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(Original Article)

Relationship Between the *Fiorinia phoenicis* Counts and Biochemical Traits and Nutritional Status of Certain Date Palm Cultivar leaflets

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Abstract

The investigation assessed the relationships between the biochemical characteristics and nutritional status of six date palm cultivars and the damage rates caused by *Fiorinia phoenicis* (Hemiptera: Diaspididae). *F. phoenicis* populations were present on all date palm cultivars throughout the year. Comparing the leaflets of the 'Bartamoda' cultivar with other tested date palm cultivars, the 'Bartamoda' cultivar recorded the highest pest infestation rate and the highest estimates of leaflet-specific weight, moisture content, one-hour drying weight, fat content, crude protein, carbohydrates, and feed quality index. In contrast to other tested varieties, date palm leaflets of the “Balady” (local) cultivar recorded the highest scores in the following assessments: leaflet area, specific leaflet area, chlorophyll a, b, carotenoids, dry matter, moisture loss, wax content, tannins, and phenols.

Using Euclidean distance and the unweighted paired group technique with arithmetic average (UPGMA), a heat map and hierarchical clustering of 19 evaluated features on six date palm cultivars over two-year averages were carried out. With the use of the similarity coefficient matrix data, a dendrogram was created. Date palm cultivars were divided into two major groups using the heat map. Three date palm cultivars, one strongly linked and the other weakly associated, were grouped in each group. For every index system, each group was further subdivided into subgroups.

In an unconventional integrated pest management method for *F. phoenicis* control, knowing the amounts of wax, tannins, and phenols in date palm cultivars' leaves may assist in forecasting the date palms' resistance to *F. phoenicis* populations.

Keywords: *Biochemical traits, Date palm cultivars, Fiorinia phoenicis, Nutritional status.*

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Introduction

The date palm, also known as *Phoenix dactylifera* L. (Arecaceae Family), has a tremendous economic impact. It is regarded as a symbol of Egyptian desert life and plays a vital role in the social and economic lives of the populace (Salem *et al*., 2020). The date palm is among the oldest fruit plants in arid and semi-arid areas (Krueger, 2021). Due to their high concentration of vital nutrients, dates offer nutritional security to millions of people in dry regions of the world. They are also essential for good nutrition (Chao and Krueger, 2007). Date palms are one of the most important horticultural items that orchards may use to augment their revenue, regardless of whether they are grown commercially (Salman *et al*., 2012a). Palm trees are the foundation of the local economy when exporting to significant international trade hubs (Rathore *et al*., 2020). According to Alaoui and Joutei (2024), date palm plants are susceptible to infection by several insect pests.

A major pest of date palm plants is the Fiorinia date scale (FDS), known as *Fiorinia phoenicis* Balachowsky (Hemiptera: Diaspididae) (Bakry and Tolba, 2025). Field investigations revealed that the pinnae of older date palm fronds (lower fronds) were more heavily infested with *F. phoenicis* than the fresher ones. In addition to occasionally infecting the dates, FDS mostly targets the fronds of date palms (Elwan *et al.,* 2011). When the crawlers infest the date bunches during the ripening season and produce thick crusts, the dates are no longer acceptable for human consumption. Youssef *et al.* (2015) stated that the severe infestation had a major effect on the growth of the date palm, especially on the offshoots, which produced yellowish pinnae and dry fronds. This insect uses its mouthparts to drain plant sap, destroying palm tree leaves, fronds, and fruits because of its poisonous saliva (Radwan, 2012). Crop yield is lowered as a result of frond mortality, leaf fall, and deformities (Elwan, 2000). Respiration and photosynthesis are decreased, and damaged palm leaves change form, become yellow, and fall off (Moussa *et al.,* 2012). The presence and accumulation of date palm scales on date palm leaves is the primary feature of date palm scale infestations, according to El-Sherif *et al.* (2001). Farmers think it is difficult to control after it has spread across the orchard (Elwan *et al.,* 2011).

Insects have the potential to provide biotic stress to their host plants. In response to insect attacks, plants alter their physical makeup and release secondary metabolites (Jan *et al.,* 2021).

Therefore, controlling pest numbers below the point of economic harm would be possible without increasing pollution or producer costs. Understanding the characteristics that encourage or prevent insects from selecting host plants is essential for identifying low-susceptibility cultivars.

Insect populations thrive on leaflets with a proper nutritional balance, and herbivores need nutritive elements from their diet. Herbivores require nutritive components from their diet, whereas insect populations flourish on leaflets with an appropriate nutritional balance. It is often believed that proteins and carbohydrates are the major arrestants (chemicals that act as an efficient phagostimulant and prolong the pest's eating) for insects of distinct species (Chapman, 2003).

Date palm plants respond differently to an insect epidemic depending on their morphological characteristics or the chemical makeup of their leaves. While physical characteristics significantly influence the pest's feeding, activity, and ingestion strategies, biochemical aspects significantly influence the pest's behavior and metabolic processes. Depending on their morphology or the chemical makeup of their leaves, date palm plants react differently to insect infestations. According to Karar *et al*. (2015), morphological traits have a substantial impact on the pest's feeding, activity, and ingesting habits, whereas biochemical parameters have a major impact on the pest's behavior and metabolic processes.

For insects, proteins are the primary source of amino acids and nitrogen, whereas carbohydrates are their primary energy source (Jain *et al.*, 2002).

The intentional adoption of resistant crop cultivars, either alone or in conjunction with other IPM components, is necessary for an IPM approach to lessen the detrimental impacts of insects on date palm yield or quality (Jindal *et al.*, 2013).

Plant resistance to insect pests is the development of a resistance-associated characteristic by a plant that occurs concurrently with one or more aspects of the interaction between an insect pest and a target plant (Stout, 2014).

Different palm cultivars' responses to pest infestation are influenced by genetic diversity as well as the mineral and nutritional composition of the soil. Cultivars of plants resistant to insects are advised for integrated pest management, which lessens the harm that infestations cause (Bakry and Abdel-Baky, 2020). Finding cultivars with minimal susceptibility requires an understanding of insect traits (Salem *et al.,* 2006).

Resistant cultivars may be used in integrated pest management techniques to determine the optimal date palm cultivar for *F. phoenicis* control. According to Horgan *et al.* (2020), resistance is an essential trait that enables a plant to prevent the spread of insects or to recover from the harm inflicted by populations that were not prevented from surviving. The authors are aware of very little data about the impact of varying *F. phoenicis* infestation rates on the nutritional quality and biochemical characteristics of certain date palm cultivar leaflets. Due to the favorable growing circumstances and the lack of reports of comparable studies, the majority of dry date palm cultivars are cultivated in the Aswan region, especially in Kom Omboo province. Thus, this study aimed to assess the link between the nutritional quality and some biochemical characteristics of specific date palm cultivar leaflets and the population density of *F. phoenicis* over the two consecutive seasons of 2022–2023 and 2023–2024.

Materials and Methods

1. Population ecology

a. Abundance of the fiorinia date scale (FDS), *F. phoenicis*, on date palm trees

Field assessments of certain date palm cultivars were carried out in 2022–2023 and 2023–2024 at a private date palm plantation in the El-Bayyarah zone, Kom Ombo area, Aswan governorate, southern Egypt. The plantation is situated along the Nile River at 24º30'55" N, 32º57'15" E. The plantation is around 24,000 square meters in size. The six mature female date palm tree cultivars—Bartamoda, Shamia, Gendeila, Balady, Malakaby, and Sakkoty—that had the highest economic value in the Kom Ombo area of Aswan were selected for this study. Before and throughout the trial period, no pest management methods were applied to the date palm trees that were chosen at random. Two biological factors are used in this study: the occurrence of *F. phoenicis* and the proportion of damaged palm leaflets.

The population abundance of *F. phoenicis* is the first requirement. Each cultivar of date palm has five trees. The trees that were chosen at random all exhibited normal growth and were the same age (10 years). The horticultural methods used on these plants were comparable. Samples were gathered every six weeks. There are 200 leaflets in each cultivar, with 40 leaflets per tree. 28,800 leaflets (i.e., six cultivars × five trees × 40 leaflets × 24 sampling days) were sampled during the two years, for a total of 57,600 leaflets. To examine the date palm leaflets under a stereomicroscope, samples were taken at random from each section and stratum of the tree, put in paper bags, and transported to the laboratory. Individuals of *F. phoenicis* were carefully counted and recorded on the palm leaflet surfaces according to the inspection day.

b. The proportion of damaged leaflets is the second criterion

This criterion, which is the proportion of damaged leaflets at each test date over the research years, was used by direct visual assessment of palm leaflet samples. This was calculated by multiplying by 100 and dividing the average number of leaflets damaged by the total number of leaflets inspected (Bakry and Abdel-Baky, 2023). To create statistical analysis and visualizations, the data was categorized using a Microsoft Excel. The collected data were subjected to analysis of variance using SPSS software (1999), and means were compared at a significance threshold of 5% using Tukey's HSD test.

2. Six date palm cultivar leaflets' biochemical characteristics and nutritional circumstances

To ascertain the relationships between the parameters that were checked and the infestation rates by *F. phoenicis*, the following biochemical and nutritional status assessments of certain date palm cultivar leaflets were documented. Ten leaves from five trees of each cultivar were collected. As uniformly as feasible, these trees were infested with this insect and were almost identical in terms of age (10 years), size, shape, height, vigor, and infection. Every year in early February, samples of leaflets from middle-aged (2-year-old) leaves were picked at random from every section of the tree and stored in the field under normal circumstances. Younger leaves are more efficient and highly productive, and they also have more chlorophyll, which maximizes the storage of most nutrients.

Determining the pigment and measuring the leaves

A leaflet area meter was used to measure the leaflet area (m^2), which was then computed using the formula published by Ahmed and Morsy (1999).

Length × width + 10.29 = 0.37 (cm^2) is the leaflet area.

The leaflet area multiplied by the number of leaflets per leaf yielded the area for the entire leaf (m^2).

Plant pigments, as described by Lichtenthaler and Wellburn (1983), one square inch of longitudinal slices of fresh leaflets was used to extract the chlorophyll a, b, and total carotenoids in 85% acetone. Measurements of carotenoids, chlorophyll a, and b were made using an English double-beam spectrophotometer CECIL (CE 7400) at wavelengths of 470, 646, and 663 nm, respectively.

The following formulas were used to determine the levels of carotenoids, chlorophyll a, and b:

$$\text{Chl. a} = 12.21\ A_{663} - 2.81\ A_{646}.$$

$$\text{Chl. b} = 20.131\ A_{646} - 5.03\ A_{663}.$$

$$\text{Total carotenoids} = (1000 \times A_{470} - 3.27\ \text{chl. a} - 104\ \text{chl. b})/198.$$

Biochemical characteristics

To get rid of dust and other impurities, new samples of date palm cultivar leaflets were selected and cleaned first with tap water and then with distilled water. These samples were then dried for 48 hours at 70ºC in an electric oven. All studied date palm cultivars' fresh weight, dry weight, and weight after one hour of air drying were noted for the date palm leaflets (Cardoso *et al*., 2024).

Specific leaflet area (SLA)

The proportion of leaf area to dry weight is known as specific leaf area, or SLA. One of the most commonly utilized keys for leaf features in the study of leaf qualities is specific leaf area.

SLA (cm^2/g) is equal to leaflet area (cm^2) divided by leaflet dry weight (g).

Specific leaflet weight (SLW)

SLW is a measure of photosynthetic velocity and leaf toughness. Leaflet dry weight (g) divided by leaflet area (cm^2) equals SLW (g/cm^2).

The proportion of moisture and dry matter in leaflets from date palms

The amount of water in the leaf component is reflected in its moisture content. Because the moisture content has an impact on the leaflets' weight but has no nutritional benefit. However, contents that remain after water is removed are referred to as dry matter.

$$\text{Moisture (\%)} = (\text{Fresh weight - Dry weight / Fresh weight}) \times 100$$

$$\text{Dry matter (\%)} = (\text{Average dry weight /Average fresh weight}) \times 100$$

The reduction in moisture proportion in the leaf was registered (According to Brainerd and Fuchigami (1981):

$$\text{Loss in moisture (\%)} = \frac{\text{Fresh weight - Dry weight after 1 hour in air}}{\text{Fresh weight} - \text{Dry weight}} \times 100$$

Wax content in leaflet

A thick cuticle, a waxy outer coating of lipid material that prevents water loss and acts as a barrier against some insects, is how plants defend themselves (Taiz and Zeiger, 1998). The outermost fresh, leaflets of comparable age were removed and rinsed in chloroform for 15 seconds to quantify the epicuticular waxes (Schuck, 1976). To determine the wax content (g/g) of the leaflet, chloroform extracts were filtered.

Nutritional status of date palm leaflets

Based on dry weight, the percentages of carbohydrates, crude protein, lipids, and tannins in the date palm ' leaflets were calculated.

According to Jones (2001), the amount of nitrogen (N) in mango leaves was measured on a dry weight basis. The dried material was placed in a tiny paper bag for examination after being processed in an electric mill. Using H_2SO_4, plant materials were broken down. According to Ni *et al*., (2001), semi-micro Kjeldahl techniques were used to assess nitrogen concentration.

On a dry weight basis, the percentage of crude protein in the leaflets was calculated using the Winkleman *et al*. (1986) method:

$$\text{Crude Protein (\%)} = \text{Nitrogen percent} \times 6.25$$

Carbohydrates

The anthrone reagent was used to measure the total soluble carbohydrates according to Association of Official Agricultural Chemists (A.O.A.C.) (2000).

Tannins

Association of Official Agricultural Chemists (A.O.A.C.) (2000) was used to determine total condensed tannins (TCT).

Food quality index estimation

According to Habemann (2000), a food quality index (FQI) was computed by dividing the total of the concentrations of protein (B) and soluble carbohydrates (A) by the condensed tannin content (C).

$$(\text{FQI}) = (\text{A+B}) \;/\; \text{C}$$

Total phenols soluble

In order to estimate the total soluble phenols, Vucane *et al*. (2024) used the colorimetric technique of analysis to extract fresh leaflets.

Fats Extraction

The total of the fats obtained from the extracts were determined using the ratio of 2:1 chloroform:methanol, shaking for 2 hours, filtering, and repeating five times (De Caterina and Massaro, 2005).

For chemical study, all leaflet samples were sent to the Agricultural Research Center of the Ministry of Agriculture in Giza's Central Laboratory.

The correlation between the biochemical traits and nutritional status of certain date palm cultivar leaflets and *F. phoenicis* estimations and percentages of damaged leaflets

F. phoenicis estimates and percentages of damaged leaflets are correlated with the nutritional status and biochemical characteristics of certain date palm cultivar leaflets.

Pearson's correlation coefficient and basic regression models applied with SPSS (1999), were used to assess the relationship between the average number of *F. phoenicis* individuals per leaflet/year and the percentages of damaged leaflets of each date palm cultivar and the nutritional status and biochemical characteristics of specific date palm cultivar leaflets. Microsoft Excel 2007 was used to calculate, visualize, and display all collected data. They used the R tool to plot Pearson's simple correlation values between various parameters (R Core Team 2023).

Heat map and hierarchical clustering for evaluated traits on six date palm cultivars over the average of both studied years:

Applying the studied parameters, the unweighted paired group method with arithmetic average (UPGMA) was used to do the hierarchical clustering analysis (HCA) using Euclidean distance.

Statistical analysis

Using R software and the average of two years' worth of biochemical characteristics and nutritional status tests, a dendrogram based on a similarity coefficient was created for six date palm cultivars (R Core Team 2023).

Results

1. **Occurrence of *F. phoenicis* on six date palm cultivars**

***F. phoenicis* estimations**

Individuals of *F. phoenicis* were found on every date palm cultivar during the two years, as illustrated in Fig. 1. The Bartamoda cultivar had the greatest mean number of *F. phoenicis* counts per leaflet throughout the two-year average (77.29 ± 3.81 individuals per leaflet). However, the cultivar that got the fewest *F. phoenicis* was Balady, which averaged 28.49 ± 1.23 insects per leaflet. However, as shown by the results in Fig. 1, the date palm cultivars Gendeila, Shamia, Malakaby, and Sakkoty experienced moderate infestation, with mean numbers of 65.33 ± 3.22, 53.65 ± 3.52, 44.89 ± 2.6, and 36.27 ± 1.85 individuals per leaflet, respectively.

Based on the average *F. phoenicis* estimates per leaflet throughout the two study years, the evaluated varieties are ranked in ascending order as follows:

Balady < Sakkoty < Malakaby < Shamia < Gendeila < Bartamoda

Significant differences between date palm cultivars were found by statistical analysis of the data concerning the two-year average of the general average of *F. phoenicis* individuals, as illustrated in Fig. 2. The F value = 1262.18, df = 429, P ≤ 0.0000, and the coefficient of variation value = 9.87% between the cultivars in the two-year average.

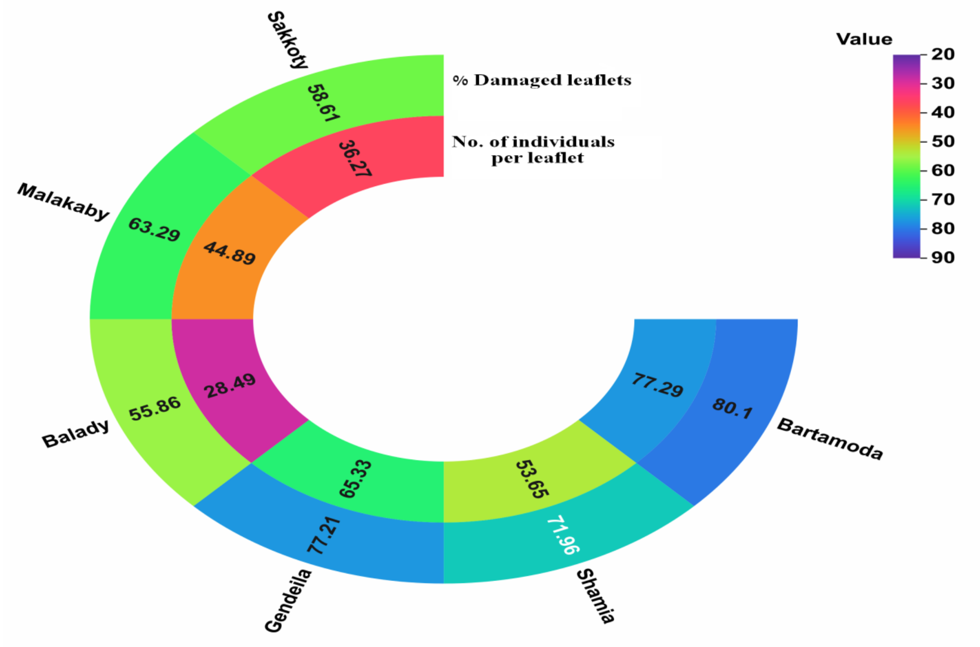

Fig. 1. General averages of *F. phoenicis* count per leaflet and the percentages of damaged palm leaflets of certain date palm cultivars based on two-year averages.

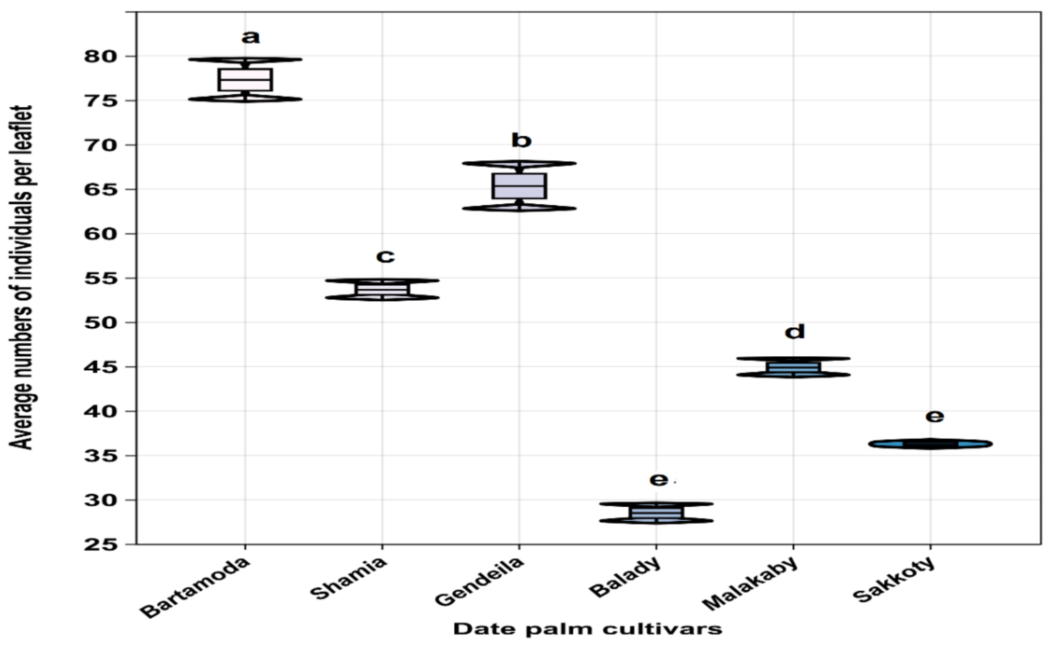

Fig. 2. Violin plot displaying the average numbers of *F. phoenicis* individuals per leaflet on six date palm cultivars during the two-year average. Different lowercase letters indicate significant difference among the tested date palm cultivars (ANOVA, Tukey's Honestly Significant Difference Test, P ≤ 0.05).

Percentage of damaged palm leaflets

Over a two-year average, the percentages of palm leaflets damaged by *F. phoenicis* were noted on all date palm cultivars that were studied. The Bartamoda cultivar had the greatest proportion of damaged palm leaflets by *F. phoenicis* during the two-year average (80.10 ± 1.90%). However, with an average of 55.86 ± 1.46%, the Balady cultivar had the lowest proportion of damaged palm leaflets. According to the findings in Fig. 1, the date palm cultivars Gendeila, Shamia, Malakaby, and Sakkoty experienced moderate infestation, with mean percentages of 77.21 ± 2.07, 71.96 ± 1.41, 63.29 ± 1.47, and 58.61 ± 1.46%, respectively.

Based on the average infestation throughout the two study years, the evaluated cultivars are ranked in ascending order as follows:

Balady < Sakkoty < Malakaby < Shamia < Gendeila < Bartamoda

The average proportion of damaged palm leaflets for the two years varied significantly between palm cultivars, according to statistical analysis of the data, as illustrated in Fig. (3). The F value = 575.255, df = 429, P ≤ 0.0000, and the coefficient of variation value = 6.05% between the cultivars in the two-year average.

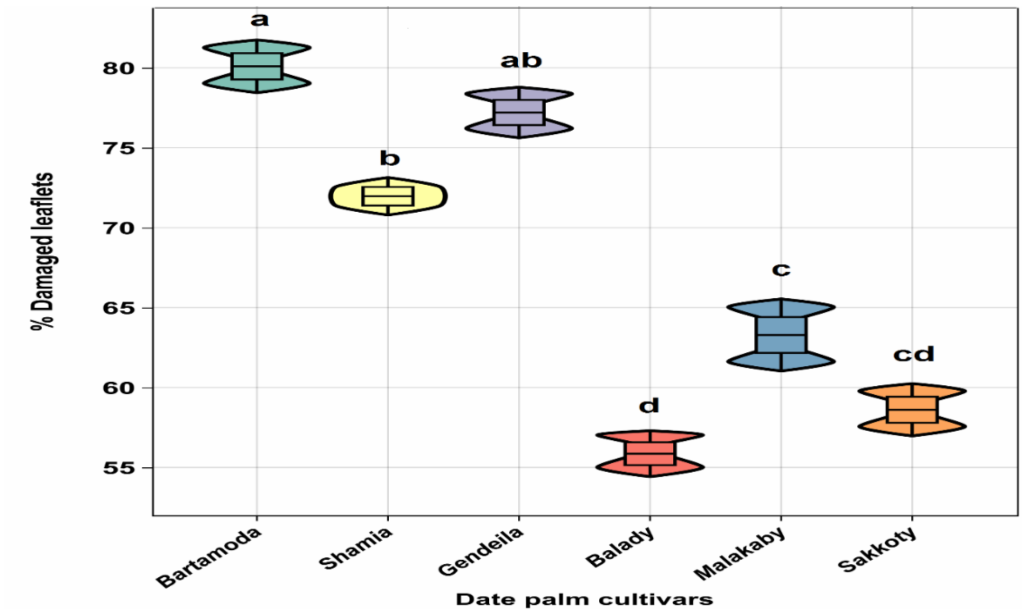

Fig. 3. Violin plot displaying the average rates of damaged date palm leaflets for six date palm cultivars throughout the two-year average. Different lowercase letters indicate significant difference among the tested date palm cultivars.

2. Evaluation of the biochemical characteristics and nutritional value of the leaflets of certain date palm cultivars

The data presented in Table 1 demonstrated that, in comparison to the other tested palm varieties, the Bartamoda date palm leaflets had the highest count and damage to the leaflets caused by the pest. They also had the highest measurements of leaflet-specific weight, moisture content, weight after an hour of drying, fat content, crude protein, carbohydrates, and food quality index. On the other hand, when compared to the other palm cultivars that were tested, the leaflets of the Balady (local) date palm had the highest estimates of leaflet area, specific leaflet area, chlorophyll a, b, carotenoids, dry matter, moisture loss, wax content, tannins, and phenolics, as well as the lowest number and leaflet damage caused by *F. phoenicis*.

Given this, the leaflets of the Balady date palm may have a higher concentration of wax, tannins, and phenolics, which might contribute to the defensive mechanism against *F. phoenicis* and decrease infestation. Moreover, the higher fat, crude protein, and carbohydrate content of the Bartamouda date palm's leaves might contribute to the proliferation of *F. phoenicis* populations and a rise in infestation. As shown in Table 1, all investigated metrics across the various date palm cultivars showed very statistically significant variances.

3. **The relationship between *F. phoenicis* estimates and percentages of damaged leaflets and the biochemical characteristics and nutritional quality of certain date palm cultivar leaflets**

The quantity of individuals of *F. phoenicis*

The data shown in Table (2), indicate that the average number of *F. phoenicis* per leaflet was negatively correlated with the leaflet characteristics, such as leaflet area, specific leaflet area, and pigment measurements, such as carotenoids, chlorophyll a, and Over the two-year average, the comparable r-values were -0.97, -0.98, -0.92, -0.90, and -0.91, respectively.

However, the relationship between the specific weight of leaflets and the average number of *F. phoenicis* individuals per leaflet was highly statistically significant and positively correlated (r-value reached 0.99) on average over the two years, as shown in Table (2).

According to the data in Table (2), the relationship between the chemical measurements (i.e., moisture content, weight after an hour, and fat content) and the average number of *F. phoenicis* individuals per leaflet was highly statistically significant and positively correlated (r-value reached 0.97, 0.98, and 0.91, respectively) over the two-year average.

However, as indicated in Table (2), there was a highly significant and negative correlation between the dry matter, percentage of moisture lost, wax content of date palm leaflets, and the average number of *F. phoenicis* individuals per leaflet (r-value reached -0.97, -0.94, and -0.99, respectively, on the average of the two years).

Furthermore, Table (2) show that the average number of *F. phoenicis* individuals per date palm leaflet and the nutrients (i.e., crude protein and carbohydrates) and food quality index of the leaflets were highly statistically significant and positively correlated (r-value reached 0.97, 0.99, and 0.98, respectively, on the average of the two years).

The nutritional inhibitors (tannins and phenolics) of date palm leaflets, which are (-0.93 and -0.95), respectively, on average throughout the two years, have highly significant negative associations with the *F. phoenicis* estimates, as seen in Table (2).

Table 1. Effect of infestation by *F. phoenicis* (Hemiptera: Diaspididae) on leaflet parameters, pigments, chemical properties, leaflet quality, essential nutrients and their inhibitors in leaflets of some date palm cultivars, over the two-year average.

Measurements	Cultivars	Means of parameters						
		Bartamoda	Shamia	Gendeila	Balady	Malakaby	Sakkoty	C.V.%
Leaf measurements and pigments	Leaflet area	28.36 d	40.59 bc	35.91 cd	51.88 a	42.44 bc	48.22 ab	10.51
	SLA	19.27 c	26.71 ab	24.16 bc	31.32 a	27.38 ab	29.58 a	9.23
	SLW	0.05 a	0.04 ab	0.04 ab	0.03 b	0.04 ab	0.03 b	9.73
	Chl a	1.12 b	1.16 b	1.15 b	1.70 a	1.30 ab	1.46 ab	17.92
	Chl b	0.70 b	0.76 b	0.70 b	1.11 a	0.78 b	0.90 ab	19.49
	Caro	0.48 b	0.53 b	0.50 b	0.84 a	0.58 b	0.64 ab	17.20
Chemical measurements	Moisture	60.10 a	56.12c	58.08 b	48.95 f	53.91 d	51.20 e	1.24
	Dry matter	39.90 f	43.88 d	41.92 e	51.05 a	46.09 c	48.80 b	1.53
	Weight after hour(g)	3.42 a	3.21 bc	3.27 b	3.00 d	3.11 cd	3.10 cd	2.57
	% Lost moisture	12.16 c	12.94 bc	13.46 bc	15.52 a	14.14 ab	13.86 abc	6.89
	Fats	3.09 a	3.05 a	3.05 a	2.93 b	3.02 a	3.02 a	1.33
	Wax content	0.02 a	0.02 a	0.02 a	0.02 a	0.02 a	0.02 a	5.76
Nutrients	Crude protein	8.04 a	7.73 ab	7.88 a	7.40 bc	7.33 c	7.17 c	2.57
	Carbohydrates	8.00 a	7.38 ab	7.73 ab	7.00 b	7.37 ab	7.10 b	5.03
Inhibitors	Tannins	1.26 c	1.33 c	1.26 c	1.53 a	1.42 b	1.59 a	2.09
	Phenolics	1.20 c	1.47 b	1.21 c	1.57 a	1.54 a	1.56 a	2.36
Food quality index		12.77 a	11.39 ab	12.39 a	9.41 c	10.35 bc	8.99 c	6.85

Explanations: *C.V.*= coefficient of variation. Different lowercase letters in each row indicate significant difference among the tested date palm cultivars (ANOVA, Tukey's Honestly Significant Difference Test, $P \leq 0.05$).

Table 2. Simple correlation, regression coefficients, and explained variance estimates between the *F. phoenicis* counts per leaflet and the percentages of damaged palm leaflets and the biochemical traits and nutritional status of certain date palm cultivar leaflets based on two-year averages.

Measurements	Parameters	Average number of insects per leaflet						% Damaged leaflets					
		r	b	S.E	T-test value	E.V.%	P	r	b	S.E	T-test value	E.V.%	P
Leaflet measurements and pigments	Leaflet area	-0.97	-1.82	0.21	8.63	94.91	0.00	-0.96	-0.98	0.15	6.45	91.24	0.00
	SLA	-0.98	-3.38	0.32	10.53	96.51	0.00	-0.96	-1.81	0.28	6.60	91.58	0.00
	SLW	0.99	2265.36	460.8	4.87	97.50	0.00	0.95	1194.73	310.34	3.81	89.50	0.00
	Chl a	-0.92	-73.42	16.00	4.57	84.55	0.01	-0.95	-41.75	6.94	5.97	90.22	0.00
	Chl b	-0.90	-105.25	24.28	4.33	81.63	0.01	-0.92	-58.69	12.65	4.63	83.76	0.000
	Caro	-0.91	-130.35	28.78	4.56	83.25	0.01	-0.91	-71.91	15.92	4.53	83.63	0.01
Chemical measurements	Moisture	0.97	4.72	0.59	7.97	94.12	0.00	0.98	2.62	0.28	9.47	95.76	0.00
	Dry matter	-0.97	-4.72	0.59	7.97	94.12	0.00	-0.98	-2.62	0.28	9.47	95.76	0.00
	Weight after hour(g)	0.98	119.78	10.44	11.50	96.97	0.00	0.99	66.04	5.63	11.74	97.28	0.00
	% Lost moisture	-0.94	-17.68	3.27	5.42	87.93	0.00	-0.90	-9.38	2.23	4.21	81.58	0.01
	Fats	0.91	266.70	60.03	4.41	83.00	0.01	0.88	141.21	38.95	3.59	76.79	0.02
	Wax content	-0.99	-12877.99	1669.2	7.15	98.52	0.00	-0.99	-7082.95	918.08	7.16	98.36	0.00
Nutrients	Crude protein	0.97	50.01	6.48	7.68	93.54	0.00	0.96	27.26	4.04	6.73	91.70	0.00
	Carbohydrates	0.99	44.03	3.75	11.74	97.10	0.00	0.95	23.36	3.83	6.10	90.22	0.00
Inhibitors	Tannins	-0.93	-115.94	22.42	5.13	86.49	0.00	-0.96	-66.03	9.05	7.24	92.59	0.00
	Phenolics	-0.95	-98.05	15.77	6.15	90.88	0.00	-0.94	-53.17	9.89	5.31	88.20	0.00
Food quality index		0.98	10.99	1.20	9.12	95.42	0.00	0.99	6.11	0.50	12.32	97.44	0.00

r = Simple correlation; *b* = Simple regression; S.E. = Standard error; E.V% = Explained variance; Highly significant at $P \leq 0.01$; Significant at $P \leq 0.05$.

The damaged leaves' percentage

According to the information shown in Table (2), the percentage of leaves damaged by *F. phoenicis* was negatively correlated with the leaflet characteristics (leaflet area and specific leaflet area) and pigment estimations (carotenoids, chlorophyll a, and b). Over the two-year average, the corresponding r values are -0.96, -0.96, -0.95, 0.92, and -0.91, in that order.

The most noticeable sign of plant damage on date palm leaflets following *F. phoenicis* feeding is chlorosis, which is a sign of chlorophyll loss. The considerable decrease in the amounts of carotenoids and chlorophyll a and b found in the infected date palm leaflets may counteract.

However, as Table (2) demonstrate, there was a highly statistically significant and positive correlation (r-value reached 0.95) between the specific weight of leaflets and the proportion of leaves damaged by *F. phoenicis* on average during the two years.

The chemical measurements—moisture content, weight after an hour, fat content, and the percentage of leaves damaged by *F. phoenicis*—were highly statistically significant and positively correlated (r-values reached 0.98, 0.99, and 0.88, respectively) throughout the two-year average, as shown by the data in Table (2).

However, as Table (2) demonstrate, the relation between the percentage of damaged leaves by *F. phoenicis*, the dry matter, the percentage of moisture lost, and the wax content of date palm leaflets was highly statistically significant and negatively correlated (r-value reached -0.98, -0.90, and -0.99, respectively) on average over the two years.

Furthermore, as shown in Table (2), there was a strong, statistically significant, and positive correlation between the nutrients (i.e., crude protein and carbohydrates) and the food quality index of date palm leaflets and the percentage of leaves damaged by *F. phoenicis* (r-value reached 0.96, 0.95, and 0.95, respectively, on the average of the two years).

The nutritional inhibitors (tannins and phenolics) of date palm leaflets and the percentage of leaves damaged by *F. phoenicis* have extremely significant negative connections, as seen in Table (2). On average, these associations are -0.96 and -0.94, respectively, over the two years.

At the same time, Fig. 4 provided is a correlation matrix exhibiting the associations among the different parameters and indicating correlations among *F. virgata* estimates & damaged leaflet percentages and the tested traits of certain date palm cultivar leaflets. The intensity of color reveals the strength of correlations; the red (and various tones of red) reveals a negative correlation. As one parameter increases, the other decreases. And the blue (and various tones of blue) reveals a positive correlation. As a parameter increases, the other increases as well. The "Correlation matrix" legend on the top right indicates the range of correlation coefficients, from -1 (strong negative correlation) to 1 (strong positive correlation).

The correlation between the *F. phoenicis* estimates and damaged leaflet percentages is dark blue. This indicates a strong positive correlation. This refers to the increase in *F. phoenicis*, which would increase the damaged leaflets. As well, the relationship between the number of *F. phoenicis* individuals and chemical measurements (moisture content, weight after an hour, fat content, specific weight of leaflets, crude protein, carbohydrates, and food quality index) was highly positively correlated (dark blue cells), as illustrated in Fig. (4).

The results of the study showed a negative correlation between *F. phoenicis* counts and leaflet characteristics (leaflet area, specific leaflet area) and chemical attributes (carotenoids and chlorophyll a and b, dry matter, percentage of moisture lost, wax content, tannins, and phenolics) (dark red cells). Similarly, these results of the percentage of dead leaves are the same as the results of the pest count, as shown in Fig. (4).

As regards the simple correlation between the biochemical traits and nutritional status characteristics of certain date palm cultivar leaflets (Fig. 4). The results showed that the relation between leaf area (LA) and specific leaf area (SLA) exhibited a positive correlation (blue cell). This means that plants with larger leaf areas tend to have higher specific leaf areas. Also, the relation between the leaf area (LA) and specific leaf weight (SLW) showed a negative correlation (red cell). This implies that plants with larger leaf areas might have lower specific leaf weights. At the same time, the relation between the chlorophyll (Chl a, Chl b, and carotenoids) exhibited a positive correlation (blue cell) because they are both main pigments and often vary together. Furthermore, the relation between moisture (M) and dry matter (DM) is a strong negative correlation (dark red cell).

As shown by the nutritional components and their inhibitors in leaflets (Fig. 4), the relationship between the protein and the fat is a strong positive relationship (dark blue cell). Also, the association between fat and carbohydrates is a high positive correlation (dark blue cell). In addition, the relationship between the FQI and the Fat is positive and strong (dark blue cell). Furthermore, the relationship between the protein and carbohydrates is positive (strong positive correlation, dark blue cell). As well, the association between wax and tannins is a high positive correlation (dark blue cell)

While the association between the tannins and the phenols is a highly positive correlation (dark blue cell).

However, the association between the protein and tannins is a significant negative correlation (dark red cell). In this context, the relationship between the tannins and the fat is a strong negative correlation (dark red cell). But the correlation between the tannins and the FQI is strongly negative (dark red cell).

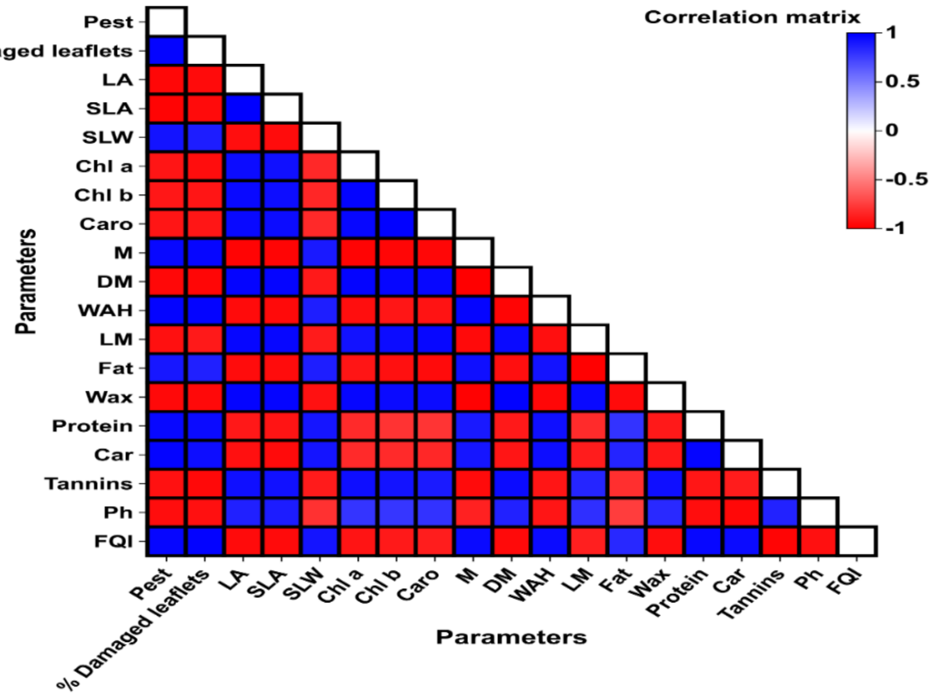

Fig. 4. Correlation matrix between *F. phoenicis* counts per date palm leaflet and (i) the percentage of damaged palm leaflets, and (ii) the biochemical traits and nutritional status of a given date palm cultivar, based on a two-year average. Color intensity indicates the strength of the relationship: shades of red represent negative correlations, and shades of blue represent positive correlations. The legend "Correlation matrix" (top right) shows correlation coefficient values ranging from −1 (strong negative) to +1 (strong positive).

4. Heat map and hierarchical clustering for 19 tested traits on six date palm cultivars over the average of both studied years:

To demonstrate the assessment of date palm cultivars based on *F. phoenicis* estimations, leaflet damage percentages, biochemical features, and nutritional condition of date palm leaflets (Fig. 5). This heatmap shows the similarity or dissimilarity by Euclidean distance) of date palm cultivar traits, accompanied by dendrograms on both the row (cultivars) and column (19 parameters) axes. The heatmap colors: the darker red represents a lower Euclidean distance and is considered more similar; the values are significantly below the mean (negative value). While the darker blue represents a larger Euclidean distance and is considered more dissimilar, the values are significantly above the mean (positive value). The legend ranges from -2 (dark red) to 2 (dark blue). The dark red color was desirable for studied traits that were increased, while the dark blue color was desirable for traits that were decreased (Fig. 5).

Based on the 19 traits that were assessed, all entries were grouped into two major categories. The relationship heat map (Fig. 5) categorized the date palm cultivars into two main groups. Each group included three date palm cultivars clustered together, one of which had a strong correlation for *F. phoenicis* numbers, damaged leaflets, and measured traits, while the other group had a weak correlation. Each group was divided into subgroups for each index scheme.

The Bartamoda cultivar is included in one subgroup that includes two varieties that are remarkably similar in the studied traits, namely the Gendeila and Shamia cultivars. The Bartamoda cultivar emerged with a strong association with *F. phoenicis* count, damaged leaflet percentages, specific leaflet weight, moisture content, weight after one hour of drying, fat content, crude protein, carbohydrates, and food quality index, and it exhibited a poor association with leaflet area, specific leaflet area, chlorophyll a, b, carotenoids, dry matter, % lost moisture, wax content, tannins, and phenolics.

In contrast, the Balady cultivar leaflets are included in one subgroup that includes two cultivars with similar characteristics, namely the Malakaby and Sakkoty cultivars. The Balady cultivar showed strong correlations with the leaflet area, specific leaflet area, chlorophyll a, chlorophyll b, carotenoids, dry matter, % lost moisture, wax content, tannins, and phenolics. It also showed negative correlations with *F. phoenicis* count, damaged leaflet percentages, specific leaflet weight, moisture content, weight after one hour of drying, fat content, crude protein, carbohydrates, and food quality index. The heatmap results provide additional supporting evidence for Pearson's correlation analysis.

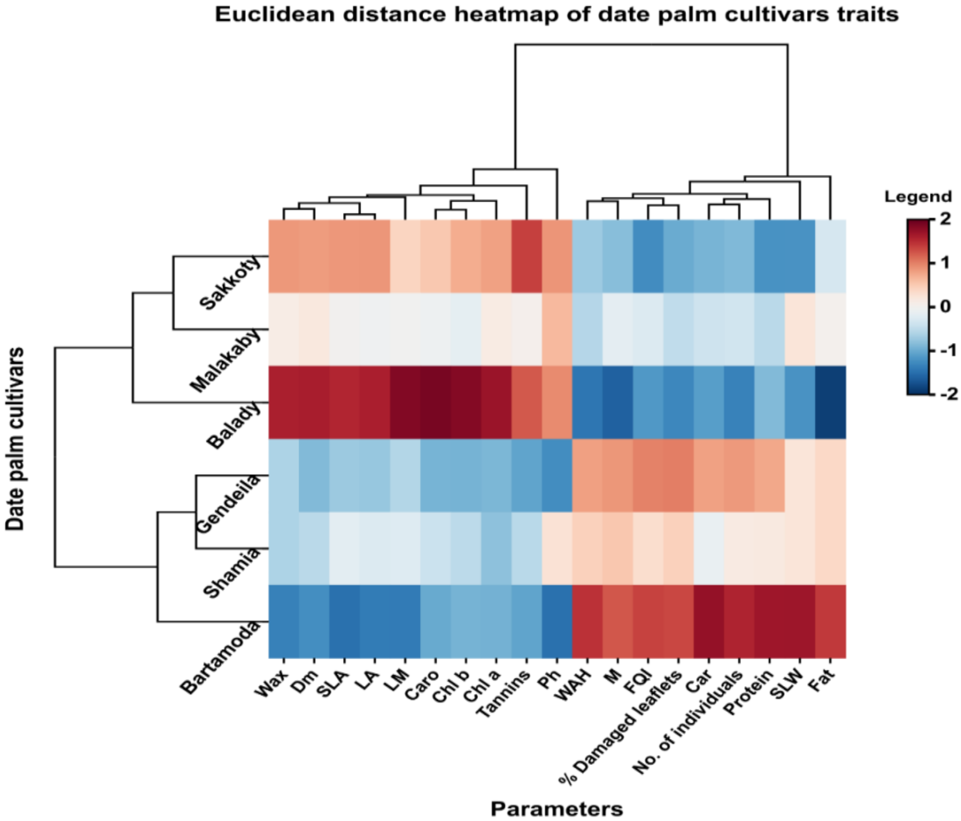

Fig. 5. The heat map analysis illustrates a similarity matrix of six date palm cultivars by Unweighted Pair Group Method with Arithmetic Means (UPGMA) clustering method with Euclidean distance matrix used based on 19 traits evaluated, on two-year averages. The row and column dendrograms show clustering of the cultivars and measured variables, respectively. On the legend (scale), dark red was desirable for traits that were increasing, while dark blue was desirable for traits that were decreasing.

Discussion

One of the major pests of date palm plants is the Fiorinia date scale, *Fiorinia phoenicis* Balachowsky (Hemiptera: Diaspididae) (Bakryand Tolba, 2025). Severe infestation by the pest had a significant impact on the growth of date palms, especially on the branches, resulting in yellow feathers and dry fronds (Youssef *et al.,* 2015).

The results showed considerable differences in the date palm cultivars' sensitivity to *F. phoenicis*. The results showed that *F. phoenicis* populations were present on all date palm cultivars throughout the year. Despite differences in date palm cultivars, infestation zones, and insect pests, the present results are mostly in line with the data already available. According to Moussa *et al*. (2012), leaflet thickness had little bearing on susceptibility, and the Amhat date palm cultivar had the largest scale population, followed by Samani and Hayani. In Egypt, Youssef (2002), discovered that the Hayany cultivar was more vulnerable to *Parlatoria blanchardi*. Jamahor *et al.* (2007) reported that Bekrari had the highest population density, and the Saeds variety showed no signs of infestation. In Iraq, Al-Dosary (2009) discovered that the Khadrawi cultivar had the lowest infection severity and the greatest infestation percentage, followed by the Hillawi cultivar. In Egypt, the parlatoria scale insect invaded the white date palm cultivar, followed by Malakaby, Balady, and Shamia. The species Gendeila was the least affected, according to Moussa *et al.* (2012). Significant differences in *F. phoenicis* counts were observed amongst palm types by El-Shafei and Attia (2023), with Siwi having the highest numbers, followed by Bartamoda and Samani.

Comparing the leaflets of the 'Bartamoda' cultivar with other tested date palm cultivars, the 'Bartamoda' cultivar recorded the highest pest infestation rate and the highest estimates of leaflet-specific weight, moisture content, one-hour drying weight, fat content, crude protein, carbohydrates, and feed quality index. In contrast to other tested varieties, date palm leaflets of the “Balady” (local) cultivar recorded the highest scores in the following assessments: leaflet area, specific leaflet area, chlorophyll a, b, carotenoids, dry matter, moisture loss, wax content, tannins, and phenols.

According to Salman *et al.* (2012b), the white date palm cultivar had the highest invasion of *Parlatoria blanchardi* (Targ.) (Homoptera: Diaspididae) and the highest levels of crude proteins, total carbohydrates, and food quality index. However, when compared to other tested varieties, the infested leaflets had the lowest levels of total tannins and phenols. The Gendeila variety, on the other hand, was the one least affected by this pest. Additionally, it was noted that all evaluated kinds of date palm leaflets with infestations had lower levels of total soluble carbohydrates and crude proteins than the uninfested ones, whereas the uninfested varieties had lower amounts of tannins and phenols. Furthermore, a drop in insect population density in the Shamia variety may be the cause of the rise in soluble condensed tannin and phenol contents in leaflets. Additionally, it was determined that the White date palm type, which was thought to have the most serious *P. blanchardi* infestation, was displaying a greater N content. According to Moussa *et al.* (2012), the uninfested date palm leaflets from all studied kinds had considerably greater fresh weight, weight after an hour of drying, dry weight, moisture content, epicuticular wax, leaflet area, specific leaflet area, and photosynthetic pigments compared to the infested ones. In comparison to uninfested leaflets, the infected leaflets exhibited a considerable increase in dry matter, moisture content loss, and specific leaflet weight. With the highest proportion of dry matter and specific leaflet weight increase in the infested leaflets in comparison to the uninfested ones, the white date palm variety was thought to have the most serious infestation of *P. blanchardi*. It also shows the highest loss in moisture content, epicuticular wax, leaflet area, specific leaflet area, chlorophyll (a), and carotenoids.

The characteristics that this study examined may be significant factors in determining the quality of leaves as food for generalist insect herbivores. Rather than the absolute concentrations of individual leaf compounds, the food quality index, which measures the relative concentrations of compounds with distinct physiological effects, such as inhibitors and arrestants, determines the quality of leaves in relation to generalist herbivorous insect species (Lunderstadt, 1980). It is unknown if any phytophagous insect can taste all its vital elements, and their capacity to distinguish between different nutrients is restricted. Because leaflets contain the right chemical composition and quantities (i.e., FQI), the insects obtain a nutritional balance primarily "adventitiously" (Chapman, 2003). As a result, an insect population that consumes leaflets with a higher FQI expands more rapidly than one that consumes leaflets with a lower FQI.

Given this, the leaflets of the Balady date palm may have a higher concentration of wax, tannins, and phenolics, which might contribute to the defensive mechanism against *F. phoenicis* and decrease infestation. Moreover, the higher fat, crude protein, and carbohydrate content of the Bartamouda date palm's leaves might contribute to the proliferation of *F. phoenicis* populations and a rise in infestation. This might be because sucking sap is drained away from the other plant components and assimilated by the insect, which could lead to a decrease in metabolism (Miles, 1989).

The suppression of pigment production, which can be brought on by changes in mineral nutrition, a shortage of assimilates that drain to the insect, or the impact of reactive oxygen species on these pigments, could be the cause of the decline in photosynthetic pigments (Stacey and Keen, 1996).

The current findings are consistent with those of several writers; higher plants generate phenolic chemicals for a variety of purposes, including defense against herbivores (Riipi *et al*., 2002). Plant-herbivore interactions have been thought to be significantly influenced by phenols. The kind of phenols determines their capacity to prevent food absorption and digestion (Salem *et al*., 2006). Since they lower the number of pests on the resistant plants, phenolic chemicals play a significant role in plant resistance to insects. According to Golawska *et al*. (2008), the existence of different chemical compounds in plant tissues determines their bioactivity, which would prevent insects from eating them.

According to Taiz and Zeiger (1998), plants defend themselves by developing a thick cuticle, or waxy outer coating, containing lipid material that prevents water loss and acts as a barrier against some insects.

Pearson's correlation coefficient analysis was used to assess the link between the *F. phoenicis* individuals and the percentages of damaged leaflets, as well as the biochemical characteristics and nutritional quality of certain date palm cultivar leaflets.

Using Euclidean distance and the unweighted paired group technique with arithmetic average (UPGMA), a heat map and hierarchical clustering of 19 evaluated features on six date palm cultivars over two-year averages were carried out. With the use of the similarity coefficient matrix data, a dendrogram was created. Two major groupings of date palm cultivars were identified using the heat map.

Date palm cultivars were divided into two major groups using the heat map. Three date palm cultivars, one strongly linked and the other weakly associated, were grouped together in each group. For every index system, each group was further subdivided into subgroups. In an unconventional integrated pest management method for *F. phoenicis* control, knowing the amounts of wax, tannins, and phenols in date palm cultivars' leaves may assist in forecasting the date palms' resistance to *F. phoenicis* populations.

These findings are in line with those of Khattab (2007), who reported that the infested cabbage leaves had less soluble protein than the uninfested ones. This drop in soluble protein biosynthesis may have been caused by the phloem-sucking aphid draining assimilates like amino acids. The protein banding pattern (amino acids) on rose plants changed as a result of infection with the rose aphid, *Macrosiphum rosae* (L.) (Hemiptera: Aphididae), according to Emam (2009).

The findings agree with Salman *et al.* (2012a), who mentioned that the percentage decrease in crude proteins, carbohydrates, and the food quality index was positively correlated with the rate of *P. blanchardi* infestation. On the other hand, there were negligible unfavorable associations between the percentage decrease in tannins, lipids, phenols, and insect infestation.

In comparison to the free and lightly infested leaves, the *Parlatoria oleae*-heavily infested leaves showed the greatest reduction in all measured parameters, except for dry weight, dry matter, loss of moisture content, specific leaf weight, and K and Ca elements, according to the results explained. Salman *et al.* (2012b), noted that date palm leaflets infested with *P. blanchardi* may reduce pigment concentrations, which might interfere with regular photosynthesis. Stomata resistance may rise as a result of the initial impact of feeding behavior, which is the continuous piercing of leaves' stomata by insect mouthparts. This suggests that stomata responses are not functioning properly. It caused photosynthesis to decline and gas exchange to be restricted. Additionally, the leaf moisture stress subsides when an insect sucks the sap from the leaves, impairing guard cell activity and resulting in stomata closure. Additionally, it was discovered that the scale insect that attacked leaves and consumed sap decreased the amount of carotenoids, photosynthesis, and chlorophyll in the leaves (Moussa *et al.,* 2012).

Conclusion

Overall, the current study indicates that, when compared to the other five cultivars, the Bartamoda cultivar had the highest pest infestation and the highest measurements in terms of specific leaflet weight, moisture content, weight after an hour of drying, fat content, crude protein, carbohydrates, and food quality index. The combined activity of vital nutrients and their inhibitors in date palm leaflets, which affects the quality of the leaflets, determines the vulnerability of date palm types to infection by *F. phoenicis*. Numerous variables, such as the extent and duration of infection, as well as vital nutrients and leaf inhibitors, contributed to the lower measured values. Depending on the cultivar, these elements may have varied relative roles. In a novel integrated pest management method for *F. phoenicis* control, knowing the amounts of wax, tannins, and phenols in date palm cultivars' leaves may assist in forecasting the date palms' resistance to *F. phoenicis* populations. Therefore, it was determined that while developing an IPM program for the control of *F. phoenicis*, particular consideration was to be provided to the Balady cultivar of date palm.

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العلاقة بين أعداد حشـــرة فيورينيا النخيل القشـــرية *Fiorinia phoenicis* والصـــفات البيوكيميائية والحالة الغذائية لبعض وريقات أصناف نخيل البلح.

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الملخص

يركز البحث على تقييم العلاقة بين أعداد حشـــرة فيورينيا النخيل القشـــرية *Fiorinia phoenicis* والصـفات البيوكيميائية والحالة الغذائية لبعض وريقات أصـناف نخيل البلح. أظهرت النتائج، أن حشـرة فيورينيا النخيل القشـــرية تتواجد على وريقات جميع أصـــناف نخيل البلح على مدار العام. كما وجد أن الصـنف "نخيل البلح بارتمودا" سـجل أعلى إصـابة بالحشـرة ويحتوي على أعلى تقديرات للوزن النوعي للوريقة، ونسبة الرطوبة الكلية والوزن الجاف بعد ساعة واحدة وأعلى تركيزات لنسبة الدهون والبروتين الخام والكربوهيدرات الكلية ودليل جودة الوريقة كغذاء للآفة، مقارنة أصـــناف نخيل البلح الأخرى المختبرة.

وعلى العكس، سـجّلت وريقات صـنف "نخيل البلح البلدي" (صـنف محلي) أقل إصـابة بالحشـرة وعرض أعلى تقديرات لمســاحة الوريقة والمســاحة النوعية للوريقة ومحتواها من الكلوروفيل (أ)، (ب) والكاروتينات والمادة الجافة والرطوبة المفقودة والشـــمع والتانينات والفينولات في الوريقات مقارنة بوريقات أصناف نخيل البلح الأخرى.

باسـتخدام المسـافة الأقليدية وطريقة المجموعات المزدوجة غير المرجحة مع المتوسـط الحسـابي (UPGMA)، أُجريت الخريطة الحرارية والتجميع الهرمي لـ 19 صفة تم تقييمها على ستة أصناف من نخيل البلح على أساس متوسطات عامين من الدراسـة. وباسـتخدام بيانات مصـفوفة معاملات التشـابه، تم أُنشاء مخطط شجري.

وأتضح من النتائج باستخدام الخريطة الحرارية، أن أصناف نخيل البلح تم تقسيمهم إلى مجموعتين رئيسيتين إحداها مرتبطة ارتباطًا وثيقًا بالصـفات المختبرة والأخرى ضـعيفة الارتباط، في كل مجموعة، وقُسِّمت كل مجموعة إلى مجموعات فرعية.

هناك طريقة غير تقليدية للإدارة المتكاملة لمكافحة حشـــرة فيورينيا النخيل القشـــرية، من خلال معرفة محتواها من نسـبة الشـمع والتانينات والفينولات في وريقات أصـناف نخيل البلح، ربما قد تسـاعد هذه المواد في التنبؤ بمقاومة أشجار النخيل البلح لهذه الحشرة.

الكلمات المفتاحية: *الصفات البيوكيميائية، أصناف نخيل البلح، فيورينيا النخيل القشرية، الحالة الغذائية*