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Influence of Armenian Cucumber (*Cucumis melo* var. *flexuosus*) Varieties on the Performance and Behaviour of *Lysiphlebus testaceipes* (Hymenoptera: Braconidae) against *Aphis gossypii* Glover (Hemiptera, Aphididae)

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Abstract

Host plant traits can strongly mediate tri-trophic interactions and influence the efficacy of biological control agents. This study evaluated the effects of three Armenian cucumber (*Cucumis melo* var. *flexuosus*) varieties (Vert d'Armenie, Mornagui and Arbi) on the behaviour and performance of the aphid parasitoid *Lysiphlebus testaceipes* (Cresson) parasitizing *Aphis gossypii* Glover. Laboratory bioassays were conducted under controlled conditions to assess parasitoid fitness parameters (mummification rate, adult emergence, and sex ratio) and behavioural responses (antennal contacts, oviposition activity, and patch residence time) under both choice and no-choice conditions. Despite the quantitative assessment of morpho-physiological traits revealing that the Arbi variety possessed significantly higher leaf chlorophyll content and trichome density compared to other cultivars, statistical analysis indicated no significant variation in parasitoid biological or behavioral parameters ($P > 0.05$). This suggests a degree of robustness in *L. testaceipes* performance across the tested host-plant architectures. Subsequent greenhouse trials focusing on the tolerant Mornagui variety characterized the population dynamics of *A. gossypii* and the functional activity of natural enemies following a single inundative release of mass-reared *L. testaceipes*. A peak parasitism rate of 18.6% was recorded during the fourth week of monitoring. These findings underscore the potential of integrating varietal tolerance with the release of *L. testaceipes* as a sustainable strategy for aphid management in Tunisian protected crops.

1. INTRODUCTION

In Tunisia, the management of the cotton-melon aphid, *Aphis gossypii* Glover (Hemiptera, Aphididae) remains a formidable challenge for protected cultivation, primarily due to the pest's high biotic potential (Ben Halima, 1991; Ben Halima and Ben Hamouda, 1998). This species is characterized by exceptional fecundity, high survival rates during pre-imaginal stages, and a rapid generation turnover (Blackman and Eastop, 2006), enabling it to cause severe direct damage and forms potent vector for phytoviruses (Guerrieri and Digilio, 2008). Within these systems, Armenian cucumber (*Cucumis melo* var. *flexuosus*) (Cucurbitaceae, Cucurbitales) exhibits high susceptibility to infestation (Bouker *et al*., 2025), necessitating robust management frameworks. Integrated pest management (IPM) strategies for *A. gossypii* currently rely on a multifaceted approach involving physical, agronomic, chemical, and biological controls (Jacobson and Croft, 1998**;** Eid *et al.,* 2018**;** Adly and Sanad, 2024). While chemical insecticides have been the historical mainstay, their extensive application is increasingly associated with non-target toxicity toward beneficial arthropods (Desneux *et al.,* 2007) and the rapid evolution of insecticide's resistance (Shi *et al.,* 2023; Wang *et al.,* 2024). Consequently, there is a shifting focus toward sustainable alternatives. Physical control, such as monitoring winged aphids via colored sticky traps (Dieckhoff and Meyhöfer, 2023), and agriculture practices, including intercropping and crop rotation (Fernandes *et al.,* 2018), have become essential cultivation interventions. Furthermore, the use of biopesticides and allelochemicals, such as cucurbitacin B, rosemary extracts, and tannic acid, represents a promising frontier in reducing synthetic chemical dependency (Ma *et al.,* 2019; Zhao *et al.,* 2021; Homayoonzadeh *et al.,* 2022; Eldesouky *et al.,* 2024).

Biological control, particularly through the release of parasitoids like *Lysiphlebus testaceipes* and *Aphidius colemani*, or predators such as *Coccinella septempunctata*, has demonstrated success in greenhouse environments (De Souza *et al.,* 2009; Eid *et al.,* 2018). The efficacy of biological control programs is inherently dependent upon the strategic selection of natural enemies tailored to the specific agroecosystem. Previous investigations have established the koinobiont endoparasitoid *Lysiphlebus testaceipes* as a highly effective agent for the suppression of *Aphis gossypii* across various horticultural systems (Rochat, 1997; Lopes, 2007). Given its proven functional response and adaptability, this hymenopteran was utilized in the present study to assess its biocontrol performance against *A. gossypii* populations hosted on Armenian cucumber (*Cucumis melo* var. *flexuosus*). However, the efficacy of this natural enemy is often mediated by the host plant's own defense mechanisms. *C. melo* var. *flexuosus* has evolved a range of morpho-physiological traits that mitigate pest impact. For instance, physical attributes such as host-leaf trichome density can significantly alter the demographic and life table parameters of *A. gossypii* (Madahi *et al.,* 2018). Similarly, leaf chemical properties, specifically chlorophyll content, influence aphid feeding behavior; varieties with lower chlorophyll concentrations are often more susceptible to colonization (Zhang *et al.,* 2022). Understanding these tri-trophic interactions is therefore essential for optimizing the synergy between varietal resistance and biological control.

It is hypothesized that varietal differences in Armenian cucumber significantly alter both parasitoid performance and aphid population suppression. To test this hypothesis, a multi-tiered research approach was adopted, comprising: (i) the evaluation of parasitoid performance through controlled bioassays, where the foraging efficiency, host recognition, and parasitism potential of *L. testaceipes* were quantified across three distinct cultivars (Arbi, Mornagui, and Vert d'Armenie) to determine variety-mediated fitness and behavioral responses; (ii) characterization of host plant traits, specifically leaf trichome density and chlorophyll content, to elucidate their role in driving *Aphis gossypii* biological performance and the subsequent success of its parasitoid and **(**iii) the validation of population dynamics via greenhouse experiments using *Cucumis melo* var. *flexuosus* (cv. *Mornagui*), focusing on the real-time monitoring of *A. gossypii* and its natural enemies following controlled parasitoid releases.

2. MATERIALS AND METHODS

2.1. Insects and plants

Three local Armenian cucumber (*Cucumis melo* var. *flexuosus*) varieties were selected for laboratory bioassays, differed in fruit morphology and plant growth. Vert d'Armenie produces long, smooth green fruits, Mornagui bears medium-sized fruits with slightly rough surfaces and Arbi is characterized by dark green fruits and vigorous growth, distinguishing it from the other two varieties. Experiments were conducted under controlled conditions at 21 °C, 60–70% relative humidity (RH), and a 14 h:10 h (L:D) photoperiod.

For greenhouse experiments, the variety Mornagui was selected based on the findings of Bouker *et al.* (2025), who identified this variety as the most tolerant to *Aphis gossypii* infestation among the tested Armenian cucumber varieties. This classification was established according to the three main resistance mechanisms (antibiosis, antixenosis, and tolerance) as well as the Plant Resistance Index (PRI). Consequently, greenhouse trials were carried out exclusively using the Mornagui variety.

A laboratory colony of the parasitoid *L. testaceipes* was maintained on the aphid *Rhopalosiphum padi* (L.), reared on barley plants (*Hordeum vulgare* L.), which served as the host system. Colonies of *L. testaceipes*, *R. padi*, and *A. gossypii* were maintained on Armenian cucumber and barley plants at 20 ± 2 °C, 40–50% RH, and a 16 h:8 h (L:D) photoperiod in the Entomology Laboratory of the Higher Agronomic Institute of Chott Mariem.

2.2. Laboratory bioassays under controlled conditions

2.2.1. Effects of host plant variety on the fitness of *Lysiphlebus testaceipes*

The effect of host plant variety on the behavioral response of *L. testaceipes* was evaluated under controlled laboratory conditions using a Plexiglas cage (405 × 270 × 330 mm). Three *C. melo* var. flexuosus (fakous) plants, corresponding to the varieties Arbi, Mornagui, and Vert d'Armenie, were placed in experimental cage, each. Each plant was artificially infested with 60 individuals of *A. gossypii*, including a balanced representation of developmental stages (L1–L4 nymphs and adults), in order to approximate natural infestation levels.

L. testaceipes females were reared under controlled laboratory conditions, as described above. Newly emerged females were paired with males for 24 h in Petri dishes supplied with diluted honey to ensure mating. A single mated female of *L. testaceipes* was released at the center of the cage at a standardized distance of 60 mm from each plant and allowed to forage for a period of 24 h. Two experimental conditions were established: (i) five choice test replicates, in which the three plant varieties were simultaneously available within the same cage, enabling free host selection by the parasitoid, and (ii) nine no-choice test replicates, in which three plants of the same variety were provided, thereby excluding varietal preference.

Experimental assessments were conducted at 8, 10, 12, 14, and 16 days following parasitoid introduction. At each observation date, the number of surviving aphids and the number of aphid mummies were recorded. All mummies were individually collected, transferred to labeled Petri dishes, and maintained under controlled conditions until adult emergence, which was used as an indicator of parasitism success.

Parasitoid performance was evaluated using several biological parameters, including the mummification rate, defined as the mean number of mummies produced by a female during her lifetime divided by the mean aphid population size (Latham and Mills, 2010), Additionally, we recorded the adult emergence rate, was calculated as the mean number of adults emerging from their hosts divided by the total number of mummies, and the sex ratio, represents the proportion of males among the total emerging progeny from the host (Force and Messenger, 1964).

2.2.2. Behavioural responses of *Lysiphlebus testaceipes* to host plant variety

The experiment was conducted in 90-mm-diameter glass Petri dishes containing three leaf fragments (25 × 25 mm), each originating from one of the three tested Armenian cucumber (*C. melo* var. *flexuosus*) varieties: Vert d'Armenie, Mornagui, and Arbi. Each leaf fragment was infested with 10 individuals of *A. gossypii*. The fragments were arranged in an equilateral triangular configuration, with a distance of 20 mm separating each fragment.

A single mated female of *L. testaceipes*, previously provided with a nutritional supplement for 24 h, was gently introduced at the center of the Petri dish. Observations commenced immediately after parasitoid release and were continued for a period of 30 min. The number of antennal contacts and ovipositor insertions on aphids, as well as patch residence time, were recorded. A parasitoid was considered to have left a patch when it remained outside of the patch limit (a 60 mm diameter circle was drawn with red ink around the Armenian cucumber leaves) for more than 60 sec (Attia *et al*., 2019).

The experiment was conducted under two conditions: five no-choice replicates, consisting of three leaf fragments from a single Armenian cucumber variety, and seven choice replicates, in which fragments from the three varieties were simultaneously available.

The behavioral parameters evaluated in this study included latency time and the degree of host acceptance. Latency time was defined as the time elapsed between the release of the female and the occurrence of the first recorded behavioral event, regardless of its type (e.g., antennal movements or). The degree of host acceptance refers to the parasitoid's willingness to accept a host after initial contact and evaluation. In this study, host acceptance was quantified following Albittar *et al.* (2016) as the ratio between the number of ovipositor insertions and the number of antennal contacts, expressed as a percentage. This parameter reflects the influence of the host plant on parasitoid decision-making during host assessment.

2.2.3. Host Plant Traits

In the experiment designed to measure chlorophyll pigment content, an extract was prepared according to the method of Torrecillas *et al.* (1984): 0.25 g of Armenian cucumber leaves were grounded in a volume of 2.5 ml of 80% acetone. The mixture was filtered and stored in the dark for 72 h to measure the optical density (OD) at 645 nm, and 663 nm using a UV-Visible spectrophotometer (UV-3802, UNICO).The calculation of chlorophyll a, chlorophyll b, and total chlorophyll content was determined using the equations of Wellburn (1994) and were expressed in μg/ml.

To determine trichome density, mature leaves were selected from the same growth stage and position on the plant to ensure consistency across samples and to minimize potential diurnal variations in leaf characteristics. Five replicates per Armenian cucumber variety were considered for measuring trichome density. A binocular microscope (Leica DM750) was utilized to observe and count trichomes on each leaf sample, including both the upper and lower surfaces. Specifically, a 1 cm^2 section near the midrib was analyzed (Watts and Kariyat, 2021). Trichome density across different leaf areas was quantified using Image J Launcher Software version 2006.

2.3. Greenhouse experiments on *Cucumis melo* var. *flexuosus* (Mornagui variety)

2.3.1. Monitoring of *Aphis gossypii* and its natural enemies

The greenhouse covered 384 m2 (32 m long × 12 m wide), was planted on 20/10/2023 and located at the Technical Center of Organic Farming (CTAB) in Chott Mariem. Twenty plants were randomly selected for observation. Weekly surveys were conducted to monitor the population dynamics of *A. gossypii* and its associated natural enemies. For each monitored plant, the number of aphid colonies and the presence of beneficial arthropods including adults, larvae, and mummies, were recorded.

No chemical treatments were applied throughout the study to prevent any disruption of the natural population dynamics. Specimens were carefully collected using fine brushes and collection tubes, and all samples were preserved for subsequent mounting and identification under controlled laboratory conditions.

2.3.2. Effect of parasitoid release on the population dynamic of *A. gossypii*

A.gossypii population's dynamic (including both live and dead individuals) were evaluated before and after the introduction of mass-reared parasitoids. Given the heterogeneous spatial distribution of the pest within the greenhouse, a stratified systematic sampling design was adopted. The greenhouse was divided into three transverse blocks (North, Central, and South) oriented perpendicularly to the *C. melo* var. *flexuosus* crop rows, with each block functioning as an experimental unit.

A total of 36 plants were selected using a regularized sampling grid to ensure spatial representativeness. For each selected plant, the observation unit was defined as a single mature leaf, which was uniquely identified with color-coded markers to facilitate longitudinal tracking throughout the experimental period.

For each sampled plant, the selected leaf was categorized into one of the abundance classes defined by Lapchin *et al.* (1997) based on the estimated number of adult aphids or mummies.

A unique parasitoid release was performed in the greenhouse of 50 parasitoids on 20/12/2023. The number of aphids and mummies per plant and the height of the mornagui plants were recorded weekly.

2.4. Statistical analysis

The impact of Armenian cucumber varieties on life table biological parameters of *A. gossypii* was analyzed with One Factor analysis of variance (ANOVA) with a significance level α =0.05 and means of treatments were compared using the Student-Newman-Keuls (S.N.K.) multiple comparisons post-hoc test. All statistical analyses were performed using SPSS Statistics for Windows version 17.00 (IBM,. 2008).

3. RESULTS

3.1. Laboratory bioassays under controlled conditions

3.1.1. Effects of host plant variety on the fitness of *Lysiphlebus testaceipes*

The impact of the parasitoid *Lysiphlebus testaceipes* on the population growth of the cotton aphid *Aphis gossypii* was strongly influenced by host plant variety and experimental conditions. In the choice experiments (Fig. 1a), a significant reduction in the final aphid population was observed on the Mornagui variety (30.75±11.8 aphids) compared with Arbi (138.50±73.18) and Vert d'Armenie (288.25±74.00 aphids). Conversely, under no-choice conditions (Fig. 1b), the Arbi cultivar supported the lowest final aphid population (32.25±12.45 individuals) This density represented a significant reduction compared to Mornagui (91.50±28.00 aphids), while Vert d'Armenie variety displayed an intermediate response (49.75±15.30 aphids).

In addition to its effect on aphid population dynamics, host plant variety also significantly affected parasitoid development (Fig. 1c). The shortest generation time of *L. testaceipes* was recorded on the Arbi variety, with a mean duration of 11.5 ±0.35 days.

Similarly, host plant variety exerted a significant influence on the mummification success of *L. testaceipes* under no-choice conditions (Fig. 1d). The Mornagui variety showed the highest mummification rate (28.54±3.82%), significantly higher than those recorded on Arbi (8.21±3.75%), and Vert d'Arménie (4.93±3.90%),). In contrast, during choice experiments, no significant differences in mummification rates were detected among varieties.

The adult emergence rate showed contrasting patterns (Fig. 1e). Under choice conditions, significant variations were observed among host varieties. The highest emergence success was recorded on Mornagui (70.75±6.25%) and Arbi (58.50±6.40%), whereas emergence was significantly lower on Vert d'Armenie (27.12±6.32%). In contrast, no significant differences in emergence rates were observed among varieties in the no-choice experiments.

Finally, the progeny sex ratio remained predominantly female-biased, particularly on the Mornagui variety in both choice (75.12±8.40%) and no-choice (78.25±9.15%) experiments (Fig. 1f). While Vert d'Armenie exhibited a trend toward a lower female proportion (down to 24.80±12.30% in no-choice), these variations did not reach statistical significance (p>0.05).

3.1.2. Behavioural responses of *Lysiphlebus testaceipes* to host plant variety

The behavioral responses of *Lysiphlebus testaceipes* were significantly influenced by host plant variety. Abdominal bending was significantly more frequent than antennal and ovipositor contacts on the Arbi variety. No significant differences were observed for antennal contact (F = 2.23, P = 0.147) or ovipositor contact (F = 2.43, P = 0.128) among the varieties (Fig. 2a).

Latency time did not differ significantly among varieties (Fig. 2b). However, the shortest mean latency was recorded on Mornagui (8.75 s), followed by Arbi (31.50 s), whereas the longest latency time was observed on Vert d'Armenie (105.25 s).

The time spent outside aphid patches differed significantly among varieties (Fig. 2c). *L.*

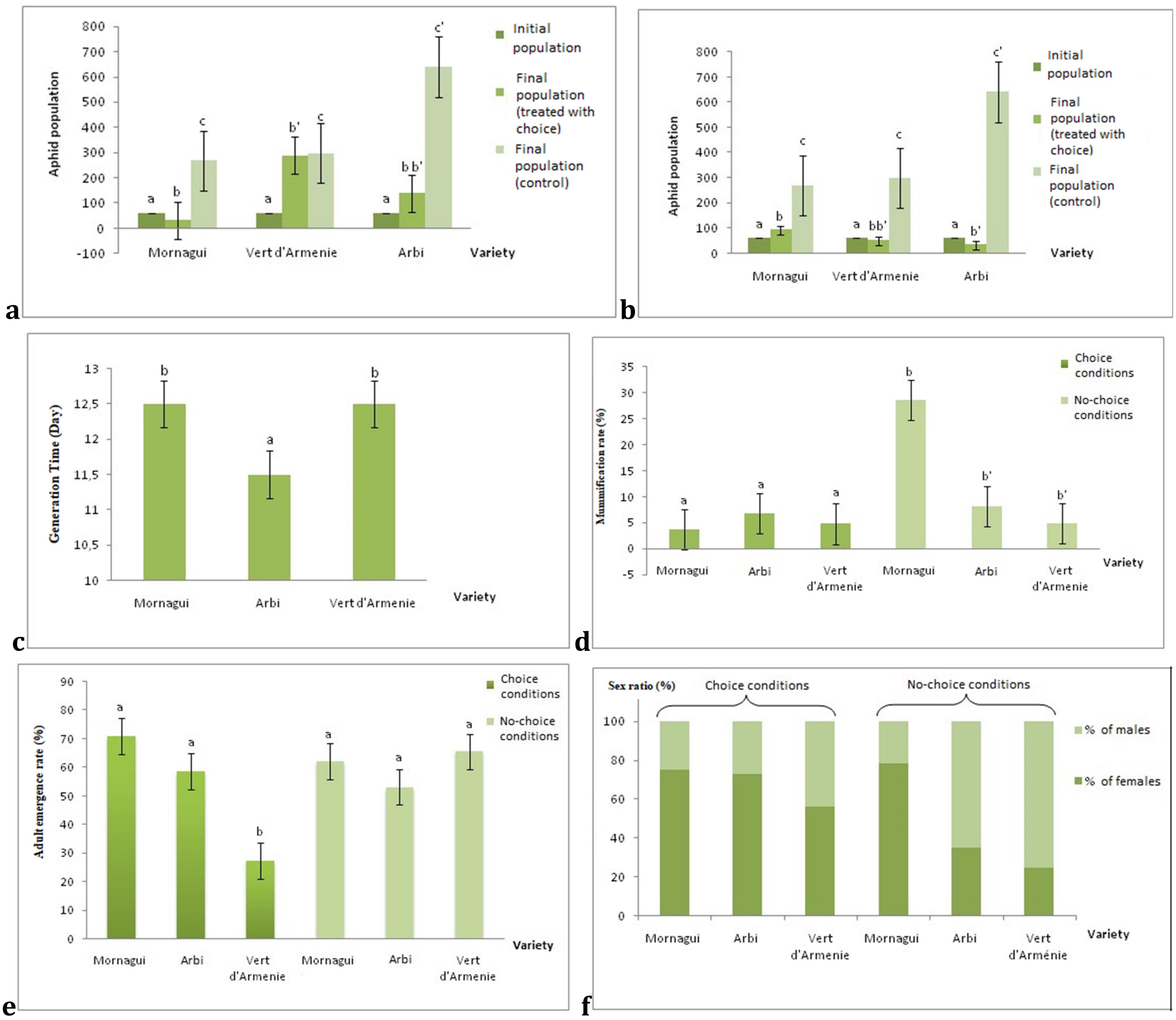

Fig. 1. Effects of host plant variety on the fitness of *Lysiphlebus testaceipes.*

testaceipes spent the shortest time outside patches on Mornagui (278.50±80.6s), which was significantly lower than that recorded on Vert d'Armenie (441.75±85.3 s) and Arbi (566.25± 90.4 s).

Although no significant differences were observed in overall host acceptance among varieties (Fig. 2d), a tendency was observed, with the highest acceptance recorded on Vert d'Armenie (63.47%), followed by Arbi (60.12%), whereas the lowest value was observed on Mornagui (48.03%).

3.1.3. Host Plant Traits

The Arbi variety exhibited a significantly higher chlorophyll content compared to the two other varieties (Fig. 3a). Additionally, our results indicated that Arbi variety had the highest trichome density on both leaf surfaces, with a significant difference compared to the other varieties (Fig. 3b).

3.2. Greenhouse experiments on *Cucumis melo* var. *flexuosus* (Mornagui variety)

3.2.1. Monitoring of *Aphis gossypii* and its natural enemies

Following the monitoring of fakous (*C. melo* var. *flexuosus*) populations in the greenhouses, several biological control agents were identified. Among the parasitoids, *L. testaceipes* was

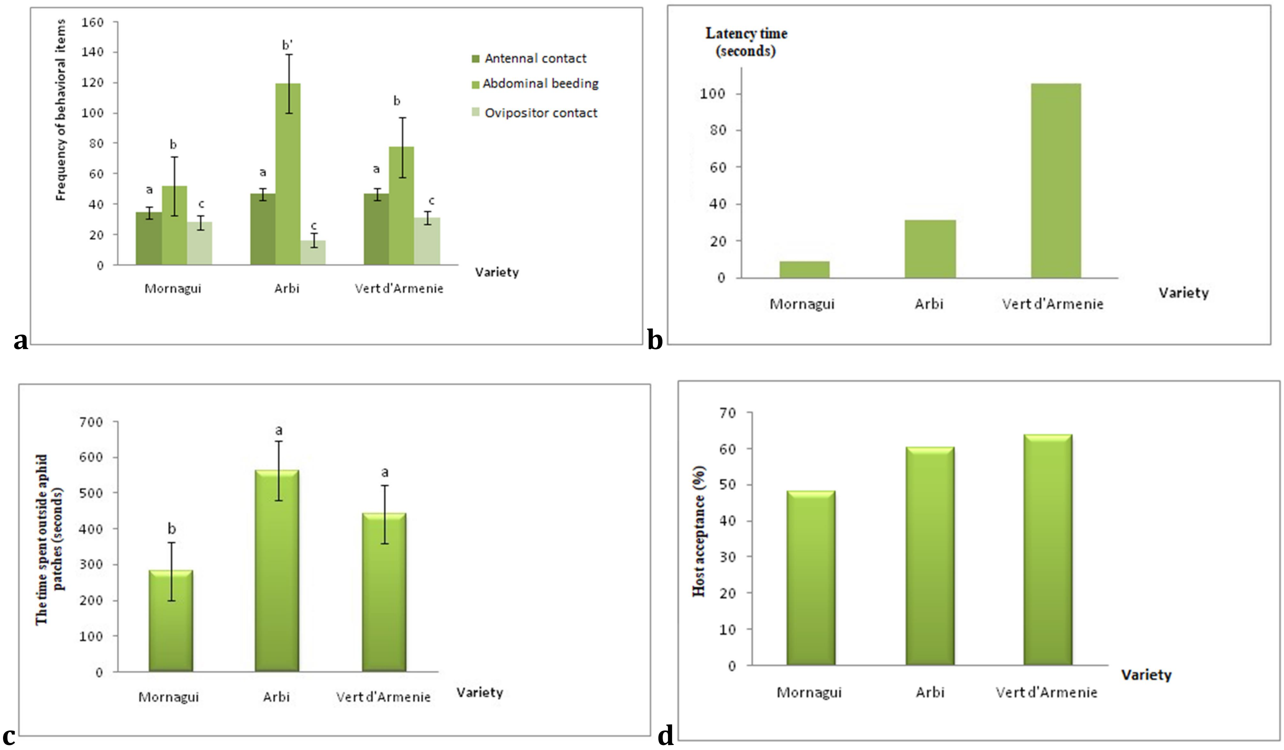

Fig. 2. Behavioural responses of *Lysiphlebus testaceipes* to host plant variety.

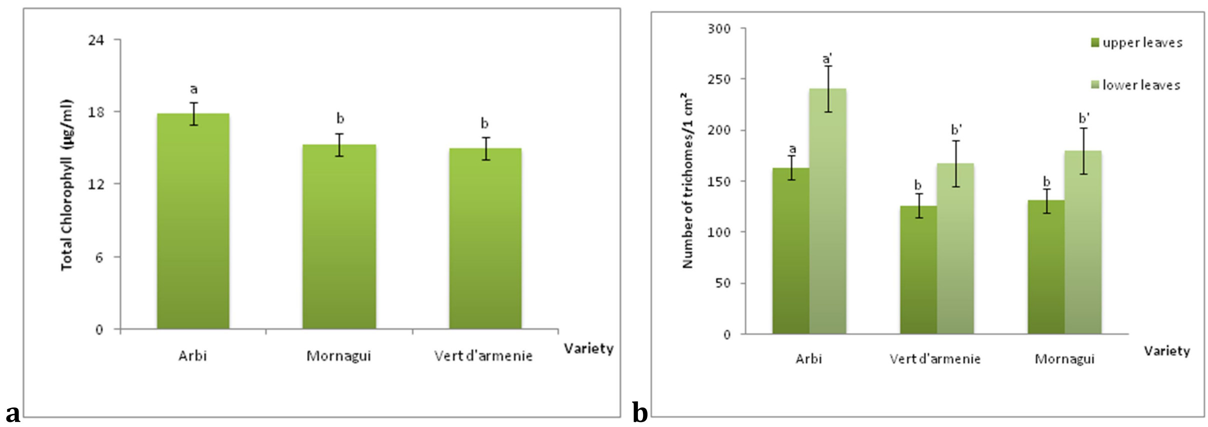

Fig. 3. Host Plant Traits.

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particularly prominent, representing approximately 45% of the total observed natural enemy population. In addition, several natural predators were recorded, including the ladybird beetles *Coccinella septempunctata,* accounting for 25%, and *Hippodamia variegate* for 12%, the lacewing *Chrysoperla carnea* represented 10%, while the predatory bug *Orius laevigatus* accounted for 8% of the natural enemies.

3.2.2. Monitoring of *Aphis gossypii* population dynamics after parasitoid release

Phenological measurements were recorded for various parameters, specifically plant height, total leaf count (distinguishing between infested, curled, and healthy leaves), the number of aphids and mummies present on mature leaves, and leaf dimensions (length and width). The results indicated that both the number of leaves and plant height varied significantly depending on the greenhouse orientation (Table 1).

Table 1. Phenological Characterization of *Cucumis melo* var. *flexuosus* cv. 'Mornagui' under Greenhouse Conditions at the Technical Center of Organic Agriculture (CTAB), Chott Mariem, Tunisia.

Greenhouse Orientation	Plant Height (cm)	Number of Leaves	Leaf Length (cm)	Leaf width (cm)	Number of Branches	Number of Fruits
North	31.50 ± 13.27^{a}	17.00 ± 4.41^{a}	9.50 ± 2.06^{a}	6.85 ± 2.05^{a}	1.70 ± 0.48^{a}	0.30 ± 0.67^{a}
Central	54.88 ± 20.53^{b}	23.00 ± 8.45^{ab}	10.50 ± 2.00^{a}	7.65 ± 1.75^{a}	1.75 ± 0.44^{a}	0.75 ± 0.77^{a}
South	58.00 ± 10.85^{b}	24.00 ± 3.94^{b}	11.20 ± 1.54^{a}	8.40 ± 1.07^{a}	1.80 ± 0.42^{a}	1.00 ± 0.66^{a}
ANOVA	**	*	n.s	n.s	n.s	n.s

*n.s : not significant, * : significant p<0.05, ** : significant p<0.01*

Initial infestation levels exhibited significant spatial heterogeneity, with the southern zone showing the highest aphid density (mean = 2.78 per leaf) compared to the central (1.0) and northern (0.56) zones. This initial distribution was likely influenced by prevailing winds facilitating the dispersal of winged colonizers. By the mid-monitoring period, infestation levels in the central and southern zones had increased substantially (means of 11.78 and 14.11, respectively), remaining significantly higher than in the northern zone (mean = 3.0). However, by the end of the study, the infestation had become generalized across the greenhouse, with no significant differences observed between the three zones

A peak of parasitism was recorded during the fourth week of monitoring, reaching a maximum value of 18.6%. This high level coincided with a high aphid density, which is favorable for parasitoid foraging activity and increased parasitic pressure. These results also suggest a good ecological adaptation of *Lysiphlebus testaceipes* to the microclimatic conditions of greenhouses, thereby reinforcing its potential as an effective biological control agent in protected cropping systems.

4. DISCUSSION

The current study highlights a definitive influence of *C. melo* var. flexuosus varieties on both aphid population performance and the fitness traits of *L. testaceipes*. These findings underscore the critical role of 'bottom-up' effects in shaping host-parasitoid dynamics, emphasizing that varietal selection is a primary driver of biological control efficacy in greenhouse environments.

The lower aphid densities observed on the Arbi variety suggest that this variety possesses strong resistance traits that limit aphid population growth. However, despite active parasitism by *L. testaceipes*, some aphid populations persist. This is explained by the latency period, during which parasitized aphids continue to feed and reproduce before the parasitoid completes development and emerges (Engel *et al*., 2025). This phenomenon highlights that even on resistant plants, parasitized hosts can contribute temporarily to population maintenance.

This underscores the necessity of combining resistant varieties with biological control agents for synergistic pest regulation. Interestingly, the shorter generation time of *L. testaceipes* on Arbi suggests improved host suitability for development, a factor known to enhance parasitoid population growth (Van Steenis, 1994). In contrast, higher mummification rates of *L. testaceipes* on *A. gossypii* individuals on the Mornagui variety under no-choice conditions indicate that parasitoid efficiency is significantly enhanced when host selection is constrained, effectively bridging the efficiency gap reported by Rodrigues and Bueno (2001) (who identified *A. gossypii* as a challenging host compared to *Schizaphis graminum* (Rond.)). Furthermore, parasitoid fitness remains inextricably linked to developmental synchrony; as Vieira *et al.* (2019) demonstrated, 3rd and 4th instar nymphs are superior hosts, yielding larger wasps with higher initial egg loads. The Mornagui variety appears to optimize the encounter with these high-quality stages, thereby maximizing the reproductive potential of *L. testaceipes*.

Finally, host acceptance patterns indicate a strategic divergence: Mornagui appears to elicit a more rigorous evaluation of host quality, whereas Vert d'Armenie promotes more immediate, albeit potentially less selective, oviposition decisions.

Our results indicate that varietal identity modulates both physical accessibility and host-herbivore defensive dynamics. While Hopkinson *et al.* (2013) identified cornicle secretions as a primary deterrent, our study suggests that the 'Mornagui' variety may weaken these defenses or improve physical accessibility via reduced trichome density, thereby increasing patch residence time and oviposition success for *L. testaceipes*. Conversely, the Arbi variety exhibited significantly higher photosynthetic capacity and trichome density. Although high chlorophyll content typically signals a more nutritious host to pests (Everingham *et al.* 2024), the metabolic advantage in Arbi may enhance overall resistance by modulating leaf physical and chemical properties (Goławska *et al.,* 2010; Zhang *et al.,* 2022). Furthermore, the Arbi variety possessed the highest trichome density on both leaf surfaces, a trait strongly associated with resistance in cucumber crops (Zahedi *et al,* 2019). These structures act as physical barriers that damage aphid mouthparts (Nalam *et al.,* 2019; Kabir *et al.,* 2024) and disrupt reproduction. Additionally, glandular trichomes likely provide chemical defenses through the release of flavonoids and alkaloids, which negatively impact aphid reproductive performance (Glas *et al.,* 2012; Madahi *et al.,* 2018). Thus, selecting varieties with optimal chlorophyll and leaf toughness, as suggested by Kim and Lee (2009), remains a critical strategy for improving aphid resistance.

Our findings establish that biological control success in protected environments is a synergistic outcome of cultivar identity, microclimatic synchronization, and thermal buffering. This aligns with Soglia *et al.* (2006) who identified cultivar identity as a primary driver of efficacy, noting parasitism declines (68.4% to 50%) on resistant cultivars; similarly, our observation of variety-specific mummification rates—peaking at 18.6%—confirms that the nutritional and physiological quality of the host, dictated by the plant, directly impacts the third trophic level. Furthermore, our results suggest that favorable host-plant traits in the Mornagui variety may buffer the negative effects of thermal stress. While Satar *et al.* (2018) demonstrated that parasitism on *A. gossypii* (a host requiring 175.44 degree-days) collapses from 70.7% (22°C) to 20.0% (27°C), the sustained efficiency we recorded at 25°C underscores the importance of 'bottom-up' effects. Ultimately, orientation-related microclimatic factors—including solar radiation and light distribution—act as critical agronomic variables that shape these plant-insect interactions, determining the success of IPM in Tunisian greenhouse systems.

5. CONCLUSION

Successful IPM in Armenian cucumber production relies on the optimized interaction between varietal resistance and natural enemy performance. The Mornagui cultivar, in particular, demonstrates a superior capacity to maximize the reproductive potential of *L. testaceipes*. To ensure the long-term sustainability of these strategies, future research should characterize the specific volatile organic compounds (VOCs) mediating parasitoid attraction and validate these tri-trophic dynamics under fluctuating field conditions. Such an integrated approach is essential for the regional scaling of sustainable biological control frameworks across Tunisia.

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