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EVALUATION OF THE SUSCEPTIBILITIES OF SOME SELECTED EGGPLANT ACCESSIONS TO MAJOR INSECT PESTS IN THE FIELD AND UNDER SCREENHOUSE CONDITIONS.

BY

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THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF AN MPHIL IN ENTOMOLOGY DEGREE

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Collaborating Departments: Animal Biology and Conservation Science (School of Biological Sciences) and Crop Science (School of Agriculture and Consumer Sciences).

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DECLARATION

I certify that this is the outcome of my original research work that I have submitted to the University of Ghana for the award of a Master of Philosophy degree in Entomology, except for properly cited sources. Nothing previously submitted or accepted, in whole or in part, for the award of any other academic degree in this thesis.

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DEDICATION

I dedicate this thesis to the real superhero in my life, my dad, Mr. Gabriel Doe Tamakloe of blessed memory. I am eternally grateful for your selflessness and support. With you, all the good things in my life are made better. God bless you!

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"*Not that we are adequate in ourselves to consider anything as coming from ourselves, but our adequacy is from God*" - 2 Corinthians 3:5.

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LIST OF ABBREVIATIONS

Acetyl-CoA	Acetyl Coenzyme A
ANOVA	Analysis of Variance
BMI	Body Mass Index
CG	Control Group
cm	Centimetre
CO_2	Carbon dioxide
COVID-19	Coronavirus Disease 2019
CRD	Completely Randomized Design
DBM	Diamondback Moth
EFSB	Eggplant Fruit and Shoot Borer
ETL	Economic Threshold Limit
FAO	Food and Agriculture Organization
FOHCREC	Forest and Horticultural Crops Research Centre
g/L	Grams per Litre
HPR	Host Plant Resistance
i.e.	That is
IPM	Integrated Pest Management
kg	Kilogram
kg/ha	Kilogram per Hectare
LED	Light-emitting Diode
LSD	Least Significant Difference
m	Metre(s)

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m^2	Metre Square/Squared Metre
MoFA	Ministry of Food and Agriculture
MRL	Maximum Residual Limit
NPK	Nitrogen Phosphorus Potassium
O_2	Oxygen gas
^oC	Degree Celcius
pH	Power of Hydrogen/Potential of Hydrogen
PLD	Percentage of Leaf Damage
PPRSD	Plant Protection and Regulatory Services Directorate
RCBD	Randomised Complete Block Design
S.E.	Standard Error
sp./spp.	Species
t/ha	Tonnes per Hectare
TG	Treatment Group
TL_{14}	Total Leaves in 14 days
TLD	Total Leaves Damaged
WAT	Weeks after Transplanting

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ABSTRACT

The scarlet eggplant, *Solanum aethiopicum*, holds significant importance for indigenous communities in Africa. Although its production is widespread, it faces a common challenge: depredation by insect pests, including the destructive eggplant fruit and shoot borer (EFSB), *Leucinodes* spp. The larvae of this pest feed by tunnelling into tender shoots or boring into fruits, leading to plant wilting or death and loss of fruit value and aesthetics. Farmers often resort to synthetic insecticides to manage these insects, but this approach has negative implications, such as residues in fruits, the development of insect resistance, and environmental pollution. Consequently, there is a growing need for safe, cost-effective, and sustainable management options. One such option is host plant resistance, a natural phenomenon based on the plant's self-defence mechanisms. In this study, the performance of five eggplant accessions (RV100213, RV100248, RV100250, RV100307, and Legon1) was evaluated against EFSB. The evaluation was conducted in open fields at the Forest and Horticultural Crop Research Centre (FOHCREC), Kade, and under screen-house conditions during two cropping seasons in 2022. Plant growth parameters, fruit yield, insect damage or incidence, and plant hardiness were used as indices for plant performance against EFSB. The data collected indicated significant differences ($P \leq 0.05$) in plant height and the number of leaves among the accessions in both the open field and screen house experiments. Fruit yield also varied significantly among the accessions. The percentage of EFSB infestation ranged between 29 – 45 for shoots and 20 – 62 for fruits. Generally, infestation on shoots and fruits for all the tested accessions was considered high and were ranked between moderately susceptible to highly susceptible on a 6-point scale (1-immunity, 2-resistant, 3-Moderately resistant, 4-moderately susceptible, 5-susceptible, 6-highly susceptible) for host plant resistance against the eggplant fruit and shoot borer. The findings of this study can be used to

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determine the optimal time to initiate management procedures to prevent ESFB infestation in the fields.

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CHAPTER ONE

1.0. INTRODUCTION

1.1. Background

Vegetables are edible plant parts that are consumed worldwide either raw or minimally processed (FAO, 2020), providing a rich source of vitamins and minerals that enhance the taste, texture, and diversity of global cuisines (Muimba-Kakonlogo, 2018). Their inclusion in a balanced diet is crucial for maintaining optimal health, fitness, and well-being (Aetiba and John, 2015). Vegetables play a significant role in reducing BMI and the risk of chronic diseases such as cardiovascular diseases, diabetes, stroke, and cancer, and they are even more important than animal products (Tello, 2018).

Before the COVID-19 pandemic, there was a 50% increase in global vegetable production between 2000 and 2020, with the Family Solanaceae (nightshade plants) leading the way. Eggplant is a key crop in this family, estimated with an annual production of over 54 million tonnes valued at $10 billion (FAO, 2020), however, potatoes, tomatoes, peppers, and tobacco have more economic importance (FAO, 2014; Taher *et al.*, 2017). Known as the "King of Vegetables", eggplants are celebrated for their nutritional value and versatility (Gowda, 2016), with the most popular varieties being *Solanum melongena* (aubergine or brinjal), which is grown worldwide, and the native African varieties *S. aethiopicum* (scarlet eggplant) and *S. macrocarpon* (gboma eggplant), which are grown primarily in Africa (Duanay and Hazra, 2012; Taher *et al.*, 2017).

Solanum macrocarpon, primarily found in tropical and subtropical Africa's wetter regions, is consumed as a green vegetable, with its young leaves often used in curries, meat dishes, and soups. The young leaves are often cooked and used in curries, meat dishes, and soups. It has 89.7% moisture, 4.3% protein, 1.4% crude fibres, 0.6% fat, and 1.3% ash in its fresh leaves. It shares

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physiological and morphological similarities with *S. melongena* and can be used as a genetic resource to improve brinjal's agronomic qualities (Singh *et al.*, 2010).

Solanum aethiopicum thrives in warm Afrotropical climates and is a staple in Sub-Saharan Africa. The crop is simple to grow, high-yielding, and easy to harvest and handle. Its fruit is a popular meat substitute in vegan dishes, and its high water, vitamin, mineral, and fibre content makes it an excellent addition to protein and carbohydrate-rich diets (NRC, 2006; Okon *et al*., 2010). The leaves are consumed fresh or cooked in soups and sauces (PROTA, 2013), and the fruits, leaves, and roots are rich in bioactive compounds and other phytochemicals with pharmacological properties such as anthocyanin and phenolic acids, carotenoids and glycoalkaloids (Gajewski *et al.*, 2009; Plazas *et al.*, 2013; Braga *et al.*, 2016; Gurbuz *et al*., 2018).

In Ghana, the scarlet eggplant is cultivated year-round in the southern and central regions, particularly in the forest zones, provided there is adequate water supply (Owusu-Ansah *et al.*, 2001). The crop is consumed locally, especially in rural and peri-urban areas, and is also exported mainly to Europe and other international markets (Horna *et al.*, 2008; Bonsu, 2017). It is a vital crop, contributing about 60% of revenue for smallholder farmers and rural households (Aetiba and John, 2015), and remains affordable even when other vegetable prices increase (Hanson *et al.*, 2006).

However, eggplants are susceptible to various insect pests from the nursery stage through to harvest. They are often cultivated intensively with minimal rotation in confined spaces, creating ideal conditions for insect pests to proliferate and inflict damage. Aphids, whiteflies, thrips, flea beetles, lace bugs, and grasshoppers are among the most common pests (Mensah *et al.*, 2022). The primary pest in all eggplant-growing regions is Leucinodes spp., also known as the eggplant fruit

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and shoot borer (EFSB), which is prevalent in Africa (CABI, 2022). The larvae are in the destructive stage, causing damage that can reach 70% and over, depending on their abundance and infestation rates (Netam *et al.*, 2018; Taiwo *et al.*, 2020). The larvae bore into the tender shoots and feed there, leading to wilt, tip death, and a decrease in yield. They also create distinctive circular holes with frass in the fruits, causing quality and marketability blemishes. Due to its significant potential for damage, it is categorized as a quarantine/regulated pest in regions outside its host range (EFSA PLH Panel, 2021).

Infestations have significantly increased farmers' reliance on pesticides, as they provide the most cost-effective and efficient pest control results (Horna *et al.*, 2008). To harvest unblemished marketable fruits and reduce post-harvest losses, some farmers excessively spray insecticides and apply other chemical concoctions to crops at random intervals, disregarding pre-harvest periods (Avicor *et al.*, 2011). These practices harm the environment by negatively impacting both beneficial and non-target species. The minimum residual limits (MRL) of pesticides are likely to be exceeded, potentially contributing to the relatively shorter shelf-life of harvested produce and posing a significant consumer health concern (Ntow *et al.*, 2006). Over-reliance on pesticides is likely to increase production costs and reduce profit margins.

Furthermore, the demand for vegetables will continue to rise due to population growth and shifting consumer preferences. Although agriculture forms the backbone of nearly all African economies (Baumuller *et al*., 2020), food security issues persist, particularly in Sub-Saharan Africa (Mohajan, 2022). Scarlet eggplant is commonly produced in the region and has the potential to contribute significantly to the food supply (NRC, 2006), although farmers still prefer local landraces. There is a need for improved varieties that are resistant to pests and high-yielding (Dinssa *et al.*, 2016),

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even though finding the source of resistance in eggplants remains a major challenge (Pugalendhi *et al.*, 2010).

It is crucial to address and resolve the issues of insect pests sustainably to protect the environment and consumers' health and meet demands. As such, integrated pest management (IPM) is a prudent and highly sought strategy with host plant resistance (HPR) as the foundation and major component (Than *et al.*, 2008). Resistant varieties have the inherent ability to restrict, retard, or recover from infestation and significantly minimise pest damage (Ayyaz *et al.*, 2017). Although the genetic diversity in *S. aethiopicum* is high, it is still largely unexploited through research and falls far short of its potential compared to its Asian counterpart, *S. melongena* (Grubben and Denton, 2004).

1.2. Objectives

The primary objective of this study is to evaluate the susceptibility of five eggplant accessions to major insect pests, both in the field and under screen house conditions.

The specific objectives are as follows:

1. To identify the major insect pests and monitor their population trends on the eggplant accessions in the field.
2. To evaluate the growth parameters and yield of the eggplant accessions in the field and under screen house conditions.
3. To quantify the percentage of leaf damage on the eggplant accessions in the field.
4. To determine the percentage of fruit and shoot damage caused by the eggplant fruit and shoot borer on the eggplant accessions in the field and under screen house conditions.
5. To ascertain the resistance or susceptibility of the five eggplant accessions to the eggplant fruit and shoot borers.

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CHAPTER TWO

2.0. LITERATURE REVIEW

2.1. Vegetables

A vegetable is defined as any part of a wild or cultivated plant that is harvested and consumed, either fresh or processed, to meet human nutritional needs (Welbaum, 2015). Vegetables are a vital component of many diets due to their high content of vitamins, minerals, dietary fibre, and other essential secondary constituents that promote good health (Amo-Adjei and Kumi-Kyereme, 2015). However, the composition of vegetables can vary significantly depending on their origin and cultivar (Belitz *et al.*, 2008).

In Ghana, a variety of vegetables, both indigenous and introduced, are consumed and have become an integral part of the local culture and traditions. Indigenous vegetables are particularly well-adapted to the regional growing conditions (Hughes and Ebert, 2013), and they offer a promising source of household income and contribute to food security (Amagloh *et al.*, 2017). Despite their significant potential, some indigenous vegetables remain under-utilized and marginalized, with insufficient efforts made to enhance their production, use, and recognition (Nyaruwata, 2019). The scarlet eggplant, *S. aethiopicum*, is one such example.

2.2. The scarlet eggplant, *Solanum aethiopicum*

2.2.1. Origin, Taxonomy and Botany

Solanum aethiopicum, also known as the scarlet eggplant, bitter tomato, or garden eggs, is a plant in the Solanaceae family (nightshade plants). It is native to Africa and was domesticated from the tropical African species *S. anguivi* and *S. distichum* (Grubben and Denton, 2004; Lim, 2015).

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The scarlet eggplant is a deciduous shrub often cultivated as an annual crop, but it can also be a perennial depending on the variety. The crop thrives in deep, well-drained soils (Han *et al.*, 2021). It has a root system that spreads both laterally and vertically for anchorage. The stems are woody and branching, bearing broad leaves that are alternately arranged with smooth or lobed margins. Some varieties may have stems and leaves that are either hairy or glabrous (Grubben and Denton, 2004). The flowers, which are either white or pale purple, are typically bisexual. They mostly self-pollinate, but with the help of insect pollinators, they can cross-pollinate to increase gene exchange and hybrids in a natural population, thereby reducing inbreeding (Prasad and Prakash, 1968). The fruits, which are produced either singly or in clusters, vary in size, shape, colour, and flavour or taste (NRC, 2006). The crop produces a large yield and is ready for harvest 100 to 120 days after sowing. The seeds are small, lenticular, flattened, and either pale yellow or brown (Lester and Seck, 2004).

The taxonomy of *S. aethiopicum* is complex and highly variable due to the vast morphological differences in the many forms and types of local varieties (NRC, 2006). The species comprises four distinct groups: Gilo, Kumba, Shum, and Aculeatum (Poligano *et al.*, 2010).

The Gilo group is the most cultivated throughout sub-Saharan Africa for its edible fruits, particularly in humid regions. The fruits can be spherical or elongated, spindly or egg-shaped, smooth or ribbed, and white, light to dark green, or striped. Immature fruits are preferred over fully ripe fruits; some are sweet, while others are bitter. The leaves of the Gilo group are hairy and inedible.

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Plate 2.1: Different shapes and colours of fruits in the Gilo group.

The Kumba group is characterized by large glabrous leaves and stout stems, and its fruits are ribbed and flattened, resembling small pumpkins. Some varieties have robust thorns or spikes on the stems and leaves. This group is often cultivated in the semi-arid regions of tropical Africa, and both the fruits and leaves are consumed either cooked or raw. The colour of the fruits can vary depending on the variety. The fruits of the Kumba group are depicted in Plate 2.2.

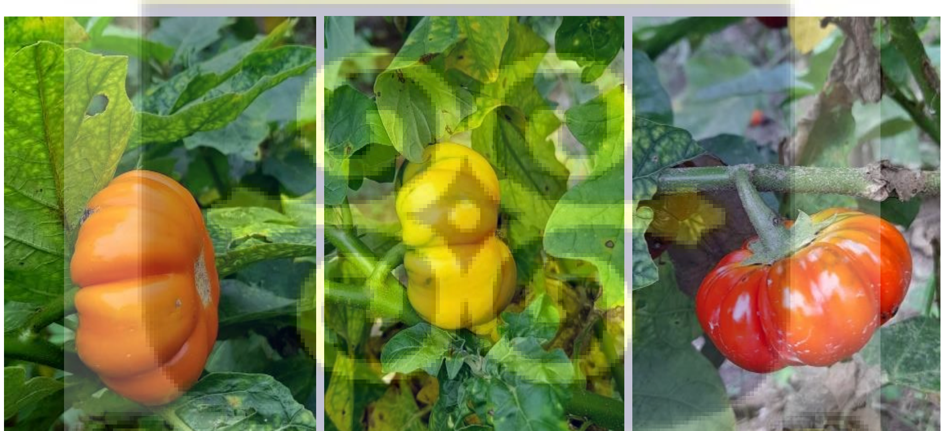

Plate 2.2: Fruits of the Kumba Group

The Shum group is characterized by small, glabrous leaves and short, heavily branched shoots, which are consumed as green vegetables. The fruits of this group are tiny and round, typically

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measuring 1.5–2.0 cm in diameter. While these fruits are edible, they are extremely bitter and are therefore only consumed occasionally.

Plate 2.3: The Shum group: plants in the field and fruits

The Aculeatum group is characterized by inedible fruits and leaves and stems that are both hairy and prickly. These plants are used for medicinal purposes, as ornamentals, and in breeding for resistance (Daunay, 2008). The fruits are typically round, large, and striped (Plate 2.4).

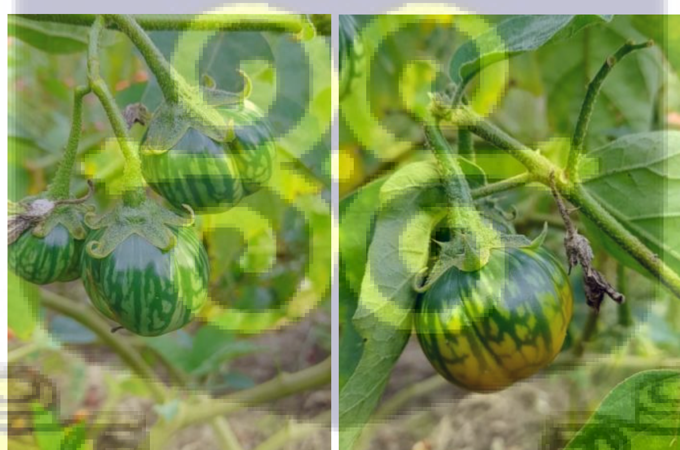

Plate 2.4: Fruit of Aculeatum group

2.2.2. Distribution and Diversity

The Solanaceae family, which includes the nightshade plants, adapts well to agroecological zones worldwide (Moenga and Odeny, 2022). However, *S. aethiopicum*, also known as the scarlet

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eggplant, is endemic to tropical Africa and is intensively cultivated from southern Senegal to Nigeria in West Africa, across Central Africa southward to Angola, Zimbabwe, Mozambique, and Eastern Africa (NRC, 2006). The crop is also grown in Asia, South America (particularly Brazil), and Europe (specifically the southernmost parts of France and Italy), where production is seasonal (Carney, 2013). Although the crop is grown across Ghana, economic production occurs only in the forest zones (Owusu-Ansah *et al.*, 2001).

The scarlet eggplant exhibits various agronomic, morphological, physiological, and biochemical characteristics (Collonnier *et al.*, 2001). Some characteristics are unique to a growing area due to local environmental conditions and consumer preferences. The selection of specific characteristics over time culminates in creating a landrace or cultivar. Farmers look for traits such as early maturation, disease and pest resistance, heat and drought tolerance, high yield, and market preferences (Yang and Ojiewo, 2013).

Varieties are dispersed not just in geographic locations, but also often have different names. Biotic and abiotic factors may cause variations. Despite being identical in genotypes, there may be differences in phenotypic qualities, such as taste, size, colour, and shape (Han *et al.*, 2021). For instance, the colour palettes include dusky black, multi-coloured, striped, white, yellow, cream, green, lemon/lime, orange, and red as well as various shades of violet and purple. Sizes range from small to large, with the latter in considerable demand. The shape is a crucial element that consumers use to determine taste. Evenly rounded fruits with smoother skin are usually considered sweet (NRC, 2006). Besides, environmental factors may also influence taste (Horna *et al.*, 2007). The World Vegetable Centre has the world's largest collection of African Solanaceae. Over 3,200 accessions of 30 eggplant species from 90 countries, including *S. aethiopicum*. Traditional

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landraces, critical genetic resources for plant breeders due to significant genotypic diversity, are included in these collections.

2.2.3. Utilization and Importance

Despite the global obscurity of *S. aethiopicum* compared to the Asian globetrotter *S. melongena*, all crop parts are used in diverse ways and have considerable importance. In Africa, the leaves and immature fruits are popular vegetables and an essential part of many diets. They are chopped, cooked, grounded, or otherwise prepared and mixed into a variety of vegetable, meat, or fish stews and sauces and sometimes eaten raw. They can be stored for up to three months, transported well, or preserved dry for later use.

The red eggplant has a wide range of nutrients that can be used as dietary supplements and health boosters, including proteins, minerals, vitamins, carbohydrates, fat, and crude fibre. Fruits have a high moisture content and a low dry matter content (Eletta *et al.*, 2017). They contain calcium, potassium, magnesium, sodium, iron, manganese, copper, phosphorus, and zinc, among other minerals. These minerals help to maintain heart rhythm, muscle contraction, bone and tooth growth, acid-base equilibrium, enzymatic reactions, and cellular metabolic control (Michael *et al.*, 2017). Moreover, it is high in vitamins (A, B, C, D, and E), which are essential for the body's healthy functioning (Kamga *et al.*, 2013; Offor and Igwe, 2015).

The fruits of the scarlet eggplant contain phytochemicals such as alkaloids, flavonoids, phytosterols, steroids, saponins, and tannins, as well as a trace amount of terpenoids (Chinedu *et al.*, 2011; Eletta *et al.*, 2017). Alkaloids, primarily glycoalkaloids, contribute to the bitterness in eggplants, affecting their suitability for human consumption. Toxic glycoalkaloids can cause

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diarrhea-induced poisoning in some Solanum species, and carcinogenic glycosides can lead to excessive calcium deposition in tissues (Han *et al.*, 2021).

Studies have confirmed that the saponins in eggplant used in traditional medicine formulations cause the breakdown of terpene glycosides, thereby preventing the toxicity associated with intact molecules (Asl and Hosseinzedah, 2008). Nutraceuticals with antibacterial properties in saponins protect against microbial infections, while ascorbic acid and flavonoids exhibit high antioxidant potential (Diatta *et al.*, 2020). Traditional medicine in several tropical African nations uses the fruits of bitter cultivars to treat various ailments (Sodipo *et al.*, 2012). The alcoholic leaf extracts are used as a tranquillizer, anxiolytics, antiemetics, and to treat tetanus. The roots and fruits, known for their calming and soothing effects, are used to treat colic in children and high blood pressure, while the aqueous leaf juice aids with uterine issues (Tchoupang *et al.*, 2017). The juice of cooked roots may be used to treat hookworms and as a purgative, while crushed leaves can remedy digestive problems (Lim, 2015). Diabetes, cholera, otitis, toothache, dysuria, bronchitis, skin infections, dysentery, asthenia, and haemorrhoids are all treated with various plant parts, including powder and ash. Furthermore, due to their phytochemicals, eggplants have anticancer, antiviral, anticonvulsant, and antibacterial properties and are also associated with antirheumatic and anti-asthmatic properties (Yang and Ojiewo, 2013).

In addition to their significance in diets, nutrition, and medicine, eggplant production promotes sustainable environments, enhances inclusivity and the livelihoods of all stakeholders working along the value chains, and increases productivity (FAO, 2020). The plant could benefit conservation programs by covering bare soil in the spaces between main and taller crops such as bananas, cassava, and trees because they tend to tolerate shade (Yang and Ojiewo, 2013). They

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thrive in many challenging soils, are well-suited to infertile locations, and are likely candidates to profit from various "agricultural wastelands" (NRC, 2006).

Moreover, the vegetable has a significant place in some indigenous customs. It is offered as a gift to guests, during marriage and naming rituals, and other social occasions in several Sub-Saharan African societies, mostly as a sign of good fortune, fruitfulness, and blessings (Chinedu *et al.*, 2011). The crop is primarily farmed, harvested, and sold in the surrounding area, and it plays a vital role in the rural economy and women's livelihoods (Okon *et al.,* 2010; Horna *et al.*, 2007). The plants are notable for their ease of cultivation and high yield in a small space. Even a few plants in garden pots can produce a bountiful crop, and they can profit from small plots.

2.2.4. Cultivation and Production

The three edible groups of the scarlet eggplant (Shum, Gilo, and Kumba) prefer deep, well-drained soils in humid and semi-arid climates. They cannot withstand waterlogged and extremely cold conditions (Han *et al.*, 2021). The crop requires a pH of 5.5-6.5 and night and day temperatures of 20-27°C and 25-35°C, respectively (Nyadanu & Lowor, 2015). Cultivation primarily depends on rain, but irrigation is most effective in the dry seasons. Because salt influences the crop's anatomical and morphological characteristics, it is preferable to cultivate on soil with low to moderate salinity to promote maximum growth and development (Mensah *et al.,* 2020).

Seeds for propagation are extracted from fully matured fruits. They are sown directly in the field, nursery beds, or seed trays. Under ideal conditions, seedlings emerge in 5-8 days. After 30-35 days and when they have 5-7 leaves and are about 15-20 cm tall, seedlings are transplanted to the field. Before uprooting and transplanting, seedlings must be watered to ensure proper root-to-soil contact. Seedlings grown in containers or cells are best for transplant because the root system is

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not disturbed and establishes a uniform and complete plant stand. To keep the soil moist during the dry season, mulching is advised. Depending on the soil type, watering two to three times per week is usually sufficient during the reproductive (flowering and fruiting) stage.

Planting 60-75 cm between rows and 90-120 cm within rows is recommended by AVDRC (2003). Due to their high nutritional needs, eggplants require up to 400 kg/ha of compound fertilizer, such as NPK (20-10-10, 30-10-10, or 15-15-15), which must be applied twice, once during transplanting and once six weeks later. To maximize yield, a balanced supply of nitrogen and potassium is needed. Many farmers engage in organic farming, primarily for export, using agricultural waste (50 to 80 tons/ha) along with biopesticides and botanicals. Even though the fruit produced by this method is of higher quality, it typically yields less than more traditional, intensive methods (Yang and Otiewo, 2013).

Fruits of many varieties mature for harvest approximately 2.5-3 months after transplant. Fruits are harvested in the early morning or late evening using a sharp knife or pruning scissors and kept in a cool, dry, shaded area. Also, varieties with edible leaves are harvested when they are immature and fresh.

Africa's production increased significantly from 606,672 tons in 1994 to 2,079,920 tons in 2018 (Oguntolo *et al.*, 2022). In Ghana, current data are lacking; however, Horna *et al.* (2007) estimated that national production is around 30,000 tonnes per annum. Due to the government initiative "Planting for Food and Jobs", which took effect in 2017, it is predicted that there will be an appreciable increase in production in recent years if reported (Horna *et al.* 2007).

There are numerous challenges that farmers must overcome during production, including the issues of climate change, the land tenure system, labour, availability of inputs, ready markets, pricing, pests and diseases, among other factors (Steenwerth *et al.*, 2014).

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2.3. Major Insect Pests of Scarlet Eggplant

The Plant Protection and Regulatory Services Directorate (PPRSD) of the Ministry of Food and Agriculture (MoFA) in Ghana listed 68 insect and mite pest species that attacked various parts of eggplants from nursery to harvesting in 2020. These pests are classified as major or minor depending on the injury and damage they cause. Depending on the prevailing seasonal conditions and populations, some become more harmful or cause severe damage. Pests that cause significant damage include the eggplant fruit and shoot borer, grasshoppers, aphids, thrips, whiteflies, leafhoppers, lace bugs, and spider mites (Amengor *et al.*, 2017; Mensah *et al.*, 2022). Additionally, some beneficial insects are associated with the crop and must be conserved.

2.3.1. Eggplant fruit and shoot borer, *Leucinodes* spp.

This moth is a member of the Lepidoptera family Crambidae (previously known as Pyralidae). It is common in subtropical and tropical Asia as well as sub-Saharan Africa (CABI, 2022). The fruits and tender shoots of *S. melongena* and *S. aethiopicum* are the main sources of internal feeding for the larvae, which are primarily pests of solanaceous crops. Their infestation could significantly lower crop yields, with over 65% reported output losses (Netam, 2018).

Due to internal larval feeding, pest damage may go unnoticed during pre-export inspections and international trade. In several places outside of its natural habitat, *L. orbonalis* is a quarantine/regulated pest (EFSA PLH Panel, 2021).

According to Mally *et al.* (2015), *L. orbonalis* is endemic to Asia and is not conspecific with other species found in Africa. So far, the African species reported include *L. rimavallis*, *L. ethiopica*, *L. africensis*, *L. pseudorbonalis*, *L. ugandensis*, *L. kenyensis*, *L. ethiopica*, *L. laisalis* and *L. malawiensis* (Mally *et al.*, 2015).

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i. Description

Eggs are laid by mature females on plant foliage (Plate 2.5). The typical female can lay between 80 and 253 eggs per cycle (Owusu, 2012). They are laid one at a time on the surface of fruit calyxes, flower buds, new shoots, and young leaves during oviposition, which takes place at night. The eggs are 0.5 mm in diameter, oval, and flattened. When laid, they are creamy-white, and they hatch in 3 to 6 days (Owusu, 2012).

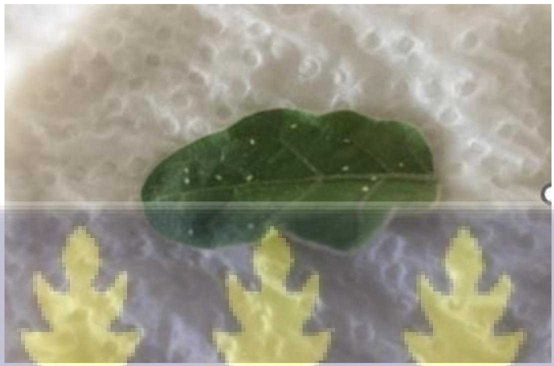

Plate 2.5. Eggs (white pecks) of EFSB on an eggplant leaf.

Larva. The larva's colour ranges from light brown to pinkish-brown (Plate 2.6). It starts looking for food as soon as it hatches on the plant's foliage and then bores into the fruits or shoots to keep eating as it grows and matures. A fully developed larva measures between 1.8 and 2.3 cm in length. It has 4 to 6 instars and a larval stage that lasts 12 to 22 days, depending on humidity and temperature.

Plate 2.6. Larvae of EFSB.

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Pupa. Mature larvae crawl out of their feeding tunnels and pupate in hard, silky cocoons on the soil's surface near the plant's base. Among plant debris and discarded leaves, cocoons are frequently observed. Because of how well the cocoon's colour and texture match the surroundings, it can occasionally be challenging to see. The cocoons can also be found at depths bet 1 to 3 cm. The pupal stage can last between 6 to 17 days, depending on the conditions (Plate 2.7).

Plate 2.7. A collection of EFSB pupae.

Adult. At night, pupae emerge from their cocoon. Young adults (Plate 2.8) are often found on the lower leaf surfaces after emergence. The female moth has a pointed abdomen that curves upward, while the male has a blunt abdomen. The dorsum of the moth is white, with dark brown or black patterns on the thorax and abdomen. The white, pinkish, or bluish-tinged wings are bordered by tiny hairs on the apical and anal sides. There are numerous black, white, and light brown dots all over the forewings. The wingspan of the moth is between 20-22 mm. Males can live up to three days longer than females, and females can live two to three days longer.

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Plate 2.8. Adults of EFSB.

ii. Nature of Damage

The first symptom of feeding damage is wilting shoots (Plate 2.9). By making tiny pores, the larvae enter the fruits, shoot, and burrow inside to continue feeding. Frass (waste products), which is released during feeding, provides the perfect environment for microbes to cause decay.

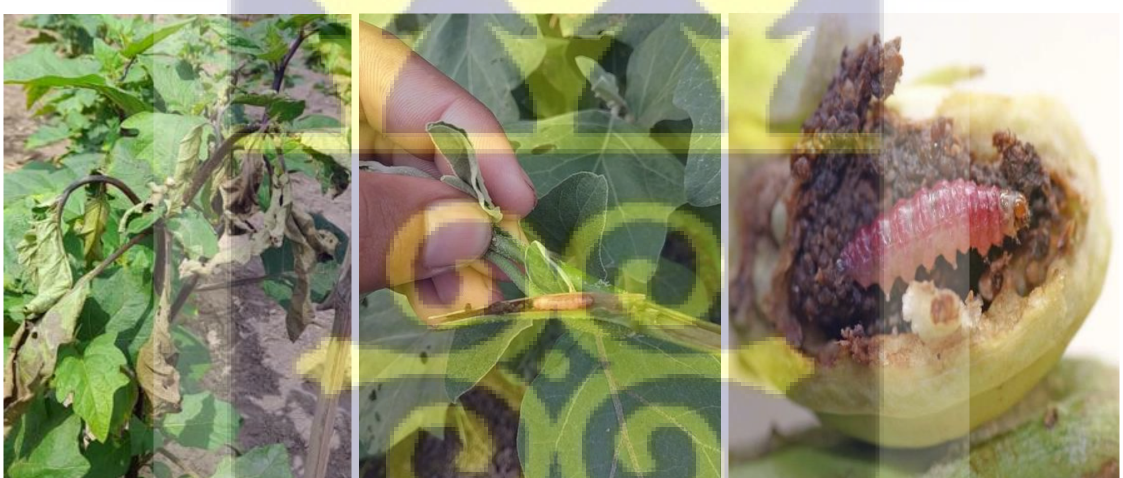

Plate 2.9. Nature of damage by EFSB on shoots and fruit.

2.3.2. Aphids (*Aphis gossypii*)

They are sluggish, small, globose and soft-bodied insects with a pair of cornicles (honey tubes) on their abdomens. They have piercing mouthparts for sucking sap. They often feed in clusters on the stems, fresh shoots, buds, flowers, and the underside of leaves. They reproduce by thelytokous parthenogenesis associated with viviparity (Guerrieri and Digilio, 2008). Adult aphids are mainly

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apterous; winged forms appear to respond to overcrowded or fully exploited hosts (Plate 2.10). They fly to a new uninfested plant, mainly in the direction of the wind. Heavy infestation causes severely distorted leaves, stippling, chlorosis, and eventually wilt and stunted growth because of excessive sap removal. During feeding, they excrete large amounts of honeydew that coats plant surfaces. Sooty moulds grow on honeydew deposits turning leaves and branches black, thereby reducing photosynthesis. More so, aphids are vectors of several plant viruses. The combination of feeding and reproduction of aphids makes them one of agriculture's most economically significant pests.

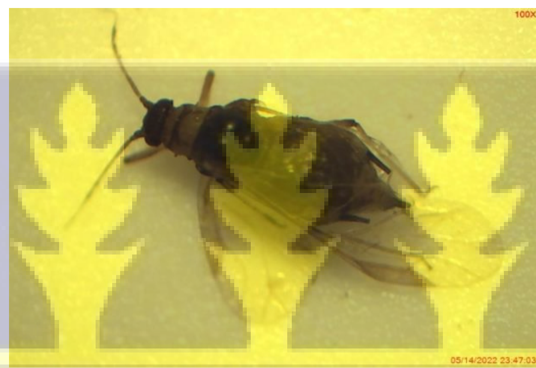

Plate 2.10. Image of an adult aphid.

2.3.3. Whiteflies (*Bemisia tabaci*)

They are little yellowish insects with two pairs of white wings and a piercing, sucking mouthpart (Plate 2.11). The body and wings are covered with a white, powdered, waxy material. It causes direct damage by piercing and sucking sap and indirectly by excreting honeydew and spreading viruses. Feeding in adults and nymphs causes chlorotic spotting, growth deformation, and early leaf loss. The honeydew excreted coats the foliage and fruit's surface and serves as a substrate for sooty moulds. Moulds reduce the photosynthetic potential of the infested plant, blemish fruits, and the crop's market value. The viruses vectored by whiteflies have the most significant economic

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impact because they have the potential to cause the total failure of susceptible crops. These viruses include Begomovirus, Geminivirus, Nepovirus, Closterovirus, Potyvirus, and Carlavirus.

Plate 2.11. An image of adult whiteflies.

2.3.4. Thrips (*Thrips tabaci*)

Thrips (Plate 2.12) are small, thin, yellowish-green or even black insects that require a hand lens to view. They either have wings or do not. Thrips are distinguished by their winged morphology, which has two sets of thin and elongated wings fringed by long hairs. Using a saw-like ovipositor, they lay their eggs in leaves, flower petals, and soft parts of stalks. Thrips feed by ruffling the surface of plant tissues and sucking up emerging fluid, killing the surrounding tissues. Stippling, or tiny silver-grey scars on fruits and leaves resulting from feeding, can cause stunted growth. Leaves that have been damaged lose chlorophyll and vigour and may become distorted and papery. Infested leaf terminals turn brown, roll, and drop prematurely.

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Plate 2.12. An image of an adult thrip.

2.3.5. Leafhoppers (*Empoasca* spp.)

Leafhoppers are wedge-shaped both as adults (Plate 2.13) and as nymphs, but nymphs don't have wings. On new shoots and the undersides of leaves, they are frequently found grouped. Many plants display feeding-related damage, such as yellowing between the veins, whitish mottling, and browning or yellowing of the leaf margins, but some hosts do not. During the feeding process, injected saliva causes damage.

Plate 2.13. An image of an adult leafhopper

2.3.6. Flea Beetle (*Epitrix* spp.)

Flea Beetles primarily attack young plants. They often chew on the leaves' undersides, creating tiny, asymmetrical holes (often less than 3 mm in diameter) and occasionally through the leaf itself. The beetles do not feed much in one location since it is small and active. The larvae feed on roots, and the adults chew the leaves and sprouting shoots. This feeding activity reduces leaf surface area hence photosynthesis and causing stunted growth (Agegnehu, 2021).

Plate 2.14. Images of some common flea beetles of eggplants.

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2.3.7. Grasshoppers (*Atracromorpha acutipennis* and *Zonocerus variegatus*)

They are polyphagous insects that actively chew the leaves of crops. Both nymphs and adults defoliate leaves and reduce the area available for photosynthesis. They are active during the day and spend the night and cold hours of the day resting on crop leaves. They can cause considerable damage of about 25–80% yield loss (Kekeunou *et al.*, 2006).

Plate 2.15. Images of some common grasshoppers on eggplants.

2.3.8. Eggplant lace bugs (*Urenthius hystricellus*)

The eggplant lace bugs cause severe damage in drier seasons or regions. They are small and brownish bugs with a length of about 3 mm. Its wings have a characteristic lace-like appearance, and its body is coated in spines. Nymphs have an adult appearance but lack wings, but they develop wings as they grow. Both adults and nymphs cluster on the underside of leaves. They cause whitish to yellowish speckled areas on the leaves after sucking sap, and the leaves fall off. The bugs' faeces are visible as little, shiny black patches on the attacked leaves (Bellon *et al*., 2018).

Plate 2.16. Eggplant lace bugs on the underside of an eggplant leaf.

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2.4. Integrated Pest Management (IPM) of the Pests of Eggplants.

The sustainability of agricultural systems has received a lot of attention in recent years. Concerns about global population expansion, climate change, the reduction of beneficial species, and biodiversity loss have spurred interest in agricultural system health. Sustainable insect pest control is gaining popularity among both producers and the general population. The goal of integrated pest management is to keep the system sustainable and to prevent insect pests from acquiring resistance to any form of pest control treatment (Javier *et al.*, 2010). Integrated pest management combines various pest management approaches to lessen selection pressure against any one strategy and avoid resistance. Integrated pest management in the prevention of pests acquiring resistance to pesticides or other insect control strategies, which can result in epidemics. In reaction to the misuse of pesticide spraying, IPM was developed (Javier *et al.,* 2010). Integrated pest management still allows for the use of pesticide spraying, which is commonly used to manage pest populations that have surpassed a particular threshold. Insect pests that pesticides are unable to suppress are controlled in various ways, at a lesser cost to farmers, while also lowering insect numbers and increasing output. Resistant cultivars, botanicals, essential oils, and pheromones, as well as physical, cultural, and biological approaches, are all used (Romeh, 2019; Gross and Gündermann, 2016).

i. Physical and Cultural Control

Unlike physical control, which involves using mechanical forces or physical labour to prevent insects from feeding, sheltering, and reproducing, cultural control approaches involve manipulating the crop environment and management. Field sanitation before, during, and after cropping, handpicking of large larvae or adults, eliminating pests' alternate hosts, and installing physical barriers are some cultural and physical control strategies for managing pests in the field.

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Physical and cultural control methods produce tangible and immediate results; however, they take time.

Breaking lumps in the soil and removing pupa are encouraged before transplanting to reduce EFSB populations (Dent *et al.*, 2003). Also, avoid planting over-aged seedlings; they should not remain in the nursery for too long as they become weak due to competition for space, light and nutrients (FAO, 2003). Seedlings, when crowded, can be a breeding ground for fruit and shoot borer. Tomato, potato, and turkey berries (*Solanum torvum*) are alternative host plants for the ESFB (EFSA PLH Panel, 2021). New eggplant fields or nurseries should be maintained free of or sited far away from already established or old fields of these Solanum species. It is uncertain, though, whether the EFSB population will expand and move from these additional hosts to nearby fields. Another possibility is that nearby eggplant fields' soil-dwelling pupae could produce an EFSB infestation (Srinivasan, 2008).

Farmers occasionally store dried eggplant stalks from previous crops as firewood for cooking, a significant EFSB infestation source (Alam *et al.*, 2003). Farmers sometimes establish eggplant nurseries near dried eggplant stubble piles, risking a high infestation of EFSB that emerges from the piles. Growing seedlings far away from dry eggplant stubble piles is ideal; otherwise, net tunnels or fences can act as a barrier to restrict migration when the nursery is nearby.

A recommended strategy to manage the EFSB on eggplant is to regularly remove and promptly destroy the infested shoots and fruits (Srinivasan and Huang, 2009). Early pruning of infested shoots is crucial, and it should continue to the final harvest. However, it will be more effective and successful if practised as an area-wide strategy rather than just for individual and isolated farmers. Since infested shoots wither and die, pruning them will not adversely impact plant growth and yield (Srinivasan, 2008). To lessen fruit and shoot borer infestation, intercrop eggplants with herbs

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like *Nigella sativa*, *Foeniculum vulgar*, and *Coriandrum sativum* close to each other. The adult EFSB is small, and a poor flier and inter-filed migration could be interrupted using appropriate barriers. Using nylon netting as a physical barrier recorded significantly less damage to shoots and prompt pruning of infested shoots than employing only the nylon net or sanitation (Alam *et al.*, 2003). Fruit damage was not as severe, despite a 33 per cent reduction in damage compared to the untreated control. With this outcome, some states in India have adopted protective cultivation methods like a greenhouse or net-house production systems are becoming more common (Srinivasan, 2008). When promoting this technology to farmers who lack access to resources, the economic feasibility should be taken into account.

ii. Biological Control

Natural enemies of pests, such as entomopathogens, parasitoids, and predators, can help suppress the EFSB population below economically damaging levels. Among the natural enemies of EFSB in Asia, *Trathala flavoorbitalis* is notable for its wide distribution and high parasitism rate in the field (Alam *et al*., 2003). However, it is not a specialized parasitoid of EFSB, as it also attacks other pyralid insect pests (Heinrichs and Muniappan, 2016). Other natural enemies of EFSB include *Goryphus nursei, Elasmus corbetti, Euagathis* spp., *Pristomerus testaceus*, *Trichogramma chiloni*, *Eriborus sinicus*, and *Cotesia* spp., but their parasitism rates vary (Alam *et al.*, 2003). Ants, ladybird beetles, praying mantids, earwigs, lacewings, and dragonflies are some of the beneficial insects that play key roles in pest management, especially in the field.

iii. Pheromone Lures

Sex pheromones are essential for IPM operations, as they are used to monitor and mass-trap male EFSB, a technique for area-wide management. The lures are used with funnel and delta traps in

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the field. However, the trap design that attracts the most insects depends on the location and trap height (Alam *et al*., 2003; Cork *et al.*, 2003).

iv. Insecticides/Chemical Control

Insecticides are recommended for pests such as the eggplant lace bug, but they can also harm beneficial insects (Atanasova and Leather, 2018). Essential oils and aqueous extracts from plants such as neem kernel oil, lemon grass extracts, peppermint (*Mentha piperita*), rosemary (*Salvia rosmarinus*), thyme (*Thymus vulgaris*), Norwegian angelica (*Angelica archangelica*), cloves (*Syzygium aromaticum*), basil (*Ocimum basilicum*), and cashew nut shell liquid (*Anacardium occidentale*), among others, have recently emerged as alternatives to insecticides (Pavela *et al.*, 2013; Saroukolai *et al*., 2014; Ayse *et al.*, 2016; Renkema *et al.*, 2016; Atanasova and Nenov, 2017; Buxton *et al*., 2017; Atanasova and Leather, 2018). These plant-based products are being studied because they are easily degradable and safe for direct contact with food crops (Tripathi *et al.*, 2009). These plant-based treatments can prevent oviposition, repel insects, kill them, reduce development, and stop feeding (Koul *et al.*, 2008).

2.5. Host Plant Resistance (HPR)

Insect pest-resistant varieties are an essential component of any IPM programme. The complexity of the relationships between plants and insects is explained by their coevolution over time. Plants develop defences against insect pests in natural environments, while insect pests respond by employing strategies to overcome plant defences and use plant resources for survival (Douglas, 2018). In general, insects move to and from plants mainly for food, reproduction (oviposition), and refuge.

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2.5.1. Definitions of HPR

Host plant resistance has been defined by many scientists with some similarities and differences. Some of the definitions reviewed are:

Host plant resistance is the term for plant traits that enable it to tolerate, avoid, or recover from insect infestation in situations where it would severely damage other plants of the same species (Snelling, 1941). The number of heritable traits in the plant affects the insect's ability to cause damage, while Painter (1951) defines HPR as the ability of a specific variety to produce larger, higher-quality products than other varieties at the same level of pest infestation.

Resistance is the collective hereditary traits of a plant that make it less likely that an insect will successfully use it as a host (Beck, 1965). This definition emphasizes the restriction of the interaction to the point where an insect effectively utilizes a plant as a host, but it ignores the plant's ability to recover after injury.

According to Robinson (1973), a host is resistant when it can resist a pest, pathogen, or disease-causing agent that attacks it. Maxwell *et al*. (1972) expanded on Painter's (1951) concept by considering environmental factors and insect infestation severity; they defined resistance as the inherited traits of the plant that determine the degree of damage caused by the insect. This definition refers to a variety's ability to produce a higher quality crop than other varieties under similar pest attacks and environmental conditions.

Russell (1978) defined resistance as the collective hereditary traits of a plant that make it less likely that an insect will successfully use it as a host. This definition emphasizes the limitation of the interaction to the point where an insect effectively utilizes a plant as a host, but it ignores the plant's ability to recover after injury.

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On the contrary, Horber's (1980) definition of host plant resistance focuses on an insect's ability to feed, develop, reproduce and survive on a specific plant species. When the insect can perform its activities without hindrance, it may also cause relative qualitative or quantitative damage to the host plants. Host plant resistance is the inherited ability of a plant to suppress insect population growth and to recover from any injury caused by the populations that initially infested the plant. Insect population growth is typically inhibited by morphological and biochemical characteristics of a plant that influence an insect's behaviour or metabolism to reduce the potential harm these insects can cause (Kogan, 1986). Dhaliwal *et al*. (1993) state that a plant with inherited HPR characteristics will result in a minimum per cent drop in production compared to conspecific plants grown under comparable conditions. The focus of this definition is the percentage yield loss compared to the yield achieved before the insect attack, not the absolute yield difference between a resistant and susceptible plant. It implies that a plant may produce poor yields despite having resistance genes or produce well despite having no resistance genes. Smith (2005) also noted that resistance results from inherited plant characteristics that cause it to sustain less damage than plants without similar characteristics.

2.5.2. Mechanisms of HPR

Resistance mechanisms are classified in several ways. The most widely accepted functional classifications include tolerance, antibiosis, and non-preference/antixenosis. These resistance mechanisms can be studied using different techniques under different conditions (Chakravarthy and Selvanarayanan, 2019).

2.5.2.1 Antixenosis/Non-preference

The first step of plant-insect interactions is non-preference or antixenosis. This term refers to host features that inhibit or reduce insect colonization. Painter (1958) used the term 'non-preference',

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but Kogan and Ortman (1978) preferred the term antixenosis. Antixenosis may result from certain morphological or biochemical traits that are present or absent in a host plant. This defence mechanism may help the plant avoid infestation by insect pests, especially for feeding and oviposition (Chakravarthy and Selvanarayanan, 2019).

Oviposition by an adult female insect is a crucial step in the host selection process. It indicates that the insect can reproduce using a specific plant. Ovipositional preferences can be estimated by the number of eggs laid (Chakravarthy and Selvanarayanan, 2019). Herbivory is another important aspect of insect-plant interactions, and feeding bioassays are tools for examining insect feeding preferences.

2.5.2.2. Antibiosis

Antibiosis is the most common, long-lasting, and favoured mode of resistance. It is the effect of a plant on an insect's growth and development. A resistant host plant limits insect growth and development, while a susceptible plant is weak and stimulates insect growth and development (Sharma *et al*., 2005).

In other words, the antibiotic factor depends on the age and stage of the host plant, and it affects the insect's growth and development through continuous feeding on a resistant host plant. The properties of the host plant interfere with the insect's normal biology, behaviour, and physiology (Chakravarthy and Selvanarayanan, 2019).

The antibiosis resistance mechanism is often assessed with insects confined to whole plants, parts, or even plant materials. The tests are mainly conducted in the laboratory or greenhouse, with some rare field tests. Artificial diets are sometimes used.

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2.5.2.3. Tolerance

Tolerance refers to a plant's ability to recover from or withstand damage while maintaining a high yield of fruit under pest pressure (both in terms of quantity and duration). Tolerance has little or no effect on how insect species have evolved since it does not apply any selection pressure to insect populations. The main drawback of this mechanism is that it allows the insect population to increase, which could harm other crops. Tolerant plants are preferred in the field because they are often more resilient and stable than resistant plants (Vasantharaj and Ramamurthy, 2011).

2.5.3. Resistance-Related Traits in Eggplants

There are two types of insect-resistant traits: (1) biophysical or morphological and (2) biochemical. These traits act as defence systems against insect pests regardless of the category. They are either inducible, meaning they only appear in response to a pest attack, or constitutive (performed), meaning they appear regardless of pest presence or activity. Most resistance-related traits directly affect pests and indirectly enhance the effectiveness of natural enemies.

2.5.3.1. Morphological/Biophysical Traits

Plant morphological and biophysical traits physically disrupt the insects' systems of locomotion, especially those related to host selection, feeding, or oviposition. For example, trichomes and surface waxes on the plant surface, the hardness of plant tissues, the thickness of the epidermis, and colour, shape, and size are all morphological traits that resist insect pest infestations and attacks. They are long-lasting and cannot be easily degraded by pests.

Trichomes are hair-like growths on the plant epidermis. They are collectively called pubescence when they cover the surfaces of plants. They have various sizes, shapes, and forms, and they give plants important ecological, physiological, and mechanical benefits (Jeffree, 1996). In

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Solanaceous plants, eight different types of trichomes have been found, and they are either glandular or non-glandular (Glas *et al*., 2012).

The glandular trichomes secrete toxic chemicals that act as repellents and deterrents, obstruct feeding, and negatively affect the survival of insects that encounter them (Kennedy, 2003). Additionally, trichomes secrete sticky exudates that trap and immobilize small insects and larvae. The secondary metabolites that are associated with these exudates can also influence the behaviour of parasitoids and predators (Riddick and Simmons, 2014). Non-glandular trichomes, which are dense, erect, and longer, act as barriers to prevent leafhoppers, aphids, whiteflies, and thrips from feeding (Pompon *et al*., 2010).

Spodoptera littoralis and *Helicoverpa armigera*, which feed on pubescence to reach the epidermis, have high larval mortality rates due to the high cellulose and lignin contents of undigested hairs piercing the thin gut wall (Schillinger and Gallun, 1968; Wellso, 1973). Some insect species' oviposition is hampered by the length and density of pubescence (Sharma *et al*., 2009). According to Butter and Singh (1996), it may also encourage oviposition in other insect species. For example, the whitefly *Bemisia tabaci* prefers to oviposit on pubescent eggplant cultivars (Balaji and Veeravel, 1994), and *B. argentifolii* oviposited more eggs on thick-haired tomato leaves (Heinz and Zalom, 1995).

Epicuticular/surface wax. A thin layer of hydrophobic chemicals coats the surface of most vascular plants. The waxy layer protects the plant surface from desiccation and disease, but it also affects insect behaviour by serving as a feeding deterrent or phagostimulant (Norris and Kogan, 1980). Insect sensory organs on the tarsi and mouth sense these compounds in surface waxes and they deter or repel them from attacking the plant (Wang *et al*., 2020).

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Thickness/toughness/hardness of plant tissues make chewing and access to phloem difficult and thus act as a feeding barrier, a common resistance mechanism. Some plants have high silica content in the leaves (Pathak, 1969), pectin in the cellular middle lamella (Dreyer and Campbell, 1984), cellulose, lignin, and calcium carbonate (Lanning *et al.*, 1980) accumulate in their tissues, and defend themselves against insect attacks. For feeding and oviposition, many insect pest species prefer young, tender plant parts over mature plant parts, and vice versa. For instance, the structure, compactness, and resistance to EFSB of eggplant are all related (Panda and Khush, 1995). Due to the toughness and hardness of the skin and fruit pulp, Aushey (a cultivar of brinjal) is less susceptible to EFSB (Lall and Ahmad, 1965). The *Amrasca biguttula* (jassid) infestation is positively correlated with the thickness of the brinjal leaf and midrib (Gaikwad *et al.*, 1991).

Size, shape, and ***colour*** all affect how phytophagous insects choose their hosts and are related to resistance. Although plants lack insect resistance related to colour, genetically altered plant colour typically affects some basic physical plant processes (Norris *et al.*, 1980). The Rhagoletis fly can distinguish between hosts and non-hosts by the colour, shape, and size of foliage (Boller and Prokopy, 1976). Alate aphids are attracted to plants at an optimal growth stage, just as they are attracted to leaves reflecting approximately 500nm light in all plant species (Kennedy *et al.*, 1961). Also, the pea aphid, *Acyrthosiphon pisum*, prefers yellow-green plants to green ones (Cartier, 1963; Döring, 2014).

2.5.3.2. Biochemical Traits

Plant tissues contain many biochemicals, mostly volatile substances that are released into the environment. These biochemicals are classified as nutrients, phytochemicals, and semiochemicals that have antibiotic and non-preference effects on host plants (Mani *et al.*, 2022). They affect the

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insect pest infestation of plants by influencing feeding preference, ingestion and utilization of digested materials, growth and development, adult longevity, fecundity and survival. The host plant's ability to interfere with any of these biological functions of insect pests explains its resistance to insect attacks. Biochemical components are often responsible for the insect resistance of plants, rather than physical or dietary factors.

Semiochemicals are important for the physiological and behavioural interactions of organisms. Pheromones are intraspecific semiochemicals, while allelochemicals are interspecific ones. While some allelochemicals are phagostimulatory, most are deterrents. They alter the availability of N by creating chemical compounds that contain proteins but cannot be used, and they affect the nutritional physiology of the insect. Several allelochemicals inhibit insect development. Allelochemicals are ecological and chemical demands of plants because they keep insects associated with their hosts and protect plants from other insects, diseases, and herbivores that have not yet overcome these plants' biochemical defences (Brown *et al.*, 1970). Alkaloids, non-protein amino acids, glucosinolates, phenolics, tannins, terpenoids, saponins, and epicuticular lipids are examples of compounds that enhance host plant defence against insect pests.

Non-protein amino acids. These compounds allow plants to avoid auto-toxicity by not being incorporated into proteins (Baldwin and Callahan, 1993). They are toxins that act as enzyme inhibitors, causing the insect to lose control of the water balance and die (Schlesinger *et al*., 1977). Some of the non-protein amino acids that are biologically active in insects are canavanine, cyano-alanine, canaline, diaminobutyric acid, and propionic acid. For example, canaline is a potent neurotoxin. It causes severe developmental abnormalities, interferes with efficient larval-pupal ecdysis, and results in malformed insect pupae (Kammer *et al*., 1978).

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Alkaloids are diverse and complex secondary plant metabolites. About 20% of all plants from 150 families contain alkaloids, especially the Solanaceae family (Hartman, 1991). Many alkaloids have been used as insecticides against a range of insect pests because they interfere with critical aspects of acetylcholine transmission in the nervous system. Examples include indole alkaloids, quinolizidines, pyrrolizidines, benzylisoquinolines, methylxanthines, and steroid alkaloids (Mahanil *et al.*, 2008; Bhonwong *et al.*, 2009). They affect insects by preventing both larva and adult from feeding and inhibiting larval growth because of their bitter or spicy taste (Norris and Kogan, 1979; Chowański *et al.*, 2016). The potential for engineering alkaloid metabolism in transgenic plants is exciting as new knowledge of alkaloid biosynthesis, biochemistry, and molecular and cell biology emerges (Sadasivam and Thayumanavam, 2003).

Glucosinolates contain sulphate and thioglucose moiety. They belong to a family of nonvolatile, hydrophilic, and water-soluble anionic alkaloids that insects can only detect through touch. Most generalist insects, like aphids and grasshoppers, benefit from their breakdown by enhancing their chemical defences, and some specialist feeders use it to locate hosts. The concentrations of glucosinolates have a significant impact on beetle oviposition, egg hatchability, and larval and adult nutrition. As glucosinolate content increases, herbivorous insect damage decreases (Nielson *et al.*, 1979). Their insecticidal effects result from metabolic changes in insects, particularly the suppression of glycolysis and the Krebs cycle, leading to reduced total O_2 intake and CO_2 expiration (Sadasivam and Thayumanavan, 2003). Plants engineered to have high levels of glucosinolate in their leaves exhibit advantageous interactions with herbivores, pathogens, and insects (Bak *et al*., 1998).

Phenolics/phenols, secondary plant metabolites encompassing lignin, phenylpropanoids, flavonoids, and tannins, control several lepidopteran and coleopteran pests (Duffey and Stout,

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1996; Kang *et al*., 2010). Phenols generate reactive O_2 species, transforming into volatile quinones through the oxidative enzyme polyphenol oxidase, inhibiting insect growth and causing toxicity (Duffey and Stout, 1996). Terthienyl and furanocoumarin emerge as promising agents for field insect control due to their effectiveness at low doses. Rotenone effectively combats aphids, caterpillars, and leaf-chewing beetles. However, *Trichoplusia ni*, a cabbage semi-looper, shows resistance to coumestrol's antifeedant and antibacterial properties (Cornell and Hawkins, 2003).

Tannins, unbound phenolic polymers that attach to proteins, cause insects to consume less food, utilize resources less effectively, and gain less weight (Butter *et al.*, 1992).

Terpenoids/Isoprenoids. Terpenes are lipophilic compounds synthesized from acetyl-CoA and mevalonic acid. Composed of two or more units of five-carbon isoprene, they are classified based on the number of carbon atoms in their structures (Taiz and Zeiger, 1991). Terpenes are well-known in the scientific community for their allomonic effects on insect behaviour, metabolism, growth rates, metamorphosis, fertility, fecundity, and longevity. They can mask insecticide-repelling traits, attract beneficial insects to specific environments, or lure insects to pesticides. For instance, volatile terpenes released when an insect herbivore feeds on a host plant serve as cues for parasitoids and predators to find and locate their prey, providing an indirect form of defence (Bruce, 2015). According to Kant *et al.* (2004), plants infested with spider mites (*Tetranychus urticae*) emit more terpenes, which increases the attraction of predatory mites to the infected plants. Numerous beetles, grasshoppers, and lepidopterans are poisoned by sesquiterpene lactones. While sesquiterpenes and their derivatives help insects resist herbivores naturally, they can also attract herbivores (Proffit *et al.,* 2011). Genetically engineered tomatoes cultivated to produce high quantities of 7-epizingiberene showed reduced survival rates and fertility in both spider mites and whiteflies (Bleeker *et al.*, 2012). Monoterpenoids can interfere with crucial physiological,

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biochemical, metabolic, and behavioural processes in insects. A prime example of a monoterpene derivative that is toxic to insects is a pyrethroid. These neurotoxins, known as pyrethroids, cause insect hyperexcitation, jerky movements, and paralysis.

Ketones derived from fatty acids and often associated with trichomes are toxic to a wide variety of young insects. This toxicity results in increased larval and pupal mortality, extended developmental times, and pupal deformity in many pests (Leite *et al.,* 2001). Additionally, it deters adult insects from ovipositing and feeding (Rose *et al.,* 1991).

Toxins often the same substances that can result in antixenosis, are released by the disruption of plant cells. The plant then releases signalling molecules like gibberellic, jasmonic, salicylic, and abscisic acids, which trigger immediate chemical defence reactions (Pompon *et al*., 2010). Toxins produced by the *Bacillus thuringiensis* (*Bt*) bacteria are used to combat Lepidopteran pests, but they also inhibit the development and reproduction of aphids and beetles (Ashouri *et al.,* 2001).

2.5.4. Insect Responses to Counter Plant Resistance

Insects have evolved various strategies to suppress and counteract plant defences to survive and reproduce. These strategies include detoxifying and sequestering plant defence chemicals, using allomones as kairomones or nutrients to enhance nutrition from host plants, suppressing plant pheromone communication, avoiding plant allelochemicals, using alternate plants as diet (generalist feeders), and increasing the rate of feeding (Ram *et al.*, 2005).

2.5.5. Intensity of HPR

The level of resistance is measured by the damage to a test plant. The observed damage may affect the leaves or fruiting portions, the yield loss or reduction percentage, and the overall health of the plant. Additionally, it can affect pest fecundity, feeding preference, growth rate, digestion and

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nutrient utilization, and the mortality and lifespan of insects (Kogan, 1982). The levels of resistance in host plants can vary, ranging from high susceptibility to immunity. Plants can be either unsuitable or completely suitable hosts for the development and growth of the insect (Horber, 1980). The resistance criterion varies for different insect species depending on the type of injury.

2.5.6. Advantages of HPR

According to Stout (2014) and Sharma (2007), any pest management strategy must be built on HPR to insects because it: (i) naturally has no adverse effects on non-target organisms and is selective to a target or group of pests; (ii) has a cumulative effect on insect populations over successive generations due to decreased survival and fecundity, and delayed development; (iii) is persistent, except for certain environmental conditions where repeated pesticide applications are necessary; and (iv) it works well with other pest control strategies and (v) farmers do not have to pay for it. Extreme degrees of resistance may not be required or even possible. Pest damage can be decreased to levels below the economic threshold levels (ETL) in a few generations with the aid of a variety that can lower the pest population by 50% per generation. In contrast to the cumulative and long-term impacts of HPR, pesticides have explosive effects, with the insect population increasing significantly faster following pesticide application due to the lack of natural enemies (Kambrekar, 2016).

2.5.7. Constraints of HPR

The use of HPR does not address every insect problem. The HPR approach to pest management will have its limitations and challenges according to Sharma (2007). It takes a lot of knowledge and resources to create cultivars that are resistant to insects. For plant resistance efforts to be successful overall, a funding commitment over a relatively long period is essential. Plant resistance

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tactics include using resources differently to produce new structures or releasing defence chemicals at the expense of other critical physiological processes, such as those that boost yield. However, HPR has limitations: (i) developing resistant varieties takes a longer time (several years); (ii) using plant resistance for pest management might be hindered by a lack of significant resistance levels in the germplasm available; (iii) the use of specific insect-resistant varieties may be limited by new biotypes of the target pest, and (iv) certain plant traits may make the plant susceptible to some pests while conferring resistance to others.

Despite the importance of HPR as an IPM component, breeding plants with insect resistance has not gained as much traction as developing cultivars with disease resistance due to the ease of controlling insects with pesticides (Sharma, 2007). It is essential to create insect-resistant cultivars for crops like eggplants due to the rise in pests that are resistant to insecticides.

Significant success has been achieved in identifying and utilizing agricultural germplasm to combat insect pests (Smith, 2005). Resistance breeding projects against a few crop pests are currently underway. The development of insect-resistant cultivars has been slow due to challenges in producing a substantial insect infestation for resistance screening and the presence of low levels of resistance to specific pest species in cultivated germplasm (Sharma and Ortiz, 2002). Making a meaningful assessment becomes difficult when the insect infestation in the natural environment is either too low or excessively high. Therefore, it is crucial to establish protocols for evaluating insect pest resistance at optimal infestation levels and under similar environmental conditions. Additionally, while insect-rearing systems can be costly, they may take years to advance technologically.

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CHAPTER THREE

3.0. MATERIALS AND METHODS

3.1. Study Area

The research took place from April to November 2022 at the Forest and Horticultural Crop Research Centre (FOHCREC) Okumening, Denkyembuor District in the Eastern Region, Ghana. The district has a semi-equatorial climate with bi-modal rainfall. The major cropping season (April to July) has a peak rainfall in June, while the minor season (August to November) has a peak rainfall in October. The average relative humidity during the major season is over 80%, while it is around 60% during the minor season. The temperature ranges from a low of 23.0ºC to a high of 35.0ºC. The soil type in the study area is classified as the Oda and Temang series (MoFA; 2010).

3.2. Source and Description of the Accessions Used in the Study

The seeds of the Solanum aethiopicum accessions used in this study were provided by the FruitBunch Project at FOHCREC. The accessions used and their resistance statuses are shown in Table 3.1 below.

Table 3.1.: *Solanum aethiopicum* accessions used in the study

Treatments	*Accessions*	*Resistance Status*
T1	Legon 1	Susceptible
T2	RV100213	Unknown
T3	RV100248	Unknown
T4	RV100307	Unknown
T5	RV100250	Unknown

Legon1 is an advanced cultivar developed at the University of Ghana, Legon, hence the name. It is an interspecific hybrid of common eggplant and African garden egg (Horna *et al.*, 2007). It is one of the most widely grown eggplants in Ghana. As seen in Plate 3.1, the leaves are hairy and inedible, and the fruits are egg-shaped, smooth, white/cream to light yellow when unripe but

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orange to red when fully mature. Usually, unripe fruits are preferred over fully matured and ripe ones.

Plate 3.1.: Picture showing the fruits of the Legon 1

RV100213. This accession belongs to the Gilo group (Plate 3.2). The leaves have simple or stellate hairs on both sides. The fruits are spherical, smooth, or slightly ribbed, green when immature but orange to red when fully ripe. This accession may look similar to *S. macrocarpon*, but the fruits of *S. macrocarpon* are partly covered by the calyx lobes, light green when immature and yellow-brown at maturity. The epidermis becomes hard and cracks when dry. Also, the leaves are glabrous, fleshy, leathery, oval and lobed with wavy margins.

Plate 3.2.: Picture showing the fruit of RV100213

RV100248. This accession has the characteristics of the Kumba group (plate 3.3). The plants have very few branches but stout stems bearing large leaves with robust spikes/thorns on both branches

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and leaves. The fruits are flattened and ribbed, cream/pale yellow when unripe but orange to red when fully ripe.

Plate 3.3.: Picture showing the fruit of RV100248.

RV100307. The plants are branched and tall, with glabrous shoots, and small, flattened, and ribbed fruits as shown in Plate 3.4. When immature, the fruits are green, but when fully matured and ripe, they become orange to red.

Plate 3.4.: Picture showing the fruits of RV100307.

RV100250. This accession exhibits Shum group features. They are branching and short, with little glabrous leaves and branches. The fruits are tiny, spherical, and smooth, with a diameter of 1.5-3.0cm. When immature, they are green, but when ripe, they become orange to red as shown in Plate 3.5. Like RV100213, RV100250 is not *S. macrocarpon*.

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Plate 3.5.: Picture showing the fruits of RV100250.

3.3. Nursery and Seedlings

Plastic cell trays were filled with well-sterilized soil (at 80 °C for 2 hours) but not compacted to allow for aeration. To enhance germination, seeds were soaked overnight before planting in nursery trays, two (2) seeds per cell and labelled with the accession numbers. To maintain moisture, the trays were covered with paper, which was later removed as soon as the seeds started to sprout. A measured amount, 2 g/L of NPK 30:10:10 (starter solution) was applied five (5) days after seed emergence. Seven (7) days after seed emergence, thinning was done on one seedling per cell. Watering was done once or twice daily to keep the soil moisture within an optimal range. To prevent damping-off (fungal infection), overhead watering, especially in the evening, was avoided. Seedlings were nursed for seven (7) weeks with 15 g/L of NPK. 30:10:10 solution applied weekly. Plate 3.6 shows eggplant seedlings on seed trays

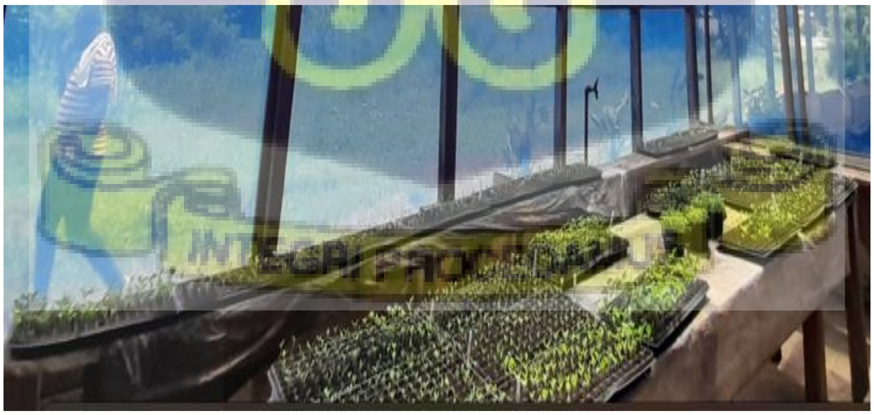

Plate 3.6.: Picture showing an eggplant nursery in a net cage

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3.4. Experimental Design and Procedures

The study consisted of two stages: an open field and a screen house. The open field experiment aimed to collect insects and determine their population trends, damage to leaves, yield and growth parameters, and shoot and fruit infestation by EFSB. The screen house experiment involved releasing EFSB and assessing growth parameters and shoot and fruit infestation.

3.4.1. Open Field Work

Field experiments were conducted from April to July and from August to November 2022, coinciding with the major and minor rainy seasons.

3.4.1.1. Site Preparation and Layout

The experimental field, measuring 16.5 m × 16.5 m (272.25 m^2), was weeded and cleared (Plate 3.7). It was then divided into 25 sub-plots.

Plate 3.7.: A picture showing the preparation of the experimental plot

The twenty-five (25) plots were arranged in a Randomised Complete Block Design (RCBD) with five (5) treatments (S. aethiopicum accessions) and five (5) replications. Each sub-plot was 2.1 m × 2.1 m (4.41 m^2) in size, with 1.5 m between plots as boundaries/guard rows. Each plot had 16

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plants (4 columns and 4 rows), with a 0.70 m spacing between plants and rows. Fig. 3.1 shows how each plot was demarcated and labelled, and how plants were tagged for data collection.

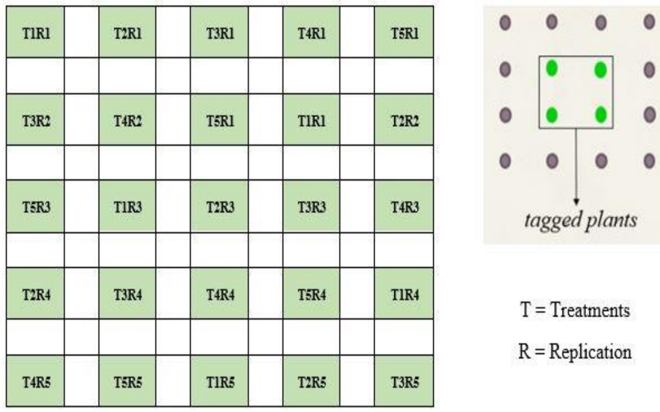

Figure 3.1.: Diagram showing the layouts of the experimental field and plot.

3.4.1.2. Transplanting in the field

Seven (7) weeks after seed sowing, healthy seedlings were transplanted (see Plate 3.8). The seedlings had 4-6 leaves and were 10-15 cm tall on average. The seedlings were watered well before being removed from the cell trays. After transplanting, the seedlings were watered again to reduce stress and improve root-to-soil contact. Watering was done daily, especially during the first four weeks after transplanting, and dead plants were replaced. To improve soil fertility, NPK 15:15:15 was applied at a rate of 15 g per plant after weeks one (1) and six (6). Weeds were controlled by hoeing when necessary. No pest management was employed in the study.

Plate 3.8.: Seedlings transplanted onto the experimental field.

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3.4.1.3. Field Data Collection

Data collection started two weeks after transplanting (WAT) and was done at biweekly intervals.

i. Insect Sampling

Insect abundance in the eggplant fields was evaluated using direct examination and yellow pan traps as shown in Plate 3.9. Direct examinations were carried out between 7:00 and 9:00 in the morning. The contents of the yellow pan trap were sieved through white nylon mesh, and insects were sorted under a dissecting microscope. Insect sampling continued until harvest.

Plate 3.9.: Yellow pan trap set in the field.

ii. Morphological Identification of Insect Pests

Under a dissecting microscope, the wing pattern, abdomen, and genitals of EFSB were used as the diagnostic features for species identification following zoo keys by Mally *et al.* (2015). The ratios of antenna processus terminalis and base, and siphunculi and cauda confirmed the identity of *Aphis gossypii* following the zoo keys by Lagos-Kutz *et al*. (2014) and Wang *et al.* (2016). Morphometric procedures outlined by Li *et al.* (2013) were used to identify *Bemisia tabaci*, *Thrips tabaci* (Mehle *et al*., 2012), *Empoasca* spp. (Gopurenko *et al*., 2013), *Dysdercus* spp. (Schaefer and Ahmad, 2000), *Attractomorpha acutipennis* and *Zonocerus variegatus* (Song, 2017).

iii. Growth Parameters and Leaf Damage

The growth parameters measured were plant height and number of leaves.

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Plant Height (cm). A tape measure was used to measure the plant's height from the base or soil surface to the tip of its apical leaf.

Number of Leaves. All fully opened leaves on the plant, except for apical buds on shoots, were counted.

Leaf Damage. The total number of damaged leaves (TLD) and the number of leaves produced by a plant in 14 days (TL_{14}) were counted and recorded. A leaf was considered damaged when 75% of it was missing. The percentage of leaf damage (PLD) was calculated using the following formula (Owusu, 2012):

$$PLD = [TLD / TL_{14}] \times 100$$

iv. Yield (t/ha).

At the fully matured stage, the fruits were handpicked. The weight of the harvested fruits (kg) was recorded using a weighing balance. The weight obtained was then converted to tonnes per hectare.

v. Fruit and Shoot Infestation by Eggplant Fruit and Shoot Borer.

The infestation was detected visually by the appearance of feeding scars, frass, or emergent holes on shoots, as well as wilting/drooping shoots. All harvested fruits were dissected and inspected for the presence of EFSB larvae. Infested and whole fruits were sorted and counted separately. Infested fruits were calculated as a proportion of gathered fruits. The percentage of shoot and fruit infestation was computed using the formula provided by Rahman *et al*. (2014).

$$\%\ shoot/fruit\ infestation = \frac{number\ of\ infestation\ shoots/fruits}{total\ number\ of\ shoots/fruits} \times 100$$

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3.4.2. Screen House and Laboratory Work

3.4.2.1 Preparation of Screen House

A screen house made of wood, with a nylon net covering and a roof with a clear transparent plastic sheet for light penetration (Plate 3.10), was constructed at the FOHCREC for this study. The net screen house had the following dimensions: height = 2.5m, width = 3.5m, and length = 6.0m. Platforms/benches in the screen-house had a height of 85cm. The screen house was thoroughly cleaned, after which it was sprayed with ATTACK® insecticide at the recommended dosage to kill all insects in the benches, floors, nets, corners, cracks, and crevices. The screen house was left for two weeks before the trial.

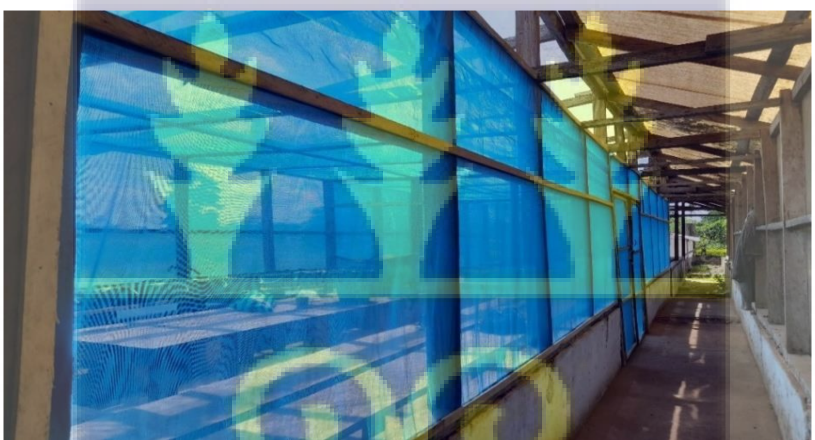

Plate 3.10.: Picture showing front view of screen-house.

3.4.2.2. Culturing Eggplant fruit and shoot borer

Infested fruits from the field were transferred to the laboratory for incubation in a basin covered with a muslin cloth as shown in Plate 3.11, following modified protocols reported by Arivudainambi and Selvanarayanan (2000) and Ambhure *et al.* (2016). The larvae in the fruits were allowed to feed undisturbed, and when they reached maturity, they emerged and pupated in the basin. The pupa was collected onto Petri dishes and placed in an insect-rearing cage until adults

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emerged (Plate 3.12). The newly emerging adults were placed in mating cages and fed 10% sugar in soaked cotton wool for 24 hours to enable mating.

Plate 3.11.: Picture of basins for incubating infested fruits.

Plate 3.12.: Picture showing an insect cage for rearing EFSB.

3.4.2.3. Experimental Setup in Screen-house

Sterilised soil (soil heated at 80 °C for 2 hours) weighing 5.5 kg was potted into fifty (50) 5L buckets with perforations underneath to allow for drainage. Each bucket had 5.5kg of sterilised soil, enough to hold the plants for the experimental period. Seven (7) week-old seedlings with 4-6 leaves and 10-15 cm plant height were transplanted into the pots (Plate 3.13). The potted plants were separated into a Control Group (CG) and a Treatment Group (TG). Each group had twenty-

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five (25) potted plants consisting of five (5) accessions replicated 5 times, arranged in a Completely Randomised Design (CRD). Fifty (50) pairs of adult males and females of EFSB were released (Plate 3.14) in the TG in the screen house after 5, 6, 7, 8, 9, and 10 WAT using van Hung *et al.* (2020) as a guide. On the other hand, there was no release of EFSB onto the potted plants in the CG.

Plate 3.13.: Picture showing potted plants layout in the screen house.

The same management practices were carried out on TG and CG throughout the experiment. All potted plants were irrigated with a measured quantity of water daily. The volume of irrigation water increased with time as plants became bigger. To boost soil fertility, fertiliser (NPK 15:15:15) was administered at a rate of 15g per plant during weeks one (1) and six (6).

Plate 3.14.: Opened cage to release EFSB in the screen house.

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On all of the potted plants, observations were conducted and data were recorded. Weather data, growth indices (plant height and the number of leaves), yield, and fruit and shoot damage % were all gathered. Temperature and relative humidity were measured every day with a thermohydrometer that was mounted in the screen house (Plate 3.15).

Plate 3.15.: Thermohydrometer collecting weather data in the screen-house

3.5. Resistance/Susceptibility Index

Based on the percentage damage to the fruits/shoots caused by EFSB, the resistance status of each accession was determined using the scale for Lepidoptera borer insects by Chakravarthy and Selvanarayanan (2019), as indicated in Table 3.2.

Table 3.2: Lepidoptera borer insects resistance scale.

Rating	***Damaged Fruits (%)***	***Status***	***Grade***
1	No damage	Highly resistant	I
2	0 – 10	Resistant	R
3	10 – 20	Moderately resistant	MR
4	20 – 30	Moderately Susceptible	MS
5	30 – 40	Susceptible	S
6	Above 40	Highly susceptible	HS

3.6. Statistical Analysis

Statistical Analysis All collected data was formatted into an Excel spreadsheet and analyzed with GenStat software (12th Edition). Original data were reported in the results, but those that did not

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meet the assumptions/conditions of ANOVA were transformed before being analysed. Count and percentage data were transformed using logarithm and square root, respectively. Repeated measures ANOVA using the REML function was used to analyze the effects of time (WAT), treatments (accessions) and the interaction between time and the accessions on the incidence of insect pests in the field during the study. Analysis of variance (ANOVA) was used to compare growth, yield and damage parameters between the accessions and Fisher's protected LSD was employed to separate the means. Lastly, an unpaired t-test was used to compare parameters between the Treatment and Control Groups in the screen house. The significance level for all statistical comparisons was set at 0.05.

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CHAPTER FOUR

4.0 RESULTS

4.1. Insect Collection and Classification from the Field

For the two seasons, a total of 29,279 individual insects were collected and sorted under a dissecting microscope and classified into Orders/Sub-orders, as shown in Table 4.1. Table 4.1. Insect orders/sub-orders abundance during two seasons in eggplant fields

Orders	Sub-order / Infra-order	Major Season	Minor season	Total
Coleoptera		135	123	**258**
Dermaptera		3	0	**3**
Diptera		292	200	**492**
Hemiptera	Auchenorrhynca	2,019	1,031	**3,050**
	Heteroptera	274	762	**1,036**
	Sternorrhyncha	6,969	2,936	**9,905**
Hymenoptera		2,469	1,679	**4,148**
Blattodea	Isoptera	79	20	**99**
Lepidoptera		2,234	1,494	**3,728**
Mantodea		5	3	**8**
Odonata		0	5	**5**
Orthoptera		1,088	1,565	**2,653**
Thysanoptera		1,948	1,946	**3,894**
Total		**17,515**	**11,764**	**29,279**

It was observed that all the insect orders/sub-orders collected were more abundant in the major season, except for Orthoptera and Heteroptera, which were more abundant in the minor season. About 17,515 insects were collected during the major season, whereas 11,764 were collected in the minor season (Table 4.1).

Different insect species were observed to infest or attack the different growth stages (vegetative, flowering and fruiting) of the eggplant accessions in the field. The growth stages were represented at different weeks after transplant (WAT) in the field, 1-6 WAT for the vegetative stage, 6-8 WAT for the flowering stage and, 8 WAT and beyond for fruiting.

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4.2. Major Insect Pests and Abundance in the Field.

The field study identified nine (9) insect species collected and classified as major pests. These insect species were the most abundant in both seasons relative to other insect species per incidence on the crops and have also been listed as major insect pests of eggplants by the PPRSD of the MoFA in Ghana. They include *Aphis* sp., *Atractomorpha acutipennis*, *Bemisia tabaci*, *Dysdercus* sp., *Empoasca* sp., *Leucinodes* sp., *Thrips* sp., *Urentius hystricellus* and *Zonocerus variegatus*. All these insect species were collected in both seasons except *U. hystricellus*, collected only during the minor season, and Dysdercus sp. during the major season (Table 4.2).

Table 4.2. Seasonal occurrences of major insect pests during the study.

Insect Species	**Major Season**	**Minor Season**
Aphis sp.	+	+
Atractomorpha acutipennis	+	+
Bemisia tabaci	+	+
Dysdercus sp.	+	-
Empoasca sp.	+	+
Leucinodes sp.	+	+
Thrips sp.	+	+
Urenthius hystricellus	-	+
Zonocerus variegatus	+	+

NB: + and – denotes present and absent, respectively.

4.2.1. *Aphis* sp. incidence on eggplants

As shown in Fig. 4.1a, the highest *Aphis* sp. population per plant in the major season was recorded at 2 WAT for all the accessions but decreased greatly at 4 WAT and then fluctuated throughout the rest of the season. At the end of 10 WAT, the number of aphids per plant on each accession was; RV100250 (1,073), which is the highest, followed by Legon 1 (956), RV100248 (897), RV100213 (871), and the least was on RV100307 (731). Based on WAT, a significant difference was observed in the incidence of *Aphis* sp. ($F(4, 100) = 19.88$, $p < 0.001$). Contrarily, no significant

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difference was found in the incidence of *Aphis* sp. across different accessions ($F(4, 100) = 1.25$, $p = 0.294$), nor the interactions between the accessions and WAT ($F(4, 100) = 1.12$, $p = 0.344$).

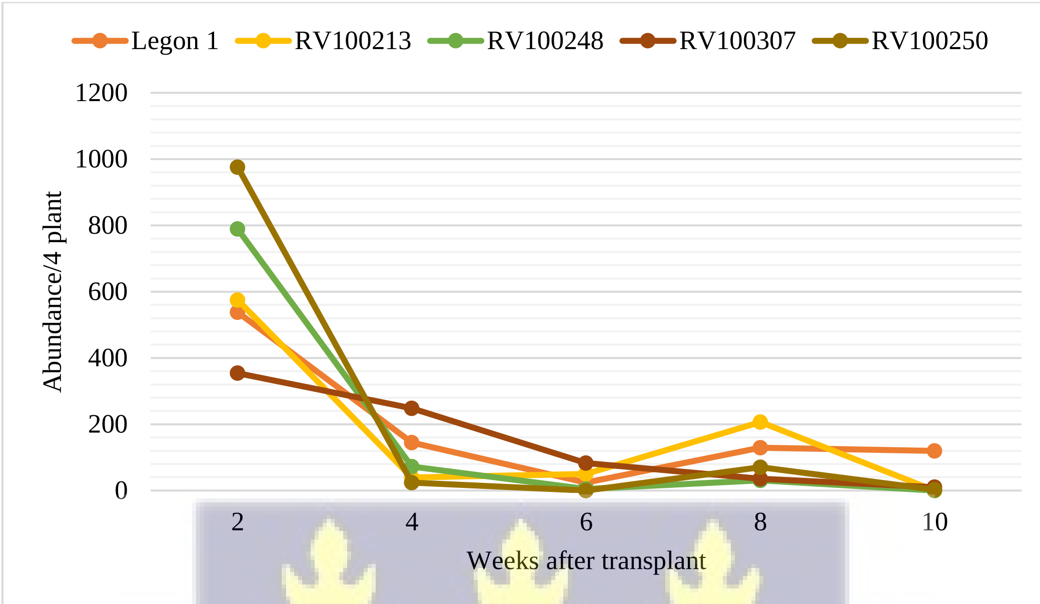

Figure 4.1a. The abundance of *Aphis* sp. in eggplant fields during the major season

For the minor season, RV100213 (234) and RV100248 (280) recorded the highest number of *Aphis* sp. per plant at 2 WAT for the respective accessions, but there was a steady decline until 10 WAT, where both accessions recorded no infestation. Aphid population, on the other three accessions, fluctuated throughout the season, as shown in Fig. 4.1b. Between the accessions, RV100248 (524) recorded the highest population per plant, followed by RV100213 (501), Legon 1 (486), RV100307 (413), and the least, was RV100250 (339). There was a statistically significant effect of time (WAT) on the numbers of aphids recorded, $F(4, 100) = 9.44$, $p < 0.001$, whereas there was no statistically significant effect of treatments/accessions ($F(4, 100) = 1.59$, $p = 0.182$) and the interaction between the treatments/accessions and WAT ($F(4, 100) = 1.10$, $p = 0.361$).

The total number of *Aphis* sp. recorded throughout the study was 6,818. The *Aphis* sp. population in the major season (4,555) and the minor season (2,263) was significantly different, $p = 0.030$.

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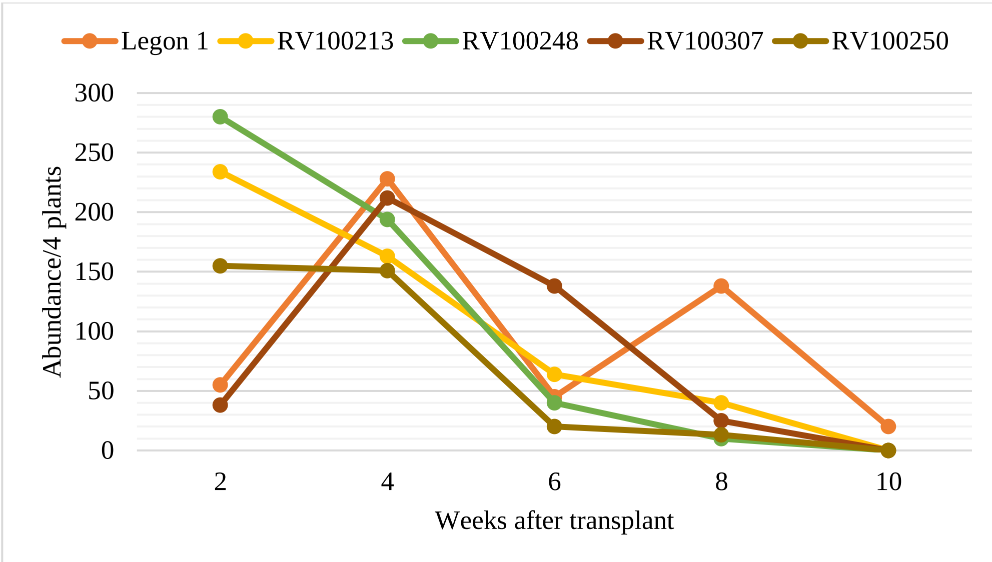

Figure 4.1b. The abundance of *Aphis* sp. in eggplant fields during the minor season.

4.2.2. *Atractomorpha acutipennis* incidence on eggplants

During the major season, the populations of *A. acutipennis* per plant fluctuated, as shown in Fig. 4.2a. Legon 1 had the highest number of A. acutipennis (25), followed by RV100307 (24), RV100213 (14), RV100248 (11), and RV100250 had the lowest (9). Based on WAT, a significant difference was observed in the incidence of *A. acutipennis* ($F(4, 100) = 7.77$, $p < 0.001$). Contrarily, no significant difference was found in the incidence of *A. acutipennis* across different accessions ($F(4, 100) = 1.54$, $p = 0.196$), nor the interactions between the accessions and WAT ($F(4, 100) = 0.87$, $p = 0.599$).

In the minor season, the populations of *A. acutipennis* per plant also fluctuated on all the accessions. As shown in Fig. 4.2b., there was a sharp increase at 6 WAT for all the accessions. RV100248 (59) had the highest population, followed by Legon 1 and RV100307 (39), RV100213 (26), and RV100250 (22). There was a statistically significant effect of time (WAT) ($F(4, 100) = 10.20$, $p < 0.001$) and of treatments/accessions ($F(4, 100) = 2.67$, $p = 0.037$) on the numbers of *A.*

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acutipennis recorded, whereas the interaction between the treatments/accessions and WAT did not show a statistically significant difference ($F(4, 100) = 1.64$, $p = 0.071$).

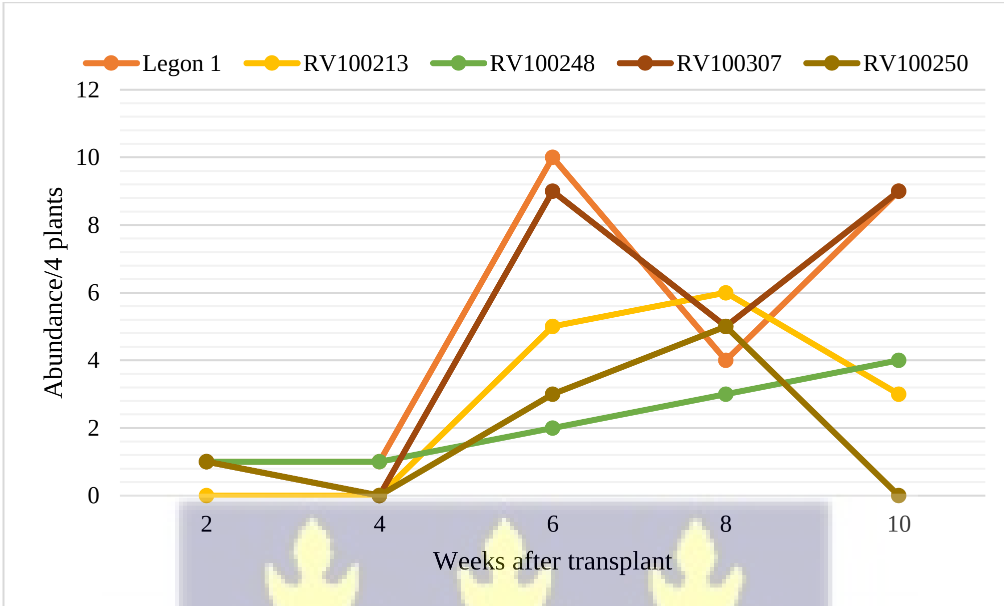

Figure 4.2a. The abundance of *A. acutipennis* in eggplant fields during the major season

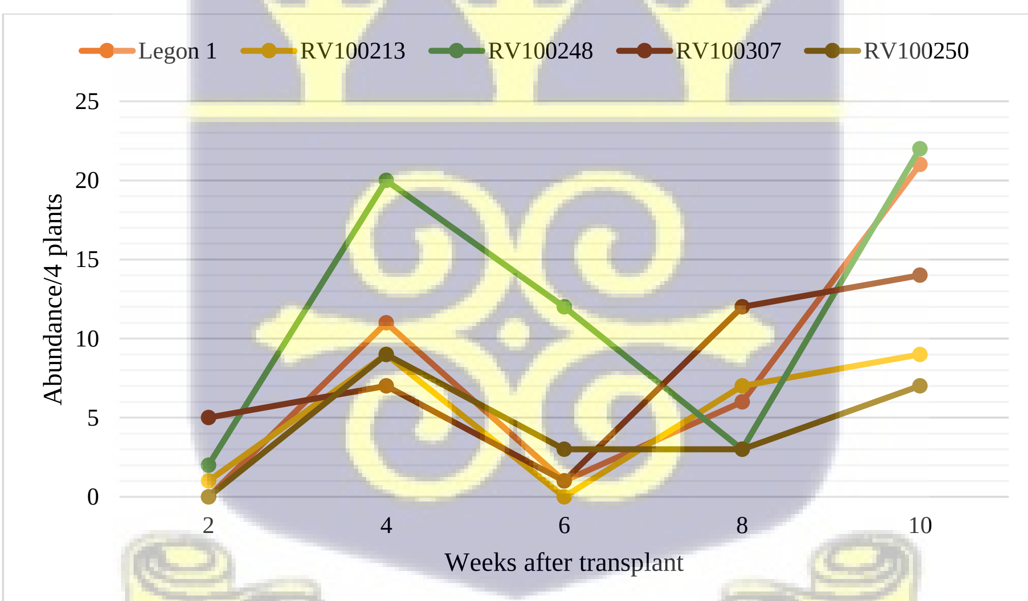

Figure 4.2b. The abundance of *A. acutipennis* in eggplant fields during the minor season

The total number of *A. acutipennis* recorded throughout the study was 274, with 89 in the major season and 185 in the minor season. The incidence between the seasons showed a significant difference, $p = <0.001$.

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4.2.3. *Bemisia tabaci* incidence on eggplants

Figure 4.3a shows that the incidence of *B. tabaci* per plant peaked at 2 WAT on all the accessions during the major season. The incidence declined sharply from 4 WAT until the end of the season, with RV100307, RV100213 and RV100250 reaching zero at 10 WAT. RV100213 had the highest number of *B. tabaci* per plant (570), followed by Legon 1 (532), RV100248 (479), RV100250 (468) and RV100307 (365). The study revealed significant statistical effects on the incidence of *B. tabaci* to WAT ($F(4, 100) = 24.69$, $p < 0.001$), the accessions ($F(4, 100) = 3.17$, $p = 0.018$), and the interactions between the accessions and WAT ($F(4, 100) = 2.46$, $p = 0.004$).

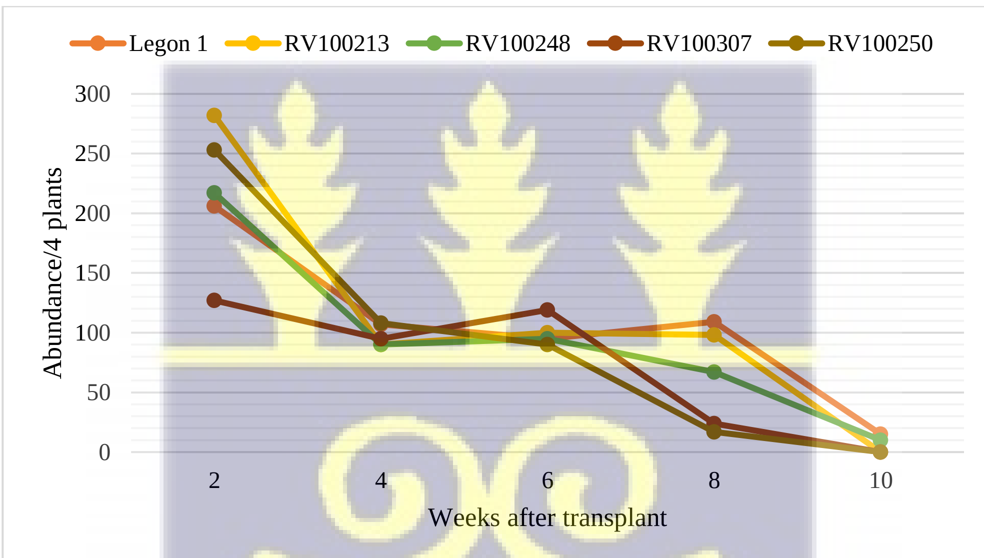

Figure 4.3a. The abundance of *B. tabaci* in eggplant fields during the major season

In the minor season, the incidence of *B. tabaci* per plant increased from 2 WAT and peaked at 6 WAT on all accessions, except RV100307 which peaked at 4 WAT and then declined continuously until 10 WAT, as shown in Fig. 4.5b. The number of whiteflies per plant on each accession during the minor season was RV100213 (103), Legon 1 (105), RV100250 (118), RV100248 (151), and RV100307 (196). There was a statistically significant effect of time (WAT) on the numbers of *B. tabaci* recorded, $F(4, 100) = 18.76$, $p < 0.001$, whereas there was no statistically significant effect

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of treatments/accessions (*F*(4, 100) = 1.03, *p* = *0.398*) and the interaction between the treatments/accessions and WAT (*F*(4, 100) = 1.52, *p* = *0.107*).

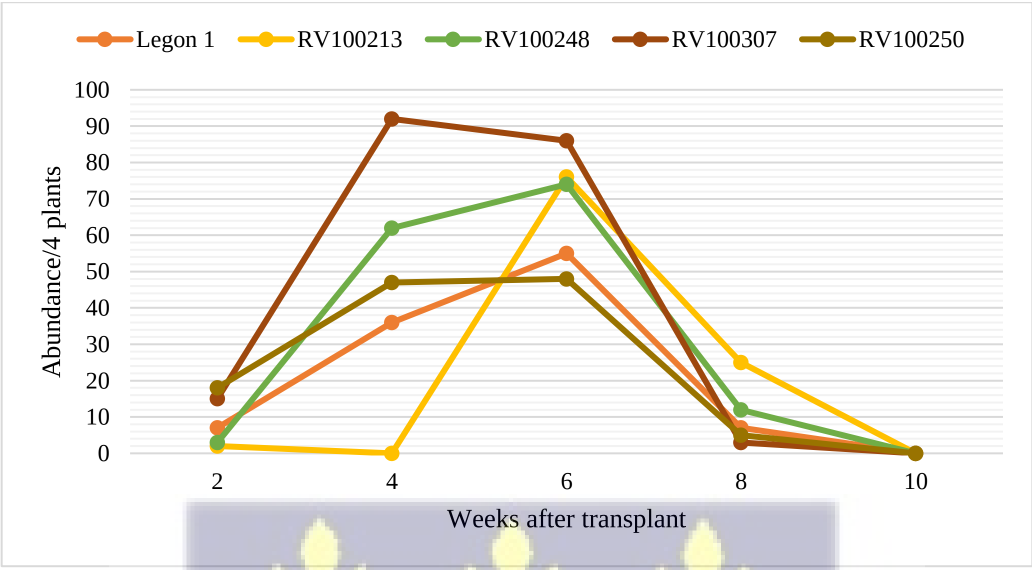

Figure 4.3b. The abundance of *B. tabaci* in eggplant fields during the minor season

The total number of *B. tabaci* recorded throughout the study was 3,087, with 2,414 in the major season and 673 in the minor season. The incidence between the two seasons showed a significant difference, *p* < *0.001*.

4.2.4. *Dysdercus* sp. (Cotton stainer) incidence on eggplants

A total of 234 *Dysdercus* sp. was collected in the major season, as shown in Figure 4.6. The number of cotton stainers per plant on Legon 1 (20) and RV100250 (13) increased and peaked at 4 WAT and then declined steadily to zero at 10 WAT. For RV100213 (33) and RV100248 (12), the incidence increased and peaked at 6 WAT, then declined to zero at 10 WAT. The number of cotton stainers per plant on RV100307 increased from 2 WAT and reached a peak between 4 WAT and 8 WAT (15) and then declined to 1 at 10 WAT. By the end of the season, 33 cotton stainers were collected on RV100250, 34 on RV100248, 48 on Legon 1, 49 on RV100307 and 70 on RV100213. Based on WAT, a significant difference was observed in the incidence of *Dysdercus* sp. (*F*(4, 100)

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= 5.49, $p = 0.004$). However, no significant difference was observed in the incidence of *Dysdercus* sp. across different accessions ($F(4, 100) = 1.51$, $p = 0.208$), nor the interactions between the accessions and WAT ($F(4, 100) = 0.66$, $p = 0.826$).

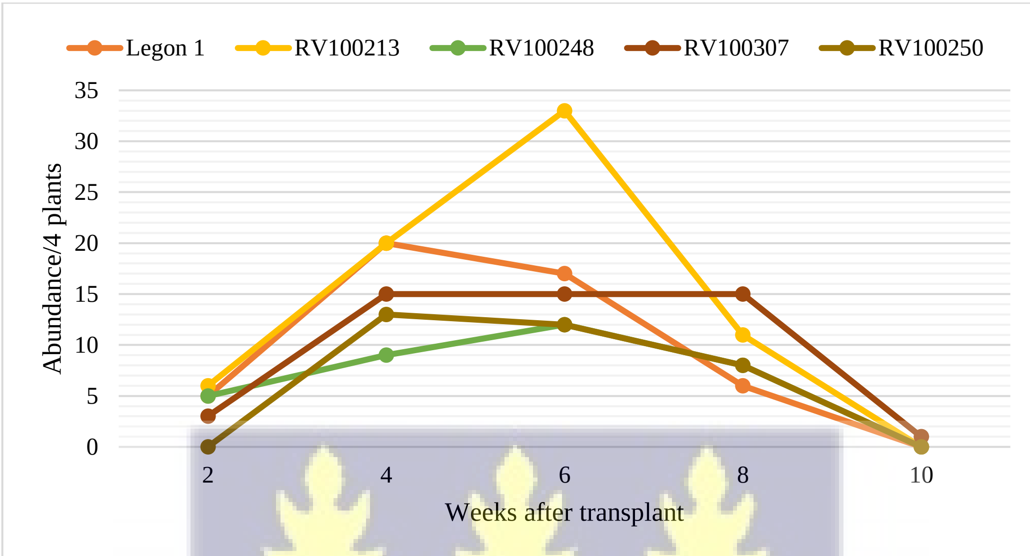

Figure 4.4. The abundance of *Dysdercus* sp. in eggplant fields during the major season.

4.2.5. *Urentius hystricellus* (eggplant lace bug) incidence on eggplants

The eggplant lace bug, *U. hystricellus*, was recorded only in the minor season with a total incidence per plant of 737 distributed on: Legon 1 (127), RV100213 (144), RV100248 (226), RV100307 (87) and RV100250 (153) (Fig. 4.5). The first and highest incidence occurred at 4 WAT, which sharply declined from 6 WAT until 10 WAT. At 4 WAT, RV100248 (204) had the highest incidence, followed by RV100250 or RV100213 (123), Legon 1 (101), and RV100307 (66). The numbers of *U. hystricellus* recorded were significantly influenced by both time (WAT) ($F(4, 100) = 93.12$, $p < 0.001$). However, the treatments/accessions ($F(4, 100) = 0.53$, $p = 0.712$), and the interaction between the treatments/accessions and WAT ($F(4, 100) = 0.84$, $p = 0.637$) did not result in a statistically significant difference.

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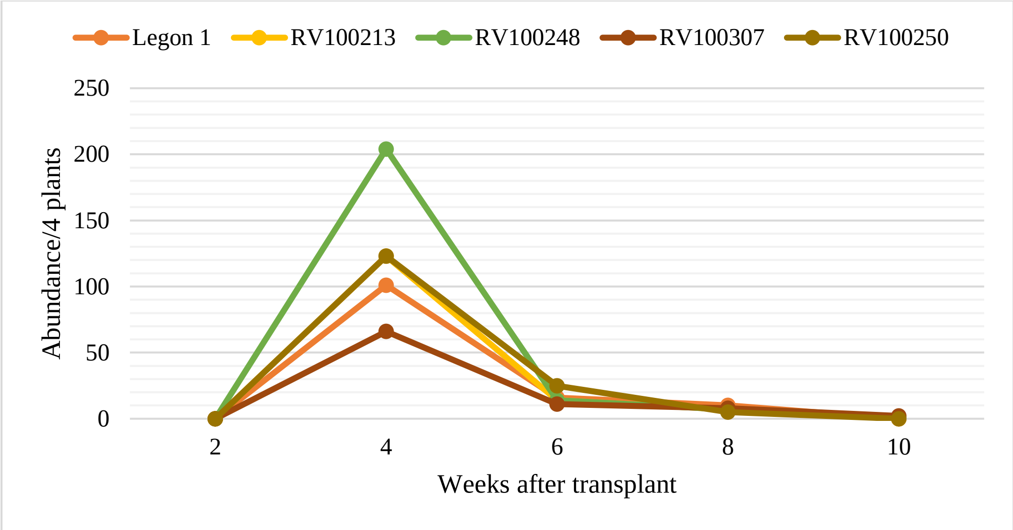

Figure 4.5. The abundance of *U. hystricellus* in eggplant fields during the minor season.

4.2.6. Incidence of *Empoasca* sp. (Leafhopper) on Eggplants

Populations of *Empoasca* sp. per plant on the eggplant accessions were high from 2WAT to 6WAT, then declined after 8WAT. By 10WAT, the number of leafhoppers collected or observed on all the accessions was zero. The highest population of leafhoppers recorded during the major season was at 6WAT on RV100307 (145), as shown in Fig. 4.6a. There was a statistically significant effect of time (WAT) ($F(4, 100) = 113.31$, $p < 0.001$) and of treatments/accessions ($F(4, 100) = 2.95$, $p = 0.024$) on the numbers of *Empoasca* sp. recorded, whereas the interaction between the treatments/accessions and WAT did not show a statistically significant difference ($F(4, 100) = 1.17$, $p = 0.309$).

In the minor season, an increased number of leafhoppers per plant was recorded on all the accessions from 4WAT, which decreased gradually until no incidence in any of the accessions at 10WAT. There were fluctuations in some accessions as shown in Fig. 4.6b. The highest incidence per plant recorded was on Legon 1 (101) at 4WAT. The numbers of *Empoasca* sp. recorded were significantly affected by time (WAT) ($F(4, 100) = 36.60$, $p < 0.001$). However, in

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treatments/accessions (F(4, 100) = 0.91, *p* = *0.461*), the interaction between the treatments/accessions and WAT (F(4, 100) = 0.42, p = *0.976*) did not result in a statistically significant difference.

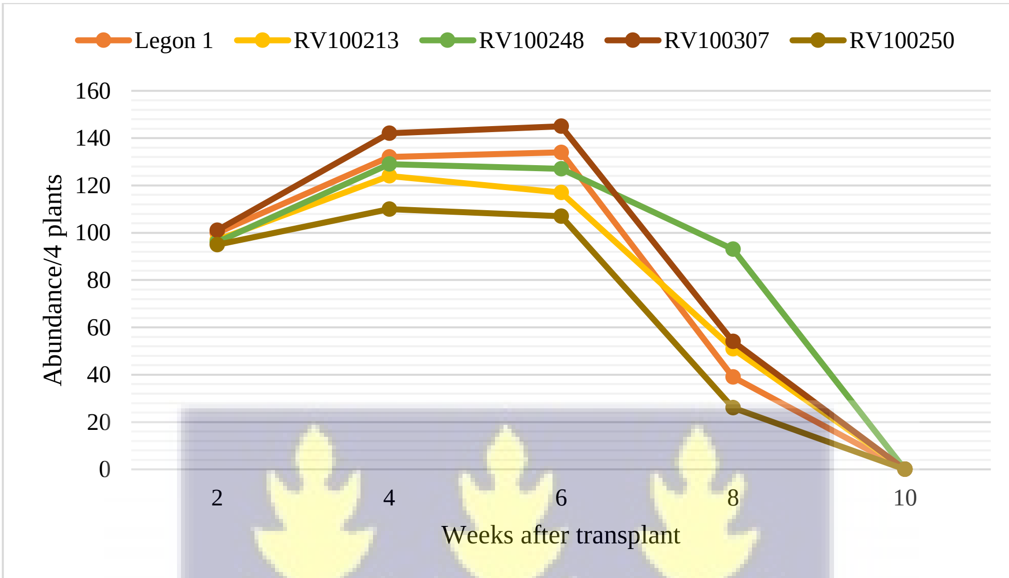

Figure 4.6a. The abundance of *Empoasca* sp. in eggplant fields during the major season.

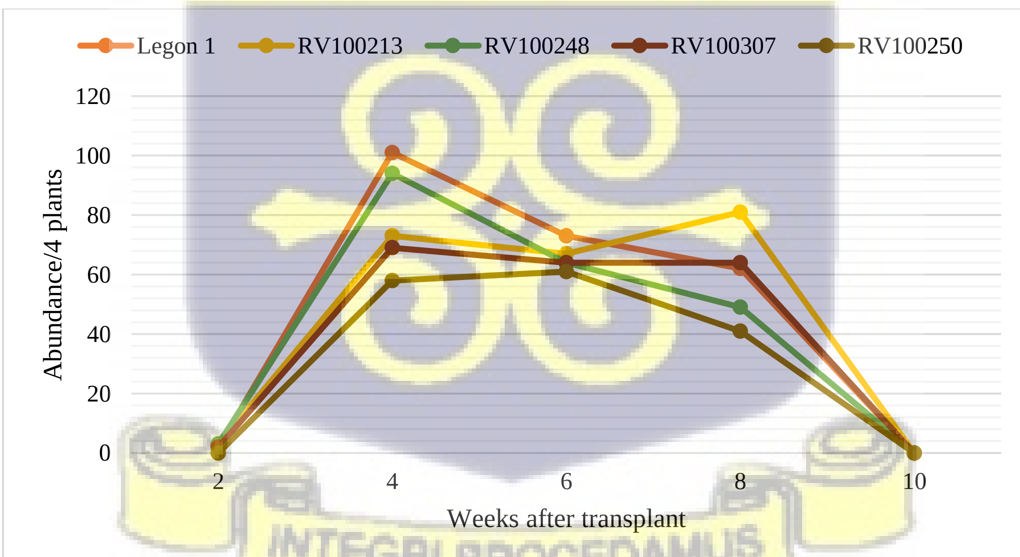

Figure 4.6b. The abundance of *Empoasca* sp. in eggplant fields during the minor season.

The incidence of leafhoppers during the major and minor seasons, however, differed significantly (*p* = < *0.001*).

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4.2.7. Incidence of *Thrips* sp. on Eggplants

In the major season, the thrips population per plant on all the accessions was zero (0) as at 2WAT. However, along the season, there was a gradual increase that peaked at 10WAT for all the accessions, as shown in Fig. 4.7a. The highest population of thrips was collected on Legon 1 (316), and the lowest was RV100248 (173). The incidence of *Thrips* sp. across WAT ($F(4, 100) = 98.52$, $p < 0001$) and the different accessions ($F(4, 100) = 2.83$, $p = 0.029$) revealed significant differences, whereas, in the interactions between the accessions and WAT, there was no significant difference ($F(4, 100) = 1.19$, $p = 0.289$).

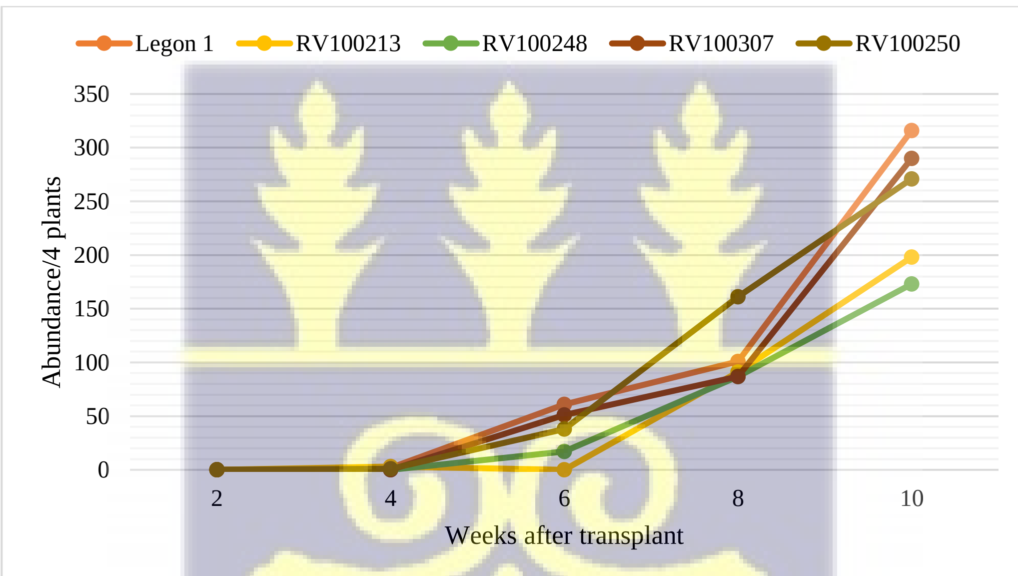

Figure 4.7a. The abundance of *Thrips* sp. in eggplant fields during the major season.

Like the major season, a similar incidence trend was seen in the minor season as shown in Fig. 4.7b. At 10WAT, the highest thrips incidence per plant was recorded on RV100250 (349), and the lowest was on Legon 1 (162). There was a statistically significant effect of time (WAT) on the numbers of aphids recorded, $F(4, 100) = 55.48$, $p < 0.001$, whereas there was no statistically significant effect of treatments/accessions ($F(4, 100) = 1.19$, $p = 0.322$) and the interaction between the treatments/accessions and WAT ($F(4, 100) = 0.61$, $p = 0.865$).

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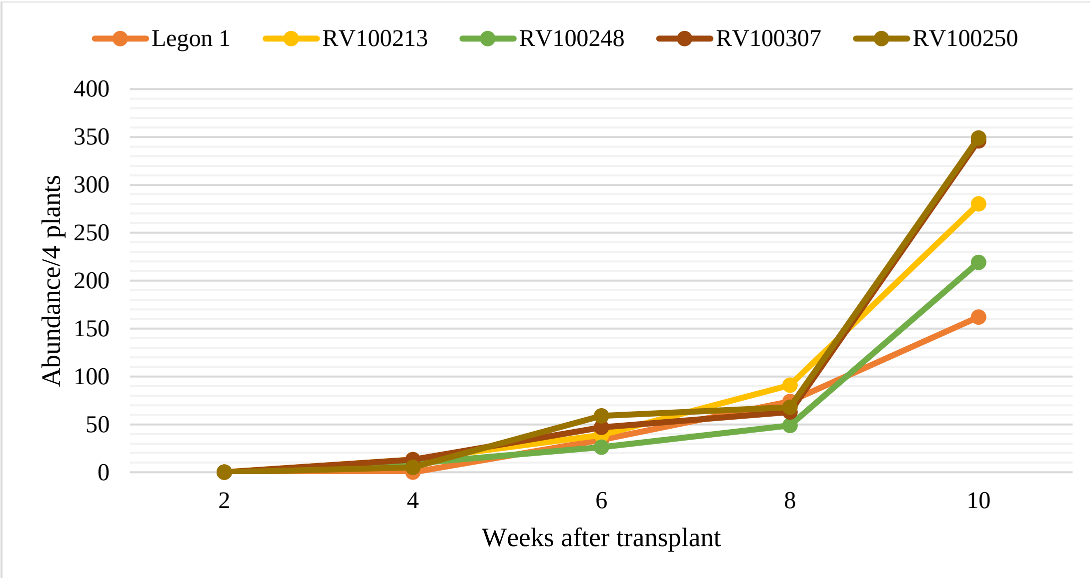

Figure 4.7b. The abundance of *Thrips* sp. in eggplant fields during the minor season.

The total number of *Thrips* sp. recorded throughout the study was 3,894; that is, the major season (1,948) and the minor season (1,946). However, there was no difference in the incidence between the two seasons, $p = 0.990$.

4.2.8. Incidence of *Zonocerus variegatus* (Variegated Grasshopper) on Eggplants

Zonocerus variegatus incidence in the major season was zero on all the accessions at 2WAT. From 4WAT, there was an increase throughout the season for RV100213, RV100248, and Legon 1, which peaked at 10WAT. RV100307 and RV100250, on the other hand, peaked at 8WAT and only slightly decreased at 10WAT, as shown in Fig. 4.8a. On RV100307 (91) at 8WAT, the highest incidence per plant of the variegated grasshopper was recorded over the entire major season. The study revealed a significant difference in the incidence of *Z. variegatus* to WAT ($F(4, 100) = 46.12$, $p < 0.001$), between the across accessions ($F(4, 100) = 6.43$, $p < 0.001$), and in the interactions between the accessions and WAT ($F(4, 100) = 1.10$, $p = 0.018$).

Zonocerus variegatus on RV100213 and RV100248 increased steadily during the minor season, whereas on Legon1, RV100250, and RV100307, there was fluctuation. Except for RV100307

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which peaked at 8WAT, *Z. variegatus* incidence peaked at 10WAT for all accessions, as shown in Fig. 4.8b. On RV100213 (179), the highest population incidence was recorded at 10WAT. The study revealed significant statistical effects on the incidence of *Z. variegatus* to WAT ($F(4, 100) = 135.37$, $p < 0.001$), the accessions ($F(4, 100) = 7.20$, $p < 0.001$), and the interactions between the accessions and WAT ($F(4, 100) = 7.40$, $p < 0.001$).

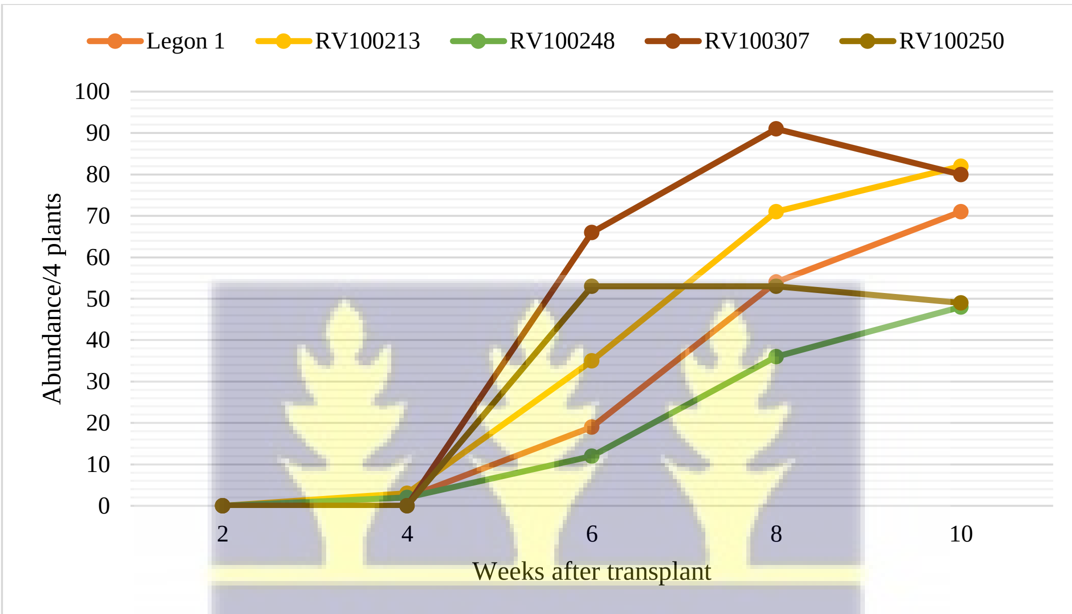

Figure 4.8a. The abundance of *Z. variegatus* in eggplant fields during the major season.

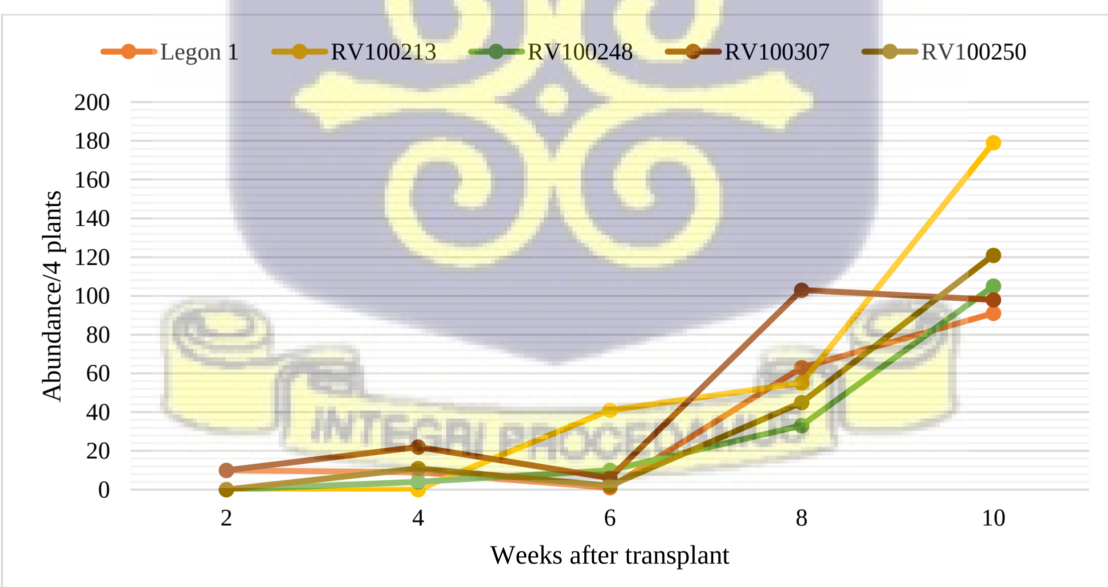

Figure 4.8b. The abundance of *Z. variegatus* in eggplant fields during the minor season.

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At the end of the study, the incidence of *Z. variegatus* recorded was 1,846 throughout the study, including the major season (827) and the minor season (1,019). $P = 0.187$ indicates that there was no significant difference between the two seasons.

4.2.9. *Leucinodes* sp. (eggplant shoot and fruit borer) incidence on eggplants

The incidence of ESFB on all the accessions increased until 11WAT in the major season, except for RV100250, which showed a slight decline. The ESFB population increased again from 12WAT and reached the highest level on Legon1 and RV100307 at 14WAT. RV100213, RV100248 and RV100250 declined slightly at 14WAT, as shown in Fig. 4.9a. Legon1 had the highest ESFB incidence (200) at 14WAT. The study revealed significant statistical effects on the incidence of EFSB to WAT ($F(4, 100) = 149.08$, $p < 0.001$), the accessions ($F(4, 100) = 8.23$, $p < 0.001$), and the interactions between the accessions and WAT ($F(4, 100) = 3.10$, $p < 0.001$).

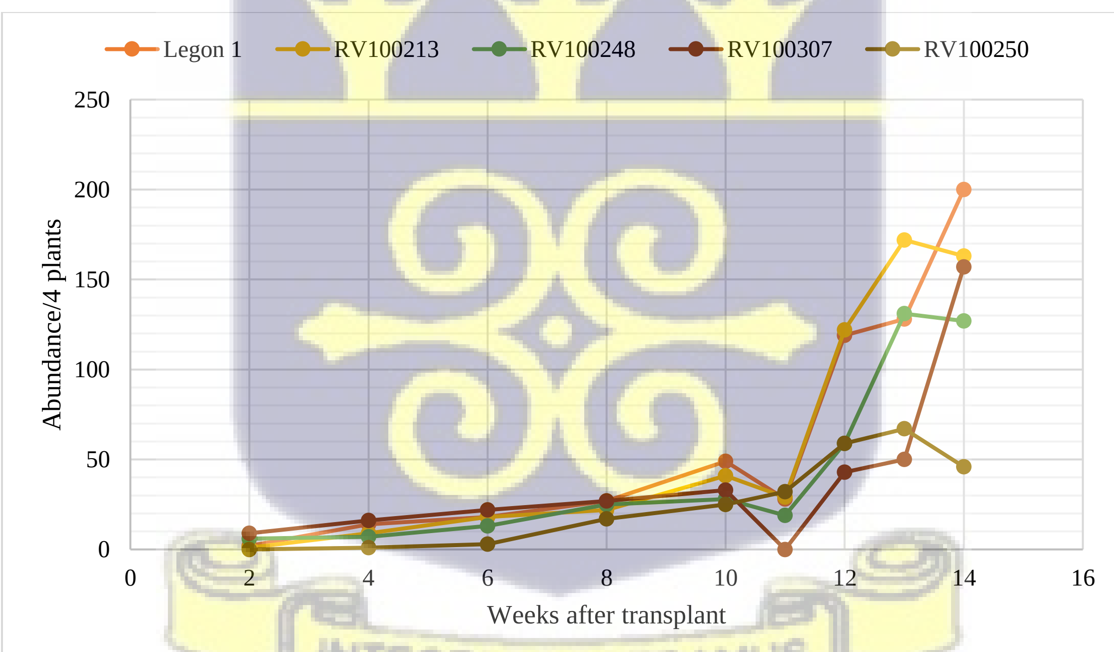

Figure 4.9a. The abundance of *Leucinodes* sp. in eggplant fields during the major season.

A similar trend was observed in the minor season, as shown in Fig. 4.9b. Legon1 had the highest ESFB incidence in the major season, while RV100307 had the highest incidence (157) in the minor

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season. However, there was no significant difference in ESFB incidence among the accessions in the minor season (p = 0.916). The total ESFB population in the fields was 3,661, with 2,184 in the major season and 1,477 in the minor season. There was a statistically significant effect of time (WAT) on the numbers of EFSB recorded, $F(4, 100) = 62.59$, $p < 0.001$, but there was no statistically significant effect of treatments/accessions ($F(4, 100) = 0.82$, $p = 0.513$). Also, the interactive effect between the treatments/accessions and WAT on the incidence of EFSB recorded was statistically significant ($F(4, 100) = 2.28$, $p < 0.001$).

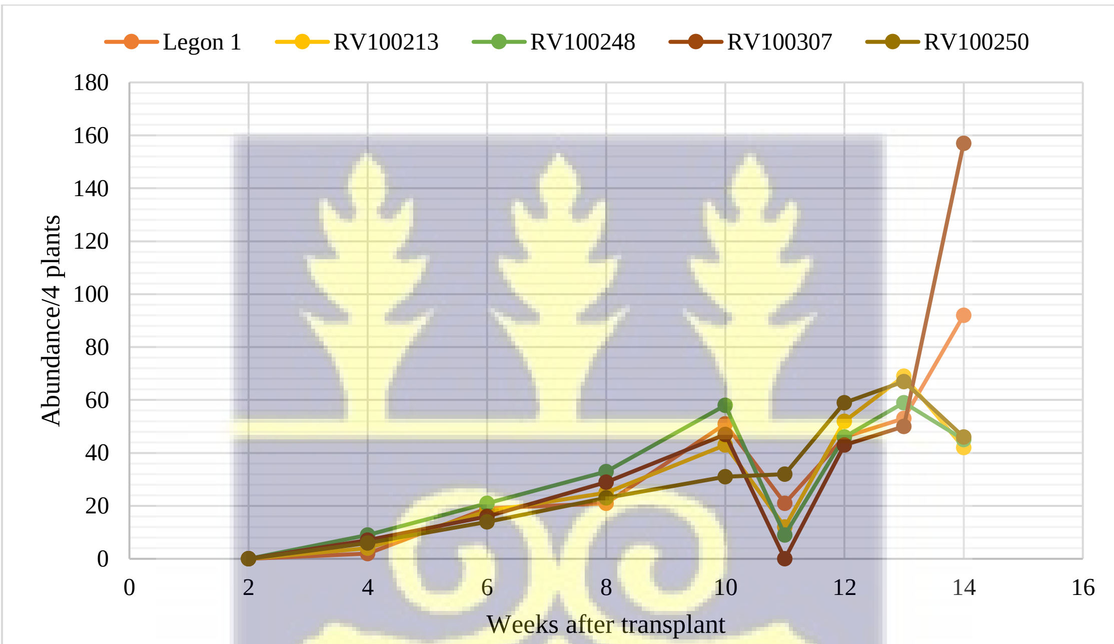

Figure 4.9b. The abundance of *Leucinodes* sp. in eggplant fields during the minor season.

4.3. Growth Parameters, Leaf Damage, and Yield of the Accessions

4.3.1. Plant height (cm)

Tables 4.3a and b show the mean plant heights in the major and minor seasons, respectively, at 2, 4, 6, 8 and 10WAT. There was no significant difference (p = 0.403) in mean plant height among the accessions at 2WAT in the major season. RV100307 was the tallest (19.60 ± 1.04 cm) and Legon1 was the shortest (15.55 ± 0.93 cm). At 4WAT, there was a significant difference (p=0.001)

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in mean plant height among the accessions, with RV100307 being the tallest (43.00 ± 1.69 cm) and RV100213 being the shortest (32.25 ± 1.35 cm). At 6, 8, and 10WAT, there were significant differences (p = 0.001) in mean plant height among the accessions, with RV100307 being the tallest (74.55 ± 2.79 cm, 97.95 ± 3.44 cm, and 122.40 ± 3.28 cm), and RV100248 being the shortest (49.70 ± 2.75 cm, 65.80 ± 3.08 cm, 82.80 ± 2.11 cm), respectively.

Table 4.3a. The mean height of the accessions in the major season.

Accessions	(Mean Plant Height ± S.E.) cm				
	2WAT	**4WAT**	**6WAT**	**8WAT**	**10WAT**
Legon 1	15.55 ± 0.93a	34.90 ± 1.50ab	62.25 ± 1.93b	84.40 ± 2.67b	105.05 ± 2.82b
RV100213	16.85 ± 1.23a	32.25 ± 1.35a	59.10 ± 2.57b	81.60 ± 3.01b	102.85 ± 3.13b
RV100248	17.90 ± 0.88a	34.15 ± 1.88ab	49.70 ± 2.75a	65.80 ± 3.08a	82.80 ± 2.11a
RV100307	19.60 ± 1.04a	43.00 ± 1.69c	74.55 ± 2.79c	97.95 ± 3.44c	122.40 ± 3.28c
RV100250	17.10 ± 1.12a	36.95 ± 1.90b	61.60 ± 2.92b	77.75 ± 3.24b	99.50 ± 3.42b
l.s.d	***2.83***	***4.53***	***7.27***	***8.32***	***8.23***
Fpr	***0.403***	***<0.001***	***<0.001***	***<0.001***	***<0.001***

Means that do not share the same letter in a column are significantly different.

In the minor season (Table 4.3b), there was no significant difference (p = 0.11) in mean plant height among the accessions at 2WAT, with Legon1 being the shortest (12.50 ± 0.86 cm) and RV100250 being the tallest (16.80 ± 0.90 cm). There was also a significant difference (p = 0.004) in mean plant height among the accessions at 4WAT, with Legon1 being the shortest (20.05 ± 1.11cm) and RV100307 being the tallest (27.85 ± 2.10cm). At 6, 8, and 10WAT, there were significant differences (p = <0.001) in mean plant height among the accessions, with RV100307 being the tallest (54.30 ± 2.60cm, 85.20 ± 3.12cm, and 111.50 ± 3.72cm), and RV100248 being the shortest (40.55 ± 1.85cm, 58.25 ± 2.61cm, and 73.75 ± 3.11cm).

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Table 4.3b. Mean plant height of the accessions in the minor season.

Accessions	(Mean Plant Height ± S.E.) cm				
	2WAT	**4WAT**	**6WAT**	**8WAT**	**10WAT**
Legon 1	12.50 ± 0.86a	20.05 ± 1.11a	43.10 ± 1.78a	75.05 ± 2.27b	89.85 ± 2.66b
RV100213	14.90 ± 0.83ab	21.45 ± 1.50a	41.50 ± 2.40a	76.25 ± 2.70b	89.95 ± 2.72b
RV100248	15.40 ± 1.02b	21.65 ± 1.01a	40.55 ± 1.85a	58.25 ± 2.61a	73.75 ± 3.11a
RV100307	16.10 ± 0.86b	27.85 ± 2.10b	54.30 ± 2.60b	85.20 ± 3.12c	111.50 ± 3.72c
RV100250	16.80 ± 0.90b	22.25 ± 1.59a	49.35 ± 2.20b	73.45 ± 2.81b	85.65 ± 3.53b
l.s.d	***2.48***	***4.14***	***5.96***	***7.52***	***8.61***
Fpr	***0.011***	***0.004***	***<.001***	***<.001***	***<.001***

Means that do not share the same letter in a column are significantly different.

In the screen-house, data on plant heights were collected on potted plants in both the Treatment Group (T.G.) and Control Group (C.G.) at biweekly intervals until 14WAT, and the mean plant heights are shown in Table 4.3c. There were significant differences in mean plant height between T.G. and C.G. for Legon1 (p = 0.261), RV100213 (p = 0.099), RV100248 (p = 0.740), and RV100307 (p = 0.513), but not for RV100250. The mean plant height of RV100250 differed significantly between T.G. and C.G., p=0.004.

Table 4.3c. Mean plant height of the accessions in the screen house.

WAT	Group	(Mean Height ± S.E) cm				
		Legon 1	**RV100213**	**RV100248**	**RV100307**	**RV100250**
2	**TG**	12.80 ± 2.13	8..00 ± 0.55	12.30 ± 0.94	10.70 ± 1.18	8.50 ± 0.63
	C.G.	12.50 ± 2.06	7.80 ± 0.58	11.40 ± 0.80	10.20 ± 1.08	9.80 ± 0.97
4	**T.G.**	24.70 ± 4.98	14.40 ± 1.53	26.10 ± 4.65	19.30 ± 4.06	14.70 ± 1.41
	C.G.	21.90 ± 4.86	12.20 ± 1.54	22.20 ± 3.14	13.60 ± 3.17	18.50 ± 2.83
6	**T.G.**	51.00 ± 8.44	36.40 ± 4.50	55.60 ± 9.47	47.60 ± 8.01	41.60 ± 5.45
	C.G.	47.00 ± 8.06	31.00 ± 5.94	49.00 ± 7.81	37.40 ± 6.87	46.00 ± 6.72
8	**T.G.**	68.80 ± 10.80	50.60 ± 7.54	69.80 ± 13.40	73.80 ± 12.80	54.60 ± 6.10
	C.G.	77.60 ± 9.37	59.20 ± 5.94	72.00 ± 8.97	73.60 ± 11.20	83.40 ± 5.98
10	**T.G.**	75.80 ± 9.17	59.00 ± 10.70	73.40 ± 14.50	78.60 ± 16.70	58.00 ± 9.58
	C.G.	104.20 ± 5.88	92.60 ± 3.97	89.00 ± 9.71	100.60 ± 10.10	108.40 ± 4.01
12	**T.G.**	90.60 ± 9.04	67.00 ± 10.50	90.90 ± 16.60	89.30 ± 17.60	66.50 ± 9.75
	C.G.	116.70 ± 7.34	98.40 ± 5.36	100.40 ± 10.30	110.80 ± 10.80	118.20 ± 4.81
14	**T.G.**	104.50 ± 10.90	73.40 ± 10.50	104.70 ± 18.00	97.90 ± 20.30	72.70 ± 10.50
	C.G.	126.10 ± 9.03	104.80 ± 3.76	111.20 ± 12.10	120.00 ± 10.90	126.90 ± 6.64
P value		***0.261***	***0.099***	***0.740***	***0.513***	***0.004***

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4.3.2. Number of Leaves

The mean number of leaves in the major and minor seasons are shown in Tables 4.3a and 4.3b, respectively. During the major season, there was a significant difference in the number of leaves among the accessions in all seasons. A similar trend was evident at 2 WAT (p = 0.032) and 4WAT (p < 0.001), where RV100250 had the highest number of leaves (20.20 ± 2.08) and (59.95 ± 3.42), respectively, while RV100307 had the lowest number of leaves (12.25 ± 1.29) and (38.65 ± 1.92), respectively. At 6WAT, there was a significant difference (p < 0.001) in the number of leaves; RV100250 had the highest (126.10 ± 4.69), while the lowest was RV100248 (64.40 ± 4.64). A similar trend was observed for 8 WAT (p < 0.001) and 10WAT (p < 0.001), where RV100250 had the highest number of leaves (126.10 ± 4.69) and (146.55 ± 5.23), respectively, while RV100248 had the lowest (79.90 ± 5.06) and (102.05 ± 4.53), respectively. Table 4.4a. The mean number of leaves in the major season.

Accessions	Mean Number of Leaves ± S.E.				
	2WAT	**4WAT**	**6WAT**	**8WAT**	**10WAT**
Legon 1	12.70 ± 1.65a	42.80 ± 2.56a	72.30 ± 3.01ab	107.30 ± 4.01b	131.45 ± 3.24b
RV100213	12.85 ± 1.60a	38.70 ± 2.86a	77.85 ± 3.93bc	111.95 ± 5.04b	135.95 ± 4.03bc
RV100248	13.75 ± 1.87a	39.20 ± 3.63a	64.40 ± 4.64a	79.90 ± 5.06a	102.05 ± 4.53a
RV100307	12.25 ± 1.29a	38.65 ± 1.92a	88.50 ± 5.79cd	113.00 ± 5.77bc	142.50 ± 3.64bc
RV100250	20.20 ± 2.08b	59.95 ± 3.42b	92.85 ± 4.86d	126.10 ± 4.69c	146.55 ± 5.23c
l.s.d	***4.89***	***7.69***	***12.54***	***13.63***	***11.59***
Fpr	***0.032***	***<0.001***	***<0.001***	***<0.001***	***<0.001***

Means that do not share the same letter in a column are significantly different.

In the minor season, there were significant differences in the number of leaves at 2, 6, 8, and 10 WAT (p < 0.001), but at 4WAT (p = 0.011), as shown in Table 4.4b. At 2WAT, RV100250 (12.05 ± 0.76) was the highest and RV100307 (5.45 ± 0.60) was the lowest. At 4WAT, Legon1 (19.90 ± 2.22) was the lowest, while RV100250 (33.10 ± 3.72) was the highest. Similarly, at 6, 8, and 10 WAT, RV100250 (65.65 ± 2.99, 113.70 ± 4.46, and 135.00 ± 4.61) were the highest, while RV100248 (47.30 ± 3.29, 70.80 ± 5.54 and 86.15 ± 5.80) were the lowest.

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Table 4.4b. The mean number of leaves in the minor season.

Accessions	Mean Number of Leaves ± S.E.				
	2WAT	**4WAT**	**6WAT**	**8WAT**	**10WAT**
Legon 1	6.60 ± 0.71a	19.90 ± 2.22a	49.40 ± 2.78a	90.55 ± 4.20b	115.30 ± 3.68b
RV100213	7.20 ± 1.06a	21.25 ± 2.78a	46.95 ± 3.54a	102.45 ± 5.23bc	119.95 ± 5.04bc
RV100248	7.20 ± 0.78a	23.25 ± 2.73a	47.30 ± 3.29a	70.80 ± 5.54a	86.15 ± 5.80a
RV100307	5.45 ± 0.60a	22.25 ± 2.30a	52.40 ± 2.80a	101.60 ± 6.01bc	128.55 ± 4.28cd
RV100250	12.05 ± 0.76b	33.10 ± 3.72b	65.65 ± 2.99b	113.70 ± 4.46c	135.00 ± 4.61d
l.s.d	***2.22***	***7.95***	***8.35***	***14.29***	***13.20***
Fpr	***<0.001***	***0.011***	***<0.001***	***<0.001***	***<0.001***

Means that do not share the same letter in a column are significantly different.

The number of leaves of the accessions in both groups was collected for 14WAT biweekly. Plants in T.G. were exposed to ESFB, while plants in C.G. were not. The number of leaves in T.G. and C.G. did not differ significantly for Legon 1 (p=0.200), RV100213 (p=0.239), RV100248 (p=0.316), and RV100307 (p=0.164), but they did for RV100250 (p=0.024). Table 4.3c shows the mean number of leaves of the accessions in the screen house.

Table 4.4c. The mean number of leaves of the accessions in the screen house

WAT	Group	Number of Leaves ± S.E.				
		Legon 1	**RV100213**	**RV100248**	**RV100307**	**RV100250**
2	**TG**	5.40 ± 1.03	3.40 ± 0.51	3.80 ± 0.80	4.20 ± 0.97	6.00 ± 1.14
	C.G.	4.40 ± 0.40	3.20 ± 0.37	3.80 ± 0.49	2.60 ± 0.40	5.60 ± 0.68
4	**T.G.**	12.00 ± 2.41	5.80 ± 0.37	10.80 ± 2.48	6.60 ± 1.60	13.20 ± 3.26
	C.G.	9.60 ± 1.54	5.20 ± 1.02	9.80 ± 1.98	6.40 ± 1.29	14.00 ± 3.62
6	**T.G.**	21.00 ± 4.34	13.00 ± 3.07	26.80 ± 5.95	11.80 ± 1.98	29.00 ± 5.28
	C.G.	14.00 ± 2.07	10.20 ± 2.06	22.40 ± 4.99	10.40 ± 1.57	27.00 ± 4.21
8	**T.G.**	36.00 ± 3.67	23.00 ± 3.16	47.80 ± 10.50	27.40 ± 7.19	36.80 ± 6.55
	C.G.	33.60 ± 5.42	25.20 ± 4.60	49.00 ± 9.27	30.00 ± 4.53	58.80 ± 8.07
10	**T.G.**	47.60 ± 3.72	44.00 ± 7.56	91.20 ± 21.20	42.40 ± 11.90	73.20 ± 14.10
	C.G.	73.60 ± 5.95	62.40 ± 8.98	124.40 ± 17.10	66.20 ± 8.82	138.40 ± 16.80
12	**T.G.**	53.00 ± 4.35	47.40 ± 7.51	95.00 ± 21.70	46.60 ± 12.60	79.20 ± 14.80
	C.G.	78.00 ± 6.34	65.60 ± 9.03	128.20 ± 17.60	68.80 ± 9.03	134.00 ± 15.10
14	**T.G.**	59.60 ± 5.75	49.80 ± 7.31	102.00 ± 23.40	49.00 ± 13.30	86.40 ± 15.60
	C.G.	83.20 ± 6.72	67.60 ± 9.57	134.20 ± 18.70	72.60 ± 9.93	150.40 ± 17.80
P-value		***0.200***	***0.239***	***0316***	***0.164***	***0.024***

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4.3.3. Percent Leaf Damage in the Field

Table 4.5a shows the mean per cent leaf damage recorded among the accessions during the major season. The lowest leaf damage was recorded on RV100250 at 2WAT (9.25 ± 0.75%), 4WAT (7.00 ± 0.56%), and 6WAT (6.50 ± 0.64%), on RV100248 (7.50 ± 0.57%) at 8WAT, and RV100250 and Legon1 (5.50 ± 0.34%) at 10WAT. On the other hand, the highest leaf damage was recorded on RV100307 at 2WAT (19.75 ± 2.96%), 8WAT (10.25 ± 1.12%) and 10WAT (7.00 ± 3.0.76%), and on RV100248 at 4WAT (17.60 ± 1.04%) and 6WAT (7.75 ± 0.85%). The p-values at 2WAT ($p = 0.002$) and 4WAT ($p < 0.001$) indicate significant differences in the mean per cent leaf damage among the accessions; however, there were no significant differences at 6 WAT ($p = 0.835$), 8 WAT ($p = 0.193$), and 10 WAT ($p = 0.221$).

Table 4.5a. Mean per cent leaf damage in the major season

Accessions	Mean Leaf Damage ± S.E. %				
	2WAT	**4WAT**	**6WAT**	**8WAT**	**10WAT**
Legon 1	13.00 ± 2.16ab	10.00 ± 0.96b	6.75 ± 0.66a	8.50 ± 0.82a	5.50 ± 0.34a
RV100213	12.35 ± 1.30ab	12.25 ± 1.12b	7.25 ± 0.85a	9.50 ± 1.02a	6.50 ± 0.64a
RV100248	15.50 ± 2.05bc	17.60 ± 1.04c	7.75 ± 0.85a	7.50 ± 0.57a	6.500 ± 0.53a
RV100307	19.75 ± 2.96c	15.75 ± 1.71c	7.25 ± 0.85a	10.25 ± 1.12a	7.00 ± 3.0.76a
RV100250	9.25 ± 0.75a	7.00 ± 0.56a	6.50 ± 0.64a	8.50 ± 0.73a	5.50 ± 0.34a
l.s.d	***5.46***	***2.87***	***2.20***	***2.20***	***1.54***
Fpr	***0.002***	***<0.001***	***0.835***	***0.193***	***0.221***

Means that do not share the same letter in a column are significantly different.

There were significant differences in leaf damage among the accessions at 2WAT ($p = 0.015$), 4WAT ($p < 0.001$), 6WAT ($p < 0.001$), and 10WAT ($p = 0.010$), but not at 8WAT ($p = 0.112$) during the minor season, as shown in Table 4.5b. At 2 WAT, RV100307 (22.75 ± 3.29 %) had the highest leaf damage, while RV100250 (11.50 ± 1.09 %) had the lowest. Likewise, at 4 WAT, RV100307 (15.15 ± 1.77 %) had the highest, and RV100250 (7.20 ± 0.92 %) had the lowest. At 6 WAT, RV100248 (6.75 ± 0.83 %) had the highest, and Legon1, RV100213, RV100248 and

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RV100250 (5.00 ± 0.00 %) all had the lowest. Finally, at 10 WAT, RV100248 (6.00 ± 0.46 %) had the lowest, while RV100213 (8.75 ± 0.88 %) had the highest.

Table 4.5b. Mean per cent leaf damage in the minor season.

4.8	**Mean Leaf Damage ± S.E. %**				
Accessions	**2WAT**	**4WAT**	**6WAT**	**8WAT**	**10WAT**
Legon 1	15.00 ± 2.24a	7.20 ± 0.80a	5.00 ± 0.00a	5.25 ± 0.25a	7.50 ± 0.77ab
RV100213	16.50 ± 1.71ab	9.35 ± 1.29a	5.00 ± 0.00a	6.25 ± 0.50a	8.75 ± 0.88b
RV100248	16.25 ± 3.42ab	13.70 ± 1.68b	6.75 ± 0.83b	5.50 ± 0.34a	6.00 ± 0.46a
RV100307	22.75 ± 3.29b	15.15 ± 1.77b	5.00 ± 0.00a	5.75 ± 0.41a	6.25 ± 0.62a
RV100250	11.50 ± 1.09a	7.20 ± 0.92a	5.00 ± 0.00a	5.00 ± 0.00a	6.50 ± 0.53a
l.s.d	***6.63***	***3.34***	***1.03***	***0.97***	***1.64***
Fpr	***0.015***	***<0.001***	***<0.001***	***0.112***	***0.010***

Means that do not share the same letter in a column are significantly different.

4.4. Damage to Shoots and Fruits Caused by EFSB

4.4.1. Percent shoot damage in the field

The percent shoot damage for the two seasons was recorded for each accession and the means were calculated, as shown in Table 4.7. Legon1 had the highest shoot damage in both the minor season (25.27 ± 3.09%) and the accession RV100248 during the minor seasons (28.99 ± 4.03%), while RV100250 had the lowest in the major season (12.48 ± 1.96%). There was no significant difference in the minor season, however, a significant difference in the percentage of shoot damage among the accessions in the major seasons (*p = 0.002*). The mean per cent shoot damage of the two seasons also showed that RV100250 was the lowest (15.64 ± 2.04%), and RV100248 had the highest mean per cent shoot damage (26.30 ± 2.56%). The mean percentage shoot damage of all the accessions differed significantly, *p = 0.033*.

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Table 4.7. Per cent shoot damage between the accessions caused by *Leucinodes* spp. in the field

Accessions	Shoot Damage ± S.E %		
	Major Season	**Minor Season**	**Mean**
Legon 1	25.27 ±3.09b	25.49 ± 3.63a	25.38 ± 3.14b
RV100213	20.19 ± 2.83b	25.17 ± 3.25a	22.68 ± 2.84ab
RV100248	23.60 ± 2.22b	28.99 ± 4.03b	26.30 ± 2.56b
RV100307	24.19 ± 1.38b	25.40 ± 3.40a	24.80 ± 2.12b
RV100250	12.48 ± 1.96a	18.80 ± 2.32a	15.64 ± 2.04a
l.s.d	***6.74***	***9.57***	***7.32***
Fpr	***0.002***	***0.328***	***0.033***

Means that do not share the same letter in a column are significantly different.

4.4.2. Percent fruit damage in the field

The per cent fruit damage for the two seasons was recorded for each accession in the field, as shown in Table 4.8. The accession RV100248 had the highest percentage of fruit damage in both the major season (60.91 ± 4.80 %) and minor seasons (63.14 ± 6.67 %), while RV100250 had the lowest in the major season (28.18 ± 2.94 %) and the minor season (25.34 ± 3.07 %). The mean per cent fruit damage for the two seasons showed that the accession RV100250 (26.76 ± 2.38) was the lowest, and RV100248 was the highest (62.03 ± 5.16). The per cent fruit damage among the accessions was significantly different in both the major and the minor seasons, as well as the mean per cent fruit damage, p = <0.001.5663

Table 4.8. Per cent fruit damage between the accessions caused by *Leucinodes* spp. in the field.

Accessions	Fruit Damage ± S.E %		
	Major Season	**Minor Season**	**Mean**
Legon 1	38.22 ± 4.49ab	49.51 ± 4.63bc	43.86 ± 3.65b
RV100213	43.99 ± 4.38b	42.34 ± 5.29b	43.17 ± 3.61b
RV100248	60.91 ± 4.80c	63.14 ± 6.67c	62.03 ± 5.16c
RV100307	29.29 ± 4.11a	25.73 ± 5.84a	27.51 ± 4.11a
RV100250	28.18 ± 2.94a	25.34 ± 3.07a	26.76 ± 2.38a
l.s.d	***11.81***	***14.81***	***11.00***
Fpr	***<0.001***	***<0.001***	***<0.001***

Means that do not share the same letter in a column are significantly different

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4.4.3. Shoot and fruit damage in the screen-house

Table 4.9 shows the per cent fruit and shoot damage in the screen-house. Both the per cent fruit damage (p = 0.432) and shoot damage (p = 0.859) among the accessions in the screen house were not significantly different.

Table 4.9. Percentage of shoot and fruit damage caused by *Leucinodes* spp. in the screen-house

	% Damage	
Accession	**Shoots**	**Fruits**
Legon 1	46.87 ± 6.71a	36.00 ± 4.00a
RV100213	45.56 ± 17.95a	30.00 ± 6.33a
RV100248	31.11 ± 8.21a	36.00 ± 4.00a
RV100307	38.33 ± 12.53a	22.00 ± 12.00a
RV100250	45.71 ± 7.86a	20.00 ± 6.33a
l.s.d	***35.57***	***22.57***
F pr	***0.859***	***0.432***

Means that do not share the same letter in a column are significantly different

4.3.3. Yield (tonnes per hectare, t/ha)

There was no significant difference in yield among the accessions during the major season (p = 0.324), minor season (p = 0.197), and the total (p = 0.445) in the field.

Table 4.10. The yield of the accessions in the eggplant fields

Accessions	(Yield ± S.E) t/ha		
	Major Season	**Minor Season**	**Total**
Legon 1	4.168 ± 0.735a	2.865 ± 0.358a	7.033 ± 0.917a
RV100213	3.885 ± 0.898a	3.585 ± 0.791a	7.470 ± 1.679a
RV100248	2.599 ± 0.541a	1.840 ± 0.452a	4.439 ± 0.793a
RV100307	2.940 ± 0.658a	2.960 ± 0.567a	5.899 ± 1.155a
RV100250	2.643 ± 0.628a	3.915 ± 0.896a	6.557 ± 1.460a
l.s.d	***1.946***	***1.827***	***3.577***
Fpr	***0.324***	***0.197***	***0.445***

Means that do not share the same letter in a column are significantly different.

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4.5. INTENSITY OF RESISTANCE/SUSCEPTIBILITY OF THE ACCESSIONS

4.5.1. Shoot and Fruit Damage in the field.

Based on shoot damage, RV100250 was graded moderately resistant, while Legon1, RV100213, and RV100307 were all moderately susceptible. For fruit damage, Legon 1, RV100213 and RV100248 were graded highly susceptible, while RV100250 and RV100307 were moderately susceptible (Table 4.11).

Table 4.11. Resistance ratings of shoot and fruit damage caused by *Leucinodes* spp. in the field.

Accession	% Shoot Damage		% Fruit Damage	
	Mean Percent	Rating	Mean Percent	Rating
Legon 1	25.38 ± 3.14	Moderately Susceptible	43.86 ± 3.65	Highly susceptible
RV100213	22.68 ± 2.84	Moderately Susceptible	43.17 ± 3.61	Highly susceptible
RV100248	26.30 ± 2.56	Moderately Susceptible	62.03 ± 5.16	Highly susceptible
RV100307	24.80 ± 2.12	Moderately Susceptible	27.51 ± 4.11	Moderately susceptible
RV100250	15.64 ± 2.04	Moderately resistant	26.76 ± 2.38	Moderately susceptible

4.5.2. Shoot and Fruit Damage in the Screen-house

Results obtained in the screen house differed from those from the field experiments. For shoot damage, RV100250, Legon 1 and RV100213 were highly susceptible, while RV100307 and RV100248 were susceptible. For fruit damage, Legon 1, RV100213, and RV100248 were susceptible whereas RV100307 and RV100248 were all moderately susceptible (Table 4.12).

Table 4.12. Resistance ratings of damage caused by *Leucinodes* spp. in the screen-house.

Accession	% Shoot Damage		% Fruit Damage	
	Mean Percent	*Rating*	*Mean Percent*	*Rating*
Legon 1	46.87 ± 6.71	Highly susceptible	36.00 ± 4.00	Susceptible
RV100213	45.56 ± 17.95	Highly susceptible	30.00 ± 6.33	Susceptible
RV100248	31.11 ± 8.21	Susceptible	36.00 ± 4.00	Susceptible
RV100307	38.33 ± 12.53	Susceptible	22.00 ± 12.00	Moderately susceptible
RV100250	45.71 ± 7.86	Highly susceptible	20.00 ± 6.33	Moderately susceptible

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CHAPTER FIVE

5.0. DISCUSSIONS

5.1. Insect collections and major insect pests in the field

During the field studies, several insect species were observed at various growth stages of the crops and on different parts, mainly the stems, leaves, flowers, and fruits. However, the abundance varied from one accession to another and from season to season. This variation may primarily be due to differences in the crop's phenology and environmental factors (both biotic and abiotic) (Rice and Pedigo, 2014). These insect species occupy niches that allow them to play specific roles in the ecosystem as pests, natural enemies, and beneficial insects such as pollinators, while some are just occasional visitors.

Nine insect species were identified as major pests. These include aphids (*Aphis* sp.), leafhoppers (*Empoasca* sp.), whiteflies (*Bemisia tabaci*), eggplant lace bug (*Urentius hystricellus*), cotton stainer (*Dysdercus* sp.), grasshoppers (*Zonocerus variegatus* and *Atractomorpha acutipennis*), thrips (*Thrips* sp.), and the most destructive pest, *Leucinodes* spp. (eggplant fruit and shoot borers).

The hemipterans, *Aphis* sp., *B. tabaci*, and *Empoasca* sp., were present and attacking at all growth stages of the accessions in both seasons. They often lived in colonies or clusters on the underside of leaves, where they pierce plant tissues to access sap (Dent *et al.*, 2003). Like aphids, whiteflies excrete large amounts of honeydew that coats plant surfaces. Deposits of honeydew develop sooty moulds that turn the leaf and branch surface black, reducing the plant's capacity for photosynthetic activity. It was also observed that ants were always present wherever there were aphid colonies, indicating a mutualistic relationship between the two species. This finding is supported by Zhou *et al.* (2015), who explained that ants use honeydew as a food source and, in exchange, protect the species that produce honeydew from natural enemies that would otherwise manage the pest

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population. Aphids reproduce by thelytokous parthenogenesis associated with viviparity (Guerrieri and Digilio, 2008), meaning their populations can grow exponentially quickly and hence should be managed. Heavy infestations of aphids and whiteflies cause severely distorted leaves, stippling, chlorosis, and eventually wilt and stunted growth because of excessive sap removal (Ramasamy, 2009). Also, whiteflies and aphids vector viruses have some of the most significant economic impacts because they can potentially cause the total failure of susceptible crops (Srinivasan, 2009). The feeding activities of leafhoppers lead to crinkling, curling, whitish mottling, and browning or bronzing of leaf margins, also referred to as "hopper burn" due to injected saliva during feeding, but some hosts do not show feeding damage. These hemipteran pests easily build resistance to insecticides in short periods, and the situation in Ghana is no different per the study conducted by Owusu (1997). It is, therefore, prudent to constantly rotate the insecticides (preferably botanicals) used for the management.

Generally, the eggplant lace bug does not cause problems every season, but they are occasional pests whose populations can explode under favourable conditions and kill plants before detection. In this study, it was encountered only in the minor season during the vegetative stage of the crops, as was the case in the study of Mensah *et al.* (2022). They are mottled greyish to dark brown, dorsoventrally flattened with lace-like wings. Nymphs lack wings, whereas adults have wings. Plants are sucked from the underside of the leaves by aggregations of adults and nymphs. The upper surface of the infested leaves exhibits stippling, bleaching, or burning; as populations grow, the whole plant may die. Cast skins abound on heavily infected leaves, and the underside has dark, shiny faecal deposits.

Routine inspection for pests on the underside of leaves should be conducted in eggplant fields. When populations are low, the nymphs and adults may be handpicked and crushed, and weeds

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must be routinely cleared to get rid of alternative hosts. Generalist natural enemies such as ladybugs and spiders should be conserved when possible. Botanicals such as neem oil, pyrethrins, and insecticidal soaps can also be used to manage the pest situation. When infestations are heavy, the use of recommended insecticides for treatment is advised.

No thrips infestation was observed at 2 WAT in the field, but at 4 WAT, a few infestations were noted. These gradually grew until they peaked at 10 WAT on all accessions. When thrips populations had peaked in the field, all the accessions had entered the fruiting stage, and thrips populations seen on the fruits were far more than on the leaves. This finding is consistent with Capinera (2020), which establishes that thrips initially aggregate and feed on leaves but eventually migrate to flowers and then fruits. Also, thrips prefer more succulent plant parts; hence they are often abundant in the fruiting stage of the crops they attack. However, their feeding activities cause stippling or tiny silver-grey scars and deformities on fruits, and abortion has been reported in fruits which reduces yield and causes economic losses (Kotey *et al.,* 2013). Since thrips are more abundant in the fruiting stages of the crops, desisting from using chemical insecticides to manage their populations is advisable. Many thrips species are attracted to blue colour, so using blue sticky cards or light traps with blue LED is an effective strategy to control them (Lu, 1990; Roditakis *et al.,* 2001).

Although cotton stainers are not typically a pest of eggplants, they are noteworthy due to their sporadic harm to fruits and ornamentals (Mead and Fasulo, 2021). Cotton stainers were only collected during the major season on the shoots, and fruits on the accessions at the vegetative and flowering stages. The study field was located near an old okra field (cotton stainers are major pests of okra); therefore, the probability that the pests came from the old okra field is very high. Cotton stainers puncture and suck juices from immature fruits preventing them from reaching maturity.

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They pierce the fruit with their beaks fully extended, sometimes without leaving any visible wounds or injuries. Despite this, a single piercing can cause fruit or flower buds to drop and decompose within a few days (Callan, 1947, Shah, 2014). To prevent or manage their infestations, ensure farm sanitation and hygiene by clearing debris that could serve as breeding grounds. For light infestation on crops, spray soapy water to dislodge and kill the bugs or shake off the pest into a tray/pan of soapy water. Traps can be attracted with small piles of seeds or sugarcane scraps as bait.

The voracious defoliators, the grasshoppers, *A. acutipennis* and *Z. variegatus* chew the leaves and new shoots of a variety of plants, lowering their photosynthetic productivity. They gather to feed, and a severe infestation could kill the entire plant or make it so weak that the fruit's formation is hindered (Oso and Borisade, 2017). The levels of infestation encountered on the field were within tolerable limits. Managing these pests requires that the crops and the surrounding fields be sprayed with insecticides (preferably botanical/biopesticides) in the early morning or the evening when the insects are active.

Leucinodes spp. was present at the vegetative, flowering, and fruiting stages. Plant growth and the incidence of EFSB are found to be positively correlated. As the crop grows, so does the abundance of EFSB on all the accessions in the field. According to Singer (1986), females of insects whose larvae are less mobile prefer favourable egg-laying sites with readily available food and nutrients. Growing seedlings under an insect-proof net to prevent moths from laying their eggs on the crop is an early preventive measure for controlling EFSB.

Several beneficial insects were observed, including ants, ladybug beetles (*Cheilomenes* sp.), wasps, bees, praying mantis, earwigs, hoverflies, and spiders. According to Forchibe *et al.* (2017),

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nymphs and adults of ladybug beetles (*Cheilomenes* sp.) prey on the eggs and aphids. Hoverflies also prey on thrips (Rodatakis *et al.*, 2001), while spiders, praying mantis, and earwigs are generalist predators (Amengor *et al.*, 2017). Butterflies, bees, and wasps serve as pollinators (Mayes, 2011), and some wasp species also act as natural enemies (parasitoids) of some pests (Harush *et al.*, 2021).

Typically, insect populations on crops increase with time. This observation is explained by Adagba *et al.* (2015) that as plants grow vegetatively, they emit semiochemicals that attract insects. As plants grow in mass, they present suitable and optimal niches for insects to exploit; for example, egg-laying sites and food sources become abundant (Kadam *et al.*, 2006). However, this assertion did not corroborate with all the insect pests collected in this study, with most insect populations fluctuating throughout the season.

Numerous eggplant cultivars exhibit tolerance to insect pests such as leafhoppers, whiteflies, aphids, and thrips, albeit to a lesser extent (Rotino *et al.*, 1997; Daunay *et al.*, 1991). Despite the varying degrees of damage and injuries caused by aphids, thrips, and eggplant lace bugs in the field, they did not pose significant problems. This is because the pests did not coincide with the plant's phenological 'susceptibility window', or the plant's natural resistance typically increases with age (age-related resistance) (Dent *et al.*, 2003). Moreover, plants can compensate for damaged tissue by accelerating their growth rate (Sarwar and Sattar, 2013).

Mechanical obstruction, coupled with the production of semiochemicals like phenolic compounds (Avé and Tingey, 1986) and sucrose carboxylic acid esters (Neal *et al.*, 1990), reduces the attack of flea beetles, leafhoppers, and aphids on eggplants (Flanders *et al.*, 1992). As these semiochemicals act as resistance stimulants, genotypes with moderate to high levels of these biochemical components tend to experience less infestation (Prabhu *et al.*, 2007; Dar *et al.*, 2017).

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5.2. Growth parameters and yield

According to data from World Eggplant Production (2022), the average eggplant yield in Ghana is 8.7517 t/ha per year. Compared to other eggplant-producing countries like China (25 t/ha per year), Ghana's productivity is typically low due to the use of varieties with limited genetic diversity and soils with naturally low fertility (Dauda *et al.*, 2003). According to Law-Ogbonna *et al.* (2009), unimproved local cultivars are commonly planted with little plant stands, inappropriate planting intervals, and a lack of other improved agricultural inputs in crop management, resulting in low yields. This claim is also supported by the fact that the highest yield for this study was recorded on RV100213 (7.470 ± 1.679) t/ha, which is even lower than Ghana's productivity. On the other hand, improved eggplant cultivars grown in ideal conditions can produce between 50 and 80 tonnes/ha (Kotey *et al.*, 2013).

Several compounded factors may account for the inability of no/poor fruiting in the screen-house. South Africa's Directorate of Plant Production of the Department of Agriculture, Forestry and Fisheries (2011) claims that because eggplants won't set fruit in extremely high or low temperatures, they are not suitable for production in greenhouses or screen houses. If daytime temperatures are higher than 35°C, fruit abscission may occur. Also, pollen deformity increases if night temperatures drop below 16°C, producing less/no fruit. During the study, temperature observations/recordings, particularly on sunny and hot days, reached as high as 37 °C in the screen-house, which may be the principal factor of flower abscission/abortion hence there was no fruiting.

Fertilizing the soil is crucial for maximizing plant growth and yield, which are essential for agronomic activities. Applying nitrogen (N), potassium (K), and phosphorus (P) fertilizers results in productive eggplants (Oloniruha, 2011). Prabhu *et al.* (2006) investigated the impact of different nitrogen and phosphorus application rates on eggplant production. They discovered that increasing

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the phosphorus and nitrogen doses to 100 and 200 kg/ha, respectively, significantly increased the crop yield per hectare. In this study, NPK 15.15.15 was applied in amounts of 15g at 1WAT and 6WAT, which might not have been sufficient for plant growth and yield. Following appropriate fertilizer recommendations will maximize yield.

Growing plants experience an irreversible increase in their growth parameters, which are crucial to the ecology of plants. Plant height has a significant impact on a plant's capacity to compete for light, which is also closely related to its lifespan, time to maturity, and yield (Moles *et al.*, 2009). Plant height is also related to important ecosystem variables like the diversity of pests found on it (Falster and Westoby 2003). Also, a study by Cho and Son (2007) reveals that a plant's leaf area is a key factor in light absorption and, consequently, transpiration, photosynthesis, and plant productivity/yield, are predicted by the number of leaves on the plant (Rouphael, 2006, 2007, 2010a, b).

5.3. Leaf damage in the field

Insects consume plant tissue or sap by chewing or sucking. Insects that chew on leaf tissue, such as the grasshopper species *Z. variegatus,* and *A. acutipennis,* reduce the photosynthetic material available to the plant, but their infestation or numbers in the field was very low compared to the numbers of the hemipterans and thrips recorded in the field. These sap-sucking insects cause direct harm by feeding on plant leaves, which may cause the leaves to lose their vigour, wilt, and die, as well as indirect damage through the spread of plant viruses in some situations. Crop insect pests are usually associated with a certain type of damage. Examples of damage are feeding-related injuries that reduce the quality of the harvestable crop, as well as indirect injuries caused by insects that function as disease-transmission vectors (Dent *et al.*, 2003).

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Results from the field during the major season show that mean per cent leaf damage was at its highest at 2 WAT on RV100307 (19.75 ± 2.96), whereas at 10 WAT, the highest was on RV100250 (5.50 ± 0.34). In the minor season, the highest at 2 WAT was on RV100307 (22.75 ± 3.29), whereas the highest was at 10 WAT, RV100213 (8.75 ± 0.88). This result clearly shows that leaf damage decreases as the plant grows. It is observed that among the major pests identified in the study that attack the leaves (hemipterans and grasshoppers), the hemipteran pests were more abundant in the vegetative state (2 and 4 WAT), but the grasshoppers were more abundant at the latter stages of plant growth (8 and 10 WAT). However, because of age-related resistance, the feeding effect of hemipterans on the leaves was much higher in the later stages compared to that of the defoliators (grasshoppers). This claim explains why, in the major season, there were statistical differences between the accessions at 2WAT ($p = 0.002$) and 4WAT ($p = 0.001$) but not at 6WAT ($p = 0.835$), 8WAT ($p = 0.193$), and 10WAT ($p = 0.221$). The minor season showed statistical differences at 2WAT ($p = 0.015$), 4WAT ($p = 0.001$), 6WAT ($p = 0.001$), and 10WAT ($p = 0.010$) but not at 8WAT ($p = 0.112$) because abiotic factors like temperature, rainfall, and humidity can also influence pest abundances that are somewhat related to leaf damage.

5.4. Fruit and shoot damage caused by eggplant fruits and shoot borer.

The larvae of the eggplant fruit and shoot borer cause the most damage of any insect pest by tunnelling into the young and tender shoots. As a result, the infested shoots lose their vitality and begin to droop, causing the leaves to fall off and killing the entire shoot. The larvae also bore into fruits and consume fruit tissues. As it develops and matures into the last larval instar, it creates tiny pores and exits the fruit. When feeding in either shoots or fruits, frass (waste products) is released, creating an ideal environment for microbes to cause decay. Consequently, the larval

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feeding activities cause direct yield loss due to crop consumption and a reduction in the product's value by causing a decrease in quality.

Shoot infestations from EFSB began at 2WAT (major season) and 4WAT (minor season) when the crops were in the vegetative stage. The number of EFSB that infest shoots increased as the crops grew from the vegetative stage through the flowering to the fruiting stage at 10 WAT, where the peak was recorded for all the accessions in the study. Harvested fruits were also inspected for EFSB infestations after harvesting at 11, 12, 13 and 14 WAT, and the number of EFSB was recorded. These results show a similar trend as shoot infestation, i.e., the number of EFSB was higher in subsequent harvests. This trend of EFSB damage corroborates the study of Mensah *et al.* (2022). According to Koundinya *et al*. (2018), the low number of infested shoots is attributable to late infestation and duration of fruiting. This is also the reason why EFSB larvae prefer fruits to shoots for feeding. Based on fruit infestation, Yousafi *et al.* (2016) established that the 13 EFSB collected per 15 days in eggplant fields cause 10% fruit damage. This economic threshold level (ETL) can be used to determine when it is best to start management procedures to prevent ESFB infestation in eggplant fields. Also, the findings of this study indicate that at 6WAT, accessions had over 13 EFSB incidences, therefore the best time to start EFSB management tactics is six (6) weeks after transplanting to the field.

The mean per cent shoot damage of Legon 1 (36.20 ± 2.53), RV100213 (35.63 ± 2.63) and RV100248 (44.80 ± 1.99) was seen to be lower than their mean per cent fruit damage Legon 1 (43.86 ± 3.65), RV100213 (43.17 ± 3.61) and RV100248 (62.03 ± 5.16). Reports of Hazra *et al.* (2004) and Prasad et al. (2014) further explained that the feeding stimulating nature of Total soluble solids (TSS), total sugars, total proteins, and moisture content in fruits make them more palatable and succulent to EFSB, hence preferred than the shoots. Additionally, Koundinya *et al.*

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(2018) reported that anthocyanins in peel and fruit colour positively correlate with larvae per fruit and rate of fruit infestation.

On the contrary, the mean per cent shoot damage of RV100307 (34.98 ± 2.33) and RV100250 (29.84 ± 1.73) was superior to the mean per cent fruit damage of RV100307 (27.51 ± 4.11) and RV100250 (26.76 ± 2.38). EFSB infestation and total sugars were found to be negatively correlated, according to Chandrasekhar *et al.* (2008). Furthermore, Hezra *et al*. (2004) discovered that the presence of phenolic compounds inhibited EFSB's propensity for feeding on eggplant fruits. Polyphenol oxidase transforms phenols into harmful quinones, protective pigments, and other oxidized compounds, which stimulate tolerance by deterring insects from feeding on them.

Under a scenario of climatic change, there is a slight increase in EFSB shoot and fruit infestation during the minor season (late August to mid-November) due to elevated temperatures, but a slight decrease was observed during rainy periods. This finding is consistent with Rao and Bhavani (2010).

5.5. Susceptibility/resistance of the *S. aethiopicum* accessions to *Leucinodes* sp.

The results show that none of the five accessions used in the study exhibited resistance to either shoots or fruits in the field or the screen house; all five accessions exhibited significant susceptibility levels ranging from moderately susceptible to highly susceptible to EFSB. The susceptibility statuses recorded may result from the fact that no pest management strategy was employed in the study, and also the high pest incidences.

Over the years, EFSB has been a menace to eggplants across the globe. The intensive successive monocropping of vegetables including eggplants, the concealed nature of the fruit and shoot borer, the reliance on landraces with little or no crop improvement and exploitation of germplasm, the

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poor natural enemy complex in Ghana, and the indiscriminate use of chemicals for pest management have contributed encouragingly to the destructive pedigree of the pest.

The EFSB is becoming more tolerant of and resistant to these chemicals as a result of farmers' indiscriminate use of insecticides to protect crops and reduce losses or damages, making it economically impossible to control the pest with the same chemicals and leading to ecosystem disruption by eliminating the majority of natural enemies. Natural enemies are frequently left to proliferate on their own under natural circumstances because biological control of eggplants is not a common practice. In some regions of Asia, 16 parasitoids, 3 predators, and 3 entomopathogens have been identified as being host- and crop-specific for managing Leucinodes orbonalis (Alam *et al.*, 2003; Srinivasan, 2009). *Trichogramma chilonis* is the most effective egg parasitoid of EFSB among these natural enemies, while *Goryphus nursei*, *Pristomerus testaceus*, *Elasmus corbetti*, and *Euagathis* sp. are also somewhat effective depending on local environmental conditions and their abundance. Also, it has been noted that *Trathala flavoorbitalis* (a potential biocontrol agent) has a higher parasitism rate everywhere it is found. The identification of the eggplant fruit and shoot borer's natural enemies, not to mention their rearing and release into the wild to manage EFSB, haven't received much attention in Africa, or Ghana for that matter.

Larvae of the EFSB enter fruit or shoots just hours after hatching from eggs. For consumer health and safety reasons, systemic insecticides are not recommended, while fruits are already infested with larvae. However, EFSB has developed resistance to insecticides due to their frequent use and is now difficult to control using some insecticides (Srinivasan, 2009). Moreover, broad-spectrum insecticides kill naturally occurring enemies that are helpful to farmers, such as spiders, mantids, earwigs, ladybird beetles, wasps, and ants among others in the field (Srinivasan, 2009). These predators used to prey on pests and minimize damage to the eggplant crop before farmers began

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using pesticides. It is wise to take advantage of the pest's host range in Ghana to effectively plan management strategies because EFSB can also attack crops other than eggplant (EFSA, 2021).

Local landraces are cultivated because they have desirable qualities like early maturity, higher yield, and better quality. Despite growing interest in better cultivars, not many new varieties have been introduced. It is challenging to focus on the desirable traits (like resistance) needed for crop improvement because the desired traits in landraces are widely dispersed across the major agro-ecologies.

INTEGRI PROCEDAMUS

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CHAPTER SIX

6.0. CONCLUSION AND RECOMMENDATIONS

6.1. Conclusions

The conclusions of this study are as follows:

The major insect pests in the field are *Aphis* sp., *Atractomorpha acutipennis*, *Bemisia tabaci*, *Dysdercus* sp., *Empoasca* sp., *Leucinodes* sp., *Thrips* sp., *Urentius hystricellus, and Zonocerus variegatus.*

The growth parameters (the number of leaves and plant height) differ significantly between the accessions. For yield, there was no difference between the accessions in both seasons in the field. The mean per cent leaf damage was different between the accessions in the field except at 8WAT in both seasons and at 6 and 10WAT only in the major season.

In the screen house, all the accessions showed lower fruit damage than shoot damage except RV100248. The mean percentage of shoot damage is lower compared to fruit damage during both seasons in the field.

Only RV100250 of the accessions used in this study showed a level of resistance to EFSB. All five accessions showed various levels of resistance/susceptibility, that is, from moderately resistant to highly susceptible.

6.2. Recommendations

Based on the conclusions of this study, the following recommendations are made:

Expand, screen and exploit more germplasms of *S. aethiopicum* for desirable traits, such as tolerance/resistance to pests, that could be included in crop improvement programs.

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Because of the challenge of fruiting, experiments that require confining pests onto eggplants should be conducted under field conditions. A netting cage around eggplants planted in the field would be better than planting in pots in the greenhouse or screen house.

Work should be conducted to explore natural enemies for the eggplant fruit and shoot borer species in Ghana and how the natural enemies can be multiplied and introduced since natural enemies seem to be a more sustainable strategy considering the concealed nature of the damaging stage of the pest.

Antibiosis studies should be carried out to determine if any landrace/genotype has an antibiotic effect on feeding, growth rate, longevity, and survival, among other factors.

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APPENDICES

Appendix 1: Repeated Measures ANOVA (using REML function) for *Aphis* sp. abundance between the accessions in the field (major & minor seasons)

Variate: Aphid(major)

Fixed term	Wald statistic	n.d.f.	F statistic	d.d.f.	F pr
WAT	79.54	4	19.88	100.0	<0.001
TRT	5.01	4	1.25	100.0	0.294
WAT.TRT	17.98	16	1.12	100.0	0.344

Variate: Aphid(minor)

Fixed term	Wald statistic	n.d.f.	F statistic	d.d.f.	F pr
TRT	6.37	4	1.59	100.0	0.182
WAT	37.74	4	9.44	100.0	<0.001
TRT.WAT	17.67	16	1.10	100.0	0.361

Appendix 2: Summary of the t-test for comparing *Aphis* sp. abundance between the major and minor seasons

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
Aphids (major)	125	36.54	7265	85.23	7.624
Aphids (minor)	125	18.62	1062	32.59	2.915

Test of null hypothesis that mean of Aphids(major) is equal to mean of Aphids(minor)
Test statistic t = 2.20 on approximately 159.49 d.f.
Probability = 0.030

Appendix 3: Repeated Measures ANOVA (using REML function) for *A. acutipennis* abundance between the accessions in the field (major & minor seasons)

Variate: Atractomorpha(major)

Fixed term	Wald statistic	n.d.f.	F statistic	d.d.f.	F pr
WAT	31.08	4	7.77	100.0	<0.001
TRT	6.17	4	1.54	100.0	0.196
WAT.TRT	13.99	16	0.87	100.0	0.599

Variate: Atractomorpha(minor)

Fixed term	Wald statistic	n.d.f.	F statistic	d.d.f.	F pr
TRT	10.66	4	2.67	100.0	0.037
WAT	40.81	4	10.20	100.0	<0.001
TRT.WAT	26.31	16	1.64	100.0	0.071

Appendix 4: Summary of the t-test for comparing *A. acutipennis* abundance between the major and minor seasons

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
Atractomorpha(major)	125	0.704	1.500	1.225	0.1096
Atractomorpha(minor)	125	1.480	4.510	2.124	0.1899

Test of null hypothesis that mean of Atractomorpha(major) is equal to the mean of Atractomorpha(minor)
Test statistic t = -3.54 on approximately 198.29 d.f.
Probability < 0.001

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Appendix 5: Repeated Measures ANOVA (using REML function) for *B. tabaci* abundance between the accessions in the field (major & minor seasons)

Variate: Whitefly(major)

Fixed term	Wald statistic	n.d.f.	F statistic	d.d.f.	F pr
WAT	98.78	4	24.69	20.0	<0.001
TRT	12.66	4	3.17	80.0	0.018
WAT.TRT	39.32	16	2.46	80.0	0.004

Variate: Whitefly(minor)

Fixed term	Wald statistic	n.d.f.	F statistic	d.d.f.	F pr
TRT	4.10	4	1.03	100.0	0.398
WAT	75.04	4	18.76	100.0	<0.001
TRT.WAT	24.35	16	1.52	100.0	0.107

Appendix 6: Summary of the t-test for comparing *B. tabaci* abundance between the major and minor seasons

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
Whitefly(major)	125	19.11	467.5	21.62	1.934
Whitefly(minor)	125	5.44	85.8	9.27	0.829

Test of null hypothesis that mean of Whitefly(major) is equal to mean of Whitefly(minor)

Test statistic t = 6.50 on approximately 168.05 d.f.

Probability < 0.001

Appendix 7: Repeated Measures ANOVA (using REML function) for *Dysdercus* sp. abundance between the accessions in the major season

Variate: Cotton_stainer

Fixed term	Wald statistic	n.d.f.	F statistic	d.d.f.	F pr
WAT	21.97	4	5.49	20.0	0.004
TRT	6.02	4	1.51	80.0	0.208
WAT.TRT	10.52	16	0.66	80.0	0.826

Appendix 8: Repeated Measures ANOVA (using REML function) for *U. hystricellus* abundance between the accessions in the minor season

Variate: Lacebug

Fixed term	Wald statistic	n.d.f.	F statistic	d.d.f.	F pr
TRT	2.13	4	0.53	100.0	0.712
WAT	372.48	4	93.12	100.0	<0.001
TRT.WAT	13.46	16	0.84	100.0	0.637

Appendix 9: Repeated Measures ANOVA (using REML function) for *Empoasca* sp. abundance between the accessions in the field (major & minor seasons)

Variate: Leafhopper(major)

Fixed term	Wald statistic	n.d.f.	F statistic	d.d.f.	F pr
TRT	11.81	4	2.95	100.0	0.024
WAT	453.23	4	113.31	100.0	<0.001
TRT.WAT	18.65	16	1.17	100.0	0.309

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Variate: Leafhopper(minor)

Fixed term	Wald statistic	n.d.f.	F statistic	d.d.f.	F pr
TRT	3.64	4	0.91	100.0	0.461
WAT	146.42	4	36.60	100.0	<0.001
TRT.WAT	6.65	16	0.42	100.0	0.976

Appendix 10: Summary of the t-test for comparing *Empoasca* sp. abundance between the major and minor seasons

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
Leafhopper(major)	125	16.16	122.7	11.08	0.9908
Leafhopper(minor)	125	8.25	94.4	9.71	0.8689

Test of null hypothesis that mean of Leafhopper(major) is equal to the mean of Leafhopper(minor)
Test statistic t = 6.00 on 248 d.f.
Probability < 0.001

Appendix 11: Repeated Measures ANOVA (using REML function) for *Thrips* sp. abundance between the accessions in the field (major & minor seasons)

Variate: Thrips(major)

Fixed term	Wald statistic	n.d.f.	F statistic	d.d.f.	F pr
WAT	394.07	4	98.52	100.0	<0.001
TRT	11.31	4	2.83	100.0	0.029
WAT.TRT	19.05	16	1.19	100.0	0.289

Variate: Thrips(major)

Fixed term	Wald statistic	n.d.f.	F statistic	d.d.f.	F pr
TRT	4.74	4	1.19	100.0	0.322
WAT	221.92	4	55.48	100.0	<0.001
TRT.WAT	9.84	16	0.61	100.0	0.865

Appendix 12: Summary of the t-test for comparing *Thrips* sp. abundance between the major and minor seasons

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
Thrips(major)	125	15.60	558.7	23.64	2.114
Thrips(minor)	125	15.64	619.7	24.89	2.227

Test of null hypothesis that mean of Thrips(major) is equal to mean of Thrips(minor)
Test statistic t = -0.01 on 248 d.f.
Probability = 0.990

Appendix 13: Repeated Measures ANOVA (using REML function) for *Z. variegatus* abundance between the accessions in the field (major & minor seasons)

Variate: Zonocerus (major season)

Fixed term	Wald statistic	n.d.f.	F statistic	d.d.f.	F pr
WAT	184.50	4	46.12	16.0	<0.001
TRT	25.70	4	6.43	80.0	<0.001
WAT.TRT	33.21	16	2.08	80.0	0.018

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Variate: Zonocerus(minor)

Fixed term	Wald statistic	n.d.f.	F statistic	d.d.f.	F pr
TRT	28.79	4	7.20	100.0	<0.001
WAT	541.49	4	135.37	100.0	<0.001
TRT.WAT	118.37	16	7.40	100.0	<0.001

Appendix 14: Summary of the t-test for comparing *Z. variegatus* abundance between the major and minor seasons

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
Zonocerus(major)	125	6.576	59.99	7.745	0.6928
Zonocerus(minor)	125	8.152	117.60	10.844	0.9699

Test of null hypothesis that mean of Zonocerus(major) is equal to the mean of Zonocerus(minor)
Test statistic t = -1.32 on approximately 224.39 d.f.
Probability = 0.187

Appendix 15: Repeated Measures ANOVA (using REML function) for EFSB abundance between the accessions in the field (major & minor seasons)

Variate: EFSB(minor)

Fixed term	Wald statistic	n.d.f.	F statistic	d.d.f.	F pr
TRT	32.91	4	8.23	180.0	<0.001
WAT	1192.67	8	149.08	180.0	<0.001
TRT.WAT	99.12	32	3.10	180.0	<0.001

Variate: EFSB(major)

Fixed term	Wald statistic	n.d.f.	F statistic	d.d.f.	F pr
TRT	3.29	4	0.82	180.0	0.513
WAT	500.72	8	62.59	180.0	<0.001
TRT.WAT	72.97	32	2.28	180.0	<0.001

Appendix 16: Summary of the t-test for comparing EFSB abundance between the major and minor seasons

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
EFSB(major)	225	17.26	526.6	22.95	1.530
EFSB(minor)	225	8.85	86.6	9.31	0.620

Test of null hypothesis that mean of EFSB(major) is equal to mean of EFSB(minor)
Test statistic t = 5.09 on approximately 295.74 d.f.
Probability < 0.001

Appendix 17: ANOVA for plant height between the accessions in the field

Major Season

Variate: PH_2WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps2 stratum	4	0.27731	0.06933	1.75	
Treatment2	4	0.16102	0.04025	1.02	0.403
Residual	91	3.60481	0.03961		
Total	99	4.04314			

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Variate: PH_ 4WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps4 stratum	4	0.097326	0.024332	3.24	
Treatment4	4	0.180262	0.045065	5.99	<.001
Residual	91	0.684359	0.007520		
Total	99	0.961947			

Variate: PH_6WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps6 stratum	4	0.047826	0.011957	1.72	
Treatment6	4	0.335345	0.083836	12.03	<.001
Residual	91	0.634015	0.006967		
Total	99	1.017187			

Variate: PH_8WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps8 stratum	4	0.060451	0.015113	2.84	
Treatment8	4	0.319038	0.079759	14.99	<.001
Residual	91	0.484050	0.005319		
Total	99	0.863539			

Variate: PH_10WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps10 stratum	4	0.023916	0.005979	2.01	
Treatment10	4	0.288289	0.072072	24.25	<.001
Residual	91	0.270416	0.002972		
Total	99	0.582621			

Minor Season

Variate: PH_2WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	4	0.09941	0.02485	1.88	
Treatment	4	0.18370	0.04593	3.47	0.011
Residual	91	1.20462	0.01324		
Total	99	1.48773			

Variate: PH_4WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps4 stratum	4	0.30697	0.07674	1.60	
Treatment4	4	0.25486	0.06371	1.33	0.266
Residual	91	4.36982	0.04802		
Total	99	4.93165			

Variate: PH_6WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps6 stratum	4	0.083770	0.020942	2.57	
Treatment6	4	0.235575	0.058894	7.24	<.001
Residual	91	0.740514	0.008138		
Total	99	1.059858			

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Variate: PH_8WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps8 stratum	4	0.039622	0.009906	1.84	
Treatment8	4	0.300480	0.075120	13.93	<.001
Residual	91	0.490669	0.005392		
Total	99	0.830771			

Variate: PH_10WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps10 stratum	4	2095.1	523.8	2.79	
Treatment10	4	14772.8	3693.2	19.67	<.001
Residual	91	17084.9	187.7		
Total	99	33952.8			

Appendix 18: Summary of the t-test comparing plant height of each accession in the screenhouse

Variates: Legon1

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
TG	35	61.17	1294	35.97	6.079
CG	35	72.29	2069	45.49	7.689

Test of null hypothesis that mean of TG is equal to the mean of CG
Test statistic t = -1.13 on 68 d.f.
Probability = 0.261

Variates: RV100213

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
TG	35	44.11	816	28.57	4.829
CG	35	58.00	1602	40.03	6.766

Test of null hypothesis that mean of TG is equal to the mean of CG
Test statistic t = -1.67 on 68 d.f.
Probability = 0.099

Variates: RV100248

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
TG	35	61.83	1626	40.33	6.817
CG	35	65.03	1614	40.17	6.791

Test of null hypothesis that mean of TG is equal to the mean of CG
Test statistic t = -0.33 on 68 d.f.
Probability = 0.740

Variates: RV100307

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
TG	35	59.60	1776	42.14	7.123
CG	35	66.60	2197	46.87	7.923

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Test of null hypothesis that mean of TG is equal to the mean of CG
Test statistic t = -0.66 on 68 d.f.
Probability = 0.513

Variates: RV100250
Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
TG	35	45.23	767	27.69	4.681
CG	35	73.03	2161	46.49	7.858

Test of null hypothesis that mean of TG is equal to the mean of CG
Test statistic t = -3.04 on approximately 55.43 d.f.
Probability = 0.004

Appendix 19: ANOVA for the number of leaves between the accessions in the field

Major Season

Variate: NL_2WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps2 stratum	4	2.564	0.641	0.59	
Treatment2	4	11.961	2.990	2.78	0.032
Residual	91	98.042	1.077		
Total	99	112.567			

Variate: NL_4WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps4 stratum	4	17.4283	4.3571	5.11	
Treatment4	4	34.8589	8.7147	10.22	<.001
Residual	91	77.6242	0.8530		
Total	99	129.9114			

Variate: NL_6WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps6 stratum	4	9.815	2.454	1.97	
Treatment6	4	34.442	8.610	6.91	<.001
Residual	91	113.465	1.247		
Total	99	157.721			

Variate: NL_8WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps8 stratum	4	8.894	2.224	1.98	
Treatment8	4	59.597	14.899	13.25	<.001
Residual	91	102.355	1.125		
Total	99	170.846			

Variate: NL_10WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps10 stratum	4	4.6534	1.1633	1.77	
Treatment10	4	51.3733	12.8433	19.54	<.001
Residual	91	59.8274	0.6574		
Total	99	115.8540			

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Major Season

Variate: NL_2WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps2 stratum	4	2.2339	0.5585	1.58	
Treatment2	4	14.5798	3.6449	10.29	<.001
Residual	91	32.2402	0.3543		
Total	99	49.0539			

Variate: NL_4WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps4 stratum	4	4.455	1.114	0.59	
Treatment4	4	17.657	4.414	2.35	0.060
Residual	91	170.934	1.878		
Total	99	193.046			

Variate: NL_6WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps6 stratum	4	10.8833	2.7208	3.26	
Treatment6	4	22.5581	5.6395	6.75	<.001
Residual	91	75.9987	0.8352		
Total	99	109.4401			

Variate: NL_8WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps8 stratum	4	7.652	1.913	1.39	
Treatment8	4	61.106	15.276	11.06	<.001
Residual	91	125.694	1.381		
Total	99	194.452			

Variate: NL_10WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps10 stratum	4	5.2623	1.3156	1.33	
Treatment10	4	69.0949	17.2737	17.40	<.001
Residual	91	90.3254	0.9926		
Total	99	164.6826			

Appendix 20: Summary of the t-test comparing the number of leaves of each accession in the screenhouse

Variates: Legon 1

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
TG	35	33.51	455.1	21.33	3.606
CG	35	42.34	1167.2	34.16	5.775

Test of null hypothesis that mean of TG is equal to the mean of CG

Test statistic t = -1.30 on approximately 57.01 d.f.

Probability = 0.200

Variates: RV100213

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Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
TG	35	26.63	469.1	21.66	3.661
CG	35	34.20	952.6	30.86	5.217

Test of null hypothesis that mean of TG is equal to the mean of CG
Test statistic t = -1.19 on approximately 60.95 d.f.
Probability = 0.239

Variates: RV100248
Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
TG	35	53.91	2503	50.03	8.457
CG	35	67.40	3735	61.12	10.331

Test of null hypothesis that mean of TG is equal to the mean of CG
Test statistic t = -1.01 on 68 d.f.
Probability = 0.316

Variates: RV100307
Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
TG	35	26.86	649.9	25.49	4.309
CG	35	36.71	1049.7	32.40	5.476

Test of null hypothesis that mean of TG is equal to the mean of CG
Test statistic t = -1.41 on 68 d.f.
Probability = 0.162

Variates: RV100250
Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
T5	35	46.26	1397	37.38	6.318
C5	35	75.46	4116	64.15	10.844

Test of null hypothesis that mean of TG is equal to the mean of CG
Test statistic t = -2.33 on approximately 54.70 d.f.
Probability = 0.024

Appendix 21: ANOVA for % leaf damage between the accessions in the field (major & minor seasons)

Minor season

Variate: LD_2WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps2 stratum	4	23.541	5.885	4.63	
Treatment2	4	16.579	4.145	3.26	0.015
Residual	91	115.763	1.272		
Total	99	155.884			

Variate: LD_4WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

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Reps4 stratum	4	16.3504	4.0876	6.14	
Treatment4	4	23.9465	5.9866	8.99	<.001
Residual	91	60.6044	0.6660		
Total	99	100.9013			

Variate: LD_6WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps6 stratum	4	0.54708	0.13677	2.16	
Treatment6	4	1.32855	0.33214	5.25	<.001
Residual	91	5.76074	0.06330		
Total	99	7.63637			

Variate: LD_8WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps8 stratum	4	0.27245	0.06811	0.89	
Treatment8	4	0.59297	0.14824	1.93	0.112
Residual	91	6.97946	0.07670		
Total	99	7.84488			

Variate: LD_10WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps10 stratum	4	6.1103	1.5276	7.80	
Treatment10	4	2.7921	0.6980	3.56	0.010
Residual	91	17.8234	0.1959		
Total	99	26.7258			

Major Season

Variate: LD_2WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps2 stratum	4	8.5519	2.1380	2.29	
Treatment2	4	16.6089	4.1522	4.45	0.002
Residual	91	84.8582	0.9325		
Total	99	110.0190			

Variate: LD_4WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps4 stratum	4	10.4514	2.6128	7.21	
Treatment4	4	28.5604	7.1401	19.70	<.001
Residual	91	32.9813	0.3624		
Total	99	71.9931			

Variate: LD_6WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps6 stratum	4	0.5536	0.1384	0.42	
Treatment6	4	0.4834	0.1208	0.36	0.835
Residual	91	30.3204	0.3332		
Total	99	31.3575			

Variate: LD_8WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps8 stratum	4	8.3876	2.0969	6.82	

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Treatment8	4	1.9150	0.4787	1.56	0.193
Residual	91	27.9885	0.3076		
Total	99	38.2910			

Variate: LD_10WAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps10 stratum	4	0.6423	0.1606	0.91	
Treatment10	4	1.0251	0.2563	1.46	0.221
Residual	91	15.9945	0.1758		
Total	99	17.6619			

Appendix 22: ANOVA for yield between the accessions in the field

Variate: Major_season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	4	17.290	4.322	2.05	
Treatments	4	10.670	2.668	1.27	0.324
Residual	16	33.714	2.107		
Total	24	61.674			

Variate: Minor_season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	4	11.911	2.978	1.60	
Treatments	4	12.689	3.172	1.71	0.197
Residual	16	29.724	1.858		
Total	24	54.325			

Variate: Total

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	4	41.129	10.282	1.44	
Treatments	4	27.969	6.992	0.98	0.445
Residual	16	113.895	7.118		
Total	24	182.993			

Appendix 23: ANOVA for % shoot and fruit damage between the accessions in the field (major & minor seasons)

Variate: Major Season-Shoot damage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	4	93.5	23.4	0.16	
Treatment	4	2710.0	677.5	4.67	0.002
Residual	116	16811.5	144.9		
Total	124	19614.9			

Variate: Minor season-shoot damage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	4	315.0	78.8	0.27	
Treatment	4	1364.1	341.0	1.17	0.328
Residual	116	33838.2	291.7		
Total	124	35517.3			

Variate: Mean-shoot damage

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Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	4	107.7	26.9	0.16	
Treatment	4	1851.8	462.9	2.71	0.033
Residual	116	19791.0	170.6		
Total	124	21750.5			

Variate: Major season-fruit damage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	4	3.409	0.852	0.26	
Treatment	4	87.678	21.919	6.60	<.001
Residual	91	302.130	3.320		
Total	99	393.217			

Variate: Minor season-fruit damage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	4	15.186	3.797	0.63	
Treatment	4	140.023	35.006	5.84	<.001
Residual	91	545.566	5.995		
Total	99	700.776			

Variate: Mean_fruit damage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	4	2.634	0.659	0.24	
Treatment	4	104.228	26.057	9.67	<.001
Residual	91	245.265	2.695		
Total	99	352.127			

Appendix 24: ANOVA for % fruit and shoot damage between the accessions in the screenhouse

Variate: %_Shoot_Damage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	4	1809.4	452.3	0.64	
Treatment	4	905.0	226.3	0.32	0.859
Residual	16	11261.3	703.8		
Total	24	13975.7			

Variate: %_Fruit_Damage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	4	584.0	146.0	0.51	
Treatment	4	1144.0	286.0	1.01	0.432
Residual	16	4536.0	283.5		
Total	24	6264.0			

Appendix 25: Photo gallery of major insect pests (A, B, C, D, E, F, G, H and I)

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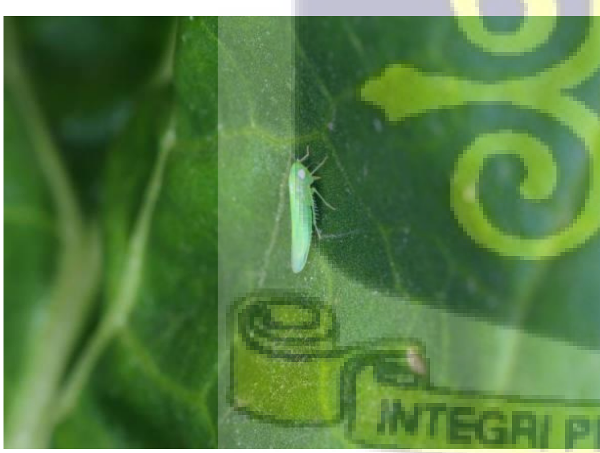
A: Adult *Thrips* sp. under a microscope

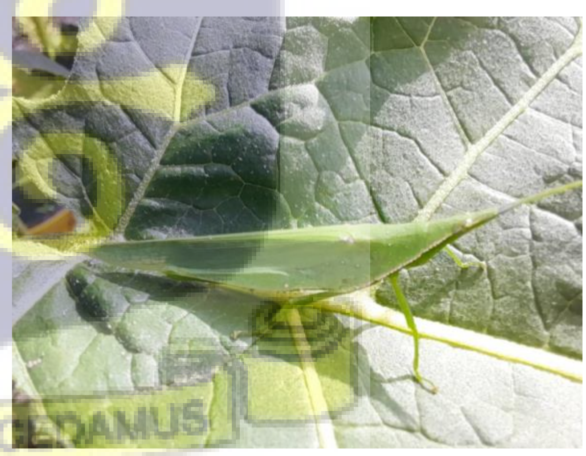
B: Winged adult *Aphis* sp. under a microscope

C: Nymph of a *Dysdercus* sp.

D: Cluster of *U. hystricellus* on a leaf



E: Adult of *Empoasca* sp. on a leaf



F: Adult of *A. acutipennis* on a leaf

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G: Adult of *Z. variegatus* on a leaf

H: Adult of *Leucinodes* sp.

I: Adult whiteflies (*B. tabaci*) on the underside of a leaf

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