Economic importance of eggplant	21

2.4. Constraints in eggplant cultivation	23
2.4.1. Biotic stresses	23
2.5. The biology and distribution of whitefly (<i>Bemisia tabaci</i> Gennadius)	25
2.6. Host range and damage caused by <i>B. tabaci</i>	28
2.7. Whiteflies management (WFM) strategies	32
2.7.1. Traditional strategies	32
2.7.2. Cow based products for whitefly control	32
2.7.3. Ash and kerosene for whitefly management	33
2.7.4. Cultural practices in whitefly control	34
2.7.5. Plant based products and whitefly management	39
2.7.6. Biological strategies for whitefly control	44
2.7.7. Synthetic chemicals and whitefly control	49
2.7.8. Biotechnological strategies for whitefly control	52
2.7.8.1. Transgenesis and whitefly control	52
2.7.8.2. Exogenous application of DsRNA to control whiteflies	53
2.7.8.3. Control of <i>B. tabaci</i> through nanotechnology	54
2.7.8.4. Whitefly control through IPM methods	58
2.8. Research gap	63
CHAPTER THREE	64
3.0. MATERIALS AND METHODS	64
3.1. Study area	64
3.2. Seed procurement, germination and viability testing	64
3.2.1. Seedlings production	64
3.3. Soil analysis	65
3.4. Field clearance	66
3.5. Assessment of damage caused by whiteflies on eggplant	66
3.5.1. Plant culture and insect collection	66
3.5.2. Experimental design for damage assessment	66
3.6. Analyzing the efficacy of traditional strategies for the control of whiteflies	72
3.6.1. Seedlings production	72
3.6.2. Experimental design	72

3.6.3. Preparation of the treatments	73
3.7. Effect of plant-based extracts in whitefly management	76
3.7.1. Seedlings procurement	76
3.7.2. Experimental design	76
3.7.4. Preparation of aqueous plant extracts	76
3.7.5. Preparation of fermented extracts	77
3.7.6. Preparation of essential oils	78
3.7.7. Spray of the treatments and data collection	78
3.8. Efficacy of integrated pest management (IPM) strategy in whitefly control.	80
3.8.1. Field clearance and seedlings production.	80
3.8.2. Supply and preparation of the treatments	80
3.8.3. Experimental design	80
3.8.4. Spray of the treatments and data collection	81
3.8.5. Statistical analysis	83
CHAPTER FOUR	84
4.0. RESULTS AND DISCUSSION	84
4.1. Soil properties	84
4.2. Effects of whitefly infestation on the eggplant growth parameters in the field experiment	84
4.2.1. Plant height (cm)	84
4.2.2. Number of leaves	86
4.2.3. Leaf area (cm ²)	87
4.2.5. Leaf dry weight (g)	89
4.2.6. Dry matter (%)	90
4.2.7. Absolute growth rate (AGR, g day ⁻¹)	91
4.2.8. Relative growth rate (RGR, g ⁻¹ day ⁻¹)	92
4.2.9. Net assimilation rate (NAR, g m ⁻² day ⁻¹)	94
4.3. Effects of whitefly infestation on the eggplant growth parameters in the pot experiment	95
4.3.1. Plant height (cm)	95
4.3.2. Number of leaves	96

4.3.3. Leaf area (cm ²)	97
4.3.4. Fresh weight of leaves (g)	98
4.3.5. Dry weight of the leaves (g)	100
4.3.6. Dry matter (%)	101
4.3.7. Absolute growth rate (AGR) g day ⁻¹)	103
4.3.8. Relative growth rate (RGR, g ⁻¹ day ⁻¹)	104
4.3.9. Net assimilation rate NAR (g m ⁻² day ⁻¹)	105
4.4. Whitefly parameters on eggplant in the field experiment	107
4.4.1. Whitefly count in the field experiment	107
4.4.2. Whitefly infestation and symptoms development in the field experiment	114
4.4.3. Whitefly count on eggplant in pot experiment	117
4.4.4. Symptoms development and leaf damage in the pot experiments	124
4.4.5. Plant yield (kg/ha)	127
4.5. Reduction (%) in eggplant growth parameters by whitefly infestation	131
4.5.1. Reduction (%) under field experiment	131
4.5.2. Reduction (%) in pot experiment	134
4.6. Effects of traditional treatments against the whitefly (<i>B. tabaci</i> G.)	141
4.6.1. Effects on adult population	141
4.6.2. Effects of traditional treatments on the nymphs' population	149
4.7. The traditional treatments and reduction in whitefly population	158
4.7.1. Percentage reduction in adult population	158
4.8. Effects of plant-based treatments against the whitefly (<i>B. tabaci</i> G.)	169
4.8.1. Effects on the adults population	169
4.8.2. Effects on the nymphs population	178
4.8.3. Reduction (%) in whitefly population after the spray of plant-based treatments	185
4.8.3.1. Reduction (%) in adult population	185
4.9. Effect of IPM strategy and the synthetic chemical against the whiteflies	192
4.9.1. Effect on adult population	192
4.9.2. Effects on the nymphs' population	195

4.9.3. Reduction in average adults and nymphs population during the experiments	197
CHAPTER FIVE	204
6.0. SUMMARY, CONCLUSION AND RECOMMENDATIONS	204
6.1. Summary	204
6.2. Conclusion	204
6.3. Recommendations	205
BIBLIOGRAPHY	206
APPENDIXES	251
Appendix I	251
List of publications	251
List of conferences	257
Workshop attended	260

LIST OF TABLES

Table No.	Title	Page No.
2.1	Annual eggplant production by different countries (FAO STAT 2022)	10
2.2	Reports on the impact of whiteflies infestation on crop plants	31
2.3	Traditional whitefly management strategies on different crop plants	36
2.4	Reports on the use of plant-based products for whiteflies management	41
2.5	Reports on the biological methods for whiteflies control	46
2.6	Reports on the use of chemicals for Whiteflies management (WFM)	51
2.7	Reports on the use of genetic engineering strategies for whiteflies management (WFM)	56
2.8	Reports on the use of IPM strategies for whiteflies management (WFM)	60
3.1	Methods of testing the properties of the experimental soil	66
3.2	Various traditional treatments for whitefly management	75
3.3	Details of botanical treatments used against the whiteflies	79
4.1	Physico-chemical properties of the experimental soil	84
4.2	Effect of whitefly infestation on the plant height (cm) during the 2022 and 2023 field experiments	86
4.3	Whitefly infestation effect on the number of leaves during the 2022 and 2023 field experiments	87
4.4	Whitefly infestation effect on the leaf area (cm ²) of eggplant during the 2022 and 2023 field experiments	88
4.5	Effect whitefly infestation on the fresh weight (g) of the leaves during the 2022 and 2023 field experiments	89
4.6	Effect of whitefly infestation on the leaf dry weight (g) during the 2022 and 2023 field experiments	90
4.7	Effect of whitefly feeding on the leaf dry matter (%) during the 2022 and 2023 field experiments	92
4.8	Effect of whitefly feeding on the absolute growth rate (AGR, g day ⁻¹) of eggplant during the 2022 and 2023 field experiments	93
4.9	Whitefly feeding effects on the RGR of eggplant (g ⁻¹ day ⁻¹) during the 2022 and 2023 field experiments	94
4.10	Effect of whitefly infestation on the net assimilation rate of eggplant (g m ⁻² day ⁻¹) during the 2022 and 2023 field experiments	95
4.11	Effect of whitefly infestation on the plant height (cm) during the 2022 and 2023 pot experiments	97
4.12	Whitefly infestation effect on the number of leaves of eggplant during the 2022 and 2023 pot experiments	98
4.13	Whitefly infestation effect on the leaf area (cm ²) of eggplant during	99

	the 2022 and 2023 experiments	
4.14	Effect whitefly infestation on the fresh weight (g) of leaves during the 2022 and 2023 pot experiments	100
4.15	Effect of whitefly infestation on the leaf dry weight (g) during the 2022 and 2023 pot experiments	102
4.16	Effect of whitefly infestation on the eggplant dry matter (%) during the 2022 and 2023 pot experiments	104
4.17	Effect of whitefly feeding on the absolute growth rate (g day^{-1}) during the 2022 and 2023 pot experiments	105
4.18	Effect of whitefly infestation on the relative growth rate ($\text{g}^{-1} \text{day}^{-1}$) of eggplant during the 2022 and 2023 pot experiments	107
4.19	Effect of whitefly infestation on the net assimilation rate ($\text{g m}^{-2} \text{day}^{-1}$) during the 2022 and 2023 pot experiments	108
4.20	Average adult whitefly population/eggplant leaf during the 2022 and 2023 field experiments	110
4.21	Average nymph whitefly population/eggplant leaf during the 2022 and 2023 field experiments	112
4.22	Average whitefly egg counts /eggplant leaf during the 2022 and 2023 field experiments	114
4.23	Leaf damage (%) due to whitefly infestation during the 2022 and 2023 field experiment	117
4.24	Average adult whitefly population/leaf of eggplant during 2022 and 2023 pot experiments	120
4.25	Average nymph population/leaf of eggplant during 2022 and 2023 pot experiments	122
4.26	Average egg count/leaf of eggplant during the 2022 and 2023 pot experiments	124
4.27	Leaf damage (%) due to whitefly infestation during the 2022 and 2023 pot experiments	127
4.28	Plant yield (kg/ha) under field condition during 2022 and 2023 field experiments	131
4.29	Plant yield (kg/ha) during the 2022 and 2023 pot experiments	132
4.30	Average adult whitefly population on the eggplant leaves before and after the 1 st foliar spray of traditional treatments during the 2022 and 2023 cropping seasons	146
4.31	Average adult whitefly population on the eggplant leaves after the 2 nd foliar spray of traditional treatments during the 2022 and 2023 cropping seasons	148
4.32	Average adult whitefly population on the eggplant leaves after the 3 rd foliar spray of traditional treatments and their effect on plant yield during the 2022 and 2023 cropping seasons	150

4.33	Average nymph whitefly population on the eggplant leaves before and after the 1 st foliar spray of traditional treatments during the 2022 and 2023 cropping seasons	154
4.34	Average nymph whitefly population on the eggplant leaves after the 2 nd foliar spray of traditional treatments during the 2022 and 2023 cropping seasons	156
4.35	Average nymph whitefly population on the eggplant leaves after the 3 rd foliar spray of traditional treatments during the 2022 and 2023 cropping seasons	158
4.36	Average adult whitefly population on the eggplant leaves before and after the 1 st foliar spray of plant-based extracts during the 2022 and 2023 cropping seasons	170
4.37	Average adult whitefly population on the eggplant leaves after the 2 nd foliar spray of plant-based extracts during the 2022 and 2023 cropping seasons	172
4.38	Average adult whitefly population on the eggplant leaves after the 3 rd foliar spray of plant-based extracts and their effect on plant yield during the 2022 and 2023 cropping seasons	174
4.39	Average nymph whitefly population on the eggplant leaves after the 1 st foliar spray of plant-based extracts during the 2022 and 2023 cropping seasons	177
4.40	Average nymph whitefly population on the eggplant leaves after the 2 nd foliar spray of plant-based extracts during the 2022 and 2023 cropping seasons	179
4.41	Average nymph whitefly population on the eggplant leaves after the 3 rd foliar spray of plant-based extracts during the 2022 and 2023 cropping seasons	181
4.42	Effect of bio pesticides (A) and synthetic chemical (B) against the adult whitefly population after the 1 st , 2 nd and 3 rd sprays in 2022 experiments	192
4.43	Effect of the bio pesticides (A) and synthetic chemical (B) against the adult whitefly population after the 1 st , 2 nd and 3 rd sprays in 2023 experiments	193
4.44	Effect of bio pesticides (A) and synthetic chemical (B) against the nymphs' population after the 1 st , 2 nd and 3 rd sprays in 2022 experiment	195
4.45	Effect of bio pesticides (A) and synthetic chemical (B) against the nymphs' population after the 1 st , 2 nd and 3 rd sprays in 2023 experiment	196

LIST OF FIGURES

Figure No.	Title	Page No.
2.1	The whitefly life cycle	29
3.1	Fig 3.1: Map of Aliero Local government Area, kebbi State Nigeria	
3.2	Field layout showing the experiment plots divisions	
3.3	Insect collection from the farmers' field	69
3.4	Field layout for damage assessment in the field experiment	70
3.5	Field layout for damage assessment in the pot experiment	71
3.6	Data collection on plant growth parameters	71
3.7	Recording data on whitefly parameters	72
3.8	Field plots for assessing the effects of different treatments against the whiteflies	81
3.9	Spray of the treatments and data recording from the field experiments.	82
3.10	IPM modules for whitefly management	82
4.1	Symptoms development due to whitefly infestation and on the eggplant leaf during the 2022 and 2023 cropping seasons	130
4.2	Yield percentage in the experimental plots for the respective cropping seasons	133
4.3	Reduction in growth parameters 30 days after infestation in 2022 and 2023 field experiments	135
4.4	Reduction (%) in growth parameters 60 days after infestation in 2022 and 2023 field experiments.	136
4.5	Reduction (%) in growth parameters 90 days after infestation in 2022 and 2023 field experiments.	137
4.6	Reduction (%) in growth parameters in the pot experiment 30 days after infestation in 2022 and 2023 experiments.	138
4.7	Reduction (%) in growth parameters in the pot experiment 60 days after infestation in 2022 and 2023 experiments.	139
4.8	Reduction (%) in growth parameters in the pot experiment 90 days after infestation in 2022 and 2023 experiments.	140
4.9	Reduction (%) in adult whitefly population 15 days after the 1 st spray of traditional treatments in 2022 and 2023 experiments	161
4.10	Reduction (%) in adult whitefly population 15 days after the 2 nd spray of traditional treatments in 2022 and 2023 experiments	161
4.11	Reduction (%) in adult whitefly population 45 days after the 3 rd spray of traditional treatments in 2022 and 2023 experiments	162
4.12	Reduction (%) in nymph whitefly population 15 days after the 1 st spray of traditional treatments in 2022 and 2023 experiments	163
4.13	Reduction (%) in nymph whitefly population 30 days after the 2 nd spray of traditional treatments in 2022 and 2023 experiments	163

4.14	Reduction (%) in nymph whitefly population 45 days after the 3 rd spray of traditional treatments in 2022 and 2023 experiments	164
4.15	Reduction (%) in adult whitefly population 15 days after the 1 st spray of plant extracts in 2022 and 2023 experiments	184
4.16	Reduction (%) in adult whitefly population 30 days after the 2 nd spray of plant extracts in 2022 and 2023 experiments	184
4.17	Reduction (%) in adult whitefly population 45 days after the 1 st spray of plant extracts in 2022 and 2023 experiments	185
4.18	Reduction (%) in nymph whitefly population 15 days after the 1 st spray of plant extracts in 2022 and 2023 experiments.	186
4.19	Reduction (%) in nymph whitefly population 30 days after the 2 nd spray of plant extracts in 2022 and 2023 experiments.	186
4.20	Reduction (%) in nymph whitefly population 45 days after the 3 rd spray of plant extracts in 2022 and 2023 experiments.	187
4.21	Average adult whitefly number per trap in 2022 and 2023 experiments	
4.22	Reduction trends in average adult whitefly population/leaf of eggplant during the 2022 experiments	193
4.23	Reduction trends in average adult whitefly population/leaf of eggplant during the 2023 experiment	197
4.24	Reduction trends in average nymphs' whitefly population/leaf of eggplant during the 2022 experiment	198
4.25	Reduction trends in average nymphs' whitefly population/leaf of eggplant during the 2022 experiment	198

LIST OF ABBREVIATIONS

Abbreviation	Full form
ANOVA	Analysis of variance
AE	Aqueous extract
AGR	Absolute growth rate
Cm	Centimeter
cm ²	Centimeter square
CD	Critical difference
CID	Confidence interval of the difference
CRD	Completely randomized design
DAS	Days after the spray
DF	Degree of freedom
DLCV	<i>Duranta leaf curl virus</i>
DW	Dry weight
DM	Dry matter
DsRNA	Double stranded ribonucleic acid
EM	Effective microorganism
ETL	Economic threshold level
EFSB	Eggplant fruit and shoot borer
EMLMV	Eggplant mild leaf mottle virus
EO	Essential oil
FE	Fermented extract
FBEs	Fermented botanical extracts
Fw	Fresh weight
G	Gram
Ha	Hectare
h	Hour
IPM	Integrated pest management
ITK	Indigenous technical knowledge
IU	International unit
Kg	Kilogram
L	Liter
l/ha	Liter per hectare
LA	Leaf area
M	Meter
MD	Mean difference
Min	Minutes
MtCOI	Mitochondrial cytochrome oxidase subunit
MEAM1	Middle East-Asia Minor 1
Mg	Milligram
mL	Milli liter

mL/L	Mill liter per liter
NS	Non-significant
NAR	Net assimilation rate
pH	Hydrogen ion concentration
RBD	Randomized blocked design
RGR	Relative growth rate
SD	Standard deviation
SEM	Standard error mean
TOG	Total organic carbon
ToTV	Tomato torado virus
ToCV	Tomato chlorosis virus
TYLCV	Tomato yellow leaf curl virus
UV	Ultra-violet
V/V	Volume by volume
WFM	Whiteflies management
w/v	Weight by volume
°C	Degree celsius
%	Percentage

CHAPTER ONE

1.0. INTRODUCTION

1.1. Background of the study

The eggplant (*Solanum melongena* L., family Solanaceae: widely recognized as brinjal), is an important agricultural crop cultivated universally (Asia, Europe, and Africa) for its diverse nutritional and health benefits (Quamruzzaman 2021; Mwinuka et al.2022). The family solanaceae includes other vegetable crops like green pepper (*Capsicum* sp), tomato (*Lycopersicon* sp.) and potato (*Solanum* sp.) species (Motti, 2021; Ibade et al. 2022).It is among the most widely cultivated vegetables worldwide, covering an estimated area of about 2 million hectares, yielding around 33 million tons, with a net value surpassing US\$10 billion annually (Taher et al. 2017; Farouk et al. 2021). Currently, China holds the top position among the eggplant producing nations with more 50% of the global area used for eggplant cultivation. India comes in second and account for one quarter of the worldwide production followed by Indonesia, Egypt, Turkey, and Iraq being among the major eggplants producing countries globally (FAO 2019; Farouk et al. 2021).

Morphologically, the stem of eggplant is simple, long characterized with branches on which coarsely lobed leaves with green color are placed alternatively. The crop has purple flowers that are 3–5 cm in diameter. The fruits are huge, fleshy ovoid berry having shiny soft skin containing many seeds that may grow to a height of 40 cm (15.7 in) long. The fruit's color may differ, ranging from green, yellow, white, black to purple. The eggplant crop can grow to a height of 1.5 m (4.9 ft.) under ideal environmental conditions. Although eggplant species are perennial crops, they are mostly planted as annuals (Gowda 2016; Naeem and Ugar 2019; Jaiswal 2020; Fallahi et al. 2022). This vegetable (*Solanum melogena* L.) is scientifically placed under the order solanales and family solanaceae (PBI 2011; Knapp et al. 2019).

Eggplant has been cultivated for centuries being a significant source of dietary fiber (9%), proteins (12.55–12.77%), vitamins (7–22%), carbohydrates (62–68%) and minerals

(283.8 mg/100 g) (Farouk et al. 2021; Bunmee et al. 2022). The fruits of eggplant are also known for being low in calories (24 calories/100g of the fruits), moisture, and fat (0.3g/100g) respectively (Saeedifar et al. 2014). In terms of physiochemical properties, the crop is well known to possess useful substances including phenolic (caffeic, p-coumaric, chlorogenic acid etc.), flavonoids (nasunin, delphinidin3coumaroylrutinoside-5-glucoside etc.) (Padmanabhan 2016), steroid alkaloids (nicotinoid alkaloids) (Moldoveanu et al. 2016), tropane, aspartic acid (Naeem and Ugur 2019), glycoalkaloids (α -solamargine, α -solasonine etc.) (Friedman 2015), tryptophan, lanosterol, and oxalic acid among others (Padmanabhan 2016; Naeem and Ugur 2019; Sharma and Kaushik 2021). these compounds were reported to be effective in the treatment of various ailments, as they served as anti-cancer, antiinflammatory, anti-asthmatic, antioxidants and antimicrobial substances that are hepato as well as cardio protective (Naseem and Ugur 2019; Sharma and Kaushik 2021; Agregan et al. 2021).

Considering the diverse functions of eggplant in different areas of human perspectives, the crop productivity needs to be enhanced globally, and particularly in the developing nations. However, the production of this crop is currently constrained by both biotic and abiotic factors, hindering the potential of the crop (Magioli and Mansur 2005; Alam and Salimullah 2021). This is due to the fact that most of the cultivated genotypes lacked sufficient tolerance levels to the biotic and abiotic stresses (Magioli and Mansur 2005). Fluctuation in temperature (IPCC 2007; Concellon et al. 2007), salinity (Al-Zubaidi 2018), drought (Monti et al. 2006; Sohrabi et al. 2023), waterlogging (Alam and Salimullah 2021), and heavy metal concentrations (Youssef and Abd El-Gawad 2018) are among the abiotic factors affecting eggplant cultivation worldwide. Similarly, several biotic factors including pathogenic organisms such as fungi and bacteria (Bhatti et al. 2013; Nishat et al. 2015; Nahar et al. 2019), viruses (Lu et al. 2019; Estefanía Rodríguez et al. 2019) and insect pests (aphids, colorado potato beetles, shoot and fruit borer, thrips, spotted beetles, leafhopper, stem borer, blister beetles, spider mites and whiteflies) also affect the production potential of this vegetable (Sani et al. 2020; Ugwu et al. 2021; Alam and Salimullah, 2021; Manna et al. 2023).

1.2. Research problem

Eggplant is among the most popularly grown vegetables in the family solanaceae (Chapman 2019), as it was ranked 5th following tomatoes, onions, cucumbers and gherkins, as well as cabbages with regards to total universal production (Alam and Salimullah 2021). The members of this family provide good number of nutrients and other substances that are beneficial to human health, which explains in part why it has a high variety of species utilized for food or medication (Meyer et al. 2015; Chapman 2019). Eggplant is also recognized as a rootstock for tomatoes due to its tolerance to waterlogging and pathogenic attack (Bletsos et al. 2003; Meyer et al. 2015).

Despite all these benefits, eggplant growth has been hindered by whitefly infestations (Islam et al. 2011; Lee et al. 2018). Decrease in the fresh leaf area, leaf fresh and dry weights were reported as 26.6, 21.8 and 19.27% respectively due to whitefly feeding effects (Islam and Shunxiang 2009). Similarly, the chlorophyll content and photosynthetic activity were negatively affected and reduced by 9.7 and 65.9% respectively (Islam and Shunxiang 2009). Furthermore, infestation by large population of whiteflies leads to dropoff of immature leaves, and release of sugary excreta (honeydew) that provides breeding ground sooty mold. Sooty mold turns the leaves black, decrease the rate of photosynthesis, affect plant vigor and consequently the quality of farm produce (Boopathi et al. 2015; Solanki et al. 2018; Perring et al. 2018). Whiteflies feeding also lead to leaf mosaic and wrinkling, which cause stunting and disfigured fruits (Sayed et al. 2009; Sani et al. 2020). Beside the physiological effects, whitefly infestation also affects eggplant structural tissues causing multiple necrotic rings on the leaves (Abubakar et al. 2022), blanching of vegetative structures, and irregular ripening or other abnormalities of fruiting structures. As a phloem feeder, *B. tabaci* can also reduce the eggplant productivity by directly consuming the carbohydrates along with other nutrients through the plant's vascular system. Islam and Shunxiang (2009) reported that leaf anatomy particularly the vascular tissue of eggplant was negatively affected by whitefly infestation. where they demonstrated that the xylem of damaged vascular bundles of infested leaf could not transport water and dissolved ions from the roots to the leaves as they are

composed of various cell types including tracheids and vessel elements. The phloem was unable to transport synthesized organic substances such as carbohydrates and other products of photosynthesis from the leaves to other regions of the plant. However, they reported that the eggplant epidermis and mesophyll were not damaged by whitefly infestation but there were some damage tissue observed in the vascular bundle of infested leaf (Islam and Shunxiang 2009).

Whitefly was also known to vector more than 350 species of viruses in plants (Gotz and Winter 2016; Lu et al. 2019; Estefanía Rodríguez et al. 2019). Eggplant, tomato, potato and soybean have been reported to be susceptible to such viruses (Kedar et al. 2014). Begomoviruses are the primary cause of crop reduced productivity, extending from 20–100% losses in crop yield worth millions of dollars (Gangwar et al. 2018). Eggplant mild leaf mottle virus (EMLMV) (lapidot et al. 2014), Tomato torado virus (ToTV) (Amari et al. 2017), Tomato chlorosis virus (ToCV) and Tomato yellow leaf curl virus (TYLCV) which are vectored by whiteflies and frequently seen in tomatoes also affect eggplants (Fidan and sarikaya 2020). In a nut shell, whiteflies are among the common destructive agricultural pests, affecting various vegetables and other food crops characterized with both primary and secondary effects causing crop losses of up to 100% (Barkman 2013; Singh and Aggarwal 2023).

1.3. Justification/research rationale

Whiteflies (*Bemisia tabaci* Genn.) are phytophagous aggressive hemipteran species that depend primarily on plants leaf tissue and spread deadly viruses, causing substantial losses in different crop plants. They are now exclusively controlled using chemical insecticides, but their ability to develop resistance to insecticide has made their management extremely difficult (Muhammadali et al. 2019). Also, the injudicious application of the chemicals has led to different negative effect to human health and ecosystem (Sani et al. 2020). The development of a safer and cost-effective alternatives for the management of such destructive insect species is therefore crucial. Various techniques have been used in this regard, for instance, the transgenic technology using plants containing insecticidal toxins developed through nuclear or chloroplast

transformation is a potential medium for whitefly management (Suhag et al. 2020). Non transgenic technique has also been used to introduce DsRNA to manage whitefly population in different crop varieties and it was found to be effective. However, these techniques are very expensive, time consuming and are associated with various ethical issues in different part of the world. Moreover, even the Btbrinjal which is tolerant to attack by lepidopterans, is susceptible to whiteflies because the Bt toxin is ineffective against the sap sucking insect pests like aphids and whiteflies (Nasif 2017; Singh 2018). Similarly, many plant based products like plant essential oils and plants extracts have a wide range of effects against different insect pests. They have long been reported as appealing alternatives to synthetic chemicals for insect pest management being safe/less harmful to the environment (Wagan et al. 2018; Zeshan et al. 2020). Despite reports from the various studies demonstrating the effectiveness of plant-based chemicals against the arthropods and little negative effects on the ecosystem, very few botanicals are currently employed in agriculture in the industrialized world, and novel botanical products have minimal economic possibilities (Tembo et al. 2018). Indigenous technical knowledge including the application of fermented curd water, cow dung with fermented plant extracts, cow urine-water formulations and the use of ash have also been used traditionally to control several insect pests on agricultural crops (Kumar et al. 2002; Shailaija et al. 2012; Celsia and Janarthanan 2019; Papnai et al. 2020). However, these techniques are mostly applied unilaterally instead of using integrated pest management to improve the efficacy. As a result, insect pest control that is both ecologically and economically viable has caught the attention of crop producers globally. At this point, the use of indigenous technical practices, plant-based phytochemicals and integrated pest management strategies using natural products will be substantial in the achievement of this goal. Considering their effectiveness, it is hypothesized that their application in an integrated pest management regime can go a long way in providing effective alternative to synthetic chemicals (Chhetri, 2018). The results of this study will be of great importance to the society particularly small-scale farmers cultivating eggplants in the area who struggle to keep up with the recurrent increase in the cost of synthetic chemicals.

It might also lead to decrease in over dependence on the harmful synthetic pesticides, enhance agricultural productivity, reduce the cost of crop production and the farm products and increase farmers' profitability. To the best of my knowledge, there was no report on the application of these strategies for whitefly management on vegetables, specifically green round eggplant (*Solanum melongena* L.) cultivar in the study area.

1.4. Scope of the study

In the current study, the effects of whitefly infestations on eggplant were evaluated using both open field and indoor trials. An attempt was made to provide a robust, ethically viable, safe and cost-effective strategy for the management of whitefly feeding effects on eggplant crop under field conditions. Different strategies including the use of indigenous locally available natural products that are harmless or have little effects to the humans and ecosystem were deployed. Plant based products including the aqueous extracts, fermented extracts and essential oils were also examined during the study. Additionally, indigenous technical practices like the use of cow urine, cow dung, and fermented curd water neem leaf and chili pods extracts along with liquid detergents have been covered as well during the research. Furthermore, an integrated pest management (IPM) approach was assessed using the most effective treatments from the plant-based and traditional methods along with yellow sticky traps for effective control of whiteflies on eggplants in the study area. All the experimental works were carried out in the agricultural research farm of Kebbi State University of Science and Technology, Aliero, Kebbi State, Nigeria during the 2022 and 2023 cropping seasons.

1.5. Aim and objectives of the research

This study aims to determine the extent of damage and the effects of different management strategies (traditional, botanicals, IMP approach: limited use of chemicals) for the control of whitefly infestation for sustainable eggplant cultivation in North West, Nigeria. The specific objectives were:

1. To assess the extent of damage caused by whiteflies on eggplant.
2. To analyze the efficacy of traditional strategies for the control of whiteflies.
3. To examine the effect of botanical extracts for the control of whiteflies.
4. To evaluate an IPM strategy against the whiteflies.

CHAPTER TWO

2.0. LITERATURE REVIEW

2.1. Botanical description of eggplant (*Solanum melongena* L.)

2.1.1. Eggplant botanical features

Eggplant is a vegetable crop found in the tropical and subtropical regions of the globe which belongs to the nightshade/solanaceous family, a taxon of flowering plants in the order solanales (Ghosh 2022). Members of this family vary greatly in terms of appearance and ecology, and they are well recognized to contain a varied variety of alkaloids that are either useful or harmful in nature (Sharma and Kaushik 2021; Agregan et al. 2021). The plant possesses multiple branches and leaves characterized with a star-like (stellate) hair and stems. It is an annual herb to a short-lived perennial sub-shrub that grows 40 to 150 cm high in full sunlight with plenty of moisture and needed amount of nutrients. The crop is heterozygous with $2n = 24$ as the chromosomal number. The vegetable possessed an erect or semi-spreading habits/features (Srinivasan, 2009; Portis et al. 2015). The stem can be either spiny or non-spiny, with or without purple pigmentation owing to the presence of anthocyanin. In some eggplant cultivars, the stems, leaves, and calyx are also spined in nature (DBT 2014; Ro et al. 2022). Eggplants are generally known to have branching stems upon which simple, flat, long, green colored and coarsely lobed leaves are alternately arranged. The foliage pattern is typically opposite, big, and single lobed, with abundant wool-like hairs on the interior of most of the cultivars (DBT 2014; Ro et al. 2022). The midrib regions may or may not have spines while the tip angle and leaf blade are acute to highly obtuse in nature. The plant displays a solitary flowering pattern most of the time, but it may have a cluster of 2-5 flowers on certain varieties, rendering the single or clustered inflorescence an inherent characteristic that varies depending on the cultivar (Oladosu et al. 2021; Moenga et al. 2022). The color of eggplant leaves is predominantly green; however, this may differ depending upon the age and plant variety. Numerous eggplant varieties have conventional purple-tinged

leaves, while others have beautiful white or light green lining on the surface of the leaf. The leaves of the wild species had complex uni-pinnate venation, indicating separate vein size orders that are discrete in nature. The primary vein, also known as the midvein, is continuous with the vascular stem bundles that runs along the leaf length (Agregan et al. 2021; Ghosh, 2022).

Various shapes and sizes of nutritious/edible and attractive fruits are produced by eggplant. The fruit of eggplant is berry, fleshy, pendent, and developed singly or in groups with a variety of sizes, shapes, and colors. (DBT 2014; Mangino et al. 2021). The fruit has numerous seeds internally, that can range in shape from depressed globose to ellipsoid, ovoid, obovoid, oblong, round, cylindrical, or even serpentine. Its length and width are 2-35 and 2-20 cm respectively (Sharma and Kaushik 2021; Mangino et al. 2021). The color of grown-up fruit varies greatly depending on the cultivar ranging from green, white, purple, yellow, pale violetpurple hues to black, occasionally netted or streaked when fully ripped. The fruit is also known to have a smooth, glossy thin skin on the outside, and its interior consists of white pulp with centrally arranged, small, soft seeds (Bose et al. 2002; DBT 2014). The fruits contain numerous small edible seeds that have a mild taste but a slightly bitter flavor due to the presence of nicotinic alkaloids (Bose et al. 2002; DBT 2014). The seeds are pale-brown, flattened, and have a lenticular to reniform shape, measuring around 2.8–3.9 and 2.5–3.5 mm in length and width respectively (Ghosh et al. 2022). Each fruit can contain about fifty to a large number of seeds, although dormancy is often observed, depending on the harvest conditions and the specific variety being cultivated (DBT 2014; Taher et al. 2017). Breaking of seed dormancy can be achieved by storing the seeds in chilled environmental conditions for a short period of time (Daunay et al. 2004; Yogeasha et al. 2006).

The eggplant flower is highly attractive due to its vibrant violet color, and it can be found either individually or in clusters of 2-7 flowered cymes. Its star-shaped structure is supported by short stalks and features five stamens attached to the corolla tube, along with a single superior ovary (DBT 2014; Ghosh 2022). This flower is hermaphroditic, exhibiting both male and female reproductive organs. It follows a pentamerous pattern,

characterized by its complete and symmetrical nature. The calyx, which forms a cup-like structure at the base, consists of five lobes that are fused together and persist over time. The calyx may have either spiny or non-spiny attributes. The flower comprises five united and persistent sepals (calyx), five united and mostly cup-shaped petals (corolla), five stamens alternating with the corolla (androecium), and united carpels with a superior ovary (gynoecium) (DBT 2014; Ghosh 2022). The eggplant flower displays corolla lobes of varying shapes and colors, such as purple, light pink, or white. The stamens are unattached/free and are positioned at the corolla throat, creating a loose cone around the style. The anthers are separate and open through pores, forming a cone-shaped structure. The gynoecium of the eggplant flower is syncarpous and hypogynous, located obliquely to the median. In most cultivars, the perfect flowers are solitary and grow opposite the leaves (DBT; 2014). The ovary has two chambers with numerous ovules, consisting of two fused carpels and positioned below the other floral parts (hypogynous) with basal placentation. Heterostyly, where flowers have different styles and stamen lengths, is a common characteristic of eggplant flowers (Bose et al. 2002). From a taxonomic perspective, *Solanum melongena* L. belongs to the kingdom Plantae, division Tracheophyta, class Magnoliopsida, order Solanales, family Solanaceae, and genus *Solanum* (Iqbal and Qadeer, 2022)

2.2. Global production of eggplant

Eggplant is a universally grown being cultivated in Asia, Europe, Africa and America (Nino-Medina et al. 2017). The high interest in eggplant cultivation is driven by its rich nutritional profile and its versatility in various culinary preparations. This includes its use in creating fresh, frozen, or canned dishes, such as pickled, fried, grilled, or stuffed eggplant, as well as its incorporation into a wide range of cuisines, including eggplant kibbeh, and various stews that feature eggplant as a main component (Gürbüz et al. 2018; Kumar et al. 2020). The data on the global production of eggplant are presented in table2.1. The data revealed a global production of up to 54,108,247tons. As depicted in the table, over 94% of global eggplant production is attributed to Asia, with Africa contributing 3.4% and Europe accounting for 1.7% of the total production, with

estimated global eggplant cultivation area of 1,865,801 ha (Karimi et al. 2021). China is the global leading producer of eggplant with 34,137,557 tons/year followed by India (12,826,000) and Egypt being the third largest producer with up to 1,409,202 tons/year (Faostat, 2022).

Table 2.1: Annual eggplant production by different countries (FAOSTAT 2022)

Country	Total production (Tons)	Production/person (Kg)	Area covered (Ha)	Yield (Kg/ha)
China	34,137,557	24.491	804,618	42,427
India	12,826,000	9.597	736,000	17,426.6
Egypt	1,409,202	14.454	46,849	30,079.5
Turkey	836,284	10.349	23,969	34,890.9
Iran	666,838	8.156	21,492	31,028
Indonesia	551,552	2.081	44,016	12,530.7
Japan	300,400	2.375	8,970	33,489.4
Italy	298,313	4.936	9,560	31,205
Philippines	244,838	2.301	21,651	11,308.3
Spain	238,325	5.108	3,619	65,853.8
Algeria	181,618	4.269	5,978	30,382.5
Mexico	179,656	1.44	2,330	77,106.9
Romania	137,829	7.059	9,025	15,271.9
Sri Lanka	129,212	6.026	10,834	11,926.5
Syria	128,290	7.016	6,336	20,248.9
Iraq	113,699	2.89	6,307	18,028
United States of America	103,003	0.314	2,581	39,915.5
Côte d'Ivoire	100,146	4.021	17,619	5,684

Kazakhstan	95,233	5.212	4,213	22,603.8
Sudan	92,558	2.269	6,710	13,794.6
Pakistan	87,587	0.434	8,575	10,214.2
Mali	80,528	4.214	5,227	15,406.2
Azerbaijan	79,724	8.054	4,583	17,395.5
Jordan	71,473	6.986	2,105	33,951.2
Greece	70,940	6.588	1,670	42,479
Ukraine	68,510	1.621	5,200	13,175
Palestinian Territories	59,480	13.073	1,212	49,073.5
The Netherlands	55,000	3.188	105	523,809.5
Rwanda	53,277	4.439	4,914	10,842.3
Ghana	53,114	1.794	6,266	8,477.2
Morocco	52,754	1.517	1,962	26,894.7
Israel	51,404	5.771	1,130	45,484
North Korea	48,561	1.896	5,463	8,888.4
Guyana	47,992	61.353	735	65,304.5
Lebanon	41,621	6.83	1,539	27,036.1
Taiwan	34,561	1.466	1,298	26,626.3
Oman	32,214	6.429	690	46,687
France	31,989	0.475	796	40,187.2
Albania	31,491	10.971	1,168	26,961.5
Malawi	29,242	1.631	967	30,239.9
Kuwait	27,601	6.53	328	84,149.4
Dominican Republic	26,851	2.615	4,150	6,469.6

Saudi Arabia	25,384	0.76	1,453	17,470
United Arab Emirates	20,859	2.186	453	46,046.4
Thailand	19,926	0.288	651	30,595.2
Venezuela	17,206	0.541	1,479	11,634.7
Bulgaria	11,260	1.597	439	25,649.2
Uzbekistan	10,935	0.335	493	22,196.1
Belgium	10,120	0.886	22	460,000
Honduras	9,948	1.104	321	30,991
Niger	8,512	0.397	584	14,565.9
South Korea	5,472	0.106	324	16,875.4
Portugal	5,209	0.506	113	45,906.7
Moldova	5,022	1.414	472	10,639.8
Yemen	4,809	0.166	609	7,892.7
Georgia	3,700	0.992	483	7,667.2
Senegal	3,655	0.232	383	9,540.3
Libya	3,529	0.545	181	19,508.2
Colombia	3,524	0.071	446	7,895.8
Qatar	2,902	1.184	116	25,017.2
Congo-Brazzaville	2,651	0.491	309	8,588
Mauritius	2,495	1.973	255	9,784.3
Fiji	2,424	2.739	110	22,036.4
Cameroon	2,386	0.1	314	7,594.2
Cyprus	2,335	2.732	31	75,322.6
Lithuania	2,200	0.786	1,062	2,071.7

Serbia	2,040	0.291	100	20,472.6
Madagascar	2,035	0.077	503	4,044.2
Bahrain	1,456	0.973	22	67,362.3
Austria	1,130	0.128	9	122,804.3
Macedonia	1,035	0.499	56	18,469.2
Tunisia	884	0.077	63	13,968.5
Hungary	867	0.089	66	13,136.4
Haiti	856	0.077	70	12,262.4
Malta	838	1.762	29	28,917.7
Croatia	585	0.14	55	10,636.4
Bhutan	585	0.805	165	3,545.5
Kyrgyzstan	563	0.089	264	2,130
Trinidad and Tobago	488	0.36	299	1,632.1
Peru	476	0.015	38	12,562
Antigua and Barbuda	416	4.821	67	6,216
Jamaica	385	0.141	33	11,538.9
Brunei	283	0.67	35	8,000.4
Gabon	244	0.118	46	5,268.6
Costa Rica	96	0.019	18	5,252.9
Djibouti	55	0.052	N/A	N/A
Total	54,108, 247	315,573	1,865,801	3,028,663.40

2.2.1. Climate and soil requirements in eggplant production

The ideal temperature in eggplant cultivation ranges from 21-30°C for high yields, being a warm-season crop that is negatively affected by severe frost (DBT 2014; Shimira and Taskin, 2022). The crop is sensitive to frigid temperatures and severe frost and it needs a

lengthy growing season with averagely high day and night temperature for the seed to germinate and high yield be achieved. The growth of younger plants is retarded when night temperature falls below 16°C, with fruit setting getting retarded also when the temperature is cool with cloudiness (DBT 2014; Shimira and Taskin, 2022). The crop is drought and high rainfall tolerant, but fails to grow properly when the temperature surpass 30°C. The vegetative development of the plant is high under high temperatures and humidity, but the fruit setting and crop yield are highly influenced by high day and night temperatures ranging from 33-35°C to 22-24°C (Kumar et al. 2000; Potop et al. 2014). Eggplants thrive under optimal conditions of sunlight, temperature, humidity, and watering, but these conditions can be challenging to maintain in open-field environments (Sade et al. 2012). Proper germination of eggplant pollen as well as fruit setting require night and day temperatures above 15 °C and 40 °C respectively, although ideal development occurs at roughly 22 °C with high light conditions (Uzun 2007; Makrogianni et al. 2018). Vegetables including eggplants are additionally vulnerable to adverse abiotic factors (heat, drought, and salt stress), which have been shown to raise the osmotic molecules and antioxidants concentration in the fruit, affecting both leaf and fruit aesthetics as well as their nutritional values (Mibei et al. 2017; Lin et al. 2022). Eggplant can be cultivated in a diverse range of soils. However, it is generally preferred to be grown in a well-drained, fertile soil with organic-rich content and a pH level between 5.5 and 6.6 (Ghosh, 2022). In certain cases, specific eggplant varieties can tolerate higher pH levels by applying adequate organic manure prior to transplanting (Bose et al. 2002). Sandy loam soil is often the favored choice, especially when early eggplant yield is desired. It is important to avoid waterlogged and highly acidic soils as they can lead to the development of root-rotting disorders. Eggplant plants thrive and produce abundant yields during the rainy season, particularly in warm and humid climatic conditions. However, growing eggplants in heavy clay and saturated soils can contribute to the accumulation of root-rot disease. The crop should not to be rotated with other solanaceous crops like tomato, pepper, and potato, as they are prone to similar diseases and insect pests attack (Ghosh, 2022).

2.2.2. Agronomic practices in eggplant farming

2.2.2.1. Cultivar selection

Several eggplant cultivars including landraces and improved varieties differing morphologically in terms of shape, size, and fruits color are produced in various regions across the globe. The selection of the appropriate eggplant cultivar is crucial for successful cultivation, taking into account consumer preferences and the specific conditions of each region. Farmers typically consider several factors when choosing eggplant varieties for their farms. Some of the important traits and characteristics they look for include:

1. **Pest and disease resistance:** Farmers prefer cultivars that exhibit tolerance or resistance to common pests and diseases that affect eggplants, such as aphids, mites, fruit borers, and fungal infections. This helps reduce the need for excessive pesticide applications and ensures better crop health.
2. **High yield:** Varieties with high yield potential are desirable for commercial production. Farmers look for cultivars that consistently produce a good number of high-quality fruits per plant, as this directly impacts their profitability.
3. **Fruit quality:** Consumers often prefer eggplants with certain characteristics, such as soft flesh, low seediness, attractive glossy skin, and appealing fruit color. Varieties that meet these preferences tend to have better market acceptance.
4. **Growth habit:** Upright and sturdy growth habits are beneficial for ease of management, harvesting, and supporting the weight of the fruit. Compact and well-branched plants are also preferred as they can optimize space utilization and increase overall productivity.
5. **Low solanine content:** Solanine is a natural toxic compound found in nightshade vegetables, including eggplants. Varieties with low solanine content are generally preferred as they pose fewer health risks (Alicia et al. 2019; Ghosh, 2022).

In addition to these factors, farmers may also consider the adaptability of the cultivar to local climatic conditions, such as temperature and humidity, as well as its response to specific soil types. To make informed decisions about the appropriate eggplant cultivars, vegetable producers often rely on local agricultural research institutions, extension services, and seed suppliers. These sources can provide valuable information on cultivar performance, disease resistance, agronomic practices, and market demands specific to their region. It's important for farmers to balance consumer preferences, market demands, and agronomic requirements to choose the most suitable eggplant cultivars that align with their production goals and local conditions (Caruso et al. 2017; Singh et al. 2019; Alicia et al. 2019; Ghosh, 2022).

2.2.2.2. Field preparation

Proper soil drainage is essential for successful eggplant cultivation. To achieve this, the soil should be prepared by ploughing multiple times until it reaches a fine tilth. Adding a substantial amount of organic fertilizer, such as decomposed cow dung or farmyard compost, has to be added and mixed thoroughly with the soil after the final ploughing to improve yields. Soil sterilization methods like steam or solar radiation can be employed to reduce pests, diseases, and weed presence before sowing seeds in the cultivation area (Caruso et al. 2017; Ghosh, 2022)

2.2.2.3. Sowing and transplanting

The eggplant planting periods are determined by the agro-climatic conditions in each region. Typically, the most common sowing seasons for autumn, spring, and summer crops are June/July, November, and April, respectively. However, eggplant can be grown throughout the year in various parts of the world, with the major sowing seasons starting from July to August. In hilly areas, seeds are sown in March or April (Adamczewska-Sowińska et al. 2022; Ghosh et al. 2022). For eggplant cultivation, the seeds are planted on raised nursery beds to prevent waterlogging. The beds are usually prepared to be 7.2 × 1.2 meters in size and 10-15 cm in height. A distance of 70 cm is maintained between two beds for better production operations. Organic manures are mixed with each bed to promote better growth, and a small amount of superphosphate may be applied.

Carbendazim, diluted with 15-20g per 10 L of water, can be used to prevent fungal diseases by drenching the beds. The seed rate depends on the seed type and seedbed. Pure line varieties typically require about 500-750 g/ha, while hybrid varieties require around 250 g/ha (Caruso et al. 2017; Ghosh, 2022). These variations in seed rates ensure proper plant density and spacing for optimal growth and yield.

To prevent future infections and contamination, it is essential to perform proper routine seed treatment before sowing. This involves various methods and practices, such as using 4g of *Trichoderma Viride* per kilogram of seed or 2g of Thiram per kg of seed to protect them against fungal attacks. Additionally, 40g of *Azospirillum* per 400g of seeds can be applied to enhance nitrogen fixation. Seed dormancy can be broken by storing the seeds for up to one year at chilled or ambient temperatures. Sowing the seeds at a depth of 2-3 centimeters, lightly covering them with soil, and providing light watering is recommended. Grass or organic mulches can be utilized to cover the beds, maintaining suitable temperature and moisture levels (Caruso et al. 2017; Ghosh, 2022). After germination, the mulches are removed. Seedlings are hardened in the nursery beds during the last week and transplanted when they developed 4 to 6 true leaves. The seedlings, around 12 to 15 centimeters tall without root injuries, are uprooted and transplanted into prepared fields. Transplanting is preferably carried out in the evening, and it is recommended to dip the seedling roots in a systemic insecticide like dimethoate at a concentration of 0.02% before transplanting. This treatment helps prevent little leaf disorder and control insect infestations. Since eggplants are cross-pollinated, proper spacing is essential. Spacing requirements vary based on the cultivar and planting time. For highly spreading varieties, the spacing can range from 75 × 60 cm to 75 × 75 cm. Non-spreading and bushy varieties typically require a spacing of 50 to 60 cm both between rows and between plants. These spacing recommendations ensure adequate room for growth, airflow, and access to light, leading to optimal development and productivity (Hautea et al. 2016; Caruso et al. 2017; Ghosh, 2022).

2.2.2.4. Cropping patterns

While many farmers traditionally practice mono-cropping of eggplant, it is beneficial to cultivate this crop with different plant cultivars to reduce susceptibility to various pest infestations. A highly cross-pollinated crop and, inter specific hybridization should be practice so that tolerance features can pass from the wild cultivars to cultivated ones. Intercropping eggplant with other crops such as cabbage, maize, marigold, and soybeans can lead to improved yield and harvest. Additionally, incorporating french beans into the crop rotation can help minimize the risk of bacterial wilt disease (Sirisena and Suriyagoda 2018; Ghosh, 2022). Rotating eggplant with crops like wheat and sorghum can also be effective in preventing root knot nematodes from affecting the eggplant crop. By diversifying the planting patterns and incorporating intercropping and crop rotation practices, farmers can mitigate pest infestations and reduce the impact of specific diseases. This approach promotes a more sustainable and resilient eggplant cultivation system (Sirisena and Suriyagoda 2018; Ghosh, 2022)

2.2.2.5. Water management

Irrigation is essential for the proper growth and development of eggplant, including flowering, fruit setting and development (Serhat 2017; Plazas et al. 2019). During summers, the crop may require irrigation every 3 or 4 days, while during winters, irrigation can be done every 7 to 12 days. It is important to provide sufficient irrigation during the early stages. However, excessive irrigation can lead to damping-off disease in seedlings, while stagnant water during the vegetative phase can cause soil-borne diseases that hinder growth. Drip irrigation is a highly recommended technique for eggplant cultivation as it optimizes water usage by providing precise irrigation directly to the plant's root zone. Drip irrigation is particularly beneficial for eggplant cultivation due to its efficiency in meeting water requirements (Serhat, 2017; Plazas et al. 2019; Kishore et al. 2022). Maintaining adequate moisture levels, especially in the first 70 days, is crucial. Drip irrigation offers advantages such as water conservation, improved fertilizer application efficiency, and high-quality crop production.

2.2.2.6. Manure and fertilizer application

Brinjal, a long-duration vegetable crop, has the potential for high yield. However, poor soil fertility can negatively affect flower and fruit production. To address this, it is recommended to add approximately 25 tons of organic manure per hectare during the final ploughing. Additionally, a common practice for achieving high eggplant productivity is the application of wet cow dung as a band, around 10-12 cm away from the plant, followed by earthing up at fortnightly intervals during the rainy season (Kumar 2016; Rakibuzzaman et al. 2019; Palia et al. 2021). The fertilizer requirements of the crop depend on factors such as variety, season, and soil type. As a general guideline, it is suggested to apply 25 tons of farmyard manure (FYM) per hectare, along with nitrogen and phosphorus (50 kg each), as well as 30 kg of potassium per hectare as a basal dose. An additional fifty (50) kg of nitrogen per hectare should be applied 30 days after transplanting during the earthing up process (Kumar, 2016; Rakibuzzaman et al. 2019; Palia et al. 2021). Moreover, it is beneficial to add 2 kg of azospirillum and phosphobacteria in the main field at planting to promote beneficial microbial activity. To enhance yield, a foliar spray can be administered. This spray can consist of 2 ppm (1 mL in 500L) of triaccontanol plus sodium borate or borax at a concentration of 35 mg/L of water (Kumar, 2016; Rakibuzzaman et al. 2019; Palia et al. 2021). This spray should be applied 15 days after transplanting and during full bloom. By incorporating these recommended practices, such as organic manure addition, appropriate fertilizer application, microbial inoculation, and foliar sprays, the yield potential of the crop can be enhanced (Kumar, 2016; Rakibuzzaman et al. 2019; Palia et al. 2021).

2.2.2.7. Weeds management

Weed management is crucial in eggplant fields as these unwanted plants compete with the main crop for vital resources such as light, nutrients, and space. It is important to remove weeds to ensure optimal soil aeration and root development, ultimately leading to higher productivity. Manual methods, such as hand picking and hoeing, are commonly employed to remove weeds from eggplant fields (Uma Maheswari and Arthanar 2017; de Ocampo et al. 2021). Additionally, the use of black polythene mulching is an effective

technique as it prevents light penetration, thereby inhibiting weed germination. Chemical methods can also be utilized to either destroy existing weeds or prevent their growth. Implementing a combination of these weed management practices helps maintain a weed-free environment for the successful growth and development of eggplants (Radicetti et al. 2016; Uma Maheswari and Arthanar, 2017; de Ocampo et al. 2021).

2.2.2.8. Harvesting and yield

Eggplants can be harvested within a range of 60 to 150 days after transplanting, depending on the specific variety being cultivated. It is important to harvest the fruits at the appropriate developmental stage, ensuring they are picked when they have reached maturity but before they become overly large. Over-matured fruits can develop a bitter taste. Since eggplant fruits mature at different times, harvesting needs to be done at different intervals (Radicetti et al. 2016; Ghosh, 2022). Care must be taken during harvesting to avoid bruising and injury to the fruits. The yield of eggplant is influenced by factors such as the variety being grown and the seasonal conditions in which the crop is planted. When all the required agronomic practices are followed, the average yield of eggplants can range from 20 to 30 tons per hectare. It is important to note that specific yields can vary depending on the specific cultivation practices, environmental factors, and the genetic potential of the chosen eggplant variety (Radicetti et al. 2016). Proper timing and care during harvest, along with adherence to recommended agronomic practices, can contribute to achieving optimal yield and high-quality eggplant produce (Ghosh 2022).

2.3. Economic importance of eggplant

On a worldwide scale, the economic value of eggplant is significant, with a net value surpassing USD 10 billion annually (FAOSTAT 2019). This value is determined based on farm-gate prices and global production figures. Eggplant holds the fifth position within the vital family solanaceae, following potato, tomato, pepper, and tobacco (FAO 2017).

It is notably well-grown within Asian and Mediterranean areas, where it ranks fifth among all grown vegetables (Frary et al. 2007). However, accurately determining the

precise quantities of eggplant production can be challenging, especially for subsistence farming. Nevertheless, eggplant cultivation covers over 1.8 million hectares worldwide, resulting in a total annual production of more than 54 million tons (FAO 2019; Rakha et al. 2021). These figures highlight the significant scale and importance of eggplant production globally.

The nutritional value of vegetables and fruits, particularly their role as natural sources of bioactive compounds, is widely recognized in human nutrition. Eggplant, being a low-calorie fruit vegetable, is notable for its abundance of vitamins, antioxidants, and phenolic compounds (Plazas et al. 2013; Docimo et al. 2016; Gürbüz et al. 2018; Naeem and Ugwu, 2019). According to Quamruzzaman et al (2020), every 100 g of edible eggplant provides about 25 kilocalories and 2.2 mg of vitamin C. The pro-vitamin A content is around 1 microgram per 100g. Anthocyanins, a major group of compounds known for their antioxidant capacity, are found in the skin of eggplant. Purple-colored eggplant varieties have higher anthocyanin concentrations compared to non-colored varieties (Niño-Medina et al. 2017). Phenolic compounds, including various phenolic acids and flavonoids, are present in eggplant, with phenolic acids being particularly highly valuable (Plazas et al. 2013; Stommel et al. 2015). In eggplant, the phenolic compounds of particular significance are delphinidin, which is found in the skin, and chlorogenic acid, which is present in the flesh (Niño-Medina et al. 2017; Rakha et al. 2021). Eggplants are relatively low in proteins, fats, soluble carbohydrates, essential vitamins, and minerals. However, they are rich in dietary fiber, which offers a number of health benefits. The high fiber content in eggplants can help regulate blood sugar levels, reduce plasma cholesterol levels, and decrease aortic cholesterol content. Despite their modest nutritional profile, eggplants can be a valuable part of a balanced diet due to their fiber and other beneficial compounds. Moreover, the presence of high quantities of anthocyanins in most eggplant cultivars contributes to their positive effects on human health (Alam and Salimullah 2021). Eggplant fruits are known for containing highest quantity of chlorogenic acid (5-O-caffeoyl-quinic acid, or CGA) compared to other vegetables, fruits, and plant products commonly consumed in human diets. Chlorogenic

acid exhibits antioxidant, anticarcinogenic, anti-inflammatory, cardioprotective, anti-obesity, and antidiabetic effects, providing various health benefits (Rakha et al. 2021). However, the quantity of chlorogenic acid in eggplant can vary, ranging from 0.15% to 2.8% of dry weight (Rakha et al. 2021). These findings highlight the nutritional and health benefits of eggplant, particularly its fiber content, the presence of anthocyanins, and the high levels of chlorogenic acid. Including eggplant in the diet can contribute to a range of positive health effects associated with these bioactive compounds.

2.4. Constraints in eggplant cultivation

Eggplant production, like many other crops, faces numerous challenges that hinder the yields in different regions worldwide. These challenges encompass both living and non-living factors. The majority (80%) of eggplant production occurs in areas occupied by subsistence, marginal, and resource-poor farmers, who often lack resources to mitigate environmental constraints such as temperature fluctuations, drought, salinity, insect infestations, and pathogenic attacks. In contrast, developed countries rely on biotechnological control measures, application of hormones as well as adoption of improved varieties to achieve higher crop productivity (Choudhary and Gaur 2009; Barik et al. 2020). Key constraints affecting eggplant production are discussed below.

2.4.1. Biotic stresses

Eggplant, being a widely cultivated crop adaptable to various agro-climatic environments, is exposed to diverse insect infestations and pathogenic attacks, resulting in substantial economic losses (Estefanía Rodríguez et al. 2019). One of the most devastating insects is *Leucinodes orbonalis* commonly referred to as eggplant fruit and shoot borer (EFSB), which can cause yield losses of up to 65% (Hautea et al. 2016). The EFSB larvae bore into young shoots, leading to wilting and the inability of the plant to bear fruits. They also tunnel into the fruits, rendering them unmarketable. The presence of these pests within the plant's system provides them protection against insecticides. Additionally, other pests such as eggplant fruit borers (*Helicoverpa armigera*), stem borers (*Euzophera perticella*), hadda beetles (*Epilachna vigintiopunctata*), sap-sucking pests (*Bemisia tabaci*), and parasitic nematodes (*Meloidogyne* spp) significantly impact eggplant production by

causing significant damage to the plants (Nishat et al. 2015; Nahar et al. 2019; Lu et al. 2019; Estefanía Rodríguez et al. 2019).

In eggplant farming, pathogens present in the soil can pose significant threats, particularly in conditions of high soil moisture. Various fungal genera, including *Fusarium*, *Verticillium*, *Rhizoctonia*, *Sclerotium*, and *Phytophthora*, are known to cause wilt disease in eggplant, leading to substantial crop yield losses (Nishat et al. 2015; Nahar et al. 2019). Wilt diseases are characterized by yellowing of leaves, drooping of the apical shoot, and eventual plant death. Pathogens (*Pythium* spp, *Phytophthora parasitica*, and *Sclerotium rolfsii*) can infect seedlings in nursery beds, causing sudden wilting (Nishat et al. 2015; Nahar et al. 2018). A bacteria species (*Pseudomonas solanacearum*) also leads to Bacterial wilts in eggplant that have been reported economically significant in eggplant farming (Gopalakrishnan et al. 2014; Kaniyassery et al. 2023).

Viral diseases transmitted by aphids, such as Potato Virus Y, result in mosaic and mottling of leaves, stunted growth, and the development of deformed fruits and leaves in eggplant crops. Other viral pathogens affecting eggplant include Cucumber mosaic virus, Potyvirus, Eggplant mottled crinkle virus, and Alfalfa mosaic virus (Mituti et al. 2019; Iqbal et al. 2022). These various pathogens can have detrimental effects on eggplant production, leading to reduced yields and compromised crop quality (Palaniswami 2020; Iqbal et al. 2022; Jhonston et al. 2022). Implementing appropriate disease management strategies, including sanitation practices, crop rotation, resistant varieties, and the use of disease-free planting material, is crucial for mitigating the impact of these pathogens on eggplant farming. Mycoplasma is responsible for causing little leaf disease in eggplant, which is transmitted through the sap by sap-sucking insects (Sani et al. 2020). This disease manifests as chlorosis (yellowing) in young leaves accompanied by the proliferation of axillary buds. Affected plants show reduction in plant aerial parts, resulting in a bushy plant appearance. Extensive infections have the potential to result in infertility, causing minimal flower and fruit setting, as well as significant stunted growth (Solanki and Jha 2018; Perring et al. 2018). Eggplant growing regions worldwide have reported various diseases, leading to the failure of diseased plants to produce marketable

fruits or products and resulting in substantial yield losses, up to 90% in some cases (Solanki et al. 2018; Perring et al. 2018). Effective disease management strategies, including the use of resistant varieties, insect control measures, and regular monitoring, are crucial to mitigate the impact of little leaf disease and other diseases on eggplant cultivation.

Furthermore, several insect pests including aphid (*Aphis gossypii* Glover), colorado potato beetle (*Leptinotarsa decemlineata* Say), shoot and fruit borer (*Leucinodes orbonalis* Guenee), thrips (*Thrips leucadophilus* Priesner), spotted beetles (*Pelidnota punctata* Thomas casey), leaf hopper (*Empoasca devastans* Dist), stem borer (*Mylabris pustulata* Thunberg), blister beetles (*Tetranychus takafujii* Ehara & Ohashi) and whiteflies (*Bemisia tabaci* gennadius) also affect the eggplant productivity (Amin et al. 2018). Whiteflies are highly destructive on this crop as their infestation lead to reduction in the plant vigor, drop off and discoloration of leaves. They also release large amount of honeydew which leads to sooty mold development and reduction in the photosynthetic rate of the crop. Moreover, whiteflies serve as vectors of several viruses that affect different vegetable crops negatively (Sani et al. 2020; Ugwu et al. 2021; Abubakar et al. 2022). Begomoviruses vectored by whiteflies cause reduction in eggplant productivity, resulting in significant yield losses worth millions of dollars (Gangwar et al. 2018). Uncontrolled infestations by whiteflies may lead to 100% yield losses (Taher et al. 2020) while about 20-40% damage have been reported in vegetable crops due to insect pest infestations (Sani et al. 2020).

2.5. The biology and distribution of whitefly (*Bemisia tabaci* Gennadius)

The whitefly (*B. tabaci* Gennadius; Hemiptera: Aleyrodidae) is a global agricultural pest that affects various crops, particularly in the plant families of Cucurbitaceae, Fabaceae, and Solanaceae (Cruz-Estrada et al. 2012; Mudereri et al. 2020). *Bemisia tabaci* adults are small in size, measuring around 1 to 3 mm in length. They have four wings, which are covered with a powdery whitish wax. They are sexually dimorphic, with females being slightly larger than males (Kanakala et al. 2019; Sani et al. 2020). Both male and female adults derive their nourishment from the leaf tissue using their mouthparts. The females

are capable of reproducing through parthenogenesis, as they can reproduce without the need for fertilization (Sani et al. 2020). The biology of *B. tabaci* can vary to some extent depending on certain factors such as environmental conditions, host plants, and geographical location (Sani et al. 2020). Whitefly was demonstrated to have a wide host range, being capable of infestating up to 600 plant species, rendering it among the most invasive and destructive pests of agricultural importance (Kumar et al. 2019; Parry et al. 2020).

The life cycle of whitefly begins with the laying pear-shaped eggs by female *Bemisia tabaci*. The egg is approximately 0.2 mm in length, and normally laid on the inner leaf surface, often in a semi-circular pattern. However, solitary eggs have also been observed. The eggs hatch within a period of 5 to 9 days, depending on factors including the host variety, humidity and heat (Gwangwar et al. 2018; Solanki and Jha 2019). The first instar nymphs, also known as "crawlers," are whitish-yellow in color, flat, and ovate in shape. In the second instar, they develop into yellowish and cylindrical-shaped nymphs. The freshly molted third instar nymphs are brightly yellow and gradually darken while appearing slightly constricted in structure (Kedar et al. 2014). The fourth instar nymphs, also called "pupae" or "red-eyed nymphs," are yellowish-white in color characterized with bulging eyes that protrude through the integument (Perring et al. 2018). During this stage, the nymphs are relatively flat and produce periodic waxy filamentous fluids. The adult of *B. tabaci* emerges via an upturned "T"-shaped incision on the dorsal side of the pupal case. The female adult has a large, spherical stomach, while the male adult has a pointed stomach. The complete life cycle of *Bemisia tabaci* typically ranges from 16 to 31 days. However, variation can occur based on the environmental conditions, host plants, and whitefly species (Fekrat et al. 2007; Perring et al. 2018) (Fig 1) (Abubakar et al. 2022).

Whitefly has been reported to be a cosmopolitan insect pest, responsible for significant crop losses in different parts of the world. This poses a severe threat to the livelihoods of a teeming global population particularly in the developing nations (Gangwar and Charu, 2018; Mudereri et al. 2021). Although they originated from Southern Asia, these tiny

sugar-robbing insect pests are now found worldwide, predominantly in tropical regions (Brown and Bird 1992; De Barro et al. 2011), excluding Antarctica (Kanakala and Ghanim 2019). However, it was reported that some countries in the Europe like Ireland and United Kingdom), have not yet reported the incidence of *B. tabaci* (Gwangar and Charu 2018; Sani et al. 2020)

2.5.1. Taxonomy of *B. tabaci*

Whiteflies as a group, are classified under the Aleyrodidae family, which is further divided into three subfamilies: Aleurodicinae, Aleyrodinae, and Udamoselinae. The Aleurodicinae subfamily includes approximately 20 genera and around 130 known species, primarily located in Central and South America as well as the Caribbean. On the other hand, the Aleyrodinae subfamily encompasses the majority of whitefly species, with about 140 genera, and they are predominantly distributed in pan-tropical and warm-temperate regions. The Udamoselinae subfamily consists of a single genus, Udamoselis, having only two South American species: *Udamoselis pigmentaria* Enderlein and *Udamoselis estrellamarinae* Martin (Gullan and Martin 2009; Boykin et al. 2013; Liu et al. 2015). Njoroge et al (2017) reported that *B. tabaci* has been found to disseminate approximately 111 viruses, while *T. vaporariorum* and *T. abutilonia* have been observed to transmit 3 viruses each. Recently Chandrashekar et al (2020) reported that the solanum whitefly, (*Aleurothrixus trachoides*) is capable of transmitting Duranta leaf curl virus (DLCV) to tomato, bell pepper, and potato crops in India. Recent studies have revealed that the *Bemisia tabaci*, previously regarded as complex species, is actually a cryptic complex comprising of morphologically similar but reproductively isolated species. These species were previously referred to as biotypes (Dinsdale et al. 2010; Abubakar et al. 2022). The identification and classification of *B. tabaci* genotypes and species have been achieved through the use of molecular markers (Shatters et al. 2009; Guo et al. 2013). Currently, about 43 genotypes of *B. tabaci* have been approximately described using mitochondrial cytochrome oxidase subunit (mtCOI) analysis (Boykin et al. 2013; De Marchi et al. 2018; Kanakala and Ghanim 2019). Previously, *Bemisia tabaci* was classified primarily into two variants: Middle East-Asia Minor 1 (MEAM1) and the

Mediterranean (MED), known to infest a wide range of host species (Perring et al. 2018; Shadmany et al. 2019). However, it has been discovered that *B. tabaci* genotypes exhibit a significant variability in various aspects such as viral transmission efficiency, development of phytotoxic disorders, food consumption mechanisms, and biological control effectiveness, despite their similarities morphologically. This variation has been observed in studies on *B. tabaci*, highlighting the diverse characteristics and behaviors within this complex species (Bedford et al. 1994; Pan et al. 2012).

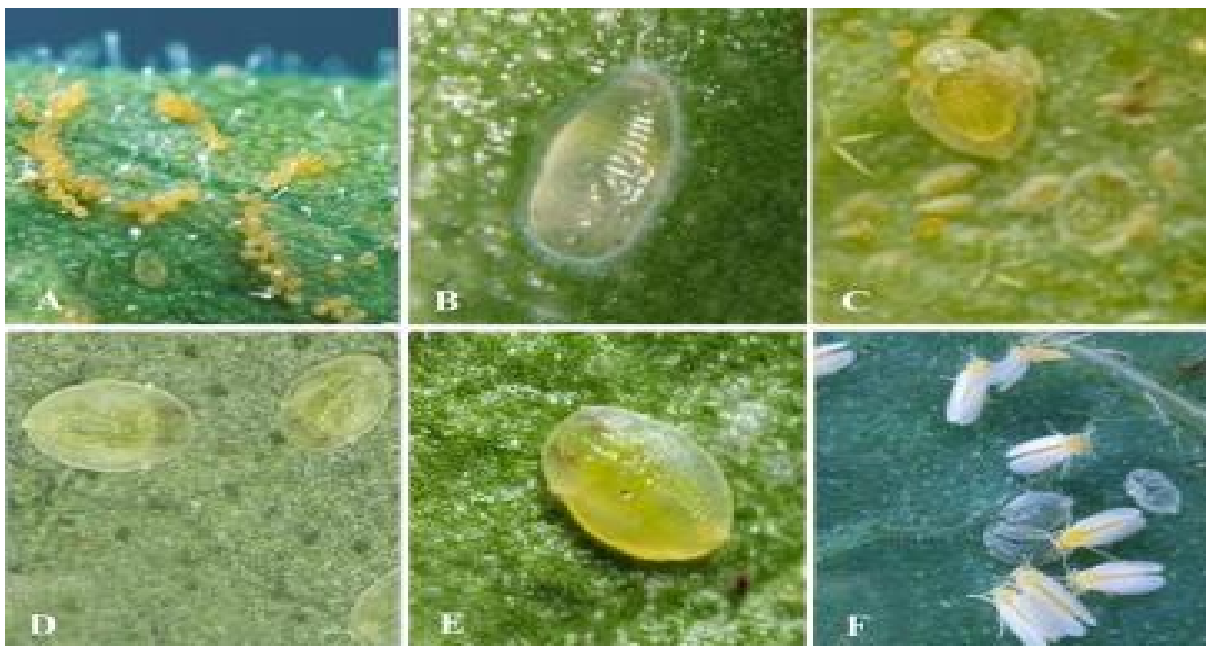


Fig2.1: The whitefly life cycle. A: Oval-shaped eggs attached to the leaf via a stalk-like structure for fluid uptake, B: the 1st instar nymph, C: 2nd, 3rd, and 4th instar nymphs, D: red-eyed 4th instar nymph, E: pharate adult stage or pupal stage, F: emergence of adult whiteflies after metamorphosis leaving the transparent shells (Abubakar et al. 2022).

2.6. Host range and damage caused by *B. tabaci*

The whitefly (*B. tabaci*) being a polyphagous insect pest was reported to have a wide host range. Some of the popular crops affected by *B. tabaci* include but are not limited to cassava (Nwezeobi et al. 2020), tomato (Baldin et al. 2012), eggplants (Islam and Shuxhang 2009), cowpea (Okolo and Iledun 2019) cinnamon, curcubits (Tressia 2007)

muskmelon (Bar et al. 2019), okra, pepper (Farook et al. 2021), cucumber (Tian et al. 2015), sunflower (Qiu et al. 2007), tobacco (Dong et al. 2020), groundnut, cabbage (Maranha and Amaranha 2006), soybeans (Prayogo and Bayu 2020) potatoes (Cabanillas and Jones 2009), cauliflower (Soumia et al. 2020), cotton (Shukla et al. 2016), lettuce (Ibrahim et al. 2017) and numerous other crops of great agricultural importance. They caused serious crop damage and yield losses as they feed on the susceptible crops, through the release of honeydew and dissemination of diverse species of viruses (Gangwar et al. 2018; Sani et al., 2020; Nwezeobi et al., 2020), posing a significant threat to agricultural production and extensive damage to crops on a worldwide scale. This indicates that *B. tabaci* is not only capable of causing direct damage through feeding but also poses a substantial risk as a vector for viral diseases, making it a highly destructive insect pest in different crop plants. While deriving its nutrients from the host plant, the nymphs of *B. tabaci* was reported to be responsible for releasing some enzymes that disrupt the crop physiological functions, resulting in reduced internal pigmentation and poor fruit ripening. In addition, the sugary excreta (honeydew) produced by *B. tabaci* provides as a breeding ground for the sooty mold on the leaves. These causes decrease in photosynthetic efficiency and, as a result, the quality and quantity of agricultural produce (Perring et al. 2018; Solanki and Jha 2018). Moreover, *Bemisia tabaci* can also cause physical damage to plants. Khan and Wan (2018) observed that the insect's feeding behavior leads to yellowing and folding of leaves. This can result in decreased plant development and the production of disfigured fruits. Over 350 species of viruses have been shown to be vectored by *B. tabaci* in different vegetable crops (tomato, okra, pea, bean, pepper etc.). These viruses belong to Begomovirus, Carlavirus, Crinivirus, Ipomovirus, and Torradovirus genera (Lu et al. 2019; Estefanía Rodríguez et al. 2019). Begomoviruses are responsible for reduced crop productivity, causing up to 100% yield losses (Gangwar et al. 2018). In cassava crops, *B. tabaci* has been reported to be responsible for the dissemination of two devastating viral diseases: cassava mosaic and cassava brown streak. These diseases affect approximately half of the cassava crops worldwide, leading to annual yield losses exceeding 1 billion USD annually (Legg et

al.2014). It was reported that the economic injury level of *Bemisia tabaci* was four nymphs per leaf. This indicates that the presence of four nymphs per leaf of tomato plant can result in significant economic damage (Hasanuzzaman et al. 2016). Table 2.2 provides a summary of the findings on the impact of feeding by whitefly on various crop plants.

Table 2.2: Reports on the impact of whiteflies infestation on crop plants

Crop name	Study location	Damages caused	Reference
Melons	California	The total damages caused to summer and fall crops have been assessed to exceed 120 million USD.	Perring et al (1990)
Vegetables	Texas	Economic loss of 29 million USD was recorded.	Norman et al (1991)
Tomato	Florida	Economic losses exceeding 125 million USD have been reported	Schuster (1992)
Cole and melons	California	Feeding effects on the crops resulted in losses of approximately 111 million USD.	Gonzalez et al (1992)
Tomato	Israel	Various symptoms like leaf curling and flower dropping, shortened internodes, stunting, and the development of leathery leaves were observed.	Cohen and Antignus (1994)
Vegetables	Arizona	Damages caused by whiteflies led to yield losses of 55 million USD.	Renfrow (1995)
Collard	Texas	The crop was unmarketable due to damages caused by heavy infestations.	Liu (2000)
Watermelon	California	Various direct feeding damages and virus transmission.	Simmons and Levi (2002)
Fruit vegetables	America	Whiteflies spread different viruses, causing diverse diseases and crop yield losses.	Wintermantel (2004)
Zucchini	Florida	Chlorophyll content reduced by 66% in petioles.	McAuslane et al (2004)
Tomato	Spain	Multiple infestation symptoms including necrotic rings on the leaves were observed.	Calvo et al (2009)
Eggplant	China	The reductions observed were 26.6% for leaf area, 21.8% for fresh weight, and 19.27% for dry weight. Chlorophyll composition and photosynthesis decreased by 9.7% and 65.9% respectively.	Islam and Shunxiang (2009)
Squash,	Australia	Stunted growth, leaf and fruit deformation,	McDougall

zucchini and pumpkin		defoliation, reduced yields and plant death were reported.	(2009)
Potato	India	There was 40–75% incidence of viruses transmitted by the whiteflies.	Chandel et al (2010)
Cantaloupe, cucumber and zucchini	Saudi Arabia	Pigments reduced to 0.87, 1.12, and 0.54 in cucumber, zucchini and cantaloupe compared to the control with 1.13, 2.09 and 1.05 respectively.	Al-shereef (2011)
Tobacco	China	The plant height, length of internode and rate of photosynthesis decreased by 32.7, 4 and 81.5 % respectively.	Li et al (2013)
Tomato	Spain	Numerous holes have been reported to develop during the summer and winter trials respectively.	Calvo et al (2016)
Squash	Georgia	Yield loss of up to 35% was reported.	Little (2016)
Vegetable crops	Georgia	Up to 132.3 million USD was reported as the economic losses.	Little (2016)
Snap bean	Georgia	Yield loss of up to 45% reported in snap bean.	Little (2017)
Cassava	Fiji Island	Reduction in conductivity rates ($M= 11.90 \text{ mmol m}^2\text{s}^{-1}$) and ($M= 17.80 \text{ mmol m}^2\text{s}^{-1}$) was recorded for treated and control plots.	Chand et al (2018)
Tobacco	China	Reductions in chlorophyll A levels: 42.36%, 56.96%, and 81.43%, were reported at 11, 14, and 20 days respectively.	Li et al (2018)
Vegetables	South Carolina	Thickened, distorted, curled and crumpled leaves were reported.	Attaway (2019)
Coconut	India	Sixty (60%) of the leaf was invaded by the nymphs, causing yellowing, necrosis, and plant dehydration.	Selvaraj et al (2019)
Tomato	Egypt	Chlorophyll A and B reduced by 8 and 12.8% respectively.	Bughdady et al (2020)
Sugarcane	Iran	Chlorophyll content decreased to 0.583mg/g lower than the control (1.48mg/g) group.	Saeedi and Ziaee (2020)
Soybeans	Brazil	Decrease in grain weight by 33g per 1000 grains and a loss in protein contents of 440kg per hectare were observed. These results indicate the detrimental effects of the whitefly infestations on both grain weight and protein content in the crop.	Schutze et al (2021)
Vegetables	India	Whitefly feeding leads to plant weakening,	Ghosh (2022)

		early wilting, reduced growth, and lower yield.	
Cotton	Pakistan	Transmission of begomoviruses causing cotton leaf curl disease, with great economic losses.	Afzal et al (2023)

2.7. Whiteflies management (WFM) strategies

To address the food crisis for the teeming, ever increasing global population, extensive and voluminous researches have been conducted in recent decades to address the damages and losses caused by *Bemisia tabaci* and other insect pests in different crops. Various approaches have been explored, including physical and mechanical methods (Perring et al. 2018), traditional knowledge (Elango et al. 2020), biological control (Isman et al. 2014), plant-based products (Patel et al. 2019), biotechnological strategies (Malik et al. 2016; Ibrahim et al. 2017), and the use of synthetic pesticides through foliar spray (Horowitz et al. 2011). IPM is a widely recognized strategy that aims to minimize the negative environmental and health concerns associated with synthetic pesticide application (Shejulpatil et al. 2019; Estefana et al. 2019). The diverse range of methods and approaches employed to effectively manage whiteflies and other destructive pests to improve crop production are discussed below.

2.7.1. Traditional strategies

Traditional methods of controlling whiteflies have relied on Indigenous Technical Knowledge (ITK) and practices. These approaches involve utilizing locally available materials, techniques, and expertise, as elaborated in the following sub-headings.

2.7.2. Cow based products for whitefly control

In certain regions of Asia and Africa, fermented curd water, also known as buttermilk, is utilized against insect pests including whiteflies, jassids, aphids, and other aphid-related pests (Abubakar et al. 2022). Cow's milk, being a dairy product, is believed to have advantageous spreading and sticking properties attributed to the presence of casein protein, which exhibits exceptional adhesive characteristics. Buttermilk at 10% v/v concentration effectively reduced the insect density and powdery mildew. Moreover, the

application of butter milk on chili plants has been observed to confer a systemically acquired tolerance by chili plant to viral pathogens (Kumar et al. 2002; Elango et al. (2020). The use of cow urine proved potent in controlling mealy bugs, thrips, and mites as well as post-blooming insect pests in cowpea crops (Bhattacharya and Goswami (1987). Five 5 kg of the leaves of *azadirachta indica* is crushed and mixed with 5L of cow urine and 2 kg of cow dung. This mixture is left to ferment for 24 h with intermittent shaking, then sieved and diluted in 100 L of tap water for foliar application over an acre of land. This extract has demonstrated high efficacy against sucking insect pests and mealy bugs. Shailaja et al (2012) discovered that the application of cow urine at 10% with 1% starch, either singly or synergistically with a chlorantraniliprole 18.5 SC, was found to be a cost-effective measure against different pests in brinjal crops. In a study by Mandal et al (2018), it was found that a combination of cow dung and urine, when mixed with ash and slurry, led to a significant reduction in insect pest populations in eggplant. Similarly, the use of cow urine along with botanical extracts demonstrated significant suppression of insect pest density and increased yields in cowpea plants (Patel et al. 2019). In another study, a mixture of cow urine and vermiwash caused up to 50% mortality in whiteflies when sprayed on brinjal crops (Karker 2014). Singh et al (2021) found that the spray with plant extracts (chili, garlic, and neem) when mixed with cow urine led to substantially lessen the density of whiteflies (95.2%), leafhoppers (94.6%), and blister beetles (94.6%) on okra plant. Additionally, Patel et al. (2017), explained that the combination of cow urine with various plant extracts effectively managed sap-sucking pests like whiteflies and aphids in eggplant crops

2.7.3. Ash and kerosene for whitefly management

To safeguard agricultural crops from whiteflies and other pests, a thick coating of ash is either placed around them in the soil or dusted on their leaves. Apart from functioning as a toxin, ash coating on the leaves alters the molecular signals of the plants and thus blocks insects from locating their original host (Abubakar et al. 2022). Ashes from burnt fronds and bundles of palm tree have been used in Nigeria for centuries in the form of powder to protect vegetables against leaf-damaging insects, including whiteflies and

Podagrica spp (Padhi and Misra 1987). In brinjal crops, the application of 50 kg/ha of ash, 5% kerosene, and spinosad 45SC yielded a high benefit-to-cost ratio of approximately 4.8:1 (Shailaja et al. 2012). Ash is readily available to farmers and, when combined with detergent, can provide immediate reduction of insect pests during an epidemic, to give chance for the implementation of preferred control methods. The use of a kerosene-soap-water technique as a contact pesticide for controlling diverse species of piercing and sucking insects has been previously documented. However, it is important to note that biweekly treatments with kerosene resulted in a reduction of two-thirds of *B. tabaci* number on tomato leaves, but led to reduction in yield compared to untreated plants (Celsia and Janarthanan 2019).

2.7.4. Cultural practices in whitefly control

Cultural method of insect pests control involves manipulating agricultural practices to create an unfavorable environment for pests. The combined effect of water and nutrient regulation play a crucial role in controlling *B. tabaci* on vegetable crops (Simmons and Abd-rabou 2008; Athar et al. 2010). For instance, implementing drip irrigation on daily basis has decreased the density *B. tabaci* and prevalence of viruses disseminated by whitefly vector in a number of crops compared to furrow and spray irrigation methods (Abd-rabou and Simmons 2012). Similarly, sprinkler irrigation in tomato crops has led to decrease in *B. tabaci* populations and associated viruses when intercropped with coriander crops (Togni et al. 2018).

Another important cultural control approach for managing *Bemisia tabaci* and related viruses is extending the host-free intervals or reducing the intercrop movement (Ellsworth and Martinez 2001; Mohamed et al. 2012). Maintaining host-free areas for a minimum of two months during the wet summer period has been demonstrated to provide a notable reduction in both the whitefly population and the incidence of related viruses in different vegetable crops. (Abd-Rabou and Simmons 2012). The use of an electromagnetic screen has proven effective in repelling and/or capturing *Bemisia tabaci* from tomato crops grown in vented greenhouses. Organic and artificial mulches have been employed as a means to control *Bemisia tabaci* infestations. For instance, in tomato

plants, the use of organic mulches has been found potent in lessening the number of *B. tabaci* and the occurrence of related disorders in the crop. Similarly, in zucchini squash (*Cucurbita pepo* L.), organic mulches have demonstrated efficacy in lowering *B. tabaci* populations and related disease incidence (Nyoike et al. 2008; Manandhar et al. 2009). In addition, ultra-violet (UV) absorbing substances have been utilized to manage *B. tabaci* infestations in controlled cultivation systems. The work of (Antignus et al. 1998; Kumar et al. 2006) have shown that the use of UV-absorbing polymer sheets or film covers over tomato crops can significantly reduce whitefly density and the prevalence of related viral disorders. In UV-blocked greenhouses, viral disease loads in tomato were as low as 6%–10%, whereas non-UV-blocked environments recorded 96%–100% (Kumar et al. 2006). These findings highlight the potential of UV-absorbing materials for effective management of the whitefly and reducing the incidence of related viral infections in tomato crops.

Intercropping is another vital cultural control method that prevents *Bemisia tabaci* from locating their host plants. Intercropping tomato with coriander, squash, maize, chili pepper, cucumber, and French bean was effective in reducing *B. tabaci* populations (Abd-Rabou and Simmons 2012; Fargalla et al. 2011; Verma et al. 2012; Tagni et al. 2018). Similarly, planting okra along with coriander or ginger was demonstrated as a substantial method of reducing the *B. tabaci* populations in okra crops (Sharma et al. 2018). Additionally, intercropping cucumber with lettuce led to a 69.7% decrease in *B. tabaci* adults on cucumber (Yang et al. 2004), thus highlighting the potential of intercropping as a strategy to reduce *B. tabaci* populations and mitigate its impact on various crops. The various reports on traditional methods in whitefly control are summarized in the table 2.3 below.

Table 2.3: Traditional whitefly management strategies on different crop plants

Crop	Materials used	Preparation methods	Effects on the whiteflies	Reference
Cotton	Various type of traps (non-sticky, yellow sticky and colorless sticky)	The traps with 7.5x12.5-cm, 72 cm ² and 93.75 cm ² were used.	Sticky traps were more effective with 523 whiteflies while colorless cards were less effective with 37 whiteflies/trap.	Hoelmer et al (1998)
Tomato	Sticky traps	Taylor's power law and spatial autocorrelation statistics.	Large number of whiteflies trapped the sticky traps.	Kim et al (2001)
Crop plants	Butter milk	Butter milk prepared by fermentation.	Different insect pests like whitefly and aphids were effectively managed.	Kumar et al (2002)
Cotton	Sticky traps	The traps were hunged at 60, 80, 100, and 120 cm above ground level.	Traps placed at 60 cm had the highest number of whiteflies while those at 120 cm had the least.	Atakan and Canhilal (2004)
Greenhouse plants	Different colored traps	The traps were vertically placed in the greenhouse.	Blue and yellow traps were more attractive to thrips, while no significant differences were found for whitefly attraction.	Kaas (2005)
Okra	Butter milk	Ten (10) L of butter milk was fermented, diluted with water at 1:9 and sprinkled on the crops.	Whitefly population reduced by 60%.	Karthikeyan et al (2006)
Tomato	Yellow sticky traps	The traps were installed both vertically and horizontally in the tomato	The vertically positioned traps caught 66.57 whiteflies/trap per single row.	Gu et al (2008)

		field.		
Agricultural crops	Cow dung and urine with fermented plant extracts	Fermented plant extracts, cow dung/urine in a ratio of 1:20 water.	The insect pests were substantially reduced.	Radhakrishman et al (2009)
Eggplant	Yellow traps	The traps were placed at a height of 30cm above the plants one trap/ 5m ² .	Yellow sticky traps recorded 27 whiteflies in 6 days.	Lu et al. (2012)
Eggplant	Cow urine and vermin-wash	They were prepared at 20, 30, 40, and 50% concentrations.	50% concentration most was the most effective against the whiteflies.	Karker (2014)
Eggplant	Cow and plant-based products with vermiwash	Different concentration of cow-urine (20, 30, 40, and 50%), mixed with vermiwash and plant extracts.	The least whitefly number (2.22) was observed in CU + neem leaf extract at 20 and 10% respectively.	Patel et al. (2017)
Eggplant	Sludge/slurry, ashes, cattle urine, and dung	Plant ash sprayed at 50g/plant, while cow urine, cow dung, and water sprayed at 1:10 ratio for five days.	Pest density effectively minimized with lower cost benefits.	Mandal et al. (2018)
Cowpea	Cow urine with botanical extracts	Different concentration of cow urine (25, 50, 75 and 100%) mixed with 1% neem seed extract.	About 3.26 whiteflies/leaf were recorded.	Patel et al. (2019)
Crop plants	Kerosene-	Kerosene-	All insects under	Celsia and

	soap-water emulsion	soapwater-formulation.	study were minimized substantially.	Janarthanan (2019); Papnai et al. (2020)
Crop plants	Liquid soap in Plants extracts	Plant extracts mixed and diluted with water at a 1:2 ratio. One teaspoon of soap was added to a l of the mixture, and sprayed.	The formulation was effective against the sap-sucking pests.	Elango et al. (2020)
Cotton	Traps/barrier crops and parasitoids	Intercropping and perimeter planting technique using 3 intercrop and peripheral plantings.	Nymph and adult whiteflies were 1.44 and 1.15/ 100 cm ² on the leaf surface.	Zhang et al. (2020)
Black gram	Soap, indoneem, neem, butter milk, actara and lisapol detergents.	The treatments were used separately and in combination.	The whitefly density was reduced to 7.56/leaf in treated plots compared to 37.11/leaf in the control.	Taggar et al. (2020)
Okra	Cow urine with plant extracts	The plant extracts and cow urine were mixed at quaternary level were prepared and applied at 10% w/v.	Whitefly number reduced by 95.2%.	Singh et al. (2021)

Cotton	Yellow sticky traps	The traps were hung vertically at 45 cm above the plant using a wooden pole.	The traps caught 34.07 whiteflies on average and whitefly number decreased to 0.83 whiteflies/leaf in treated plot.	Bhutto et al. (2021)
Tomato	Several colored and shaped adhesive traps	Different rates (2, 4, and 6) of traps were placed/250 m ² .	The yellow rectangular traps were more effective with 5.7 whiteflies/trap.	Nair et al. (2021)
Potato	Different bio pesticides	Leaf dip bioassay.	Tamarlassi was found to be most toxic to the nymphs, followed by fermented buttermilk and fermented cow urine.	Kumari et al (2022)

2.7.5. Plant based products and whitefly management

Several reports proved the effectiveness plant-based products for whiteflies control using different crops (Hussein et al. 2017; Kumar et al. 2021). It was reported that 10 chili pod extracts and 500 g of the entire marigold plant were chopped and soaked in 15L of water overnight. The 1:2 water-filtrate ratio along with 1 teaspoon of liquid soap per l of extract was effective as foliar spray against hemipteran insects (Mkenda et al. 2015; Tembo et al. 2018). Twenty (20g) of crushed roots of turmeric (*Curcuma domestica*) were mixed with cattle urine (200 mL) and allowed to ferment for some hours. The concoction was diluted with 2-3 L of water, followed by addition of liquid detergent solution (8-12 mL). Whiteflies, aphids, and many other insects as well as powdery mildew were substantially managed through the foliar spray of these extracts (Chabra et al. 1988). Moreover, neem-based formulations (Lynn et al. 2012), milkweed (*Calotropis* sp) and garlic extracts (Barati et al. 2013) and *Jatropha curcas* L. extracts (Diabate et al. 2014), have also been used successfully in insect pest management (Nzanza et al. 2012). Foliar spray with the NeemAzal immersion, a marketed neem-based preparation, has caused up to 90% in the

nymphs of *B. tabaci* on tomato crops (Kumar et al. 2006). Furthermore, there has been substantial research into the use of plant-based essential oils for the management of *B. tabaci* (Baldin et al. 2012).

Pumnuan et al. (2017) examined the effects of essential oils from 18 medicinal plants and reported 82 to 100% mortality of adult whiteflies and aphids under control conditions. Kumar et al. (2019) also reported that castor essential oils caused 42.8 and 64.2% reduction in whitefly number under field and laboratory trials respectively. Wagan et al. (2018) also demonstrated the effect of *Gardenia jasminoides* essential oil causing 89.59% repellency and 80.08% toxicity on the adults and nymphs of whitefly 24h after the spray under greenhouse conditions. Several other reports from the previous researches (Kumar et al. 2019; Peres et al. 2020; Sweetha, 2021) proved the effectiveness of plant essential oils in whitefly management. The following table summarized the reports on the use of plant extracts in whitefly control (Table 2.4).

Table 2.4: Reports on the use of plant-based products for whiteflies management

Crop name	Plant extracts involved	Findings	Reference
Sweet potato	Use of plant extracts (Petunia).	Whitefly controlled at 0.5 and 1mg mL ⁻¹ concentrations (70% and 82% for adult and eggs mortality).	Nottingham and Chalfant (1994)
Cucumber and beans	Fruits and leaf extracts from chinaberry.	Methanol extract reduced the whitefly number to 1.44± 0.24 per plant.	Hammad et al. (2000)
Tomato	Seeds and leaf extracts from eight plant species.	The highest lethality (41%) was caused by <i>Jatropha dhofanica</i> while 30.85% was caused by <i>Azadirachta indica</i> as the lowest fatality rate.	Azam et al. (2002)
Tomato	Ginger oils.	The oils were effective in repelling the whitefly on tomatoes.	Zhang et al. (2004)
Melon	Essential oils from thyme and peppermint.	The extracts were effective with 62.78% (peppermint) and 100% (thyme) fatality rate.	Aroiee et al. (2005)

Tomato	Seed extracts from <i>Trichillia havanensis</i> and <i>Passiflora edulis</i> .	<i>Passiflora edulis</i> led to 60% lethality while <i>Trichillia havanensis</i> caused 70% whiteflies fatality.	Aldana et al. (2006)
Winged soapberry	Crude and semi-purified saponin extracts were from <i>Sapindus saponaria</i> fruits.	Whitefly lethality increases as the quantity of unrefined and semi-purified saponin preparations increases (20 to 80%).	Porras et al. (2009)
Soybean, cotton and melon	Oils of sugar apple.	Whitefly nymphs shrunk and detached from the surface of the leaf after being exposed to the seed oil.	Lin et al. (2009)
Coleus plant	Essential oils from various plant species.	After one, two, and three weeks of treatment, none of the essential oil offered sufficient suppression of whitefly.	Raymond et al. (2009)
Sweet potato	Aqueous plant extracts.	The extracts are as lethal as Imidacloprid to the sweet potato whitefly.	Ateyyat et al. (2009)
Laboratory	Mint and colothyn foliar extracts (crude or formulated).	At LC ₅₀ , the extracts were effective (100%) toxicity against whiteflies and aphids respectively.	Sayeda et al. (2009)
Dry bean	Neem oils.	On the 6th day after treatment, the fatality rate for first to third instars has been above 80% at 1% concentration.	Penheiro et al. (2009)
Laboratory	Essential oils from 4 different plants.	Mortality of u to 79% was recorded from the report.	Yang et al. (2010)
Tomato	Plant derived pesticides (neem).	The oviposition, egg hatching, and adult eclosion were reduced by 23.1, 53.2, and 26.6% compared to control.	Lynn et al. (2010)
Cotton	Essential oils from five aromatic plants.	<i>Mentha pulegium</i> and <i>Mentha viridis</i> essential oils 78.75% and 78.19% mortality in <i>B. tabaci</i> adults.	Zandi-Sohani (2011)
Different crops	Essential oils from aromatic plants.	The essential oils (EOs) serve multiple purposes, functioning as repellents, insecticides, and	Regnault-Roger et al. (2012)

		growth inhibitors.	
Tomato	Fermented botanicals from four plants species.	The highest effect was recorded with marigold extracts.	Baloc et al. (2013)
Laboratory	Essential oils and secondary metabolites from plants (cumin, cinnamon, lemongrass and citronella grass).	Cinamaldehyde was found to be a deterrent at a concentration of 0.084 mg/L and lethal at 8.4 mg/L. In contrast, linalool exhibited a retarding effect at a concentration of 0.006 mg/L although its lethality level is unknown.	Barkman, (2013)
Y-tube olfactometer	Volatile compounds derived from six plant species.	The results showed an attraction response of over 80%, a deterrent effect of more than 62%, and an anti-oviposition effect of over 80%.	Li et al. (2014)
Chili	Aqueous extracts.	A mortality rate of up to 96.67% was observed in the nymphs of whiteflies.	González et al. (2014)
Tomato	Foliar water extracts.	Lethality rates ranging from 80% to 97% were recorded for the whiteflies.	Gonzalez et al. (2014)
Okra	Plant extracts.	A substantial reduction in the whitefly population was observed, with percentages ranging from 5.19% to 63.17%.	Rehmana et al. (2015)
Tomato	Essential oils from different plant species.	Both the adult and egg numbers decreased to 6.6 ± 0.93 and 6.0 ± 2.39 , respectively, compared to 22.6 ± 2.23 and 70.6 ± 19.29 in the control group.	Fanela et al. (2015)
Potato	Plant extracts from five plant species viz: neem, liquorice, turmeric, pomegranate and thyme.	Neem oil demonstrated highest efficacy in reducing whitefly density, causing 66.79% reductions in 2014 and 67.71% in 2015.	Ezzat et al. (2015)
Laboratory	Essential oils from lemongrass, cumin and	At 24 hours, cinnamaldehyde was the most lethal to	Deletre et al. (2016)

	cinnamon.	whiteflies (100%), while citronellol was less (17.1%).	
Cucumber	Plant extracts and commercial insecticides.	Whitefly density reduced by 80%.	Moghadam et al. (2018)
Eggplant	Bio pesticides.	Whitefly mortality (64.04 to 83.94%) was reported.	Ghosal et al. (2018)
Cowpea	Plant extracts (neem leaves).	The whiteflies, aphids and pod borer were effectively managed.	Okolo and Iledun, (2019)
Diets bioassays	Aqueous and methanolic extracts from marigold plant.	An anti-oviposition rate of up to 80% was recorded against the whiteflies.	Fabrick et al. (2020)
Snap bean	Nanoencapsulated oils of <i>Xylopi aromatic</i> .	Up to 98% anti-oviposition was recorded.	Peres et al. (2020)
Different plants	Lemon peel essential oils.	A mortality rate of 99% to 100% was observed in both whiteflies and mealy bugs.	Sweetha (2021)
Tomato and Strawberry	Neem oils and chamomile extracts.	Neem oil exhibited a lethality rate of 71.3%, followed by chamomile and lechuguilla extracts with 62%.	Peryra et al. (2021)
Cotton	Volatile compounds derived from <i>Ocimum gratissimum</i> and <i>Cymbopogon citratus</i> .	A lower dose of <i>C. citratus</i> led to a reduction in whitefly numbers to $3.77 \pm 0.51/30$ plants, while a higher dose of 5% of <i>O. gratissimum</i> reduced the whitefly number to $3.38 \pm 0.53/30$ plants.	Kobenan et al. (2021)
Laboratory	Avacado Kernel extract.	Significant reductions (90 and 98.3%) were observed in adults and nymphs respectively.	de Carvalho et al. (2021)
Tomato	Anona sp ethanol extracts.	Effective against the whiteflies.	Soares et al. (2021)
Petri dishes	Moringa alcoholic leaf extracts.	Up to 91 and 95% reductions were recorded for adult and nymphs respectively.	Taaban (2022)
Tobacco	Essential oils of thyme and wormwood.	Significant repellent effects were observed against the whiteflies.	Li et al. 2022
Cotton	Different plant extracts.	Adult and nymph whiteflies were reduced by 55 and 52% respectively.	Hameed et al. 2023

Cassava	Patchouli and neem essential oils.	Patchouli oil was more effective causing 85 and 89% repellency and anti-oviposition effects.	Amour et al (2023)
Cassava	Volatile organic compounds from cassava.	(E)- β -Ocimene had a great repellent effect on the whiteflies.	Ribeiro et al (2023)

2.7.6. Biological strategies for whitefly control

Biological control involves using one organism to control the population of another. This method has a historical and effective role in managing destructive insect pests, such as whiteflies, on economically important agricultural plants. It typically employs parasitoids, entomopathogenic organisms, and predators (Perrings et al. 2018; Horowitz et al. 2020).

Up to 150 insect species have been shown as natural enemies of whitefly. However, only a few have been well researched. Some of the known predators of *B. tabaci* include coccinellid beetles, lacewings, and phytoseiid mites (Tan et al. 2016). *Delphastus catalinae* is a commonly used biological predator to control *B. tabaci* in greenhouse crops, causing significant reductions in whitefly density (Heinz et al. 1995). Predators like *Macrolophus pygmaeus* and *Nesidiocoris tenuis*, have also been effective in suppressing *B. tabaci* populations in greenhouse and field conditions (Calvo et al. 2009). In some cases, a combination of predators, like *Eretmocerus mundus* and *Macrolophus melanotoma*, has been successful in controlling *B. tabaci*, resulting in reduced whitefly number on the crops (Karut et al. 2018).

Parasitoids play a crucial role as biocontrol agents against *B. tabaci* in an IPM module. The well-known parasitoids used for *B. tabaci* control are *Encarsia* and *Eretmocerus* (Hymenoptera: Aphelinidae) (Perrings et al. 2018; Horowitz et al. 2020). *Encarsia Formosa* is commonly used against the *B. tabaci* on leafy vegetables. Introduction of low-density of *E. Formosa* led to significant parasitism with up to 77.9% whitefly reduction in sweet potato fields. *Eretmocerus* species, particularly *E. eremicus* and *E. mundus*, are also crucial biological control agents against the *B. tabaci*, showing significant reduction in whitefly eggs and nymphs on various crops under greenhouse conditions (Kumar et al. 2016). Combining *E. mundus* with other predators like

Amblyseius swirskii or *Macrolophus caliginosus* led to reduction in *B. tabaci* densities vegetables (Calvo et al. 2009). Furthermore, the use of *Eretmocerus warrae* in greenhouses has demonstrated substantial whitefly mortality regardless of the whitefly population (Hanan et al. 2017).

Entomopathogens (fungi, viruses, nematodes, protists, and bacteria) are a critical part of IPM modules in reducing the density of many agricultural pests (Eslamizadeh et al. 2015). Entomopathogens are promising alternatives to synthetic insecticides due to their lower toxicity to humans, non-target species, and the environment. Additionally, they can help delay the development of pesticide resistance among pest species (Li et al. 2018). Entomopathogenic nematodes play a crucial role in controlling whiteflies on vegetables, as demonstrated in studies involving *Steinernema feltiae* and *Steinernema carpocapsae*. These nematodes, when used alone or in combination with synthetic pesticides, significantly reduced whitefly survival rates by 86.5% and 94.3% in tomato and verbena crops. Similarly, *Steinernema feltiae* has proven effective in reducing the whiteflies density by 32% and 28% on tomato and cucumber plants (Li et al. 2018; Abubakar et al. 2022). The table below summarized the reports on biological whitefly management strategies (Table 2.5).

Table 2.5: Reports on the biological methods for whiteflies control

Crop name	Biological agents involved	Effects	Reference(s)
Predators			
cucumbers and lima beans	<i>Chrysoperla rufilabris</i> and <i>C. carnea</i> .	Both predators were found to eliminate 25 - 75 whiteflies/day.	Legaspi et al (1996)
Cucumber	<i>Macrolophus caliginosus</i> , <i>Dicyphus tamaninii</i> , <i>Orius majusculus</i> and <i>O. laevigatus</i> .	<i>D. tamaninii</i> were effective in reducing the whitefly density compared to <i>O. majusculus</i> and <i>M. caliginosus</i> .	Montserrat et al (2000)
Cucumber	<i>Euseius scutalis</i> (Athias-Henriot) and <i>Typhlodromips swirskii</i> (Athias-Henriot).	Both predators effectively suppressed the whiteflies.	Nomikou et al (2003)
Cotton	<i>Spanagonicus albofasciatus</i> Miridae.	30–50% of the ova or mature females were reactive for <i>B. tabaci</i> antigen.	Hagler and Naranjo (2005)
Soybean, collards, and tomato	<i>Nephaspis oculatus</i> Coccinellidae.	Within a 24-hour timeframe, an average egg reduction of 72.55% was documented.	Legaspi et al (2006)
Cucumber	<i>Amblyseius swirskii</i> (Athias-Henriot) and <i>Euseius ovalis</i> (Evans).	Whitefly and thrips population was drastically minimized.	Messelink et al (2008)
Greenhouse vegetables	<i>Dicyphus Hesperus</i> with <i>Beauveria bassiana</i> .	Nymphs and adult density were reduced by 31.7% 22.3% in <i>B. bassiana</i> -treated plants.	Labbé et al (2009)
Cucumber	<i>Chrysoperla carnea</i> (Steph.), and <i>Phytoseiulus persimilis</i> Athias-Henrio.	The combined predation had a more effective suppression of whiteflies on cucumber plants.	Adly (2016)
Poinsettia	<i>Serangium parcesetosum</i> Coccinellidae.	<i>B. tabaci</i> reduced 60% using four predators/plant.	Razze et al (2016)
Tomato	<i>Dicyphus Hesperus</i> .	Whitefly density reduced by 88.8%.	Calvo et al (2016)
Cotton	<i>Geocoris punctipes</i> Hemiptera.	<i>B. tabaci</i> density effectively reduced.	Razze et al (2016)

Cotton ficus hedge	<i>Delphastus pallidus</i> Coccinellidae.	Mortality rates of approximately 68.0% for eggs and 55.1% for nymphs were observed.	Ahmed et al (2017)
Cotton	<i>Collops vittatus</i> Melyridae.	<i>B. tabaci</i> number reduced by 86%.	Vandervoet et al (2018)
Entomopathogenic fungi			
Vegetable crops	(<i>Aschersonia aleyrodis</i> Webber, <i>Verticillium lecanii</i> (Zimmerman) Viégas and <i>Paecilomyces fumosoroseus</i> (Wize) Brown & Smith.	Provide high whitefly management effect	Osborne and Landa (1992)
Melon, Zucchini squash and cucumber	<i>Beauveria bassiana</i> and <i>Cordyceps fumosorosea</i> .	Provide >90% suppression of the whitefly.	Wraight et al (2000)
Cotton	<i>Verticillium lecanii</i> , <i>Beauveria bassiana</i> , and <i>Paecilomyces</i> spp.	The mortality rate ranged from 57.1 to 100% depending on the strain deployed.	Kim et al. (2001)
Cucumber, Melon, Tomato	<i>Verticillium lecanii</i> strains	Reduction in whitefly population and symptoms of powdery mildew disease.	Masanori et al. (2004)
Cucumber, tomato, melon, and many other crops	<i>B. bassiana</i>	The mean fatality for larvae raised on cotton: 52.3±7.3, cucumber: 91.8±5.8.	Maranha and Amaranha (2006)
Sweet potato	<i>Isaria</i> spp	Second instar LC ₅₀ : 72–118 spores/mm ² ; third instar: 166–295 spores/mm ² ; fourth instar: 166–295 spores/mm ² .	Cabanillas and Jones (2009)
Eggplant	<i>Isaria fumosoroseus</i>	It caused 91%, 90%, 86%, and 89%, reduction in eggs, second, third, and fourth instar nymphs respectively.	Rahim et al (2013)
Tomato	<i>Aschersonia placenta</i>	It led to mortality rate ranging from 93% to 100%.	Qiu et al (2013)
Cotton	<i>Trachelas</i> spp. Corinnidae	Approximately 33.3% of individuals tested positive	Hagler and Blackmer

		for <i>B. tabaci</i> DNA, resulting in lower species densities.	(2013)
Cucumbers	<i>Isaria fumosoroseus</i>	The second instar was found to be the most vulnerable stage, with a mortality rate of 83%.	Tian et al (2015)
Cucumber and pepper	<i>Teinernema feltiae</i> and <i>Heterorhabditis bacteriophora</i>	Both life stages of the whiteflies were vulnerable to infection by nematode species.	Rezae et al (2015)
Cotton and Tomato	<i>Beauveria bassiana</i>	Whitefly eggs and nymphs reduced by 65.30% and 88.82% respectively.	Zafar et al (2017)
Cotton	<i>B. bassiana</i>	Up to 56% reduction was observed at higher dosage of 1107 spores/mL.	Imam (2017)
Soybean	<i>Aschersonia aleyrodis</i>	Whitefly number reduced by 99%.	Prayogo and Bayu (2020)
Eggplant	<i>Metarhizium anisopliae</i> , <i>Verticillium lecanii</i> , and <i>Beauveria bassiana</i>	Whiteflies number reduced from 126± 2.8 to 62.8± 3.3, 130 ±3.8 to 61.4± 2, and 165.6± 2.2 to 62.4± 3.5 by the 3 species.	Nada et al (2021)
Parasitoids			
Egg plants	<i>Metarhizium anisopliae</i>	A high reduction of up to 84.3% was documented.	Islam et al (2014)
Hibiscus	<i>Encarsia noyesi</i> , <i>Idioporous affinis</i> and <i>Entedononecremnus krauteri</i>	The average parasitism rates were as follows: 28 ± 2% for <i>Idioporous affinis</i> , 28.7 ± 1.9% for <i>Encarsia noyesi</i> , and 1 ± 0.0% for <i>Entedononecremnus krauteri</i> respectively.	Schoeller and Redak (2020)
Tomato	<i>Encarsia formosa</i> and <i>Encarsia sophia</i> (Hymenoptera: Aphelinidae).	Sixty (60%) parasitism rate was observed.	Tan et al (2016)
Cotton	<i>Encarsia sophia</i> and <i>Eretmocerus hayati</i> (Hymenoptera: Aphelinidae).	<i>En. sophia</i> exhibited a cumulative host consumption rate (C0) of 84.1 whiteflies per individual, whereas E.	Xu et al (2018)

		hayati had a C0 of 17.6 whiteflies per individual.	
Cotton	<i>Eretmocerus hayati</i>	2 nd nymphs were most parasitized with highest incidence (62.03%) of <i>E. hayati</i> .	Ou et al (2019)
Cotton	<i>Eretmocerus hayati</i>	Whitefly density was significantly reduced.	Zhang et al (2020)
Poinsettias	<i>Eretmocerus eremicus</i> (Rose & Zolnerowich) and <i>Amblyseius swirskii</i> compared to synthetic insecticides	The average density of whiteflies nymphs per plant for the IPM was recorded to be 3.5 ± 1.09.	Vafaie et al (2021)
Cassava	<i>Encarsia sophia</i> and <i>En. Lutea</i>	The highest parasitism rates were observed for <i>E. lutea</i> with 48.2%.	Tize et al (2023)
Green house vegetables	<i>Encarsia Formosa</i>	It exhibited a higher parasitism rate of 37.2 and 36.4% on fourth and third-instar nymphs.	Ghongade et al (2023)
Tomato	<i>Encarsia Formosa</i>	Whitefly density was substantially reduced.	Sood et al (2023)

2.7.7. Synthetic chemicals and whitefly control

The most common strategy used by farmers to manage various insect pests of agricultural importance is through chemical pesticides. It was reported that in open-field vegetable production systems, there is still a high reliance on synthetic pesticides to control *B. tabaci* (Perring et al. et al. 2018; Horowitz et al. 2020; Abubakar et al. 2022). Common types of pesticides that are used against *B. tabaci* include growth regulators such as pyriproxyfen and buprofezen, ketoenols like spiromesifen and spirotetramat, and diamides including anthranilic diamides, cyantraniliprole, and chlorantraniliprole. Additionally, various chemical pesticides like organochlorines, organophosphates, carbamates, pyrethroids, triazines, and neonicotinoids are widely employed to combat different insect pests (Nicolopoulou-Stamati, 2016). The earliest neonicotinoid to be commercially available in the markets was imidacloprid, and it continues to become the world's most highly utilized pesticide with high effectiveness against sap-sucking insects

like *B. tabacum* different food and vegetable crops worldwide (Ellsworth and Martinez 2001). Detergents and soaps have been extensively used for controlling *Bemisia tabaci* as well (Horowitz et al. 2020). Despite the several negative effects related to the application of such pesticides on human and ecological safety (Zheng et al. 2016; Vafaie et al. 2021), they have been used severally to suppress sap-sucking pests on different crops. Whiteflies were reported to be substantially managed using thiamethoxam 25 WG a 100g/ha on eggplant with a total (100%) mortality (Kumar et al. 2017). Magsi et al (2017) also examined several chemical pesticides including sulfoxaflor, diafenthiuron, confidor, imidacloprid and agrovista with imidacloprid being highly effective causing up to 93.24% mortality 2 hours after treatment on tomato crops. This is similar to what was reported (Saleem et al. 2022) with imidacloprid lowering the whitefly densities to 1.0 whiteflies/leaf 2 weeks after spray on eggplant. The following table depicts the various chemical pesticides used against the whiteflies (Table 2.6)

Table 2.6: Reports on the use of chemicals for Whiteflies management

Crop name	Pesticides used	Result	Reference
Lobia leaves	Chlorpyrifos and endosulfan,	They resulted to LC ₅₀ s: 17.37, 9.62, 5.5 and 15.49 ppm, respectively.	Yassin et al (1990)
Cotton	Buprofezin	Whitefly density effectively reduced.	Rami Horowitz and Ishaaya (1992)
	Buprofezin, abamectin and imidacloprid	There was substantial reduction in whitefly population.	Gorman et al (2002)
Tomato and Verbena	Buprofezin, teflubenzuron imidacloprid and nicotine	Buprofezin was most effective (79.8%) while imidacloprid was lowest (58.5%) mortality.	Cuthbertson (2003)
Cabbage	Seventeen insecticides including abamectin, acephate, acetamiprid, cartap, imidacloprid, and malathion etc	Highest mortality (100%) was found with Cartap while trichlorphon had the least (4%).	Bacci et al. (2007)
Strawberry	Imidacloprid, thiamethoxam and dinotefuran	Imidacloprid resulted in 63.58% adult mortality, while thiamethoxam led to 41.95%	Bi et al. (2007)

		mortality.	
Citrus	Diazinon, endosulfan, imidacloprid,	There was total mortality (100%) 10 weeks after the various sprays.	Jamieson et al. (2010)
Eggplant	Four insecticides viz; fipronil, imidacloprid, buprofezin and thiamethoxam along with emamectin benzoate	Confidor was more potent causing 69.0% whitefly mortality.	Das and Islam (2014)
Okra	Lambdacyhalothrin	It 63.94% mortality 7 days post-treatment, but decreased to 18.99% 15 days after the spray.	Nadeem et al. (2015)
Tomato	Profenophos, imidacloprid, cypermethrin, and indoxacarb.	Imidacloprid was effective (58.1%) reduction while indoxacarb was less potent with 51.40% efficacy.	Jha and Kumar (2017)
Cotton	Seven common insecticides: cyantraniliprole, sulfoxaflor, spirotetramat, flonicamid, acetamiprid etc	Sulfoxaflor exhibited the highest relative toxicity (13.86%).	Chen et al. (2018)
Zucchini	Acetamiprid, pymetrozine with phosphoric soap and spirotetramat along with azadirachtin	Whiteflies were suppressed by up to 44%.	Rodríguez et al. (2019)
Eggplant	Actara, Confidor, Calypso, Polo, and Confidor	Actara led to 89.06% reduction, being more effective 14 days after spray.	Mohammadali et al. (2019)
Chilli	Spinetoram, Bifenthrin + Abamectin Sulfoxaflor	The combined effect of bifenthrin and abamectin had proved most effective reducing whitefly density by 84.46%.	Parhyar et al. (2019)
Tomato	Dimethoate, imidacloprid, lambdacyhalothrin, novaluron, imidacloprid, indoxacarb, azadirachtin	Imidacloprid has lowest whitefly density (2.18 adult/leaf) compared to control 5.69 adults/leaf.	Thorat et al. (2020)
Tomato	Thiocyclam (hydrogen oxalate), Acetambrid and	Higher toxicity of about 86.98 ± 2.63 and 84.19 ± 1.56	Zawra et al. (2020)

	Imidacloprid	were recorded in abamectin and imidacloprid.	
Okra	Imidacloprid	It reduced the whiteflies density to 3.90 whiteflies/15 leaves 15 days after the spray.	Jain et al. (2021)
Potato	Emamectin, thiodicarb, diafenthiuron, chlorpyrifos, chlorfenapyr, cyantraniliprole, bifenthrin and spiromesifen	Spiromesifen 22.9 SC at a 1.00 mL/L concentration demonstrated the highest effectiveness against the mites and whiteflies.	Natikar and Balikai (2021)
Eggplant	Lambda-cyhalothrin	Lambda-cyhalothrin reduced the whitefly average whitefly density dramatically (2.21/leaf) 15 days after application.	Sana et al. (2021)
Tomato	Thiamethoxam, cyantraniliprole and sulfoxaflor	Whitefly density was effectively reduced.	Mao et al (2022)
Laboratory	Bifenthrin, cartap, chlorfenapyr and chlorpyrifos	About 80 to 100% mortality was observed in adult whiteflies.	Kon et al (2023)

2.7.8. Biotechnological strategies for whitefly control

Biotechnological techniques, such as transgenesis and RNA interference (RNAi), offer great potential for effective regulation of whitefly density on various agricultural crops. This can be achieved by introducing pesticidal toxins or lectins into transgenic crops through nuclear or chloroplast modification, as demonstrated (Shukla et al. 2016; Suhag et al. 2020). The genetically modified crops can be used as a means of controlling whiteflies and other pests' population on vegetable crops.

2.7.8.1. Transgenesis and whitefly control

One of early success in plant biotechnology was the introduction and commercialization of transgenic crops with resistance to important insect pests, including whiteflies. Agricultural plants like tomatoes and lettuce were genetically engineered to tolerate attacks from *B. tabaci* and related viruses. By producing insecticidal Bt proteins, genetic

engineering has been highly effective in developing various agricultural plant species that can resist insect infestations (Shukla et al. 2016). These proteins have a well-established safety record, as they are highly specialized to target lepidopteron and coleopteran insects, with minimal impact on non-target beneficial species, and no harm to humans or organisms lacking receptors for these peptides. The *vip3* gene, extracted from an Egyptian strain of *Bacillus thuringiensis*, was successfully amplified (2.4 kbp) and expressed using a bacterial system. Transgenic plants producing DsRNA that encode crucial insect genes can effectively silence target genes in affected whiteflies, leading to their death, growth retardation, and/or sterility (Grover et al. 2018). Whitefly densities were dramatically lowered in tobacco plants modified to express DsRNA that targeted v-ATPase A (Thakur et al. 2014) and osmoregulators (Maliket al. 2016), leading to 100% mortality. Similarly, genetically engineered lettuce carrying the v-ATPase DsRNA also showed comparable results, significantly decreasing whitefly numbers (Ibrahim et al. 2017). In another study, the DsRNA of BtGSTs5, a gene involved in the insect's ability to counteract toxic substances, was effectively down regulated specifically in the intestinal tract of whiteflies by *Arabidopsis thaliana* genetically modified plants. This prolonged the developmental stages of *B. tabaci* nymphs and caused a notable decline in *B. tabaci* populations (Eakteiman et al. 2018).

2.7.8.2. Exogenous application of DsRNA to control whiteflies

Recently, non-transgenic (GMO-free) RNAi strategies have emerged as potential alternatives to transgenic techniques for pest control (Zotti et al. 2015; Suhag et al. 2020). These methods involve the application of exogenous RNA fragments to target specific insects that feed on plants, either through leaf spray, soil treatment, or stem injections. In the case of chewing pests, the exogenous RNA fragments are effectively delivered to the insects when they consume the plants. For insects that feed through the vascular system, such as phloem-feeding pests, the RNA fragments can be transported to neighboring and distal plant tissues via the vascular pathway, providing protection to even unprotected plant parts (de Andrade and Hunter 2016). These non-transgenic RNAi methods have

proven effective in silencing genes in a short period without causing heritable changes to the organism's genome, making them more publically/socially acceptable. Two such methods, foliar spraying, and submerging leaf petioles in dsRNA solutions, have been employed to control whiteflies successfully. Additionally, in a separate study, exogenous delivery of DsRNA particles to tomato seedlings resulted in DsRNA uptake by sap-sucking insects, including whiteflies, aphids, and mites, indicating their potential for broader application in pest control (Suhag et al. 2020). According to studies by Gogoi et al (2017), siRNAs (small interfering RNAs) produced from DsRNA were found in mites and aphids but not in whiteflies. This difference in siRNA synthesis might be attributed to reduced absorption or uptake of DsRNA in whiteflies, leading to insufficient levels for effective RNAi production. To address this discrepancy and to control various insect species that infest crops in succession, sprays containing multiple DsRNA can be used. This approach offers an environmentally friendly solution as the dsRNA does not persist on the foliage for an extended period, and thus possess great potential of being adopted by the farmers (Suhag et al. 2020).

2.7.8.3. Control of *B. tabaci* through nanotechnology

The raw DsRNA have a limited lifespan when applied directly to crops or delivered through fluids for uptake by the leaves or soil, as they can be degraded by solar radiation, microbial species, or cellular enzymes in the surrounding environment. However, recent research has shown that DsRNA loaded onto layered double hydroxide (LDH), clay nanostructures (Bio Clay) or carbon nanotubes with an average diameter of less than 0.1 μm (Zhang et al. 2019) can be readily absorbed into cell membranes without the need for external assistance or the incorporation of heritable modifications into the chromosome of the treated plant. These nanomaterials not only stabilize DsRNA for prolonged continuous delivery but also protect them from being degraded by proteolytic enzymes. For successful application, these nanomaterials should be recyclable and non-toxic. By directly applying these nanomaterials to transport RNAi to plants, it becomes a straightforward and environmentally friendly method to provide effective defense to

crops against pests and pathogens. A recent study (He et al. 2020) reported that nanomaterials loaded with insect receptor protein DsRNA to control 3rd phase nymphs of *B. tabaci*. The study aimed to assess the role of nuclear receptor (NR) alleles in insect metamorphosis/transformation. The utilization of nanoencapsulated *Xylopia aromatica* essential oils protects them from environmental degradation and extends their biological activity (Peres et al. 2020). Moreover, *Cordyceps fumosorosea* derived zero-valent iron (ZVI) (fungal) nanoparticles exhibit remarkable effects against *B. tabaci* nymphs and pupae, due to their prolonged fungal activity, and effectively prevented their early degradation (Wagan et al. 2019). The reports on biotechnological methods in whitefly control are presented in table 2.7.

Table 2.7: Reports on the use of genetic engineering strategies for whiteflies management

Crop name	Biotechnology involved	Results	Reference
Tomato	RNA interference using Mi-1.2 gene	The Mi-1.2 gene conferred resistance in the crop to root-knot nematodes, aphids and whiteflies.	Nombela et al (2003)
Micro-injection DsRNA	dsRNA introduction into whiteflies (0.1–0.5 µg)	A significant reduction of 75% in salivary gland expression and a 60% decrease in midgut expression were observed.	Ghanim et al (2007)
Tomato	Root inoculation of Bt strains	Treatment with BsDN led to a significant decrease in the number of <i>B. tabaci</i> pupae developing into adults on the treated plants.	Valenzuela-Soto et al (2010)
Tobacco	Chloroplast transgenics (Transplastomic plants)	The mortality rate for all the insects was 100%.	Jin et al (2011)
Tobacco	dsRNA applied exogenously to plants (0.5 mg/mL)	In 4th instar nymphs of whiteflies, <i>Cyp315a1</i> was down-regulated by approximately 80%, while <i>Cyp18a1</i> was down-regulated by 46%.	Luan et al (2013)

Cotton	RNA interference using <i>v-ATPaseA</i>	After consuming transgenic plants, the transcript level of <i>v-ATPaseA</i> in whiteflies was lowered by up to 62 %.	Thakur et al (2014)
Tobacco	Nuclear transgenics (<i>A. tumefaciens</i>)	A complete mortality (100%) rate of <i>Bemisia tabaci</i> was achieved	Javaid et al (2016)
Cotton	Nuclear transgenics	Modified cotton with Tma12 gene at a 0.01% concentration caused whitefly up to 90% whitefly mortality.	Shukla et al. (2016)
Cotton	RNA interference using DsRNA	Up to 90% mortality was observed 2 days after treatment.	Malik et al. (2016)
Lettuce	RNA interference using <i>v-ATPase A</i>	Whiteflies mortality ranges from 83.8–98.1 % 5 days after feeding.	Ibrahim et al. (2017)
Tomato	Plant mediated RNAi (<i>A. tumefaciens</i>)	Whitefly mortality rates of up to 50% were observed.	Luo et al. (2017)
Tomatoes	Application of dsRNA through the roots	At a concentration of 5 µg/mL, the highest mortality rate (84%) recorded was.	Ludba (2018)
Cotton	Nuclear transgenics	Six days after spray, a mortality rate of 18.37% was recorded among nymphs, and 9.65% was among adults.	Anwar et al. (2019)
Tomato	RNA interference induced by plants (via siRNA) transgenic	There was a significant decrease in whitefly reproduction (81.8%) and a substantial increase in mortality (85.6%).	Kanalaka et al. (2019)
Tobacco	RNA interference using	High resistance to whitefly was observed in transgenic plants as compared to control groups.	Zubair et al. (2020)
Cotton	Transgenic using ZmASN gene under constitutive promoter (<i>A. tumefaciens</i>)	About 95% mortality rate has been recorded for whiteflies	Gul et al. (2020)
Tobacco	Chloroplast mediated RNAi	The introduction of <i>BtACTB</i> in transgenic plants led to a mortality rate of 80% for <i>B. tabaci</i> .	Dong et al. (2020)
Tobacco	Artificial miRNA mediated resistance	When compared to the control, the modified plant exhibited	Zubair et al. (2020)

		abnormal egg hatching and poor nymph development.	
Citrus and cassava	Exogenous application of modified dsRNA via NRAi methods	In genetically modified species, the mortality increases from 12% to 35% when compared to non-modified plants.	Hunter and Wnintermantel (2021)
Cotton	Gene silencing (RNAi)	Oral administration of dsRNA resulted in several effects, including a 42.5% mortality in adults, decreased fertility with 36.57 eggs per female, and a significant 62.50% reduction in larval density.	Puri and Jindal (2021)
Tomato	RNA interference	The mortality rate in transgenic line 4.4.1 was 57.1%, while the control group had a mortality rate of 7.6%.	Pizetta et al (2022)
Cotton	RNRi of CAPAr gene	Oral delivery of dsRNA targeting the CAPAr gene led to a 30.74% mortality rate in adult whiteflies and significantly reduced female fecundity, while gene expression analysis confirmed downregulation of CAPAr.	Thakur and Jindal (2022)
Tobacco	Silencing of BtTPS gene	Transgenic tobacco plants targeting BtTPS1 and BtTPS2 caused reduced nymph growth, hatchability, high adult mortality (90%), and decreased fecundity.	Gong et al (2022)
Diet bioassay	Knockdown of TRPV nan gene	Bemisia tabaci resistance to afidopyropene has been decreased by 86-fold.	Wang et al (2023)
Diet bioassay	RNA interference	High mortality of 68.36% was observed in the nymphs of whiteflies.	Karthigai et al (2023)

2.7.8.4. Whitefly control through IPM methods

Integrated Pest Management (IPM) is a universally recognized approach for pest control, aiming to reduce the ecological and public health hazards related to synthetic insecticides. In the case of *Bemisia tabaci*, the IPM approach includes biocontrol, crop plant resistance, physical and mechanical measures, and limited use of selected pesticides when necessary (Horowitz et al. 2011). Islam et al (2011) demonstrated that combining neem oil with *Beauveria bassiana* led to reduction in *B. tabaci* larvae on eggplant leaves. However, higher concentration of neem extract (above 0.5%) had detrimental effects on the eggplant seedlings. Another study investigated the combined impact of neem leaves extract and *B. bassiana* on *Bemisia tabaci* using different neem concentrations (0.25, 0.55, and 1.0%) and three quantities of *B. bassiana* (106, 107, and 108 conidia/mL). The findings revealed that the combination of 1.0% neem with the entomopathogen resulted in the highest mortality (92.3%) of whitefly nymphs. In another study by El Shafie and Abdelraheem (2012), the effectiveness of three bio pesticides, namely NeemAzal®, XenTari®, and Spinosad® were tested against the major tomato insect pests including the whiteflies, aphids, and African bollworm. The use of these biopesticides significantly reduced the densities of the insect pests examined. Mushtak et al (2019) conducted a study to assess the effectiveness of various neonicotinoid pesticides against cotton whiteflies. They found that foliar applications of Actara and Confidor were highly potent in reducing the whitefly populations one day of treatment. In contrast, soil treatments using Actara and Confidor were the least successful in lowering the number of nymphs a day after application in all treatments. Three different approaches for whitefly control were tested: biological, chemical, and integrated pest management (IPM) in a greenhouse trial. The effectiveness of these methods was evaluated in multiple trials to determine the most efficient strategy for whitefly and associated virus suppression. The results showed that the combined effects of the control measures had the highest potential (73%) compared to deploying these methods independently (Estefana et al. 2019).

In their study (Wawdhane et al. 2020), the efficacy of three treatments - synthetic pesticides, plant-based products, and microbes - was investigated, and spiromesifen was found to have the greatest effect with 82.27% reduction in whitefly number. Neem oil at a concentration of 2%, neem seed extract at a concentration of 5%, and tobacco leaf extract at a concentration of 10% also showed effectiveness in reducing sap-sucking pests. Among the microbes, *Verticillium lecanii* at a concentration of 1x10⁸ CFU/mL was effective against aphids, whiteflies, and thrips. Kumar et al. (2020), studied the comparative efficacy of various modern insecticides and biocontrol agents against whitefly in brinjal crops. All the treatments were found to be significantly more successful than the control in reducing the whitefly populations with improved yield. Although, *Bacillus thuringiensis* at 1.0kg/ha showed less effectiveness compared to chemical treatments, it was still considerably better than the control group. Table 2.8 presented some reports on the use of IPM in whitefly management modules.

Table 2.8: Reports on the use of IPM strategies for whiteflies management (WFM)

Crop name	Treatments deployed	Results	References
poinsettias	Mycoinsecticide and <i>Beauveria bassiana</i>	Both nymph and adult population were significantly reduced.	Olson and Oetting (1999)
Collards and tomato	Surfactants, mineral oil, cotton seed and vegetable oils	Whitefly mortality ranged from 22.1 to 95%.	Liu et al (2000)
Citrus	Novel and conventional insecticides	Fenprothrin + surfactant caused 100% mortality 9 days after application.	Legaspi et al (2000)
Tomato	Plant extracts, tween 20 and biological agent (predator)	Leaf and fruit extracts + tween-20 resulted in death rates ranging from 34.6 to 67.9 % for leaf and 53.5 to 74.1 % for fruits, respectively.	Jazzar et al (2003)
Tomato and verbena	Chemical insecticides and entomopathogenic nematode	The combined effect of nematodes and imidacloprid caused 70.9% <i>B. tabaci</i> larval mortality.	Cuthbertson et al (2003)
Cucurbita spp	Synthetic mulches with and without	Whitefly number/leaf: Reflective mulches (15.22), buckwheat	Tressia (2007)

	imidacloprid	(17.09), reflective+admire2f (10.38), buckwheat + admire2f (10.40) and control (38.27).	
Tomatoes	Parasitoids, predators and insecticides	The most effective treatments were a mix between <i>Eretmocerus mundus</i> and <i>Amblyseius swirskii</i> with an average of 0.7 ± 0.18 whiteflies per leaf.	Calvo et al (2009)
Tomatoes	Chemical insecticides and entopathogenic nematode	The use of nematodes+thiacloprid and spiromesifen resulted in a greater <i>B. tabaci</i> lethality (86.5 and 94.3%), compared to nematodes alone (75.2%).	Cuthbertson et al (2009)
Brinjal	Botanicals and synthetic insecticides	The 5% neem extract led to 3.5 whiteflies as compared to (8.0 whiteflies/leaf in the control group.	Mandal et al (2010)
Eggplant	Entomopathogenic fungi and plant extracts	The highest impact on both whitefly eggs (88.25%) and adult whiteflies (80.15%) was observed when Neem (1%) extract was used in conjunction with <i>B. bassiana</i> .	Islam et al (2011)
Cucumber	Botanicals and synthetic insecticides	The treatments caused 73.42% to 90.29% whitefly mortality.	Golmohammadi et al (2014)
Soybeans	Different chemical pesticides	Egg hatching greatly reduced to 4.35% compared to 95% in the control.	Abd-Allah et al (2015)
Tomato	Zinc sulfate and plant extracts	Plant oils caused 90% mortality while the integrated effect of the zinc sulfate, orange and clove oils caused up to 97% mortality.	Ebadah et al (2016)
Tomato	Physical method (Use of Kaolin, a clay minerals)	A significant reduction in adult and nymph density 91.6% and 89% were observed at 5% (w/v) concentration.	Baiomy (2017)
Sweet potato	Entomopathogenic fungi and aqueous plant extracts	The combination of naturalis and <i>Calotropis procera</i> extract resulted in the most substantial reduction, with a 62.6% decrease in eggs, a 67% decrease in nymphs, and a 65.2% decrease in adult whiteflies.	Jaber et al (2018)
Cucumber	Plant extracts and commercial	The spray of the extracts alongside the pesticides caused 80%	Moghadam et al (2018)

	insecticides	reduction on cucumber.	
Tomatoes	Metallic reflective mulches, insecticides and resistant cultivar	The use of metallic reflective mulches significantly reduced both insect density and symptoms of disease on crop.	Riley and Srinivasan (2019)
Eggplant	Bio pesticides and synthetic insecticides	Compared to the control group (11.04), all treated crops recorded lower whiteflies number (3.20 to 5.49 whiteflies/leaf).	Shejulpati et al (2019)
Ash gourd	Synthetic chemicals, sticky traps, plant extracts, farmers practices and micronutrients	Whiteflies reduced by 100% 18 days after application, with 1.86 adult/plant 60 days after spray.	Tamilnayagan et al. (2019)
Tomato	Botanical oils and chemicals	The combined effect led to 80.5% whitefly mortality.	Kumar et al (2019)
Crop plants	Mixture of cow urine with nettle leaves, wild azadiracta and holy basil	The mixture demonstrated remarkable efficacy in managing crop pests with minimal expenses.	Papnai et al (2020)
Orange	Different organic pesticides	All the substances tested did not cause any notable mortality on any of the orange spiny whitefly instars.	Mokrane et al (2020)
Potatoes	Mineral oils and synthetic chemicals	The combination of imidacloprid, thiamethoxam, and mineral oils led to a notable reduction in the Bemisia tabaci population, with a decrease of 74.5%, as well as a substantial reduction in disease incidence, reaching 93.0%.	KamLesh et al (2021)
Cotton	Three bio pesticides along with synthetic insecticides	There was 60% mortality in Eco-Bb® treated plots while 67% was found in Karate®.	Malinga and Laing (2021)
Poinsettia	Integrated using systemic and trans laminar insecticides	Imidcloprid has lowest (1.0±0.5) whitefly number.	Gill and Chong (2021)
Tomatoes	Biopesticides and synthetic chemical	The use of cytraniliprole + lambda-cyhalothrin at a rate of 50 + 30 g	Arnemann et a. (2021)

		a.i. ha-1 resulted in a 64% reduction in whitefly populations. Conversely, employing a mixture of 0.5% flaxseed and 0.3% sodium bicarbonate led to a larval mortality rate of 72%.	
Tomato	Plant derivatives with the neonicotinoid insecticide	Up to 94.4% mortality rate was recorded.	Soares et al (2021)
Eggplant	Botanicals and synthetic insecticides	In the integrated treatments, the average number of whiteflies was 2.37 higher than lambda cyhalothrin treatment with 2.21 whiteflies/leaf.	Sana et al (2021)
Tomato	Microbial, botanicals and insecticides	About 58.48 to 100% and 52.06 to 100% reductions were recorded for the nymphs and adults whiteflies respectively.	Gebremariam et al (2022)
Tomato	Thiamethoxam, sulfoxaflor and cyantraniliprole	Upt 98% anti-ovipotion effect was recorded.	Mao et al (2022)
Cotton	Bioinsecticides and synthetic insecticides	The combined effects led to 14-63% and 16-62% mortality for nymphs and adults whitefly respectively.	Iqbal et al (2022)
Soybean	Bioinsecticides and synthetic insecticides	Mortality rate ranging from 34 to 83% was observed during the study.	Bevilaqua et al (2023)
Zucchini	Plastic mulch color, exclusionary row covers, particle clay, and organic insecticidal solutions	Neem oil, particle caly and soap were effective against the whiteflies and in increase in yield in zucchini crop.	Díaz-Pérez et al (2023)
Squash	Intercropping and insecticidal soap	Whiteflies and aphids' populations were reduced substantially.	Lopez and Liburd (2023)

2.8. Research gap

Eggplant is among most susceptible vegetable crops to whiteflies infestations (Islam et al. 2011; Kumar et al. 2019; Manna et al. 2023) but there are limited scientific reports on the effects of whiteflies infestation on the green round cultivar in Kebbi State, Nigeria. Synthetic chemicals remained the most applied pesticides to control whiteflies and other insect pests on different vegetable crops in the area despite their negative effects on human health and the ecosystem (Muhammadali et al. 2019; Sani et al. 2020; KamLesh et al. 2021). Indigenous technical practices are given less attention by scientific community in the area despite being cost-effective and eco-friendly techniques with promising effects against the sap-sucking pests (Papnai et al. 2020). Similarly, there are few accessible scientific evidences of their efficacy and safety (Dougoud et al. 2019). Despite the various reports demonstrating the effectiveness of plant-based extracts against the arthropod pests with little or no negative effects on human health and ecosystem, very few phytochemicals are currently employed against the whiteflies in the area, and the novel botanicals have minimal economic possibilities (Tembo et al. 2018). Furthermore, these approaches are mostly applied unilaterally/separately for the control of whiteflies and only few IPM approaches describing the synergistic effects of different treatments are deployed for whiteflies control on eggplants (Struelens and Silvie 2020; Deguine et al. 2021). As a result, the level of damage caused by *B. tabaci* on the most cultivated but susceptible eggplant variety (green round) in the area was assessed and alternative strategies to synthetic pesticides from the natural and locally available sources were explored. These products and techniques are easily obtainable with simple preparation procedure in addition to their safety, cost-effective and eco-friendly nature. This was done to determine an efficient and robust whitefly management strategy for sustainable production of eggplant in the study area.

CHAPTER THREE

3.0. MATERIALS AND METHODS

3.1. Study area

The experimental works were carried out in agricultural research farm of the Kebbi State University of Science and Technology, Aliero, Nigeria (**Fig 3.1**). The area is on the latitude 12° 13' 19.88" N, longitude of 4° 22' 46.67"E." The area has dry and wet seasons. The wet season begins in May and extended to late September while dry season lasts from October to May. The mean annual rainfall is of the area 500 mm and that of temperature is 31°C respectively. Most of the occupants in the area are farmers cultivating different food and vegetable crops for their sustenance (Abubakar et al. 2020).

3.2. Seed procurement, germination and viability testing

The plant used for the experiment is the green round eggplant cultivar ('Yalo-Dan Hausa'), being the most cultivated variety by the farmers in the area. The seeds were procured from Afrimash Company Limited, Ibadan, Nigeria and used for the experiment. Prior to experiments, the germination percentage and viability of the seeds were tested using three earthen pots. The pots were filled with fertile organic soil and hundred seeds were broadcasted in each pot, and lightly covered with a layer of soil. Irrigation was maintained to moist the soil when required, and the germination percentage was monitored for fourteen days. Up to 75% germination was recorded two weeks after sowing. The seeds were then used to raise the seedlings used for the conduct of the experiments.

3.2.1. Seedlings production

The site of seedling production was initially cleared and ploughed up manually with a hoe. Nursery beds of 1×3m dimensions were designed and 1 wheel barrow full of organic manure was added and mixed thoroughly with the soil. The beds were irrigated sufficiently, and the seeds were broadcasted manually on the beds and lightly covered with a layer of soil after broadcasting. Organic mulches were then added to the beds to preserve the moisture, maintain the optimum temperature and also to protect the

germinating seedlings from rodents and birds. After germination, the organic mulches were pushed off the seedlings to allow the sunlight and the seedlings were watered regularly until the emergence of 4 to 6 true leaves. Watering was then reduced a week prior to transplanting to harden the seedlings. The seedlings were uprooted along with some soil and transplanted immediately in the experimental plots at 60×60 cm spacing. Standard/recommended agronomic practices including irrigation, weeding, and fertilizer application were equally provided in all the plots during the trial (Rehmana et al. 2015). The infestation by whiteflies was allowed to occur naturally. The spray of the treatments commenced when the whitefly population goes beyond the economic threshold level (ETL) (8 to 10 whiteflies/leaf) in the experimental plots.

3.3. Soil analysis

To know the status of the soil in the experimental site prior to transplanting, soil testing was carried out using standard methods. A random sampling was used in the collection of soil samples from the ten places within the experimental field at a depth of 0-15cm. Twenty (20g) of the soil was weighed from each of the ten samples collected, and placed into a silver plate to make a composite sample of about 200g. A representative sample was made from the composite samples and sieved through a 2mm sieve and analyzed for total organic carbon (TOG), pH, and nutrients (NPK) availability according to standard methods (Table 3.1).

Table 3.1: Techniques involved in assessing the properties of the experimental soil

S.No.	Soil properties tested	Method deployed
1	pH	Glass electrode method pH meter (Motsara and Roy 2008)
2	Organic carbon (%)	Rapid titration method (Walkley and Black 1934 as modified by Nelson and Sommers 1982)
3	Nitrogen (kg/ha)	Kjeldahl method as (Bremner and Mulvaney 1982)
4	Phosphorus (kg/ha)	Olsen and Sommers (1982)
5	Potassium (kg/ha)	Flame photometry (Helmke and Sparks 1996)

3.4. Field clearance

All the experimental sites were initially cleared and ploughed manually several times using hoe and the soil was prepared to a fine tilth prior to transplanting so as to provide proper drainage in the experimental plots (Ghosh 2022).

3.5. Assessment of damage caused by whiteflies on eggplant

3.5.1. Plant culture and insect collection

The seedlings raised from the green round eggplant variety were used for this experiment, being the most cultivated cultivar in the area. The insects used for the study (*Bemisia tabaci* Genn.) were collected from the vegetables (watermelon, eggplants and tomatoes) at the research farm of Kebbi State University of Science and technology, Aliero, Kebbi State, Nigeria using aspirators. The required number of whiteflies for each plot was counted as they were being caught from the field and they were released gently by slightly shaking the aspirator at the lower surface of the eggplant leaves in the experimental plots (fig 3.3).

3.5.2. Experimental design for damage assessment

To assess effect *B. tabaci* infestation on *S. melongena*, an open field and indoor experiments were conducted. For open field trials, randomized block design (RBD) consisting of four plots and four treatments ($T_1= 15$, $T_2= 30$, $T_3= 45$ and $T_4=$ control with 0 whiteflies/plots) replicated four times was adopted. The trial consists of total of sixteen (16) plots, each measuring $1 \times 1 \text{m}^2$ with 0.5 m space between the plots, thus measuring $5.5 \times 5.5 \text{m}^2$ as its wide and length respectively. Each plot was transplanted with three seedlings in a triangular setting at 60x60cm spacing and demarcated with mosquito nets (fig 3.4). The required number of *Bemisia tabaci* Genn for each plot (15, 30, 45, and 0 whiteflies) were counted as they were caught from the vegetable fields using aspirator and then released into the demarcated plots by gently shaking the aspirator at the lower surfaces of the eggplant leaves, a week after transplanting (Nikpay and Goebel 2016; Padilh et al. 2021). Similar experiment with the same measurements was designed in an

indoor setting using completely randomized design (CRD). In each plot, three earthen pots were installed in a triangular setting at 60x60cm spacing and each pot was transplanted with a single eggplant plantlet and the plots were demarcated with mosquito nets (fig 3.5). The recommended agronomic practices which include irrigation, weeding, and fertilizer application were provided uniformly in all the plots throughout the trials.

3.5.3. Parameters recorded for damage assessment

Plants growth parameters were recorded from both the field and indoor experiments after the release of whiteflies on eggplant at an interval of 30 days (approximate time for single whiteflies life cycle) throughout the plant growth period. The plant parameters recorded were plant height (PH, cm) using a measuring tape, leaf area (LA, cm²) using the formula, F (L x W) (where F= constant factor, L= leaf length and W = width of the leaf), leaf fresh weight (FW, g) and dry weight (DW, g) using digital weighing device (M-METLAR digital balance) and number of leaves/plants (by counting the total number of leaves per each plant). After determining the fresh weight of the leaves, they were oven dried at 60°C for 8 hours, and their dry weights were then measured (Islam et al. 2011) (fig 3.6). The dry matter (DM) in percentage (%) was determined using the formula: DM (%) = final dry weight (g)/initial wet weight (g) x 100. The data on absolute growth rate (AGR, g day⁻¹), relative growth rate (RGR, g⁻¹ day⁻¹), and net assimilation rate (NAR, g m⁻² day⁻¹) were then calculated using the equations of Radford (1967) and Watson (1952), as given below:

$$\text{AGR} = \frac{W_2 - W_1}{T_2 - T_1};$$

$$\text{RGR} = \frac{\log_e W_2 - \log_e W_1}{T_2 - T_1}; \text{ and}$$

$$\text{NAR} = \frac{(W_2 - W_1) (\log_e LA_2 - \log_e LA_1)}{(T_2 - T_1) (LA_2 - LA_1)}$$

Where W₁ = dry weight 1 at time one (T₁), W₂ = dry weight 2 at time two (T₂), LA₁ = leaf area at time one (T₁), LA₂ = leaf area at time two (T₂).

The percentage reduction (%) per the growth parameters of eggplant was determined using following equation: Reduction (%) = (control – infested)/control x 100 (Islam et al.

2011; Saeedi and Ziaee 2020). Plant yield per plot was then determined at harvest. The data on whitefly parameters which include adults and nymphs' population, oviposition (using field lens), symptoms of whitefly infestations (leaf chlorosis, honey dew deposition, leaf yellowing and distortion etc.) were recorded weekly. Three leaves (from the top, middle and bottom regions) of each plant were selected randomly for the whitefly data collection. To assess the leaf damage caused by whiteflies per plant, a visual rating scale of 1 – 5 was adopted; where 1 = 0 – 20%, 2 = 21 – 40%, 3 = 41 – 60%, 4 = 61 – 80% and 5 = 81 – 100% of foliage damaged by whiteflies (Anjorin et al. 2013) (fig 3.7).

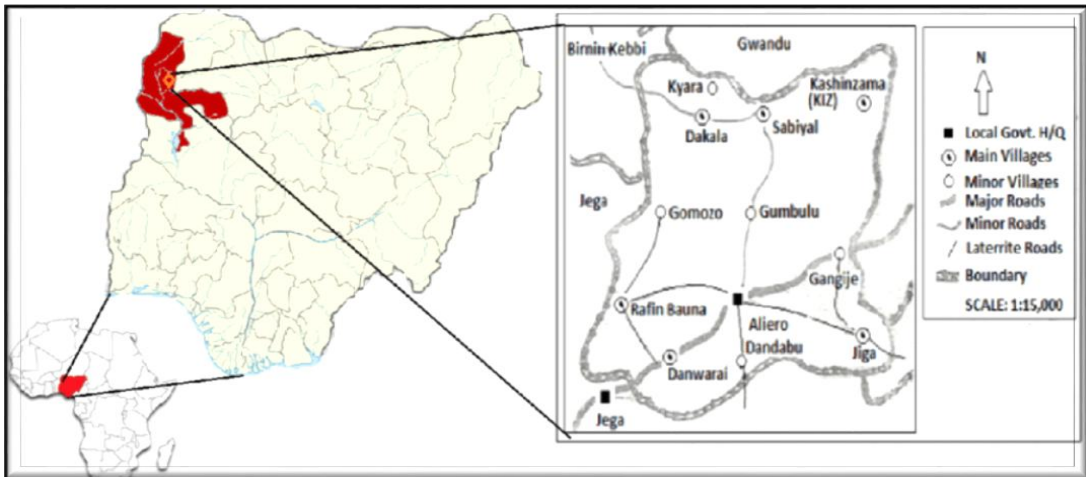


Fig 3.1: Map of Aliero Local government Area, Kebbi State Nigeria



Fig 3.2: Field layout showing the experiment plots division



Fig 3.3: Insect collection from the farmers' field. A: Whitefly collection; B: Whiteflies in the aspirator; C: Whitefly released.



Fig 3.4: Field layout for damage assessment in the field experiment. A: Experimental plots after transplanting; B: plots demarcated with nets.



Fig 3.5: Field layout for damage assessment in the pot experiment. A: plantlets after transplanting; B: plots demarcated with nets.



Fig 3.6: Data collection on plant growth parameters. A: Fresh weight; B: Dry weight; C: Plant height; D: Leaf area.

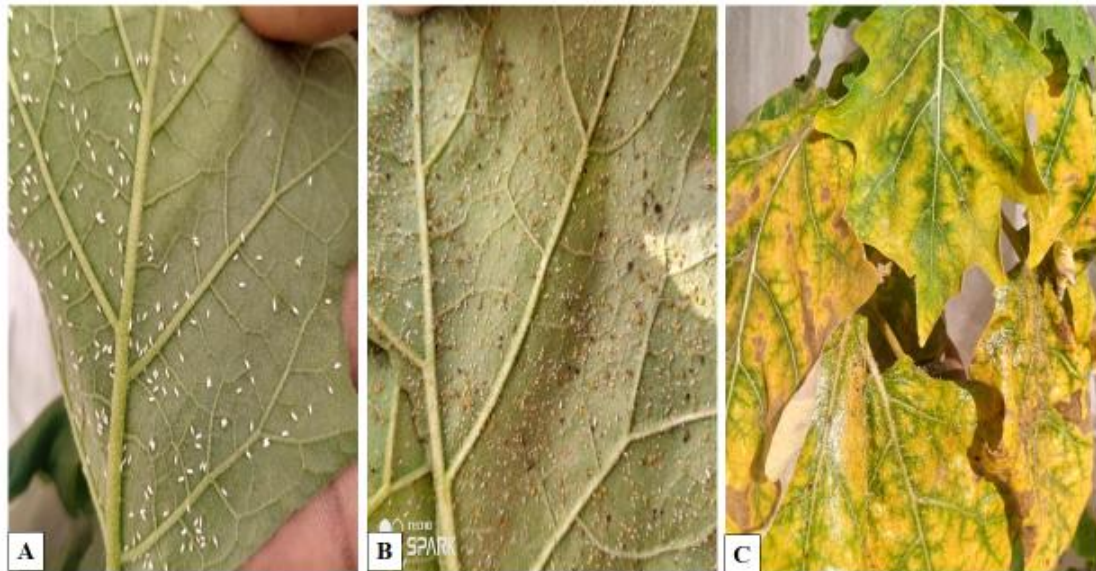


Fig 3.7: Recording data on whitefly parameters. A: Adult whitefly; B: Eggs and Nymph; C: Leaf chlorosis.

3.6. Analyzing the efficacy of traditional strategies for the control of whiteflies

3.6.1. Seedlings production

The seedlings were raised using the same procedure described in the first objectives and transplanted in the experimental plots to analyze the effects of traditional treatments for whitefly control.

3.6.2. Experimental design

Randomized block design was used to determine the efficacy of traditional methods in the control of whitefly on eggplant. The trial consists of seventeen experimental plots, including the control with each plot measuring 3x3m², separated by 0.5m between the plots, and replicated three times. Chemical pesticide (Malathion 50% EC) was applied as positive control while negative control plots were sprayed with tap water only. The seedlings were transplanted in the experimental plots at 60x60 cm spacing and the recommended agronomic practices which include irrigation, weeding, and fertilizer application was provided uniformly in all the plots throughout the trial (Rehman et al. 2015). Infestation by whiteflies was allowed to occur naturally while the spray of the

treatments commenced when the whitefly population goes beyond the economic threshold level (ETL) in the experimental plots (fig 3.8).

3.6.3. Preparation of the treatments

Fresh fruits of the red chili (*Capsicum annum* L.), commonly known as ‘Cayenne long slim variety’ (locally called ‘Tanka Dan Fura’), were purchased from the local market (Dodoru, Gwandu LGA, Nigeria) in a polythene bag and taken to the botany laboratory, KSUSTA. About 1 kg of fresh fully matured chili pods measuring 7.6–10.4 cm in length with seeds intact were crushed using an electric mixer grinder machine. A small amount of water was added to the crushed product in a 3 L earthen pot and boiled for ½ an hour. Thereafter, ten L of water was added to make the final concentration 10% w/v (Singh et al. 2021). About 0.5% of liquid soap was then added to the filtrate to serve as an emulsifier and surfactant and to enhance the effect of the treatment. The mixture was stirred vigorously for 5 min using a metal rod and filtered twice using a muslin cloth. The solution was then stored at 4 °C in an airtight clean container before use. The extract was sprayed at three different doses (20, 40, and 60mL/L)(Shailaji et al. 2012; Patel et al. 2017).

Fresh cow dung of the “White Fulani cattle breed (Diali)” was collected from the local cattle herders in the area. This breed is characterized by long horns and white fur, with red marks on their ears and legs. They were fed on a diet consisting of pearl millet straw, cassava peels mixed with wheat bran, cowpea (black eye pea) hay, and soybean husks, mixed in a ratio of 3:2:1:1:1, respectively. About 1.5 kg of fresh cow dung was collected in a clean polythene bag and placed in a 5 L earthen pot containing 3 L of tap water. The cow dung was allowed to ferment for 72 h with daily intermittent stirring. Thereafter, the slurry was strained thrice using a muslin cloth and stored at 4 °C in a 5 L plastic container before usage. The treatment was also sprayed at three different doses (50, 100, and 150 mL/L, respectively) (Kumawat et al. 2014).

To prepare the fermented curd water, 4 L of fresh cow milk of the “White Fulani cattle breed (Diali)” was purchased from Fulani herdsmen in the study area and placed in a 5 L

sterile plastic container. The fresh milk was allowed to ferment for one week, and then 4 L of distasteful buttermilk (curd that has been stored for up to 7 days) were added to 8 L of water and mixed (50% v/v). The mixture was covered and allowed to ferment further for one week. It was then hand-shaken vigorously for 5 min. The solution was strained twice using a cotton muslin cloth, which was then used as a foliar spray at three different doses (50, 100, and 150 mL/L) (Meena et al. 2021).

Fresh cow urine of the “White Fulani cattle breed (Diali)” was obtained from the local cattle herders in the study area in a 5 L sterile plastic container. The urine was then filtered using Whatman No. 1 filter paper to remove debris and precipitated substances. Subsequently, the strained urine was placed in an airtight container and allowed to ferment for seven days. Before application, the fermented concentrated urine was diluted in tap water (50% v/v), a concentration previously reported as effective for insect pests and disease management. The solution was hand-shaken vigorously for 5 min to ensure proper mixing, strained twice via Whatman No. 1 filter paper, and applied at 3 different doses (25, 50, and 75 mL/L) (Chand and Tiwari, 2012; Patel et al. 2017).

Fresh neem leaves (*Azadiracta indica* Juss), commonly known as Margosa/Indian lilac (locally called “Dogonyaro”), were obtained from the university farm and taken to the botany laboratory at KSUSTA for the extract preparation. The leaves were collected in a polythene bag from the upper regions of newly produced branches from the first to third internodes. They were carefully and thoroughly washed under tap water to remove the dust. About 400 g of the cleaned leaves were crushed in an electric grinding machine (Prestige 750 w grinder mixer, India). The crushed material was added to 4 L of tap water containing 0.5% liquid detergent. The mixture was thereafter boiled in an earthen pot for ½ hour. The mixture was allowed to cool, filtered thrice to obtain a clear extract, and then stored refrigerated to maintain the freshness and potency of the extract before use. The extract was sprayed at three different doses (20, 40, and 60 mL/L) (Lynn et al. 2012; Asare-Bediako et al. 2014)

The various treatments were sprayed on the eggplant leaves (covering upper and lower surfaces of the leaves) at an interval of two weeks, using a 15L (MT-107, China) Knapsack sprayer. Normal tap water and malathion 50% EC were used as negative and positive controls (Table 3.4). The data on the effects of the treatments were recorded based on the whitefly population in each of the experimental plots at 1, 2, 3, 5, 7 and 15 days after each spray. The detail of the plant-based treatments is presented in table 3.3. Yield (kg/ha) was also recorded at harvest from five randomly selected plants in each plot, by considering both the number and weight of the fruit during 2022 and 2023 experiments.

Table 3.2: Various traditional treatments for whitefly management

Treatments	Details	Concentration (%)	Dosage (mL/L)
T1	Chili pods	10% w/v	20
T2	” ” ”	” ” ”	40
T3	” ” ”	” ” ”	60
T4	Cow dung	50% w/v	50
T5	” ” ”	” ” ”	100
T6	” ” ”	” ” ”	150
T7	Butter milk	50% v/v	50
T8	” ” ”	” ” ”	100
T9	” ” ”	” ” ”	150
T10	Cow urine	50% v/v	25
T11	” ” ”	” ” ”	50
T12	” ” ”	” ” ”	75
T13	Neem leaf	10% w/v	20
T14	” ” ”	” ” ”	40
T15	” ” ”	” ” ”	60
T16	Malathion EC 50%		6

3.7. Effect of plant-based extracts in whitefly management

3.7.1. Seedlings procurement

The seedlings were raised using the same procedure described in the first objectives and transplanted in the experimental plots to analyze the effects of plant-based treatments for whitefly control.

3.7.2. Experimental design

The trial was conducted using randomized block design (RBD) to examine the efficacy of plant-based chemicals in the control of whitefly on the eggplants. The trial consists of twenty (20) experimental plots (3x3m², separated by 0.5m) with three replications. Chemical pesticide (Malathion 50% EC) and water were applied as positive and negative controls. The seedlings were transplanted in the experimental plots at 60x60 cm spacing. Standard/recommended agronomic practices including irrigation, weeding, and fertilizer application were equally provided to all the plots during the trial (Rehmana et al. 2015) (fig 3.9).

3.7.3. Collection of plant-based treatments

The plant material (citrus fruits) was procured from the local market (Dodoru) in Gwandu Local Government Area, Kebbi State while the eucalyptus leaves were obtained from the agricultural farm, Kebbi State University and Technology Aliero, Kebbi State, Nigeria. The plant materials were used for the preparation of aqueous and fermented extracts. Hundred percent (100%) pure steam distilled essential oils of *Citrus aurantium* Christm and *Eucalyptus camaldulensis* Dehnh were procured from Amazon India for the experiments.

3.7.4. Preparation of aqueous plant extracts

The fresh plant materials of *Citrus aurantifolia* Christm (key lime peels obtained from fully matured fruits) and leaves of *Eucalyptus camaldulensis* Dehnh (river red gum leaves obtained from the upper regions of newly produced branches from the first to third

internodes.) were collected in a polyethylene bag and transported to the laboratory, department of plant science and biotechnology, Kebbi State University of Science and Technology Aliero. They were washed carefully using tap water to remove the dust and then shade dried for one week. They were then pulverized to powder using an electric mixer grinder. The aqueous extract was prepared in distilled water by dissolving 100g of the plant powder in 1L of water using 2L sterile conical flasks. The flask was plugged with sterile cotton and placed in an incubator shaker (Kottermann, Germany) at 200 rpm for 24 h. The solution was then removed and filtered through muslin cloth, and the process was repeated thrice to get a clear aqueous extract of the plant which was then kept at 4°C until use (Al-manhel et al. 2015).

3.7.5. Preparation of fermented extracts

Fermented botanicals extracts (FBEs) were prepared using the method of Baloc et al (2015) and Khadem et al (2022). The fresh plant materials were brought to the laboratory in polythene bag and washed thoroughly in a bleach germicidal cleaner (Clorox 0.1% v/v) for 3-5 minutes and then rinsed thrice using distilled water. The cleaned botanicals were then crushed into smaller pieces using an electric mixer grinder (750 W). Five hundred g of the crushed materials were mixed with distilled water and molasses at a ratio of 3:10:1 in a clean 5L plastic bucket. Hundred (100) mL of effective microorganisms was then added to the mixture to enhance the fermentation process while the molasses was added to supply the microbes with sufficient energy needed for the fermentation. The 100% pure solution of effective microorganism (EM.1) was obtained from Amazon and used for the experiment. The stock solution is composed of photosynthetic bacteria, yeast and lactic acid bacteria. The bucket was firmly sealed, and the contents were left to ferment anaerobically for three weeks. The sealed buckets were left at room temperature and the gas as a byproduct of fermentation was released once weekly by opening the seal of the containers in a laminar airflow. The filtration of FBEs after incubation was done using Whatman No.1 filter paper (9 cm-diameter) on the Corning™ 50 mL conical centrifuge tubes. The resulting filtrates were diluted with 0.5% water and frozen at -35°C overnight before being freeze-dried at -110°C and then stored refrigerated until use.

3.7.6. Preparation of essential oils

The formulation of the oil emulsions was made using the method of Gahukar (1996) and Kumar et al (2019). Thirty mL of the essential oil was added into 1L of distilled water in a 2L plastic container, containing 0.5% liquid detergent which acts as surfactants and carrier for easy spreading and mixing of the treatment. The mixture was stirred vigorously using a metal rod to ensure the proper mixing and spreading of the treatments. The solution was kept refrigerated until use.

3.7.7. Spray of the treatments and data collection

All the plant-based treatments (6 treatments with 3 doses each) were sprayed on the eggplant leaves (covering upper and lower surfaces of the leaves) at an interval of two weeks, using a 15L (MT-107, Zhejiang Jinnong Medical Machinery Co., Ltd, procured from Afrimash Company Ltd., Ibadan, Nigeria) Knapsack sprayer. The data on the effects of the treatments were recorded based on the whitefly population in each of the experimental plots at 1, 2, 3, 5, 7 and 15 days after each spray. The detail of the plant-based treatments is presented in table 3.3. Yield (kg/ha) was also recorded at harvest by considering the weight of the fruits from five randomly selected plants in each plot, during 2022 and 2023 experiments.

Table 3.3: Details of botanical treatments used against the whiteflies

Treatments	Details	Concentration (%)	Dosage (mL/L)
T 1	Citrus aqueous extract	10% w/v	100
T2	” ” ”	10% w/v	150
T3	” ” ”	10% w/v	200
T4	Citrus fermented extracts	10% w/v	100
T5	” ” ”	10% w/v	150
T6	” ” ”	10% w/v	200
T7	Citrus essential oils	5% v/v	10
T8	” ” ”	5% v/v	20
T9	” ” ”	5% v/v	30
T10	Eucalyptus aqueous extracts	10% w/v	100
T11	” ” ”	10% w/v	150
T12	” ” ”	10% w/v	200
T13	Eucalyptus ferment extracts	10% w/v	100
T14	” ” ”	10% w/v	150
T15	” ” ”	10% w/v	200
T16	Eucalyptus essential oils	5% v/v	100
T17	” ” ”	5% v/v	150
T18	” ” ”	5% v/v	200
T19	Malathion 50% EC		6
T20	Control		1.2

3.8. Efficacy of integrated pest management (IPM) strategy in whitefly control.

3.8.1. Field clearance and seedlings production.

The field clearance and seedlings production were the same as that of the previous objectives

3.8.2. Supply and preparation of the treatments

The fresh neem leaves (*Azadirachta indica* A. Juss) were collected from the premises of Kebbi State University of Science and Technology, Aliero and used for the preparation of the aqueous extracts. The essential oil (100mL) of *Eucalyptus camaldulensis* Dehn (100% pure steam distilled oil) was procured from amazon India for the conduct of the experiment. One liter of the synthetic chemical (chlorophyriphus 20% EC) was purchased from Agritropic Limited Kano, Nigeria. The aqueous extract of *Azadirachta indica* A. Juss and *Eucalyptus camaldulensis* Dehn essential oil were prepared using the same procedures described in the 2nd and 3rd objectives. The yellow sticky traps were prepared as rectangular 8x8cm² using a 25L yellow jerry cans. The traps were cleaned up using tap water and allowed to dry. Petroleum jelly was then applied on the inner surfaces of the traps before installation in the experimental field.

3.8.3. Experimental design

A Student T-test design was used to evaluate the synergistic effect of organic pesticides (*Azadirachta indica* A. Juss and *Eucalyptus camaldulensis* Dehn essential oil) along with yellow sticky traps and the synthetic chemical against the whiteflies. The trial consists of two plots (A and B) with a plot size each measuring 20x20m² (fig 3.10). Plot A is an IPM strategy consisting of yellow sticky traps, the neem leaf aqueous extract and eucalyptus essential oil. The second schedule (B) was treated with chlorpyriphos 20% EC, one of the common insecticides sprayed most often by the farmers in the area to control the agricultural insect pests on their vegetables.

3.8.4. Spray of the treatments and data collection

The yellow sticky traps were hung vertically in the experimental plot (1 trap/5 m²) at 45 cm above the plant using wooden poles two weeks after transplanting. The combined plant products (neem extract + eucalyptus oil at 10 and 5%) and the synthetic chemical (chlorpyrifos 20% EC at 3mL/L) were sprayed in plot A and B respectively 27 days after transplanting, when the whitefly density raised above the economic threshold level (8-10 whiteflies/leaf). The whiteflies were allowed to occur naturally in the experimental plots. All the treatments were sprayed thrice covering upper and lower surfaces of the leaves at an interval of two weeks using 15L (MT-107, China) Knapsack sprayer. The data on both the nymphs and adult whitefly population were collected from 50 randomly selected plants using the upper, middle and lower regions leaves in each schedule three times per week during the trials.



Fig 3.8: Field plots for assessing the effects of different treatments against the whiteflies. A: Field layout; B: Transplanting; C: Irrigation.

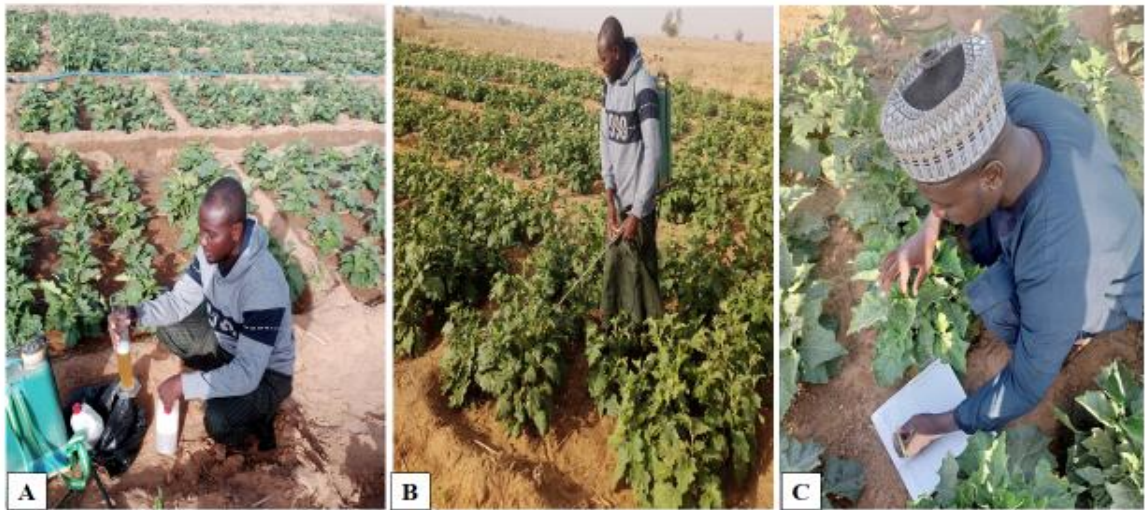


Fig 3.9: Spray of the treatments and data recording from the field experiments. A: While measuring the treatments; B: Spray of the treatments; C: Data recording from the field.



Fig 3.10: IPM modules for whitefly management. A= Synthetic chemical, B = Bio pesticide along with sticky traps.

3.8.5. Statistical analysis

The data analysis for objective 1 was carried out in a statistical tool for agricultural research (STAR version 2.0.1) by means of ANOVA and means were separated using least significant difference (LSD) at 5% level of significance. The data analysis for objective 2 and 3 was also conducted in statistical tool for agricultural research (STAR version 2.0.1) using analysis of variance (ANOVA) and means were separated using Duncan' Multiple Range Test (DMRT) at 5% level of significance. The percentage reduction in whitefly population was calculated in excel (2013) using the equation;

$$\text{Reduction (\%)} = \frac{\text{Control plots} - \text{treated plots}}{\text{control plots}} \times 100$$

Where reduction = percentage decrease in whitefly number, control plots = plots treated with water only, treated plots = plots sprayed with the various traditional and plant-based extracts as well as the absolute control (Malathion 50% EC). For IPM strategy in objective 4, T-test was used to analyze the data in SPSS version 29 at 5% level of significance. The average weekly whitefly population were used to plot the graphs of trends of reduction in whitefly number using excel version 13. All the figures were prepared using excel version 13.

CHAPTER FOUR

4.0. RESULTS AND DISCUSSION

4.1. Soil properties

The test on the soil properties shows that the pH of the soil is normal (6.7), with low organic carbon (0.186%) while the nutrients concentration (N: 245, P: 13.45, K: 117kg/ha) were on medium levels as presented in **table 4.1**

Table 4.1: Properties of the experimental soil

S.No.	Soil properties	Result	Status
1	pH	6.7	Normal
2	Organic carbon (%)	0.186	Low
3	Nitrogen (kg/ha)	245	Medium
4	Phosphorus (kg/ha)	13.45	Medium
5	Potassium (kg/ha)	117	Medium

4.2. Effects of whitefly infestation on the eggplant growth parameters in the field experiment

4.2.1. Plant height (cm)

Table 4.2 presents the results of whitefly feeding effects on the plant height in the two consecutive cropping periods (2022 and 2023) in field experiment. The treatments differed significantly from each other and from the untreated control ($P < 5\%$) in most of the data recording periods during the two cropping seasons. In 2022, the treatments were similar ($P = 0.705$) at 48 h after infestation, with plant height being highest in T₄ (14.7cm), followed by T₂ (14.3cm) while the least was recorded in T₃ (13.7 cm). The plant height was also highest in T₄ (36.2, 51.0 and 69.0cm) and lowest in T₃ (24.8, 41.9 and 44.7cm) at 30, 60 and 90 days respectively as the treatments differed significantly ($P = 0.001, 0.026$ and 0.0001) during the respective data record periods. In 2023, the treatments were statistically similar at 48 h ($P = 0.967$) and 30 days ($P = 0.063$) after infestations. Plants in T₁ had the highest plant height (14.7 and 31.4 cm) during the respective periods. The

results however, differed significantly at 60 ($P = 0.018$) and 90 ($P < 0.0001$) days after infestation. Plants in T_3 were more affected (39.1 and 41.2 cm) while those in T_1 were least affected (45.7 and 47.2 cm) as compared to the control group (49.8 and 67.4 cm) at 60 and 90 days respectively (Table 4.2).

Table 4.2: Effect of whitefly infestation on the plant height (cm) during the 2022 and 2023 field experiments

Treatments	Data record periods							
	2022				2023			
	48HAI	30DAI	60DAI	90DAI	48HAI	30DAI	60DAI	90DAI
T1	13.9 ^a	31.1 ^b	44.9 ^b	49.4 ^b	14.7 ^a	31.4 ^a	45.7 ^{ab}	47.2 ^b
T2	14.2 ^a	27.5 ^c	43.4 ^b	47.6 ^b	13.9 ^a	28.5 ^a	42.7 ^{bc}	43.6 ^{bc}
T3	13.7 ^a	24.8 ^c	41.9 ^b	44.7 ^b	14.5 ^a	25.4 ^a	39.1 ^b	42.2 ^c
T4	14.7 ^a	36.2 ^a	51.0 ^a	69.0 ^a	14.4 ^a	34.7 ^a	49.8 ^a	67.4 ^a
C.D.	0.0	3.0	5.8	7.3	0.0	0.0	6.2	9.9
SEM±	0.6	1.2	2.5	3.2	1.7	3.0	2.7	2.1
C.V. (%)	8.4	6.2	8.0	8.5	16.9	14.2	8.6	6.0
P-value (5%)	0.705	0.001	0.026	0.0001	0.967	0.063	0.018	<0.0001

Means with the same common letter in the same column are not significantly different from each other ($P < 0.05$). C.D. = Critical difference, C.V.= Coefficient of variance, SEM =Standard error means, HAI=Hours after infestation, DAI= Days after infestation, T=Treatment (T1= 15, T2= 30, T3= 45 and T4= control with 0 whiteflies/plot).

4.2.2. Number of leaves

The effect of whitely feeding on the number of leaves was shown in table 4.3. In 2022, There is no significant difference between all the treatments at 48 h ($P= 0.402$) and 60 days ($P=0.145$) after infestation. Plants in T_1 and the control group had the highest number of leaves (5.3 leaves/plant each) while those in T_3 had the lowest (4.3 leaves/plant) at 48 h after infestation. At 30 days, Plants in T_3 were most affected (7.8 leaves/plant) as they differed significantly ($P= 0.004$) from the remaining treatments. Similar result was recorded at 90 days, with plants in T_3 being more affected (40.3 leaves/plant) differing significantly ($P<0.0001$) from all the treatments including the control (61.5 leaves/plant) during the 2022 trial. In 2023, the treatments had similar effects at 48 h ($P=0.197$), but differed significantly at 30 days ($P=0.002$) with plants in T_2 being more affected (8.6 leaves/plant), followed by those in T_3 (9.4 leaves/plant) while those in T_1 were least affected (10.3 leaves/plant) as compared to the control (T_4) with 12.5 leaves/plant. The result also differed significantly at 60 ($P=0.044$) and 90 ($P<0.0001$) days with plants in T_3 being more affected with 37.7 and 39.5 leaves/plant while those in T_1 were the least affected with 43.4 and 52.1 leaves/plant (Table 4.3).

Table 4.3: Whitefly infestation effect on the number of leaves during the 2022 and 2023 field experiments

Treatments	Data record periods							
	2022				2023			
	48HAI	30DAI	60DAI	90DAI	48HAI	30DAI	60DAI	90DAI
T1	5.3 ^a	9.4 ^{ab}	44.3 ^a	50.3 ^b	5.5 ^a	10.3 ^b	43.4 ^{ab}	52.1 ^b
T2	4.8 ^a	8.6 ^{bc}	38.9 ^a	46.2 ^b	5.0 ^a	8.6 ^c	40.9 ^b	45.9 ^c
T3	4.3 ^a	7.8 ^b	39.9 ^a	40.3 ^c	6.1 ^a	9.4 ^{bc}	37.7 ^b	39.5 ^d
T4	5.3 ^a	10.6 ^a	46.0 ^a	61.5 ^a	5.5 ^a	12.5 ^a	48.2 ^a	57.5 ^a
C.D.	0.0	3.0	0.0	4.55	0.0	3.2	7.12	3.52
SEM±	0.5	0.6	3.2	2.0	0.3	0.7	3.1	1.5
C.V. (%)	15.6	8.7	10.5	5.7	11.1	9.9	10.2	4.5
P-value (5%)	0.402	0.004	0.145	<0.0001	0.197	0.002	0.044	<0.0001

Means with the same common letter in the same column are not significantly different from each other (P< 0.05). C.D. = Critical difference, C.V.= Coefficient of variance, SEM =Standard error means, HAI=Hours after infestation, DAI= Days after infestation, T=Treatment (T1= 15, T2= 30, T3= 45 and T4= control with 0 whiteflies/plot).

4.2.3. Leaf area (cm²)

Table 4.4 presents the result of whitefly feeding effect on leaf area of eggplant. The results revealed that at 48 h, the treatments were statistically similar (P=0.337) from each other including the control during the 2022 trial. Plants in T₃ had the least leaf area (20.2 cm²) while those in T₂ recorded the highest (21.6 cm²) as compared to the control (T₄) (22.7cm²). The result differed significantly at 30 (P=0.0003), 60 (P<0.0001) and 90 (P<0.0001) days, with plants in T₃ being more affected with 76.2, 157.7 and 162.5 cm² respectively. Similar results were found in 2023, as there is no significant difference between the treatments at 48 h (P=0.391). The results differed significantly at 30 ((P<0.0004), 60 (P<0.0001) and 90 (P<0.0001) days after infestation during the

experiment. Plants in T₃ had less leaf area on on 30th, 60th, and 90th day(78.6, 160.6 and 167.3 cm²) as compared to the control group with 120.2, 227.2 and 303.5 cm²respectively during 2023 trial (**Table 4.4**).

Table 4.4: Whitefly infestation effect on the leaf area (cm²) of eggplant during the 2022 and 2023 field experiments

Treatments	Data periods							
	2022				2023			
	48HAI	30DAI	60DAI	90DAI	48HAI	30DAI	60DAI	90DAI
T1	20.9 ^a	93.4 ^b	200.6 ^b	226.3 ^b	22.3 ^a	90.8 ^b	212.7 ^b	220.6 ^b
T2	21.6 ^a	78.6 ^{bc}	170.6 ^c	215.9 ^b	23.6 ^a	84.7 ^b	177.9 ^c	206.6 ^c
T3	20.2 ^a	76.2 ^c	157.7 ^d	162.5 ^c	21.2 ^a	78.6 ^b	160.6 ^d	167.3 ^d
T4	22.7 ^a	125.6 ^a	230.7 ^a	317.6 ^a	21.3 ^a	120.2 ^a	227.2 ^a	303.5 ^a
C.D.	0.0	16.9	11.97	11.31	0.0	14.3	8.34	11.31
SEM±	1.3	7.4	5.2	3.9	1.5	6.2	3.6	4.9
C.V. (%)	8.6	11.1	3.9	3.0	9.7	9.4	2.6	3.1
P-value (5%)	0.337	0.0003	<0.0001	<0.0001	0.391	0.0004	<0.0001	<0.0001

Means with the same common letter in the same column are not significantly different from each other (P< 0.05. C.D. = Critical difference, C.V.= Coefficient of variance, SEM =Standard error means, HAI=Hours after infestation, DAI= Days after infestation, T=Treatment (T1= 15, T2= 30, T3= 45 and T4= control with 0 whiteflies/plot).

4.2.4. Fresh weight of leaves (g)

Whitefly infestation also affectsthe fresh weightof eggplant leaf as presented in table 4.5. In 2022, the effect was similar (P=0.249) with all the treatments at 48 h, with T₁ recording the higher fresh weight value (6.2g), followed by T₄ (5.3g) while T₃ has the least (3.8g). The results differed significantly between the treatments at 30 (P=0.002), 60 (P=0.043) and 90 (P=0.001) days after infestation. Plants in T₃ had least fresh weight (5.4, 13.5 and 13.9g) with those in T₁ and T₂ having the highest (6.9, 16.7 and 14.9 g) as

compared to the control with 9.2, 19.4 and 24.9 g respectively. In 2023, the results differed significantly between the treatments (T₁-T₄) in all the data taking periods except at 48 h after infestations. Plants in T₃ also had the least fresh weight values (5.7, 12.9 and 12.6 g) on 30th, 60th and 90th day respectively while those in T had the least (7.8, 15.2 and 17.1 g), as compared to the control with 9.9, 17.3 and 22.4g respectively during 2023 experiment (Table 4.5).

Table 4.5: Effect whitefly infestation on the fresh weight (g) of the leaves during the 2022 and 2023 field experiments

Treatments	Data record periods							
	2022				2023			
	48HAI	30DAI	60DAI	90DAI	48HAI	30DAI	60DAI	90DAI
T1	6.2 ^a	6.9 ^b	16.1 ^b	14.6 ^b	5.4 ^a	7.8 ^b	15.2 ^b	17.1 ^b
T2	4.0 ^a	6.7 ^b	16.7 ^{ab}	14.9 ^b	4.6 ^a	6.7 ^b	13.9 ^c	13.9 ^b
T3	4.0 ^a	5.4 ^b	14.5 ^b	13.9 ^b	5.3 ^a	5.7 ^c	12.9 ^c	12.6 ^b
T4	5.3 ^a	9.2 ^a	19.4 ^a	24.9 ^a	5.5 ^a	9.9 ^a	17.3 ^a	22.4 ^a
C.D.	0.0	1.5	3.2	4.4	0.0	1.0	1.5	5.2
SEM±	0.8	0.6	1.4	1.9	0.7	0.5	1.5	2.3
C.V. (%)	25.1	13.0	11.9	15.9	19.7	8.6	14.2	19.5
P-value (5%)	0.249	0.002	0.043	0.001	0.660	<0.0001	0.007	0.009

Means with the same common letter in the same column are not significantly different from each other (P < 0.05). C.D. = Critical difference, C.V.= Coefficient of variance, SEM = Standard error means, HAI=Hours after infestation, DAI= Days after infestation, T=Treatment (T₁= 15, T₂= 30, T₃= 45 and T₄= control with 0 whiteflies/plot).

4.2.5. Leaf dry weight (g)

The results on dry weight showed that the control plots have greater dry weight values at all the data record periods with 0.4, 0.9, 2.8 and 3.5g and 0.5, 0.9, 2.7 and 4.1g during the 2022 and 2023 experiments. The least dry weight values were recorded in T₁ and T₂(0.3g at 48 h), T₃ (0.6g at 30 days), T₁ and T₂ (1.5g each at 60 days) and T₃ (1.1 g at 90 days) in 2022. In 2023, similar results were recorded with T₃ having the least dry weight (0.5, 1.6

and 1.3g) at 30, 60 and 90 days respectively. There is significant difference between the treatments in all the data taking periods ($P < 0.05$) during the respective experiments. However, no significant difference was observed at 48 h in 2022 and 2023, and at 30 days after infestation in 2022 trial (Table 4.6).

Table 4.6: Effect of whitefly infestation on the leaf dry weight (g) during the 2022 and 2023 field experiments

Treatments	Data record periods							
	2022				2023			
	48HAI	30DAI	60DAI	90DAI	48HAI	30DAI	60DAI	90DAI
T1	0.3 ^a	0.7 ^a	1.7 ^b	1.7 ^b	0.3 ^a	0.6 ^a	2.0 ^b	1.8 ^b
T2	0.3 ^a	0.7 ^a	1.5 ^b	1.3 ^{bc}	0.4 ^a	0.6 ^b	1.8 ^b	1.6 ^b
T3	0.4 ^a	0.6 ^a	1.5 ^b	1.1 ^c	0.3 ^a	0.5 ^b	1.6 ^b	1.3 ^b
T4	0.4 ^a	0.9 ^a	2.8 ^a	3.5 ^a	0.5 ^a	0.9 ^a	2.7 ^a	4.1 ^a
C.D.	0.0	0.0	0.5	0.5	0.0	0.3	0.5	0.8
SEM±	0.1	0.1	0.2	0.2	0.1	0.1	0.2	0.3
C.V. (%)	18.3	20.7	17.9	17.3	26.9	24.8	16.3	22.0
P-value (5%)	0.110	0.102	0.001	<0.0001	0.211	0.049	0.005	0.0001

Means with the same common letter in the same column are not significantly different from each other ($P < 0.05$). C.D. = Critical difference, C.V. = Coefficient of variance, SEM = Standard error means, HAI=Hours after infestation, DAI= Days after infestation, T=Treatment (T₁= 15, T₂= 30, T₃= 45 and T₄= control with 0 whiteflies/plot).

4.2.6. Dry matter (%)

The dry matter (%) was also affected by whitefly feeding as presented in table 4.7. In 2022 trial, the results showed that the treatments were similar at 48 h ($P=0.182$) and 30 ($P=0.625$) days after infestation. The highest effect was recorded in T₂ having less dry matter (5.9%) while the least effect was found in T₃ (9.7%) at 48 h after infestation. At 30 days, T₁ had the lowest dry matter (9.1%) with T₂ having higher (11.4%) than the control (T₄) (10.3%). The result differed significantly at 60 ($P=0.007$) and 90 ($P=0.023$) days,

with T₂ and T₃ being more affected at 60 (9.0%) and 90 (8.0%) days with plants in T₁ being less affected (11.2 and 11.3%). In 2023, no significant difference was observed between the treatments at 48 h (P=0.564) and 30 days (P=0.296) after infestation. At 60 and 90 days, plants in T₃ were most affected with 7.9 and 7.3% respectively, as the treatments differed significantly (P= 0.049 and 0.002) with plants in T₁ being less affected with 10.7 and 11.2% respectively (Table 4.7).

Table 4.7: Effect of whitefly feeding on the leaf dry matter (%) during the 2022 and 2023 field experiments

Treatments	Data record periods							
	2022				2023			
	48HAI	30DAI	60DAI	90DAI	48HAI	30DAI	60DAI	90DAI
T1	6.3 ^a	9.1 ^a	11.2 ^{ab}	11.3 ^{ab}	6.1 ^a	8.1 ^a	10.7 ^{ab}	11.2 ^b
T2	5.9 ^a	11.4 ^a	9.0 ^c	8.9 ^b	6.2 ^a	9.2 ^a	9.4 ^{ab}	8.1 ^{bc}
T3	9.7 ^a	10.1 ^a	10.1 ^{bc}	8.0 ^b	7.1 ^a	7.7 ^a	7.9 ^b	7.3 ^c
T4	10.9 ^a	10.3 ^a	13.3 ^a	14.1 ^a	8.4 ^a	9.8 ^a	12.2 ^a	15.6 ^a
C.D.	0.0	0.0	3.9	4.0	0.0	0.0	2.3	3.7
SEM±	2.5	1.7	1.0	1.7	1.8	0.8	1.3	1.6
C.V. (%)	42.9	23.4	12.2	12.7	36.9	18.5	18.8	21.5
P-value (5%)	0.182	0.625	0.007	0.023	0.564	0.296	0.049	0.002

Means with the same common letter in the same column are not significantly different from each other (P< 0.05). C.D. = Critical difference, C.V. = Coefficient of variance, SEM =Standard error means, HAI=Hours after infestation, DAI= Days after infestation, T=Treatment (T₁= 15, T₂= 30, T₃= 45 and T₄= control with 0 whiteflies/plot).

4.2.7. Absolute growth rate (AGR, g day⁻¹)

The result on the effect of whitefly infestation on the absolute growth rate showed that the treatments were similar (P=0.293) at 30 days after infestation. However, plants in T₃ had the least AGR (0.01 g day⁻¹) while the remaining treatments had the highest (0.02 g day⁻¹ each). At 60 and 90 days, significant differences (P=0.009 and <0.0001) were found

with in plants in T₂ and T₃ being more affected recording 0.03 g day⁻¹ at 60 and -0.07 g day⁻¹ at 90 days respectively. There was zeroAGR in all the treatments 48 h afterinfestation. In 2023, the result was similar with all the treatments having no significant difference at 30 days, (P= 0.076). The treatments differed significantly at 60 (P=0.03) and 90 (P<0.0001) days with plants in T₃ being more affected (0.01 and -0.01 g day⁻¹) while those in T₁ were least affected (0.08 and 0.06 g day⁻¹) respectively (**Table 4.8**).

Table 4.8: Effect of whitefly feeding on the absolute growth rate(AGR, g day⁻¹) of eggplant during the 2022 and 2023 field experiments

Treatments	Data record periods							
	2022				2023			
	48HAI	30DAI	60DAI	90DAI	48HAI	30DAI	60DAI	90DAI
T1	0.00 ^a	0.02 ^a	0.09 ^b	0.01 ^b	0.00 ^a	0.02 ^a	0.08 ^{ab}	0.06 ^b
T2	0.00 ^a	0.02 ^a	0.03 ^b	0.01 ^b	0.00 ^a	0.02 ^a	0.01 ^b	0.02 ^b
T3	0.00 ^a	0.01 ^a	0.04 ^b	-0.07 ^c	0.00 ^a	0.006 ^a	0.01 ^b	-0.01 ^c
T4	0.00 ^a	0.02 ^a	0.2 ^a	0.49 ^a	0.00 ^a	0.03 ^a	0.16 ^a	0.36 ^a
C.D.	0.0	0.0	0.08	0.08	0.0	0.0	0.11	0.08
SEM±	0.00	0.003	0.04	0.001	0.00	0.01	0.05	0.04
C.V. (%)	0.00	14.8	61.2	43.0	0.00	65.3	66.9	45.8
P-value (5%)	0.00	0.293	0.009	<0.0001	0.00	0.076	0.030	<0.0001

Means with the same common letter in the same column are not significantly different from each other (P< 0.05). C.D. = Critical difference, C.V.= Coefficient of variance, SEM =Standard error means, HAI=Hours after infestation, DAI= Days after infestation, T=Treatment (T₁= 15, T₂= 30, T₃= 45 and T₄= control with 0 whiteflies/plot).

4.2.8. Relative growth rate (RGR, g⁻¹ day⁻¹)

The result on the effect of whitefly infestation on RGR revealed that, the treatments had similar effect at 30 (P= 0.877) and 90 (P=0.569) days after infestation in 2022 experiment. Plants in T₃ had the least AGR at 30 (0.03g⁻¹ day⁻¹) and 90 (-0.02 g⁻¹ day⁻¹) while those in T₁

had the highest (0.04 and 0.004 g⁻¹ day⁻¹) respectively. The treatments differed significantly (P=0.033) at 60 days, with plants in T₂ having the least RGR (0.001 g⁻¹ day⁻¹) while those in T₁ had the highest (0.02 g⁻¹ day⁻¹), similar to the control group in 2022. In 2023, no significant difference was recorded at 30 days (P=0.078) between the treatments. However, the treatments differed significantly at 60 (P= 0.019) and 90 (P<0.0001) with plants in T₃ being more affected (0.004 and -0.01 g⁻¹ day⁻¹) while those in T₁ were less affected (0.01 g⁻¹ day⁻¹ each). There were zero RGR (0.00 g⁻¹ day⁻¹) with all the treatments during the consecutive cropping seasons at 48 h after infestation (**Table 4.9**).

Table 4.9: Whitefly feeding effects on the RGR of eggplant (g⁻¹ day⁻¹) during the 2022 and 2023 field experiments

Treatments	Data record periods							
	2022				2023			
	48HAI	30DAI	60DAI	90DAI	48HAI	30DAI	60DAI	90DAI
T1	0.00 ^a	0.04 ^a	0.02 ^a	0.004 ^a	0.00 ^a	0.05 ^a	0.01 ^a	0.01 ^b
T2	0.00 ^a	0.04 ^a	0.001 ^c	-0.001 ^a	0.00 ^a	0.04 ^a	0.01 ^a	0.002 ^b
T3	0.00 ^a	0.03 ^a	0.01 ^{bc}	-0.02 ^a	0.00 ^a	0.01 ^a	0.004 ^b	-0.01 ^b
T4	0.00 ^a	0.05 ^a	0.02 ^{ab}	0.01 ^a	0.00 ^a	0.29 ^a	0.03 ^a	0.12 ^a
C.D.	0.0	0.0	0.01	0.0	0.0	0.0	0.02	0.03
SEM±	0.00	0.02	0.01	0.01	0.01	0.10	0.01	0.01
C.V. (%)	0.00	24.2	17.9	-13.3	0.00	15.6	90.3	46.4
P-value (5%)	0.00	0.877	0.033	0.569	0.00	0.078	0.019	<0.0001

Means with the same common letter in the same column are not significantly different from each other (P< 0.05). C.D. = Critical difference, C.V. = Coefficient of variance, SEM =Standard error means, HAI=Hours after infestation, DAI= Days after infestation, T=Treatment (T1= 15, T2= 30, T3= 45 and T4= control with 0 whiteflies/plot).

4.2.9. Net assimilation rate (NAR, g m⁻² day⁻¹)

There were zero NAR in all the treatments at 48 h after infestation in the respective cropping seasons. In 2022, the least NAR values (0.002, 0.0002 and -0.001 g m⁻² day⁻¹) were found with T₃ while the highest (0.003, 0.001 and 0.002 g m⁻² day⁻¹) were recorded with T₁ at 30, 60 and 90 days respectively. In 2023, similar result was observed with plants in T₃ being more affected and those in T₁ being less affected as compared to the control. There is no significant difference (P>5%) between all the treatments in 2022 and 2023 data recording periods, except on 30 days after infestation in 2023 trial (P=0.021) (Table 4.10).

Table 4.10: Effect of whitefly infestation on the net assimilation rate of eggplant (g m⁻² day⁻¹) during the 2022 and 2023 field experiments

Treatments	Data record periods							
	2022				2023			
	48HAI	30DAI	60DAI	90DAI	48HAI	30DAI	60DAI	90DAI
T1	0.00 ^a	0.003 ^a	0.001 ^a	0.002 ^a	0.000 ^a	0.0003 ^{ab}	0.0006 ^a	0.0001 ^a
T2	0.00 ^a	0.004 ^a	0.001 ^a	0.000 ^a	0.000 ^a	0.0005 ^a	0.0004 ^a	0.0002 ^a
T3	0.00 ^a	0.002 ^a	0.0002 ^a	-0.001 ^a	0.000 ^a	0.0002 ^b	0.0002 ^a	0.0001 ^a
T4	0.00 ^a	0.003 ^a	0.001 ^a	0.002 ^a	0.000 ^a	0.0003 ^{ab}	0.002 ^a	0.003 ^a
C.D.	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000
SEM±	0.00	0.001	0.001	0.0001	0.000	0.0001	0.001	0.001
C.V. (%)	0.00	33.3	12.2	63.2	0.00	45.7	32.3	84.1
P-value (5%)	0.00	0.481	0.435	0.077	0.00	0.021	0.111	0.069

Means with the same common letter in the same column are not significantly different from each other (P< 0.05). C.D. = Critical difference, C.V. = Coefficient of variance, SEM =Standard error means, HAI=Hours after infestation, DAI= Days after infestation, T=Treatment (T1= 15, T2= 30, T3= 45 and T4= control with 0 whiteflies/plot).

4.3. Effects of whitefly infestation on the eggplant growth parameters in the pot experiment

4.3.1. Plant height (cm)

The whitefly feeding effects on the plant height during the two consecutive cropping periods (2022 and 2023) in the pot experiment were presented in table 4.11. At 48 h, there is no significant difference between all the treatments ($P=0.871$) with plant height being highest in T_3 (14.3 cm) after the control plot (T_4) (14.8 cm), while T_1 has the least (13.9cm) in 2022. At 30 and 90 days, significant differences were observed ($P<0.0001$) with plants in T_3 also having the less (27.1 and 37.6 cm) while those in T_1 have the highest (35.6 and 54.8 cm). Similar result was also recorded ($P=0.102$) at 60 days after infestation with plants in T_3 having the least (42.4 cm) and those in T_1 having the highest (51.9 cm) in 2022. In 2023, no significant differences were found at 48 h ($P=0.059$) and 60 ($P=0.221$) days after infestation, but at 30 ($P=0.003$) and 90 ($P<0.0001$) days, the treatments differed significantly with plants in T_3 being more affected (29.1 and 38.9 cm) and those in T_1 being less affected (37.0 and 52.5 cm) as compared to the control plots (38.5 and 72.9 cm) (Table 4.11).

Table 4.11: Effect of whitefly infestation on the plant height (cm) during the 2022 and 2023 pot experiments

Treatments	Data record periods							
	2022				2023			
	48HAI	30DAI	60DAI	90DAI	48HAI	30DAI	60DAI	90DAI
T1	13.9 ^a	35.6 ^b	51.9 ^a	54.8 ^b	12.2 ^b	37.0 ^a	48.1 ^a	52.5 ^a
T2	14.2 ^a	31.3 ^c	46.6 ^a	41.6 ^c	15.0 ^a	32.7 ^b	44.8 ^a	43.4 ^{bc}
T3	14.3 ^a	27.1 ^d	42.4 ^a	37.6 ^c	13.1 ^b	29.1 ^c	40.9 ^a	38.9 ^c
T4	14.8 ^a	39.1 ^a	54.5 ^a	70.6 ^a	13.2 ^a	38.5 ^a	52.0 ^a	72.9 ^a
C.D.	0.0	2.9	0.0	6.3	0.0	3.0	0.00	11.5
SEM±	1.0	1.3	4.7	2.9	0.9	1.6	2.3	4.7
C.V. (%)	9.6	5.7	13.8	7.9	9.6	6.6	15.7	12.8

P-value (5%)	0.871	<0.0001	0.102	<0.0001	0.059	0.003	0.221	<0.0001
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Means with the same common letter in the same column are not significantly different from each other ($P < 0.05$). C.D. = Critical difference, C.V.= Coefficient of variance, SEM =Standard error means, HAI=Hours after infestation, DAI= Days after infestation, T=Treatment (T₁= 15, T₂= 30, T₃= 45 and T₄= control with 0 whiteflies/plot).

4.3.2. Number of leaves

The effects of whitely feeding on the number of leaves were shown in table 4.12. The results were statistically similar at 48 h ($P=0.093$) and 60 days ($P=0.457$) between all the treatments. Plants in T₁ had the highest (5.1 leaves/plant) followed by those in T₄ (5.0leaves/plant) while those in T₂ recorded the lowest (4.2 leaves/plant) at 48 h after infestation. At 60 days, plants in T₃ were most affected (34.3 leaves/plant) while those in T₁ were less affected (37.1 leaves/plant) in 2022 trial. Similar results were found at 30 and 90 days with plants in T₃ being more affected while those in T₁ and T₂ were less affected on the respective days (30 and a 90) after infestation. In the 2023, T₄ has the highest number of leaves (5.7 leaves/plant) with T₂ having the least (4.7 leaves/plant) 48 h after infestation as there is no significant difference ($P=0.598$) between the treatments. At 30 days, T₃ differed significantly (0.013) from the remaining treatments with 7.4 leaves/plant while T₂ had the highest (11.0leaves/plant) as compared to the control (12.8 leaves/plant). At 90 days, plants in treated plots were similar, but differed significantly ($P=0.001$) with those in control plots in 2023 trial. The control plots maintained the highest number of leaves at 60 (41.9 and 41.2 leaves/plant) and 90 (54.5 and 56.1 leaves/plant) days after infestation, with T₃ and T₂ having the least recording 32.3 leaves/plant each, in the year 2022 and 2023 respectively (**Table 4.12**).

Table 4.12: Whitefly infestation effect on the number of leaves of eggplant during the 2022 and 2023 pot experiments

Treatments	Data record periods							
	2022				2023			
	48HAI	30DAI	60DAI	90DAI	48HAI	30DAI	60DAI	90DAI
T1	5.1 ^a	11.0 ^a	37.1 ^a	33.2 ^b	5.1 ^a	9.4 ^{bc}	38.9 ^a	32.3 ^b
T2	4.2 ^a	8.9 ^b	36.7 ^a	39.7 ^b	4.7 ^a	11.0 ^{ab}	35.1 ^a	41.3 ^b
T3	4.6 ^a	7.2 ^c	34.3 ^a	32.3 ^b	5.6 ^a	7.4 ^c	33.8 ^a	33.4 ^b
T4	5.0 ^a	10.8 ^a	41.9 ^a	54.5 ^a	5.7 ^a	12.8 ^a	41.2 ^a	56.1 ^a
C.D.	0.0	1.7	0.0	10.2	0.0	3.1	0.0	9.8
SEM±	0.3	0.6	2.8	3.3	0.6	1.0	4.4	3.1
C.V. (%)	11.5	11.8	12.3	16.4	21.2	19.5	16.5	15.4
P-value (5%)	0.093	0.001	0.547	0.002	0.598	0.013	0.345	0.001

Means with the same common letter in the same column are not significantly different from each other ($P < 0.05$). C.D. = Critical difference, C.V.= Coefficient of variance, SEM =Standard error means, HAI=Hours after infestation, DAI=Days after infestation, T=Treatment (T1= 15, T2= 30, T3= 45 and T4= control with 0 whiteflies/plot).

4.3.3. Leaf area (cm²)

Table 4.13 presents the result of whitefly feeding effects on leaf area in the pot trials during the 2022 and 2023 cropping seasons. The results showed that there is no significant difference among all the treatments at 48 h ($P=0.085$ and 2023 ($P=0.679$) in 2022 and 2023 respectively. The results differed significantly at 30 ($P=0.0003$) and 90 ($P < 0.0001$) days after infestation, with plants in T₃ being most affected with 67.6 and 191.2 cm² respectively during the year 2022. In 2023, significant differences were also observed with plants in T₃ having the least leaf area at 30 (67.8 cm²), 60 (226.7 cm²) and 90 (191.2 cm²) days after infestation. The untreated controls (T₄) have the highest leaf area at all the data recording periods in the respective experiments with the highest leaf number found at 90 days (281.5 and 280.7 cm²) in T₄ and lowest (17.7 and 19.8 cm²)

were recorded in T₁ at 48 h after infestation in the respective cropping seasons (Table 4.13).

Table 4.13: Whitefly infestation effect on the leaf area(cm²) of eggplant during the 2022 and 2023 experiments

Treatments	Data record periods							
	2022				2023			
	48HAI	30DAI	60DAI	90DAI	48HAI	30DAI	60DAI	90DAI
T1	20.8 ^a	91.2 ^a	249.3 ^b	200.8 ^b	20.5 ^a	90.4 ^a	242.0 ^b	225.8 ^b
T2	22.4 ^a	72.0 ^b	234.8 ^c	198.3 ^{bc}	22.1 ^a	72.9 ^b	230.5 ^{bc}	197.3 ^c
T3	17.7 ^a	67.6 ^b	241.3 ^c	191.2 ^c	19.8 ^a	67.8 ^b	226.7 ^c	191.2 ^c
T4	23.8 ^a	103.5 ^a	257.9 ^a	281.5 ^a	22.6 ^a	97.4 ^a	262.0 ^a	280.7 ^a
C.D.	0.0	0.9	8.72	7.71	0.0	14.30	13.86	11.9
SEM±	1.6	0.3	3.6	2.38	1.9	4.4	4.27	4.9
C.V. (%)	14.0	10.6	2.1	2.7	17.4	9.7	3.6	3.1
P-value (5%)	0.085	0.0003	0.002	<0.0001	0.679	0.001	0.0004	<0.0001

Means with the same common letter in the same column are not significantly different from each other (P< 0.05). C.D. = Critical difference, C.V.= Coefficient of variance, SEM =Standard error means, HAI=Hours after infestation, DAI= Days after infestation, T=Treatment (T₁= 15, T₂= 30, T₃= 45 and T₄= control with 0 whiteflies/plot).

4.3.4. Fresh weight of leaves (g)

The whitefly infestation also affects the fresh weight of eggplant leaves in the pot experiments. At 48 h, the treatment was not significantly different from each other and from the untreated control (P=0.190 and 0.740) in 2022 and 2023 experiments. Plants in T₄ recorded the higher fresh weight value (3.8 g), followed by T₂ (3.2g) while T₁ has the least (2.3g) in 2022. In 2023, T₄ has the highest (3.6g) followed by T₁ (3.1g) with T₂ having the least (2.8g). At 30, 60 and 90 days, the control plots had higher fresh weight values (8.3, 22.1 and 22.7g) with T₃ having the least (4.8 and 16.4g) at 30 and 60 days while T₂ recorded the least (11.9g) at 90 days after infestation in 2022 trial. In 2023, T₃

had the least fresh weight values (4.9, 14.4 and 11.7g) while T4 had the highest (7.2, 24.7 and 26.2g) at 30, 60 and 90 days respectively. The results differed significantly between T₁ and the rest of the treatments at 90 days after infestations in 2022, while in 2023, the control (T₄) differed significantly (P<0.0001) from the remaining plots at 90 days after infestation (**Table 4.14**).

Table 4.14: Effect whitefly infestation on the fresh weight (g) of leaves during the 2022 and 2023 pot experiments

Treatments	Data record periods							
	2022				2023			
	48HAI	30DAI	60DAI	90DAI	48HAI	30DAI	60DAI	90DAI
T1	2.3 ^a	7.1 ^b	18.9 ^a	14.2 ^b	3.1 ^a	5.9 ^a	16.7 ^b	17.1 ^b
T2	3.2 ^a	5.9 ^c	17.3 ^a	11.9 ^b	2.8 ^a	6.2 ^a	18.5 ^{ab}	14.0 ^c
T3	2.8 ^a	4.8 ^d	16.4 ^a	13.8 ^b	2.9 ^a	4.9 ^a	14.4 ^b	11.7 ^c
T4	3.8 ^a	8.3 ^a	22.1 ^a	22.7 ^a	3.6 ^a	7.2 ^a	24.7 ^a	26.2 ^a
C.D.	0.0	0.9	0.0	3.8	0.0	0.0	5.9	3.7
SEM±	0.6	0.3	1.7	1.5	0.5	0.6	1.9	0.9
C.V. (%)	29.4	8.8	15.0	13.9	35.0	20.5	15.7	10.8
P-value (5%)	0.190	<0.0001	0.226	0.0004	0.740	0.117	0.017	<0.0001

Means with the same common letter in the same column are not significantly different from each other (P< 0.05). C.D. = Critical difference, C.V.= Coefficient of variance, SEM =Standard error means, HAI=Hours after infestation, DAI= Days after infestation, T=Treatment (T₁= 15, T₂= 30, T₃= 45 and T₄= control with 0 whiteflies/plot).

4.3.5. Dry weight of the leaves (g)

The dry weight of the leaves was also affected by whitefly infestation in the pot experiments as presented in table 4.15. There were no significant differences between the treatments at 48 h ($P=0.078$) in 2022 and at 48 h ($P=0.626$) and 30 days (0.120) during the 2023 trial. T₂ and T₄ had the highest (0.2g each) while T₁ and T₃ recorded the least (0.1g each) at 48 h after infestation in 2022 trial. In 2023, T₂ had the least (0.1 g) while the remaining treatments recorded 0.3g each 48 h after infestation. The untreated plots (T₄) had the highest dry weight at 30, 60 and 90 days respectively. The least value (0.4, 1.5 and 1.3g) and (0.6, 1.2 and 1.2 g) were found in T₃ at 30, 60 and 90 days during the year 2022 and 2023 respectively (Table 4.15).

Table 4.15: Effect of whitefly infestation on the leaf dry weight (g) during the 2022 and 2023 pot experiments

Treatments	Data record periods							
	2022				2023			
	48HAI	30DAI	60DAI	90DAI	48HAI	30DAI	60DAI	90DAI
T1	0.1 ^a	0.8 ^a	1.9 ^b	1.4 ^b	0.3 ^a	0.8 ^a	1.9 ^b	2.1 ^b
T2	0.2 ^a	0.7 ^b	2.1 ^{ab}	1.8 ^b	0.1 ^a	0.6 ^a	1.8 ^{bc}	1.8 ^b
T3	0.1 ^a	0.4 ^{bc}	1.5 ^b	1.3 ^b	0.3 ^a	0.6 ^a	1.2 ^c	1.2 ^b
T4	0.2 ^a	0.9 ^a	3.2 ^a	4.0 ^a	0.3 ^a	0.9 ^a	2.9 ^a	5.4 ^a
C.D.	0.0	0.2	1.4	1.0	0.0	0.0	0.7	1.4
SEM±	0.1	0.1	0.4	0.3	0.1	0.2	0.3	0.4
C.V. (%)	48.6	15.3	36.1	38.2	69.2	32.0	21.9	37.1
P-value (5%)	0.078	0.0001	0.046	0.004	0.626	0.120	0.001	0.001

Means with the same common letter in the same column are not significantly different from each other ($P < 0.05$). C.D. = Critical difference, C.V.= Coefficient of variance, SEM

=Standard error means, HAI=Hours after infestation, DAI= Days after infestation, T=Treatment (T1= 15, T2= 30, T3= 45 and T4= control with 0 whiteflies/plot).

4.3.6. Dry matter (%)

The effect of whitefly infestation on the leaf dry matter (%) was presented in table 4.16. The results revealed that there are no significant differences at 48 h ($P=0.460$) and 30 days ($P=0.201$) between the control and treated plots in 2022 trial. Plants in T₁ recorded the least dry matter (3.7%) at 48 h, while those in T₃ had the least (9.0%) at 30 days, with T₄ having the highest (6.6 and 11.5%) during the respective periods. Significant differences were observed at 60 ($P=0.0004$) and 90 (<0.0001) days after infestation, with plants in T₃ being more affected with 9.3 and 9.7% respectively. In 2023, no significant differences were recorded between the treatments at 48 h ($P=0.744$) and 60 days ($P=0.140$) after infestation. At 30 and 90 days, the treatments differed significantly ($P=0.005$ and 0.008) with plants in T₃ being most affected with 7.5 and 7.8% dry matter, while those in T₂ were least affected with 14.4 and 13.3% on the respective days (**Table 4.16**).

Table 4.16: Effect of whitefly infestation on the eggplant dry matter (%) during the 2022 and 2023 pot experiments

Treatments	Data record periods							
	2022				2023			
	48HAI	30DAI	60DAI	90DAI	48HAI	30DAI	60DAI	90DAI
T1	3.7 ^a	11.5 ^a	12.4 ^{bc}	10.1 ^c	6.0 ^a	9.8 ^{bc}	12.0 ^a	8.8 ^b
T2	4.9 ^a	11.2 ^a	12.3 ^b	14.7 ^b	4.5 ^a	12.0 ^{ab}	14.4 ^a	13.3 ^b
T3	5.4 ^a	9.0 ^a	9.3 ^c	9.7 ^c	6.0 ^a	7.5 ^c	10.2 ^a	7.8 ^b
T4	6.6 ^a	11.5 ^a	16.0 ^a	20.1 ^a	6.4 ^a	12.6 ^a	17.5 ^a	22.2 ^a
C.D.	0.0	0.0	2.77.	3.0	0.0	2.7	0.0	6.6
SEM±	1.1	0.9	1.1	1.2	1.3	1.2	2.1	2.1
C.V. (%)	45.7	17.4	13.1	12.3	30.3	15.6	31.4	36.5
P-value (5%)	0.460	0.201	0.0004	<0.0001	0.744	0.005	0.140	0.008

Means with the same common letter in the same column are not significantly different from each other ($P < 0.05$). C.D. = Critical difference, C.V.= Coefficient of variance, SEM =Standard error means, HAI=Hours after infestation, DAI= Days after infestation, T=Treatment (T1= 15, T2= 30, T3= 45 and T4= control with 0 whiteflies/plot).

4.3.7. Absolute growth rate (AGR) g day⁻¹)

The result on the absolute growth rate during the 2022 and 2023 trials were similar among all the treatments (P<5%) with zero AGR (0.00 g day⁻¹) at 48 h after infestation. At 30 and 60 days, the effects were higher in T₃ (0.01 and 0.02 g day⁻¹) and least in T₁ and T₂(0.03 and 0.13 g day⁻¹) in 2022 trial, as the treatments differed significantly (P<0.0001 and 0.037) on the respective days. At 90 days, plants in T₁ were most affected with 0.03 g day⁻¹ while those in T₂ were less affected (0.09g day⁻¹) following the control group (T₄) with 0.23 g day⁻¹.In 2023, the most affected plants were found in T₁ and T₃ (0.01 g day⁻¹ each) at 60 days, and in T₁ (0.002 g day⁻¹)at 90days while the least affected were recorded in T₂ (0.09 and 0.04 g day⁻¹) followingthe control group (T₄) recording 0.04, 0.12 and 0.058 g day⁻¹ at 30, 60 and 90 days respectively (**Table 4.17**).

Table 4.17: Effect of whitefly feeding on the absolute growth rate (g day⁻¹)during the 2022 and 2023 pot experiments

Treatments	Data record periods							
	2022				2023			
	48HAI	30DAI	60DAI	90DAI	48HAI	30DAI	60DAI	90DAI
T1	0.00 ^a	0.03 ^a	0.05 ^b	0.03 ^a	0.00 ^a	0.030 ^{ab}	0.01 ^a	0.002 ^a
T2	0.00 ^a	0.02 ^b	0.13 ^{ab}	0.09 ^a	0.00 ^a	0.03 ^{ab}	0.09 ^a	0.036 ^b
T3	0.00 ^a	0.01 ^c	0.02 ^b	0.07 ^a	0.00 ^a	0.02 ^b	0.01 ^a	0.004 ^a
T4	0.00 ^a	0.03 ^a	0.40 ^a	0.23 ^a	0.00 ^a	0.04 ^a	0.12 ^a	0.058 ^a
C.D.	0.00	0.033	0.00	0.00	0.00	0.02	0.00	0.00
SEM±	0.00	0.003	0.10	0.08	0.00	0.01	0.008	0.004
C.V. (%)	0.00	16.3	52.3	132.5	39.3	39.3	61.0	21.5
P-value (5%)	0.00	<0.0001	0.037	0.610	0.042	0.042	0.618	0.445

Means with the same common letter in the same column are not significantly different from each other (P< 0.05). C.D. = Critical difference, C.V.= Coefficient of variance, SEM =Standard error means, HAI=Hours after infestation, DAI= Days after infestation, T=Treatment (T1= 15, T2= 30, T3= 45 and T4= control with 0 whiteflies/plot).

4.3.8. Relative growth rate (RGR, g⁻¹ day⁻¹)

The results on the effect of whitefly infestation on RGR revealed that plants in T₃ had were most effect in most of the data record periods. In 2022, there was zero RGR in all the treatments while at 30 days, the treatments differed significantly (P=0.022) with plants in T₃ having the lowest RGR (0.04g⁻¹ day⁻¹) while those in T₁ had the highest (0.09 g⁻¹ day⁻¹). No significant difference was observed at 60 (P=0.144) and 90 (P=0.625) days between the treatments. Plants in T₁ were most affected (-0.005 g⁻¹ day⁻¹) at 60 days while those in T₃ were most affected (-0.005 g⁻¹ day⁻¹) at 90 days after infestation. In 2023, similar result was recorded as in 2022 at 48 h after infestation. At 30 days, no significant difference was observed while at 60 and 90 days, the treatments differed significantly (P=0.031 and 0.038) with plants in T₂ being most affected (0.0002 and 0.005 g⁻¹ day⁻¹) while those in T₁ were less affected (0.009 and 0.016 g⁻¹ day⁻¹) (**Table 4.18**).

Table 4.18: Effect of whitefly infestation on the relative growth rate ($\text{g}^{-1} \text{day}^{-1}$) of eggplant during the 2022 and 2023 pot experiments

Treatments	Data record periods							
	2022				2023			
	48HAI	30DAI	60DAI	90DAI	48HAI	30DAI	60DAI	90DAI
T1	0.00a	0.09 ^a	-0.005 ^a	-0.003 ^a	0.00a	0.05 ^a	0.009 ^b	0.016 ^b
T2	0.00a	0.06 ^b	0.003 ^a	0.007 ^a	0.00a	0.05 ^a	0.0002 ^c	0.005 ^b
T3	0.00a	0.04 ^b	0.001 ^a	-0.005 ^a	0.00a	0.02 ^a	0.007 ^b	0.008 ^b
T4	0.00a	0.06 ^b	0.020 ^a	0.006 ^a	0.00a	0.07 ^a	0.038 ^a	0.047 ^a
C.D.	0.00	0.033	0.00	0.00	0.00	0.0	0.025	0.031
SEM\pm	0.00	0.010	0.001	0.007	0.00	0.019	0.008	0.014
C.V. (%)	0.00	34.9	31.1	20.3	0.00	56.7	120.1	102.7
P-value (5%)	0.00	0.022	0.144	0.625	0.00	0.199	0.031	0.038

Means with the same common letter in the same column are not significantly different from each other ($P < 0.05$). C.D. = Critical difference, C.V.= Coefficient of variance, SEM =Standard error means, HAI=Hours after infestation, DAI= Days after infestation, T=Treatment (T1= 15, T2= 30, T3= 45 and T4= control with 0 whiteflies/plot).

4.3.9. Net assimilation rate NAR ($\text{g m}^{-2} \text{day}^{-1}$)

There were zero results on NAR in all the treatments at 48 h after infestation in the 2022 and 2023 respectively. The result differed significantly at 60 days ($P=0.0003$) but was insignificant at 30 ($P= 0.426$) and 90 ($P=0.835$) days with plants in T₃ being most affected at 30 days after infestation. Plants in T₃ were also found most affected at 60 (0.0003) and 90 (0.0002) days respectively in 2022 trial. Similar results were recorded in 2023 with treatments differing significantly at 30 and 60 days ($P= 0.004$ and 0.017), while at 90 days, no significant difference was observed ($P=0.187$). The highest effects on NAR were found in T₁(0.0005 $\text{g m}^{-2} \text{day}^{-1}$) at 60 and T₃ (0.0002 $\text{g m}^{-2} \text{day}^{-1}$) at 90

days respectively. The least effect ($0.0005 \text{ g m}^{-2} \text{ day}^{-1}$) was recorded in T₁ at 90 days after infestation in 2023 trial (Table 4.19).

Table 4.19: Effect of whitefly infestation on the net assimilation rate ($\text{g m}^{-2} \text{ day}^{-1}$) during the 2022 and 2023 pot experiments

Treatments	Data record periods							
	2022				2023			
	48HAI	30DAI	60DAI	90DAI	48HAI	30DAI	60DAI	90DAI
T1	0.00 ^a	0.001 ^a	0.001 ^b	0.0005 ^a	0.00 ^a	0.0005 ^a	0.0005 ^b	0.0005 ^a
T2	0.00 ^a	0.001 ^a	0.001 ^b	0.0007 ^a	0.00 ^a	0.0003 ^b	0.0006 ^b	0.0003 ^a
T3	0.00 ^a	0.0003 ^a	0.0003 ^b	0.0002 ^a	0.00 ^a	0.0002 ^b	0.0008 ^b	0.0002 ^a
T4	0.00 ^a	0.02 ^a	0.004 ^a	0.0004 ^a	0.00 ^a	0.0006 ^a	0.004 ^a	0.007 ^a
C.D.	0.00	0.00	0.001	0.00	0.00	0.0002	0.003	0.000
SEM±	0.00	0.010	0.0001	0.000	0.00	0.0001	0.001	0.0002
C.V. (%)	0.00	39.3	99.8	70.1	0.00	36.1	103.2	28.7
P-value (5%)	0.00	0.426	0.0003	0.835	0.00	0.004	0.017	0.187

Means with the same common letter in the same column are not significantly different from each other ($P < 0.05$). C.D. = Critical difference, C.V. = Coefficient of variance, SEM = Standard error means, HAI = Hours after infestation, DAI = Days after infestation, T = Treatment (T₁ = 15, T₂ = 30, T₃ = 45 and T₄ = control with 0 whiteflies/plot).

4.4. Whitefly parameters on eggplant in the field experiment

4.4.1. Whitefly count in the field experiment

After the release of whiteflies in the field experimental plots, the adult, nymph and egg counts were recorded and results were presented in the tables 4.20 to 4.22. There is significant difference ($P < 0.0001$) between the treatments in most of the data recording periods during 2022 and 2023 experiments. Plants in T₃ had the highest adult population throughout the trials with the highest densities (277.6 and 288.5 adult/leaf) recorded at week 11 and 10 during 2022 and 2023 respectively. The least adult number (4.7 and 3.9 adult/leaf) were found in T₁, 48 h after the release of whiteflies in the experimental plots during the respective experiments. The highest adult population in the control plots (2.0 and 1.1 adults/leaf) were recorded at week 7 and 5 in 2022 and 2023 experiments (**Table 4.20**). The result on nymphs' population revealed that no nymph was observed in all the treatments at 48 h and week 1 after infestation in both the years (2022 and 2023). The results however, varied statistically ($P < 0.0001$) between the control and treated plots during the 2022 and 2023 trials at all the remaining data record periods. The emergence of nymphs commenced at week 2 after the release of adult whiteflies in the experimental plots with plants in T₃ having the high density (5.7 and 5.0 nymphs/leaf) during 2022 and 2023 cropping periods. The highest nymph population (310.8 and 283.2 nymphs/leaf) were recorded in T₃ at week 11 after infestation during the respective years (**Table 4.21**). The result on the egg count showed that no egg was released by whiteflies at 48 hours after infestation in all the treatments (0.00 eggs/leaf) in 2022 trial, but in the 2023, 0.6 eggs/leaf were recorded in T₃, 48 h after infestation. The highest egg densities (575.6 and 592.3 eggs/leaf) were recorded in T₃ at week 12 after infestation during 2022 and 2023 experiments (**Table 4.22**).

Table 4.20: Average adult whitefly population/eggplant leaf during the 2022 and 2023 field experiments

Treatments	Data record periods												
	2022												
	48HAI	1WAI	2WAI	3WAI	4WAI	5WAI	6WAI	7WAI	8WAI	9WAI	10WAI	11WAI	12WAI
T1	4.7 ^c	5.9 ^c	7.6 ^c	11.8 ^b	17.7 ^c	21.8 ^c	23.2 ^c	30.3 ^c	79.1 ^c	116.3 ^c	123.3 ^c	139.0 ^c	154.0 ^b
T2	9.3 ^b	9.3 ^b	15.6 ^a	21.5 ^a	22.8 ^b	32.7 ^b	36.9 ^b	52.5 ^b	96.2 ^b	190.9 ^b	198.8 ^b	156.1 ^b	162.0 ^b
T3	13.8 ^a	14.9 ^a	22.8 ^b	26.0 ^a	30.7 ^a	41.0 ^a	50.3 ^a	80.6 ^a	173.3 ^a	248.6 ^a	260.9 ^a	277.6 ^a	255.7 ^a
T4	0.0 ^d	0.0 ^d	0.5 ^c	0.3 ^c	1.1 ^d	1.8 ^d	1.6 ^d	2.0 ^d	0.7 ^d	0.5 ^d	0.9 ^d	1.2 ^d	0.3 ^d
C.D.	1.6	1.4	7.2	7.0	7.0	7.3	9.9	5.9	6.2	7.5	8.6	8.2	13.4
SEM_±	0.5	0.4	2.2	2.1	1.2	2.0	2.2	2.8	2.7	1.5	3.8	3.5	4.1
C.V. (%)	14.1	11.4	38.2	21.1	9.5	11.8	11.0	9.5	4.4	1.6	3.6	3.6	5.8
P-value (5%)	<0.0001	<0.0001	0.0003	<0.0001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	2023												
T1	3.9 ^c	4.6 ^c	6.6 ^c	8.5 ^c	15.0 ^b	22.4 ^c	27.6 ^c	38.4 ^c	82.3 ^c	111.4 ^c	137.3 ^c	151.4 ^c	164.9 ^c
T2	8.8 ^b	9.0 ^b	12.9 ^b	17.9 ^b	20.1 ^b	30.8 ^b	41.3 ^b	64.8 ^b	118.9 ^b	168.9 ^b	194.3 ^b	209.0 ^b	190.1 ^b
T3	13.8 ^a	15.2 ^a	19.9 ^a	23.5 ^a	27.2 ^a	42.0 ^a	53.8 ^a	100 ^a	169.1 ^a	238.2 ^a	288.5 ^a	269.0 ^a	218.8 ^a
T4	0.0 ^d	0.0 ^d	0.3 ^d	0.5 ^d	0.0 ^c	1.1 ^c	0.7 ^d	0.3 ^d	0.9 ^d	0.2 ^d	0.9 ^d	0.2 ^d	0.1 ^d
C.D.	1.3	1.9	4.9	5.4	6.1	8.4	9.4	14.7	2.7	7.1	5.2	5.2	4.3
SEM_±	0.5	0.8	2.2	1.7	2.7	3.6	1.1	4.5	1.2	3.1	2.3	2.3	1.9
C.V. (%)	11.6	16.1	30.7	26.6	24.4	21.4	18.7	17.8	1.8	3.4	2.1	2.0	2.0
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

(5%)

Means with the same common letter in the same column are not significantly different from each other ($P < 0.05$). C.D = Critical difference, C.V.= Coefficient of variance, SEM =Standard error mean, WAI= Week after infestation, HAI= Hours after infestation, T=Treatment (T1= 15, T2= 30, T3= 45 and T4= control with 0 whiteflies/plot).

Table 4.21: Average nymph whitefly population/eggplant leaf during the 2022 and 2023 field experiments

Treatments	Data record periods												
	2022												
	48HAI	1WAI	2WAI	3WAI	4WAI	5WAI	6WAI	7WAI	8WAI	9WAI	10WAI	11WAI	12WAI
T1	0.0 ^a	0.0 ^a	2.1 ^c	6.4 ^b	11.6 ^b	16.1 ^c	19.4 ^b	28.4 ^b	41.5 ^b	82.8 ^c	180.8 ^c	219.3 ^c	210.8 ^b
T2	0.0 ^a	0.0 ^a	3.4 ^b	11.3 ^a	15.1 ^{ab}	21.1 ^b	23.6 ^b	30.1 ^b	43.3 ^b	99.7 ^b	241.2 ^b	251.9 ^b	203.4 ^b
T3	0.0 ^a	0.0 ^a	5.7 ^a	13.1 ^a	17.6 ^a	24.6 ^a	28.4 ^a	50.0 ^a	64.7 ^a	165.9 ^a	284.2 ^a	310.8 ^a	275.9 ^a
T4	0.0 ^a	0.0 ^a	0.0 ^d	0.3 ^c	0.2 ^c	0.8 ^c	0.0 ^c	0.5 ^c	0.0 ^c	0.0 ^d	0.4 ^d	0.2 ^d	0.0 ^c
C.D.	0.0	0.0	3.5	7.9	4.6	4.0	7.5	18.6	14.6	5.2	4.1	8.5	13.2
SEM_±	0.0	0.0	1.4	1.3	2.0	1.1	1.8	2.4	2.9	3.6	1.3	3.6	5.7
C.V. (%)	0.00	0.00	11.1	23.6	25.5	9.7	14.4	12.2	11.1	3.4	1.5	2.7	4.7
P-value (5%)	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	2023												
T1	0.0 ^a	0.0 ^a	1.5 ^c	4.4 ^c	9.6 ^c	18.4 ^b	17.5 ^b	23.9 ^a	33.6 ^b	77.3 ^c	155.8 ^c	197.1 ^c	203.4 ^b
T2	0.0 ^a	0.0 ^a	3.2 ^b	9.4 ^b	14.9 ^b	23.8 ^{ab}	19.9 ^b	33.8 ^a	47.1 ^b	95.7 ^b	226.5 ^b	238.8 ^b	234.9 ^a
T3	0.0 ^a	0.0 ^a	5.0 ^a	14.0 ^a	18.0 ^a	26.3 ^a	29.1 ^a	40.6 ^a	70.8 ^a	156.4 ^a	263.4 ^a	283.2 ^a	195.1 ^b
T4	0.0 ^a	0.0 ^a	0.0 ^a	0.0 ^d	0.3 ^d	0.0 ^c	0.5 ^c	1.3 ^b	0.1 ^c	0.0 ^d	0.9 ^c	0.8 ^b	0.3 ^c
C.D.	0.0	0.0	2.2	3.5	2.6	6.4	9.1	7.1	14.4	4.0	3.7	6.0	12.6
SEM_±	0.0	0.0	0.4	1.5	1.1	2.8	3.8	7.5	4.5	1.8	1.6	2.4	5.5

C.V. (%)	0.0	0.0	22.7	30.9	14.9	22.9	33.4	42.7	23.5	3.0	1.4	1.9	4.9
P-value (5%)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0004	<0.003	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Means with the same common letter in the same column are not significantly different from each other ($P < 0.05$). C.D. = Critical difference, C.V. = Coefficient of variance, SEM = Standard error mean, WAI= Week after infestation, HAI= Hours after infestation, T=Treatment (T1= 15, T2= 30, T3= 45 and T4= control with 0 whiteflies/plot).

Table 4.22: Average whitefly egg counts /eggplant leaf during the 2022 and 2023 field experiments

Treatments	Data record periods												
	2022												
	48HAI	1WAI	2WAI	3WAI	4WAI	5WAI	6WAI	7WAI	8WAI	9WAI	10WAI	11WAI	12WAI
T1	0.0 ^a	0.9 ^c	3.8 ^c	4.80 ^c	9.8 ^c	11.3 ^b	18.8 ^b	18.7 ^c	42.6 ^c	106.5 ^c	157.5 ^c	249.9 ^c	411.0 ^b
T2	0.0 ^a	4.0 ^b	13.7 ^b	17.9 ^b	11.5 ^b	14.5 ^b	17.5 ^b	28.8 ^b	52.5 ^b	168.4 ^b	322.2 ^b	289.3 ^b	558.3 ^a
T3	0.0 ^a	6.0 ^a	20.4 ^a	27.4 ^a	22.7 ^a	37.6 ^a	39.2 ^a	36.8 ^a	71.9 ^a	282.5 ^a	338.2 ^a	334.8 ^a	575.6 ^a
T4	0.0 ^a	0.0 ^c	0.0 ^c	0.3 ^d	0.0 ^d	0.0 ^c	0.1 ^c	0.0 ^d	0.1 ^d	0.0 ^d	0.9 ^d	0.1 ^d	0.0 ^c
C.D.	0.0	4.5	5.7	5.3	4.9	4.9	2.1	3.09	2.3	5.3	5.1	7.4	13.4
SEM_±	0.0	0.5	1.8	1.6	1.4	2.1	0.9	1.4	1.0	2.2	2.2	3.2	8.8
C.V. (%)	0.0	29.0	25.5	26.2	14.5	18.8	6.7	9.1	3.4	2.3	1.5	2.1	2.1
P-value (5%)	0.0	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	2023												
T1	0.0 ^a	0.3 ^a	2.0 ^b	4.2 ^c	3.8 ^c	9.7 ^b	5.9 ^c	12.7 ^b	38.9 ^c	90.2 ^c	140.9 ^c	162.9 ^c	274.5 ^b
T2	0.0 ^a	0.9 ^a	5.4 ^b	14.8 ^b	10.6 ^b	11.5 ^b	10.7 ^b	22.9 ^a	48.7 ^b	155.3 ^b	274.4 ^b	296.7 ^b	582.6 ^a
T3	0.6 ^a	1.0 ^a	11.5 ^a	24.7 ^a	22.3 ^a	19.2 ^a	20.2 ^a	23.9 ^a	76.5 ^a	260.6 ^a	355.1 ^a	348.9 ^a	592.8 ^a
T4	0.0 ^a	0.0 ^a	0.0 ^b	0.0 ^d	0.4 ^c	1.1 ^c	0.5 ^d	0.3 ^c	0.8 ^d	0.0 ^d	0.1 ^d	0.3 ^d	0.1 ^c
C.D.	0.0	0.0	5.6	9.1	6.1	6.9	5.6	6.7	18.7	8.1	6.0	5.9	13.6
SEM_±	0.3	0.3	2.4	1.9	2.7	3.0	2.0	2.9	1.2	3.5	2.4	1.8	4.2
C.V. (%)	34.2	102.5	73.4	24.1	40.5	41.0	30.7	27.4	4.0	4.0	1.8	2.0	2.3
P-value	0.0	0.079	0.005	<0.0001	0.0001	0.002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

(5%)

Means with the same common letter in the same column are not significantly different from each other ($P < 0.05$). C.D. = Critical difference, C.V. = Coefficient of variance, SEM = Standard error mean, WAI= Week after infestation, HAI= Hours after infestation, T=Treatment (T1= 15, T2= 30, T3= 45 and T4= control with 0 whiteflies/plot).

4.4.2. Whitefly infestation and symptoms development in the field experiment

Various infestation symptoms relevant to whitefly feeding were observed and recorded during the experiments. Such symptoms include leaf chlorosis/mosaic, leaf folding, distortion, and stunting growth, honey dew deposition, sooty mold development, holes on leaves and leaf dehydration (**Fig 4.1**). The accumulation of these symptoms resulted in significant leaf damage (%) with the treatments differing significantly ($p < 0.0001$) from week 3 to 12 in both the 2022 and 2023 experiments. The highest leaf damages (85.8 and 88.0%) were recorded at week 12 with plants in T₃ while the least (0.3 and 0.2%) were recorded in T₁ at week 2 and 3 respectively during 2022 and 2023 experiments. Based on the visual rating scale, all the treatments were under scale 1 (0-20% leaf damage) four weeks after infestation. At week 8, T₁ recorded least damage falling in scale 1 while T₃ had the highest being on scale 3 (41-60% leaf damage) during 2022 and 2023 trials. The severity increases at week 12 after infestation, with plants in T₂ recording 80.0 and 81.0% and those in T₃ recording 85.8 and 88.0% being most affected, falling in scale 5 (81-100% leaf damage). The least (0.1%) and highest (4.4%) leaf damage in the control group were recorded at week 7 and 11 respectively during the two consecutive experimental periods (**Table 4.23**).

Table 4.23: Leaf damage (%) due to whitefly infestation during the 2022 and 2023 field experiment

Treatments	Data records periods												
	2022												
	48HAI	1WAI	2WAI	3WAI	4WAI	5WAI	6WAI	7WAI	8WAI	9WAI	10WAI	11WAI	12WAI
T1	0.0 ^a	0.0 ^a	0.3 ^{bc}	1.1 ^c	0.8 ^c	1.6 ^c	3.1 ^c	6.0 ^c	11.0 ^c	22.0 ^c	37.9 ^c	43.9 ^c	69.2 ^c
T2	0.0 ^a	0.0 ^a	0.5 ^b	1.6 ^b	5.2 ^b	4.0 ^b	5.7 ^b	12.7 ^b	26.4 ^b	40.1 ^b	65.2 ^b	64.8 ^b	80.0 ^b
T3	0.0 ^a	0.0 ^a	1.4 ^a	4.4 ^a	7.7 ^a	7.9 ^a	10.3 ^a	29.3 ^a	44.4 ^a	63.9 ^a	76.2 ^a	84.1 ^a	85.8 ^a
T4	0.0 ^a	0.0 ^a	0.0 ^c	0.0 ^d	0.5 ^c	1.0 ^c	0.3 ^d	0.1 ^d	0.9 ^d	1.1 ^d	0.9 ^d	2.3 ^d	2.2 ^d
C.D.	0.0	0.0	0.0	2.9	3.2	1.9	1.0	1.4	2.5	5.6	4.8	5.4	2.5
SEM_±	0.0	0.0	0.1	0.2	0.1	0.8	0.5	0.6	1.1	2.4	2.1	2.3	1.1
C.V. (%)	0.0	0.0	46.2	16.4	37.3	29.5	13.2	7.3	7.7	10.9	6.5	6.8	2.6
P-value (5%)	0.0	0.0	0.0002	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
							2023						
T1	0.0 ^a	0.0 ^a	0.0 ^a	0.2 ^b	1.3 ^c	2.6 ^{bc}	5.3 ^c	6.8 ^c	12.3 ^{bc}	25.4 ^c	40.5 ^c	49.2 ^c	66.6 ^b
T2	0.0 ^a	0.0 ^a	0.0 ^a	0.7 ^b	6.2 ^b	4.0 ^b	8.1 ^b	15.8 ^b	23.6 ^b	43.4 ^b	59.3 ^b	69.4 ^b	81.3 ^a
T3	0.0 ^a	0.0 ^a	0.0 ^a	1.4 ^a	9.2 ^a	9.7 ^a	15.1 ^a	27.9 ^a	46.8 ^a	69.8 ^a	81.1 ^a	85.4 ^a	88.0 ^a
T4	0.0 ^a	0.0 ^a	0.0 ^a	0.0 ^b	0.3 ^c	1.3 ^c	1.0 ^d	1.1 ^d	2.2 ^c	2.9 ^d	2.2 ^d	4.4 ^d	3.8 ^c
C.D.	0.0	0.0	0.0	0.7	1.3	2.6	1.2	3.0	16.1	9.8	5.3	4.6	8.9
SEM_±	0.0	0.0	0.0	0.2	0.6	1.1	0.5	1.2	4.9	4.3	2.3	2.0	3.9
C.V. (%)	0.0	0.0	0.0	78.1	18.6	36.0	10.3	12.8	46.1	17.9	7.1	5.4	9.1

P-value (5%)	0.0	0.0	0.0	0.006	<0.0001	0.0002	0.0001	<0.001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001
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Means with the same common letter in the same column are not significantly different from each other ($P < 0.05$). C.D. = Critical difference, C.V. = Coefficient of variance, SEM = Standard error mean, WAI= Week after infestation, HAI= Hours after infestation, T=Treatment (T1= 15, T2= 30, T3= 45 and T4= control with 0 whiteflies/plot)

4.4.3. Whitefly count on eggplant in pot experiment

After the release of whiteflies in the pot experimental plots, adult, nymph and egg counts were recorded at different periods as presented in tables 4.24-4.26. The results showed that there is significant difference ($P < 5\%$) between all treatments in most of the data recording periods during 2022 and 2023 cropping seasons. Plants in T₃ differed significantly ($P < 0.0001$) from the remaining treatments, having highest adult densities (247.9 and 257.3 adult/leaf) at week 10 and 11 respectively during 2022 and 2023 trials. The least whitefly number (4.5 and 4.2 adult/leaf) was found in T₁ during the respective experimental seasons, 48 h after the release of whiteflies in the experimental plots. The highest adult population in the control plots (2.1 and 0.9 whiteflies/leaf) were recorded at week 10 and 11, while the least (0.03 and 0.08 whitefly/leaf) were found at week 9 and 8 respectively during the two-year trials (**Table 4.24**). The result on nymphs' population showed that, no nymph was observed at 48 h and week 1 after infestation in 2022 and 2023 experiments. However, at week 2, nymph began to emerge with plants in T₃ having high densities (5.7 and 5.5 nymphs/leaf) in 2022 and 2023. The highest nymph population (238.6 and 285.7 nymph/leaf) was recorded in T₃ and T₂ at week 10 and 12 respectively during 2022 and 2023 experiments (**Table 4.25**). The result on egg deposition showed that no egg was released at 48 h after infestation in all the treatments (0.00 eggs/leaf) during the respective trials. The highest egg densities (558.3 and 311.4 eggs/leaf) were recorded in T₂ and T₃ at week 11 and 12 while the least (0.08 and 0.03 eggs/leaf) were found in T₄ at week 7 and 8 respectively during 2022 and 2023 experiments (**Table 4.26**).

Table 4.24: Average adult whitefly population/leaf of eggplant during 2022 and 2023 pot experiments

Treatments	Data record periods												
	2022												
	48HAI	1WAI	2WAI	3WAI	4WAI	5WAI	6WAI	7WAI	8WAI	9WAI	10WAI	11WAI	12WAI
T1	4.5 ^c	5.7 ^c	5.3 ^c	9.2 ^c	14.1 ^c	18.4 ^c	21.5 ^c	24.5 ^c	64.1 ^c	118.8 ^c	174.4 ^b	143.9 ^c	167.2 ^c
T2	8.7 ^b	8.9 ^b	9.6 ^b	18.8 ^b	19.9 ^b	29.2 ^b	33.3 ^b	41.8 ^b	90.9 ^b	176.1 ^b	210.8 ^c	191.7 ^b	177.5 ^b
T3	13.8 ^a	14.5 ^a	14.8 ^a	23.7 ^a	27.7 ^a	37.5 ^a	44.7 ^a	71.0 ^a	117.7 ^a	199.6 ^a	245.3 ^a	247.9 ^a	187.5 ^a
T4	0.0 ^d	0.0 ^d	0.0 ^d	0.0 ^d	0.3 ^d	0.0 ^d	0.3 ^d	1.8 ^d	0.1 ^d	0.0 ^d	2.1 ^d	0.1 ^d	0.9 ^d
C.D.	1.2	2.2	2.2	4.9	6.2	7.3	6.0	5.9	6.8	6.7	28.0	6.1	7.8
SEM_±	0.6	0.7	1.0	2.3	1.7	2.3	2.3	2.4	3.1	3.1	8.9	2.4	3.5
C.V. (%)	11.6	19.1	19.2	24.8	16.2	21.8	15.3	9.9	6.4	3.5	11.3	2.4	3.7
P-value (5%)	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	2023												
T1	4.2 ^c	4.3 ^c	5.1 ^c	7.0 ^b	12.3 ^c	20.6 ^c	19.7 ^c	26.8 ^c	71.7 ^c	105.0 ^c	133.4 ^c	160.1 ^c	179.5 ^b
T2	9.5 ^b	7.9 ^b	8.5 ^b	16.5 ^a	21.2 ^b	31.2 ^b	35.0 ^b	49.7 ^b	101.3 ^b	205.4 ^b	183.7 ^b	187.4 ^b	198.8 ^a
T3	14.1 ^a	14.7 ^a	14.9 ^a	20.6 ^a	28.6 ^a	40.6 ^a	48.1 ^a	68.3 ^a	131.1 ^a	238.2 ^a	257.2 ^a	221.7 ^a	203.9 ^a
T4	0.0 ^d	0.0 ^d	0.0 ^d	0.0 ^c	0.0 ^d	0.7 ^d	0.0 ^d	0.8 ^d	0.1 ^d	0.2 ^d	0.5 ^d	0.2 ^d	0.9 ^c
C.D.	2.4	2.5	1.2	5.3	6.5	7.7	5.2	4.9	6.6	6.8	8.8	8.3	7.3
SEM_±	1.1	1.1	0.5	2.4	2.9	3.5	2.4	2.3	2.7	2.7	2.7	2.3	2.3

C.V. (%)	21.8	23.6	10.1	28.8	26.7	21.5	13.0	8.9	5.0	2.8	3.7	3.3	3.2
P-value (5%)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0004	<0.003	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Means with the same common letter in the same column are not significantly different from each other ($P < 0.05$). C.D. = Critical difference, SEM = Standard error mean, WAI= Week after infestation, HAI= Hours after infestation, T=Treatment (T1= 15, T2= 30, T3= 45 and T4= control with 0 whiteflies/plot).

Table 4.25: Average nymph population/leaf of eggplant during 2022 and 2023 pot experiments

Treatments	Data records periods												
	2022												
	48HAI	1WAI	2WAI	3WAI	4WAI	5WAI	6WAI	7WAI	8WAI	9WAI	10WAI	11WAI	12WAI
T1	0.0 ^a	0.0 ^a	2.1 ^c	6.4 ^b	11.6 ^b	16.1 ^b	19.4 ^c	28.4 ^b	41.5 ^b	82.8 ^c	180.8 ^c	201.5 ^c	222.8 ^a
T2	0.0 ^a	0.0 ^a	3.4 ^b	11.3 ^a	15.1 ^a	21.1 ^a	23.6 ^b	30.1 ^b	43.3 ^b	99.4 ^b	205.5 ^b	216.5 ^a	179.2 ^b
T3	0.0 ^a	0.0 ^a	5.7 ^a	13.1 ^a	17.6 ^a	24.6 ^a	28.4 ^a	50.0 ^a	64.7 ^a	165.9 ^a	238.6 ^a	208.1 ^b	158.8 ^c
T4	0.0 ^a	0.0 ^a	0.0 ^d	0.0 ^c	0.2 ^c	0.8 ^c	0.8 ^d	0.5 ^c	0.1 ^c	0.0 ^d	0.1 ^d	0.4 ^d	0.0 ^d
C.D.	0.0.	0.0	2.8	7.9	4.6	3.9	7.5	18.6	14.6	3.7	6.1	7.5	5.0
SEM_±	0.0	0.0	0.6	0.7	1.2	1.9	1.6	2.2	2.4	1.6	2.7	2.1	2.9
C.V. (%)	0.0	0.0	29.9	13.7	14.8	17.0	12.5	11.4	8.9	2.5	2.5	1.9	3.0
P-value (5%)	0.0	0.0	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	2023												
T1	0.0 ^a	0.0 ^a	1.9 ^{bc}	5.6 ^b	8.8 ^c	19.8 ^b	24.2 ^b	31.5 ^b	37.1 ^c	63.5 ^c	130.7 ^c	143.8 ^c	265.5 ^c
T2	0.0 ^a	0.0 ^a	3.9 ^{ab}	11.0 ^a	13.9 ^b	25.4 ^a	27.3 ^b	31.9 ^b	67.7 ^b	84.8 ^b	186.4 ^b	219.3 ^b	285.7 ^b
T3	0.0 ^a	0.0 ^a	5.5 ^a	11.3 ^a	18.9 ^a	26.6 ^a	35.7 ^a	42.3 ^a	117.2 ^a	197.5 ^a	224.2 ^a	236.4 ^a	205.0 ^a
T4	0.0 ^a	0.0 ^a	0.0 ^c	0.0 ^c	0.3 ^d	0.3 ^c	2.5 ^c	0.3 ^c	0.0 ^d	0.1 ^d	0.2 ^d	0.1 ^d	0.0 ^d
C.D.	0.0	0.0	2.7	5.9	4.0	6.3	8.7	10.0	5.1	6.36	6.7	9.4	8.3
SEM_±	0.0	0.0	1.2	1.5	1.8	2.7	3.8	3.4	2.1	3.2	2.3	3.0	3.8
C.V. (%)	0.0	0.0	62.0	30.1	24.2	15.6	24.2	24.1	5.3	5.2	2.4	4.0	2.9
P-value	0.0	0.0	0.005	<0.0001	<0.0001	<0.0001	0.0004	<0.003	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

(5%)

Means with the same common letter in the same column are not significantly different from each other ($P < 0.05$). C.D.

= Critical difference, C.V. = Coefficient of variance, SEM =Standard error mean, WAI= Week after infestation, HAI= Hours after infestation, T=Treatment (T1= 15, T2= 30, T3= 45 and T4= control with 0 whiteflies/plot).

Table 4.26: Average egg count/leaf of eggplant during the 2022 and 2023 pot experiments

Treatments	Data record periods												
	2022												
	48HAI	1WAI	2WAI	3WAI	4WAI	5WAI	6WAI	7WAI	8WAI	9WAI	10WAI	11WAI	12WAI
T1	0.0 ^a	1.0 ^c	3.8 ^c	4.8 ^c	9.4.0 ^c	14.3 ^c	18.4 ^b	30.2 ^b	42.8 ^c	106.5 ^c	185.5 ^c	210.0 ^c	411.1 ^c
T2	0.0 ^a	3.8 ^b	13.7 ^b	17.9 ^b	11.5 ^b	22.1 ^b	17.4 ^b	27.9 ^b	59.8 ^b	168.5 ^b	322.7 ^b	292.9 ^b	558.3 ^b
T3	0.0 ^a	6.0 ^a	20.4 ^a	27.4 ^a	22.9 ^a	37.0 ^a	38.0 ^a	47.7 ^a	80.8 ^a	238.6 ^a	333.5 ^a	335.3 ^a	550.2 ^a
T4	0.0 ^a	0.0 ^d	0.0 ^c	0.3 ^d	0.0 ^d	0.0 ^d	0.3 ^c	0.1 ^c	0.1 ^d	0.1 ^d	0.1 ^d	0.2 ^d	0.1 ^d
C.D.	0.0	4.5	5.73	5.3	4.9	2.8	2.6	3.2	7.0	10.0	7.4	9.0	13.0
SEM_±	0.0	0.5	1.1	1.7	1.1	1.3	1.1	1.6	3.2	3.7	2.9	4.2	5.4
C.V. (%)	0.0	28.0	22.3	19.7	11.3	9.9	8.6	8.3	9.9	4.1	1.9	2.8	2.0
P-value (5%)	0.0.	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	2023												
T1	0.0 ^a	0.0 ^c	2.9 ^c	6.2 ^b	8.5 ^b	11.8 ^c	19.8 ^b	26.6 ^b	35.3 ^c	133.7 ^c	163.3 ^c	177.9 ^c	211.8 ^c
T2	0.0 ^a	1.3 ^b	4.7 ^b	7.3 ^b	14.4 ^{ab}	17.0 ^b	23.6 ^a	27.4 ^b	52.8 ^b	162.7 ^b	186.6 ^b	204.8 ^b	242.6 ^b
T3	0.0 ^a	3.2 ^a	8.9 ^a	16.2 ^a	19.3 ^a	25.6 ^a	25.3 ^a	32.3 ^a	82.4 ^a	241.1 ^a	274.7 ^a	292.2 ^a	311.4 ^a
T4	0.0 ^a	0.0 ^c	0.0 ^d	0.0 ^c	0.0 ^c	0.0 ^d	0.0 ^c	0.0 ^c	0.0 ^d	0.3 ^d	0.0 ^d	0.1 ^d	0.5 ^d
C.D.	0.0	1.1	5.6	5.3	6.9	5.9	5.4	8.4	4.7	4.1	6.0	5.8	14.5
SEM_±	0.0	0.21	0.5	1.3	3.2	1.8	1.7	1.4	2.2	1.9	2.7	2.6	6.8
C.V. (%)	0.0	23.9	17.4	24.7	42.6	18.5	14.5	9.1	7.1	2.0	2.5	2.2	5.0
P-value	0.0	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0004	<0.003	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

(5%)

Means with the same common letter in the same column are not significantly different from each other ($P < 0.05$). C.D. = Critical difference, C.V. = Coefficient of variance, SEM = Standard error mean, Week after infestation, HAI= Hours after infestation, T=Treatment (T1= 15, T2= 30, T3= 45 and T4= control with 0 whiteflies/plot).

4.4.4. Symptomsdevelopment and leaf damage in the pot experiments

Similar to diverse infestation symptoms (leaf chlorosis, leaf folding, stunted growth, honey dew deposition etc.)observed in the field experiments, such symptoms were also recorded in pot trials during 2022 and 2023 cropping periods (**Fig 4.1**). The accumulation of such effects have also led to the substantial leaf damage (%) with treatments differing significantly from week 2 to 12 in the respective cropping periods. The highest leaf damage were recorded at week 12 with plants in T₃ (90.1 and 93.2%) while the least (0.4 and 0.3%) were recorded in T₄ at week 4 after infestation in 2022 and 2023 trials(**Table 4.27**).

Table 4.27: Leaf damage (%) due to whitefly infestation during the 2022 and 2023 potexperiments

Treatments	Data record periods												
	2022												
	48HAI	1WAI	2WAI	3WAI	4WAI	5WAI	6WAI	7WAI	8WAI	9WAI	10WAI	11WAI	12WAI
T1	0.0 ^a	0.0 ^a	0.0 ^b	0.9 ^b	3.4 ^b	2.6 ^c	5.9 ^c	12.2 ^b	21.1 ^c	30.2 ^c	58.5 ^b	62.0 ^c	70.0 ^b
T2	0.0 ^a	0.0 ^a	0.0 ^b	1.4 ^b	5.8 ^a	6.4 ^b	9.9 ^b	16.7 ^a	36.5 ^b	39.5 ^b	55.3 ^b	43.4 ^b	78.5 ^b
T3	0.0 ^a	0.0 ^a	0.03 ^a	3.1 ^b	5.9 ^a	8.7 ^a	14.9 ^a	16.9 ^a	42.3 ^a	67.8 ^a	80.5 ^a	81.2 ^a	90.1 ^a
T4	0.0 ^a	0.0 ^a	0.0 ^b	0.0 ^c	0.4 ^c	0.4 ^d	0.5 ^d	1.2 ^c	0.5 ^d	2.3 ^d	2.2 ^c	1.1 ^d	0.9 ^c
C.D.	0.0	0.0	0.0	0.0	0.0	5.4	5.9	1.0	3.3	3.9	6.0	3.9	11.4
SEM_±	0.0	0.0	0.02	0.4	0.8	0.5	1.4	0.7	1.5	1.8	2.7	1.6	1.4
C.V. (%)	0.0	0.0	76.9	38.9	27.8	16.3	26.2	8.6	8.5	7.1	7.7	4.8	3.5
P-value (5%)	0.0	0.0	0.156	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
							2023						
T1	0.0 ^a	0.0 ^a	0.0 ^b	0.8 ^c	2.9 ^b	3.9 ^c	6.9 ^c	9.5 ^c	18.7 ^c	32.6 ^c	43.3 ^c	57.7 ^b	68.0 ^c
T2	0.0 ^a	0.0 ^a	0.0 ^b	1.2 ^b	5.2 ^a	5.5 ^b	12.3 ^b	16.6 ^b	31.4 ^b	42.4 ^b	54.2 ^b	58.0 ^b	81.0 ^b
T3	0.0 ^a	0.0 ^a	0.3 ^a	2.2 ^a	4.7 ^a	7.8 ^a	18.1 ^a	19.6 ^a	43.5 ^a	63.7 ^a	74.8 ^a	81.2 ^a	93.2 ^a
T4	0.0 ^a	0.0 ^a	0.0 ^b	0.0 ^d	0.3 ^c	1.2 ^d	0.9 ^d	2.6 ^d	1.6 ^c	2.7 ^d	2.4 ^d	3.3 ^c	3.6 ^d
C.D.	0.0	0.0	0.0	0.5	0.0	1.8	6.7	1.7	3.6	4.6	4.5	5.0	4.3
SEM_±	0.0	0.0	0.03	0.1	0.6	0.3	2.2	0.7	1.6	1.8	2.3	1.7	1.7
C.V. (%)	0.0	0.0	54.4	16.0	27.5	10.6	32.5	9.8	9.6	7.3	7.2	4.8	4.0

P-value (5%)	0.0	0.0	<0.0001	<0.0001	<0.0001	<0.0001	0.0004	<0.003	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
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Means with the same common letter in the same column are not significantly different from each other ($P < 0.05$). C.D. =Critical difference, C.V. = Coefficient of variance, SEM =Standard error mean, WAI= Week after infestation, HAI= Hours after infestation, T=Treatment (T1= 15, T2= 30, T3= 45 and T4= control with 0 whiteflies/plot).

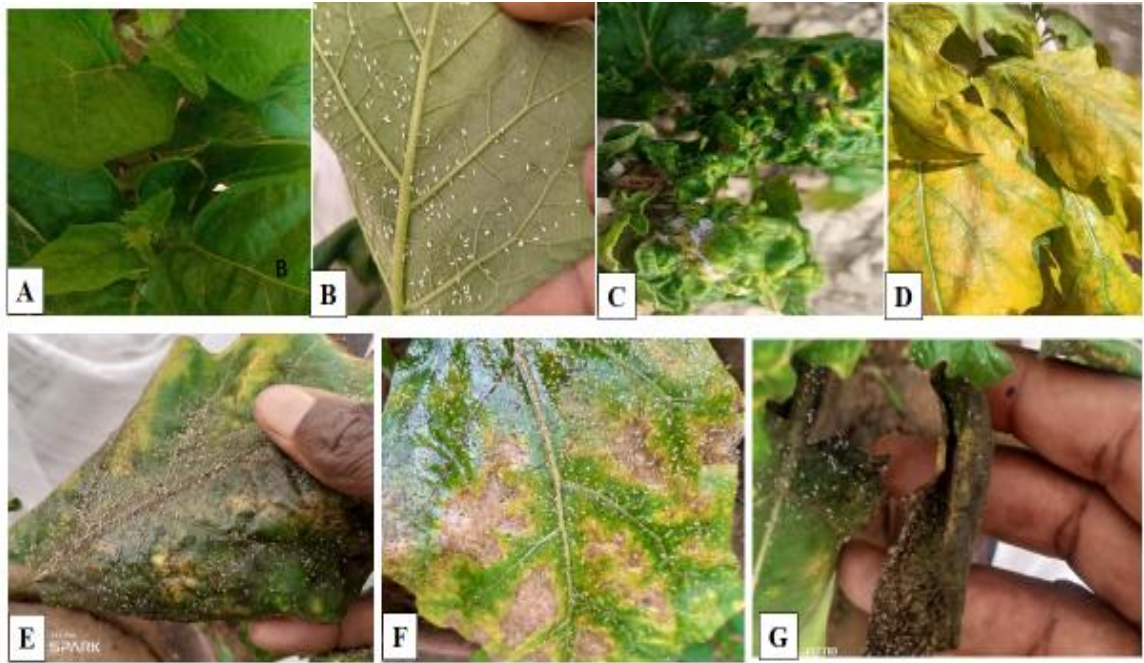


Fig 4.1: Symptoms development due to whitefly infestation and on the eggplant leaf during the 2022 and 2023 cropping seasons. A: Healthy leaves; B: Whiteflies on the leaf; C: Folded/stunted leaves; D: Leaf yellowing; E: Darkening of leaf; F: Leaf mosaic; G: Reduced blacken leaves with honey dew and sooty mold

4.4.5. Plant yield (kg/ha)

The infestation by whiteflies also affects the crop yield in both the field and pot experiments. The highest yield (563.3 and 556.6kg/ha) were recorded in the control plots (T₄) while the least were found in T₃ (44.6 and 55.1 kg/ha) during 2022 and 2023experiments under field conditions. The results differed significantly ($P<0.0001$) between the control and treated plots in 2022 trial. Similar results were recorded in 2023, with T₄ differing significantly ($P<0.0001$) from all the treated plots. However, T₂ and T₃ were statistically similar with respect to yield at harvest during 2023 cropping season (**Table 4.28**).The proportion (%) in yield by various treatments also showed

that T₄ occupied the highest portion (76 and 74%), followed by T₁ (10 and 11%) while T₃ had the least (6 and 7%) during 2022 and 2023 field experiments. In pot experiments, the treatments differed significantly (P<0.0001) from each other with plants in T₄ also having the highest yield (367.9 and 318.1 kg/ha) followed by those in T₁ (66.3 and 68.6 kg/ha) while those in T₃ had lowest yield (40.0 and 31.8 kg/ha) respectively in 2022 and 2023 experiments. Similarly, the proportion (%) covered revealed that the control plots (T₄) had the highest portion (70 and 67%), followed by T₁ (13 and 14%) while T₃ had the least (7% each) during 2022 and 2023 experiments (Fig 4.4 and 4.2).

Table 4.28: Plant yield (kg/ha) under field condition during 2022 and 2023 field experiments

Treatments	Yield (kg/ha)	
	2022	2023
T1	74.2 ^b	79.4 ^b
T2	61.3 ^c	61.0 ^c
T3	44.6 ^d	55.1 ^c
T4	563.3 ^a	556.6 ^a
C.D.	12.5	17.6
SEM _±	3.8	7.7
C.V. (%)	2.6	3.6
P-value (5%)	<0.0001	<0.0001

Means with the same common letter in the same column are not significantly different from each other (P< 0.05). C.D. = Critical difference, C.V. = Coefficient of variance, SEM = Standard error mean, g= gram, T=Treatment (T₁= 15, T₂= 30, T₃= 45 and T₄= control with 0 whiteflies/plot).

Table 4.29: Plant yield (kg/ha) during the 2022 and 2023 pot experiments

Treatments	Yield (kg/ha)	
	2022	2023
T1	66.3 ^b	68.6 ^b
T2	54.5 ^c	56.8 ^c
T3	40.0 ^d	31.8 ^d
T4	367.9 ^a	318.1 ^a
C.D.	14.0	14.4
SEM _±	4.5	4.6
C.V. (%)	4.3	4.9
P-value (5%)	<0.0001	<0.0001

Means with the same common letter in the same column are not significantly different from each other ($P < 0.05$). C.D. = Critical difference, C.V. = Coefficient of variance, SEM = Standard error mean, g= gram, T=Treatment (T1= 15, T2= 30, T3= 45 and T4= control with 0 whiteflies/plot).

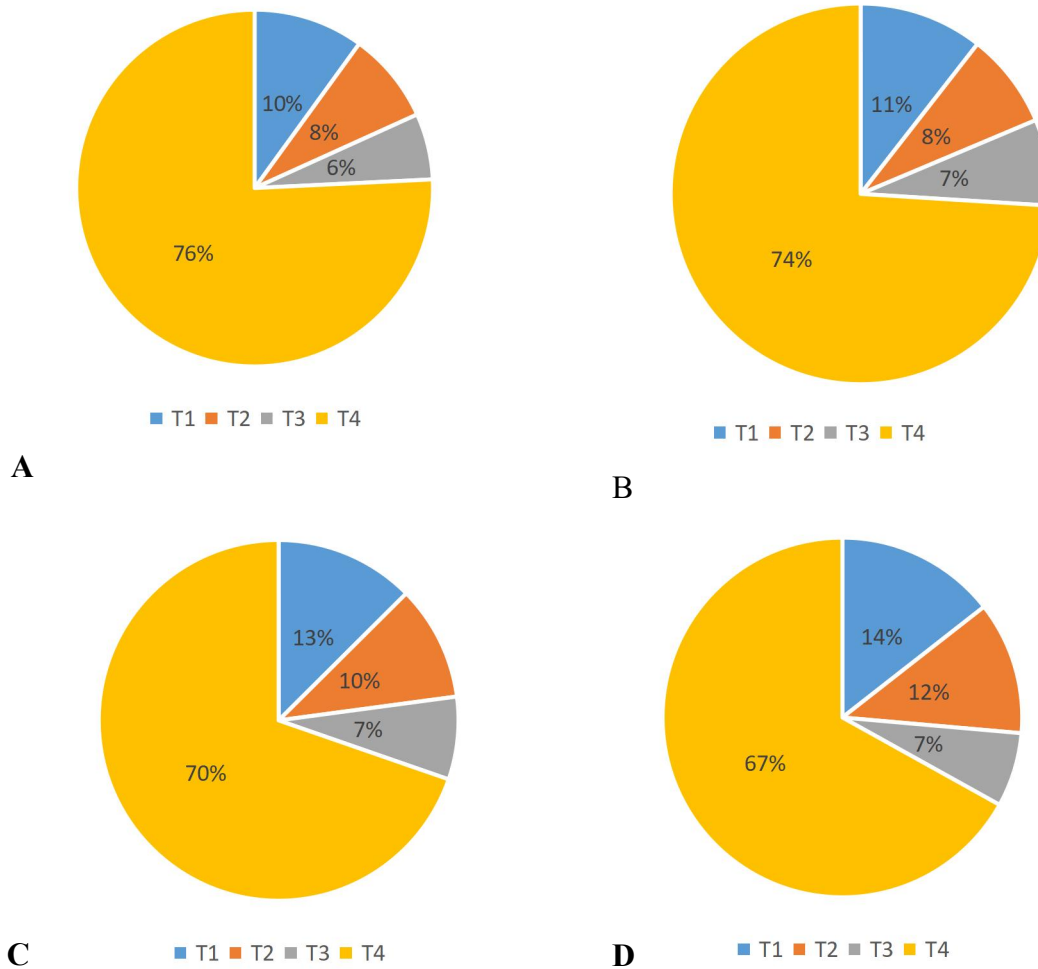


Fig 4.2: Yield percentage in the experimental plots for the respective cropping seasons. A=Yield proportion/plot in the field experiment in 2022, B= Yield proportion/plot in the field experiment in 2023, C= Yield proportion/plot in pot experiment in 2022, D = Yield proportion/plot in the pot experiment in 2023.T=Treatment (T1= 15, T2= 30, T3= 45 and T4= control with 0 whiteflies/plot)

4.5. Reduction (%) in eggplant growth parameters by whitefly infestation

4.5.1. Reduction (%) under field experiment

Most of the growth parameters of eggplant were reduced at the various data record periods during the field trials. At 30 days after the release of whiteflies in the experimental plots, plants in T₃ were most affected with respect to most of the parameters evaluated. The plant height, number of leaves, leaf area, fresh leaf weight, dry weight, absolute growth rate and relative growth rate were reduced by 31.49, 26.91, 39.33, 42.39, 26.67, 50.0 and 40.0% respectively. Plants in T₁ were found least affected with 14.09, 11.71, 25.16% reduction for plant height, number of leaves and leaf area respectively in 2022 trial. Plants in T₂ were least affected with 23.9, 18.89, 0.11% reduction in fresh leaf weight, dry weight and dry matter respectively. Similar results were recorded in 2023 with plants in T₃ being most affected while those in T₁ were least affected. **(Fig. 4.3)**. At 60 days after infestation, plants in T₃ were also most reduced (%) with respect to plant height (17.84%), leaf area (31.64%), fresh leaf weight (25.10%) and dry weight (48.21%) while least reduction (11.96, 12.78, 13.91, 39.29%) were recorded in T₁ and T₂ respectively during 2022 experiment. The highest reduction in number of leaves (15.23%), dry matter (39.04%), and absolute growth rate (81.3%) were recorded in T₂ while that of net assimilation rate (100%) was found in T₁ and T₂ respectively in 2022. Similar results were observed during 2023 trial with plants in T₃ being most reduced with respect to all parameters examined. The most affected parameter was net assimilation rate recorded with plants in T₂ and T₃ (95.0% each), while the least affected was leaf area (6.4%) with plants in T₁ at 60 days after infestation during 2023 trial **(Fig 4.4)**. The effects of direct whitefly feeding were more severe at 90 days after infestation with plants in T₃ having the highest reduction in all the parameters assessed except the absolute growth rate in which T₁ has the highest reduction (98.9%) and relative growth rate with T₂ recording the highest (95.0%). Similar result (100%) was found in all the treatments under the net assimilation rate. The results were similar in the 2023 experiments with T₃ having highest reduction in all the parameters assessed except the relative growth rate in which T₂ records the highest (99.20%). The highest effect was recorded in the net

assimilation (100%) in 2022 and relative growth rate (99.2%) in 2023 experiment. Number of was least affected with 18.09 and 9.40% reduction in 2022 and 2023 experiments. The highest effect on plant yield at harvest was found in T₃ (92.1%) while the least was recorded in T₁ (86.8%) in 2022. Plants in T₃ were also the most affected with regards to yield recording 90.1% reduction with T₁ having the least (85.7%) at harvest (Fig 4.5).

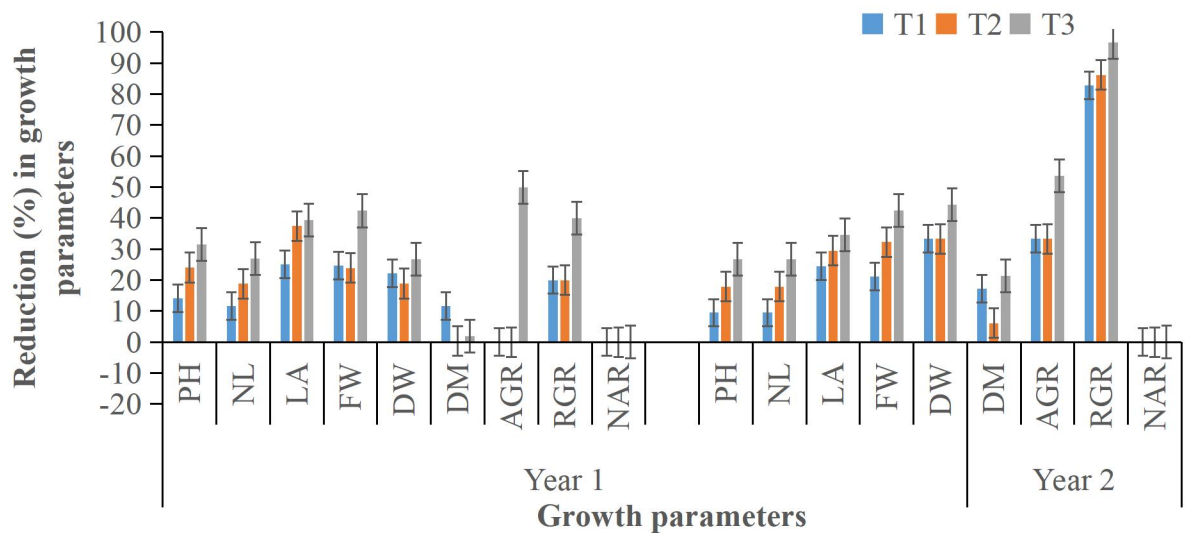


Fig 4.3: Reduction (%) in growth parameters 30 days after infestation in 2022 and 2023 experiments. PH = Plant height, NL= Number of leaves, LA= leaf area, FW = Fresh weight, DW =Dry weight, DM= Dry weight, AGR= Absolute growth rate, RGR= Relative growth rate, NAR= Net assimilation rate, T=Treatment (T1= 15, T2= 30, and T3= 45 whiteflies/plot)

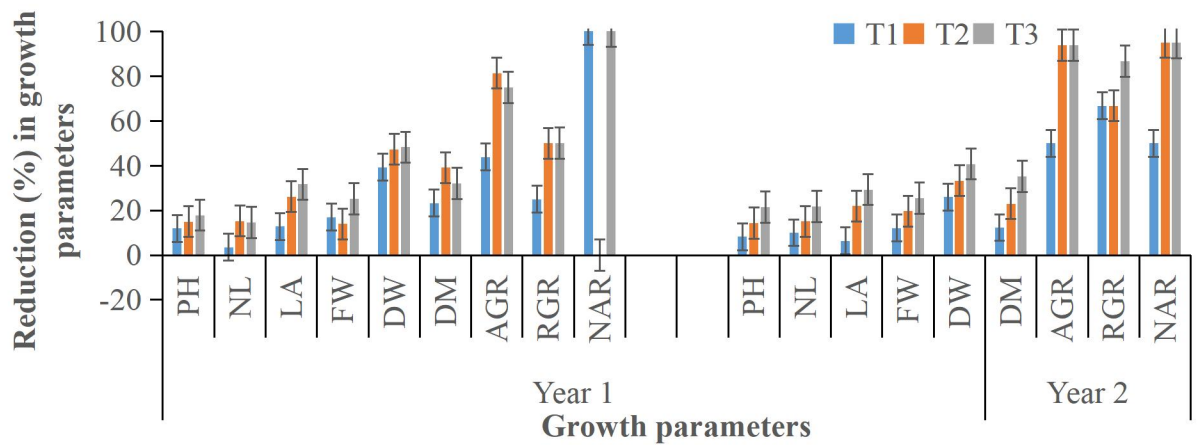


Fig 4.4: Reduction (%) in growth parameters 60 days after infestation in 2022 and 2023 experiments. PH = Plant height, NL= Number of leaves, LA= leaf area, FW = Fresh weight, DW =Dry weight, DM= Dry weight, AGR= Absolute growth rate, RGR= Relative growth rate, NAR= Net assimilation rate, T=Treatment (T1= 15, T2= 30, and T3= 45 whiteflies/plot)

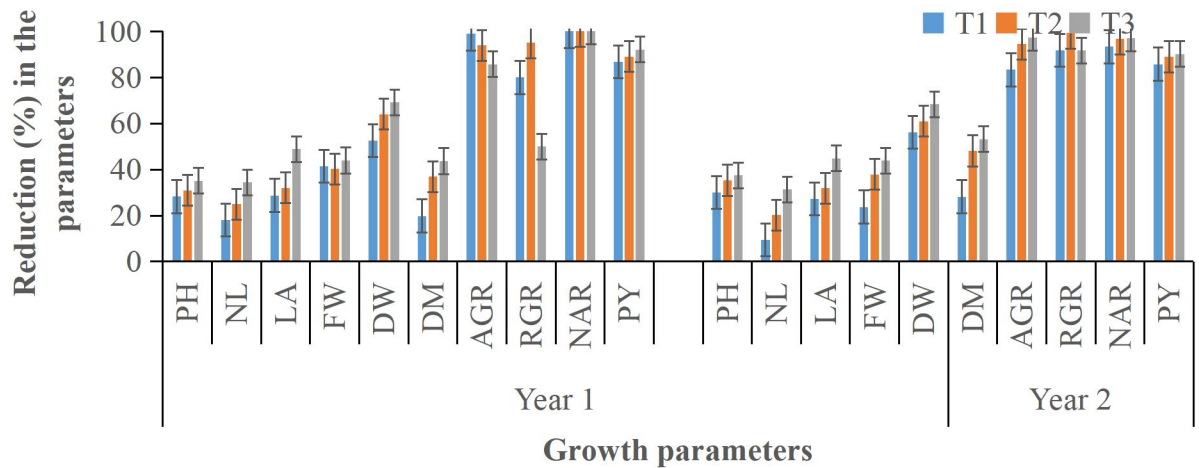


Fig 4.5: Reduction (%) in growth parameters 90 days after infestation in 2022 and 2023 experiments. PH = Plant height, NL= Number of leaves, LA= leaf area, FW = Fresh weight, DW =Dry weight, DM= Dry weight, AGR= Absolute growth rate, RGR= Relative growth rate, NAR= Net assimilation rate, PY= Plant yield, T=Treatment (T1= 15, T2= 30, and T3= 45 whiteflies/plot)

4.5.2. Reduction (%) in eggplant growth parameters during 2022 and 2023 pot experiments

The growth parameters of eggplant were also reduced at 30 days after the release of whiteflies in pot experimental plots with plants in T₃ being most affected in all the parameters evaluated. Net assimilation was most affected with followed by relative growth rate with 100 and 64.0% reduction with plants in T₃. The effect was found with plants in T₁ recording -2.56% reductions in 2022 experiment in 2022. The result remained similar during 2023 trial with plants in T₂ and T₃ being most affected while those in T₁ recorded the least. The highest effect was found in T₂ (93.3%) for net assimilation rate while the least was recorded in T₁ for plant height (3.9%). **(Fig. 4.6).** The infestation by whiteflies reduced the growth parameters further at 60 days with plants in T₃ having the highest reduction in 2022. Net assimilation rate was most reduced (97.50%) in T₂ and T₃ respectively while the leaf area is the least affected (3.35%) with plants in T₁ in 2022

experiment. In 2023, relative growth rate was most affected (97.40%) with plants in in T₂, followed by absolute growth rate (91.10%) in T₃ while the leaf number and leaf area were least affected with 5.6 and 7.6% reduction respectively (**Fig. 4.7**). The effect was more severe at 90 days after infestation with plants in T₃ being most affected in most of the parameters assessed. Relative growth rate was most reduced (94.9%) in T₁, while the least reduction (12.4%) was recorded for dry matter with plants in T₂during 2022 experiment. The result in 2023 recorded net assimilation rate as most affected parameter with about 93.8% reduction in T₁ and T₂ respectively while the leaf area is the least affected (19.6%) in T₁at 90 days after infestation. The highest reduction in yield at harvest was found in T₃ (89.4%) while the least was recorded in T₁ (82.0%) during 2022 trial. The highest effect on yield was also recorded in T₃ (90.0%) and least was found in T₁ (78.4%) in 2022trial (**Fig 4.8**).

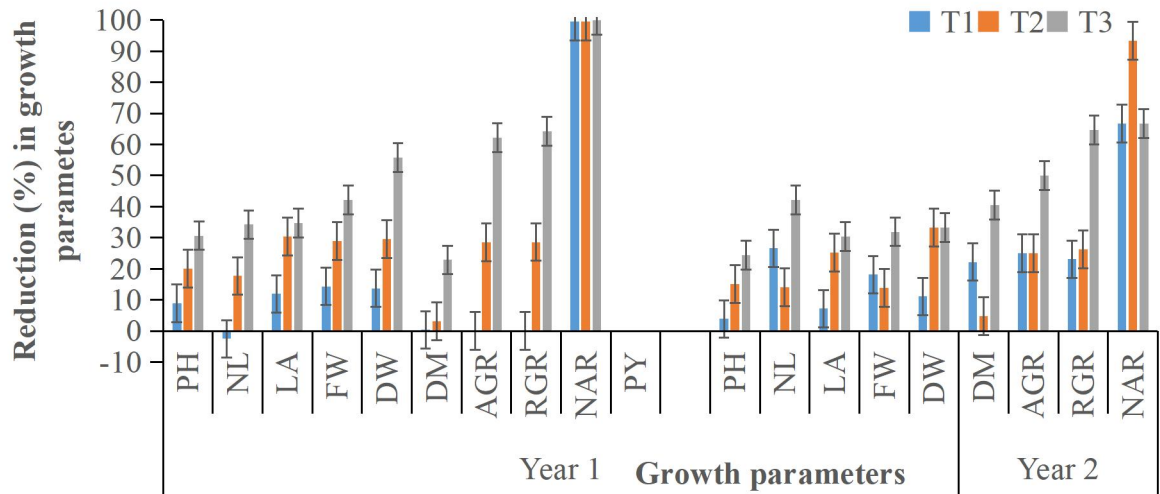


Fig 4.6: Reduction (%) in growth parameters in the pot experiment 30 days after infestation in 2022 and 2023 experiments. PH = Plant height, NL= Number of leaves, LA= leaf area, FW = Fresh weight, DW =Dry weight, DM= Dry weight, AGR= Absolute growth rate, RGR= Relative growth rate, NAR= Net assimilation rate, T=Treatment (T₁= 15, T₂= 30, and T₃= 45 whiteflies/plot)

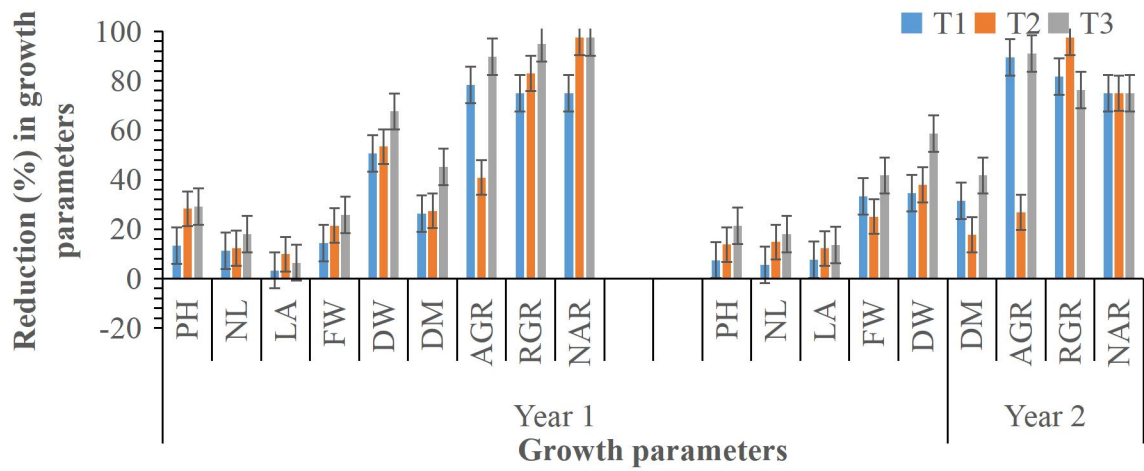


Fig 4.7: Reduction (%) in growth parameters in the pot experiment 60 days after infestation in 2022 and 2023 experiments. PH = Plant height, NL= Number of leaves, LA= leaf area, FW = Fresh weight, DW =Dry weight, DM= Dry weight, AGR= Absolute growth rate, RGR= Relative growth rate, NAR= Net assimilation rate, T=Treatment (T1= 15, T2= 30, and T3= 45 whiteflies/plot).

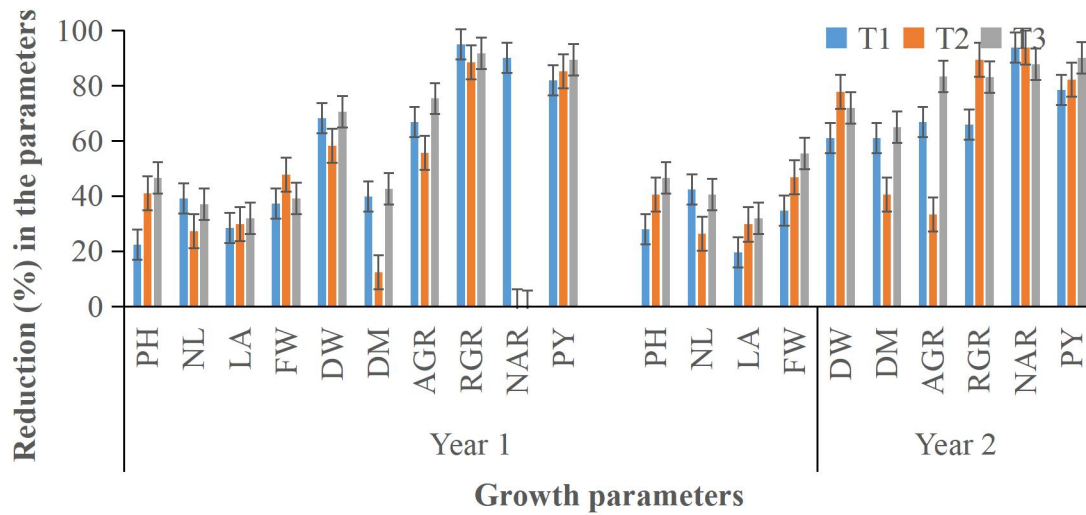


Fig 4.8: Reduction (%) in growth parameters in the pot experiment 90 days after infestation in 2022 and 2023 experiments. PH = Plant height, NL= Number of leaves, LA= leaf area, FW = Fresh weight, DW =Dry weight, DM= Dry weight, AGR= Absolute growth rate, RGR= Relative growth rate, NAR= Net assimilation rate, PY= Plant yield, T=Treatment (T1= 15, T2= 30, and T3= 45 whiteflies/plot)

Discussion

The current findings demonstrate that whitefly feeding negatively affects the leaves morphology of eggplant, leading to the development of diverse symptoms such as leaf chlorosis, stunting, leaf holes, curling, yellowing, darkening, honeydew deposition and sooty mold development, which consequently affected the entire growth parameters and yield of the crop cultivar examined. The effect and symptoms development were observed to be gradual with leaf yellowing/mosaic being the early symptoms observed while honeydew deposition, dehydration and leaf darkening were the later symptoms observed on the leaves during the experiments. The combined effects culminated to serious disorder on the plants which led to severe leaf damage and almost entire crop destruction. It was observed that plants in T₃ were most affected in most of the data taking periods with those in T₁ being the least affected while those in the control plots (T₄)

remained healthy throughout the trial periods. This signified that the effects observed were whitefly density dependent as the plots with high whitefly population were the most affected. Similarly, the cumulative effects and the leaf damage (%) were observed to be very low during the first thirty days after infestation in all the treatments. However, at sixty days, the severity increases with most of the leaves in the treated plots becoming crumbled, dehydrated, distorted and nutrients deficient in both the field and pots experiments. This indicates the influence of longer infestation period in increasing the severity of whitefly feeding effects under the field production system.

The effects of whitefly infestation on the growth parameters of eggplant such as plant height, number of leaves, leaf area, leaf fresh and dry weight, absolute growth rate, relative growth rate, net assimilation rate and plant yield showed that the control plots recorded no damages in most of the parameters compared to the infested plants at all the data record periods. The highest reduction (%) in plant heights in both the field and pot trials were recorded in T₃, which has the highest whitefly density/plant, at 90 days after infestation during the 2022 and 2023 cropping seasons. This indicates the influence of longer infestation period and larger whitefly density in causing damages on the eggplant variety examined. Plants in the pots trial were observed to be more affected than those in the opened field experiment at 90 days after infestation. The variation may be due climatic conditions which are well known to influence the activities of whiteflies. The result in the current research was higher than that were reported by of farina et al (2022) with (16.15%), Islam et al. (2010) (20.6%) and Li et al (2013) (32.7%) reductions in the plant height after infestation. The differences may be due to variation in infestation periods and the variety under study. Based on the result obtained, the number of leaves in the field and pots trials have been negatively affected with the highest reduction recorded at 90 days after infestation with the control plots (T₄) having the highest number of leaves/plants compared to the treated plots in the respective field and indoor trials. The plants in the pot trials were found to have lower number of leaves than those in the field trials during the 2022 and 2023 cropping seasons. This might be due to shortage of sunlight and variation in the temperature required for optimum crop development in the

pot trials. Whitefly feeding also affects the leaf area of eggplant in both the field and pot experiments. The control plots recorded highest leaf area while that of plants in T₃ was reduced by up to 48.8 to 70.6% in the respective experiments. This indicates the significance of whitefly presence on eggplant leaves as it led to reduced surface area, which affects the light energy absorption, thereby affecting photosynthetic rate and crop yield. Previous studies reported similar results describing the negative effects of whitefly feeding on the leaf area of eggplant (Islam and Shunxiang 2009; Islam et al. 2010; Farina et al. 2022) reporting 26.6%, 12.7% and 61.01% leaf area reduction respectively. This may be due to the fact that sap sucking by the *Bemisia tabaci* induces leaf chlorosis, leaf folding/distortion which is negatively associated with the crop photosynthetic activities and thus affecting the entire growth parameters (Li et al. 2013; 2018). Moreover, due to sap suction by whiteflies, fresh and dry weights of eggplants leaves were negatively affected. The fresh weight was reduced by about 43.9 and 47.6% in the field and pot experiments during the respective trials. The dry weights were also reduced by 69.1 and 70.6% in the field and pot trial respectively. A lower reduction (%) in the fresh and dry weights (21.8 and 19.3%) were reported in the previous works (Islam and Shunxiang 2009; Islam et al. 2011) for one whitefly life cycle (21 days) after infestation. The higher reduction (%) in the current finding might be due to variation in infestation period covering about three whitefly life cycles. The current findings are however, in contrast with what has been reported by Farari et al. (2022), who stated that the dry weight of eggplant is not affected by the presence of the whiteflies, and this could be related to the lower whitefly density and duration of their experiment.

The repetitive growth analysis in both the experiments revealed that absolute growth rate (AGR), relative growth rate (RGR) and net assimilation rate (NAR) in whitefly-infested eggplants were lower than those of control plants. The effect on these parameters (AGR, RGR, and NAR) indicates the possibility of nutrient stress, revealing the detrimental effect of whitefly infestation on chlorophyll content and the photosynthetic rate of the crop (Li et al. 2013; 2018; Saeedi and Ziaee 2020; Bughdady et al. 2020), which consequently suppressed plant growth capacity in various crop plants. Feeding by adult

and nymph whiteflies have been proved to cause leaf damages, reduce the chlorophyll content and photosynthetic capacity in tomatoes (*Lycopersicon esculentum* Mill) (Buntin et al. 1993). This is similar to report by Jimenez et al (1995) who stated that feeding by whitefly (*B. tabaci* biotype A) has led to leaves chlorosis and decreased chlorophyll content in squash plant (*Cucurbita pepo* L.). Moreover, Islam and Shunxiang (2009) reported a significant reduction of about 9.7 % and 65.9 % in the chlorophyll content and photosynthesis rate in eggplant due to infestation by *B. tabaci*. Contextually, the eggs deposited on the leaves by female whiteflies significantly reduced the stomata conductance, as they covered the stomata and reduced their access to the sunlight as well as carbon dioxide which are required for photosynthesis (Selvaraj et al. 2019). Whitefly feeding also affects the yield of eggplant as the current finding showed that plants infested with different quantity of whiteflies recorded lower fruit yield compared to the control groups. Previous studies (Chen et al. 2004) reported that there was reduction in fruits yield of zucchini crop infested with whiteflies compared to the control group. Schutze et al (2021) also reported significant reduction in the grain weight and loss in protein contents in the whitefly-infested soybeans. Similar reports (Little 2016, 2017) proved that up to 35 and 45% of the squash and snap bean were lost due to whiteflies infestation. The effects of whitefly infestation are thus of great economic importance as it affects the morphological and physiological features of different vegetables including eggplant. This necessitated the needs for developing and deploying safe, cost-effective management strategies for sustainable eggplant cultivation.

4.6. Effects of traditional treatments against the whitefly (*B. tabaci* G.)

4.6.1. Effects on adult population

The results on the effect of traditional treatments at different data recording periods (1st, 2nd, 3rd, 5th, 7th and 15th day) after the various sprays during the 2022 and 2023 experiments are presented in tables 4.30 to 4.32. The experimental plots were found with similar whitefly population per eggplant leaf at pre-treatment stage in 2022 (P=0.661) and 2023 (P=0.340) respectively. In 2022, there is significant difference between the treatments in all the data recording periods (P<5%) with the exception of day 1 (P=0.155) after the 1st spray. Neem leaf extract (60 mL/L) has the highest effect with 38.0 adult/leaf, followed by chili extract (60mL/L) with 42.7 adult/leaf while cow dung (50mL/L) has the least effect with 49.5 adult/leaf on day 1 after the 1st spray. Neem leaf extract (60 mL/L) remained most effective on the 2nd, 5th, 7th and 15th days after the 1st spray recording 29.7, 25.8, 19.3 and 15.7 adult/leaf respectively. Cow urine (75mL/L) has the highest effect (28.8 flies/leaf) on day 3 after the 1st spray in 2022 experiment. Cow dung (50mL/L) was least effective in all the data recording periods during the same season with up to 32.9 adult/leaf 15 days after the 1st spray. In 2023, similar results were recorded as in 2022, with the treatments differing significantly on the 2nd (P=0.011), 3rd (P=0.009), 5th (0.002), 7th (P<0.0001) and 15th (P=0.001) day after the 1st spray. Neem leaf extract (60 mL/L) was most effective in most of the data recording periods with 30.7 and 16.9 adult/leaf, followed by cow urine (75 mL/L) with 35.9 and 20.6 adult/leaf while chili extract (20 mL/L) was least effective with 45.5 and 31.7 adult/leaf on the 1st and 15th days respectively after the 1st spray (**Table 4.30**).

The whitefly density was reduced further as the treatments differed significantly (P<0.0001) after the 2nd spray, with neem leaf extract (60 mL/L) having the highest effect in most of the data taking periods. It was found with the least whitefly number (13.7, 2.4 and 2.8 adult/leaf), followed by cow urine (75 mL/L) with 15.6, 3.3 and 2.7 on the 1st, 7th and 15th day after the 2nd spray in 2022 experiment. The least effective treatment was found to be cow dung (50mL/L) and chili extract (20 mL/L) with 27.5 and 12.0 adult/leaf, on the 1st and 15th days respectively. The control plots differed significantly (p<0.0001)

from all the treated plots in all the data recording periods with up to 30.1 and 21.8 adult/leaf on the 1st and 15th days respectively in 2022 trial (Table 4.42). The result in 2023 was similar with that of 2022 experiment, demonstrating neem leaf extract (60 mL/L) to have the highest effect recording 13.5 and 3.4 adult/leaf on the 1st and 15th days after the 2nd spray. The least effective treatments (butter milk and cow dung) did not differ significantly on the 1st and 15th days after the 2nd spray during the 2023 experiment. They recorded 29.9, 28.8 adult/leaf on the 1st and 18.0, 13.8 adult/leaf on the 15th days of the 2nd spray (**Table 4.31**).

Cow urine (75mL/L) recorded the least whitefly number on the 1st and 5th days after the 3rd spray (2.7 and 1.7 adult/leaf) followed by same treatment (50mL/L) with 3.1 adult/leaf while cow dung (50mL/L) has the highest (10.9 adult/leaf) on day 1 after the 3rd spray. Neem extract was more effective in the remaining periods with the least whitefly number (0.7 adult/leaf) recorded on the 7th day as it differed significantly ($P < 0.0001$) from the control and most of the treatments during 2022 experiment. Cow dung was found to have least effect with 14.5 adult/leaf on the 7th day of the 3rd spray during the same trial period. Similar results were obtained in 2023 experiment with cow urine and neem leaf extract having the highest effects while butter milk and cow dung had the least as the treatments differed significantly ($P < 0.0001$) from each other after the 3rd spray. The highest densities (16.3 and 11.4 adult/leaf) were found with butter milk and cow dung, while the least (2.7 and 1.3 adult/leaf) were recorded with neem extract (60 mL/L) on the 1st and 15th days respectively, similar to malathion EC 50% (6 mL/L) with 0.9 adult/leaf, 15 days after the 3rd spray in 2023 experiment (**Table 4.32**). The treatments were crucial in increasing the yield of the crop during the experiments. In 2022, cow urine (75 mL/L) had the highest yield (1082.4 kg/ha), followed by neem extract (60 mL/L) (999.2 kg/ha) cow dung (50 mL/L) exhibited the least (747.3 kg/ha) as compared to the control plot (570.9 kg/ha). In 2023, cow urine and neem leaf extract also exhibited the highest yield (1061.6 and 1051.0 kg/ha) with cow dung being the least (769.7 kg/ha), as compared to the control plot (654.8 kg/ha) (**Table 4.32**).

Table 4.30: Average adult whitefly population on the eggplant leaves before and after the 1st foliar spray of traditional treatments during the 2022 and 2023 cropping seasons

Treatments	Average adult whiteflies/leaf							Average adult whiteflies/leaf						
	2022							2023						
	Pre-treatments	1DAS	2DAS	3DAS	5DAS	7DAS	15DAS	Pre-treatments	1DAS	2DAS	3DAS	5DAS	7DAS	15DAS
T1	53.8 ^a	48.3 ^a	47.1 ^{ab}	41.1 ^{abc}	37.7 ^{ab}	30.3 ^{bcd}	31.5 ^{abc}	49.9 ^a	45.5 ^{ab}	41.1 ^{ab}	38.3 ^{abc}	35.9 ^{abc}	34.8 ^{bc}	31.7 ^{ab}
T2	55.3 ^a	46.9 ^{ab}	42.4 ^{abc}	36.0 ^{bcd}	35.1 ^{abc}	27.0 ^{bcd}	24.1 ^{cde}	51.9 ^a	38.9 ^{ab}	37.8 ^{bc}	35.2 ^{bcd}	33.4 ^{bcd}	31.9 ^{bcd}	24.4 ^{def}
T3	51.6 ^a	42.7 ^{ab}	37.1 ^{bcd}	32.8 ^{bcd}	30.7 ^{abc}	22.2 ^{def}	21.6 ^{de}	54.2 ^a	32.9 ^{abc}	33.3 ^{bc}	30.8 ^{cd}	28.6 ^{bcd}	27.7 ^{cde}	22.6 ^{def}
T4	50.1 ^a	49.5 ^a	47.4 ^{ab}	44.1 ^{ab}	38.6 ^a	34.6 ^{ab}	32.9 ^{ab}	49.2 ^a	44.3 ^{abc}	41.7 ^{ab}	38.8 ^{abc}	36.4 ^{abc}	33.4 ^{bcd}	31.3 ^{abc}
T5	51.5 ^a	48.9 ^a	43.8 ^{abc}	40.1 ^{abc}	37.6 ^{ab}	29.7 ^{bcd}	26.5 ^{bcd}	49.4 ^a	41.1 ^{abc}	39.4 ^{abc}	37.7 ^{abc}	37.9 ^{ab}	36.5 ^b	32.5 ^{ab}
T6	50.4 ^a	47.5 ^{ab}	41.2 ^{abc}	38.7 ^{abc}	33.6 ^{abc}	28.5 ^{bcd}	27.6 ^{bcd}	51.1 ^a	39.6 ^{abc}	36.5 ^{bc}	33.5 ^{bcd}	33.1 ^{bcd}	30.1 ^{bcd}	30.9 ^{abc}
T7	54.8 ^a	48.6 ^a	44.4 ^{abc}	42.3 ^{abc}	37.1 ^{abc}	30.6 ^{bcd}	26.8 ^{bcd}	52.1 ^a	43.8 ^{abc}	41.2 ^{ab}	40.4 ^{ab}	37.9 ^{ab}	33.0 ^{bcd}	27.7 ^{cde}
T8	55.2 ^a	46.9 ^{ab}	42.2 ^{abc}	41.1 ^{abc}	34.1 ^{abc}	29.6 ^{bcd}	25.6 ^{bcd}	56.6 ^a	40.4 ^{abc}	35.4 ^{bc}	33.6 ^{bcd}	31.9 ^{bcd}	29.4 ^{bcd}	29.1 ^{bcd}
T9	57.9 ^a	43.5 ^{ab}	42.7 ^{abc}	35.6 ^{bcd}	31.8 ^{abc}	26.9 ^{bcd}	23.9 ^{cde}	54.1 ^a	36.1 ^{ab}	33.0 ^{bc}	34.5 ^{bcd}	30.0 ^{bcd}	25.7 ^{def}	25.8 ^{cde}
T10	50.1 ^a	48.9 ^a	43.2 ^{abc}	39.5 ^{abc}	34.4 ^{abc}	29.3 ^{bcd}	22.8 ^{de}	50.5 ^a	38.9 ^{abc}	35.0 ^{bc}	33.6 ^{bcd}	31.1 ^{bcd}	31.3 ^{bcd}	27.0 ^{cde}
T11	53.9 ^a	44.4 ^{ab}	41.6 ^{abc}	34.1 ^{bcd}	28.6 ^{bbc}	23.4 ^{cde}	20.1 ^{de}	51.7 ^a	37.3 ^{abc}	35.4 ^{bc}	35.3 ^{bcd}	32.2 ^{bcd}	29.3 ^{bcd}	23.2 ^{def}
T12	56.2 ^a	42.7 ^{ab}	35.2 ^{bcd}	28.8 ^d	26.3 ^{bc}	22.5 ^{cde}	15.8 ^e	53.5 ^a	35.9 ^{abc}	33.2 ^{bc}	31.5 ^{bcd}	29.1 ^{bcd}	25.1 ^{def}	20.6 ^{def}
T13	54.2 ^a	44.2 ^{ab}	41.4 ^{abc}	34.3 ^{bcd}	30.7 ^{abc}	26.3 ^{bcd}	23.0 ^{de}	50.4 ^a	38.2 ^{abc}	34.9 ^{bc}	32.9 ^{bcd}	31.4 ^{bcd}	28.0 ^{cde}	20.9 ^{def}
T14	51.9 ^a	42.2 ^{ab}	35.8 ^{bcd}	32.7 ^{bcd}	26.7 ^{bc}	24.6 ^{cde}	21.6 ^{de}	53.7 ^a	32.1 ^{abc}	29.5 ^c	29.5 ^{cd}	30.3 ^{bcd}	26.5 ^{cde}	18.7 ^{ef}
T15	55.1 ^a	38.0 ^b	29.7 ^d	29.2 ^d	25.8 ^c	19.3 ^f	15.7 ^e	48.3 ^a	30.7 ^{abc}	28.9 ^c	27.9 ^d	23.7 ^e	21.6 ^{ef}	16.9 ^f
T16	52.6 ^a	40.7 ^{ab}	34.2 ^{cd}	31.6 ^{cd}	26.4 ^{bc}	21.9 ^{ef}	22.6 ^{de}	55.9 ^a	35.0 ^{abc}	32.4 ^{bc}	30.7 ^{dc}	26.6 ^{de}	20.5 ^f	20.5 ^{def}

T17	52.3 ^a	50.2 ^a	50.3 ^a	44.8 ^a	40.0 ^a	38.4 ^a	35.6 ^a	54.2 ^a	47.5 ^a	48 ^a	45.5 ^a	43.8 ^a	47.0 ^a	40.4 ^a
C.D.	0.0	0.0	10.0	8.9	9.1	7.1	6.5	0.0	9.4	8.0	7.4	7.3	7.1	8.9
SEM _±	3.8	2.9	3.5	3.1	3.1	2.4	2.3	3.2	3.3	2.8	2.6	2.5	2.5	3.1
C.V. (%)	9.0	10.9	15.0	16.2	17.8	15.4	17.5	7.4	16.2	14.8	13.7	14.2	15.0	21.1
P-value (5%)	0.661	0.155	0.028	0.032	0.046	0.0004	<0.0001	0.340	0.089	0.011	0.009	0.002	<0.000 ₁	0.001

Means with the same common letter in the same column are not significantly different from each other ($P \leq 0.05$). DAS = Days after the spray, C.V.=Coefficient of variance, C.D. = Critical difference, SEM = Standard error mean, T=Treatment (See table 3.2)

Table 4.31: Average adult whitefly population on the eggplant leaves after the 2nd foliar spray of traditional treatments during the 2022 and 2023 cropping seasons

Treatments	Average adult whiteflies/leaf						Average adult whiteflies/leaf					
	2022						2023					
	1DAS	2DAS	3DAS	5DAS	7DAS	15DAS	1DAS	2DAS	3DAS	5DAS	7DAS	15DAS
T1	22.9 ^{bcd}	18.2 ^{bc}	13.5 ^{bcd}	10.0 ^{bcd}	9.4 ^{bcd}	12.0 ^b	27.3 ^{bcd}	28.4 ^b	23.5 ^b	18.3 ^{bc}	17.7 ^{bc}	12.9 ^{bcd}
T2	18.9 ^{cde}	17.3 ^{bcd}	10.2 ^{cde}	7.4 ^{cde}	7.3 ^{bcd}	5.8 ^{efg}	22.4 ^{cde}	20.4 ^{cde}	16.7 ^{cde}	13.6 ^{def}	12.8 ^{cde}	11.0 ^{cd}
T3	17.1 ^{cde}	11.3 ^{cde}	9.2 ^{cde}	5.8 ^{de}	4.8 ^{efd}	5.7 ^{efg}	20.2 ^{cde}	16.7 ^{efg}	12.1 ^{fgh}	8.3 ^{fgh}	6.6 ^{de}	5.1 ^{fg}
T4	27.5 ^{ab}	21.1 ^b	16.2 ^b	12.9 ^b	10.8 ^b	10.4 ^{bc}	26.5 ^{bcd}	23.9 ^{bcd}	20.7 ^{bcd}	21.3 ^{bc}	18.8 ^b	18.0 ^b
T5	21.6 ^{bcd}	16.9 ^{bcd}	13.4 ^{bcd}	9.7 ^{bcd}	7.7 ^{bcd}	7.3 ^{def}	28.8 ^{bcd}	28.5 ^b	24.5 ^b	18.9 ^{bcd}	15.6 ^{bcd}	14.3 ^{bcd}
T6	19.9 ^{cde}	12.6 ^{cde}	11.1 ^{cde}	10.0 ^{bcd}	5.3 ^{cde}	3.8 ^g	27.9 ^{bcd}	22.6 ^{bcd}	19.6 ^{bcd}	15.6 ^{cde}	11.3 ^{def}	9.4 ^{def}
T7	25.0 ^{abc}	16.8 ^{bcd}	14.6 ^{def}	10.7 ^{bc}	11.8 ^b	9.9 ^{bcd}	29.9 ^b	26.9 ^{bc}	23.1 ^b	23.7 ^b	18.5 ^b	13.8 ^{bc}
T8	17.7 ^{cde}	13.7 ^{cde}	13.2 ^{bcd}	8.9 ^{bcd}	9.6 ^{bc}	7.0 ^{def}	26.8 ^{bcd}	24.1 ^{bcd}	21.9 ^{bc}	14.2 ^{cbd}	12.7 ^{cde}	10.2 ^{cde}
T9	21.5 ^{bcd}	12.1 ^{cde}	11.8 ^{bcd}	8.0 ^{cde}	7.7 ^{bcd}	4.2 ^{fgh}	23.3 ^{cde}	19.3 ^{def}	16.3 ^{cde}	14.1 ^{def}	12.7 ^{cde}	11.9 ^{cd}
T10	20.6 ^{cde}	10.1 ^{def}	9.4 ^{cde}	6.4 ^{cde}	7.3 ^{bcd}	3.3 ^h	22.8 ^{cde}	18.9 ^{def}	14.8 ^{efg}	10.8 ^{efg}	12.6 ^{cde}	13.3 ^{bcd}
T11	17.9 ^{def}	9.4 ^{fg}	8.0 ^{def}	6.1 ^{de}	4.8 ^{def}	4.0 ^{gh}	20.5 ^{cde}	22.6 ^{cde}	15.2 ^{efd}	14.4 ^{def}	10.3 ^{def}	10.4 ^{cde}
T12	15.6 ^{ef}	8.4 ^g	6.5 ^{ef}	4.9 ^e	3.3 ^{ef}	2.7 ^h	17.8 ^{fgh}	13.7 ^{fgh}	8.9 ^{hi}	6.7 ^h	4.9 ^{gh}	5.6 ^{efg}
T13	16.9 ^{def}	12.2 ^{cde}	9.1 ^{cde}	7.0 ^{cde}	4.2 ^{ef}	7.7 ^{cde}	19.0 ^{efg}	20.7 ^{cde}	16.6 ^{cde}	16.7 ^{cde}	12.0 ^{de}	10.5 ^{cde}
T14	15.3 ^{ef}	13.2 ^{cde}	7.1 ^{def}	5.7 ^{de}	3.2 ^{ef}	3.6 ^h	16.6 ^{fgh}	13.0 ^{gh}	9.9 ^{ghi}	8.5 ^{gh}	6.5 ^{fgh}	5.1 ^{fg}

T15	13.7 ^f	9.9 ^{efg}	5.4 ^f	5.2 ^e	2.4 ^f	2.8 ^h	13.5 ^g	10.7 ^h	7.1 ^{hi}	4.9 ^h	4.3 ^h	3.4 ^g
T16	16.2 ^{def}	16.1 ^{bcd}	10.3 ^{cde}	7.4 ^{cde}	7.8 ^{bcd}	5.2 ^{efg}	11.6 ^h	10.2 ^h	6.6 ⁱ	4.5 ^h	7.5 ^{efg}	2.9 ^g
T17	30.1 ^a	27.6 ^a	27.9 ^a	26.2 ^a	26.7 ^a	21.8 ^a	43.2 ^a	37.4 ^a	39.7 ^a	32. ^a	36.4 ^a	36.4 ^a
C.D.	5.9	6.2	4.8	3.2	4.1	2.5	7.3	6.2	5.1	5.9	4.6	4.2
SEM _±	2.0	2.1	1.7	1.1	1.4	0.9	2.5	2.1	1.7	2.1	1.6	1.5
C.V. (%)	18.5	26.1	28.1	24.8	31.3	24.3	18.6	17.6	17.3	22.8	22.3	24.5
P-value (5%)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Means with the same common letter in the same column are not significantly different from each other ($P \leq 0.05$). DAS = Days after the spray, % = C.V.=Coefficient of variance, C.D. = Critical difference, SEM = Standard error mean, T=Treatment (See table 3.2)

Table 4.32: Average adult whitefly population on the eggplant leaves after the 3rd foliar spray of traditional treatments and their effect on plant yield during the 2022 and 2023 cropping seasons

Treatments	Average adult whiteflies/leaf							Average adult whiteflies/leaf						
	2022							2023						
	1DAS	2DAS	3DAS	5DAS	7DAS	15DAS	Yield (kg/ha)	1DAS	2DAS	3DAS	5DAS	7DAS	15DAS	Yield (kg/ha)
T1	8.4 ^{bcd}	8.5 ^{bcd}	5.5 ^{cd}	6.9 ^{bc}	8.0 ^{bcd}	8.8 ^{bc}	820.8 ^e	10.6 ^{cde}	9.7 ^{bcd}	11.6 ^{bc}	9.9 ^{bc}	9.2 ^{bc}	8.9 ^{bc}	803.6 ^f
T2	5.5 ^{bcd}	5.9 ^{cde}	3.2 ^{de}	3.5 ^{cde}	2.3 ^{gef}	5.5 ^{def}	805.3 ^e	7.5 ^{def}	6.2 ^{ccd}	9.3 ^{bcd}	9.3 ^{bcd}	8.3 ^{bcd}	7.2 ^{cde}	812.9 ^{fg}
T3	4.7 ^{cd}	3.6 ^f	2.2 ^{de}	2.2 ^e	1.9 ^{fg}	2.9 ^{fgh}	898.4 ^{cd}	4.2 ^{fgh}	3.6 ^d	2.7 ^e	3.2 ^e	1.3 ^{de}	2.1 ^{fg}	908.4 ^{cd}
T4	10.9 ^b	9.0 ^{bc}	9.7 ^b	7.5 ^b	14.5 ^{bc}	10.6 ^b	747.3 ^f	15.3 ^{bc}	13.4 ^b	10.9 ^{bc}	9.3 ^{bc}	12.1 ^b	10.8 ^{bc}	923.8 ^e
T5	7.9 ^{bcd}	7.7 ^{bcd}	4.1 ^{cde}	4.4 ^{cde}	3.3 ^{def}	8.4 ^{bcd}	751.9 ^f	12.3 ^{bcd}	11.1 ^{bc}	11.9 ^{bc}	11.9 ^{bc}	10.4 ^b	11.4 ^b	769.7 ^g
T6	5.8 ^{bcd}	5.7 ^{efd}	2.4 ^{de}	2.5 ^e	1.5 ^{fg}	5.2 ^{def}	919.9 ^{cd}	9.6 ^{cde}	8.1 ^{bcd}	7.8 ^{cde}	7.8 ^{cde}	6.8 ^{cde}	7.0 ^{cde}	877.3 ^e
T7	8.8 ^{bc}	9.4 ^b	7.5 ^{bc}	9.3 ^{bcd}	4.8 ^{bcd}	8.4 ^{bcd}	879.0 ^d	16.3 ^b	12.6 ^b	14.3 ^b	14.0 ^b	12.5 ^b	9.3 ^{bcd}	892.2 ^{de}
T8	6.0 ^{bcd}	4.2 ^f	2.9 ^{de}	3.2 ^{cde}	4.0 ^{fge}	3.5 ^{efg}	820.2 ^e	10.3 ^{cde}	8.2 ^{bcd}	11.3 ^{bcd}	10.5 ^{bcd}	6.2 ^{cde}	3.9 ^{efg}	896.1 ^{de}
T9	3.6 ^{cd}	3.3 ^f	2.6 ^{de}	2.9 ^{de}	10.9 ^b	2.3 ^{fgh}	912.6 ^{cd}	8.8 ^{def}	11.7 ^{bc}	5.8 ^{cde}	5.8 ^{cde}	3.6 ^{cde}	3.1 ^{efg}	992.4 ^b
T10	3.7 ^{cd}	3.2 ^f	3.6 ^{cde}	2.9 ^{de}	4.3 ^{efg}	6.4 ^{cde}	919.0 ^{cd}	10.4 ^{cde}	8.1 ^{bcd}	7.3 ^{cde}	7.3 ^{cde}	6.5 ^{cde}	5.8 ^{def}	880.4 ^{de}
T11	3.1 ^{cd}	2.7 ^f	2.1 ^{de}	1.7 ^e	1.4 ^{fg}	2.2 ^{fgh}	905.7 ^{cd}	6.9 ^{efg}	4.7 ^{cd}	4.1 ^{de}	4.2 ^{de}	2.4 ^{de}	3.6 ^{efg}	1001.2 ^b
T12	2.7 ^d	3.3 ^f	2.2 ^{de}	1.9 ^e	1.1 ^{fg}	2.1 ^{gh}	1082.4 ^a	3.5 ^{gh}	2.5 ^d	1.8 ^e	1.8 ^e	1.1 ^e	1.3 ^g	1061.6 ^a
T13	5.9 ^{bcd}	5.9 ^{cde}	3.7 ^{cde}	3.8 ^{cde}	3.2 ^{def}	3.4 ^{efg}	889.2 ^d	10.7 ^{cde}	8.7 ^{bcd}	7.4 ^{cde}	6.8 ^{cde}	4.6 ^{cde}	4.6 ^{efg}	910.4 ^{cd}
T14	4.0 ^{cd}	3.0 ^f	2.9 ^{de}	1.4 ^e	1.5 ^{fg}	2.1 ^{fgh}	891.8 ^d	5.0 ^{efg}	3.3 ^d	1.6 ^e	1.9 ^e	2.8 ^{cde}	3.9 ^{efg}	1013.3 ^b
T15	3.2 ^{cd}	2.7 ^f	1.2 ^e	2.0 ^e	0.7 ^g	1.6 ^h	999.2 ^b	2.7 ^h	2.7 ^d	2.2 ^e	2.0 ^e	1.6 ^{de}	1.3 ^{fg}	1051.0 ^a

T16	5.1 ^{cd}	4.6 ^{ef}	5.9 ^{cd}	3.5 ^{cde}	3.9 ^{def}	1.8 ^{gh}	988.0 ^{bc}	3.9 ^{gh}	2.4 ^d	2.5 ^e	2.4 ^e	1.5 ^{de}	0.9 ^g	1008.6 ^b
T17	24.5 ^a	28.0 ^a	28.0 ^a	20.8 ^a	21.1 ^a	26.2 ^a	570.9 ^g	34.6 ^a	32.5 ^a	30.8 ^a	32.6 ^a	31.5 ^a	33.4 ^a	654.8 ^b
C.D.	4.0	3.0	3.5	4.1	5.6	3.0	13.4	5.1	6.2	5.7	5.9	5.4	3.9	11.7
SEM _±	1.4	1.0	1.2	1.4	1.9	1.0	11.1	1.8	2.1	2.0	2.0	1.9	1.4	7.4
C.V. (%)	43.5	26.6	40.0	40.8	33.7	29.7	2.0	31.8	42.9	40.9	40.8	37.8	32.1	1.1
P-value (5%)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Means with the same common letter in the same column are not significantly different from each other ($P \leq 0.05$). DAS = Days after the spray, C.V. = Coefficient of variance, C.D. = Critical difference, SEM = Standard error mean, T=Treatment (See table 3.2)

4.6.2. Effects of traditional treatments on the nymphs' population

The treatments evaluated also affect the nymphs' population after the three foliar sprays for 45 days, as depicted in tables 4.33 to 4.45. In 2022, the treatments differed significantly ($P= 0.001$) on 1st and 15th days after the 1stspray with cow urine (75 mL/L) and neem leaf extract (60 mL/L) being most effective with 19.3, and 4.5 adult/leaf, followed by chili pod extract (60 mL/L) with 21.2 adult/leaf on 1stday after the 1st spray. Neem extract was most effective in all the remaining data recording periods with the exception of day 3, in which cow urine (75mL/L) had the highest effect (12.3 adult/leaf) during the 2022 experiment. The highest neem population after the 1st spray was found with cow dung (25.7 and 21.7 nymphs/leaf) being least effective on the 1st and 15th days respectively. In 2023, there is no significant difference ($P=0.474$) between all the treatments on day 1 after the 1st spray. However, cow urine (60 mL/L) and butter milk (50mL/L) recorded the least and the highest number (16.6 and 23.7 nymphs/leaf). On the subsequent days, cow urine and neem extract maintained the greatest effect with neem extract (60 mL/L) having the lowest number (4.9 nymphs/leaf), followed cow urine (75 mL/L) and chili pod extract (60 mL/L) as they differed significantly ($P<0.0001$) from the remaining treatments 15 days after the 1stspray. Butter milk and cow dung remained the least effective with 23.7 and 20.4 nymphs/leaf on the 1st and 15th days respectively (**Table 4.33**).

The results remained similar after the 2nd spray during the 2022 trial, with neem extract (60 mL/L) being most potent in most of the data recording times differing significantly ($P<0.0001$) from most of the treatments with 3.3 and 1.4 nymphs/leaf on the 1st and 15th days respectively. Cow urine has the least nymph number (0.8 nymphs/leaf) as it differed significantly ($P<0.0001$) on the 7th day after the 1st spray. Butter milk and cow dung (50 mL/L) remained the least effective with about 15.7 and 15.9 nymphs/leaf on the 1st and 15th days of the 2nd spray. In 2023 trial, malathion EC 50% (6 mL/L) exhibited the highest effect (5.1 nymphs/leaf) on the nymph population being similar to neem extract (60 mL/L) with 5.9 nymphs/leaf, as they differed significantly ($P<0.0001$) from the

remaining treatments on day 1 after the 1st spray. Cow urine (75 mL/L) had the least nymph number (2.4 nymphs/leaf) followed by neem extract (60 mL/L) being similar also to malathion EC 50% (6 mL/L) (2.2 nymphs/leaf) 15 days after the 2nd spray. The highest number (17.7 nymphs/leaf) was found with cow dung (50 mL/L) day 1 after the 2nd spray during the 2023 experiment(**Table 4.34**).

The results had similar trends after the 3rd spray as the treatments reduced the nymphs' density further. Neem extract (60 mL/L) was most effective (1.3 nymphs/leaf) as it differed significantly ($P<0.0001$) from all the treatments, while cow dung (50 mL/L) was least effective with 7.0 nymphs/leaf on day 1 after the 3rd spray in 2022 experiment. Cow urine (50 mL/L) had the least nymph number (0.4 nymphs/leaf) on day 3 after the 1st spray with butter milk (50 mL/L) having the highest (5.2 nymphs/leaf) being least effective. At 15th day after the 3rd spray, neem extract was most effective (1.3 nymphs/leaf) as it differed significantly ($P<0.0001$) from all the treatments with butter milk (50 mL/L) being the least (5.8 nymphs/leaf) in 2022 experiment. Neem leaf extract and cow urine remained most effective ($P<0.0001$) with 2.0 and 2.1 nymphs/leaf while chili pod extract (20 mL/L) was least effective with 8.0 nymphs/leaf on 1st day after the 3rd spray in 2023 experiment. Similar results were recorded in the remaining periods with cow urine and neem extract being more potent with 1.0 and 1.3 nymphs/leaf very close to malathion EC 50% with 0.7 nymphs/leaf 15 days after the 3rd spray during the 2023 experiment. Cow dung and butter milk remained the least effective with 8.5 and 8.8 nymphs/leaf on the 15th day during the same trial period (**Table 4.35**).

Table 4.33: Average nymph whitefly population on the eggplant leaves before and after the 1st foliar spray of traditional treatments during the 2022 and 2023 cropping seasons

Treatments	Average nymph/leaf							Average nymph /leaf						
	2022							2023						
	Pre-treatments	1DAS	2DAS	3DAS	5DAS	7DAS	15DAS	Pre-treatments	1DAS	2DAS	3DAS	5DAS	7DAS	15DAS
T1	29.4 ^a	21.6 ^{cde}	20.4 ^{abc}	18.7 ^{bcd}	16.8 ^{bcd}	15.1 ^{bc}	17.3 ^{cd}	32.8 ^a	23.7 ^a	21.2 ^{abc}	19.3 ^{bcd}	18.5 ^{ab} _c	17.3 ^{bcd}	17.6 ^{abc}
T2	31.8 ^a	21.2 ^{def}	19.5 ^{bc}	17.0 ^{cde}	13.9 ^{cde}	13.0 ^{cde}	12.3 ^{ef}	29.3 ^a	21.0 ^a	18.6 ^{bcd}	16.4 ^{cde}	14.3 ^{bc} _d	17.5 ^{bcd}	18.6 ^{abc}
T3	28.5 ^a	21.2 ^{def}	18.3 ^{bc}	15.1 ^{def}	13.1 ^{def}	12.2 ^{cde}	10.3 ^{fg}	30.9 ^a	16.3 ^a	17.0 ^{bcd}	14.6 ^{cde}	11.8 ^{cd} _e	8.3 ^{ef}	7.2 ^f
T4	31.5 ^a	24.2 ^{bcd}	21.8 ^{ab}	20.3 ^{bc}	21.7 ^{ab}	19.3 ^{ab}	21.7 ^b	28.9 ^a	24.3 ^a	22.8 ^{ab}	24.1 ^{ab}	21.2 ^{ab}	18.6 ^b	20.4 ^{ab}
T5	27.6 ^a	23.5 ^{bcd}	20.7 ^{abc}	18.3 ^{bcd}	17.9 ^{bcd}	15.8 ^{bc}	16.5 ^{de}	29.9 ^a	20.5 ^a	20.8 ^{abc}	19.4 ^{bcd}	17.9 ^{ab} _c	16.5 ^{bcd}	16.5 ^{bbc}
T6	29.2 ^a	25.7 ^{abc}	21.7 ^{ab}	17.3 ^{cde}	15.2 ^{cde}	13.2 ^{cde}	12.0 ^{ef}	32.9 ^a	23.6 ^a	19.8 ^{abc}	17.3 ^{cde}	15.1 ^{bc} _d	12.7 ^{cde}	12.0 ^{cde}
T7	27.7 ^a	22.3 ^{bcd}	21.9 ^{ab}	22.6 ^{ab}	18.9 ^{bc}	16.0 ^{bc}	20.8 ^{bc}	31.2 ^a	23.7 ^a	21.3 ^{abc}	20.8 ^{abc}	18.9 ^{ab} _c	18.2 ^{bc}	15.9 ^{bbc}
T8	30.4 ^a	22.8 ^{bcd}	21.2 ^{abc}	20.5 ^{bc}	17.8 ^{bcd}	14.5 ^{cd}	14.5 ^{def}	30.7 ^a	21.4 ^a	20.0 ^{abc}	18.8 ^{bcd}	16.0 ^{bc} _d	15.1 ^{bcd}	13.0 ^{cde}
T9	29.2 ^a	20.2 ^{def}	17.7 ^{bc}	16.9 ^{cde}	18.2 ^{bcd}	14.6 ^{cd}	12.3 ^{ef}	29.6 ^a	19.5 ^a	18.3 ^{bcd}	16.4 ^{cde}	16.5 ^{bc} _d	14.3 ^{bcd}	12.3 ^{cde}
T10	31.1 ^a	21.2 ^{def}	18.6 ^{bc}	15.3 ^{def}	14.0 ^{cde}	12.9 ^{cde}	14.4 ^{def}	28.4 ^a	23.3 ^a	20.8 ^{abc}	21.6 ^{abc}	19.0 ^{ab} _c	16.6 ^{bcd}	15.1 ^{bcd}

T11	28.5 ^a	20.8 ^{def}	18.2 ^{bc}	13.7 ^{ef}	10.7 ^{fg}	9.3 ^{efg}	10.3 ^{fg}	30.0 ^a	19.2 ^a	17.7 ^{bcd}	15.6 ^{cde}	12.9 ^{bc} _d	10.7 ^{def}	9.0 ^{ef}
T12	29.9 ^a	19.3 ^f	16.8 ^c	12.3 ^f	12.3 ^{efg}	8.0 ^{fgh}	6.3 ^{gh}	32.7 ^a	16.6 ^a	13.4 ^d	12.0 ^f	9.6 ^{de}	8.9 ^{ef}	5.2 ^f
T13	28.2 ^a	22.6 ^{bcd}	18.1 ^{bc}	15.9 ^{cde}	13.0 ^{def}	10.4 ^{def}	10.5 ^{fg}	30.5 ^a	20.1 ^a	17.6 ^{bcd}	18.1 ^{bcd}	17.4 ^{bc} _d	17.9 ^{bc}	14.9 ^{bcd}
T14	31.0 ^a	22.5 ^{bcd}	17.8 ^{bc}	14.5 ^{def}	10.4 ^{fg}	7.6 ^{gh}	5.9 ^h	28.9 ^a	19.9 ^a	16.2 ^{bcd}	13.8 ^{ef}	11.6 ^{cd} _e	11.6 ^{cde}	11.5 ^{def}
T15	30.5 ^a	19.5 ^{ef}	16.4 ^c	13.5 ^{ef}	9.1 ^g	5.6 ^h	4.5 ^h	33.4 ^a	17.3 ^a	15.2 ^{bcd}	12.1 ^f	9.7 ^{de}	8.8 ^{def}	4.9 ^f
T16	33.7 ^a	25.2 ^{abc}	21.9 ^{ab}	17.1 ^{cde}	17.4 ^{bcd}	13.3 ^{def}	14.4 ^{def}	29.7 ^a	16.3 ^a	14.7 ^{cd}	15.0 ^{cde}	9.0 ^{de}	7.9 ^f	6.7 ^{ef}
T17	30.4 ^a	28.1 ^a	24.9 ^a	26.2 ^a	25.1 ^a	18.4 ^a	26.4 ^a	30.3 ^a	25.3 ^a	24.8 ^a	25.9 ^a	25.8 ^a	26.8 ^a	22.4 ^a
C.D.	0.0	3.1	3.6	3.9	4.2	4.0	2.9	0.0	0.0	6.0	5.1	6.3	5.8	5.6
SEM±	2.6	1.1	1.2	1.3	1.5	1.4	2.0	1.9	2.9	2.1	1.8	2.2	2.0	2.0
C.V. (%)	10.5	9.1	12.3	14.8	17.8	18.2	17.7	7.4	23.9	21.0	19.7	28.0	24.6	26.5
P-value (5%)	0.661	0.001	0.008	<0.001	<0.001	<0.001	<0.001	0.213	0.474	0.082	0.001	0.002	<0.001	<0.001

Means with the same common letter in the same column are not significantly different from each other ($P \leq 0.05$). DAS = Days after the spray, C.V. =Coefficient of variance, C.D. = Critical difference, SEM = Standard error mean, T=Treatment (See table 3.2)

Table 4.34: Average nymph whitefly population on the eggplant leaves after the 2nd foliar spray of traditional treatments during the 2022 and 2023 cropping seasons

Treatments	Average nymph/leaf						Average nymph/leaf					
	2022						2023					
	1DAS	2DAS	3DAS	5DAS	7DAS	15DAS	1DAS	2DAS	3DAS	5DAS	7DAS	15DAS
T1	13.5 ^{bc}	10.8 ^{bc}	8.7 ^{cd}	5.5 ^{cde}	7.4 ^{bc}	6.2 ^d	15.3 ^{bc}	13.7 ^{bc}	12.2 ^b	10.1 ^b	9.4 ^{bc}	10.1 ^{bc}
T2	12.4 ^{bcd}	8.9 ^{cde}	6.6 ^{de}	5.2 ^{cde}	2.4 ^{def}	3.2 ^{def}	15.4 ^{bc}	12.9 ^{bc}	10.9 ^{bc}	9.4 ^b	7.2 ^{cde}	7.5 ^{bcd}
T3	8.7 ^{efg}	5.8 ^{efg}	5.3 ^{def}	3.0 ^{efg}	1.8 ^{cde}	2.3 ^{efg}	5.5 ^{ef}	5.5 ^{fgh}	4.2 ^{efg}	3.8 ^{def}	2.8 ^{ef}	3.7 ^{def}
T4	15.7 ^b	13.2 ^b	12.6 ^b	11.2 ^b	18.1 ^a	15.9 ^b	17.7 ^{ab}	14.7 ^b	12.2 ^b	10.0 ^b	11.7 ^b	11.0 ^b
T5	13.0 ^{bc}	11.6 ^{bc}	8.3 ^{cd}	6.1 ^{cde}	6.0 ^{bcd}	5.3 ^{def}	13.8 ^{bcd}	12.2 ^{bcd}	9.7 ^{bcd}	7.0 ^{bcd}	6.1 ^{cde}	7.0 ^{bcd}
T6	9.0 ^{def}	6.3 ^{efg}	6.2 ^{de}	5.5 ^{cde}	5.3 ^{bcd}	3.6 ^{def}	9.9 ^{cde}	8.8 ^{cde}	7.6 ^{cde}	6.6 ^{bcd}	4.4 ^{efd}	4.1 ^{def}
T7	15.8 ^b	13.1 ^b	11.5 ^{bc}	8.7 ^{bc}	9.6 ^b	10.0 ^c	13.3 ^{bcd}	11.5 ^{bcd}	11.2 ^{bc}	8.9 ^{bc}	7.2 ^{cde}	7.6 ^{bcd}
T8	12.8 ^{bc}	9.9 ^{cd}	8.4 ^{cd}	7.3 ^{cd}	7.0 ^{bcd}	4.5 ^{def}	11.4 ^{cde}	10.7 ^{bcd}	8.6 ^{bcd}	7.2 ^{bcd}	8.5 ^{bcd}	7.6 ^{bcd}
T9	10.4 ^{cde}	6.1 ^{efg}	5.4 ^{def}	4.1 ^{def}	4.4 ^{cde}	2.0 ^{efg}	10.3 ^{cde}	9.6 ^{cde}	7.8 ^{bcd}	6.1 ^{bcd}	4.6 ^{def}	4.5 ^{def}
T10	10.4 ^{cde}	7.3 ^{def}	5.3 ^{def}	3.2 ^{efg}	3.7 ^{cde}	5.4 ^{de}	12.9 ^{bcd}	10.5 ^{bcd}	8.0 ^{bcd}	10.7 ^b	8.1 ^{bcd}	6.9 ^{bcd}
T11	7.6 ^{fgh}	4.9 ^{fgh}	3.3 ^{ef}	2.7 ^{efg}	1.3 ^{ef}	1.9 ^{fg}	7.6 ^{efd}	6.8 ^{def}	5.7 ^{def}	4.4 ^{cde}	3.4 ^{ef}	4.2 ^{def}
T12	5.4 ^{ghi}	3.5 ^{ghi}	3.2 ^{ef}	1.3 ^g	0.8 ^f	1.4 ^g	5.6 ^{ef}	4.6 ^{gh}	3.9 ^{fgh}	3.4 ^{def}	2.9 ^{ef}	2.4 ^{fg}
T13	6.7 ^{fgh}	3.3 ^{hi}	2.7 ^{ef}	1.4 ^g	4.6 ^{cde}	3.0 ^{efg}	11.7 ^{bcd}	8.8 ^{cde}	7.1 ^{cde}	7.2 ^{bcd}	5.7 ^{cde}	6.0 ^{cde}
T14	4.8 ^{hi}	2.5 ⁱ	1.8 ^f	1.6 ^{fg}	3.3 ^{cde}	1.9 ^{fg}	9.3 ^{cde}	6.4 ^{efg}	4.7 ^{efg}	3.3 ^{def}	2.6 ^{ef}	2.8 ^{def}
T15	3.3 ⁱ	2.2 ⁱ	1.3 ^f	1.2 ^g	2.2 ^{ef}	1.4 ^g	5.9 ^{ef}	4.2 ^{gh}	2.8 ^{gh}	2.1 ^f	2.0 ^f	2.7 ^{efg}

T16	11.5 ^{cde}	6.7 ^{efg}	4.8 ^{def}	4.2 ^{def}	3.6 ^{cde}	4.8 ^{def}	5.1 ^f	3.3 ^h	2.5 ^h	2.2 ^{ef}	1.7 ^f	2.2 ^{dg}
T17	24.2 ^a	22.4 ^a	23.8 ^a	21.3 ^a	21.5 ^a	26.6 ^a	21.7 ^a	22.4 ^a	24.2 ^a	23.8 ^a	23.0 ^a	23.4 ^a
C.D.	2.9	2.9	3.4	3.1	4.3	3.0	5.3	4.2	4.7	3.3	3.0	3.0
SEM _±	0.9	1.0	1.2	1.1	1.5	1.0	1.8	1.5	1.6	1.2	1.1	1.0
C.V. (%)	18.1	21.6	30.3	34.6	40.2	30.4	29.3	29.5	27.7	33.9	36.8	37.0
P-value (5%)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Means with the same common letter in the same column are not significantly different from each other ($P \leq 0.05$). DAS = Days after the spray, C.V. = Coefficient of variance, C.D. = Critical difference, SEM = Standard error mean, T=Treatment (See table 3.2)

Table 4.35: Average nymph whitefly population on the eggplant leaves after the 3rd foliar spray of traditional treatments during the 2022 and 2023 cropping seasons

Treatments	Average nymph/leaf						Average nymph /leaf					
	2022						2023					
	1DAS	2DAS	3DAS	5DAS	7DAS	15DAS	1DAS	2DAS	3DAS	5DAS	7DAS	15DAS
T1	4.4 ^{bcd}	3.8 ^{cd}	2.6 ^{cd}	3.4 ^{cde}	4.0 ^{cd}	4.5 ^{bcd}	8.0 ^{bc}	6.5 ^{bc}	4.6 ^{bc}	6.8 ^{bcd}	8.9 ^b	7.4 ^{bc}
T2	3.7 ^{cde}	2.8 ^{cde}	1.4 ^{cd}	0.9 ^{ef}	2.6 ^{de}	1.7 ^d	5.6 ^{cde}	4.4 ^{bcd}	3.5 ^{bc}	3.5 ^{def}	4.3 ^{def}	5.3 ^{bcd}
T3	5.3 ^{bc}	2.1 ^{def}	2.2 ^{cd}	0.8 ^{ef}	1.7 ^{de}	1.4 ^d	2.7 ^{efg}	2.1 ^e	1.6 ^{bc}	1.5 ^{efg}	2.5 ^{efg}	1.9 ^{de}
T4	7.0 ^b	7.5 ^b	5.5 ^b	7.3 ^b	6.9 ^b	6.9 ^{bc}	9.3 ^b	7.4 ^b	6.7 ^b	7.6 ^b	8.3 ^{bc}	8.5 ^b
T5	5.4 ^{bc}	2.9 ^{cde}	2.3 ^{cd}	2.2 ^{def}	3.5 ^{cde}	3.5 ^{bcd}	5.6 ^{cde}	4.1 ^{bcd}	3.5 ^{bc}	4.9 ^{bcd}	6.6 ^{bcd}	7.1 ^{bc}
T6	3.3 ^{cde}	2.9 ^{cde}	1.9 ^{cd}	1.2 ^{ef}	2.4 ^{de}	2.1 ^d	4.3 ^{def}	3.1 ^{cde}	3.2 ^{bc}	2.7 ^{efg}	3.0 ^{efg}	2.7 ^{de}
T7	5.0 ^{bc}	4.0 ^c	5.2 ^b	5.6 ^{bc}	5.8 ^{bc}	7.1 ^b	6.5 ^{bcd}	6.9 ^b	5.7 ^{bc}	7.0 ^{bc}	6.7 ^{bcd}	8.8 ^b
T8	3.8 ^{cde}	3.1 ^{cde}	3.3 ^{bc}	4.0 ^{cd}	2.9 ^{de}	2.2 ^d	6.2 ^{cd}	4.6 ^{bcd}	3.7 ^{bc}	3.6 ^{def}	5.5 ^{cde}	7.2 ^{bc}
T9	1.8 ^{de}	1.0 ^f	1.8 ^{cd}	1.3 ^{ef}	1.5 ^{de}	1.4 ^d	4.4 ^{def}	3.0 ^{cde}	3.0 ^{bc}	2.1 ^{efg}	3.6 ^{def}	2.9 ^{de}
T10	3.8 ^{cde}	2.9 ^{cde}	1.8 ^{cd}	1.9 ^{def}	3.6 ^{cde}	2.6 ^d	5.7 ^{cde}	6.1 ^{bcd}	6.8 ^b	4.1 ^{cde}	4.4 ^{def}	3.9 ^{cde}
T11	1.6 ^{de}	0.9 ^{df}	0.4 ^d	2.4 ^{def}	2.2 ^{de}	3.5 ^{bcd}	3.5 ^{def}	2.6 ^{de}	4.1 ^{bc}	2.9 ^{efg}	3.1 ^{efg}	2.7 ^{de}
T12	2.5 ^{cde}	1.1 ^{ef}	1.4 ^{cd}	1.4 ^{def}	1.7 ^{de}	1.4 ^d	2.1 ^{fg}	1.4 ^e	1.1 ^c	0.9 ^g	0.9 ^h	1.0 ^e
T13	2.4 ^{cde}	2.1 ^{cde}	3.3 ^{bc}	3.2 ^{cde}	2.8 ^{de}	3.3 ^{bcd}	4.9 ^{cde}	5.8 ^{bcd}	5.5 ^{bc}	4.5 ^{bcd}	4.8 ^{de}	4.5 ^{cde}
T14	1.6 ^{de}	1.2 ^{ef}	1.4 ^{cd}	2.2 ^{def}	1.4 ^e	1.5 ^d	2.0 ^{fg}	1.7 ^e	1.9 ^{bc}	1.4 ^{efg}	1.2 ^{fgh}	2.8 ^{de}
T15	1.3 ^e	1.9 ^{def}	1.0 ^{cd}	1.5 ^{def}	1.3 ^e	1.3 ^d	2.1 ^{fg}	1.5 ^e	1.2 ^c	0.9 ^g	1.2 ^{fgh}	1.3 ^e
T16	5.4 ^{bc}	2.9 ^{cde}	2.4 ^c	2.8 ^{def}	2.5 ^{de}	2.9 ^{cd}	1.4 ^g	1.3 ^e	0.7 ^c	0.6 ^g	1.0 ^{gh}	0.7 ^e

T17	25.3 ^a	19.0 ^a	20.1 ^a	19.4 ^a	19.9 ^a	23.3 ^a	22.1 ^a	21.0 ^a	23.6 ^a	22.0 ^a	21.3 ^a	23.7 ^a
C.D.	2.4	1.7	2.3	6.2	5.5	4.8	2.1	2.6	3.9	2.9	2.8	2.9
SEM \pm	0.8	0.6	0.8	2.1	1.9	1.7	0.7	0.9	1.4	1.0	1.0	1.0
C.V. (%)	31.9	29.2	41.7	38.3	33.1	51.3	30.5	37.6	36.2	40.4	33.9	37.0
P-value (5%)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Means with the same common letter in the same column are not significantly different from each other ($P \leq 0.05$). DAS = Days after the spray, C.V.=Coefficient of variance, C.D. = Critical difference, SEM = Standard error mean, T=Treatment (See table 3.2)

4.7. The traditional treatments and reduction in whitefly population

4.7.1. Percentage reduction in adult population

The result on the potential of traditional treatments in reducing the whitefly number per leaf of eggplant after the foliar sprays are presented in figures 4.12-4.14. The result showed that neem leaf extract (60 mL/L) was most effective with 58.1 and 58.2% reduction, followed by cow urine (75 mL/L) with 56.7 and 50.5% respectively as they differed significantly ($P < 0.0001$) from the remaining treatments, 15 days after the 1st spray during the 2022 and 2023 experiments. Cow dung was found least effect (7.7 and 19.6%) 15 days after the 1st spray, during the respective cropping seasons (**Fig 4.9**). The treatments also differed significantly ($P < 0.0001$) in both the years (2022 and 2023), with neem leaf extract (60 mL/L) being highly effective causing 91.1 and 90.7% reduction in adult population. It was similar to cow urine (75 mL/L) with 90.9 and 84.6% while cow dung (50 mL/L) remained least with 57.5 and 50.5% reduction, 30 days after the 2nd spray in 2022 and 2023 experiments (**Fig 4.10**). The treatments reduced adult population further after the 3rd spray with neem leaf extract also being most effective (95.7 and 96.1%) with butter milk and cow dung being the least (62.3 and 65.9%), 45 days after the 3rd spray during the 2022 and 2023 experiments (**Fig 4.11**).

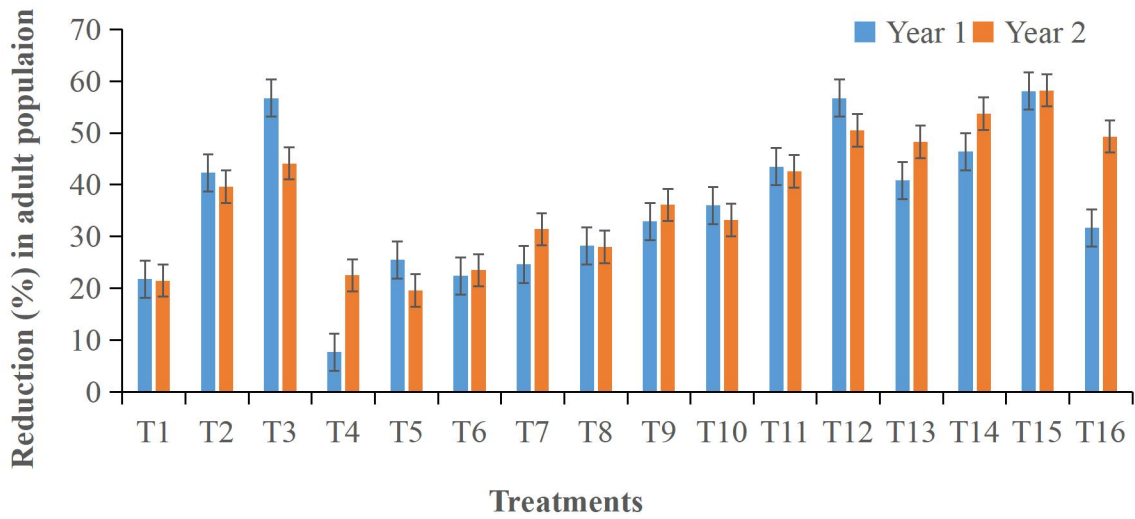


Fig 4.9: Reduction (%) in adult whitefly population 15 days after the 1st spray of traditional treatments in 2022 and 2023 experiments. T=Treatment (see table 3.2)

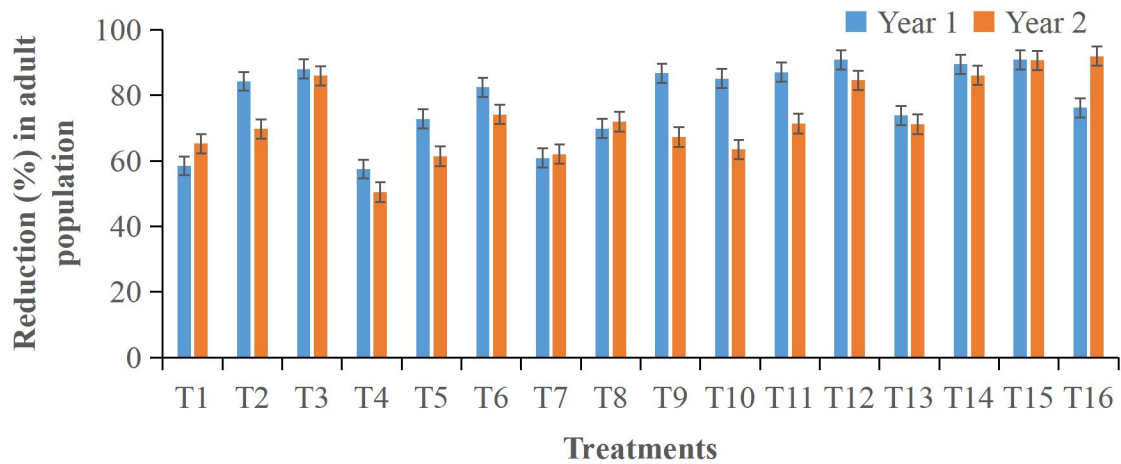


Fig 4.10: Reduction (%) in adult whitefly population 30 days after the 2nd spray of traditional treatments in 2022 and 2023 experiments. T=Treatment (See table 3.2)

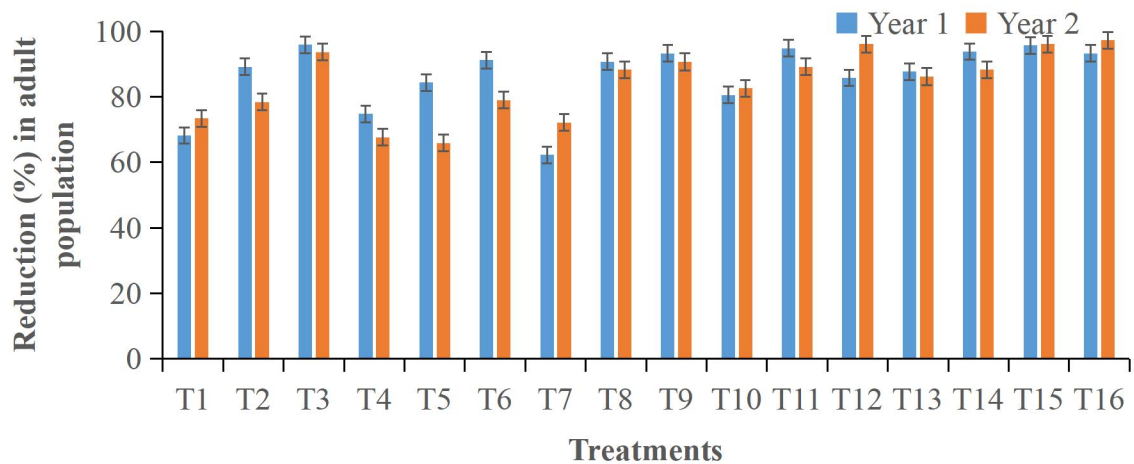


Fig 4.11: Reduction (%) in adult whitefly population 45 days after the 3rd spray of traditional treatments in 2022 and 2023 experiments. T=Treatment (See table 3.2)

4.7.2. Percentage reduction in nymphs' population

The results on nymphs' population reduction (%) during the respective cropping seasons (2022 and 2023) are presented in figures 4.15-4.17. Neem leaf extract was found most effective with 83.0 and 78.1% reduction being close to cow urine (75 mL/L) with 76.1 and 77.0% reduction while cow dung was least effective with 17.8 and 8.9% reduction 15 days after the 1st spray during the 2022 and 2023 experiments (**Fig 4.12**). Similar results were recorded at 30 days after the 2nd spray with neem leaf extract causing highest reduction (94.7 and 88.5%) after the cow urine (75mL/L) with 94.7 and 89.7% while cow dung was least effective (40.2 and 53.0%) in the respective years (**Fig 4.13**). Chili pod extract (60 mL/L) had similar effect with neem leaf extract (60 mL/L) recording 93.1%, very close to 93.6% reduction recorded with neem extract and cow urine, with cow dung being least effective (65.8%), 45 days after the 3rd spray in 2022 experiment. The result was similar in 2023 recording cow urine (75 mL/L) as most effective causing up to 95.8% reduction with cow dung being least effective with 64.1% reduction, 45 days after the 3rd spray (**Fig 4.14**).

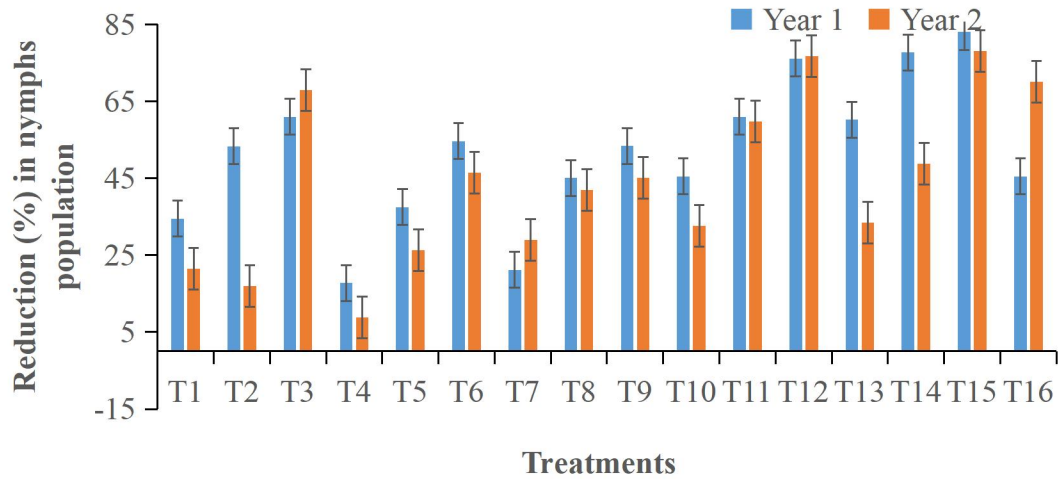


Fig4.12: Reduction (%) in nymph whitefly population 15 days after the 1st spray of traditional treatments in 2022 and 2023 experiments. T=Treatment (See table 3.2)

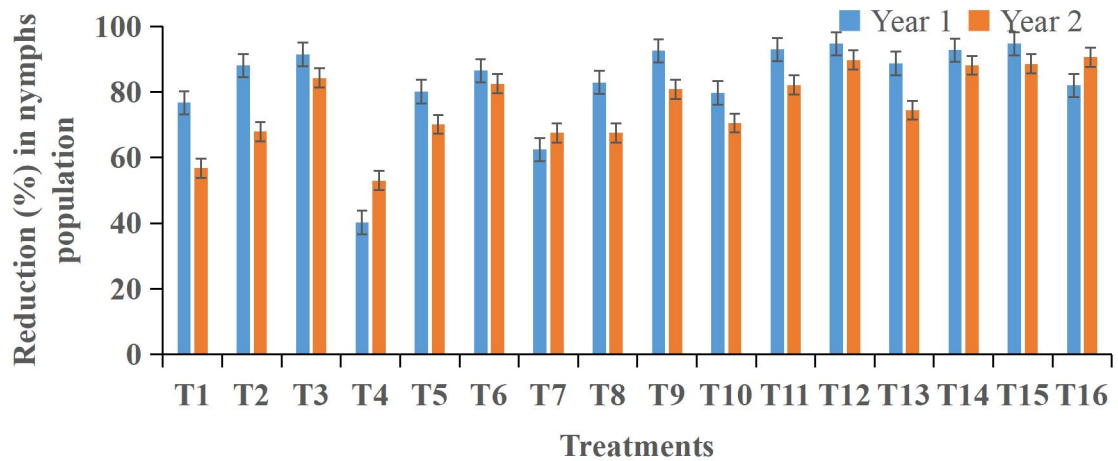


Fig 4.13: Reduction (%) in nymph whitefly population 30 days after the 2nd spray of traditional treatments in 2022 and 2023 experiments. T=Treatment (See table 3.2)

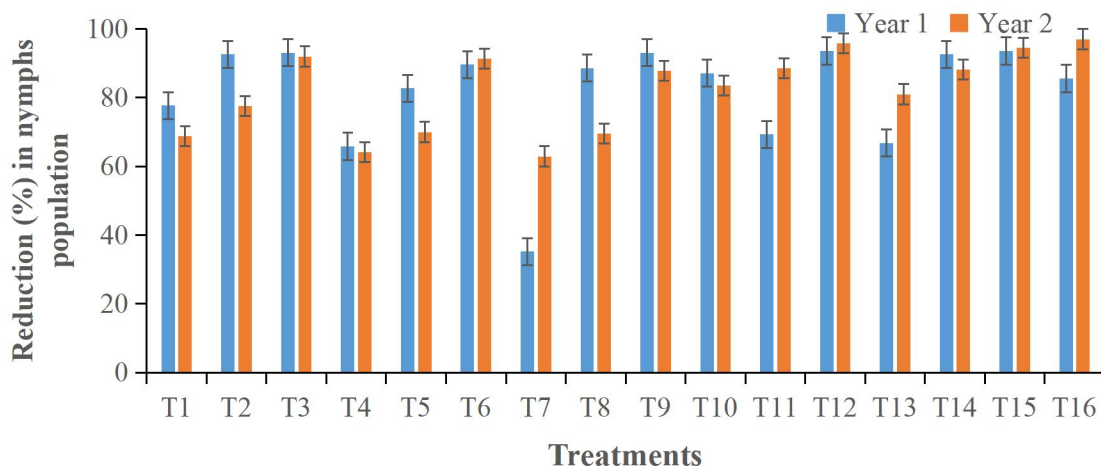


Fig 4.14: Reduction (%) in the nymph whitefly population 45 days after the 3rd spray of traditional treatments in 2022 and 2023 experiments. T=Treatment (See table 3.2)

Discussion

The current study assessed the efficacy of traditional methods for the management of whitefly, a notorious sap-sucking insect pest ravaging various agricultural crops, using eggplant as an experimental species. The treatments deployed include chili pods, cow dung, cow urine, butter milk, neem leaf extract and a synthetic insecticide.

From the result obtained, neem leaf extract (60 mL/L) has the greatest effect against the whitefly among all the biopesticides evaluated causing up to 96.1% reduction 45 days after the 3rd spray. Previous study (Dhingra et al. 2008) have demonstrated the effectiveness of neem extracts in insect control and reported up to 94.1% reduction in whitefly population at 0.05g L⁻¹ 7 days after the treatment. This is was higher than the effect recorded in the current study (58.1%) 15 days after the 1st spray but lower than that was recorded (96.1%) 45 days after the 3rd spray. The higher effect at 7 days may be due to the application of the main bio-active compound (azadirachtin) which is known to be more effective than the whole extracts while the repeated sprays might have caused more reduction observed at 45 days. The results reported by (Lynn et al. 2010) using neem-

based products was in consonance with the current report, causing reduction in adult colonization, egg hatching and oviposition by 78.2, 71.2 and 47.0% respectively. The work of (Castillo-Sánchez et al. 2015) in which a hexanic neem-based product extracted from neem seeds (NEEM-1 and NEEM-2) caused up to 100% whitefly mortality at 10% concentration 5 hours after the treatment contradicts the present study with 58.1% reduction 15 days after the treatments. The variation may be due to differences concentration of the bio-active compounds, experimental setting and the crop involved. The work of (Ali et al. 2017) also revealed that neem extract is effective in the control of whiteflies reporting up to 82.60% percentage reduction in whitefly population in brinjal at 50% w/v two weeks after application. This is higher than our finding with 58.1% reduction at 10% w/v, two weeks after the 1st spray and the higher effect could be due to the higher concentration applied used in their studies. Neem seeds (10% w/v) have been reported to caused 79% reduction in whitefly population, lower than the chemical pesticides, Flanicamid with 92% reduction in round chili crop (Hussain et al 2022), similar to the present study with malathion being more effective than the neem leaf extract. In another study, up to 80% reduction in whiteflies was reported using neem leaf extract at (5% w/v) in cotton (Akhtar and Hafeez-Ur-Rehman 2023). This is lower than 96.1% recorded in this study, which is probably due to variation in the concentration used. Similarly, leaf and seed extracts led to 1.35 and 1.10 whiteflies/leaf 10 weeks after sowing (Okolo and Iledun, 2019) as compared to the control (3.56 whiteflies/leaf) in in cowpea plant. The combined effect of neem neemactin 0.15 EC and floral extracts of spilanthes (at 1.5 and 40 ml/l) has led to 62.39% suppression in whitefly number, lower than the results in the current finding which might be due to higher dosage (60ml/l) and spray periods (45 days) in the current study. Neem leaf extract in cow urine was also shown to be effective in reducing the density of not only whiteflies (95.2%), but also leafhoppers (94.6%), and blister beetle (94.6%) in okra plant (Singh et al. 2021), similar to the effect recorded against the whiteflies in the present study. The effectiveness of the botanical extracts in comparison with the control complies with the findings of Saxena (1981), Jackai (1993), and Agona, et al. (2000) who reported that neem products showed

efficacy against different insect pests including pod borer (*Maruca vitrata*), pod sucking bug complex (*Clavigralla tomentosicollis*) and other insect pests. They also agree with reports by Gaby (2000), Okolo Iledun (2019) and (Hameed et al. 2023) that plant extracts from neem were known to possess toxic organic components that were effective in reducing the density of diverse insect pests of agricultural importance in different crop plants. The efficacy of neem extract as an insecticide is due to its diverse compound composition, with azadirachtin serving as the primary active element. These compounds, including methyl isoheptadecanoate, butyl palmitate, eicosane, 7-hexyl, oxalic acid, 2-ethylhexyltetradecylest, nonadecane, 2-Methyl-5-ethylfuran, heptacosane, and octacosane, collectively disrupt insect feeding and growth, interfering with molting, pupation, and reproduction, ultimately reducing pest populations. The bitter taste and odor of neem deter pests from feeding, and it also affects insect larvae, impeding their development and lowering their reproductive capacity, resulting in reduced egg-laying and subsequent pest population reduction (Hossain et al. 2013).

The second most effective treatment was cow urine and its potential in insect control has been reported by previous researchers. Mandal et al (2018) in their studies on the use of traditional methods in the control of sap-sucking insects on brinjal, reported that cow urine at a ratio of 1:10 urine-water caused reduction in whitefly population by 3.92 adult/leaf (31.0%) and 3.47/leaf (38.5%) in the two consecutive trial seasons. This is less than our result (91.1 and 94.0%) reduction at 50% (75 mL/L) 15 days after the 3rd spray. The higher effect may be due to variation in the concentration, duration of data record periods and the number of sprays. Cow urine was also reported to be used for various agricultural practices as it is used as pesticides against sap-sucking insects like whiteflies and aphids (Mandavgane and Kulkarni, 2020). In their studies, (Patel et al. 2019) reported that cow urine applied at 20% fortified with neem leaf extract has led to reduction of whiteflies to 2.22 flies/leaf with highest yield (287.89q/ha). The result is higher than the present finding (6.30 whiteflies/leaf) at 50% and this may be due to fortification of the urine with neem extract. However, the result of (Patel et al. 2017) proved less effective using similar concentration with up to 13.26 whiteflies/leaf. This

may be due to variation in the crop deployed and climatic conditions of the experimental sites. Moreover, the use of cow urine at 10%w/v along with plant extracts has led to higher efficacy of 95.2% percentage reduction (Singh et al. 2021). The higher potential could be related to the deployment of the treatments in an integrated setting along with plant extracts. The application 10% cow urine along with neem and *Jatropha curcas* extracts has led to 82 to 98% mortality of sucking pests on a 50-day old potato crop two weeks after the spray (Kumari and Chandla, 2010). This is higher than the current finding with 32.9 to 56.7% reduction, two weeks after the spray but similar to the result obtained 45 days after the 3rd spray (94.8 to 96.1%). The variation might be attributed to incorporation of plant extract in cow urine while the higher effect at 45 days indicates the effect of repeated long-term sprays. This is so as various combinations of cow urine, plant parts, and neem-based commercial products have been shown to have a substantial synergistic effect, enhancing product toxicity and leading to increased pest mortality (Gahukar, 2013; Pradhan et al. 2018). Similar report has also demonstrated that cow urine in garlic paste caused 75.96% 10 days after the spray (Guleria, 2013). Several other reports described the effectiveness of cow urine in insect pests' management in different crop plants (Ahirwar et al. 2010; Geetanjal and Tiwari, 2014; Shome and Mal, 2019; Singh et al. 2022). Beside crop protection against insect pests, Cow urine (50%) was also shown to increase chlorophyll and protein content in Bhindi crop as it enhances the NPK uptake through foliar spray and thus the crop yield (Pradhan et al. 2017, 2018). This complied with the current reports demonstrating the highest yield recorded in cow urine treated plots. The effectiveness of cow urine in whitefly control can be attributed to multiple factors. These include the presence of ammonia, which serves as an insect repellent and disrupts insect behavior. Additionally, the nitrogen compounds in cow urine deter insects, and its alkaline nature with a high pH is detrimental to certain pests and their larvae. The smell and taste of cow urine act as a natural repellent, discouraging insects from landing on or feeding on plants. These properties collectively make cow urine an effective and natural method for whitefly control (Devasena and Sangeetha 2017; Miah et al. 2018).

Chili pod extract was similarly effective against the whitefly causing 68.2 to 95.9% reduction in whitefly density 45 days after the 3rd spray. Previous studies have demonstrated that whitefly population have been reduced to 1.0 adult/leaf, 63 days after the sprays (Asare-Bediako et 2014). This complied with the current finding reporting an average adult population (1.10 and 2.1 adult/leaf) 45 days after repeated sprays, indicating the effect of bio-active compounds like capsaicin and its pungent odor which were known to serve as barrier that makes it difficult for whiteflies to settle and feed on the plant (Wesołowska et al. 2011; Zhang et al. 2021). This is similar to report by (Fening et al. 2014) in which pepper extract was shown to be effective in controlling insect pests of cabbage and French beans while conserving the natural enemies. Legaspi and Simmons (2012) have evaluated the anti-oviposition effects of hot pepper wax and their results showed that it was substantial in reducing the whitefly number (32.9/leaf) as compared to the control (42.9/leaf) 2 days after application. This also similar to our results with 30.2 adults/leaf compared to the control (51.5 adults/leaf) two days after the spray. Sumaili et al. (2021) reported 73.3% (chili extract only) and 77.6% (chili extract+ *Erectomocerus eremicus*) reduction in whitefly population on tomato crop 28 days after the spray. This is lower than our result (86.0 to 88.1% reduction), probably due variation in dosage, crop involved and environmental conditions of the experimental sites. They showed that the use of chili extracts and *E. eremicus* being effective against the whitefly infestations has improved the growth and yield of greenhouse tomato plants similar to the yield effect in this study. This is in compliance with the work of Singh et al. (2021), in which the use of plant extracts involving chili caused more 95% reduction in whitefly density with higher yield in okra plant. Rosulu et al. (2022) demonstrated that chili extracts at 200 and 250 l/ha significantly reduced the population of insect pests, other than whiteflies including thrips, legume pod borer in various life stages, and pod-sucking bug adults. The treatment also resulted in decreased pod damage and increased grain yields when compared to an untreated control group. However, 250 L ha⁻¹ extract caused higher levels of phytotoxicity damage compared to a 200 L ha⁻¹ extract. They suggested that chili pepper extracts can be effective in managing cowpea insect pests and improving

crop yield. The effectiveness of chili pod extract as an insecticide is attributed to its diverse compound composition, including capsaicin, pentadecanoic acid, dihydrocapsaicin, homodihydrocapsaicin, homodihydrocapsaicin II, β -amyrin α -amyrin and quercetin. They disrupt insects' nervous systems, potentially leading to paralysis or death. The extract's pungent odor and taste act as a natural repellent, deterring insect feeding. When sprayed on plant leaves, it creates a physical barrier that hinders insect settlement, feeding, and egg-laying, reducing infestations (Wesołowska et al. 2011 Zhang et al. 2021).

Butter milk was found more effective against the whitefly than the untreated control plots in the present study causing high reduction 45 days after repeated sprays. Previous study (Elango et al. 2020) reported up to 60% whitefly reduction in Bhindi crop in India. This is higher than the result in our study (32.87%) 15 days after the 1st spray but lower than the value recorded 45 days after the 3rd spray (90.7 and 93.3%) in the two respective seasons. This indicates the efficacy of repeated application over time. Tagger and Singh (2020) evaluated the effect of different insecticides against the whitefly in black gram with thiamethoxam at 100 g ha⁻¹ being most effective, resulting in a 71.17% reduction in the whitefly population while non-conventional treatments, such as buttermilk, lisapol detergent, and detergent soap, showed lower reductions (26.50–27.35%) in whitefly populations. They concluded these non-conventional treatments, while not as potent as Actara, still contributed to satisfactory grain yields. Kumari et al (2022) also examined the effect of organic pesticides with fermented butter milk at 40% v/v, causing 61.11% whitefly mortality 3 days after the spray. This is higher than our result (36.1%) 15 days after the 1st spray at 50% v/v and this could be due variation in the whitefly life stages treated (nymphs and adults) and experimental conditions (laboratory and field). Sood and Ghongade (2023) evaluated the efficacy of some natural products in which they reported fermented curd water to caused 22.68% reduction in whitefly density at 10% 2 days after spray under control conditions. This is lower than that of Kumari et al (2022) and of the current report, which is probably due lower concentration applied in their experiment, as the effectiveness of insecticides are concentration dependents (Abubakar et al. 2022).

While deploying safer approaches for managing pest populations on chili plants, Chakraborti et al. (2019) reported that the spray of plant extracts (giant milkweed, neem and lemon) and cow-based products (cow urine and buttermilk) were found to effectively suppress the growth and development of thrips, yellow mites, and whiteflies and also substantial in reducing the incidence of leaf curl disease. Jain et al (2021) demonstrated that butter was effective against the whitefly and jassids causing 64.24 and 66.12% reduction respectively in okra, 14 days after the 2nd spray. This is lower than the results in the current findings (67.3 to 86.8%) 15 days after the 2nd spray. The highest effects could be attributed to higher doses applied in the present experiment. Buttermilk's effectiveness as an insecticide can be attributed to its rich composition, including casein protein, fat, galactose, lactose, glucose, lactic acid, uric acid, acetic acid, α -ketoglutaric acid, and orotic acid. These components offer essential nutrients to plants, bolstering their health and reducing their vulnerability to insect attacks. Buttermilk's slight acidity creates an unfavorable environment for some pests and their larvae. Additionally, it may possess antifungal properties, guarding against fungal diseases that can attract insects. The distinct smell and taste of buttermilk serve as natural repellents, discouraging insects from landing on treated plants (Mandal et al. 2018; Gebreselassie et al. 2016).

Cow dung was found least effective among the treatments evaluated in the current study. Mallick et al. (2018) examined some biorational strategies against jassids and whitefly population with 3.0/3 leaves in cow dung treated plot, similar to untreated control with 3.25/3 leaves as per the whitefly population. They further concluded that despite significant variation in population density of target insects, none of the treatments examined was potent in lowering the density of the sucking pests. This is similar to our result with cow dung having higher whitefly number in most of the data recording time throughout the trials. However, it has been reported to lower pest densities, increase yield and reduce the cost of production with less effect on non-target arthropods (Shome and Mal 2019). This complied with our result 45 days after the 3rd spray with cow dung causing 68.2% whitefly reduction and higher yield at harvest than the control plot. This could be due to higher concentration (50%) and triple sprays used during experiments.

Similar report (Mandal et al. 2018) demonstrated that cow dung slurry reduced the whitefly density to 4.0/leaf as compared to 5.68 whiteflies/leaf in the untreated plots. This represents 28.9% reduction which indicates the lower efficacy of cow dung against the sap-sucking pests, similar to current result. The potential of cow dung in whitefly control could be due to the presence of different chemicals including chloride, sulphate, nitrite and phosphorus pentoxide, magnesium, copper, cobalt, sodium, manganese, nitrogen, sulfur, and potassium, being rich in nutrients like nitrogen, phosphorus, and potassium can improve plant health and growth, potentially reducing their attractiveness to pests (Gupta et al. 2016). These highlight the high potential and efficacy of the indigenous technical practices and traditional knowledge in whitefly management regimes.

4.8. Effects of plant-based treatments against the whitefly (*B. tabaci* G.)

4.8.1. Effects on the adult population

The effect of the treatments against the whiteflies on eggplant at different periods (1st, 3rd, 7th and 15th days) during the 45 days trial were presented in Tables 4.36-38. The whitefly density/leaf of eggplant was similar in the experimental plots at pre-treatment stage in 2022 (P=0.997) and 2023 (P=0.724) respectively. The effect of the treatments differed significantly (P < 5%) from each other in most of the data recording periods during the year 2022 and 2023. Eucalyptus fermented extracts (200 mL/L) and its essential oil (30 mL/L) were found to be more effective with 28.1 and 28.2 whiteflies/leaf respectively, as they differed significantly (P<0.0001) from most of the treatments. Whereas, citrus aqueous extract (100 mL/L) exhibited the lowest effect with an average of 40.7 whiteflies/leaf on day one after the 1st spray in 2022. In 2023, there was also significant difference between the treatments (P=0.05), with eucalyptus essential oil (30 mL/L) being more effective (25.7 whiteflies/leaf) followed by citrus fermented extracts (200 mL/L) with 26.6 whiteflies/leaf, and both were not statistically different from the positive control (25.7 whiteflies/leaf), on day one after the 1st spray. Citrus aqueous extract (100 mL/L) remained least effective during the same period with 36.7 whiteflies/leaf, as it differed significantly (P=0.05) from all the treatments. Citrus fermented extract (200 mL/L) differed significantly on 3rd (P <0.0001) and 15th (P<0.0001) day after the 1st spray,

with least whitefly count (21.5 and 13.4 whiteflies/leaf), in 2022 experiment. Eucalyptus oil (30 mL/L) was most effective on the 7th day, with 18.7 whiteflies/leaf, as it differed significantly ($P<0.0001$) from all the treatments, but similar to citrus fermented extracts (200 mL/L) with 19.3 whiteflies/leaf in 2022 experiment. In 2023 trial, eucalyptus oil (30 mL/L) was most effective as it differed significantly on the 3rd ($P=0.003$) and 15th ($P<0.0001$) days after the 1st spray recording 19.1 and 12.6 whiteflies/leaf respectively. The least effective treatment on the 15th day was citrus aqueous extract (100 mL/L) with 31.3 whiteflies/leaf, which was not statistically different ($P<0.0001$) from the negative control (33.1 whiteflies/leaf) (**Table 4.36**). The results with eucalyptus oil (30 mL/L) after the 2nd spray were found to be similar to that of the 1st spray, showing the highest effect, differing significantly on the 1st ($P<0.0001$) and 15th ($P<0.0001$) day, with 10.5 and 1.5 whiteflies/leaf respectively, in 2022 experiment. It was followed by eucalyptus fermented extracts (200 mL/L) with 11.1 and 1.7 whiteflies/leaf on the 1st and 15th day in 2022 experiment. Eucalyptus oil (30 mL/L) also proved to be the most effective treatment in 2023, with 10.9 and 4.5 whiteflies /leaf, having similar effect with its fermented extracts (200 mL/L) with 13.3 and 5.0 whiteflies/leaf on the 1st and 15th day, after the 2nd spray. In the year 2023, the least whitefly count was recorded with eucalyptus and citrus oils (30 mL/L) (4.5 whiteflies/leaf each), 15 days after the 2nd spray, which was similar to that of the positive control (malathion, EC 50%) with 3.7 whiteflies/leaf. The least effective treatment was that of eucalyptus aqueous extract (100 mL/L) with 16.2 and 19.2 whiteflies/leaf as compared to the control (24.2 and 28.5 whiteflies/leaf), 15 days after the 2nd spray in 2023 experiment (**Table 4.37**).

The whitefly density was reduced further after the 3rd spray. Eucalyptus oils (30 mL/L) was found to be highly effective with 2.0 and 1.8 whiteflies/leaf as it differed significantly from most of the treatments on the 1st ($P<0.0001$) and from all the treatments on 15th ($P<0.0001$) day after the 3rd spray during the 2022 experiment. It had similar effect as that of fermented extract (200 mL/L) on the 1st and 15th day after the spray with 2.5 and 2.9 whiteflies/leaf respectively, in 2022 experiment. Citrus oil (10 mL/L) was recorded as least effective on the 1st and 15th days after the 3rd spray with 14.8 and 12.2

whiteflies/leaf, as it differed significantly from all the treatments including the negative control (33.6 and 26.6 whiteflies /leaf) during the 2022 experiment. In 2023, eucalyptus oil (30 mL/L) exhibited the highest effect as in 2022, with 4.1 and 1.9 whiteflies/leaf on the 1st and 15th day after the 3rd spray. Eucalyptus fermented extract (200 mL/L) also had similar effect as that of oil, with 4.0 and 1.8 whiteflies/leaf respectively, on the 1st and 15th day after the 3rd spray. Thus, the result was significantly different from most of the treatments on the 1st ($P<0.0001$) and 15th ($P<0.0001$) day respectively during 2023 experiment (**Table 4.38**).

The treatments were found substantial in increasing the fruit yield in both 2022 and 2023 experiments. In 2022, eucalyptus fermented extract (200 mL/L) recorded the highest yield (1213.7 kg/ha) differing significantly ($P<0.0001$) from the remaining treatments, while citrus aqueous extract (100 mL/L) exhibited the least (885.9 kg/ha) as compared to the control plot (668.1 kg/ha). Similar results were found in 2023, with eucalyptus fermented extract (200 mL/L) exhibited the highest yield (1153.3 kg/ha), as it differed significantly ($P<0.0001$) from the remaining treatments. Whereas, its aqueous extract (100 mL/L) showed the lowest yield (854.4 kg/ha), as compared to the control plot (607.0 kg/ha) (**Table 4.38**).

Table 4.36: Average adult whitefly population on the eggplant leaves before and after the 1st foliar spray of plant-based extracts during the 2022 and 2023 cropping seasons

Treatments	Average adult whiteflies/leaf							Average adult whiteflies/leaf						
	2022							2023						
	Pre-treatments	1DAS	2DAS	3DAS	5DAS	7DAS	15DAS	Pre-treatments	1DAS	2DAS	3DAS	5DAS	7DAS	15DAS
T1	49.6 ^a	40.7 ^{ab}	36.5 ^a	34.03 ^b	30.1 ^{abc}	30.1 ^{bc}	27.9 ^{bc}	46.5 ^a	36.7 ^{ab}	33.0 ^a	32.5 ^{ab}	31.1 ^a	29.7 ^{ab}	31.3 ^a
T2	51.4 ^a	36.8 ^{bcd}	34.3 ^{abc}	31.7 ^{bcd}	28.2 ^{bcd}	28.2 ^{bcd}	25.0 ^{bcd}	50.3 ^a	33.7 ^{abc}	30.0 ^a	27.9 ^{abc}	26.2 ^a	23.9 ^{abc}	22.8 ^{bcd}
T3	50.2 ^a	35.6 ^{cde}	32.3 ^{bcd}	28.8 ^{def}	24.4 ^{cde}	24.4 ^{def}	24.7 ^{cd}	48.0 ^a	33.4 ^{abc}	29.3 ^a	28.2 ^{abc}	27.1 ^a	24.3 ^{abc}	21.0 ^{cde}
T4	50.9 ^a	33.5 ^{def}	30.3 ^{bcd}	26.9 ^{efg}	25.9 ^{cde}	25.8 ^{cde}	22.0 ^{def}	51.2 ^a	29.1 ^{bc}	27.7 ^a	27.7 ^{abc}	25.6 ^a	23.9 ^{abc}	22.6 ^{bcd}
T5	51.2 ^a	30.6 ^{fgh}	26.3 ^{def}	23.2 ^{gh}	21.3 ^{de}	21.3 ^{fgh}	17.8 ^{fgf}	48.9 ^a	28.3 ^{bc}	26.0 ^a	23.9 ^{cde}	21.7 ^{ab}	19.7 ^{def}	15.9 ^{def}
T6	50.4 ^a	29.3 ^{hij}	24.5 ^{ef}	21.5 ^h	19.3 ^e	19.3 ⁱ	13.4 ^h	47.9 ^a	26.6 ^c	24.1 ^a	22.0 ^{de}	20.3 ^{ab}	17.1 ^{fgh}	16.1 ^{def}
T7	48.8 ^a	37.7 ^{abc}	35.9 ^{ab}	34.1 ^b	31.9 ^{ab}	31.9 ^b	29.8 ^b	49.0 ^a	33.7 ^{abc}	31.4 ^a	28.9 ^{abc}	22.7 ^{ab}	21.3 ^{cde}	23.9 ^{bc}
T8	47. ^a	35.0 ^{cde}	32.3 ^{bcd}	29.7 ^{cde}	26.7 ^{cde}	26.7 ^{cde}	24.7 ^{cd}	45.1 ^a	30.7 ^{abc}	27.3 ^a	25.1 ^{bcd}	22.8 ^{ab}	19.9 ^{def}	18.7 ^{cde}
T9	49.3 ^a	28.3 ^j	29.3 ^{bcd}	26.7 ^{efg}	24.1 ^{cde}	24.1 ^{def}	18.4 ^{fg}	46.2 ^a	27.6 ^{abc}	25.5 ^a	22.9 ^{cde}	19.7 ^b	16.7 ^{gh}	13.3 ^{efg}
T10	52.4 ^a	39.7 ^{abc}	36.8 ^a	33.5 ^{bc}	30.3 ^{abc}	30.3 ^{bc}	27.7 ^{bc}	52.2 ^a	34.4 ^{abc}	33.9 ^a	32.1 ^{ab}	29.2 ^a	27.8 ^{abc}	27.8 ^{ab}
T11	51.5 ^a	35.1 ^{cde}	33.0 ^{bcd}	29.2 ^{def}	25.9 ^{cde}	25.9 ^{cde}	23.6 ^{cde}	47.4 ^a	31.1 ^{abc}	29.0 ^a	28.6 ^{abc}	26.7 ^a	24.4 ^{abc}	21.6 ^{cde}
T12	45.8 ^a	32.5 ^{efg}	29.2 ^{bcd}	26.2 ^{efg}	23.3 ^{cde}	23.3 ^{efg}	21.5 ^{def}	45.8 ^a	28.8 ^{bc}	28.4 ^a	26.6 ^{abc}	25.4 ^a	23.3 ^{bcd}	20.5 ^{cde}
T13	53.1 ^a	31.0 ^{fgh}	26.3 ^{def}	23.6 ^{gh}	21.0 ^{de}	21.0 ^{ghi}	18.7 ^{efg}	46.0 ^a	32.5 ^{abc}	33.2 ^a	29.7 ^{abc}	27.1 ^a	25.2 ^{abc}	22.7 ^{bcd}
T14	50.0 ^a	28.8 ^{ij}	23.6 ^{ef}	24.4 ^{gh}	19.5 ^e	19.5 ^{hi}	17.8 ^{fgh}	50.3 ^a	30.3 ^{bc}	28.2 ^a	26.0 ^{abc}	23.4 ^{ab}	23.0 ^{def}	16.8 ^{def}
T15	51.0 ^a	28.1 ^j	21.9 ^f	23.3 ^{gh}	18.9 ^e	18.9 ⁱ	14.8 ^{gh}	45.6 ^a	26.8 ^c	24.8 ^a	23.3 ^{cde}	20.7 ^{ab}	18.1 ^{efg}	15.4 ^{efg}

T16	51.8 ^a	34.1 ^{def}	31.6 ^{bcd}	29.2 ^{def}	26.2 ^{cde}	26.2 ^{cde}	20.7 ^{def}	48.0 ^a	30.5 ^{abc}	29.9 ^a	27.1 ^{abc}	23.9 ^{ab}	21.9 ^{efg}	19.4 ^{def}
T17	50.7 ^a	30.4 ^{ghi}	27.5 ^{cde}	25.2 ^{fgh}	22.5 ^{cde}	22.5 ^{efg}	20.5 ^{def}	49.5 ^a	32.9 ^{abc}	31.9 ^a	28.3 ^{abc}	26.8 ^a	23.0 ^{efg}	20.2 ^{cde}
T18	51.9 ^a	28.2 ^j	24.1 ^{ef}	22.9 ^{gh}	18.8 ^e	18.7 ⁱ	17.2 ^{fgh}	50.0 ^a	25.7 ^c	23.7 ^a	21.5 ^{de}	18.5 ^b	15.4 ^h	13.1 ^{fg}
T19	52.6 ^a	30.5 ^{ghi}	27.6 ^{cde}	25.9 ^{efg}	22.6 ^{cde}	22.6 ^{efd}	17.5 ^{fgh}	45.3 ^a	25.7 ^c	21.4 ^a	19.1 ^c	19.4 ^b	16.5 ^{gh}	12.6 ^g
T20	48.6 ^a	41.7 ^a	36.8 ^a	40.8 ^a	36.8 ^a	36.8 ^a	37.9 ^a	50.2 ^a	39.5 ^a	40.3 ^a	33.1 ^a	32.1 ^a	30.2 ^a	33.1 ^a
C.D.	0.0	4.5	3.7	3.6	4.4	4.4	6.0	0.0	0.0	0.0	7.9	7.7	6.8	6.8
SEM \pm	3.5	1.6	1.3	1.2	1.5	1.5	2.1	2.4	3.3	3.4	2.7	2.7	2.4	2.4
C.V. (%)	12.1	8.0	7.4	8.2	10.5	9.9	12.1	8.8	15.2	20.1	14.5	19.0	14.6	17.1
P-value (5%)	0.997	0.0001	<0.0001	<0.0001			<0.0001	<0.0001	0.724	0.05	0.088	0.003	0.028	<0.0001
				1									1	<0.0001

Means with the same common letter in the same column are not significantly different from each other ($P \leq 0.05$). DAS = Days after the spray, C.V.=Coefficient of variance, C.D. = Critical difference, SEM = Standard error mean, T=Treatment (See table 3.3)

Table 4.37 Average adult whitefly population on the eggplant leaves after the 2nd foliar spray of plant-based extracts during the 2022 and 2023 cropping seasons

Treatments	Average adult whiteflies/leaf						Average adult whiteflies/leaf					
	2022						2023					
	1DAS	2DAS	3DAS	5DAS	7DAS	15DAS	1DAS	2DAS	3DAS	5DAS	7DAS	15DAS
T1	21.2 ^{bcd}	16.6 ^{bcd}	15.9 ^b	10.8 ^{bc}	14.1 ^b	12.5 ^c	25.8 ^b	21.5 ^{abc}	19.5 ^{bc}	16.7 ^{bc}	17.0 ^{bc}	15.5 ^c
T2	26.0 ^b	19.1 ^{bc}	12.2 ^{cd}	9.9 ^{bc}	10.3 ^{cd}	12.1 ^c	20.5 ^{bcd}	18.6 ^{bcd}	18.7 ^{bcd}	14.4 ^{cde}	12.5 ^{de}	11.6 ^{dc}
T3	20.9 ^{bcd}	13.9 ^{cde}	9.2 ^{def}	9.1 ^{bc}	8.0 ^{def}	6.0 ^d	19.2 ^{cde}	16.9 ^{bcd}	14.4 ^{cde}	11.8 ^{def}	9.4 ^{efg}	7.4 ^{fgh}
T4	16.7 ^{efg}	14.1 ^{cde}	10.3 ^{cde}	7.7 ^{bc}	5.6 ^{fg}	5.2 ^{def}	19.7 ^{bcd}	18.3 ^{bcd}	17.1 ^{bcd}	13.0 ^{cde}	12.2 ^{de}	10.8 ^{def}
T5	15.6 ^{efg}	8.4 ^{ef}	6.1 ^{hi}	8.9 ^{bc}	4.2 ^g	6.1 ^d	14.0 ^{def}	14.0 ^{cde}	11.1 ^{efg}	9.0 ^{def}	7.5 ^{fgh}	7.2 ^{fgh}
T6	14.2 ^{ghi}	6.7 ^f	4.6 ⁱ	5.4 ^{bc}	3.2 ^g	5.5 ^{de}	13.4 ^{efg}	12.7 ^{cde}	9.7 ^{efg}	6.7 ^{efg}	5.7 ^{hij}	6.3 ^{hi}
T7	24.2 ^{bc}	19.7 ^b	13.4 ^{bc}	14.4 ^b	11.6 ^{bcd}	12.8 ^c	21.3 ^{bc}	19.0 ^{abc}	17.1 ^{bcd}	16.1 ^{bcd}	14.3 ^{cd}	12.3 ^{dc}
T8	23.5 ^{bcd}	17.1 ^{bcd}	10.2 ^{cde}	10.7 ^{bc}	10.8 ^{bcd}	6.7 ^d	16.4 ^{efg}	17.9 ^{bcd}	14.4 ^{cde}	12.0 ^{cde}	10.1 ^{def}	10.4 ^{def}
T9	16.0 ^{efg}	11.8 ^{def}	8.6 ^{def}	5.4 ^{bc}	13.1 ^{cb}	3.1 ^{def}	12.8 ^{fgh}	10.3 ^{cde}	8.2 ^{fgh}	6.8 ^{efg}	5.5 ^{hij}	4.5 ⁱ
T10	20.1 ^{cde}	18.4 ^{bc}	13.6 ^{bc}	11.7 ^{bc}	11.0 ^{bcd}	16.2 ^b	25.7 ^b	24.8 ^{ab}	21.8 ^b	20.6 ^b	19.8 ^b	19.2 ^b
T11	17.0 ^{efg}	14.5 ^{cde}	10.7 ^{cde}	13.4 ^{bc}	8.8 ^{def}	6.9 ^d	18.9 ^{cde}	15.3 ^{cde}	13.3 ^{def}	11.8 ^{def}	10.3 ^{def}	11.2 ^{de}
T12	20.0 ^{cde}	13.3 ^{cde}	11.9 ^{cd}	8.7 ^{bc}	6.6 ^{efg}	11.2 ^c	18.2 ^{cde}	14.9 ^{cde}	11.6 ^{efg}	8.0 ^{efg}	6.4 ^{ghi}	6.3 ^{hi}
T13	12.0 ^{ijk}	9.8 ^{def}	8.6 ^{def}	8.1 ^{bc}	5.9 ^{efg}	4.7 ^{def}	21.0 ^{bc}	17.6 ^{bcd}	14.5 ^{cde}	11.5 ^{def}	9.7 ^{efg}	8.5 ^{efg}
T14	14.3 ^{fgh}	8.0 ^{ef}	6.5 ^{fgh}	7.5 ^{bc}	4.1 ^g	3.3 ^{def}	14.8 ^{def}	13.1 ^{cde}	11.1 ^{efg}	8.4 ^{efg}	8.4 ^{efg}	6.8 ^{ghi}
T15	11.1 ^{jk}	10.0 ^{def}	6.9 ^{efg}	3.7 ^c	3.5 ^g	1.7 ^{ef}	13.3 ^{efg}	11.9 ^{cde}	6.7 ^{gh}	5.6 ^{fg}	4.3 ^j	5.0 ⁱ

T16	18.1 ^{def}	13.1 ^{cde}	10.0 ^{cde}	13.8 ^{bc}	9.3 ^{de}	3.3 ^{def}	20.0 ^{bcd}	16.4 ^{bcd}	14.6 ^{cde}	13.2 ^{cde}	11.2 ^{def}	9.9 ^{efg}
T17	19.3 ^{def}	10.1 ^{def}	11.5 ^{cd}	6.9 ^{bc}	9.2 ^{de}	6.1 ^d	16.7 ^{efg}	13.1 ^{cde}	10.1 ^{efg}	8.6 ^{def}	6.1 ^{ghi}	6.9 ^{ghi}
T18	10.5 ^k	6.6 ^f	6.3 ^{ghi}	7.9 ^{bc}	4.1 ^g	1.5 ^f	10.9 ^h	7.8 ^{de}	5.8 ^h	4.4 ^g	6.9 ^{ghi}	4.5 ⁱ
T19	12.8 ^{hij}	10.0 ^{def}	6.6 ^{fgh}	5.5 ^c	3.5 ^g	4.6 ^{def}	11.8 ^{gh}	6.9 ^e	6.9 ^{gh}	5.5 ^{fg}	5.0 ^{ij}	3.7 ⁱ
T20	37.1 ^a	36.5 ^a	34.5 ^a	32.2 ^a	36.4 ^a	24.2 ^a	31.8 ^a	26.9 ^a	27.7 ^a	32.4 ^a	28.9 ^a	28.5 ^a
C.D.	6.6	4.1	6.3	5.5	5.8	3.8	7.4	6.3	6.0	4.6	4.5	5.7
SEM _±	2.3	1.4	2.2	1.9	2.0	1.3	2.6	2.2	2.1	1.6	1.6	1.9
C.V. (%)	16.1	17.6	18.4	32.6	21.0	26.5	18.4	23.6	20.9	23.6	22.6	20.1
P-value	<0.0001	0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Means with the same common letter in the same column are not significantly different from each other ($P \leq 0.05$). DAS = Days after the spray, C.V.=Coefficient of variance, C.D. = Critical difference, SEM = Standard error mean, T=Treatment (See table 3.3)

Table 4.38: Average adult whitefly population on the eggplant leaves after the 3rd foliar spray of plant-based extracts and their effect on plant yield during the 2022 and 2023 cropping seasons

Treatments	Average adult whiteflies/leaf							Average adult whiteflies/leaf						
	2022							2023						
	1DAS	2DAS	3DAS	5DAS	7DAS	15DAS	Yield (kg/ha)	1DAS	2DAS	3DAS	5DAS	7DAS	15DA S	Yield (kg/ha)
T1	8.3 ^{cde}	7.9 ^{bcd}	8.9 ^b	8.4 ^b	9.8 ^b	10.0 ^{bc}	885.9 ^h	12.7 ^c	10.8 ^{bc}	11.5 ^{bc}	10.5 ^b	12.4 ^b	10.1 ^{bc}	898.0 ^{ghi}
T2	5.2 ^{ef}	8.6 ^b	6.1 ^{bcd}	10.3 ^b	4.9 ^{cde}	8.7 ^{cbd}	950.3 ^{def}	10.5 ^{dce}	8.8 ^{cde}	8.5 ^{cde}	7.5 ^{bcd}	7.3 ^{cde}	6.6 ^{de}	926.3 ^{fg}
T3	7.8 ^{de}	6.8 ^{bcd}	1.7 ^f	5.0 ^b	7.0 ^{bcd}	3.6 ^{gh}	952.8 ^{def}	5.1 ^{ghi}	4.2 ^{def}	3.7 ^{ghi}	3.8 ^{cd}	2.8 ^{ghi}	3.4 ^{efg}	1001.8 ^{cd}
T4	5.4 ^{ef}	1.7 ^{cd}	6.3 ^{bcd}	5.1 ^b	2.2 ^{de}	4.7 ^{ghf}	1140.8 ^b	10.4 ^{dce}	8.9 ^{cde}	7.8 ^{de}	8.2 ^{bcd}	6.8 ^{cde}	5.6 ^{def}	1104.8 ^b
T5	3.5 ^f	4.3 ^{bcd}	3.2 ^{efd}	2.4 ^c	1.1 ^e	3.4 ^{gh}	1153.3 ^b	8.7 ^{def}	8.4 ^{cde}	6.5 ^{efg}	5.0 ^{cd}	6.8 ^{cde}	6.8 ^{de}	1121.1 ^{ab}
T6	3.0 ^f	1.7 ^{cd}	1.7 ^f	1.6 ^c	2.5 ^{de}	3.7 ^{ghf}	1156.4 ^b	5.3 ^{fgh}	4.9 ^{def}	3.9 ^{ghi}	3.4 ^{cd}	2.5 ^{ghi}	2.2 ^{gh}	1127.0 ^{ab}
T7	14.8 ^b	2.3 ^{cd}	5.7 ^{bcd}	6.6 ^b	9.5 ^b	12.2 ^b	891.1 ^{g^h}	11.2 ^{dc}	10.4 ^{bcd}	9.4 ^{bcd}	7.4 ^{bcd}	7.4 ^{cde}	7.8 ^{cd}	914.2 ^{fgh}
T8	11.6 ^{bc}	3.4 ^{bcd}	4.5 ^{cde}	5.8 ^b	3.3 ^{cde}	5.9 ^{def}	964.7 ^{cde}	8.9 ^{def}	7.9 ^{cde}	7.6 ^{efd}	5.9 ^{bcd}	3.1 ^{ghi}	2.7 ^{fgh}	940.0 ^{ef}
T9	3.2 ^f	1.4 ^{cd}	1.4 ^f	3.7 ^c	1.0 ^e	5.5 ^{def}	932.6 ^{efg}	3.6 ^{hi}	3.2 ^{fg}	2.5 ^{hi}	3.4 ^{cd}	3.9 ^{ghi}	3.5 ^{efg}	947.8 ^{ef}
T10	9.3 ^{cd}	8.1 ^{bc}	7.5 ^{bc}	8.4 ^b	6.8 ^{bcd}	7.7 ^{cde}	971.4 ^{cde}	16.0 ^b	13.4 ^b	11.6 ^b	8.5 ^{bcd}	9.6 ^{bc}	11.3 ^b	854.4 ⁱ
T11	5.8 ^{def}	6.2 ^{bcd}	7.9 ^{bc}	5.2 ^b	5.6 ^{cde}	6.0 ^{def}	978.6 ^{cd}	10.0 ^{dce}	9.7 ^{bcd}	8.6 ^{bcd}	6.5 ^{bcd}	5.3 ^{def}	5.9 ^{def}	880.8 ^{hi}
T12	4.9 ^{ef}	4.3 ^{bcd}	2.1 ^{ef}	2.8 ^c	1.4 ^e	4.2 ^{ghf}	974.8 ^{cd}	4.9 ^{hi}	4.1 ^{def}	4.1 ^{ghi}	4.8 ^{cd}	2.4 ^{ghi}	2.2 ^{gh}	916.7 ^{fgh}
T13	4.9 ^{ef}	2.2 ^{cd}	3.4 ^{efd}	5.3 ^b	8.0 ^{bc}	3.8 ^{ghf}	880.8 ^h	7.1 ^{efg}	9.2 ^{cde}	8.7 ^{bcd}	7.0 ^{bcd}	5.9 ^{def}	6.7 ^{de}	1027.8 ^c

T14	3.3 ^f	2.6 ^{cd}	1.2 ^f	2.9 ^c	2.6 ^{de}	5.6 ^{def}	1136.3 ^b	7.3 ^{efg}	6.1 ^{cde}	4.8 ^{fgh}	4.2 ^{cd}	3.3 ^{ghi}	3.7 ^{efg}	1122.6 ^{ab}
T15	2.5 ^f	2.2 ^{cd}	2.2 ^{ef}	1.7 ^c	1.4 ^c	2.9 ^{gh}	1213.7 ^a	4.0 ^{hi}	3.9 ^{efg}	2.5 ^{hi}	2.2 ^d	1.7 ^{hi}	1.8 ^h	1153.3 ^a
T16	7.6 ^{de}	5.2 ^{bcd}	7.7 ^{bc}	6.0 ^b	8.9 ^b	9.2 ^{cbd}	970.0 ^{cde}	12.0 ^{dc}	10.3 ^{bcd}	9.8 ^{bcd}	9.1 ^{bcd}	8.4 ^{dc}	9.0 ^{bcd}	981.9 ^{de}
T17	4.7 ^{ef}	2.5 ^{cd}	3.4 ^{efd}	2.7 ^c	6.6 ^{bcd}	6.6 ^{cde}	919.7 ^{fgh}	7.0 ^{efg}	5.2 ^{def}	4.6 ^{ghi}	2.8 ^{cd}	2.4 ^{ghi}	3.0 ^{fgh}	920.3 ^{fgh}
T18	2.0 ^f	1.2 ^d	3.1 ^{efd}	1.2 ^c	2.7 ^{de}	1.8 ^h	998.1 ^c	4.1 ^{hi}	2.7 ^g	1.7 ^{hi}	1.5 ^{cd}	1.1 ⁱ	1.5 ^h	1001.1 ^{cd}
T19	1.9 ^f	2.3 ^{cd}	2.4 ^{ef}	3.1 ^c	1.4 ^c	4.9 ^{efg}	903.3 ^{gh}	2.7 ⁱ	4.3 ^{def}	1.6 ⁱ	1.1 ^d	1.5 ⁱ	1.9 ^h	877.6 ^{hi}
T20	33.6 ^a	22.9 ^a	26.7 ^a	25.0 ^a	24.5 ^a	26.6 ^a	668.1 ⁱ	29.7 ^a	30.0 ^a	31.4 ^a	32.1 ^a	31.9 ^a	33.3 ^a	607.0 ^j
C.D.	4.7	3.6	4.7	5.7	5.6	4.6		3.9	3.4	2.8	4.3	4.3	3.9	
SEM±	1.7	1.3	1.6	2.0	2.0	1.6	10.3	1.4	1.2	1.0	1.5	1.5	1.4	11.0
C.V. (%)	28.6	44.9	36.4	61.1	46.2	29.9	1.4	21.7	24.9	21.6	38.2	30.7	28.6	1.5
P-value (5%)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Means with the same common letter in the same column are not significantly different from each other ($P \leq 0.05$). DAS = Days after the spray, C.V.=Coefficient of variance, C.D. = Critical difference, SEM = Standard error mean, T=Treatment (See table 3.3)

4.8.2. Effects on the nymph population

The plant phytochemicals examined also affect the nymphs' population at different data recording periods after the sprays of the treatments are presented in tables 4.39-41. There were significant among the treatments ($P < 5\%$) in most of the data record periods during the two cropping seasons (2021/2022 and 2022/2023). Citrus fermented extracts (200mL/L) and Eucalyptus oil (30 mL/L) were the most effective treatment on the 1st (15.6 nymphs/leaf) and 15th (5.8 nymphs/leaf) while eucalyptus aqueous extract (100 mL/L) was the least effective (28.6 and 14.6 nymphs/leaf) on the 1st and 15th days during the 1st year trial. In 2023 trial, eucalyptus oil (30mL/L) was the most substantial with 14.3 and 7.2 nymphs/leaf on the 1st and 15th days respectively while its aqueous extract (100 mL/L) remained the least effective recording 24.9 and 19.6 nymphs/leaf on the 1st and 15th days respectively (**Table 4.39**). Eucalyptus oil (30mL/L) had the lowest nymph number (1.7 and 0.9 nymphs/leaf on the 1st and 5th days with citrus fermented extract (200mL/L) being more effective (0.2 and 1.4 nymphs/leaf on the 7th and 15th days of the 2nd spray during the 2022 trial. Citrus aqueous extract and its essential oil remained the least effective with up to 13.3 and 11.4 nymphs/leaf on the 1st and 15th days respectively. The result was similar in the 2023 experiment with eucalyptus oil (30 mL/L) being the most substantial in all the data record periods having 5.2 and 1.5 nymphs/leaf on the 1st and 15th days while citrus products remained the least effective with 17.5 and 13.1 nymphs/leaf (**Table 4.40**). The treatments maintained their efficiency in reducing the nymphs' density after the 3rd spray with eucalyptus products being the most effective in the respective trial periods. The least nymphs' population (0.7 nymphs/leaf) was found in eucalyptus oil on the 1st and 5th days after the 3rd spray while citrus aqueous extract (100mL/L) records the highest (9.1 nymphs/leaf) 15 days after the 3rd spray in the 1st year trial. The result remained similar in the 2nd year trial with eucalyptus oil (30 mL/L) having the least nymph density (0.6 nymphs/leaf) on the 5th day of the 3rd spray. The highest number (12.0 and 9.8 nymphs/leaf) were found in eucalyptus aqueous and fermented extract (100mL/L) on the 1st and 15th days after the last spray. (**Table 4.41**).

Table 4.39: Average nymph whitefly population on the eggplant leaves after the 1st foliar spray of plant-based extracts during the 2022 and 2023 cropping seasons

Treatments	Average nymph/leaf							Average nymph/leaf						
	2022							2023						
	Pre-treatments	1DAS	2DAS	3DAS	5DAS	7DAS	15DAS	Pre-treatments	1DAS	2DAS	3DAS	5DAS	7DAS	15DAS
T1	30.0 ^a	23.5 ^{abc}	20.6 ^{abc}	16.6 ^{abc}	13.9 ^{bcd}	11.1 ^{bcd}	12.2 ^{bcd}	31.7 ^a	21.1 ^{abc}	18.7 ^{ab}	19.8 ^{ab}	17.8 ^{abc}	15.4 ^{abc}	17.1 ^{bcd}
T2	28.5 ^a	21.8 ^{abc}	17.2 ^{abc}	14.0 ^{bcd}	12.5 ^{cde}	9.8 ^{cde}	9.3 ^{cde}	29.2 ^a	20.1 ^a	19.1 ^{ab}	17.0 ^{ab}	15.3 ^{abc}	16.4 ^{abc}	16.3 ^{bcd}
T3	29.1 ^a	17.1 ^{def}	13.3 ^e	12.7 ^{cde}	11.1 ^a	6.2 ^{efg}	5.9 ^{efg}	29.6 ^a	17.0 ^a	15.8 ^{ab}	13.4 ^{ab}	11.8 ^{abc}	11.5 ^{bcd}	11.1 ^{cde}
T4	27.1 ^a	17.4 ^{def}	13.3 ^e	12.3 ^{def}	10.3 ^{def}	6.3 ^{efg}	7.4 ^{cde}	28.2 ^a	19.2 ^a	17.3 ^{ab}	19.8 ^{ab}	17.5 ^{abc}	15.8 ^{abc}	18.2 ^{bc}
T5	28.8 ^a	16.9 ^{cdef}	12.7 ^e	11.9 ^{ef}	9.7 ^{def}	5.2 ^{hij}	6.5 ^{gh}	29.9 ^a	17.9 ^a	16.3 ^{ab}	13.9 ^{ab}	12.1 ^{abc}	10.5 ^{bcd}	11.6 ^{cde}
T6	31.4 ^a	15.6 ^f	11.2 ^e	9.8 ^f	9.0 ^{fgh}	4.5 ^{ij}	2.9 ^h	29.4 ^a	16.5 ^a	14.7 ^{ab}	12.2 ^{ab}	9.9 ^{bc}	8.1 ^{bcd}	6.9 ^e
T7	29.5 ^a	24.8 ^{abc}	21.1 ^{abc}	18.7 ^{abc}	16.1 ^{bc}	11.4 ^{bcd}	12.8 ^{bcd}	30.9 ^a	23.3 ^a	24.6 ^a	21.8 ^{ab}	19.7 ^{abc}	17.7 ^{ab}	15.2 ^{bcd}
T8	29.2 ^a	26.1 ^{abc}	20.2 ^{abc}	18.1 ^{ab}	14.9 ^{bcd}	10.8 ^{bcd}	10.3 ^{cde}	27.8 ^a	18.7 ^a	17.3 ^{ab}	15.3 ^{ab}	13.4 ^{abc}	11.1 ^{bcd}	9.5 ^{de}
T9	31.1 ^a	20.4 ^{bcd}	16.7 ^{abc}	12.4 ^{def}	11.7 ^{cde}	9.2 ^{cde}	3.8 ^{gh}	27.9 ^a	16.2 ^a	13.8 ^{ab}	11.1 ^{ab}	9.5 ^{bc}	8.0 ^{bcd}	5.7 ^e
T10	29.5 ^a	28.6 ^a	23.0 ^{abc}	20.2 ^a	17.8 ^{ab}	14.0 ^{bc}	14.6 ^b	28.8 ^a	24.9 ^a	22.6 ^{ab}	22.0 ^{ab}	18.9 ^{abc}	16.8 ^{abc}	19.6 ^b
T11	28.9 ^a	25.2 ^{abc}	21.4 ^{abc}	18.7 ^{ab}	16.1 ^{bc}	16.1 ^{ab}	13.6 ^{bc}	31.1 ^a	21.9 ^a	20.9 ^{ab}	18.6 ^{ab}	16.7 ^{abc}	14.5 ^{abc}	15.1 ^{bcd}
T12	30.2 ^a	22.9 ^{abc}	20.0 ^{abc}	17.1 ^{abc}	13.0 ^{bcd}	13.0 ^{bcd}	9.9 ^{bcd}	31.6 ^a	19.7 ^a	19.3 ^{ab}	16.4 ^{ab}	13.8 ^{abc}	10.8 ^{bcd}	10.9 ^{cde}
T13	31.7 ^a	19.3 ^{cdd}	15.4 ^{bcd}	12.7 ^{cde}	10.1 ^{def}	10.0 ^{cde}	7.7 ^{cde}	28.2 ^a	19.5 ^a	17.7 ^{ab}	16.0 ^{ab}	14.1 ^{abc}	12.5 ^{bcd}	10.4 ^{de}
T14	30.4 ^a	17.1 ^{def}	13.7 ^{de}	11.6 ^{ef}	9.3 ^{efg}	8.2 ^{def}	6.5 ^{def}	28.9 ^a	14.8 ^a	16.6 ^{ab}	18.3 ^{ab}	15.6 ^{abc}	14.2 ^{abc}	12.1 ^{bcd}
T15	30.5 ^a	15.8 ^f	12.2 ^e	11.4 ^f	8.6 ^{fgh}	6.1 ^{fgh}	6.3 ^{fgh}	32.3 ^a	15.1 ^a	12.9 ^{ab}	11.3 ^{ab}	9.8 ^{bc}	7.8 ^{bcd}	6.6 ^e

T16	28.3 ^a	21.7 ^{abc}	17.5 ^{abc}	17.7 ^{abc}	14.9 ^{bcd}	12.8 ^{bcd}	8.9 ^{cde}	29.9 ^a	22.3 ^a	22.9 ^{ab}	21.9 ^{ab}	20.5 ^{ab}	18.5 ^{ab}	19.3 ^b
T17	31.5 ^a	17.8 ^{cde}	14.7 ^{cde}	12.7 ^{cde}	10.8 ^{cde}	7.1 ^{efg}	8.2 ^{cde}	29.6 ^a	17.1 ^a	15.1 ^{ab}	13.7 ^{ab}	12.0 ^{abc}	9.4 ^{bcd}	10.2 ^{de}
T18	29.2 ^a	15.8 ^f	12.5 ^e	11.3 ^f	7.9 ^{gh}	5.6 ^{ghi}	5.8 ^h	31.1 ^a	14.3 ^a	11.9 ^{ab}	10.1 ^b	8.7 ^c	6.8 ^{cd}	7.2 ^e
T19	28.2 ^a	16.5 ^{ef}	12.6 ^e	10.0 ^f	7.0 ^h	4.4 ^j	4.9 ^{fgh}	26.4 ^a	13.9 ^a	10.9 ^{ab}	9.7 ^b	9.6 ^{bc}	5.5 ^d	5.3 ^e
T20	29.0 ^a	27.3 ^a	22.9 ^a	21.4 ^a	22.6 ^a	21.1 ^a	21.9 ^a	27.6 ^a	26.3 ^a	25.2 ^a	24.9 ^a	23.2 ^a	23.5 ^a	28.5 ^a
C.D	0.0	4.7	4.8	4.4	3.0	2.8	3.4	0.0	0.0	7.3	7.8	6.2	5.8	7.2
SEM _±	1.7	1.6	1.7	1.3	1.0	1.3	1.2	1.8	2.9	2.5	2.7	2.2	2.0	2.0
C.V (%)	7.0	13.2	12.5	11.3	14.8	17.6	23.8	7.6	26.1	24.8	28.6	25.8	27.3	19.1
P-value (5%)	0.274	<0.000 1	<0.0001	<0.000 1	<0.000 1	<0.0001	<0.0001	0.151	0.135	0.008	0.005	0.0003	<0.000 1	<0.0001

Means with the same common letter in the same column are not significantly different from each other ($P \leq 0.05$). DAS = Days after the spray, C.V.=Coefficient of variance, C.D. = Critical difference, SEM = Standard error mean, T=Treatment (See table 3.3)

Table 4.40: Average nymph whitefly population on the eggplant leaves after the 2nd foliar spray of plant-based extracts during the 2022 and 2023 cropping seasons

Treatments	Average nymph/leaf						Average nymph/leaf					
	2022						2023					
	1DAS	2DAS	3DAS	5DAS	7DAS	15DAS	1DAS	2DAS	3DAS	5DAS	7DAS	15DAS
T1	9.3 ^{bcd}	3.6 ^{def}	7.9 ^b	6.7 ^c	7.9 ^b	11.4 ^b	15.2 ^{bc}	12.2 ^{bcd}	10.4 ^{bcd}	9.4 ^{bcd}	8.9 ^{bcd}	9.4 ^{bcd}
T2	6.5 ^{cde}	4.7 ^{cde}	2.8 ^{de}	9.5 ^b	3.8 ^{cd}	6.4 ^{cde}	13.5 ^{bcd}	9.5 ^{cde}	7.5 ^{cde}	6.2 ^{cde}	4.8 ^{cde}	5.3 ^{cde}
T3	7.1 ^{bcd}	2.9 ^{efg}	4.0 ^{cde}	3.8 ^{def}	5.1 ^{bc}	4.0 ^{def}	10.1 ^{cde}	8.9 ^{def}	7.1 ^{ccde}	5.6 ^{def}	4.3 ^{cde}	3.7 ^{def}
T4	3.5 ^{de}	2.2 ^{fg}	2.1 ^{de}	6.3 ^{cd}	1.4 ^d	2.9 ^{efg}	15.3 ^{bc}	14.4 ^{bc}	12.6 ^{bc}	11.1 ^{bc}	8.9 ^{bcd}	9.9 ^{bcd}
T5	2.0 ^e	1.5 ^g	3.2 ^{de}	1.7 ^{hi}	2.6 ^{cd}	2.9 ^{efg}	10.0 ^{cde}	7.9 ^{efg}	8.3 ^{bcd}	7.3 ^{cde}	5.9 ^{bcd}	6.1 ^{cde}
T6	1.9 ^e	1.4 ^g	1.8 ^{de}	1.5 ^{hi}	0.2 ^d	1.4 ^g	6.8 ^{efg}	4.9 ^{ghi}	3.4 ^f	2.5 ^{ef}	3.0 ^{efg}	2.6 ^{ef}
T7	13.3 ^b	9.4 ^b	4.0 ^{cde}	4.8 ^{cde}	3.0 ^{cd}	8.1 ^{bc}	13.0 ^{bcd}	10.5 ^{bcd}	12.2 ^{bcd}	10.0 ^{bcd}	7.5 ^{bcd}	8.4 ^{bcd}
T8	9.5 ^{bcd}	6.8 ^{bcd}	4.7 ^{bcd}	2.9 ^{fgh}	5.5 ^{bc}	2.9 ^{efg}	8.9 ^{def}	7.0 ^{efg}	5.9 ^{def}	4.8 ^{def}	6.1 ^{bcd}	5.5 ^{cde}
T9	3.9 ^{de}	2.0 ^{fg}	3.2 ^{de}	1.6 ^{hi}	2.8 ^{cd}	6.4 ^{cde}	4.0 ^{fg}	3.0 ^{ij}	2.7 ^f	2.4 ^{ef}	2.5 ^{efg}	1.7 ^{ef}
T10	12.1 ^{bc}	8.2 ^{bc}	7.2 ^{bc}	5.0 ^{cde}	3.5 ^{cd}	8.2 ^{bc}	17.5 ^{ab}	15.4 ^b	14.2 ^b	13.3 ^b	11.2 ^b	13.1 ^b
T11	5.8 ^{cde}	6.1 ^{bcd}	4.0 ^{cde}	3.3 ^{efg}	1.2 ^d	2.5 ^{fg}	12.6 ^{bcd}	11.4 ^{bcd}	9.9 ^{bcd}	9.9 ^{bcd}	8.1 ^{bcd}	5.8 ^{cde}
T12	9.5 ^{bcd}	9.2 ^b	2.9 ^{de}	2.2 ^{ghi}	0.7 ^d	1.6 ^g	9.4 ^{cde}	7.4 ^{efg}	6.0 ^{def}	6.0 ^{cde}	4.6 ^{cde}	3.8 ^{def}

T13	5.6 ^{cde}	6.7 ^{bcd}	3.6 ^{de}	3.1 ^{efg}	5.5 ^{bc}	8.3 ^{bc}	9.6 ^{cde}	11.9 ^{bcd}	10.0 ^{bcd}	6.8 ^{cde}	7.5 ^{bcd}	6.6 ^{bcd}
T14	4.0 ^{de}	2.9 ^{efg}	1.5 ^{de}	3.0 ^{fgh}	3.5 ^{cd}	3.9 ^{def}	8.9 ^{def}	8.2 ^{efg}	6.3 ^{cde}	5.1 ^{def}	4.1 ^{def}	3.5 ^{def}
T15	1.9 ^e	1.7 ^g	1.8 ^{de}	1.8 ^{hi}	2.2 ^{cd}	1.9 ^g	4.7 ^{fg}	3.7 ^{hij}	3.2 ^f	2.6 ^{ef}	1.8 ^g	1.6 ^{ef}
T16	11.0 ^{bc}	6.1 ^{bcd}	4.8 ^{bcd}	5.6 ^{cde}	3.2 ^{cd}	7.6 ^{bcd}	16.8 ^b	13.9 ^{bcd}	11.6 ^{bcd}	12.9 ^b	10.1 ^{bc}	10.9 ^{bc}
T17	6.5 ^{cde}	7.3 ^{bc}	3.9 ^{cde}	1.5 ^{hi}	8.0 ^b	4.8 ^{cde}	7.4 ^{def}	6.4 ^{fgh}	5.3 ^{ef}	6.1 ^{cde}	4.8 ^{cde}	4.0 ^{def}
T18	1.7 ^e	2.5 ^{cde}	1.3 ^e	0.9 ⁱ	1.1 ^d	2.2 ^g	5.2 ^{fg}	3.6 ^{hij}	2.9 ^f	2.2 ^{ef}	1.5 ^g	1.5 ^f
T19	1.4 ^e	1.5 ^g	0.7 ^e	1.0 ⁱ	0.6 ^d	1.0 ^g	3.2 ^g	2.1 ^j	1.9 ^f	1.4 ^f	1.3 ^g	1.0 ^f
T20	21.1 ^a	20.1 ^a	25.4 ^a	26.9 ^a	23.2 ^a	24.8 ^a	23.3 ^a	24.5 ^a	23.6 ^a	24.9 ^a	24.3 ^a	22.7 ^a
C.D.	3.6	4.6	3.9	6.0	3.9	4.1	6.3	5.9	5.4	5.3	5.1	4.2
SEM _±	1.2	0.9	1.0	0.7	1.3	1.0	1.6	1.4	1.7	1.4	1.5	1.3
C.V. (%)	31.4	21.2	24.1	18.1	27.3	22.6	18.5	18.4	25.3	22.7	28.3	34.3
P-value	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000
	1	1	1	1	1	1	1	1	1	1	1	1

Means with the same common letter in the same column are not significantly different from each other ($P \leq 0.05$). DAS = Days after the spray, C.V.=Coefficient of variance, C.D. = Critical difference, SEM = Standard error mean, T=Treatment (See table 3.3).

Table 4.41: Average nymph whitefly population on the eggplant leaves after the 3rd foliar spray of plant-based extracts during the 2022 and 2023 cropping seasons

Treatments	Average nymph/leaf						Average nymph /leaf					
	2022						2023					
	1DAS	2DAS	3DAS	5DAS	7DAS	15DAS	1DAS	2DAS	3DAS	5DAS	7DAS	15DAS
T1	6.3 ^{bc}	6.8 ^{bc}	5.7 ^{bcd}	5.8 ^b	8.7 ^{bc}	9.1 ^b	7.4 ^{cd}	7.3 ^{bc}	6.1 ^{bcd}	8.4 ^b	7.1 ^b	8.6 ^{bc}
T2	4.1 ^{cde}	4.9 ^{bcd}	4.2 ^{bcd}	3.6 ^b	3.9 ^{def}	6.7 ^{bcd}	4.7 ^{def}	5.2 ^{cde}	4.3 ^{bcd}	3.8 ^{cde}	3.0 ^{efg}	3.3 ^{def}
T3	2.3 ^{def}	2.1 ^{ef}	2.6 ^{def}	2.1 ^b	2.6 ^{def}	2.8 ^{cde}	2.6 ^{efg}	3.1 ^{def}	4.7 ^{bcd}	3.6 ^{cde}	2.4 ^{efgh}	2.3 ^{ef}
T4	1.5 ^{ef}	4.4 ^{bcd}	2.2 ^{def}	4.9 ^b	2.5 ^{def}	6.8 ^{bcd}	7.8 ^{bcd}	6.5 ^{bcd}	6.3 ^{bcd}	5.2 ^{bcd}	6.0 ^{bc}	4.8 ^{cde}
T5	1.6 ^{ef}	4.7 ^{bcd}	2.1 ^{def}	2.9 ^b	1.9 ^{def}	3.3 ^{cde}	4.4 ^{def}	4.4 ^{cde}	3.2 ^{cde}	2.2 ^{def}	2.5 ^{efg}	4.2 ^{cde}
T6	0.8 ^f	1.8 ^{ef}	1.0 ^{ef}	2.2 ^b	4.2 ^{cde}	4.1 ^{cde}	2.1 ^{efg}	1.5 ^{efg}	1.1 ^{de}	1.1 ^{efg}	1.3 ^{gh}	1.8 ^{ef}
T7	6.3 ^{bc}	5.7 ^{bcd}	6.7 ^{bcd}	6.4 ^b	1.9 ^{def}	8.1 ^{bc}	6.4 ^{cde}	5.2 ^{cde}	5.8 ^{bcd}	5.1 ^{bcd}	5.8 ^{bc}	7.7 ^{bcd}
T8	5.4 ^{bcd}	6.3 ^{bcd}	5.2 ^{bcd}	1.3 ^c	6.8 ^{bcd}	4.2 ^{bcd}	4.8 ^{def}	5.8 ^{bcd}	4.9 ^{bcd}	5.4 ^{bcd}	4.3 ^{cde}	3.2 ^{def}
T9	1.3 ^{ef}	0.9 ^f	8.2 ^b	7.1 ^b	9.3 ^b	5.5 ^{bcd}	1.2 ^g	1.0 ^{fg}	1.5 ^{cde}	1.0 ^{fg}	1.2 ^{gh}	1.3 ^{ef}
T10	8.4 ^b	7.5 ^b	6.5 ^{bcd}	7.5 ^b	2.5 ^{def}	8.1 ^{bc}	12.0 ^b	9.8 ^b	7.9 ^b	7.0 ^{bc}	5.7 ^{bcd}	5.7 ^{bcd}
T11	4.6 ^{cde}	2.5 ^{def}	4.3 ^{bcd}	0.8 ^c	1.0 ^f	1.8 ^e	4.9 ^{def}	5.1 ^{cde}	6.5 ^{bc}	4.1 ^{cde}	3.5 ^{cde}	2.2 ^{ef}
T12	3.0 ^{cde}	5.7 ^{bcd}	2.9 ^{cde}	4.3 ^b	3.1 ^{def}	4.6 ^{bcd}	2.2 ^{efg}	3.2 ^{def}	1.8 ^{cde}	1.1 ^{efg}	1.7 ^{efgh}	1.7 ^{ef}
T13	1.9 ^{def}	5.2 ^{bcd}	3.9 ^{bcd}	4.7 ^b	4.3 ^{cde}	7.3 ^{bcd}	6.0 ^{cde}	6.3 ^{bcd}	4.3 ^{bcd}	4.1 ^{cde}	3.2 ^{def}	9.8 ^b
T14	4.8 ^{cde}	2.3 ^{def}	5.1 ^{bcd}	1.9 ^c	1.1 ^f	2.9 ^{cde}	2.8 ^{efg}	4.6 ^{cde}	6.5 ^{bc}	3.9 ^{cde}	6.0 ^{bc}	3.2 ^{def}
T15	1.7 ^{ef}	3.3 ^{cde}	2.5 ^{def}	1.3 ^c	1.5 ^f	1.6 ^e	1.3 ^g	1.7 ^{efg}	1.1 ^{de}	1.3 ^{def}	1.4 ^{gh}	1.6 ^{ef}
T16	4.5 ^{cde}	7.6 ^b	7.6 ^{bc}	6.3 ^b	5.5 ^{bcd}	4.2 ^{bcd}	10.1 ^{bc}	8.1 ^{bc}	6.5 ^{bc}	3.9 ^{cde}	5.1 ^{bcd}	4.2 ^{cde}

T17	4.9 ^{cde}	6.1 ^{bcd}	3.6 ^{bcd}	3.7 ^b	6.3 ^{bcd}	2.3 ^{de}	3.7 ^{def}	5.3 ^{cde}	1.7 ^{cde}	1.4 ^{def}	1.6 ^{gh}	2.1 ^{ef}
T18	0.7 ^f	0.8 ^f	1.0 ^f	0.7 ^c	4.4 ^{cde}	4.4 ^{bcd}	1.0 ^g	0.8 ^g	1.0 ^{de}	0.6 ^g	1.1 ^{gh}	1.1 ^f
T19	1.6 ^{ef}	2.6 ^{def}	1.8 ^{ef}	3.5 ^b	1.8 ^{ef}	3.8 ^{cde}	1.5 ^{fg}	0.8 ^g	0.4 ^e	1.8 ^{def}	0.5 ^h	1.7 ^{ef}
T20	23.5 ^a	19.4 ^a	16.8 ^a	23.5 ^a	19.7 ^a	20.0 ^a	25.6 ^a	22.6 ^a	22.9 ^a	23.5 ^a	26.7 ^a	23.6 ^a
C.D.	4.8	6.0	5.4	5.5	4.7	4.7	6.1	4.4	4.3	4.5	3.3	3.9
SEM _±	1.0	1.1	1.2	1.9	1.3	1.4	1.2	1.1	1.4	1.1	0.7	1.2
C.V. (%)	25.5	26.2	32.1	39.8	33.1	30.6	26.2	24.2	34.9	29.8	19.4	31.0
P-value	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000	<0.000
	1	1	1	1	1	1	1	1	1	1	1	1

Means with the same common letter in the same column are not significantly different from each other ($P \leq 0.05$). DAS = Days after the spray, C.V.=Coefficient of variance, C.D. = Critical difference, SEM = Standard error mean, T=Treatment (See table 3.3)

4.8.3. Reduction (%) in whitefly population after the spray of plant-based treatments

4.8.3.1. Reduction (%) in adult population

The results on the reduction (%) of whiteflies density on eggplant revealed that eucalyptus fermented extract (200 mL/L) and its essential oil (30 mL/L) had the highest effect (59.6 and 60.8%) after the malathion EC 50% (6 mL/L) with 62.3% while the least effective treatment was found to be citrus aqueous extract (100 mL/L) with 24.4 and 6.4% reduction 15 days after the 1st spray in 2022 and 2023 experiments (**Fig 4.15**). Eucalyptus oil (30 mL/L) maintained the highest effect (93.8 and 84.2% reduction) followed by its fermented extracts (92.9 and 82.5%) with its aqueous extract (100 mL/L) being the least (33.1 and 32.6%) at 30 days after the 2nd spray during 2022 and 2023 cropping seasons (**Fig 4.16**). Similar effects were recorded at 45 days after the 3rd spray with eucalyptus oil (30 mL/L) having the highest effects (93.2 and 95.5) while citrus oil (10 mL/L) and aqueous extracts (100 mL/L) were least effective with 54.1 and 67.7% respectively during the 2022 and 2023 experiments (**Fig 4.17**).

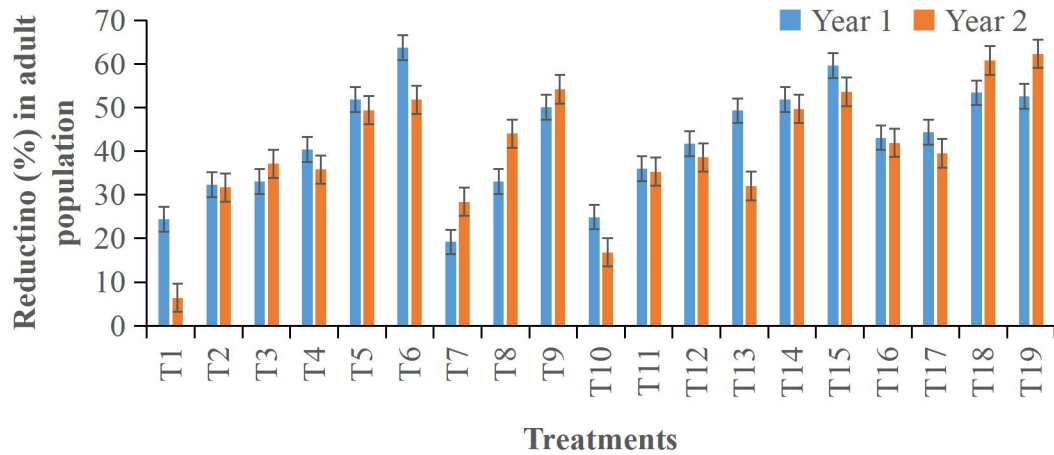


Fig4.15: Reduction (%) in adult whitefly population 15 days after the 1st spray of plant extracts in 2022 and 2023 experiments. T=Treatment (See table 3.3)

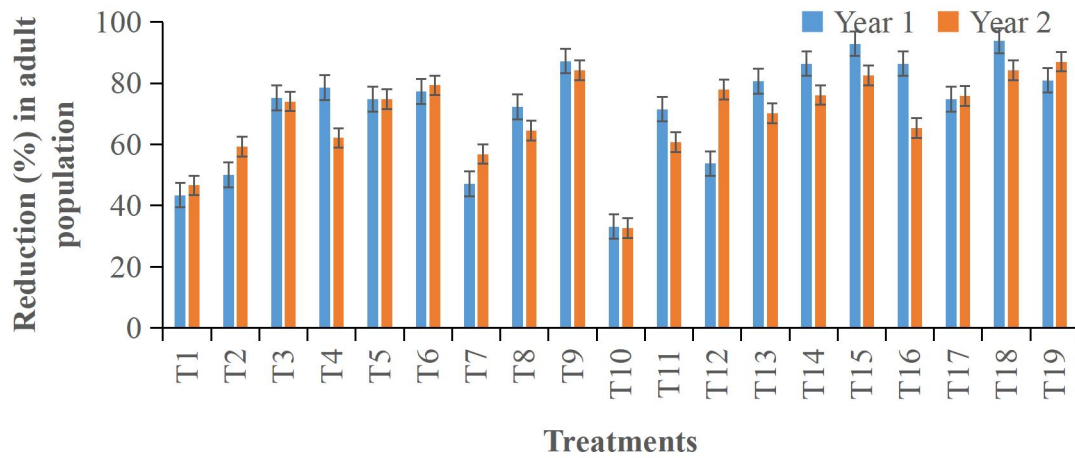


Table 4.16: Reduction (%) in adult whitefly population 30 days after the 2nd spray of plant extracts in 2022 and 2023 experiments. T=Treatment (See table 3.3)

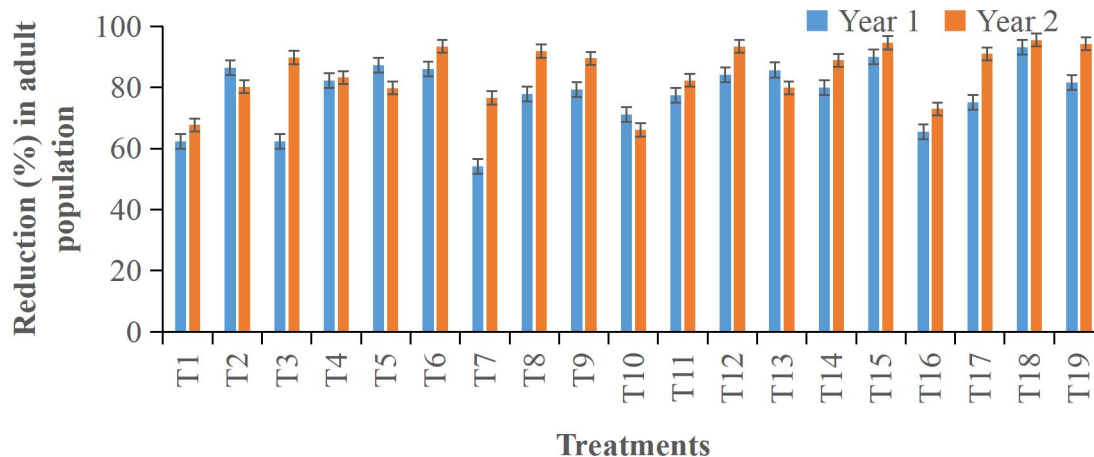
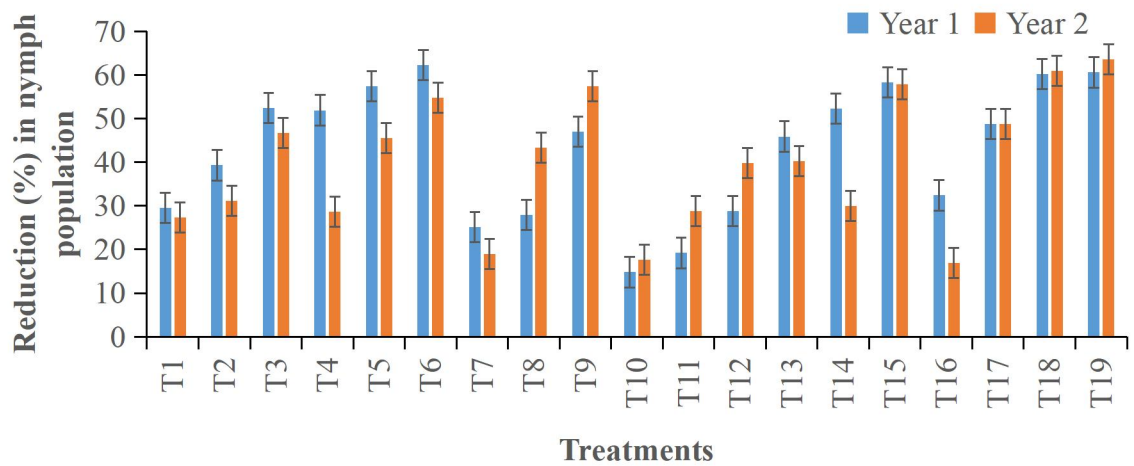


Table 4.17: Reduction (%) in adult whitefly population 45 days after the 3rd spray of plant extracts of plant extracts in 2022 and 2023 experiments. T=Treatment (See table 3.3)

4.4.4. Reduction (%) in nymph population

The nymphs' population was also affected by the phytochemicals examined at all the data record periods. Eucalyptus essential oil (30 mL/L) was most effective with 60.2 and 61.0%, very close to positive control (6 mL/L) with 60.6 and 63.6% with eucalyptus aqueous extract (100 mL/L) being the least with 14.8 and 17.6% reduction at 15 days after the 1st spray in 2022 and 2023 experiments (**Fig 4.18**). Citrus fermented extracts (200 mL/L) and eucalyptus oil (30 mL/L) caused highest reduction (94.2 and 93.1%) while their extracts (100 mL/L) caused the least (67.1 and 40.8%) at 30 days after the 2nd spray during the 2022 and 2023 experiments (**Fig 4.19**). The nymphs' density was reduced further at 45 days after the 3rd spray with eucalyptus oil (30 mL/L) having the highest effect (90.0 and 96.1%) while citrus aqueous extract (100 mL/L) had the least 63.5%) in the respective experimental periods (**Fig 4.20**).



4.18: Reduction (%) in nymph whitefly population 15 days after the 1st spray of plant extracts in 2022 and 2023 experiments. T=Treatment (See table 3.3)

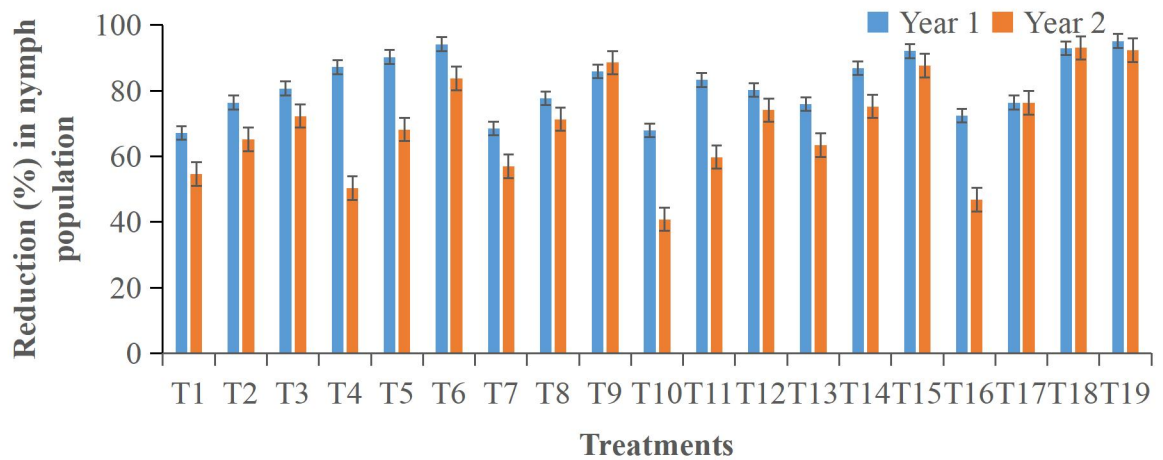


Fig4.19: Reduction (%) in nymph whitefly population 30 days after the 2nd spray of plant extracts in 2022 and 2023 experiments. T=Treatment (See table 3.3)

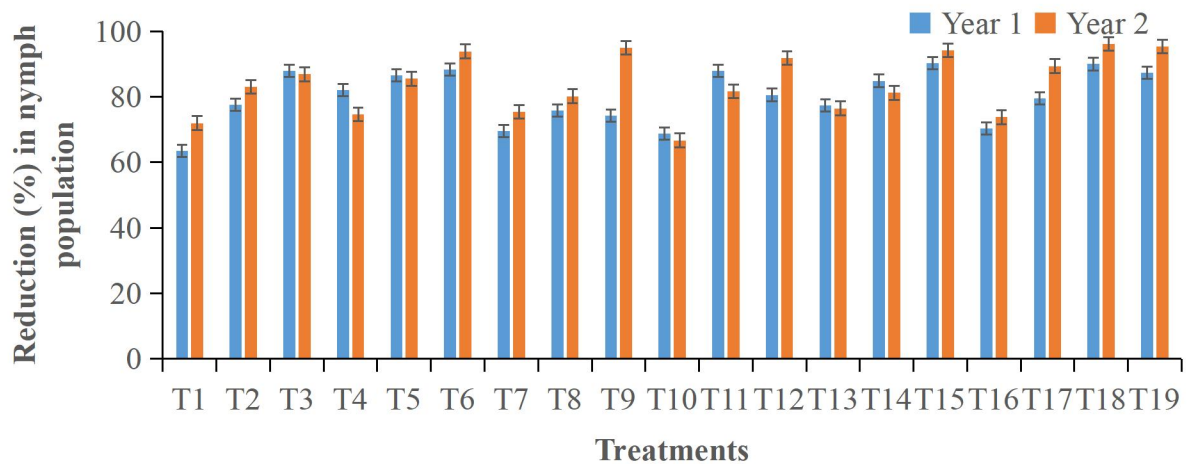


Fig4.20: Reduction (%) in nymph whitefly population 45 days after the 3rd spray of plant extracts in 2022 and 2023 experiments. T=Treatment (See table 3.3)

Discussion

The *E. camaldulensis* and *C. aurantium* extracts examined (essential oils, fermented and aqueous extracts) in this study proved effective in reducing the whitefly population on eggplant. From the results obtained, the essential oils and fermented extracts were more effective than the aqueous extracts from the respective plants. Eucalyptus oil (30 mL/L) caused maximum reduction in whitefly population during the study demonstrating their higher pesticidal potential against the whiteflies. Pumnuan et al (2017), examined the effects of essential oils from 18 medicinal plants against the whitefly and aphids under controlled conditions. They reported a significant reduction (82 to 100%) in the population of both insects. The current results (reduction in adult whitefly density of up to 95.5%) are in consonance with that of Pumnuan et al (2017). Similarly, Kumar et al (2019), reported that castor essential oil caused 42.8 and 64.2% reduction in whitefly number under field and laboratory trials respectively. These reduction percentages are lower than that was obtained in the present experiment. The variation may be due to differences in the bio-active compounds available in essential oils analyzed,

environmental conditions, duration and the concentration of the treatments. Fanela et al (2016), also evaluated the potential of various essential oils against the whiteflies on tomato crop. They reported that the essential oil extracted from *Piper callosum* was highly effective, rendered an average of 6.6 and 6.0 adults and eggs/leaf as compared to the control with 22.6 and 70.6 adult and eggs/leaf, respectively. This represents 70.8 and 91.5% reduction in the adult and eggs density, two days after the spray. These results are similar but more convincing than the results obtained in the present study. This might be due to the variation in the conditions of experimental sites (field and laboratory conditions) as the field conditions allow for quick evaporation of the chemicals used. Wagan et al (2018), examined the effect of *Gardenia jasminoides* Ellis essential oil under greenhouse conditions. They reported 89.59% repellency and 80.08% toxicity on the adults and nymphs of whiteflies respectively, 24 h after the treatment. These reduction percentages are higher than those obtained in the present study which is 32.4% reduction in adult population, 24 h after the spray, which might be due to differences in the essential oil deployed, experimental settings and the crop variety used. There are several other reports that have proved the effectiveness of plant essential oils for whitefly management (Kumar et al. 2019; Peres et al. 2020; Sweetha, 2021).

The fermented extracts examined were also effective in present report, conforming to the previous studies that proved the effectiveness of fermented plant extracts in insect control, particularly sap-sucking pests (Baloc et al. 2013). Nzanza and Mashela (2012) described the impacts of neem and wild garlic fermented extracts for whitefly management on tomatoes. The extracts reduced the whiteflies number to 10.92 adult /leaf as compared to the control (18.35 adult/leaf), five weeks after the treatments. The nymphs' population was also affected by the extracts recording 14.30 nymphs, which was lower than the control (18.0/leaf). The result is less convincing than those obtained in this report, and this could be due to variation in the phytochemical constituents of the plant extracts used. The fermented extract derived from *Sophora alopecuroides* (L.) has been reported to have a significant effect in reducing the whitefly density and yield losses in potato crop (Ayub et al. in 2021).

The aqueous plant extracts were found to be less effective in comparison to the essential oils and fermented extracts, from the respective plants. This could be attributed to the presence of highly concentrated volatile bio-active compounds in the essential oils (Benelli et al. 2019). Despite being less effective, the aqueous extracts were observed to outperform the negative control group in terms of average whitefly count on eggplant during the study. A diet bioassay containing aqueous and methanol extract from marigold foliage reduced the densities of both the *B. tabaci* and *Lygus hesperus* Knight and the mortality was shown to be concentration-dependent (Fabrick et al. 2020). This is similar to our findings, demonstrating the presence of one or more extractable toxicants that can be used against different arthropod pests (Fabrick et al. 2020). Ateyyat et al. (2009) also reported that, plant aqueous extracts have similar effects to synthetic chemicals (imidacloprid) in whitefly management. These results are in contrast to the current findings because in our study, malathion (EC 50%) was found to be more effective than the aqueous plant extracts. Aqueous and methanol extracts from chinaberry (*Melia azedarach* L.) have been reported to reduce the whitefly number to 1.44/ plant (Hammad et al. 2000), which is higher than that recorded in our study. Similarly, Lynn et al. (2010) revealed that the oviposition, egg hatching, and adult eclosion were reduced by 23.1, 53.2, and 26.6% by using neem (*A. indica*) leaf extracts. It proved the effectiveness of the aqueous extracts in whitefly management. Several reports (Rehmana et al. 2015; Ezzat et al. 2015) described the effectiveness of the phytochemicals in whitefly management regimes. The use of bio pesticides, particularly phytochemicals has been considered to be more suitable and sustainable alternative for subsistence farmers in different parts of the world (Isman 2008; 2017), as supported by the current findings.

The effectiveness of these extracts might be due to the presence of various bioactive compounds in the plants examined (Mouna et al. 2021). The leaves of *E. camaldulensis* are known to contain tannins, saponins, glycerides, alkaloids, flavonoids, steroids, terpenoids and anthraquinones. These might serve as a source of bioactive agents that could be used as bio pesticide against sap-sucking pests including whiteflies (Sani et al. 2014). Similarly, the insecticidal effects of *C. aurantium* have been shown to be due to

the presence of α -pinene, limonene and β -myrcene. Limonene is a key component of *C. aurantium* that is effective against many insect pests like whiteflies (*B. tabaci*), scale insects (*Pinnaspis aspidistrae* Signoret), mealy bugs (*D. mangiferae*) and horn flies (*Haematobia irritans irritans* L.) (Hollingsworth 2005; Showler et al. 2019). Moreover, α -pinene has been reported to have toxic effect on both the adult and larva of yellow fever mosquito *Aedes aegypti* (L.) (Lucia et al. 2007) as well as adulticidal effect against weevil (*Sitophilus zeamais* Motsch.) (Langsi et al. 2020). Besides crop protection against insects, plant-based extracts have been reported to significantly increase crop yield, which made them acceptable to small-scale farmers (Tembo et al. 2018; Okolo and Iludum, 2019) as reported in this finding.

4.9. Effect of IPM Strategy and the Synthetic Chemical against the whiteflies

4.9.1. Effect on adult population

An independent sample t-test was conducted to compare the effectiveness of plant-based extracts along with yellow sticky traps (A) with chlorpyrifos insecticides (B) for a period of 45 days. The treatments were sprayed three times at an interval of 15 days. The result varied significantly ($t(DF) = (3.4(10), P = 0.007)$) between the treatments with the mean whitefly number for A ($M = 7.63, SD = 1.52$) being higher than that of B ($M = 5.13, SD = 0.98$) in 2022 experiment. The magnitude of the difference in the means ($MD = 2.50, 95\% CI: 0.86 - 4.14$) was significant, thus the null hypothesis (H_0) was rejected after the 1st spray. The result was significantly different after the 2nd spray, ($t(DF) = (4.49(10), P = 0.001)$) for adult whitefly population with mean value for group A ($M = 3.97, SD = 0.56$) being higher than that of B ($M = 2.63, SD = 0.47$). The magnitude of the difference in the means ($MD = 1.33, 95\% CI: 0.67 - 1.99$) was significant and thus, the H_0 was also rejected. Similar result was recorded after the 3rd spray, as the treatments differed significantly ($t(DF) = (2.45(10), P = 0.034)$) with the mean adult population for A ($M = 2.02, SD = 0.25$) being higher than that of B ($M = 1.73, SD = 0.14$). The magnitude of the difference in the means ($MD = 0.28, 95\% CI: 0.03 - 0.54$) was significant, thus the H_0 was also rejected. The effect size for the 1st, 2nd and 3rd sprays ($Cohen's d = 1.96, 2.59$ and 1.41) were large in 2022

experiment (**Table 4.42**). In 2023, there was no significant difference ($t(DF) = (0.54(10), P = 0.60)$) in whitefly population as the mean number for A ($M = 9.18, SD = 1.68$) was insignificantly greater than that of B ($M = 8.70, SD = 1.41$). The magnitude of the differences in the means ($MD = 0.48$, 95% $CI: -1.51 - 2.48$) was insignificant, thus the H_0 was supported after the 1st spray. The result was statistically different after the 2nd spray ($t(DF) = (2.91(10), P = 0.02)$) with the mean adult population for A ($M = 4.33, SD = 1.30$) being higher than that of B ($M = 2.65, SD = 0.55$). The magnitude of the difference in the means ($MD = 1.68$, 95% $CI: 0.40 - 2.97$) was significant and thus, the H_0 was rejected. Similar result was recorded after the 3rd spray ($t(DF) = (2.66(10), P = 0.02)$) with adult population for A ($M = 1.05, SD = 0.34$) being significantly higher than that of B ($M = 0.48, SD = 0.39$). The magnitude of the difference in the means ($MD = 0.57$, 95% $CI: 0.09 - 1.04$) was significant, thus the H_0 was also rejected. The effect sizes for the 1st spray (Cohen's $d = 0.31$) were small while that of 2nd and 3rd sprays (Cohen's $d = 1.68$ and 1.54) were large (**Table 4.43**). The yellow sticky traps were effective in reducing the whitefly number on the leaves of eggplant during the two cropping periods. The highest average whitefly numbers (19.3 and 25.7) were recorded on week 8 while the lowest (0.6 and 0.3) were found at week 1 after the installation of the traps in the experimental plots (**Fig 4.21**).

Table 4.42: Effect of bio pesticides (A) and synthetic chemical (B) against the adult whitefly population after the 1st, 2nd and 3rd sprays in 2022 experments

No of sprays	Groups	Mean	SD	SEM±	F-value	T-stat	DF	P-value	MD	95% C.I.D		Cohen's D
										Lower	Upper	
1 st spray	A	7.63	1.52	0.62	1.26	3.40	10	0.007**	2.50	0.86	4.14	1.96
	B	5.13	0.98	0.40								
2 nd spray	A	3.97	0.56	0.23	0.12	4.49	10	0.001**	1.33	0.67	1.99	2.59
	B	2.63	0.47	0.19								
3 rd spray	A	2.02	0.25	0.10	1.49	2.45	10	0.034*	0.28	0.03	0.54	1.41
	B	1.73	0.14	0.06								

SD= Standard deviation; SEM= Standard error mean; DF= Degree of freedom; MD= Mean difference; CID= Confidence interval of the difference; NS= non-significant; *= significant; **= very significant.

Table 4.43: Effect of the bio pesticides (A) and synthetic chemical (B) against the adult whitefly population after the 1st, 2nd and 3rd sprays in 2023 experments

No of sprays	Groups	Mean	SD	SEM±	F-value	T-stat	DF	P-value	MD	95% CID		Cohen's D
										Lower	Upper	
1 st spray	A	9.18	1.68	0.69	0.08	0.54	10	0.60 ^{NS}	0.48	-1.51	2.48	0.31
	B	8.70	1.41	0.57								
2 nd spray	A	4.33	1.30	0.53	2.22	2.91	10	0.02*	1.68	0.40	2.97	1.68
	B	2.65	0.55	0.22								
3 rd spray	A	1.05	0.34	0.14	0.12	2.66	10	0.02*	0.57	0.09	1.04	1.54
	B	0.48	0.39	0.16								

SD= Standard deviation; SEM= Standard error mean; DF= Degree of freedom; MD= Mean difference; CID= Confidence interval of the difference; NS= non-significant; *= significant; **= very significant.

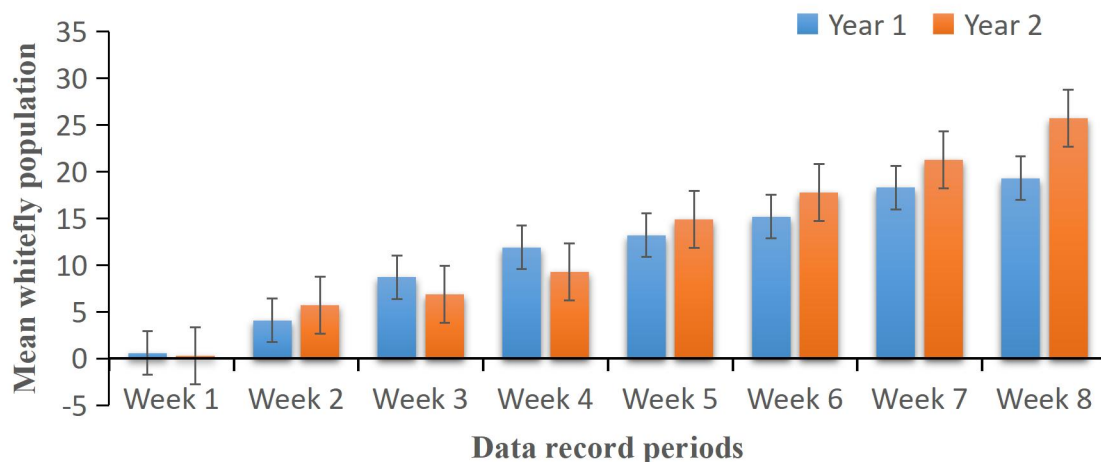


Fig 4.21: Average adult whitefly number per trap in 2022 and 2023 experiments

4.9.2. Effects on the nymphs' population

Data were also collected from the same experimental plots to compare the effectiveness of the two groups of pesticides (A and B) against the nymphs' population during the same trial periods. The result varied significantly ($t (DF) = (3.18 (10), P = 0.01)$) between the treatments after the 1st spray in 2022, with mean nymphs' number for A ($M = 2.12, SD = 0.26$) being higher than that of B ($M = 1.38, SD = 0.50$). The magnitude of the difference in the means ($MD = 0.73, 95\% CI: 0.22 - 1.25$) was significant, and thus the H₀ was accepted. The result also differed significantly after the 2nd spray, ($t (DF) = (5.44 (10), P = < 0.001)$) in the nymphs' population as the mean number for A ($M = 1.87, SD = 0.46$) was higher than that of B ($M = 0.77, SD = 0.19$). The magnitude of the difference in the means ($MD = 1.10, 95\% CI: 0.65 - 1.55$) was significant and thus, the H₀ was also rejected. The result was statistically similar after the 3rd spray, ($t (DF) = (1.62 (10), P = 0.137)$) with average nymphs' number for A ($M = 1.03, SD = 0.48$) and B ($M = 0.67, SD = 0.27$). The magnitude of the difference in the means ($MD = 0.37, 95\% CI: -0.87 - 0.087$) was not significant, thus the H₀ was supported. The effect sizes for the 1st, 2nd and 3rd sprays (*Cohen's d* =

1.84, 3.14 and 0.93) were large (Table 4.44). In 2023, there was no significant difference ($t(DF) = (0.99(10), P = 0.35)$) between the treatments as the average nymphs' number for A ($M = 4.12, SD = 0.72$) was statistically similar to that of B ($M = 3.77, SD = 0.48$) after the 1st spray. The magnitude of the difference in means ($MD = 0.35, 95\% CI: -0.44 - 0.57$) was insignificant, thus the H₀ was accepted. The results differed significantly after the 2nd spray, ($t(DF) = 3.34(10), P = 0.007$) with average nymphs' number for A ($M = 1.88, SD = 0.53$) being higher than that of B ($M = 0.95, SD = 0.44$). The magnitude of the difference in means ($MD = 0.93, 95\% CI: 0.31 - 1.56$) was significant and thus, the H₀ was rejected. The results were statistically similar after the 3rd spray, ($t(DF) = (2.66(10), P = 0.24)$) as the nymph population for A ($M = 0.78, SD = 0.52$) was statistically close to that of B ($M = 0.20, SD = 0.14$). The magnitude of the difference in means ($MD = 0.58, 95\% CI: 0.09 - 1.07$) was not significant, thus the H₀ was supported. The effect size for the 1st spray (Cohen's $d = 0.57$) was medium while that of the 2nd and 3rd sprays (Cohen's $d = 1.93$ and 1.53) were large (Table 4.45).

Table 4.44: Effect of bio pesticides (A) and synthetic chemical (B) against the nymphs' population after the 1st, 2nd and 3rd sprays in 2022 experiment

No of sprays	Groups	Mean	SD	SEM±	F-value	T-stat	DF	P-value	MD	95% C.I.D		Cohen's D
										Lower	Upper	
1 st spray	A	2.12	0.26	0.10	0.97	3.18	10	0.01*	0.73	0.22	1.25	1.84
	B	1.38	0.50	0.21								
2 nd spray	A	1.87	0.46	0.19	3.28	5.44	10	<0.001**	1.10	0.65	1.55	3.14
	B	0.77	0.19	0.08								
3 rd spray	A	1.03	0.48	0.20	3.27	1.62	10	0.137 ^{NS}	0.37	-	0.87	0.93
	B	0.67	0.27	0.11						0.14		

SD= Standard deviation; SEM= Standard error mean; DF= Degree of freedom; MD= Mean difference; CID= Confidence interval of the difference; NS= non-significant; *= significant; **= very significant.

Table 4.45: Effects of the bio pesticides (A) and synthetic chemical (B) against thenymphs' population after the 1st, 2nd and 3rd sprays during 2023 experiment

No of sprays	Groups	Mean	SD	SEM±	F-value	T-stat	DF	P-value	MD	95% CID Lower Upper	Cohen's D	
1 st spray	A	4.12	0.72	0.29	1.36	0.99	10	0.35 ^{NS}	0.35	-	1.14	0.57
	B	3.77	0.48	0.20						0.44		
2 nd spray	A	1.88	0.53	0.22	0.29	3.34	10	0.007**	0.93	0.31	1.56	1.93
	B	0.95	0.44	0.18								
3 rd spray	A	0.78	0.52	0.21	8.68	2.66	10	0.24 ^{NS}	0.58	0.09	1.07	1.53
	B	0.20	0.14	0.05								

SD= Standard deviation; SEM= Standard error mean; DF= Degree of freedom; MD= Mean difference; CID= Confidence interval of the difference; NS= non-significant; *= significant; **= very significant.

4.9.3. Reduction in average adults and nymph population during the 2022 and 2023 Experiments

The trends in average adult population are depicted in figures 4.25 and 4.26 for 2022 and 2023 trials. The IPM strategy recorded highest adult population (8.6 whiteflies/leaf) at week 2, while the least (1.9 whiteflies/leaf) was found at week 6 after the 1st and 3rd sprays. For the synthetic chemical, the highest (5.9 whiteflies/leaf) was recorded at week 1 while the least (1.7 whiteflies/leaf) was found at week 5 after the 1st and 3rd sprays in 2022 trial (**fig 4.22**). In 2023, the IPM strategy recorded the highest number (9.6 whiteflies/leaf) at week 1 with week 5 having the least (0.9 whiteflies/leaf). The results were higher than was recorded in the synthetic chemical(8.4 and 0.3 whiteflies/leaf) at week 1 and 6 respectively after the 1st and 3rdsprays (**Fig 4.23**). The results for the treatments were non-linear as the number of whiteflies fluctuates around the data taking periods during experiments. The highest nymph population (2.2 nymphs/leaf)for the IPM module was recorded at week 1 while the least (0.9 whiteflies/leaf) was found at week 6

in 2022-year trial. The average number of nymphs was lower in the synthetic chemical recording 1.5 and 0.6 nymphs/leaf at week 2 and 6 respectively. Week 3 and 5 recorded similar result (0.7 nymphs/leaf each) having a linear trend (Fig 4.24). During the 2023 trial, the highest nymph population (4.4 nymphs/leaf) for the IPM treatment was recorded at week 2 while the least (0.7 nymphs/leaf) was found at week 6 during the 2023 trial. For the synthetic chemical, the average number of nymphs was lower than in the bio pesticides recording 3.8 and 0.2 nymphs/leaf as the highest and least average number at week 1 and 6 respectively (Fig 4.25).

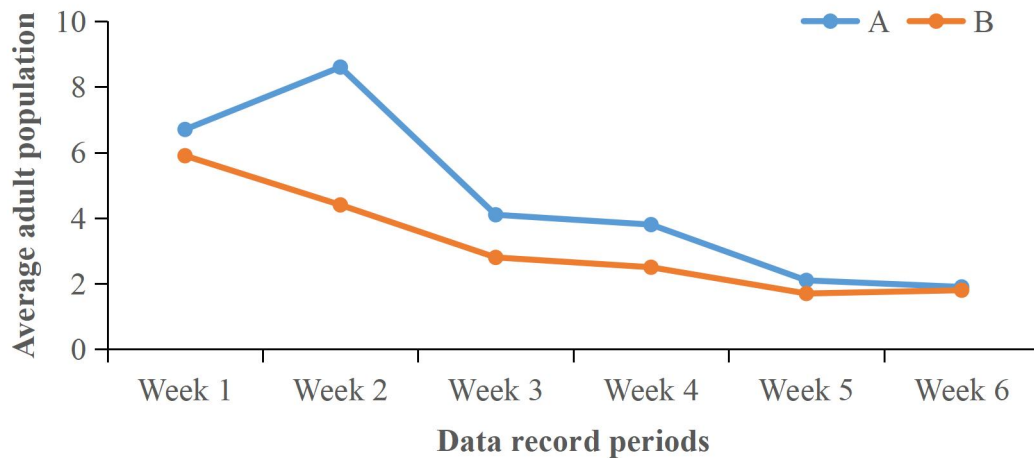


Fig 4.22: Reduction trends in average adultwhiteflypopulation/leaf of eggplant during the 2022 experiments

A= Bio pesticides; B= Synthetic chemical.

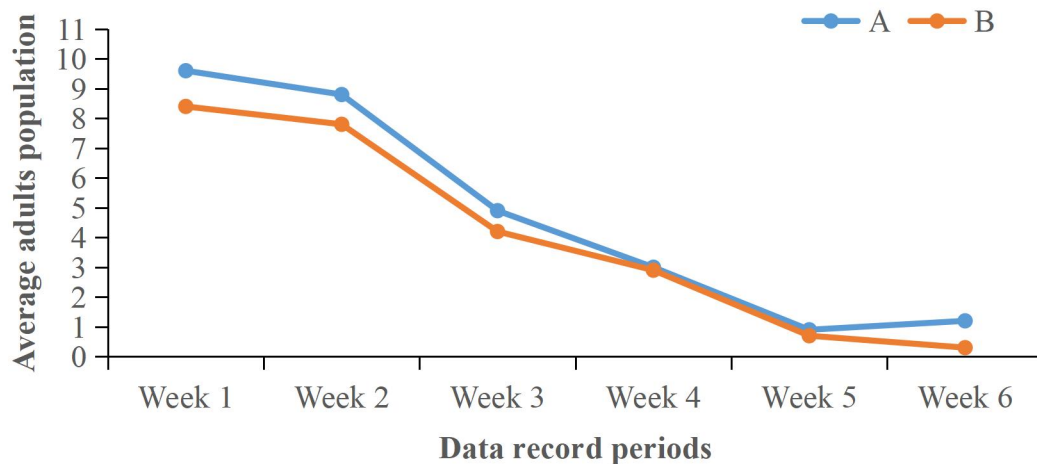


Fig 4.23: Reduction trends in average adult whitefly population/leaf of eggplant during the 2023 experiment. A= Bio pesticides; B= Synthetic chemical

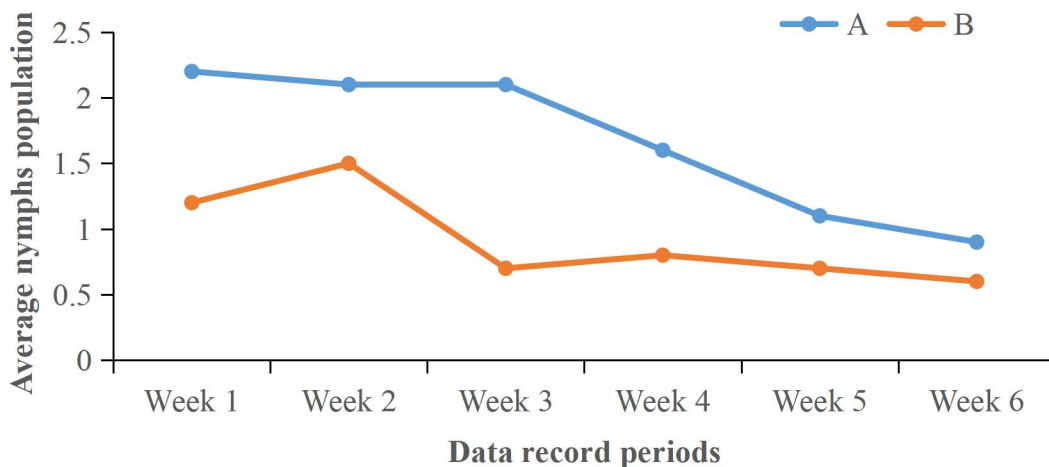


Fig 4.24: Reduction trends in average nymphs' whitefly population/leaf of eggplant during the 2022 experiment. A= Bio pesticides; B= Synthetic chemical

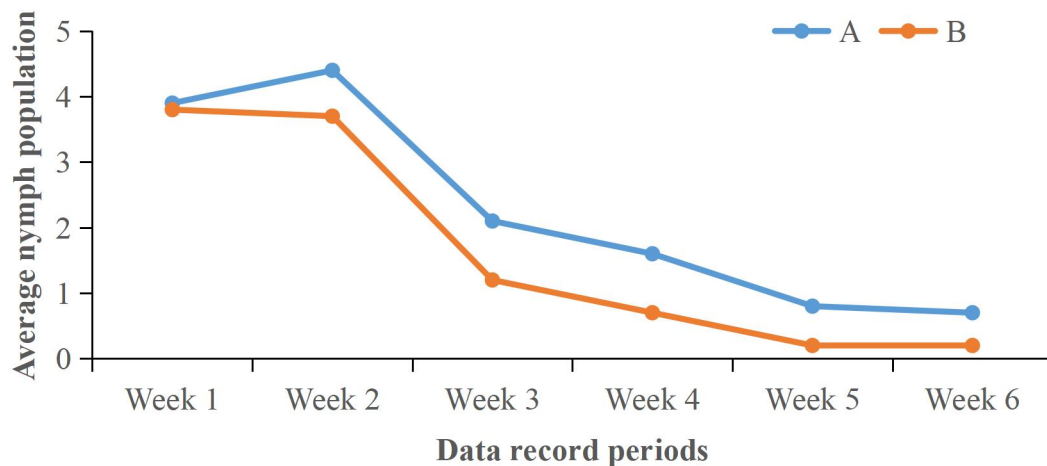


Fig 4.25: Reduction trends in average nymphs' whitefly population/leaf of eggplant during the 2022 experimentt. A= Bio pesticides; B= Synthetic chemical

Discussion

The potential of bio pesticides of plant origin along with yellow sticky traps in a synergistic manner was assessed for whitefly management on eggplant in the study area. Although the t-test results described the synthetic insecticides (chlorpyriphos 20% EC) as most effective in most of the data taking periods, the natural products examined (neem leaf extract, eucalyptus essential oil and yellow sticky traps) were found effective in reducing the whitefly density below the economic threshold level throughout the experimental periods. The IPM strategy has been demonstrated as effective insect pest management method via a combination of physical and biological practices, including the use of sticky traps (Chhetri 2018; Deguine et al. 2021). Estefana et al. (2019) examined a chemical, biological and IPM approaches in a series of experiments against the whiteflies and associated viruses and reported that the combined effects of the treatments had highpotential (73%), compared to deployment of the methods independently. Magsi et al (2022) reported that the use of yellow sticky traps along with organic pesticides in integrated pest management regimes (neem, bitter apple and tobacco extract) was substantial in reducing the percent density of flea beetle, leaf minor, whiteflies, thrips and

jassid on tomato plants. Their results demonstrated that the synthetic chemicals were more effective than the organic pesticides examined, similar to the effects described in the current study. Kumar et al. (2020) investigated the comparative efficiency of different modern insecticide along with some organic pesticides against the whitefly (*Bemisia tabaci* Gennadius) in brinjal crops. All the treatments were shown to be much more successful than control in lowering the whitefly densities, with the synthetic pesticides being more effective. Javed and Matthews (2002) also evaluated the efficacy of some new insecticides and fatty acids deposits on French bean. The results showed that fatty acid deposits caused 10.7% adults whitefly mortality, diafenthiuron caused 62.7%, and the combined effect led to 69.7% mortality. This is in compliance with the current findings revealing the higher effect of the synthetic chemical and the greatest effect of the integrated application of organic pesticides against the whitefly. Similarly, ash gourd was used to evaluate the effects of yellow sticky traps, plant extracts and synthetic chemicals in a synergistic setting and was reported to cause 100% whitefly inhibition 18 days after application (Tamilnayagan et al. 2019). This is higher than the result in the current study and the highest effect may be due the in cooperation of the synthetic chemical in the IPM regime. Several insecticides and bio pesticides were examined against the whiteflies on tomatoes in an IPM schedules where Cytraniliprole + lambda-cyhalothrin (50+30 g a.i. ha-1) reduced whitefly by 64% while about 72% larval mortality was recorded using 0.5% flaxseed + 0.3% sodium bicarbonate indicating the effectiveness of the IPM strategy in insect pest management practices (Arneemann et al. 2019). Togni et al. (2018) also reported that the integrated use of intercropping and sprinkler irrigation system was substantial in reducing the whitefly density on tomato crops. The combined effects of mineral oils along with Imidacloprid + thiamethoxam had led to reduction in *B. tabaci* population and viral disease incidence by 74.5 and 93.0% respectively. The application of clove and orange essential oils caused 70 to 90% mortality while the synergistic effects of zinc sulfate, orange and clove essential oils caused up to 97% mortality in tomatoes (Sawsan et al. 2015). Synthetic chemicals, plant extracts and entomopathogenic fungi were evaluated (Wawdhane et al. 2020) with Spiromesifen and imidacloprid being

reported to have the greatest reduction in whitefly numbers (82.27%, 80.57%) describing the higher effects of the chemicals over the plant extracts. This similar to the report of Kumar et al. (2020) who demonstrated that the field treated with synthetic chemical (imidacloprid 17.8 SL) @ 100 mL/ha recorded lowest whitefly density compared to those sprayed the with botanical extracts on the eggplants. The results in the current research complied with above scenarios and report described by Sana et al. (2021) who reported that the integrated application of botanicals was effective in reducing the average number of whiteflies per eggplant leaves (2.37) but was less substantial than the synthetic insecticides, lambda cyhalothrin with 2.21 whiteflies/leaf in their experiment. The combined application of cow urine with plant extract was also documented to caused up to 95.2% reduction in whitefly population (Singh et al. 2021) and a similar study showed that the whitefly mean number was highly reduced (2.22) using cow urine 20% + neem leaf extract 10% on the eggplant (Patel et al. 2017). Eucalyptus oil (3%) effectively reduces the population of not only whiteflies, but also hoppers and aphids with lower effects to the natural enemies. A study on the combined impact of eucalyptus and garlic oils as compared comparison to synthetic (organophosphate) insecticides against insect pests of bean and other natural enemies has been conducted (Mousa et al. 2013). Leaf hoppers density have been reduced substantially, with garlic oil having the highest effect (68.07%), followed by dimethoate and pestban (67.90%, 64.02%) while eucalyptus oil records the least (43.27%). This also described the lower effect of the eucalyptus oil than the synthetic chemicals when applied singly. Furthermore, the efficacy of the botanical oils on aphids also recorded garlic oil to be most effective (90.96%) followed by pestban (89.44%) and eucalyptus oil (80.66%) while dimethoate records the least (76.14%). This revealed that eucalyptus oil is more toxic on sap-sucking pests than the leaf hoppers, and this may be the reason for its higher effectiveness against the whiteflies in our studies.

The use of bio pesticides, particularly phytochemicals options in an integrated modules has been argued to be more suitable and sustainable alternatives for subsistence farmers across different regions of the world (Isman 2008; 2017), as supported by the current findings, demonstrating how phytochemicals can effectively manage the

population of pests and thus could be incorporated into sustainable crop production (Tembo et al. 2018). Besides crop protection against insect, plant-based products were reported to increase the agricultural yields of the crops, which made them generally accepted by smallholder farmers (Tembo et al. 2018; Okolo and Iludum, 2019). The current report has shown that integrated use of plant extracts and yellow sticky traps is substantial in reducing the whitefly number on the eggplants, and this has been in compliance with the several previous reports on the effectiveness of various IPM practices against different insect pests including the whiteflies.

CHAPTER FIVE

6.0. SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1. Summary

The green round eggplant cultivar (*Solanum melongena* L.) like many other solanaceous vegetables is of great agricultural importance in Kebbi State, Nigeria. It is the most cultivated eggplant variety in the area, mostly by subsistence farmers. It has simple agronomic maintenance practices and produce large round shaped green fruits that serve as great source of income for a vast number of families in different parts of the state. The fruits and vegetal parts mostly the leaves are eaten raw and are well known to possess diverse nutritional and health benefits to humans. Farmers are struggling hard to protect their vegetables including the eggplant against the various biotic constraints for improved crop productivity using synthetic chemicals which pose negative effects on the ecosystem and human health in addition to the recurrent price increment. This study determined the level of susceptibility and extent of damage due to whiteflies infestation on the green round variety of eggplant. To minimize the heavy reliance on chemical pesticides, different bio pesticides (traditional and plant extracts formulations) and integrated pest management schedule were explored. This was done in an attempt to provide safe, cost-effective and sustainable alternatives to synthetic chemicals for whitefly management so as to improve eggplant production in the study area.

6.2. Conclusion

In conclusion, our findings demonstrated that whitefly presence on eggplant could pose a severe leaf damage which consequently affects the entire growth parameters and crop yield. The infestation resulted to about 85.8 and 88.0% leaf damage in 2022 and 2023 respectively under field experiments. Similarly, about 90.1 and 93.2% leaf damage were recorded in the pot trials during the 2022 and 2023 experiments. As a result, a high yield loss of up to 92.1 and 90.1% were recorded for the respective field and pot trials. Among the traditional strategies examined against the whiteflies, neem leaf extract (60mL/L) and cow urine (75mL/L) proved most potent causing up to 96.1 and 95.7% reduction in

whitefly population in 2022 and 2023 experiments. From the plant-based products evaluated, eucalyptus oil (30 mL/L) and fermented extracts (200 mL/L) had the highest efficacy recording about 95.5 and 93.2% reduction in adult whitefly population 45 days after the 3rd spray in the respective years. The integrated use of the bio pesticides along with sticky traps was found effective, maintaining the adult density (2.02 and 1.05 adults/leaf) and nymphs' population (1.03 and 0.78 nymphs/leaf) below the economic threshold level during 2022 and 2023 experiments.

6.3. Recommendations

Looking at the serious menace and high degree of damage due to heavy infestation by whiteflies on the green round eggplant variety as observed in the current research, the following recommendations were raised:

There is need of urgent action and collaboration between the policy makers, scientists and farmers to provide a lasting solution on the effects of sap-sucking pests on vegetable crops in the area. This could be achieved through the development and deployment of bio pesticides from plants and animals' origins, as they are known to be safe, cost effective, eco-friendly and sustainable measures in mitigating such effects for improved crop productivity worldwide.

The effectiveness of the various organic pesticides examined in this study demonstrates that they possessed great bio pesticide potential due to the presence of diverse bio active compounds, which need to be further explored and developed in to naturally effective commercial pesticides to replace the synthetic chemicals in managing the effects of whitefly infestations for sustainable eggplant production in global perspective.

We are also suggesting that farmers should adopt the IPM strategies incorporating the diverse traditional practices along with these plants extracts and when need be, the limited use of chemicals so as to keep our environment, health and non-target beneficial insects safe from the detriments of overdependence on the synthetic chemicals against sap-sucking pests on the vegetables in the area.

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APPENDIXES

Appendix4 I

List of publications

1. **Abubakar M**, Koul B, Chandrashekar K, Raut A, Yadav D (2022). Whitefly (*Bemisia tabaci*) management (WFM) strategies for sustainable agriculture: A Review. **Agriculture**. 12(9):1317(**IF: 3.608**).
2. Koul B, Bhat N, **Abubakar M**, Mishra M, Arukha AP, Yadav D (2022). Application of natural coagulants in water treatment: A sustainable alternative to chemicals. **Water**. 14(22):3751. (**IF: 3.530**).
3. **Mustapha Abubakar**, Bhupendra Koul (2023). Field assessment of the effects of *Citrus aurantifolia* Christm and *Eucalyptus camaldulensis* Dehnh extracts for the management of *Bemisia tabaci* Gennadius on *Solanum melongena* L. in North West Nigeria. **International Journal of Tropical Insects Science** (Published) (**IF: 1.2**).
4. **Mustapha Abubakar**, Bhupendra Koul, Ankush Raut, Sanusi Muhammad (2023). Effects of feeding by whitefly (*Bemisia tabaci* G.) and its management using *Citrus aurantium* extracts on brinjal. **Indian Journal of Entomology** (Published)(**SJR:0.12**).
5. **Abubakar Mustapha**, Yadav, D.; Koul Bhupendra, Song M (2023). Efficacy of EcoFriendly Bio-Pesticides against the Whitefly *Bemisia tabaci* (Gennadius) for Sustainable Eggplant Cultivation in Kebbi State, Nigeria. **Agronomy** 2023(13): 308 (published) (**IF: 3.7**)

Review

Whitefly (*Bemisia tabaci*) Management (WFM) Strategies for Sustainable Agriculture: A Review

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Abstract: The whitefly (*Bemisia tabaci* Gennadius) is a notorious devastating sap-sucking insect pest that causes substantial crop damage and yield losses due to direct feeding by both nymphs and adults and also through transmission of viruses and diseases. Although the foliar application of synthetic pesticides is crucial for efficient control of *B. tabaci*, it has adverse effects such as environmental pollution, resistance and resurgence of the pest, toxicity to pollinators, and crop yield penalty. Thus, a suitable, safe, and robust strategy for the control of whiteflies in the agricultural field is needed. The reports on whitefly-resistant transgenic plants are scanty, non-reproducible, and/or need secondary trials and clearance from the Genetic Engineering Appraisal Committee (GEAC), the Ministry of Environment and Forests (MoEF), and the Environmental Protection Agency (EPA). The present review encompasses explicit information compiled from 364 articles on the traditional, mechanical, biological, biotechnological, and chemical strategies for whitefly management (WFM), IPM strategy, and future prospects of WFM for food and agriculture security.

Keywords: whitefly management; sap-sucking; traditional methods; botanical pesticides; biotechnological strategies; IPM



Citation: Abubakar, M.; Koul, B.; Chandrashekar, K.; Raut, A.; Yadav, D. Whitefly (*Bemisia tabaci*) Management (WFM) Strategies for Sustainable Agriculture: A Review. *Agriculture* **2022**, *12*, 1317. <https://doi.org/10.3390/agriculture12091317>

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1. Introduction

The whitefly, *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae), is a worldwide polyphagous insect pest that has wreaked havoc on agricultural productivity, particularly in some plant families such as Solanaceae, Cucurbitaceae, and Fabaceae [1,2]. Whiteflies are tiny sugar-robbers that originated from southern Asia but are now found across all regions of the globe, most notably in tropical regions [3,4], except Antarctica [5]. Their aggressive feeding on plant sap from leaf tissue causes substantial losses to agricultural crops [6]. Each female is capable of producing about 320 eggs within a single life cycle [7,8]. In a controlled environment with warm climatic conditions, whiteflies maintain a high rate of reproduction for the whole year [9,10] and have the capacity to achieve exceptionally high population size within few generations.

Whiteflies cause substantial damage and economic losses to susceptible crops [11]. Both young (nymphs) and the adult stage [12] (Figure 1) suck sap and while feeding, they excrete honeydew (sugary excreta) that promote 'sooty mold' on the foliage and fruits, leading to adverse effects on crop productivity [13,14]. Affected plants show yellowing, folding of the foliage, decreased plant development, and disfigured fruit [15]. The nymphs inject enzymes during feeding which alter the crop physiology and consequently results in decreased internal pigmentation and abnormal fruit ripening [16]. Whiteflies spread viral

Review

Application of Natural Coagulants in Water Treatment: A Sustainable Alternative to Chemicals

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Abstract: Water treatment (WT) is currently among the major areas of research due to the depletion of water resources and fearmongering regarding environmental pollution, which has compelled the upgrading of conventional WT technology towards recycling and reuse. This review aims to provide the current state of natural coagulants and their application in the purification of surface water as sufficient clean water is required for household needs, health security, and environmental safety. A thorough and systematic review of the existing literature was performed, and the information related to water treatment using natural coagulants was compiled from 237 articles under various sections using a computerized bibliographic search via PubMed, Scopus, Web of Science, Google Scholar, CAB Abstracts, and several websites. The work provides explicit information related to natural coagulants and their merits and limitations, outlines methods to increase their coagulation performance, and highlights their coagulation mechanism, efficacy, valorization potential, and sustainability. From the information obtained, it can be concluded that although chemical coagulants are efficient in WT, they are usually expensive, toxic, associated with health issues, and thus non-sustainable. A sustainable alternative is the use of natural coagulants, which are readily available, economical, easy to use, biodegradable, non-toxic, eco-friendly, effective, and generate lower sludge volumes. They work via an adsorption process that involves polymeric bridging or neutralization of the charge. The WT efficiency of natural coagulants ranges from 50–500 nephelometric turbidity units (NTUs), which is similar to chemicals. Thus, they can be deployed in WT regimes and can contribute to the health security of rural populations in developing countries. It is unfortunate that, despite the known benefits of natural coagulants, their acceptance, commercialization, and widespread industrial application across the globe are still low. Therefore, there is a need for more exhaustive investigations regarding the mode of action, adoption, and commercialization of natural coagulants as a sustainable alternative to chemicals for a circular economy.

Keywords: biodegradable; sustainable; cost-effective; eco-friendly; natural coagulants

1. Introduction

Water is an indispensable and precious substance for living beings on earth, as it is required for various domestic, agricultural, and industrial activities [1,2]. Approximately 1400 million cubic kilometers of water are available on earth, with 97.5% and 2.5% in marine and freshwater bodies, respectively [1]. Thousands of pollutants that are hazardous to man and ecosystems were identified in water bodies worldwide [3]. Water pollution is caused by several non-anthropogenic mechanisms such as hydrogeologic processes, changes in the climate, natural disasters like floods, droughts, earthquakes etc., as well as atmospheric



Field assessment of the effects of *Citrus aurantifolia* Christm and *Eucalyptus camaldulensis* Dehnh extracts for the management of *Bemisia tabaci* Gennadius on *Solanum melongena* L. in north west Nigeria

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Abstract

The whitefly (*Bemisia tabaci* Gennadius) is a destructive sap-sucking pest of agricultural importance ravaging various vegetables causing significant damage and crop yield penalty. Its management is largely dependent on the synthetic pesticides despite their negative effects on human health and environment. The aim of this study was to analyze the efficacy of *Citrus aurantifolia* Christm and *Eucalyptus camaldulensis* Dehnh extracts against the whitefly on eggplant (*Solanum melongena* L.) under field conditions during 2022 and 2023 cropping seasons. The results revealed that citrus fermented extract (200 mL L⁻¹) was more effective with an average of 13.4 whiteflies/leaf, followed by eucalyptus oil (30 mL L⁻¹) with 17.2 whiteflies/leaf, 15 days after the 1st spray in 2022 experiment. Citrus essential oil (10 mL L⁻¹) was least effective during the same period with 29.4 whiteflies/leaf as compared to the control with 36.8 whiteflies/leaf. In 2023 experiment, eucalyptus oil (30 mL L⁻¹) and citrus fermented extract (200 mL L⁻¹) effectively reduced the whitefly number (13.1 and 16.1 whiteflies/leaf) while their aqueous extracts (100 mL L⁻¹) were least effective (27.8 and 31.3 whiteflies/leaf). In both the years (2022 and 2023), eucalyptus oil (30 mL L⁻¹) remained most effective with an average of 1.8 and 1.5 whiteflies/leaf (93.23 and 95.50% reduction in whitefly count), 45 days after the 3rd spray. The phytochemicals analyzed in this research demonstrated high efficacy and are therefore recommended as eco-friendly alternatives to synthetic chemicals in the management of whiteflies for sustainable vegetable cultivation.

Keywords Plant essential oils · Fermented extracts · Eggplant · Eco-friendly extracts · Whitefly management

Introduction

Eggplant (*Solanum melongena* L.; family: Solanaceae) is an important fruit vegetable in West Africa (Hanson et al. 2006; Ndagana et al. 2020). It is a perennial crop but mostly grown as annual, and can reach a height of up to 1.5 m under ideal environmental conditions (Jaiswal 2020). Eggplant has several nutritional values, and is considered a rich source of

dietary fiber, proteins, vitamins, carbohydrates and minerals, particularly potassium, calcium, phosphorus, magnesium and iron (Anjorin et al. 2013; Farouk et al. 2021). The crop is well known to possess vital phytochemicals including flavonoids, phenolics, steroid alkaloids, ascorbic acid, riboflavin and thiamin (Naeem and Ugur 2019; Shama and Kaushik 2021). It has been reported to be effective in the treatment of various ailments due to its anti-cancer, anti-asthmatic, antioxidants, anti-diabetic and anti-inflammatory properties (Gürbüz et al. 2018; Rodan et al. 2020).

Eggplant cultivation has been constrained by various biotic agents that reduce its production and farmers' profitability (Magioli and Mansur 2005). Pathogenic organisms including fungi (Nahar et al. 2019), bacteria (Nishat et al. 2015) and viruses (Lu et al. 2019; Estefania Rodriguez et al. 2019) have become a great concern in eggplant production. Furthermore, several insect pests including aphids (*Aphis*

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EFFECTS OF FEEDING BY WHITEFLY *BEMISIA TABACI* (GENN.) ON BRINJAL AND ITS MANAGEMENT USING *CITRUS AURANTIUM* EXTRACTS

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ABSTRACT

This study examined the extent of damage caused by *Bemisia tabaci* (Genn.) on brinjal and the effects of citrus extracts in managing the menace using randomized block design during the 2022 and 2023 cropping seasons. The variety examined was highly susceptible with plants in T₂ being the most affected. Citrus extracts differed significantly ($p \leq 5\%$) with its essential oil (30 ml/l) being the most effective. The extracts are recommended to be incorporated in *B. tabaci* management practices of brinjal.

Key words: Leaf damage, brinjal, cost-effective, ecofriendly *Bemisia tabaci*, sap sucking pests, *Citrus aurantium*, pest control, susceptible, infestation, management, Nigeria

Brinjal (*Solanum melongena* L.) is an important vegetable (Anjorin et al., 2013; Chapman, 2019; Naem and Ugur, 2019). *Bemisia tabaci* is highly destructive insect pest that feeds on the phloem sap of vegetable plants, causing a range of damaging effects including reduction in plant transmission of harmful viruses (Sani et al., 2020; Ugwu et al., 2021). They also release honeydew, which lead to the development of sooty mold that blackens the leaves and affect the crop photosynthetic ability (Solanki et al., 2018; Perring et al., 2018). There is heavy reliance on synthetic pesticides for *B. tabaci* control, but the use of these chemicals posed a great health and environmental hazards and can lead to development of resistance (Shah et al., 2019; Abubakar et al., 2022). The development of safer and cost-effective alternatives for managing *B. tabaci* is therefore of utmost importance. Plant-based extracts have emerged substantial in this regard as they have been proven effective in reducing the density *B. tabaci* on various agricultural crops (Hussein et al., 2017; Kumar et al., 2019; Farina et al., 2022). There is little information on the extent of damage due to *B. tabaci* infestation, and the use of citrus extracts for its management, specifically on the green round brinjal cultivar, in Kebbi State, Nigeria. Previous studies have focused more on the effects on the physiological and biochemical parameters, neglecting the cumulative effects of infestation on plant growth (Li et al., 2013; De Lima Toledo et al.,

2021). Understanding the level of leaf damage caused is crucial and these along with plant based products of evaluated will provide cost-effective strategies. This study therefore aims to assess the extent of damage due to *B. tabaci* infestation on the green round brinjal cultivar and to evaluate the potential of *C. aurantium* essential oil extracts for its management.

MATERIALS AND METHODS

This study was carried out in the Agricultural Research Farm of the Kebbi State University of Science and Technology, Aliero, Kebbi State, Nigeria 12° 13' 19.88"N 4° 22' 46.67"E from December to May, during the 2022 and 2023 cropping seasons. The variety used was the green round brinjal cultivar, being the most cultivated in the area for which seeds were procured from Afrimash Company Limited, Ibadan, Nigeria. The seedlings were raised using portable sunken nursery beds Ghosh (2022). Randomized block design (RBD) consisting of four plots and treatments (T₁= 15, T₂= 30, T₃= 45 and T₄= control with 0 whiteflies/ plots) replicated four times was used to assess the damage caused. Each plot measuring 1x 1m² (covered with mosquito nets) with 0.5 m space between the plots was transplanted with three seedlings at 60x 60 cm spacing. The required number of *Bemisia tabaci* for each plot was counted as they were caught from the vegetables using aspirator and released into the demarcated plots. The damage assessment was done following the method

Article

Efficacy of Eco-Friendly Bio-Pesticides against the Whitefly *Bemisia tabaci* (Gennadius) for Sustainable Eggplant Cultivation in Kebbi State, Nigeria

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Abstract: The eggplant (*Solanum melongena* L.) is among the vital fruit vegetables cultivated globally for its health and nutritional benefits. However, its production has been hindered by whiteflies (*Bemisia tabaci* G.) infestation worldwide. This study aims to assess the effect of some bio-pesticides in the control of whiteflies on eggplants under field conditions. The trial consists of seventeen (17) treatments replicated three times for 45 days. From the results obtained, neem leaf extract (60 mL/L) proved more effective against whiteflies, with 1.2 and 1.3 adults/leaf, while buttermilk and cow dung (50 mL/L) were less effective (10.1 and 10.8 adults/leaf) when compared to untreated plots (26.9 and 33.4 adults/leaf), two weeks after the third spray during the first and second trials. The highest reduction (%) in whitefly population was found using neem leaf extract (95.7 and 96.1%) and cow urine (85.8 and 96.1%), with cow dung and buttermilk exhibiting the least overall averages (65.9 and 62.3%), two weeks after the third spray during the respective trials. Neem extract and cow urine were more effective among the treatments examined and, thus, recommended to be incorporated into control strategies of whiteflies for the improved production of eggplants in the area.

Keywords: *Solanum melongena* L.; whiteflies; neem leaf extract; sustainable; pest management



Citation: Abubakar, M.; Yadav, D.; Koul, B.; Song, M. Efficacy of Eco-Friendly Bio-Pesticides against the Whitefly *Bemisia tabaci* (Gennadius) for Sustainable Eggplant Cultivation in Kebbi State, Nigeria. *Agronomy* 2023, 13, 3083. <https://doi.org/10.3390/agronomy13123083>

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1. Introduction

The eggplant (family: Solanaceae), also known as brinjal (*Solanum melongena* L.), is a vital fruit vegetable in Asia, Europe, and Africa, with an acreage of over 2 million hectares and an annual yield of 33 million tons, worth USD 10 billion [1,2]. This nutritious vegetable is abundant in dietary fiber, vitamins, and several essential elements [3,4]. Furthermore, it is enriched with valuable phytochemicals such as flavonoids, phenolics, and thiamin [5,6]. These contribute to its potential role in offering various health benefits, such as anticancer, anti-asthmatic, and antioxidant, as well as antidiabetic, effects.

The whitefly (*Bemisia tabaci* Gennadius; Hemiptera: Aleyrodidae) is a highly destructive sap-sucking pest that affects various crops, particularly solanaceous vegetables [7,8]. The eggplant is among the most affected crops by whitefly infestation, causing direct and indirect feeding effects that lead to a reduction in both the physiological and morphological parameters of the crop [9,10]. An infestation by a large whitefly density also leads to the release of honeydew and sooty mold development, which blackens the leaves, reduces the rate of photosynthesis, and, ultimately, the yield of the crop [11–15]. Whiteflies are also known as vectors of more than 350 species of viruses in different vegetables. Eggplant mild leaf mottle virus (EMLMV) [16], tomato torrado virus (ToTV) [17], and tomato yellow leaf curl virus (TYLCV), which are vectored by whiteflies and frequently seen in tomatoes,

List of conferences participated

1. **Mustapha Abubakar**, Bhupendra Koul, Ankush Raut (2023). Field evaluation of the potential of cow-based products in the management of whitefly (*Bemisia tabaci* G.) on eggplant (*Solanum melongena* L.). A paper presented at **International Conference on Latest Trends and Innovations in Pharmaceutical and Biosciences (ICLTIPB-2023)** organized by Carrier Point University, Kota Rajasthan.
2. **Mustapha Abubakar**, Bhupendra Koul, Ankush Raut (2023). The potential of sour orange (*Citrus aurantifolia* L.) and eucalyptus (*Eucalyptus camaldulensis* Dehn) essential oils in the control of whiteflies (*Bemisia tabaci* G.) on Eggplant (*Solanum melongena* L.)” a paper presented at **4th International conference ‘Recent Advances on the Fundamental and Applied Sciences (RAFAS 2023)** organized by School of Chemical Engineering and Physical Sciences, Faculty of Technology and Sciences LPU India.
3. **Mustapha Abubakar**, Bhupendra Koul, Ankush Raut (2023). “Susceptibility of eggplant (*Solanum melongena* L.) to whitefly (*Bemisia tabaci* G.) infestation in Northern Nigeria” a paper presented at the **2nd International conference on Plant Physiology and Biotechnology (ICPPB-2023)** organized by School of Bioengineering and Biosciences LPU India.
4. **Mustapha Abubakar**, Bhupendra Koul, Ankush Raut, Sanusi Muhammad (2023). “Efficacy of traditional whitefly (*Bemisia tabaci* G.) management strategies for sustainable eggplant (*Solanum melongena* L.)” presented at ICAATAS, 2023.





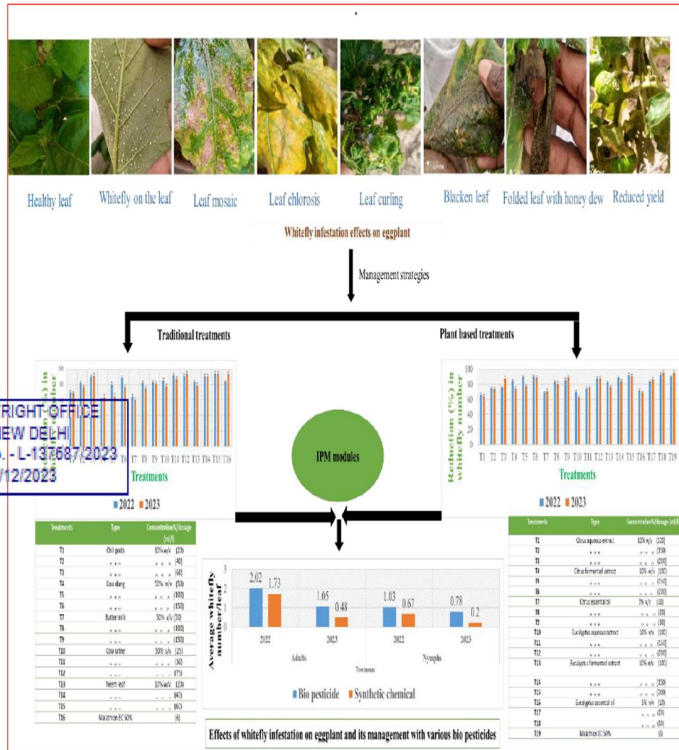
Workshop attended

1. Attended an Expert Lecture on ‘Troubleshooting Solutions in Production of Phytomolecules’ By Dr. Dharam Chand Jain organized by School of Pharmacy, Carrier Point University Kota, India.



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10. Name and address of the assignee, if any, and name, address and nationality of the assignee: UNAPPLICABLE

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12. Name and address of the assignee, if any, and name, address and nationality of the assignee: UNAPPLICABLE

13. Name and address of the licensee, if any, and name, address and nationality of the licensee: UNAPPLICABLE

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15. Name and address of the licensee, if any, and name, address and nationality of the licensee: UNAPPLICABLE

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