











Vegetative growth and fruit quality traits of six mango cultivars as affected by mealybug infestation

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Abstract: The striped mealybug (*Ferrisia virgata* Cockerell) is an agricultural pest that infests mango trees by feeding with its mouthparts, thereby impairing tree structure. Mealybugs can spread rapidly and form waxy masses on mango fruits, twigs, and leaves, reducing their nutritional, marketing, commercial, and export value. The present work evaluated the detrimental impacts of *F. virgata* on the vegetative growth features, mineral element levels, flowering characteristics, yield, and fruit quality in six mango cultivars. The findings demonstrated that *F. virgata* populations were present year-round on all six mango cultivars. Resistance to *F. virgata* varied significantly among the cultivars. The ‘Zebda’ mango cultivar was the most affected by *F. virgata* and showed the poorest vegetative growth, with the lowest levels of K, Ca, Zn, Mn, and Cu, and the lowest for flowering, yield, and fruit quality traits (physical and chemical), except for fruit acidity, as compared to the other mango cultivars tested. Conversely, the highest leaf concentrations of nitrogen, phosphorus, magnesium, and iron were recorded in ‘Zebda’, and these minerals may be associated with the increased prevalence of mealybugs in this cultivar. The heatmaps provide strong evidence that mealybug infestation is a major limiting factor for mango production in these cultivars. Selecting a mealybug-resistant cultivar (‘Taimour’) appears to be a crucial strategy for enhancing mango yield and fruit quality, as this cultivar also exhibits superior growth and nutrient status.

Keywords: fruit quality, mango cultivars, mango fruit yield, mealybugs, vegetative growth

INTRODUCTION

Mango (*Mangifera indica* L.) is a tropical fruit tree famous for their juicy and delicious stone fruit. Mealybugs are among the most destructive pests for many crops, especially mango (Bakry, 2009). The striped mealybug, *Ferrisia virgata* Cockerell (Hemiptera: Pseudococcidae), is a cosmopolitan insect that infests a variety of crop plants (Nabil *et al.*, 2020). These small, soft-bodied insects surround themselves in large cottony masses of white, waxy material and are commonly found on leaf axils, veins, stems,

branches, shoots, flowers, and fruit. The mealybug feeds on plant sap, weakening the plant and causing severe stress, which may lead to plant death (Balboul, 2003; García Morales *et al.*, 2015; Ata *et al.*, 2019). Infestations of mealybug cause leaf discoloration, stunted growth, and reduced fruit quality. They can also induce fruit drop, and branches may appear unhealthy, indicating possible dieback. Mealybugs release a sticky, fatty substance called honeydew that coats leaves, branches, and fruits. Honeydew accumulation may indicate a mealybug infestation. Honeydew also attracts ants and sooty mould growth, which can cover leaves in a black fungal layer

(Balikai, Kotikal and Prasanna, 2011). The increased activity of ants on mango trees may therefore indicate mealybug infestation (Bakry and Fathipour, 2023). Overall, mango trees experience both direct and indirect damage caused by mealybugs, which have been shown to reduce yields in both quality and quantity. Plants may suffer direct injury from sap removal, which can disrupt water flow (Bakry, Mohamed and Shehata, 2023) and nutrient flow, causing nutrient deficiencies, stunted growth, and foliar yellowing, and result in weakened plants (Mittler and Douglas, 2003). Further, mealybug presence may cause complete fruit drop (100%) and high rates of defoliation (80%) (Karar *et al.*, 2015). Indirect injury includes the transmission of viral pathogens, and severe infestations may also induce early fruit drop (Dreistadt, 2001; Golan *et al.*, 2015). As Bakry, Shehata and Tolba (2024) reported, farmers indicated that once mealybug infestations occur, they are very difficult to control.

Insects pose a threat to plants associated with biotic stress. When faced with insects, plants change their physical characteristics and produce secondary metabolites (Jan *et al.*, 2021). A better understanding of the factors that attract or deter insects in selecting host plants is vital for identifying cultivars that tolerate insect pressure. It is well understood that herbivores must obtain essential nutrients from their diet, while insect populations persist by feeding on leaves that a suitable dietary balance (Chapman, 2003). As with other insect pests, certain mango cultivars are more preferred by mealybugs, and population levels may vary among cultivars (Karar *et al.*, 2009). Mango trees also differ in their responses to insect outbreaks depending on their morphological traits and chemical composition of leaves. While physical traits can influence pest feeding and activity, during ingestion the plant's biochemical traits influence pest behaviour and metabolic processes (Karar *et al.*, 2015).

The term "plant resistance to insect pests" refers to the ability to generate resistance-associated characteristics that affect one or more aspects of the interaction between an insect pest and its host plant (Stout, 2014). The extent to which different types of mango cultivars survive and thrive during cohabitation with mealybugs infestation is influenced by genetic variation and the mineral and nutritional status of the soil. Cultivars of plants that are resistant to insects are an essential component of integrated pest management because they help reduce the negative impact of pests (Bakry and Abdel-Baky, 2020). In order to select cultivars that exhibit little susceptibility, it is important to understand the insect and plant associated characteristics linked to infestation (Salem *et al.*, 2006).

The authors are aware of only a few studies investigating how varying levels of *F. virgata* infestation affect vegetative growth, yield, and fruit quality (physical and chemical) in six different mango cultivars. The majority of mango cultivars are grown in Aswan, Egypt, particularly in Kom Ombo, where the climate is ideal. This study evaluated the relationship between vegetative growth characteristics, yield, and fruit quality (physical and chemical) in six mango cultivars infested with the striped mealybug over two consecutive seasons (2022–2023 and 2023–2024).

MATERIALS AND METHODS

Field evaluations were conducted during the 2022–2023 and 2023–2024 growing seasons in a private mango plantation in Kom Ombo, Aswan Governorate, southern Egypt (24°30'55" N,

32°57'15" E). The 240,000 m² plantation is located along the Nile River and hosts six economically significant mango cultivars: 'Zebda', 'Ewaise', 'Taimour', 'Goleck', 'Hindi Bisinnara', and 'Sediek'. These mature cultivars were chosen due to their high commercial value in the region. No pest control measures were applied to the randomly selected mango trees before or during the study.

The number of *Ferrisia virgata* individuals on mango leaf surfaces was meticulously recorded. Data were organised in Microsoft Excel, and statistical analyses were performed using SPSS (1999). Analysis of variance (ANOVA) and Tukey's HSD test ($p \leq 0.05$) were applied to compare means.

• Assessment of vegetative growth parameters and mineral nutrients

For each cultivar, six healthy ten-year-old trees were randomly selected and maintained under standard horticultural practices. Samples were collected biweekly, with 40 leaves per tree (240 leaves per cultivar per sampling day). Leaves were randomly collected from different strata and sections of each tree, placed in paper bags, and transported to the laboratory for stereomicroscope analysis.

To evaluate the relationship between *F. virgata* counts and mango cultivar traits, 40 leaves were collected from each of the six trees per cultivar. These trees were almost the same in terms of infestation level, vigour, size, shape, height, and age. Each year in early February, samples of leaves from middle-aged (2-year-old) fruiting branches were randomly selected from each portion of the tree and kept in the field under typical conditions. Younger leaves are more productive and efficient, and contain more chlorophyll, which optimises the storage of most nutrients.

To determine the shoot length, shoot thickness, number of leaves per shoot, leaf area, and leaf index (length of leaf/width of leaf), ten mature leaves per shoot (below panicles) were collected during the spring growth cycle. The leaf area was calculated using Equation (1) (Ahmed and Morsy, 1999):

$$A_{\text{leaf}} = 0.70L \cdot W - 1.06 \quad (1)$$

where: A_{leaf} = leaf area (cm²), L = maximum leaf length (cm), W = maximum leaf width (cm).

Mineral element concentrations were determined in six different mango cultivars, including nitrogen, phosphorus, potassium, calcium, magnesium, iron, zinc, manganese, and copper. Leaflets were collected and washed with tap and distilled water to remove any debris. They were then oven dried at 70°C for 48 hours (acc. to Ni *et al.*, 2001). The fresh and dry weights of the leaflets were measured and recorded. The dried material was ground using an electric mill and stored for analysis. The plant material was digested using sulfuric acid, following the method recommended by Jones (2001). The total nitrogen content was analysed using the micro-Kjeldahl method, while phosphorus was determined colorimetrically with ascorbic acid (Jones, 2001). Potassium levels were determined using a flame photometer (Brown and Lilliland, 1946). Calcium, magnesium, and trace elements like iron, zinc, manganese, and copper were analysed using an atomic absorption spectrophotometer. These analyses were all conducted on a dry weight basis, following specific procedures outlined in the literature (Carter, 1993).

• Effect of *F. virgata* on flowering, yield and quality of mango fruit

Flowering measurements were taken in both seasons at full bloom in April (spring growth cycle). Panicle length, panicle quantity per tree, and flowers per panicle were measured.

The yield indicators included weight of fruit per tree (kg), quantity of fruits per tree, and harvesting time (extended to late July for both research seasons).

Fruit quality was assessed based on the physical and chemical characteristics of twenty fully ripe fruits randomly collected from each tree at harvest.

Fruit shape (fruit length/its width ratio), fruit thickness (length and width in cm), fruit size (cm³), fruit weight (g), and average fruit length (cm) and width (cm) were measured using a vernier caliper.

The chemical properties of mango fruit were analysed in the laboratory as follows:

- total soluble solids (TSS, %) in the fruit flesh were determined using a refractometer based on the method described by Payne (1968);
- total acidity (%) in the flesh, expressed as grams of citric acid per 100 g of pulp, was determined through titration with 0.1 N NaOH using phenolphthalein indicator, following the AOAC (2000) guidelines;
- TSS/acidity ratio was calculated;
- total sugars (%) were determined volumetrically according to Lane and Eynon (1965).

All leaf samples were sent to the Water and Environment Research Department, in El-Mattana Agricultural Research Station. Fruit quality measurements were conducted at the Horticulture Research Department in El-Mattana Agricultural Research Station for chemical analysis of leaves and fruits. This research could help identify factors that promote pest infestation and lead to widespread outbreaks.

• Statistical relationship between *F. virgata* and vegetative growth traits, yield, and fruit quality

The association between the average count of *F. virgata* individuals per leaf/season of each mango cultivar and the growth, yield, and fruit quality (physical and chemical) characteristics of the six mango cultivars was evaluated using Pearson's correlation coefficient and simple statistical regression models in SPSS (1999). All gathered data were computed, graphed, and shown using Microsoft Excel 2007. Pearson's simple correlation values among several parameters were plotted using the R program (R Core Team, 2023).

Hierarchical clustering analysis (HCA) was performed employing Euclidean distance and the unweighted paired group method with arithmetic average (UPGMA). Two-year averages of growth, yield, and fruit attributes for the six mango cultivars were used to generate a similarity coefficient-based dendrogram in R software (R Core Team, 2023).

RESULTS AND DISCUSSION

POPULATION ABUNDANCE OF *Ferrisia virgata* ON CERTAIN MANGO CULTIVARS

Over the two-year study, *F. virgata* individuals were detected on all mango cultivars. The 'Zebda' cultivar exhibited the highest mean number of *F. virgata* counts per leaf (9.73 ± 1.32 individuals

per leaf). However, 'Taimour', which averaged 2.52 ± 0.32 insects per leaflet, was the cultivar that received the fewest *F. virgata*. The cultivars 'Goleck', 'Hindi Bisinnara', 'Sediek', and 'Ewaise' showed mild infestation, with mean counts of 6.56 ± 0.67 , 6.25 ± 0.72 , 4.48 ± 0.49 , and 3.88 ± 0.37 individuals per leaf, respectively (Fig. 1).

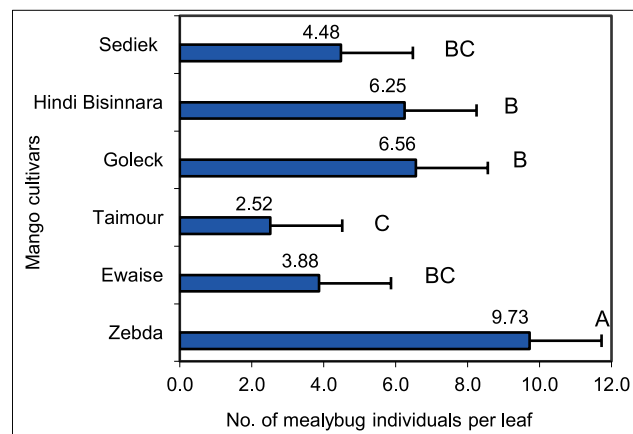


Fig. 1. Average estimations of *Ferrisia virgata* counts per leaf of six mango cultivar throughout the two-year average; means followed by the same letter(s) in each column are not significantly different at the 0.05 level of probability by Tukey's HSD test; tin line = standard deviation; source: own study

The assessed cultivars are arranged in ascending order according to the average infestation during the course of the two research seasons: 'Taimour' > 'Ewaise' > 'Sediek' > 'Hindi Bisinnara' > 'Goleck' > 'Zebda'.

For the two-year average of *F. virgata* abundance, statistical analysis revealed significant variations among mango cultivars at the 0.05 level of probability by Tukey's HSD test (Fig. 1).

The present results are mostly consistent with previously available data, although differences reflect variation in mango cultivars, infestation areas, and pest species. The high susceptibility of the 'Zebda' cultivar may contribute to severe mealybug infestation and their affinity, as it is described as low in fibre and characterised by a strong spicy flavour and a fragrant odour (Mohamed, 2024). In a similar vein, Selim (2002) examined the susceptibility of Egypt's five mango varieties ('Hindy', 'Mabrouka', 'Dabsha', 'Kobania', and 'Taimour') to infestation by two armoured scale insects, *Insulaspis pallidula* (Green) and *Aonidiella aurantii* (Mask.). Consistent with the present mealybug findings, 'Taimour' cultivar showed resilience to both scale insect infestations, whereas the 'Hindi Bisinnara' cultivar was the most susceptible. Additionally, Bakry (2009) evaluated four mango cultivars in Egypt to compare the infestation levels of same scale insects (*I. pallidula* and *A. aurantii*) and reported that 'Hindi Bisinnara' and 'Goleck' had moderate infestations. Bakry and Dahi (2020) reported that the Balady mango cultivar had the highest number of individuals and was categorised as very sensitive to infestation based on the total population size of the plum scale *Parlatoria oleae* (Colvée). In their study, the 'Zebda' mango cultivar appeared to be comparatively resistant, whilst the 'Ewaise' and 'Goleck' were classified as sensitive. Conversely, the 'Sediek' cultivar had the lowest population estimates and was assessed as having moderate, year-round pest resistance. Mokhtar (2022) reported that the 'Fagri Klan' mango cultivar had the

highest average total population of *Icerya seychellarum* (Westwood) in Egypt. Nonetheless, the 'Skare' and 'Ewaise' cultivars showed high resistance, comparable to the present mealybug research, with no indication of scale insect infestation.

ASSESSMENT OF LEAVES, FLOWERING AND FRUIT QUALITY OF CERTAIN MANGO CULTIVAR

Relative to other mango cultivars tested, the 'Zebda' cultivar's leaves were the most impacted by *F. virgata*. The cultivar showed the lowest values for shoot length, number of shoots, shoot thickness, leaf length, leaf width, and leaf area, and the highest concentrations of nitrogen, phosphorus, magnesium, and iron. In a new approach to integrated pest management, knowledge of potassium, calcium, zinc, manganese, and copper levels in mango leaves may help enhance the leave tolerance to mealybugs. Accordingly, the increased levels of nitrogen, phosphorus, magnesium, and iron in 'Zebda' leaves may be associated with increased *F. virgata* population growth and infestation. With the exception of shoot thickness and leaf index, all examined vegetative growth characteristics and mineral element levels in the evaluated mango cultivars displayed high statistically significant variances (Tab. 1).

The mineral composition of different mango cultivars varies significantly, which influences their vulnerability to mealybugs. According to Xiaowei *et al.* (2018), high K levels have been linked to increased plant vigour and stress tolerance, which can

strengthen resistance to pests such as mealybugs. Sufficient calcium levels may lessen mealybug infestation, as calcium is essential for the integrity of cell walls and overall plant structure (Zhi-Ping *et al.*, 2006). Plant metabolism and enzyme activity depend on zinc (Zn), and Zn deficiency may increase plant susceptibility to pests (Peralta-Antonio *et al.*, 2015). According to Peralta-Antonio *et al.* (2015), copper (Cu) is involved in several physiological processes and can increase plant's resistance to pest infestations. Higher K and Zn contents in the Tommy Atkins cultivar may indicate superior pest resistance compared to other cultivars (Peralta-Antonio *et al.*, 2015).

Two-season data showed that the 'Taimour' mango cultivar trees had higher flowering characteristics, such as panicle length, number of panicles per tree, and number of flowers per panicle than other tested mango cultivars. Furthermore, the 'Zebda' mango cultivar produced fewer ripe fruits, with lower fruit number and lower total fruit weight (kg) per tree than other cultivars.

With respect to fruit physical and chemical characteristics, the 'Taimour' cultivar clearly outperformed the other mango varieties in average fruit weight, volume, and dimensions, as well as total soluble solids, total soluble solids/acidity ratio, and total sugar content. It also showed a lower percentage of total acidity.

However, in contrast to the mango cultivar trees under study, the 'Zebda' mango cultivar, which was highly infested with *F. virgata*, had considerably lower values for all yield and fruit quality traits, except for total acidity. All flowering features, yield,

Table 1. Effect infestation by *Ferrisia virgata* on the vegetative growth and mineral contents on mango cultivar leaves (two-year average)

Parameter		Mean value of parameter for the cultivar						CV
		'Zebda'	'Hindi Bisinnara'	'Goleck'	'Taimour'	'Ewaise'	'Sediek'	
Vegetative growth	shoots length	16.33 B	16.59 B	16.49 B	17.23 A	17.10 A	16.77 AB	1.42
	number of leaves	13.00 B	14.38 A	14.58 A	14.96 A	14.81 A	14.71 A	3.47
	shoot thickness	0.60 A	0.61 A	0.61 A	0.62 A	0.62 A	0.62 A	1.53
	leaf length	22.75 D	23.38 BC	23.19 C	23.82 A	23.72 AB	23.40 BC	0.79
	leaf width	5.01 B	5.13 AB	5.14 A	5.25 A	5.21 A	5.17 A	1.23
	leaf area	78.76 D	82.92 BC	82.44 C	86.43 A	85.50 AB	83.60 BC	1.61
	leaf index	4.54 A	4.56 A	4.51 A	4.54 A	4.55 A	4.53 A	1.21
Macroelements (g.kg ⁻¹)	N	1.88 A	1.82 AB	1.86 A	1.76 C	1.79 BC	1.82 ABC	0.37
	P	0.26 A	0.25 AB	0.25 AB	0.23 C	0.24 B	0.24 B	1.43
	K	0.38 B	0.40 AB	0.40 AB	0.41 A	0.40 AB	0.41 A	1.27
	Ca	1.17 B	1.23 AB	1.23 AB	1.26 A	1.25 A	1.25 A	1.31
	Mg	31.46 A	30.88 C	31.14 B	29.40 F	30.06 E	30.39 D	0.38
Microelements (mg.kg ⁻¹)	Zn	29.40 F	30.39 D	30.06 E	31.46 A	31.14 B	30.88 C	0.42
	Fe	189.62 A	185.25 ABC	187.38 AB	173.25 D	183.83 BC	182.55 C	1.21
	Mn	25.33 C	26.87 B	27.06 AB	27.78 A	27.54 AB	27.38 AB	1.55
	Cu	5.63 E	5.94 D	5.92 D	6.23A	6.14 B	6.03 C	0.41

Explanations: CV = coefficient of variation; means followed by the same letter(s) in each row are not significantly different at the 0.05 level of probability by Tukey's HSD test.

Source: own study.

and fruit quality attributes differed significantly among the cultivars, as shown in Table 2.

Our findings about the physical characteristics of the fruit under investigation are generally consistent with those of Tawfik (1985) for oranges, Bakry (2009) for mango, and Mohamed and Asfoor (2004) for several sweet orange cultivars. All of these

Mg, and Fe). The findings demonstrated a significant inverse relationship between estimations of mealybug abundance and concentrations of plant elements (K, Ca, Zn, Mn, and Cu).

These results suggest that the mealybugs can alter plant nutrient transport, leading to the accumulation of micronutrients in plant tissues. Plants with higher concentrations may be more

Table 2. Effect infestation by *Ferrisia virgata* on the flowering aspects, yields and fruits quality on six mango cultivar trees (two-year average)

Parameter		Mean value of parameters for the cultivar						CV
		'Zebda'	'Hindi Bisinnara'	'Goleck'	'Taimour'	'Ewaise'	'Sedik'	
Flowering aspects	length of panicle	21.24 F	24.15 D	23.22 E	27.78 A	26.75 B	25.02 C	1.59
	number of panicles	91.24 F	97.24 D	93.66 E	113.11 A	109.47 B	101.70 C	1.02
	number of flowers per panicle	501.86 F	574.31 D	546.71 E	679.95 A	641.41 B	599.52 C	1.20
Yield per tree	number of fruits	314.26 F	334.93 D	322.62 E	392.39 A	377.59 B	351.00 C	1.01
	weight of fruits	76.94 F	87.30 D	82.83 E	99.85 A	94.86 B	91.55 C	1.24
Physical characteristics	fruit length	11.21 F	12.31 D	11.72 E	14.75 A	13.57 B	12.90 C	0.61
	fruit width	6.75 F	7.44 D	6.99 E	8.42 A	8.00 B	7.72 C	0.86
	fruit shape	1.66 B	1.65 B	1.68 B	1.75 A	1.70 AB	1.67 B	1.12
	fruit thickness	7.29 F	8.03 D	7.54 E	9.09 A	8.64 B	8.34 C	0.83
	fruit size	237.63 F	287.44 D	257.27 E	390.28 A	340.96 B	312.99 C	1.08
	weight	224.99 E	242.91 A	230.90 D	272.13 A	259.42 B	250.22 C	0.90
Chemical characteristics	TSS	18.51 F	21.59 D	19.55 E	27.87 A	24.49 B	23.09 C	0.75
	acidity	0.27 A	0.20 BC	0.22 AB	0.13 D	0.15 CD	0.17 BCD	1.22
	TSS/acidity ratio	68.49 F	105.67 D	87.33 E	207.17 A	160.01 B	133.20 C	1.84
	total sugars	10.63 F	11.80 D	11.05 E	13.84 A	13.15 B	12.56 C	1.25

Explanations: CV = coefficient of variation, TSS = total soluble solids; means followed by the same letter(s) in each row are not significantly different at the 0.05 level of probability by Tukey's HSD test.

Source: own study.

studies discovered that a number of scale insects reduced fruit weight, size, and dimensions. Regarding fruit chemical traits (TSS%, total acidity%, and total sugar content), the present findings in response to *P. oleae* infestation are broadly consistent with those reported by Bakry (2004) for mango, Mohamed and Asfoor (2004) for Navel and Valencia orange, and Bakry and Abdel-Mageed (2014) for grapes.

RELATIONSHIP BETWEEN THE AMOUNT OF *Ferrisia virgata* AND VEGETATIVE GROWTH, YIELD AND FRUIT QUALITY

The triangular heatmap in Figure 2 presents a correlation matrix defining associations among the different parameters and indicates correlations among variables related to plant growth, nutrient composition, and mealybug infestation. It is noteworthy that the mealybug population estimates had strong negative correlations with all plant morphological parameters, including bud length, leaf number, bud thickness, leaf length, leaf width, leaf area, and leaf index.

The results showed strong positive correlation between mealybug abundance and plant nutrient concentrations (N, P,

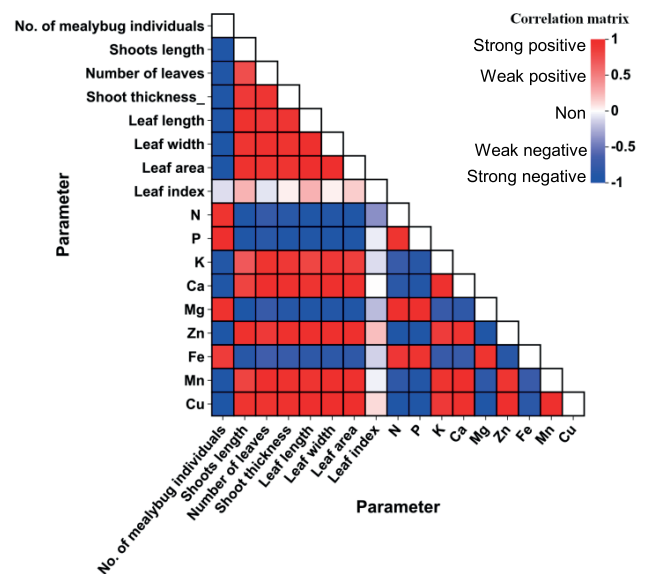


Fig. 2. The correlation matrix between the amount of *Ferrisia virgata* on mango leaves and the vegetative growth properties and mineral element contents of six mango cultivars (two-year averages); source: own study

attractive to mealybugs, and plant defence mechanisms may be effective against mealybugs.

Most plant morphological characteristics have high positive correlations (dark red) with one another. These include shoot length, number of leaves, leaf area, and leaf width, etc. This pattern is expected because, under healthy growth, morphological traits tend to increase together in size and number. Overall, the heatmap provides a comprehensive overview of how mealybug infestation is associated with both plant growth inhibition and significant alterations in the plant's nutrient profile.

The strong positive relationships between major nutrients (N, P, Mg, and Fe) and overall plant growth highlight their importance for plant performance. To fully understand the physiological or environmental mechanisms underlying these patterns, further studies are needed, particularly to explain negative relationships observed with nutrients (K, Ca, Zn, Mn, and Cu).

Interactions among the main nutrients affect root structure and metabolic processes and support physiological activity. Nitrogen, which is necessary for proteins and amino acid synthesis, strongly promotes plant development parameters, including sapling height and leaf length (Xu, Fan and Miller, 2012). Phosphorus is essential for photosynthesis and energy transfer, and its availability is associated with better root structure and more effective nutrient absorption (Singh, Gupta and Singh, 2024). Magnesium, a key component of chlorophyll, is essential for photosynthesis and enzyme activation, thereby supporting the general health of plants (Ågren and Weih, 2020). Iron deficiency can significantly restrict plant development since it is essential for the production of chlorophyll and the transfer of electrons during photosynthesis (Liu and Xu, 2023).

Although beneficial roles of these nutrients are well established, further research is needed to fully understand how they interact negatively with other nutrients, including potassium, calcium, zinc, manganese, and copper. The complexity of nutrient interactions in plant physiology is highlighted by the fact that nutrient imbalances can result in decreased plant health and productivity, making it important to understand these negative relationships (Jun, Shim and Park, 2023).

Figure 3 presents a heat map of the correlation matrix depicting the direction and magnitude of the linear association among mango fruit yield, physical and chemical parameters, and mealybug population estimates.

Nearly all desirable fruit characteristics (length, width, size, weight, TSS, and total sugars) and yield components (number of fruits/tree, weight of fruits/tree, length of panicle, number of panicles, and number of flowers per panicle) showed strong negative correlations with mealybug abundance.

In summary, the mealybug infestation negatively affect fruit growth, quality, and production. The correlations among fruit parameters (length, breadth, thickness, size, weight, TSS, and total sugars) were positive. This is expected, as larger fruits tend to be heavier and often have more sugar content.

These findings are in line with several host plant and insect species. Seni and Chongtham (2013) noted that, because mealybugs create honeydew that encourages sooty mould, infested fruits often show reduced sugar content and overall quality, thus reducing their market value. Viglianco *et al.* (2016) reported that increased mealybug occurrence was associated with declining grape pulp quality indicators, especially when more than 50% of

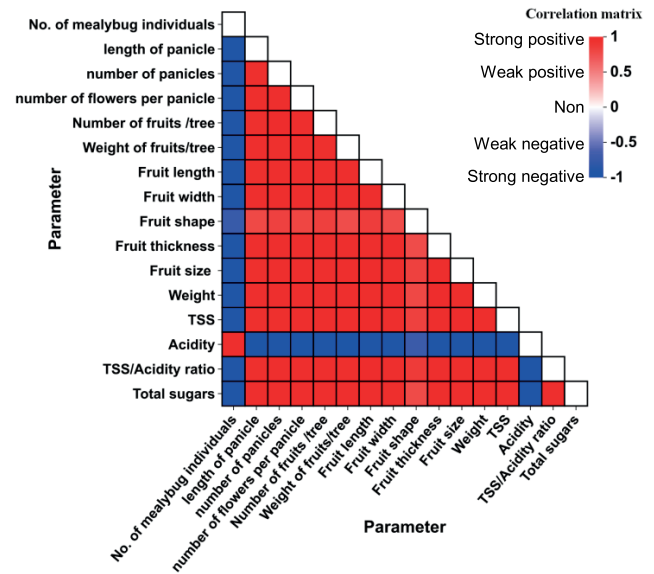


Fig. 3. The correlation matrix between the amount of *F. virgata* on mango leaves and flowering, yield and physical and chemical quality of fruit of six mango cultivars (two-year averages); TSS = total soluble solids; source: own study

clusters were affected. Gomes *et al.* (2022) also showed that mealybugs negatively affect the physical attributes of fruits, as proven by the negative effects on quality indices.

Finally, acidity showed a strong correlation with total soluble solids and total sugars, which is consistent with ripening patterns in fruit, where sugars increase as acidity declines. Studies in mango reveal that increasing sugar content is often accompanied by decreasing acidity, thereby improving the sugar/acid ratio, which is a critical component of flavour perception (Thanaraj and Terry, 2010). Flavour is greatly influenced by the ratio of sugars to acids; in mangoes, higher TSS is correlated with better flavour ratings, and higher sugar content with lower acidity is often preferred (Malundo *et al.*, 1996).

In summary, the heatmap provides a concise and effective depiction of the negative impacts of mealybug populations on fruit quality and plant productivity. The increase in mealybug populations has been shown to be positively correlated with reduced productivity, including fewer flowers, shorter spikes, and less fruit produced per tree. In addition, increased infestation was linked to smaller and less developed fruits, reflected in reduced fruit size and poorer morphology.

Lower TSS/acidity ratio is generally associated with less appealing fruit; higher acidity is typically linked to lower sugar content and reduced palatability. These results provide strong evidence of the economic damage caused by mealybug infestations, which negatively affect agricultural production and marketability.

HEAT MAP BETWEEN *Ferrisia virgata* ESTIMATES AND THE VEGETATIVE GROWTH PROPERTIES AND MINERAL ELEMENT CONTENTS

The heatmap (Fig. 4) visualises the similarity (or dissimilarity measured as Euclidean distance) among different mango cultivars based on a set of 17 measured parameters. These include leaf

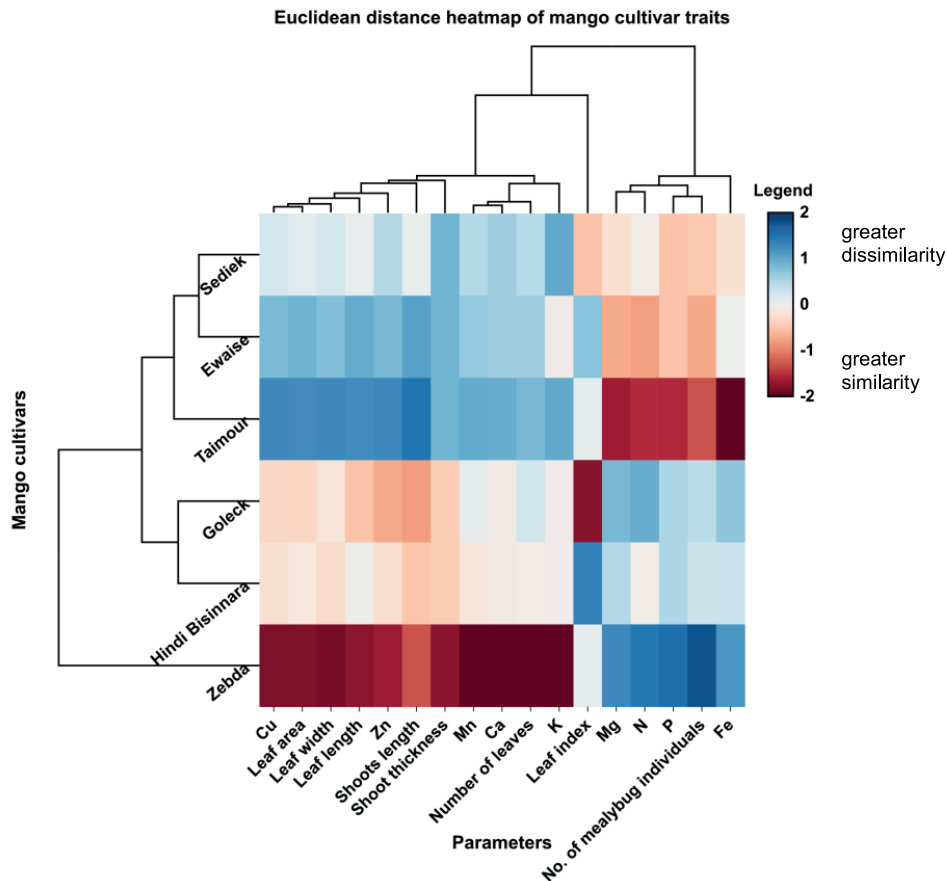


Fig. 4. The heatmap illustrating the similarity matrix of six mango cultivars based on 17 evaluated traits. Unweighted Pair-Group Method with Arithmetic Means (UPGMA) clustering and a Euclidean distance matrix were used. Row and column dendrograms indicate clustering of the cultivars and measured variables, respectively; source: own study

dimensions (area, width, length), shoot characteristics (length, thickness, and number of leaves), leaf index, and mineral content (N, P, K, Ca, Mg, Fe, Zn, Mn, and Cu), and *F. virgata* individual counts. The colour intensity indicates the distance or difference, with darker red representing closer similarity (smaller distance) and darker blue representing greater dissimilarity (larger distance). Hierarchical clustering is shown by the dendrograms on the left (cultivars) and top (traits), which group related cultivars and variables.

The ‘Zebda’ cultivar formed its own “cluster” and did not group with other cultivars, indicating a unique overall trait profile. The ‘Hindi Bisinnara’ cultivar is somewhat similar but it clustered relatively close to the ‘Taimour’ cultivar (Fig. 4).

The parameters were grouped based on how similarly they varied across the cultivars. Group 1 included Cu, leaf area, leaf width, leaf length, Zn, shoot length, and shoot thickness. These variables showed similar patterns across cultivars, and many relate to physical dimensions of leaves and some micronutrient content (Cu, Zn). Group 2 included Mn, Ca, K, number of leaves, and leaf index. This group included other micronutrients and more general indicators of plant growth. Group 3 included Mg, N, P, the number of mealybug individuals, and Fe. Notably, mealybug infestations clustered with the macronutrients, suggesting a potential association between nutrient status and pest susceptibility (Fig. 4).

‘Zebda’ cultivar showed very low Euclidean distances (dark red) for Cu, leaf area, leaf width, leaf length, Zn, shoot length,

shoot thickness, as well as for Mn, Ca, K, number of leaves, and leaf index. This means the ‘Zebda’ cultivar is quite similar to the average or has a consistent profile across these growth and micronutrient parameters. In contrast, ‘Sediek’, ‘Ewaise’, and ‘Taimour’ cultivars generally showed relatively higher Euclidean distances (blue shades) for most traits related to leaf dimensions and micronutrients within the first two parameter groups (Fig. 4).

The ‘Zebda’ cultivar showed blue shading and higher Euclidean distances, especially for Mg, N, P, number of mealybug individuals, and Fe. In contrast, the ‘Taimour’ cultivar showed red shading for Mg, N, P, mealybug abundance, and Fe, implying that the two cultivars differed for these traits (Fig. 4).

Based on their general trait profiles, the mango cultivars may be roughly divided into at least three major groups:

- group 1 included ‘Sediek’, ‘Ewaise’, and ‘Taimour’ cultivars (relatively similar);
- group 2 included ‘Goleck’ and ‘Hindi Bisinnara’ cultivars (intermediate);
- group 3 included the ‘Zebda’ cultivar (distinct and unique profiles) (Fig. 4).

The traits related to physical growth/leaf dimension and some micronutrients (Cu, Zn) appear to vary similarly across cultivars. Each of the macronutrients (Mg, N, P) and susceptibility to mealybug also constituted individual grouping, which again suggested some relationships (Fig. 4).

The ‘Zebda’ cultivar was the most distinctive, particularly in terms of its macronutrient levels (N, P, and Mg) and, most

importantly, its vulnerability to mealybug infestation, as shown by dark blue and extremely high Euclidean distance. Furthermore, the blue shading for these traits suggested that the ‘Taimour’ cultivar differed from the studied cultivars in several physical and nutritional characteristics. As shown in Figure 4, this pattern implies that the cultivar may possess defensive mechanisms or nutritional needs that make it less vulnerable to mealybugs than the other cultivars.

HEATMAP BETWEEN AMOUNT OF *Ferrisia virgata* AND YIELD AND FRUIT QUALITY CHARACTERISTICS (PHYSICAL AND CHEMICAL)

The heatmap (Fig. 5) visualises the similarity (or, in this case, dissimilarity measured as Euclidean distance) among various mango cultivars based on 16 measured traits. The colour scale represents Euclidean distance, with darker red indicating greater similarity (smaller distance) and darker blue indicating greater dissimilarity (larger distance) between each cultivar’s trait values and the mean. The heatmap helps identify cultivars with similar fruit characteristics, how they differ, and how their fruit traits might relate to mealybug presence. The dendrograms on the left

and top illustrate hierarchical clustering, grouping similar cultivars and traits (Fig. 5).

The clustering of the ‘Goleck’ and ‘Zebda’ cultivars indicates that their overall fruit-trait profiles are comparable. However, the ‘Hindi Bisinnara’ and ‘Sediek’ cultivars also form a pair, suggesting that they have traits in common. In contrast, ‘Ewaise’ formed a separate cluster, indicating a different fruit profile. However, the ‘Taimour’ cultivar was the most separated from the others, indicating that its fruit quality traits were quite distinct (Fig. 5).

The fruit traits are grouped based on how similarly they behave across the different cultivars as follows:

- group 1 included fruit thickness, fruit width, weight, total sugars, fruit size, fruit length, TSS, TSS/acidity ratio, length of panicle, weight of fruits/panicle, number of fruits/tree, and number of panicles; this large group comprises most of the physical fruit dimensions, sugar content (TSS, total sugars), and panicle/yield-related parameters these traits tend to vary in a correlated manner among the cultivars;
- group 2 included fruit shape and acidity; these two traits cluster together, suggesting their values are often correlated;
- group 3 included mealybug abundance; this trait stands alone, indicating that its variation across cultivars might be largely

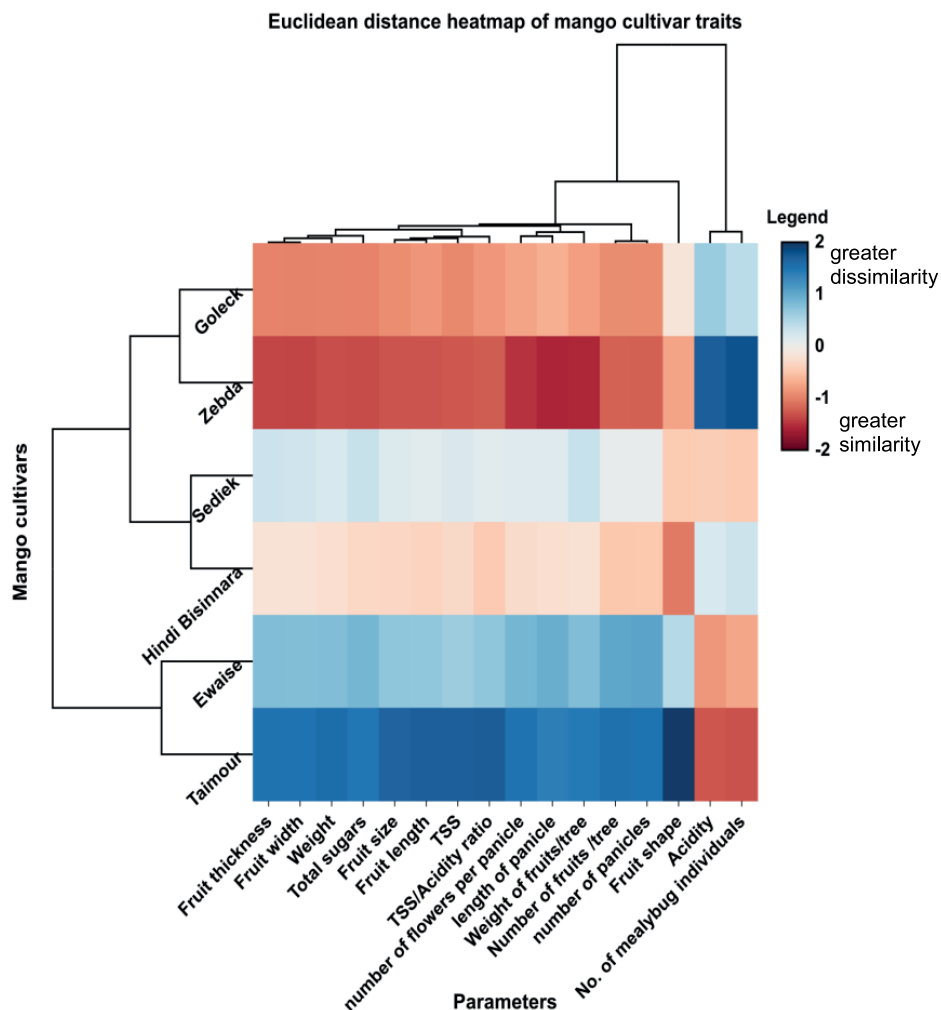


Fig. 5. The heatmap showing the similarity matrix of six mango cultivars based on two-year averages of 16 traits evaluated. Unweighted Pair-Group Method with Arithmetic Mean (UPGMA) clustering and a Euclidean distance matrix were used. Row and column dendrograms show clustering of the cultivars and measured parameters, respectively; source: own study

independent of the main fruit characteristics or that it's a critical differentiating factor.

The fruit traits are grouped based on how similarly they behave across the different cultivars (Fig. 5).

The 'Taimour' cultivar showed high Euclidean distances (dark blue) for most physical fruit characteristics (fruit thickness, fruit width, weight, total sugars, fruit size, fruit length, TSS, TSS/acidity ratio, length of panicle, weight of fruits/panicle, number of fruits/tree, and number of panicles). This suggests that 'Taimour' is very similar to the average or has very consistent values for these traits across whatever dataset this represents. However, this cultivar showed extremely low Euclidean distance (dark red) for acidity and No. of mealybug individuals. This makes 'Taimour' a unique cultivar in terms of both its fruit acidity and its resistance to mealybugs (Fig. 5).

The 'Ewaise' cultivar had a moderate Euclidean distance (bluish shades) for most fruit characteristics in the first cluster of parameters. While a moderately Euclidean distance (reddish) appeared for acidity and No. of mealybug individuals (Fig. 5).

The 'Sediek' and 'Hindi Bisinnara' cultivars showed similar patterns. For most fruit characteristics in the first cluster of parameters, they generally had moderate Euclidean distances (light blue/white and orange) indicating they are somewhat different from the average for these traits. They both show moderate to low Euclidean distance for mealybug abundance, suggesting they are closer to the average in terms of mealybug presence (Fig. 5).

The 'Goleck' and 'Zebda' cultivars also showed similar patterns. They exhibited low Euclidean distance (dark red) for most fruit characteristics in the first cluster of parameters. This suggests they were quite distinct from the other cultivars (and the overall average) in terms of their fruit dimensions, weight, and sugar content. They show high Euclidean distance (blue) for acidity (Fig. 5). It is important to note that both cultivars show a very high Euclidean distance (in blue) for mealybug abundance, indicating that these cultivars may have significantly higher mealybug infestation than other cultivars, similar to 'Taimour', but different in their fruit characteristics (Fig. 5).

Several studies have examined differences among Egyptian mango cultivars with regard to vegetative growth, nutrient uptake, yield, and yield components. Comparisons between 'Goleck' and 'Zebda' indicate that, although both are well-suited to arid and semi-arid conditions, they differ significantly in growth vigour, leaf mineral uptake, and adaptation to environmental stresses such as salinity and nutrient management (Rashedy and AbdAllatif, 2017). Under controlled conditions, 'Goleck' usually manifests more vigorous vegetative growth, whereas 'Zebda' is more resilient in calcareous soils and possesses enhanced potassium uptake, displaying the highest growth attribute values, dry matter yields, and nutrient uptake efficiency (Zagzog, Melouk and Metwally, 2010). However, both cultivars have been reported to face micronutrient deficiencies, highlighting the need for strategic fertilisation. Vegetative growth has been described as strongest in 'Goleck'. 'Taimour' has been reported to form a compact, structurally sound canopy, which may contribute to pest resistance. 'Hindi Bisinnara' and 'Zebda' have been described as having thick leaves, but due to their profuse growth, which drew pests, they may be more susceptible to infestation (Yassen, 1998; Khalil, Hamad and Oraby, 2017). Said (2001) reported that 'Goleck' and 'Zebda'

reacted positively to calcium and potassium, whereas 'Ewaise' performed well under restricted nutrition regimens. The mineral content of 'Taimour' leaves has been reported to remain stable despite pest pressure.

Regarding yield and fruit quality traits, Said (2001) reported that 'Taimour' generated heavier fruits and the longest panicles, resulting in fewer fruits per tree, whereas 'Zebda' produced more fruits. However, the highest yield was reported for 'Hindi Bisinnara'. Galal, Galal and Aboulila (2017) noted that the 'Ewaise' and 'Zebda' cultivars exhibited consistent fruit set and early flowering.

CONCLUSIONS

The results showed the presence of *Ferrisia virgata* populations throughout the year on all six mango cultivars. The resistance of mango cultivars to *F. virgata* varied significantly. The 'Zebda' cultivar was the most affected and showed the poorest vegetative growth, with the lowest K, Ca, Zn, Mn, and Cu contents, as well as the lowest values for flowering, yield, and physicochemical characteristics of fruit, except for acidity, compared to the other mango cultivars. In contrast, the highest content of nitrogen, phosphorus, magnesium, and iron was observed in 'Zebda' leaves, and these minerals may contribute to the increased incidence of mealybugs in this cultivar. Unlike other mango cultivars, 'Taimour' had the lowest *F. virgata* count, highest vegetative growth, highest estimated potassium, calcium, zinc, manganese, and copper contents, highest flowering, fruit yield, and chemical quality, and lower fruit acidity compared to other mango cultivars tested. However, the leaf potassium, calcium, zinc, manganese, and copper concentrations may contribute to protecting 'Taimour' leaves from pest infestation. Overall, heatmaps strongly indicate that mealybug infestation is an important limiting factor for the productivity of these. Therefore, selecting mealybug-resistant cultivars such as 'Taimour' is a key measure to improve mango yield and fruit quality, given their superior growth and nutrient values.

Collectively, these data provide detailed insight into mango cultivars and the complex relationships among different vegetative growth, yield, and fruit quality traits, and how these traits relate to on susceptibility to pest susceptibility. The clustering identifies groups of cultivars with similar profiles, while the correlation matrices show weak and strong associations among traits. Together, these results provide a basis for understanding pest resistance and offer valuable information to support cultivar selection and breeding programmes.

CONFLICT OF INTERESTS

All authors declare that they have no conflict of interest.

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