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Foliar application of selected insecticides and nutrients: effects on the striped mealybug control and mango fruit yield and quality

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Abstract: *Ferrisia virgata* (Cockerell) (Hemiptera: Pseudococcidae), known as the striped mealybug, is a common pest on mango trees. This pest feeds on sap, leading to tree weakening trees, and extreme case causing their death. Infestation leads to the formation of cottony masses on mango fruits, reducing their nutritional, marketing, commercial, and export value. The current experiment aimed to determine the effectiveness of some chemical insecticides, applied with or without the addition of foliar nutrients, in combating the striped mealybug and improving the productivity of 'Zebda' mango fruits.

The results exhibited that *F. virgata* nymphs were more sensitive to the tested insecticides than the females. Seven days after spraying, all insecticides resulted in a significant increase in mortality rates, which continued to rise over time for both *F. virgata* nymphs and adult females. Among the tested treatments, Imidacloprid showed to be the most effective in reducing *F. virgata* females and nymphs, while Malatox exhibited the lowest efficacy.

Spraying mango trees with Imidacloprid insecticide in addition to boron, calcium, and magnesium – each at a concentration of 2.5 $cm^3 \cdot dm^{-3}$ – led to a noticeable improvement in all physical and chemical characteristics of fruits compared to unsprayed trees. However, the lowest values were observed in trees treated with Malatox alone. In addition, the maximum avoidable loss was estimated for all studied parameters in trees treated with Malatox only, with the exception of fruit acidity.

Keywords: infestation, insecticide, *Ferrisia virgata*, nutrients, reduction of mango yield

INTRODUCTION

Mango trees (*Mangifera indica* L.) are tropical fruit trees known for their juicy, stone fruits, which take four to five months to ripen and can grow up to 30 m tall (Masroor *et al.*, 2016; Maklad, El-Sawwah and Nassar, 2020). The 'Zebda' mango variety is renowned for its sweet, spicy flavour, low fibre content, regular bearing, and mid-season ripening (Abd El-Aziz *et al.*, 2024). Mealybugs are a significant pest for many crop plants, especially mango trees (Bakry, 2009). The striped mealybug (*Ferrisia virgata* (Cockerell) (Hemiptera: Pseudococcidae)) is a globally wide-spread insect that attacks various crop plants (Nabil *et al.*, 2020). This global agricultural pest is particularly harmful to mango trees. These small, soft-bodied insects are covered in white, waxy, cotton-like filaments and are commonly found on leaf axils, veins, stems, branches, shoots, flowers, and fruit. They feed on the plant's sap, weakening the plant and potentially causing severe damage or even death (Balboul, 2003; Garcia Morales *et al.*, 2016; Ata *et al.*, 2019). Infestations cause leaf discolouration, stunted growth, reduced fruit quality, premature drop, and unhealthy branches, potentially indicating dieback. Mealybugs produce honeydew, a sticky substance that accumulates on leaves, branches, and fruits, attracting ants and promoting the growth of sooty mould, a black fungus covering leaves (Balikai, Kotikal and Prasanna, 2011; Bakry and Aljedani 2023). Increased ant activity on a mango tree may indicate a mealybug infestation (Bakry and Fathipour, 2023).

Mango trees suffer both direct and indirect damage from mealybugs, leading to low yield in both quality and quantity. Direct injury to plants occurs when sap removal disrupts water (Bakry, Mohamed and Shehata, 2023) and nutrient flow, leading to nutrient deficiencies, stunted growth, yellowing leaves, and weakened plants (Mittler and Douglas, 2003). Indirect harm involves the transmission of viral pathogens, with severe infestations causing premature fruit loss (Dreistadt, 2001; Bakry, Maharani and Allam, 2024).

Since foliar sprays with specific nutrients can enhance mango productivity, yields, and fruit quality, researchers focus on macro- and microelements used for this purpose (Khattab, Shaban and Hassan, 2016). Mango trees require boron as a micronutrient for healthy growth and fruit production. Boron is crucial for pollen germination, cell wall formation, and fruit development (Ibrahim, 2017). Shortage of boron can cause poor flower and fruit set, leading to deformed or discoloured fruits. Boron also enhances plant structural integrity and immunity against pests (Stellacci *et al.*, 2010). Calcium is crucial for mango trees, affecting plant architecture, growth, nutrient acquisition, transport, fruit quality, stress tolerance, and protection against insect pests and infestations (Singh and Maurya, 2004). Calcium is essential for mangoes' firmness and shelf life, preventing internal breakdowns and spongy tissues (Singh *et al.*, 2013). Foliar spraying should provide 20–30% of the crop's calcium requirement during the fruit development stage following full bloom (Torres *et al.*, 2017). Magnesium, another essential macronutrient for mango trees, is involved in critical photosynthesis, enzyme activation, nutrient uptake, and defence mechanisms (Bakry and Abd El-Rahman, 2021). Magnesium deficiency can cause yellowing of older leaves and can impact fruit quality and yield (Nijjar, 1985). Magnesium sulphate is used as a soil amendment and foliar spray to provide plants with magnesium, enabling efficient nitrate conversion into amino acids and proteins, reducing pest attraction (Mengel and Kirkby, 1987). Nutrients impact insect damage differently depending on plant species, pest type, and environmental conditions. Integrated Pest Management (IPM) practices, combining nutrition and cultural tactics (Bala *et al.*, 2018), are crucial for long-term pest control, considering environmental conditions and pests' behaviour (Angon *et al.*, 2023). Arbitrary pest management without balanced fertilisation does not yield good results for mango productivity and fruit quality. Regular monitoring of mango trees helps detect pest infestations, allowing for effective control measures. Optimised nutrient supply enhances tree health and yield, indirectly reducing pest populations (Bakry, Wang and He, 2025). This study aims to investigate the effectiveness of certain chemical insecticides, applied with or without foliar nutrients, in controlling the striped mealybug and improving 'Zebda' mango fruit productivity. The objective is to identify the best treatments to maximise return for growers under the experimental conditions.

MATERIAL AND METHODS

EXPERIMENT SITE

This study was conducted in a private mango orchard located in the Esna region, Luxor governorate, Egypt (25°18'56"N, 32°33'52"E) during the 2021–2022 and 2022–2023 growing seasons. The experiment was performed on 11-year-old 'Zebda' mango trees planted at 7 × 7 m spacing in clay loam soil, covering approximately 19,200 m^2. The objective was to evaluate the effectiveness of certain foliar insecticides, with or without the nutrients treatments, in controlling the striped mealybug and improving the productivity of 'Zebda' mango fruits.

EXPERIMENT TREATMENTS

Effectiveness of the tested insecticides against the striped mealybug *Ferrisia virgata*

The visual signs of the striped mealybug *F. virgata* infestation on the leaves and fruits of 'Zebda' mango trees are shown in Photo 1.

Five chemical insecticides, including Profenofos (Teliton 72% EC) at a rate of 3.5 $cm^3 \cdot dm^{-3}$ of water, Malathion (Malatox 57% EC Organophosphate) at a rate of 2.5 $cm^3 \cdot dm^{-3}$ of water, Imidacloprid (Ecomida 30.5% SC) at a rate of 0.6 $cm^3 \cdot dm^{-3}$ of water, Acetamiprid (Mospilan 20% mg) at a rate of (50 g)·(100 $dm^3)^{-1}$ of water, and Thiamethoxam (Actara 25% WG) at a rate of (40 g)·(100 $dm^3)^{-1}$ of water, were applied to evaluate their effectiveness against *F. virgata* on mango leaves. The trial also consisted of a control treatment (water spray).

Consequently, the experiment consisted of six treatments, each replicated eight time using one mango tree per replication, resulting in a total of 48 mango trees. A completely randomised block design (CRBD) was employed. The selected mango trees underwent standard and normal horticultural procedures (fertilisation and irrigation), and they had nearly the same age, size, form, height, and vegetative growth. In order to determine the number of insects present before application and 7, 14, 21, and 28 days after the spraying (DAS), twenty infested mango leaves were taken from each tree and randomly chosen to represent the four directions and various tree heights. The sampling technique followed protocol described by Mohamed and Bakry (2019).

The tested pesticides were evaluated during two periods in each season, based on pest scouting and population assessment, corresponding to the peak relative abundance of nymphs. The first application was conducted in mid-October, before the formation of overwintering females, and the second at the beginning of May, aiming to reduce the insect population in the summer and protect the newly formed mango fruits. These application timings were selected to coincide with the periods of the highest nymph density.

After being placed in paper bags, the samples were taken to the laboratory for analysis. A total of 9,600 mango leaves were examined, calculated as follows: 20 leaves x 8 trees x 6 treatments x 5 inspection dates x 2 seasons. This resulted in 4,800 leaves

Photo 1. Discolouration of leaves and deformation of 'Zebda' mango due to the infestation with the striped mealybug (*Ferrisia virgata* (Cockerell)); samples collected in July 2022 from infested mango trees by Dr. Moustafa M.S. Bakry (phot.: *Moustafa M.S. Bakry*)

analysed per season. In order to ensure complete coverage throughout the canopy, treatments were applied using a six-horsepower motor sprayer (beam) equipped with a 600-dm^3 tank and operating at a pressure of 0.14 kg·cm^{-2}. The applied dosage was 20–25 dm^3 per tree. On the two surfaces of mango leaves from pre-spraying, post-spraying, and control samples, the live nymphs and females of *F. virgata* were counted and recorded. Next, the reduction percentage (%*RP*) was calculated by applying the Henderson and Tilton (1955) formula:

$$\%RP = 1 - \frac{C_b}{C_a}\frac{T_a}{T_b} \tag{1}$$

where: %*RP* = reduction percentage, C_b = control numbers before application, C_a = control numbers after application, T_a = treatment counts following application, T_b = treatment counts prior to application.

Mortality percentages of *F. virgata* at various developmental stages were evaluated for all treatments using mean values ± standard error.

Statistical analysis: data collected over the two growing seasons were statistically analysed using a two-way ANOVA within the Generalised Linear Models (GLMs) procedure, and implemented by SPSS software (SPSS, 1999). Post hoc multiple comparisons of the observed mortality rates (both nymphs and adult females) among different treatments at different examination periods were performed using Tukey's HSD test at $p \leq 0.05$.

The combined impact of insecticide treatments against *Ferrisia virgata*, with or without nutrients mixture, on mango yield and quality

This investigation was carried out in the same orchard and the same 'Zebda' mango trees as the previous study. The trees examined in the first trial were subdivided into two groups: one receiving a mixture of boron, calcium, and magnesium, and the other without nutrient supplementation. For each treatment, four of the eight trees received an addition of a boron, calcium, and magnesium mixture, whereas the remaining four trees served as non-nutrient controls. A total of eleven treatments were executed in the experiment:

T_1 = trees were treated with Profenofos insecticide only;
T_2 = trees were treated with Profenofos insecticide in addition to a mixture of boron at 2.5 $cm^3 \cdot dm^{-3}$, calcium at 2.5 $cm^3 \cdot dm^{-3}$, and magnesium at 2.5 $cm^3 \cdot dm^{-3}$ of water;
T_3 = trees were treated with Malathion insecticide only;
T_4 = trees were treated with Malathion insecticide in addition to a mixture of boron at 2.5 $cm^3 \cdot dm^{-3}$, calcium at 2.5 $cm^3 \cdot dm^{-3}$, and magnesium at 2.5 $cm^3 \cdot dm^{-3}$ of water;
T_5 = trees were treated with Imidacloprid insecticide only;
T_6 = trees were treated with Imidacloprid insecticide in addition to a mixture of boron at 2.5 $cm^3 \cdot dm^{-3}$, calcium at 2.5 $cm^3 \cdot dm^{-3}$, and magnesium at 2.5 $cm^3 \cdot dm^{-3}$ of water;
T_7 = trees were treated with Mospilan insecticide only;
T_8 = trees were treated with Mospilan insecticide in addition to a mixture of boron at 2.5 $cm^3 \cdot dm^{-3}$, calcium at 2.5 $cm^3 \cdot dm^{-3}$, and magnesium at 2.5 $cm^3 \cdot dm^{-3}$ of water;
T_9 = trees were treated with Actara insecticide only;
T_{10} = trees were treated with Actara insecticide in addition to a mixture of boron at 2.5 $cm^3 \cdot dm^{-3}$, calcium at 2.5 $cm^3 \cdot dm^{-3}$, and magnesium at 2.5 $cm^3 \cdot dm^{-3}$ of water;
T_{11} = unsprayed trees (trees treated with water only).

The trees were sprayed with a foliar nutrient mixture containing boron (2.5 $cm^3 \cdot dm^{-3}$), calcium (2.5 $cm^3 \cdot dm^{-3}$), and magnesium (2.5 $cm^3 \cdot dm^{-3}$) three times each season in 2022 and 2023 (in the first week of January, after fruit set, and a month later). Maklad, El-Sawwah and Nassar (2020) used the same rates for these nutrients on 'Zebda' mango trees, with yield and fruit quality assessed in relation to insecticides used to control striped mealybugs, both with and without the addition of a boron, calcium, and magnesium mixture. First, at harvest, the expected yield weight (kg) was noted for every tree individually. Subsequently, twenty fruits were chosen at random from each tree for further assessments of fruit quality. **The fruit's physical characteristics:** for each tested treatment, the average mean of the following parameters was estimated: fruit weight (g), fruit dimensions (length and width in cm), fruit shape (length to width ratio), fruit thickness (cm), and fruit size (cm^3). These measurements were made using a Vernier calliper. **Chemical characteristics of fruit:** in the laboratory, the following chemical characteristics of mango fruit have been established: total soluble solids percentage (TSS%) of fruit flesh: computed according to procedures using a refractometer acc. to Payne (1968). In accordance with the AOAC (2000), the total acidity (%) was calculated. By dividing the total soluble solids percentage by the total acidity percentage, the TSS to acidity ratio was calculated. The percentage of total sugars was calculated volumetrically using Lane and Eynon (1965).

The following technique was used to determine the percentage gain in yield of each treatment and the preventable loss (*Pl*) of treated trees relative to untreated (control) trees based on the yield and quality data for 'Zebda' mango fruits (Paul, 1976).

$$\%YER = \frac{S - C}{S} \tag{2}$$

where: *YER* = yield enhancement relative to control, *S* = a particular characteristic of the treated trees, *C* = a particular characteristic of the untreated trees (control).

$$\%Pl = \frac{T - t}{T} \tag{3}$$

where: *Pl* = preventable loss, *T* = the highest yield for a particular characteristic in sprayed fruits**,** *t* = the same characteristic as in the other sprayed fruits.

Statistical analysis: all studied parameters were compared among various treatments using one-way ANOVA applying the generalised linear model (GLM) which was performed by computer using SPSS software (SPSS, 1999). Means were separated using Tukey's HSD test at $p \leq 0.05$.

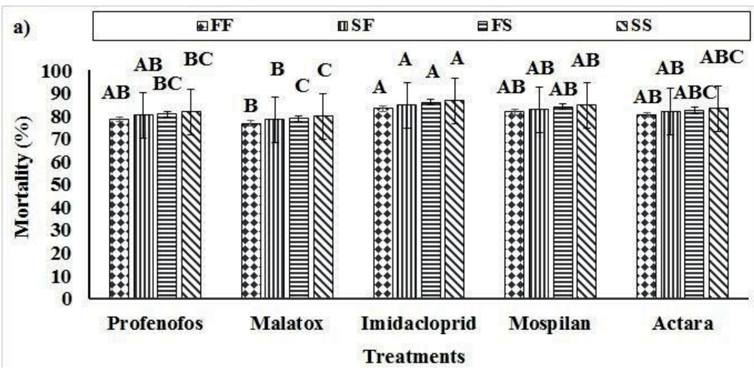
RESULTS

EFFECTIVENESS OF THE DIFFERENT INSECTICIDES ON THE POPULATION OF THE *Ferrisia virgata*

Results exhibited the effectiveness of the different insecticides on nymphs and adult females estimates after 7th, 14th, 21st, and 28th days after application in 2021/2022 and 2022/2023 seasons, respectively (Tabs. S1–S4, Figs. 1–2).

Ferrisia virgata nymphal population

The data showed that the percentages of reduction in estimates of *F. virgata* nymphs varied significantly between the five compounds tested four times after application during the two spraying periods in the two seasons (Tabs. S1–S2, Figs. 1–2).



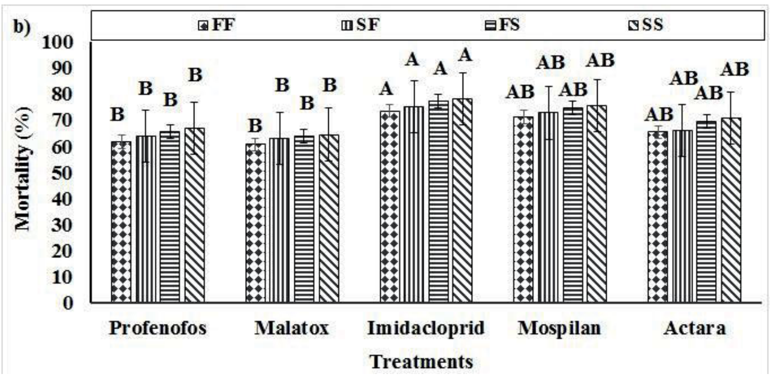


Fig. 1. Mortality percentage of *Ferrisia virgata* nymphs and adult females under the certain tested insecticides on 'Zebda' mango leaves across various field conditions in the two seasons: a) nymphs population, b) females population; FF = first spray in the first season, SF = second spray in the first season, FS = first spray in the second season, SS = second spray in the second season; values indicated by different letters for tested treatments against nymphs and adult females are statistically significant differences at $p \leq 0.05$ (Tukey's HSD test); source: own study

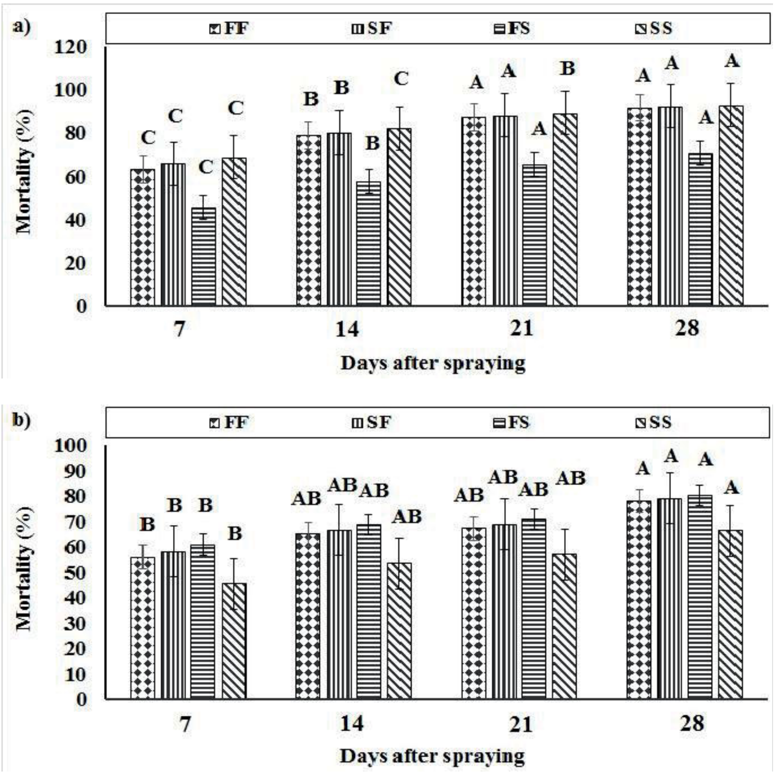


Fig. 2. Mortality percentages of *Ferrisia virgata* nymphs and adult females under the certain tested insecticides on mango leaves under field conditions in the different inspection dates (in weeks) in the two seasons: a) nymphs population, b) females population; FF, SF, FS, SS as in Fig. 1; values indicated by different letters for the different inspection dates (in weeks) tested treatments are statistically significant differences at $p \leq 0.05$ (Tukey's HSD test); source: own study

The treatment with Imidacloprid insecticidal exhibited a higher effectiveness in the percentage residual effect of the nymphs estimates by 83.32 ±0.70% and 84.54 ±1.96% for the first and second sprays over the first season (Tab. S1) and 85.89 ±1.05% and 86.48 ±1.13 % for the first and second sprays in the second season (Tab. S1), as compared to the other tested insecticides, as illustrated in Figure 1.

However, the treatment with Malatox revealed the lowest activity in the percentage of residual effect on the nymph population by 76.64 ±0.12% and 78.16 ±2.20%, for the first and second sprays over the first season (Tab. S1) and 78.67 ±1.04% and 79.65 ±0.53%, for the first and second sprays in the second season (Tab. S2), as compared to the other tested insecticides, as illustrated in Figure 1.

In this context, all the tested insecticide treatments showed a significant increase in the percentage of mortality of *F. virgata* nymphs on mango leaves, ranging from 76.64 ±0.12 to 83.32 ±0.70% in the first spray and 78.16 ±2.20 to 84.54 ±1.96% in the second spray during the first season (2021/2022), as shown in Table S1.

Statistically, there were highly significant variances in the mortality ratios of nymphs between the tested insecticides (F = 8.52, df = 38, p = 0.0001 in the first spray and F = 4.53; df = 38; P = 0.0043 in the second spray), during the first season (2021/2022), as presented in Table S1. Meanwhile, there were highly statistically significant differences in nymph mortality rates between different inspection dates (F = 240.43, df = 38, p = 0.0001 in the first spray and F = 127.11, df = 38, p = 0.0043 in the second spray), over the first season (2021/2022). However, there was no significant interaction between insecticide treatments and different inspection dates (F = 1.84, df = 38, p = 0.094 in the first spray and F = 1.53, df = 38, p = 0.082 in the second spray), over the first season (2021/2022).

In the second season (2022/2023), all the evaluated insecticides exhibited a significant increase in the mortality of *F. virgata* nymphs on mango leaves, which ranged from 78.67 ±1.04 to 83.92 ±1.00% in the first spray and from 79.65 ±0.53 to 86.48 ±1.13% in the second spray, as shown in Table S2.

Statistical analysis exhibited that there were highly significant variances in mortality between the evaluated insecticides (F = 12.65, df = 38, p = 0.0001 in the first spray and F = 12.99, df = 38, p = 0.0001 in the second spray), during the second season (2022/2023) as shown in Table S2. Furthermore, there were highly statistically significant differences in nymph mortality rates between different inspection dates (F = 251.44, df = 38, p = 0.0001 in the first spray and F = 269.21, df = 38, p = 0.000 in the second spray), over the first season (2022/2023). However, there was no significant interaction between insecticide treatments and different inspection dates (F = 1.13, df = 38, p = 0.365 in the first spray and F = 1.22, df = 38, p = 0.303 in the second spray), over the first season (2022/2023).

It is obvious from the first and second spraying periods in the two seasons that the effectiveness of five insecticides on *F. virgata* nymphs was clear, starting from the 7th days after application and continued gradually until the 28th days after spraying. Thus, the longer the period after spraying, the greater the percentages of mortality in the nymph population, as shown in Tables S1 and S2 and Figure 2.

Ferrisia virgata female adult population

As shown in Tables S3 and S4 and illustrated in Figures 1 and 2, the percentages of reduction in counts of *F. virgata* females varied significantly between five insecticides at four times after spraying during the two spraying intervals over the two seasons.

The treatment with Malatox had the lowest toxicity in the percentage of residual influence on the female population by 60.64 ±3.00% and 63.02 ±2.01% for the first and second sprays over the first season (Tab. S3) and 63.80 ±4.60% and 64.48 ±6.61% for the first and second sprays over the second season (Tab. S4), as compared to the other tested insecticides, as illustrated in Figure 1.

In comparison to the other tested insecticides, as shown in Figure 1, the treatment with Imidacloprid insecticidal, on the other hand, showed a higher effectiveness in the percentage of residual impact of the females estimates by 73.54 ±3.67% and 74.95 ±4.00% for the first and second sprays over the first season (Tab. S3), and 77.33 ±3.09% and 77.99 ±3.59% for the two sprays in the second season (Tab. S4).

Moreover, all the tested insecticide treatments exhibited a significant increase in the percentage of mortality of *F. virgata* females on mango leaves, ranging from 60.64 ±3.00 to 73.54 ±3.67% in the first spray, and by 63.02 ±2.01 to 74.95 ±4.00% in the second spray over the first season (2021/2022), as shown in Table S3.

Statistically, there were highly significant variances in the mortality of females between the tested insecticides (F = 5.56, df = 38, p = 0.0013 in the first spray and F = 5.22, df = 38, p = 0.0019 in the second spray), during the first season (2021/2022), as depicted in Table S3. Meanwhile, there were highly statistically significant differences in female mortality rates between different inspection dates (F = 17.43, df = 38, p = 0.0000 in the first spray and F = 16.61, df = 38, P = 0.0000 in the second spray), over the first season (2021/2022). However, there was no significant interaction between insecticide treatments and different inspection dates (F = 1.31, df = 38, p = 0.092 in the first spray and F = 1.28, df = 38, p = 0.086 in the second spray), over the first season (2021/2022).

Over the second season (2022/2023), all the tested insecticides showed a significant increase in the mortality of *F. virgata* females, ranging from 63.80 ±4.60 to 77.33 ±3.09% in the first spray and from 64.48 ±6.61 to 77.99 ±3.59% in the second spray, as presented in Table S4.

Statistically, the data revealed that there were highly significant variances in the mortality of females between the evaluated insecticides (F = 6.75, df = 38, p = 0.0003 in the first spray and F = 6.44, df = 38, p = 0.0005 in the second spray), during the second season (2022/2023), as shown in Table S4.

Furthermore, there were highly statistically significant differences in female mortality rates between different inspection dates (F = 16.16, df = 38, p = 0.0000 in the first spray and F = 14.85, df = 38, p = 0.000 in the second spray), over the first season (2022/2023). However, there was no significant interaction between insecticide treatments and different inspection dates (F = 1.35, df = 38, p = 0.075 in the first spray and F = 1.32, df = 38, p = 0.068 in the second spray), over the first season (2022/2023).

It is obvious from the two spraying periods in the two seasons that the effectiveness of five insecticides on *F. virgata* females was clear, starting from the 7th days after application, and continued gradually until the 30th days after spraying. Thus, the longer the period after spraying, the greater the percentages of mortality in the female population, as shown in Tables S3 and S4 and Figure 2.

The data exhibited that *F. virgata* females were less sensitive to the tested insecticides than nymphs, as depicted in Tables S1–S4.

THE OVERALL IMPACT OF INSECTICIDE TREATMENTS AGAINST *Ferrisia virgata*, WITH OR WITHOUT THE ADDITION OF NUTRIENTS, ON THE QUANTITY AND QUALITY OF MANGOES PRODUCED

Physical properties of the fruit

The physical measurements of the fruits from mango trees were affected by the combined effect of insecticidal treatments, whether with or without the addition of nutrients of water, in the two seasons studied as it shown in Table S5.

The results indicated that the mango trees treated with Imidacloprid insecticide in addition to a mixture of boron at 2.5 $cm^3 \cdot dm^{-3}$, calcium at 2.5 $cm^3 \cdot dm^{-3}$, and magnesium at 2.5 $cm^3 \cdot dm^{-3}$ of water (T_6 treatment) increased in all physical characteristics of the fruit (i.e. average weight of the fruit and dimensions of fruit – length and width, fruit shape – length to width ratio, fruit thickness, and fruit size) compared to all other different treatments during the two seasons, respectively (Tab. S5).

On the contrary, the untreated trees (T_{10}) are characterised by the lowest significant values in all physical attributes of the fruits as compared to the other treatments examined throughout the two seasons. Based on statistical analysis, it was found that all physical features of mango fruits during the two seasons showed statistically significant variations between the various treatments examined (Tab. S5).

On the fruit chemical properties

The yield productivity and fruit chemical properties of 'Zebda' mango trees were shown to be affected by spraying certain insecticides on *F. virgata* over the two seasons, with or without the addition of nutrients (Tab. S6).

The treatment (T_6), which used Imidacloprid insecticide in addition to a mixture of boron at 2.5 $cm^3 \cdot dm^{-3}$, calcium at 2.5 $cm^3 \cdot dm^{-3}$, and magnesium at 2.5 $cm^3 \cdot dm^{-3}$ of water, produced the highest values in the resulting yield and the fruit chemical properties over the two seasons as compared to the other treatments tested. However, the untreated trees (T_{10}) gave the lowest values in the resulting yield and chemical properties of the fruits during the two seasons compared to the other treatments tested (Tab. S6).

In addition, there were clear and noticeable differences between the different treatments in the resulting yield and the chemical properties of the fruits during the two seasons (Tab. S6). It is clear that, in comparison to applying pesticide treatments alone, spraying trees with certain insecticides along with the addition of boron at 2.5 $cm^3 \cdot dm^{-3}$, calcium at 2.5 $cm^3 \cdot dm^{-3}$, and magnesium at 2.5 $cm^3 \cdot dm^{-3}$of water resulted in a supplemental increase in all tested parameters. The improvement occurred in the physical characteristics of fruits, fruit quality, and resulting yield due to the insecticide treatments and the effect of nutrients (boron, calcium, and magnesium) on maintaining the vitality of trees, raising their nutritional status, and advancing fruit ripening.

THE INCREASE IN THE FRUIT PHYSICAL CHARACTERISTICS, RESULTING YIELD, AND QUALITY OF 'ZEBDA' MANGO TREES OVER THE CONTROL TREATMENT

As for the increase in the fruit physical characteristics, the resulting yield and quality of 'Zebda' mango trees compared to the untreated treatment were calculated for all the different treatments.

The results showed that, when compared to untreated trees, trees treated with Imidacloprid insecticide in addition to a mixture of boron at 2.5 $cm^3 \cdot dm^{-3}$, calcium at 2.5 $cm^3 \cdot dm^{-3}$, and magnesium at 2.5 $cm^3 \cdot dm^{-3}$ of water had the largest increases in physical traits, fruit quality, and yield (T_6). However, the trees were treated with Malathion insecticide (T_3) had the lowest of these (Tabs. S7 and S8).

PREVENTABLE LOSSES IN THE FRUIT PHYSICAL CHARACTERISTICS, RESULTING YIELD, AND QUALITY OF 'ZEBDA' MANGO TREES WHEN COMPARED TO THE STUDIED TREATMENTS

The preventable losses in the physical attributes, fruit quality, and yield of the 'Zebda' mango trees in comparison to the treatments tested were calculated for each of the various treatments that were tried.

It showed that the highest preventable loss in all the studied traits (physical characteristics of fruits, resulting yield, and fruit quality) was calculated in trees treated with Malathion insecticide only (T_3), except for the acidity trait. However, the least avoidable loss in all tested traits was in trees treated with the Imidacloprid insecticide only (T_5), as shown in Tables S9 and S10.

DISCUSSION

Mealybugs, which belong to the order Hemiptera, are small insects that are known for their protective scale-like coverings (Bakry and Arbab, 2020). They are found in various habitats worldwide, including forests, gardens, agricultural fields, and even indoor plants. Mealybugs are a major pest of mango trees (Bakry, 2009).

The literature contains limited information on the negative effects of *F. virgata*, strategies to reduce its numbers, and ways to improve mango tree productivity and enhance fruit quality. Controlling mealybugs depends mainly on the use of chemical insecticides.

Therefore, this work was carried out to evaluate the six foliar treatments for controlling the striped mealybug *F. virgata* on 'Zebda' mango trees under field conditions. A study was also executed to evaluate the combined impact of these chemical insecticides, either with or without the addition of foliar nutrients, on improving the productivity and quality of 'Zebda' mango fruits.

Obviously, according to the results, *F. virgata* nymphs were more toxic to the evaluated insecticides as compared to the adult females. According to Mohamed and Bakry (2019), nymphs of *F. virgata* nymphs had the highest sensitivity to pesticides than adults.

According to the results, the mortality percentages of *F. virgata* nymphs and adult females' counts varied significantly between the five insecticides tested in the four examination periods after application during the two spraying periods in each season.

Based on the results, the treatment with Imidacloprid insecticidal exhibited a higher effectiveness in the percentage of residual effect of the nymphs' mortalities by 83.32 ±0.70% and 84.54 ±1.96% for the first and second sprays over the first season (2021/2022) and 85.89 ±1.05% and 86.48 ±1.13% for the first and second sprays in the second season (2022/2023), as compared to the other tested insecticides. These results were consistent with those reported by Bakry, Shehata and Tolba (2024), who stated that the third instar nymphs and adult females of *F. virgata* were most effectively treated with Imidacloprid on *Acalypha* leaves.

Unlike the other insecticides tested, Malatox exhibited the least effectiveness in its residual impact on the nymph population. The recorded activity percentages were 76.64 ±0.12% and 78.16

±2.20% for the first and second applications in the 2021/2022 season, and 78.67 ±1.04% and 79.65 ±0.53% for the first and second applications in the 2022/2023 season. These results are consistent with those of Elwan, Shalaby and Khewa *et al.* (2005), who found that diminished resistance in red-stripe soft-scale ((*Pulvinaria tenuivalvata* (Newstead) Hemiptera: Coccidae) on sugarcane to the insecticide Malatox. The results showed that applying Imidacloprid insecticide (sprayed twice) in addition to a mixture of boron at 2.5 $cm^3 \cdot dm^{-3}$, calcium at 2.5 $cm^3 \cdot dm^{-3}$, and magnesium at 2.5 $cm^3 \cdot dm^{-3}$ of water (sprayed three times) per season on mango trees produced the highest productivity in all tested traits. Concisely, this can be explained by the way that the Imidacloprid pesticide reduced mealybug counts and added nutrients, which improved the fruit production of mango trees and the nutritional state of the plants so that they produced more fruits. However, the least of them were observed in the untreated trees (spraying water only).

In addition to being essential for plant health, nutrients can help lessen pest infestations. Although the precise effects of micronutrients on insect pests are not well understood, some micronutrients indirectly affect plant resistance to pests by boosting immune systems and general plant health (Marschner, 1995).

Foliar treatments of nutrients are an alternative in production, as they have direct contact with leaves and fruits to promote the accumulation inside the leaves and distribution to other areas of the plant (Bibi *et al.*, 2019). However, some factors can compromise the application success, such as the application time and the chemical form of the nutrient in the solution (Wójcik and Borowik, 2013).

The results showed that, compared to untreated trees, trees treated with Imidacloprid plus a mixture of boron at a concentration of 2.5 $cm^3 \cdot dm^{-3}$, calcium at a concentration of 2.5 $cm^3 \cdot dm^{-3}$, and magnesium at a concentration of 2.5 $cm^3 \cdot dm^{-3}$ of water achieved the greatest increase in physical characteristics, fruit quality, and yield. However, the trees were treated with Malathion insecticide only. Improved nutrient availability and fertiliser efficiency are crucial for increasing yields, with calcium being a key element determining fruit quality (Rizzi and Abruzzese, 1990).

Calcium deficiency in soil is crucial for managing fruit problems, as it affects plant dispersion and metabolic processes (Marschner, 2012). Micronutrients like calcium and zinc are crucial for pollen germination and fruit set, and their use enhances fruit set, retention, and fruiting characteristics (Tohidloo and Souri, 2009).

According to this paper, the highest avoidable loss in all the studied traits (physical characteristics of fruits, resulting yield, and fruit quality) was calculated in trees treated with Malathion insecticide only, except for the acidity trait. Contrarily, the least avoidable loss in all tested traits was in trees treated with the Imidacloprid insecticide only.

Nutrients like K, Ca, and B enhance plant growth and fruiting, while calcium aids in cell elongation and division, thereby increasing growth parameters and preventing cellular degeneration (Muengkaew, Chaiprasart and Wongsawad, 2017; Bitange *et al.*, 2019; Maklad, El-Sawwah and Nassar, 2020).

El-Kosary, El-Shenawy and Radwan (2011) found that applying boron to mango trees increased leaf physical characteristics. In turn, Singh, Dhillon and Singh (1987) stated that the foliar application of boric acid encouraged vegetative growth.

Boron application in mango trees can regulate sugar translocation, biosynthesis, cell division, water absorption, and nutrient transport, preventing nutrient losses, increasing efficiency, and reducing soil toxicity (Mengel *et al.* (eds.), 2001; Rai, Acharya and Dey, 2012; Prasad, Kumar and Prasad, 2014).

Bhatt *et al.* (2012) found that foliar application of Ca, B, and Zn in combination accelerates growth, flowering, fruiting, and fruit quality. Merwad, Eiasa and Saleh (2016) found positive effects on fruit set, retention, and fruit drop. 'Ewais' and 'Fagry Kelan' mango cultivars showed increased yield with Ca, B, and amino acid sprays (Khattab, Shaban and Hassan, 2016). Ahmad *et al.* (2018) suggested that the double dynamic approach of B and Zn improves fruit quality and decreases leaf mineral abnormalities. Maklad, El-Sawwah and Nassar (2020) argued that spraying a B, Zn, and Ca mixture on 'Ewaise' mango trees four times can provide a higher yield and also increase fruit quality, as well as decreasing the abiotic stress impact. El-Salhy*et al.* (2024) showed that the addition of Ca alongside B to the soil can enhance growth, yield, and quality of 'Ewaise' mango trees and alleviate the harmful impacts of abiotic stress on the tree.

Calcium significantly reduces insect infestation in 'Ewaise' mango trees by strengthening cell walls, thereby improving plant health and overall growth, which contributes: (a) calcium-strengthened cell walls in fruits make it harder for insects to enter, thereby reducing damage from piercing-sucking insects; (b) healthy plants with sufficient calcium are more likely to face fewer pest problems and recover faster from damage; (c) the process involves activating defence reactions and increasing the production of repellent molecules against insects; (d) the indirect effects of stronger plants with better overall health are less likely to experience damage (Kumar *et al.*, 2006; Wahdan *et al.*, 2011).

Magnesium and magnesium sulphate influence plant nutrition and pest resistance but lack direct insecticidal properties and are not commonly used for insect control. They can contribute indirectly towards pest management in two ways though. Firstly, magnesium and magnesium sulphate are crucial nutrients for plant growth, promoting health and natural defences against pests and diseases in mango trees when adequately supplied. Healthy and vigorous plants are also generally less likely to be attacked by insects. Secondly, inadequate or deficient essential nutrients can weaken plants, increasing their susceptibility to insect populations. Magnesium and magnesium sulphate application, following recommended guidelines and soil test results, can help to balance soil nutrients, promote plant health, and reduce insect pest susceptibility in mango trees. Further research is recommended to provide more robust conclusions on this particular topic.

CONCLUSIONS

The striped mealybug (*Ferrisia virgata* (Cockerell) (Hemiptera: Pseudococcidae)), on mango trees is a pest with piercing-sucking mouthparts that feeds on leaves, shoots, and flowers of mango trees. Severe infestation can result in leaf curling, yellowing, premature defoliation, drying out, and death of the tree, as well as decreased mango production in both quantity and quality.

From our results, we concluded that 'Zebda' mango trees sprayed with Imidacloprid twice in October and May each season to reduce the number of *F. virgata*, with the addition of a mixture of boron, calcium, and magnesium three times per season, in the first week of January after fruit set, and a month after that to obtain the highest tree productivity and improve the quality of fruits.

By regularly monitoring mango trees, early infestation of mealybug can be detected and take appropriate action to control the pests before they cause significant damage. Regular inspections and early intervention are vital for successful mealybug control in mango trees. The *F. virgata* control can significantly improve mango fruit yield by reducing damage to trees. The insecticides can be effective, but integrating other methods, such as cultural and mechanical practices or biological control, can enhance results. The addition of boron, calcium, and magnesium applications with other IPM strategies to manage pests effectively might further aid in nutrient uptake, overall tree health, and improving the productivity of mango fruits; however, they can also indirectly contribute to reducing insect populations. But the specific effect on 'Zebda' mango fruits would depend on many variables, such as environmental conditions, the proper time of control, and application methods.

It is important to note that insect control often requires a comprehensive integrated pest management (IPM) approach that combines various strategies. This may include cultural practices (fertilisation and pruning), biological controls (such as introducing beneficial insects), and, if necessary, targeted insecticide applications.

CONTRIBUTION OF THE AUTHORS

Moustafa M.S. Bakry: study design, data collection, statistical analysis, data interpretation, manuscript preparation, and literature search. **Amr M.M. Badawy** and **Salem, E.H.**: statistical analysis, data interpretation, manuscript preparation, and literature search. **Mahmoud Y.H., Henaish**, **Eman F.M. Tolba**, and **Lamiaa H.Y. Mohamed**: manuscript preparation and literature search. All co-authors have read and approved of the manuscript before submission.

SUPPLEMENTARY MATERIAL

Supplementary material to this article can be found online at: https://www.jwld.pl/files/Supplementary_material_66_Bakry.pdf.

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CONFLICT OF INTEREST

All authors declare that they have no conflict of interest.

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