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Original Article

Defoliation Effects of Pistachio Processionary Bud Moth (*Thaumetopoea solitaria*) larvae on Two Anacardiaceae Genus in North of Iraq

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ABSTRACT

Defoliation by Pistachio Processionary Bud Moth *Thaumetopoea solitaria* (Freyer) larvae threatens many tree species, especially pistachio trees in Mediterranean countries, including the Kurdistan Region in the northern part of Iraq. This study examines severe defoliation caused by *T. solitaria* larvae on three tree species: *Pistacia vera*, *P. khunjuk*, and *Rhus coriaria* in the Haybat Sultan Mountains of Koya District, Erbil, Iraq. Female moths lay their eggs on host trees. After the eggs hatch in early spring, during bud swelling. The larvae begin feeding on leaves, green tissues, and unopened buds. Results show that the larvae feed on new foliage, causing significant damage. *Pistacia vera* exhibited significantly higher defoliation during the first through fourth larval stages. As the larvae progress to later instars, they consume larger, mature leaves, further worsening tree injury. By the fifth instar, larvae feed throughout the night, leading to complete defoliation, especially in *Rhus coriaria*, which showed significantly greater defoliation ($p \leq 0.05$) compared to *Pistacia vera* and *P. khinjuk*, which recorded the lowest defoliation (671.1 cm^2). Results also show that larvae consumed 1699.9, 1516.5, and 752.5 cm^2 of *R. coriaria*, *P. vera*, and *P. khunjuk*, respectively, over all larval stages. These data highlight *R. coriaria* as the most affected species and are essential for understanding tree vulnerabilities and developing effective pest management strategies. Defoliation rates showed significant variation among the studied species, where *R. coriaria* had the highest rates, particularly in the later stages, while *P. khunjhuk* had the lowest at the end. A positive and significant relationship was observed between the number and area of defoliated leaves across all studied species.

Keywords: Forest trees defoliation, Insect pests, Larvae feeding, Pistacia sp., Thaumetopoea solitaria.

1 Introduction

Some members of the Anacardiaceae family, especially pistachio (*Pistacia vera* and *P. khinjuk*) and sumac (*Rhus coriaria*), have significant economic importance worldwide. Pistachios are commonly consumed as dried nuts or used as additives in the food industry. The production of pistachios generates a large amount of potentially valuable waste, such as leaves and husks that have been used as a valuable resource in traditional medicine. Nowadays, scientific papers have confirmed the presence of desirable biological compounds or ingredients. The extracts expressed high values of phytochemicals, as well as antioxidant and antimicrobial activities [1]. *Rhus coriaria* L., commonly known as sumac, is a wild edible plant growing in the Mediterranean region. It is an aromatic and medicinal plant found in Iraq, functioning as a deciduous shrub or small tree. It has an attractive economic importance due to its increasing use in the food, cosmetic, and pharmaceutical industries, where it is employed for colouring and preserving foods. It has been used as a spice, condiment, appetizer, and as a souring agent for centuries. Its fruits are commonly used as a spice in many traditional Iraqi dishes, and it also has landscaping potential in Iraq's Kurdistan region, where medicinal plants are commonly used. Its leaves are part of herbivore diets, and leaf extracts are

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believed to help treat kidney problems and stop bleeding [2-3]. A broad range of nutritionally and medicinally significant phytochemical components has been identified from various parts of sumac, such as tannins, flavonoids, anthocyanins, organic acids, flavones, proteins, fibre, volatile oils, nitrates, and nitrites [4].

One of the threats to pistachio trees in Mediterranean regions, particularly in the Kurdistan Region of Northern Iraq, is attributed to the Pistachio Processionary Bud Moth, *Thaumetopoea solitaria*, with rising temperatures associated with climate change favouring pest proliferation [5]. In addition, recent regional studies have highlighted increasing environmental pressures on natural ecosystems in the Kurdistan Region, particularly in relation to climate variability and ecological stressors affecting vegetation dynamics [6]. Such climatic influences on ecosystem behaviour have also been documented, with temperature fluctuations acting as key drivers of biological and ecological processes [7]. This pest harms plants by depleting nutrients. The life cycle of the moth starts with female adults laying eggs on the host trees. After hatching, the larvae feed voraciously on the leaves and unopened buds, predominantly targeting new foliage, leading to significant damage in *P. vera*. As the larvae develop through their instars, they transition to eating larger, more mature leaves, resulting in increased harm to the trees. This damage triggers the production of secondary metabolites and defence enzymes [5]. If pest pressure exceeds the plant's resistance, tissue damage and leaf abscission occur, indicating defoliation. Defoliation impairs insulation and nutrient transport via phloem, leading to decreased photosynthesis, respiration, and transpiration [5]. These physiological issues result in reduced growth and yields [8].

T. solitaria feeding leads to symptoms like leaf drop and reduced yields. Affected *P. vera* varieties exhibited significant drops in weight and nitrogen content, particularly the Kallehghuchi variety, which saw reductions of 26.02% and 29.76% after 10-15 days of nymph feeding [9-10]. It has also been examined the effects of larval feeding on the photosynthetic pigments of the host plants, observing a notable decrease in foliar chlorophyll levels when relative humidity fell below 40% [11].

This research emphasises the varying susceptibility of the three tree species to *T. solitaria*, with P. *vera* exhibiting the greatest vulnerability. Gaining insight into the behaviour of this pest is crucial for formulating effective management strategies to enhance plant health and improve agricultural practices. In light of the significant health risks faced by those affected by pest-related challenges [12], and the ecological consequences of deforestation driven by increasing public awareness [13], the study establishes a vital foundation for addressing these pressing issues in the Kurdistan region.

Despite some studies on defoliation effects in tree species, research on forests affected by this defoliator is limited. The present study concentrates exclusively on the pest *Thaumetopoea solitaria* (Freyer) (Lepidoptera: Thaumetopoeidae) and its effects on three species: *Pistacia vera*, P. *khunjuk*, and *Rubus coriarius*. The research is designed to achieve several objectives: (i) To measure the degree of defoliation inflicted by *T. solitaria* larvae on the aforementioned species, and the interaction between the defoliation process and some environmental factors, temperature and precipitation. This comprehensive investigation will yield significant insights into the interactions between T. *solitaria* and these specific tree species.

2 Materials and Methods

2.1 Study area and plant species

The research was conducted in the Haybat Sultan Mountains, Koysinjaq, Erbil Governorate, Kurdistan Region, Iraq. The study area is located between 36.1002° N latitudes and 44.6712° E longitudes, at elevations ranging from approximately 600 to 1000 m above sea level. Based on long-term meteorological records from the Koysinjaq station, the area is characterised by a semi-arid climatic regime, with hot, dry summers and cooler, wetter winters typical of continental conditions in northern Iraq [14]. These climatic conditions are consistent with previous environmental studies conducted in northern Iraq, which report similar semi-arid characteristics influencing vegetation patterns and ecological interactions [15]. This area includes typical formations of dry deciduous broad-leaved forest, where *Pistacia vera* (cultivated), *P. khinjuk*, and *Rhus coriaria* (natural) grow together, with *Quercus* species as the dominant trees in the forest. At the same time, *Thaumetopoea solitaria* is also a dominant insect species that occurs throughout this region, and its larvae feed on the leaves of various trees, including the species examined in our study.

2.2 Meteorological data of the study area

Meteorological data of the study location, including air temperature and precipitation during the study period, were recorded by the Agrometeorological Station at the climate centre in Koya city. Erbil, as shown in Table 1.

Table 1: Meteorological data for the study period from April 25 to May 26, 2019.

Larvae instar stages feeding		Average Temperature (◦C)	Precipitation (mm)
1st Instar (April)	25	13.31	0
	26	14.52	0
	27	15.54	0.04
	28	16.25	0.05
	29	14.55	0.56

	30	17.15	0
Average		15.22	0.11
2nd Instar (May)	1	19.45	0.11
	2	20.39	0.72
	3	18.89	0.07
	4	15.2	15
Average		18.48	3.98
3rd Instar (May)	5	17.11	0.05
	6	19.17	0
	7	20.82	0.54
	8	20.64	1.45
Average		19.44	0.51
4th Instar (May)	9	18.95	1.81
	10	15.84	2.8
	11	18.38	0
	12	20.53	0
	13	22.48	0
Average		19.24	0.92
5th Instar (May)	14	23.24	0
	15	24.21	0
	16	23.92	0
	17	23.68	0.01
	18	24.49	0.68
	19	24.48	0.41
	20	23.19	0
	21	21.25	2.08
	22	22.35	0
	23	24.28	0
	24	25.86	0
	25	27.01	0.28
	26	26.29	0.02
Average		24.17	0.27

2.3 *Thaumetopoea solitaria* and defoliation studies

This study used outdoor rearing conditions to monitor the survival and development of batch eggs throughout the winter season on three host plant species: *Pistacia vera*, *P. khunjuk*, and *Rhus coriaria*. Observations were conducted from the time of oviposition until hatching occurred in mid-March. Observations were conducted from the time of oviposition until hatching occurred in mid-March. The defoliation of leaves from April 25 (when the eggs hatch into larvae) to May 25, 2019 (when the last instar of larvae were completed) was investigated. Resistant plants experience fewer pest attacks, whereas more erratic trees are more vulnerable [16]. The larvae were divided into three distinct groups, with each group comprising 20 larvae corresponding to each type of tree, where this process was repeated three times for each species.

To prevent larval migration among trees, an oil-like moist barrier was established around the host trees. This measure was necessary because larval density was low, whereas in areas with high *T. solitaria* populations, larvae tended to remain on the same trees [17]. However, in this study, to completely control the larvae, they were investing in the trees by using a net sac, so each experimental unit consists of a net sac containing 20 larvae (three species of three trees, each tree contains three net sacs, each net sac contains 20 larvae) (Figure 1). Careful observation was maintained of the larvae from their initial to the fifth developmental instar on the same host tree.

The larval instar stages of *Thaumetopoea solitaria* were divided into five distinct stages based on their leaf-feeding behaviour, as follows:

- 1st stage: from April 25 to 30, 2019, where minor defoliation was noted; some days had no measurable loss, indicating a slow start.
- 2nd stage: from May 1 to 4, 2019, where a rising trend in defoliation emerged, highlighted by peaks on multiple days.
- 3rd stage: from May 5 to 8, 2019, where peak values were notable, especially on May 6, with averages surpassing prior recordings.

- 4th stage: from May 9 to 13, 2019, where substantial averages were recorded, particularly on May 9 and 10, indicating rising defoliation rates.
- 5th stage: from May 14 to 26, 2019, where significant increases peaked, showing intense leaf loss.

Figure 1: On left: investing larvae by a net sac on a tree branch. On right: larvae of *Thaumetopoea solitaria* with damaged leaves.

For each experimental unit before the feeding process, the average leaf water content and leaf thickness were measured using digital micro-vernier calipers, and the leaf content of chlorophylls was measured using a SPAD chlorophyll meter (SPAD-502, Japan). After the feeding process, the number and area of fed leaves were measured [18].

2.4 Statistical Analysis

Data were submitted for analysis of variance; the mean among tree species means for each instar larvae stage was done by using Duncan's Multiple Range test at a probability level of 5% using the SAS program version 9.1 [19]. Correlation analysis was done to investigate the relationship between defoliated leaves and area, and each of the air temperature and precipitation.

3 Results and Discussion

This discussion emphasizes the significant impact of *Thaumetopoea solitaria* on tree species in the region, particularly under varying conditions of leaf water content, and the environmental conditions, especially temperature and precipitation. In this study, the impact of *Thaumetopoea solitaria* larvae on the defoliation of three tree species prevalent in the Kurdistan region of Iraq: *Pistacia vera* L., *Pistacia khunjuk* Stocks., and *Rhus coriaria* L. was investigated. The defoliation rates caused by *T. solitaria* larvae on the studied tree species were recorded at different stages of larval development. During the first larval stage, the leaf area consumed was 42.8 cm^2 for *P. vera* leaves, 19.9 cm^2 for *Rhus* leaves, and 11.6 cm^2 for *P. khunjuk* leaves. As the pest progressed to the second stage, defoliation rates increased to 55.7 cm^2 for *P. vera*, 31 cm^2 for Rhus, and 14.1 cm^2 for *P. khunjuk*. In the third stage, the rates rose further to 70.2 cm^2 for *P. vera*, 53.6 cm^2 for *Rhus*, and 12.6 cm^2 for *P. khunjuk*. By the fourth stage, the defoliation percentages reached 84.7 cm^2 for *P. vera*, 48.1 cm^2 for *Rhus*, and 43.1 cm^2 for *P. khunjuk*. Up to this point, it is evident that for the stages of first to fourth, *P. vera* experiences the most defoliation, followed by *Rhus*, while *P. khunjuk* shows the least damage (Figures 2 and 3).

However, an interesting shift occurs in the final stage when *Rhus* leaves were defoliated more severely than any of the other species, recording an astonishing defoliation rate of 1547.3 cm^2. This was followed by *P. vera* at 1263.2 cm^2, whereas the lowest value was recorded for *P. khunjuk* (671.1 cm^2). Throughout the lifespan of the pest, *Rhus* leaves suffered the most extensive defoliation, totaling 1699.9cm^2, compared to *P. vera*, which reached 1516.5cm^2, and *P. khinjuk* which records 752.5cm^2, indicating differing responses to chemical content (chlorophyll and water content) and leaves structure (leaves thickness), where *Rhus* leaves had the highest average chlorophyll (39.07 SPAD unit) and less average thickness (0.11 cm) for new and mature leaves, followed by *P. vera* (39.51 SPAD unit and 0.29 cm) and the lowest values 35.09 SPAD unit and 0.22 cm were recorded by *P. khunjuk* which records the highest water content 63.34% (Table 2). *Rhus* leaves' thickness was less than that of each of *P. vera and P. khinjuk* for new and mature leaves (Table 2).

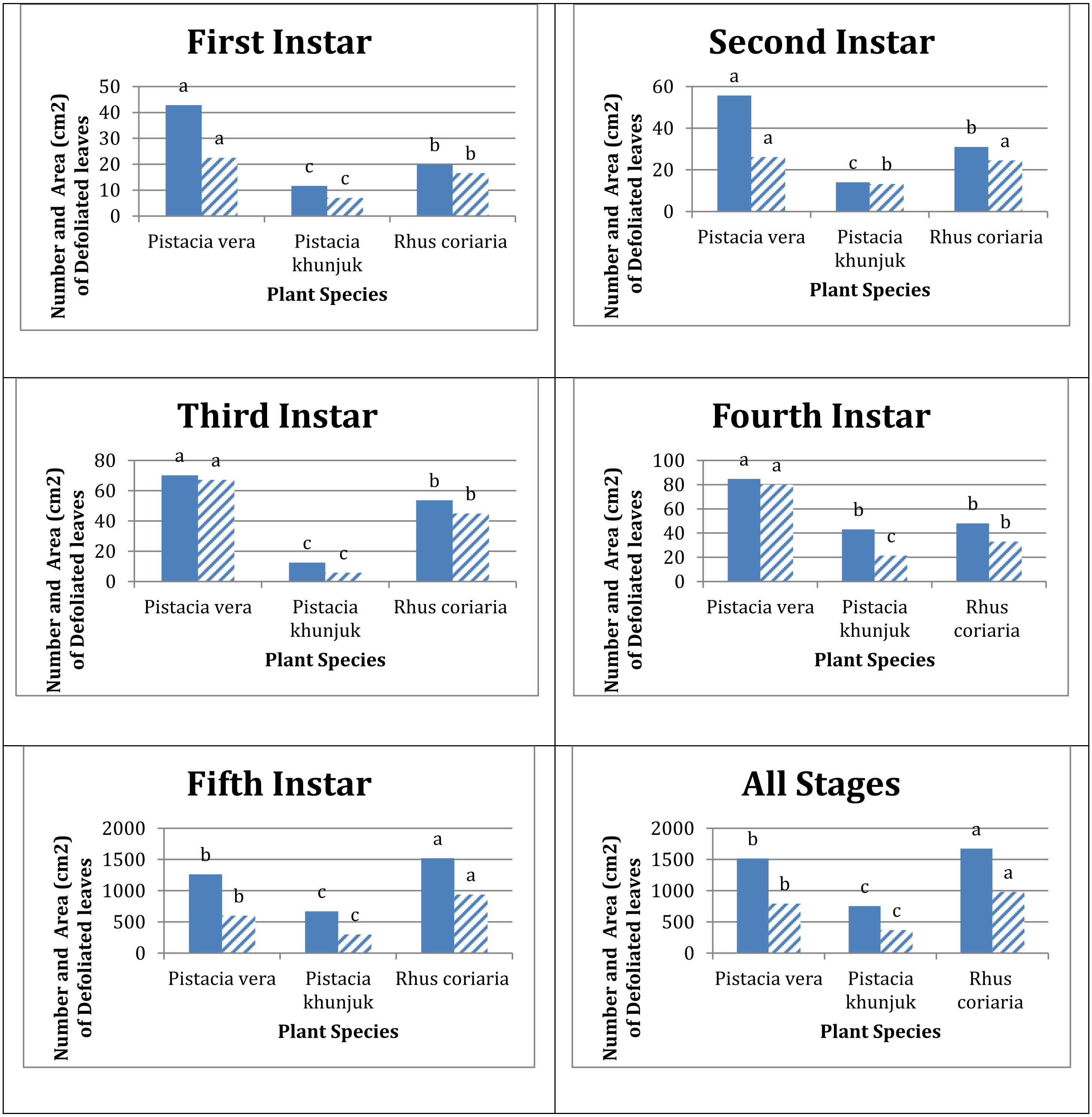

Figure 2: Trees defoliation through different *T. solitaria* larvae stages and total defoliation, where means followed by the same letters for each stage and the total of all stages are not significantly different at $p \leq 0.05$ according to Duncan`s Multiple Range test and vice versa.

Generally, chlorophyll content and leaf thickness in new leaves were less than those in mature leaves. In contrast, water content decreased in mature leaves, which may have a role in increasing the feeding process, where the lowest value was recorded in *P. khinjuk* leaves. These findings highlight the dynamics of defoliation across the different stages of pest development, revealing how species susceptibility can shift dramatically as the infestation progresses. The differences between fed leaves at different stages may also be due to the differences in environmental factors (Table 1) [20].

Plants respond to herbivorous insects through various morphological, biochemical, and molecular mechanisms to counteract the effects of herbivore attack. The defensive compounds are either produced constitutively or in response to plant damage, and affect the feeding, growth, and survival of herbivores. Host plant resistance to insects, particularly induced resistance, can also be manipulated with the use of chemical elicitors of secondary metabolites, like flavonoids, tannins, anthocyanins, lignin, and lectins, which confer resistance to insects [21]. These facts are reflected in the present study, where low defoliation in *P. khunjuk* may be due to their leaflets being dorsiventral and oriented horizontally, while *P. vara* leaflets, which have random orientation, were isobilateral [22]. In addition to the differences in the chemical constituents, *Rhus* leaves contain high tannin, phenol acids and flavonoids, such as methyl gallate, kaempferol, and quercetin gallic acid [5]. The plant's chemical composition can vary under stress, with defoliators like *Thaumetopoea solitaria* playing a key ecological role in *Rhus coriaria* by breaking down cellulose in leaves.

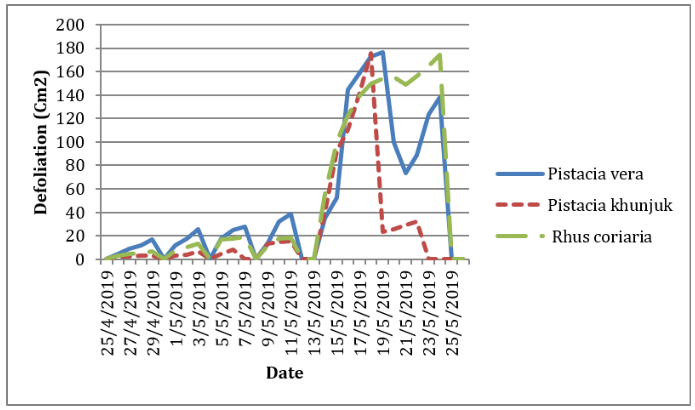

Figure 3: Trees defoliation throughout *T. solitaria* larvae stages.

Table 2: Chlorophyll, thickness, and water content for new and mature leaves for the studied species.

Tree Species	New Leaves			Mature Leaves			Average of New and Mature Leaves		
	Chlorophylls (SPAD Unit)	Leaf Thickness (cm)	Water content (%)	Chlorophylls (SPAD Unit)	Leaf Thickness (mm)	Water content (%)	Chlorophylls (SPAD Unit)	Leaf Thickness (mm)	Water content (%)
Pistacia vera	34.07	0.33	66.67	44.95	0.26	57.14	39.51	0.29	61.91
Pistacia khunjuk	20.62	0.17	66.67	49.56	0.27	60.00	35.09	0.22	63.34
Rhus coriaria L.	39.07	0.07	66.67	42.65	0.15	58.33	40.86	0.11	62.50

Because our study was conducted in spring, we observed that *P. khinjuk* experienced the lowest defoliation compared to *P. vera*. This contrasts with the findings of Marino, et al. [23], who reported greater autumn defoliation in *P. khinjuk* than in other pistachio species, while *P. vera* showed the least damage. This discrepancy may be attributed to differences in meteorological conditions (Table 1). Each of *P. khinjuk* and *R. coriaria* showed a preference for the north side of the trees, which receives less sunlight and retains moisture longer, explaining the larvae's behaviour [24]. This result reflects the increase in feeding on humid and low temperature days (Table 1) in the early stages and beyond.

Peak defoliation occurred in mid-May, particularly associated with *P. vera*, while *P. khinjuk*, whereas *R. coriaria* defoliation continued to increase throughout different larval stages. There was a highly significant correlation (P≤0.01) between temperature and the number and area of defoliated leaves (Table 3). Overall, the findings underscore the significant interplay between age, altitude, and bark thickness in determining defoliation rates, reflecting the environment's effect on leaf health across these dimensions [25], however, the time of larvae stages in Iraq was differ from other places (Figure 4), where significant feeding activity was recorded during early September, late July, and throughout August, resulting in considerable statistical variations in Chlorophyll a+b levels related to both the host plant species and the timing of feeding [26]. The length of the larval stages may reflect environmental conditions of temperature and humidity (Table 1).

Table 3: Chlorophyll, thickness, and water content for new and mature leaves for the studied species.

Species	Correlation Relationship	Coefficient of Correlation (r)	P-value
Pistacia vera	Temperature X Leaves Number	0.76	0.000
	Temperature X Leaves Area	0.77	0.000

Pistacia khunjuk	Temperature X Leaves Number	0.71	0.000
	Temperature X Leaves Area	0.64	0.002
Rhus coriaria L.	Temperature X Leaves Number	0.79	0.000
	Temperature X Leaves Area	0.78	0.000

(a)

(b)

(c)

Figure 4: A view of (a) partial defoliation of P. khunjhuk tree, (b) P. vera tree before defoliation, (c) the same tree infected by Thaumetopoea solitaria and completely defoliated.

Conclusion and Recommendations

The data indicate that the effects of defoliation vary significantly depending on multiple factors, such as plant species and environmental conditions, especially temperature, whereas precipitation didn't have such an effect. Among the plant materials investigated, *Rhus* sp. leaves emerged as a particularly advantageous host compared to the others, followed by *P. vera*. Importantly, the findings indicate that *P. khunjhuk* was less effective at attracting *T. solitaria* larvae based on assessments of feeding levels. If the incidence of infection continues at these rates, pistachio trees, especially *P. vera* will disappear in this geographical area. Therefore, combating the causes of this infection, which are available and effective, must be conducted by the Ministry of Agriculture Directorate. Further studies are recommended, especially about the internal factors and external biotic and abiotic factors on these pest larvae.

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