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Population Dynamics and Biological Control of *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) on Greenhouse Tomatoes in the Northern Algerian Sahara

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ABSTRACT

Background: In greenhouse tomato systems, *Bemisia tabaci* is a major pest. Understanding its bioecology is crucial to improve biological control, especially using parasitoids. This study focused on optimizing such strategies under protected cultivation. The research was conducted in the northeastern Algerian Sahara during the 2023-2024 growing season.

Methods: This study investigated whitefly bioecology and the effectiveness of the parasitoid *Encarsia formosa* in greenhouse tomato (var. 'Tofan'). Integrated control strategies, including insect-proof nets, were evaluated. Five parasitoid releases were conducted based on pest developmental stages. The response of four tomato varieties (Tofan, Tavira, Sahra and Zahra) to whitefly infestation was also assessed.

Result: Parasitism rate peaked during the third and fourth developmental stages of *B. tabaci*. Pest populations declined significantly, reaching a parasitism rate of 76.6%. Considering the mean larval infestation level of the whitefly, which is evaluated of 15.01 larvae.plant^{-1}, the corresponding average parasitism rate reached 11.50 parasitoids.plant^{-1}. Parasitism rate showed a significant positive correlation with temperature. No significant relationship was found between parasitism and ambient humidity. However, adult whitefly abundance was positively correlated with relative humidity. Among the four tomato varieties, 'Tofan' had the lowest infestation (5.42±0.21 insects.plant^{-1}), while 'Zahra' showed the highest adult density (11.00±0.42 insects.plant^{-1}).

Key words: *Bemisia tabaci*, Biological control, *Encarsia formosa*, Parasitism, Population dynamics.

INTRODUCTION

Whiteflies (Hemiptera: Aleyrodidae) are one of the major pests of many crops worldwide (Chandrashekar and Shashank, 2017; Seddigh and Kiani, 2012). Whiteflies are responsible for yield losses in pulse crops estimated to range between 30% and 80% (Jain *et al.*, 2025). They feed on more than 900 plant species (Simmons *et al.*, 2008). It transmits viral diseases to several important crops, resulting in severe yield and quality losses (Chandrashekar and Shashank, 2017; Waseem *et al.*, 2020). The sweet potato whitefly, *B. tabaci* (Gennadius), is considered the most devastating pest of various crops worldwide (Güz *et al.*, 2016). *B. tabaci* (Gennadius) (Hemiptera: Aleyrodidae) Mediterranean (biotype B) is a major pest of tomato (*Solanum lycopersicum* L.; Solanaceae) globally (Millán-Chaidez *et al.*, 2021). The whitefly, *B. tabaci*, is a pest known for its significant impact on the development and yield of tomatoes through direct damage (Dimase *et al.*, 2024). *B. tabaci* Middle East-Asia Minor 1 (MEAM1) and Mediterranean (MED), also known as biotypes B and Q, respectively (Kumar *et al.*, 2021). Differences among biotypes are primarily associated with their dependence on bioclimatic conditions, particularly temperature. According to Ghabeish *et al.* (2021), several biotypes have been identified, including biotypes A and B, the Indian biotype and biotypes belonging to the Old-World group. Temperature-dependent relationships were assessed for egg development, egg-to-adult developmental rate, immature mortality, adult longevity, sex ratio, pre-oviposition period and fecundity among the different biotypes (Ghabeish *et al.*, 2021). Some biotypes, such as B and Q, adapt to the same weeds as host plants (Muñiz, 2000). However, the Mediterranean putative species previously known as B biotype which is more aggressive than other biotypes (Ghabeish *et al.*, 2021). Although the excessive and indiscriminate use of insecticides has contributed to increased resistance levels in whitefly populations, insecticides continue to be regarded as an important tool for managing this pest (Singh and Chandi, 2019).

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Some pesticides, such as flunicamide 50 WG at a concentration of 0.0325%, have proven effective against whiteflies, reducing their numbers by 72.19% (Swathi *et al.*, 2018). Although foliar application of synthetic pesticides is essential to effectively control *B. tabaci*, it leads to adverse effects such as environmental pollution, pest resistance and resurgence, toxicity to pollinators and reduced crop yield (Abubakar *et al.*, 2022). Ten populations showed a significantly lower intermediate level of resistance in terms of number of dead adults, eggs, nymphs, new adults and reproductive index compared to the commercial cultivar "Bonny Best" used as a standard (Millán-Chaidez *et al.*, 2021). Whitefly populations in greenhouse tomato systems can be successfully controlled using biological approaches, such as the application of entomopathogenic fungi Pravallika *et al.* (2023), or the release of parasitoid species (Tosh and Brogan, 2015). *Encarsia sp*. is the main natural enemy of the whitefly *B. tabaci* (Gennadius) (Gnankiné *et al.*, 2005). The whitefly *B. tabaci* (Gennadius) is a notoriously devastating sap-sucking insect (Abubakar *et al.*, 2022). The two- and three-parasitoid release treatments reduced the greenhouse whitefly population below the economic damage threshold, with no significant difference observed. These treatments showed a significant difference from the first treatment and the control (Seddigh and Kiani, 2012). The objective of this study is to investigate the mortality rates and population decline of *B. tabaci* exposed to the parasitoid *E. formosa* in a greenhouse tomato crop and studying the sensitivity of four tomato varieties to whitefly attraction in the locality of Djamaa in El Meghaier region, which is an arid region and located in the northern Algerian Sahara (Khechekhouche *et al.*, 2020).

MATERIALS AND METHODS

Experimental site, cultivation techniques and experimental procedures

The study was conducted on a greenhouse tomato production farm in the Djamaa area, located 45 km south of the town of El Meghaier (in El Meghaier province). It is located at an altitude of 31 m and at the Lambert coordinates: 33°35′21.70′N and 6°01′29.00′E. A tomato variety widely grown in greenhouses in the northern Saharan regions of Algeria, namely "Tofan, Sahra, Zahra and Tavira" (Allache *et al.*, 2017; Chougar, 2020).

For cultivation techniques, the study was conducted in two greenhouses, each with a surface area of 500 m^2 (10 m × 50 m). The first greenhouse was cultivated with the Tofan tomato variety and equipped with insect-proof netting. However, a second greenhouse of 500 m^2 was divided into four compartments, in each compartment one variety was planted separately from the other varieties occupying an area of 120 m^2 or 10 m × 12 m. The varieties are "Tofan, Tavira, Zahra and Sahra". The four varieties were planted in the control greenhouse without treatment in order to control the dynamics of whitefly populations on each variety. Following soil preparation by plowing, organic fertilization was applied using dried goat manure and mineral fertilization was supplemented with NPK fertilizer (12-12-36). The nursery was established on 9 September 2023 and seedlings were transplanted to the greenhouse two weeks later. Transplanting was carried out in nine rows spaced 1 m apart, with 1 m between plants. Conventional chemical control was applied three times, at approximately two-week intervals, by foliar spraying of the product. In both greenhouses, the planting density was 0.86 plants per m^2 At a rate of 1 m between the tomato plants and 1 m between the rows. Total number of plants is 432 plant/greenhouse. The release rate per plant was determined by dividing the total number of parasitoids released by the total number of plants. Change style more correctly: Females of *E. formosa* were obtained from a commercial supplier (En-Strip®, Koppert Biological Systems, The Netherlands)., as parasitized black pupae supplied by the National Institute of Plant Protection. According to Table 1 they were released at different stages. The greenhouse treated with *E. formosa* releases was equipped with double protective netting on doors and side openings. In contrast, the control greenhouse was not fitted with protective netting and did not receive *E. formosa* releases or chemical treatments. According to Hoddle *et al.* (1997), the number of *E. formosa* indicated refers to parasitized pupae controlled alive in the laboratory. *E. formosa* pupae were provided as parasitized *B. tabaci* nymphs affixed to release cards. Upon arrival, the cards were placed in Petri dishes to allow adult emergence and thin streaks of honey were applied to the dish lids as a supplementary food source for the emerged wasps. Prior to release, adult wasps were counted in Petri dishes under a dissecting microscope in the laboratory. The dishes were then transported to the greenhouses, uniformly distributed beneath the plant canopy and opened to allow wasp release. This procedure was repeated until the predetermined number of wasps was achieved for greenhouse (Hoddle *et al.*, 1997).

Encarsia formosa cards

Parasitized whitefly pupae collected on specialized cards were stored at -4°C (Seddigh and Kiani, 2012). For the conditions to bring out the adults in the laboratory in petri dishes, at temperatures: 26,61°C (relative humidity (RH): 50±75%, photoperiod: 14L:10D) (Silvia and Botto, 1997). Releases of the parasitoid *E. formosa* were carried out in the greenhouse, with the parasitoids being released in their adult stage. The release dates and the number of *E. formosa* individuals released were recorded (Table 1).

Adult whitefly population dynamics were monitored over time in two tomato greenhouses. In the greenhouse cultivated with four varieties, four yellow pheromone sticky trap were installed, each covering an area of 120 m^2, whereas a single yellow pheromone sticky trap covering 500 m^2 was placed in the greenhouse dedicated to biological control. The traps were suspended 30 cm below

the plant canopy, replaced weekly on a fixed day and returned to the laboratory for enumeration of adult whiteflies. Macfadyen *et al.* (2018) and Omongo *et al.* (2022), they highlighted that the yellow sticky trap is one of the most used methods, especially in large-scale surveillance of *B. tabaci* incidence. The yellow sticky trap is one of the most widely used methods, especially in large-scale monitoring of the incidence of *B. tabaci* (Li *et al.*, 2021). Weekly sampling was conducted from October through the end of the growing season on April 15, 2024, during the 2023/2024 agricultural campaign. For this purpose, ten plants were randomly selected from the greenhouse under biological control using the parasitoid *E. formosa* and ten plants were selected from each plot of the four varieties in the second greenhouse. From each plant, three leaves (from the lower, middle and upper parts of the plant) were gently shaken over a white tray. The dislodged specimens were collected and preserved in plastic tubes containing 70% ethanol, then transported to the laboratory for further analysis. The yellow pheromone sticky traps were transferred to the laboratory, where adult whiteflies were counted under a binocular microscope to monitor their population dynamics over time. Leaf samples were also examined using a binocular microscope to detect and count larvae healthy larvae and parasitized larvae. In addition, whiteflies collected by shaking were counted under the same microscopic conditions. Humidity and temperature monitoring was carried out by hygrometers and thermometers in the middle of the greenhouse. Releases took place once every two weeks, starting 45 days after planting (DAP). On the 24 plants sampled, the pupae and all stages combined were counted, on the first 7 leaves starting from the 1st leaf spread from the apex of the plant, 40-60% of the pupae were distributed at the apex of the plants (De Boisvilliers, 2019).

The rate of whitefly parasitism

The parasitism rate of whiteflies, a key indicator of biological control efficiency, was calculated as the ratio of parasitized pupae (black or yellow) to the total number of pupae (healthy plus parasitized) observed on the lower leaves. According to Sadok (2019) the parasitism rate is determined according to the following formula:

$$PR = \text{Percentage of parasitism} = \frac{A + H}{A + B + H + P + L} \quad ...(1)$$

To calculate the percentage of the regulation rate, the number of predated larvae must be added to the numerator, *i.e.*:

$$TR = \text{Taux de regulation} = \frac{A + H + L}{A + B + H + P + L} \quad ...(2)$$

Where,

A: L2 + L3 + L4 parasitized.

B: L2 + L3 + L4 unparasitized.

H: Exit hole (parasite).

P: Puparia hatched from *Bemisia tabaci.*

L: Predated larvae.

Statistical calculations

An analysis of variance (ANOVA) and T-test were conducted using XLSTAT (version 16) to compare the means of the four varieties. Relationships among the quantitative variables were examined using principal component analysis (PCA). All statistical analyses were performed at a significance level of $P \leq 0.05$. When significant differences were detected, mean values of the measured traits were compared using the least significant difference (LSD) test at the 5% probability level.

RESULTS AND DISCUSSION

According to the results recorded during the vegetative cycle of the tomato crop for the four varieties, it is found that 'Zahra' variety has the greatest sensitivity to whitefly attacks. Tofan has the lowest whitefly attack. However, the other varieties, 'Tavira and Sahra', have average attacks between the two previous varieties, Tofan and Zahra (Fig 1, 2 and 3). The highest number of *B. tabaci* adults on the Zahra tomato variety is 11±0.42 individuals.plant^{-1}. It is 10.34±0.28 individuals.plant^{-1} on the Tavira tomato variety. The lowest number, 5.42±0.21 individuals.plant^{-1} of Tofan is counted and 6.26±0.15 individuals.plant^{-1} on the Sahra variety. The highest numbers of larvae are mentioned with 29.4±0.14 individuals.plant^{-1} on the Zahra variety, 28.30±0.42 individuals.plant^{-1} on the 'Tavira' variety (Fig 2). However, the analysis of variance (ANOVA) at the 0.05 significance level revealed no significant differences among the four tomato varieties with respect to adult *B. tabaci* infestation, larval abundance, or the number of eggs laid per variety. Therefore, it can be concluded that *B. tabaci* showed no preference for any of the tomato varieties. These findings are inconsistent with the observed grafting patterns, as the introduced guava variety Kazipiara exhibited greater susceptibility to whitefly infestation compared with the other varieties (Mannan *et al.*, 2005). These results are consistent with those of Kumar *et al.* (2025) who indicated that whiteflies on four soybean species showed a significant positive correlation with extreme temperature.

The lowest average number of individuals is 0.9±0.11 individuals.plant^{-1} on Tofan, 3.1±0.21 individuals.plant^{-1} on Tavira and 3.7±0.15 individuals.plant^{-1} on Zahra variety (Fig 2).

Table 1: Dates and rates of *E. formosa* parasitoid releases carried out according to the following dates.

Dates	Oct 15, 2023	Nov 15, 2023	Feb 15, 2023	Feb 15, 2024	Mar 15, 2024	Total
Number of parasitoids released	1000	1000	1000	1000	1000	5000
Number of parasitoids per plant	2.31	2.31	2.31	2.31	2.31	11.55

Same observations concerning eggs where the highest numbers were recorded which are 31±0.15 egg.plant^{-1} on Tofan variety, 33±0.24 egg.plant^{-1} on Sahra variety and 39±0.26 egg.plant^{-1} on Tavira variety and 41±0.15 egg.plant^{-1} on Zahra variety (Fig 3).

Attack rates and the presence of all three developmental stages were highest during the spring period, coinciding with the gradual increase in temperatures between mid-February and early April. However, excessively high temperature thresholds affect whitefly development, as

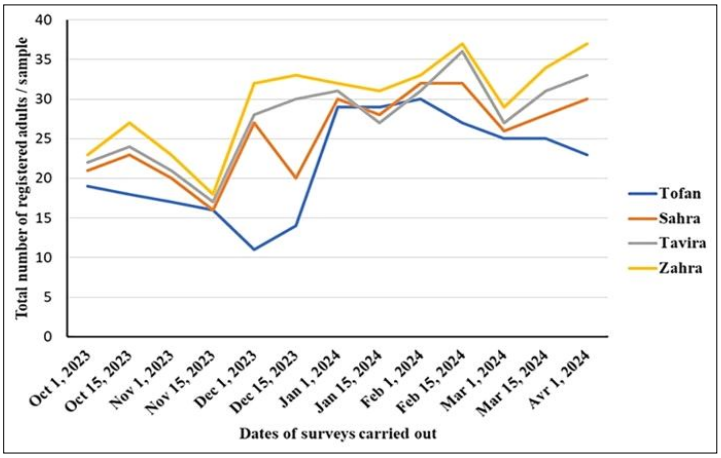


Fig 1: Total numbers of adult whiteflies recorded on the four tomato varieties during the 2023-2024 agricultural season.

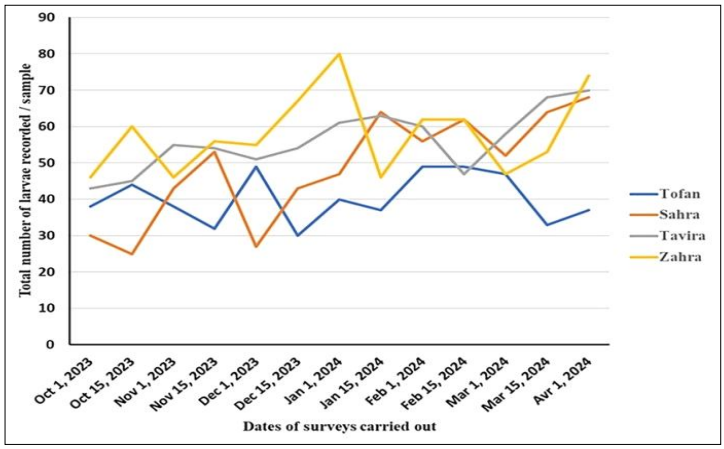


Fig 2: Total numbers of whitefly larvae recorded on the four tomato varieties during the 2023-2024 agricultural season.

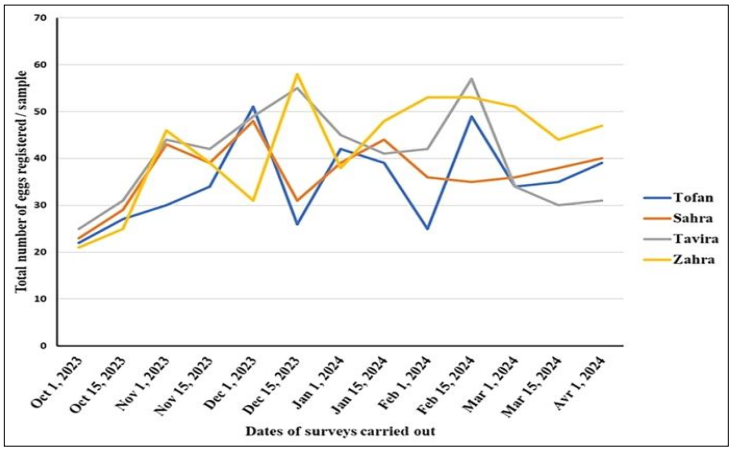


Fig 3: Total numbers of whitefly eggs recorded on the four tomato varieties during the 2023-2024 agricultural season.

reported by Aregbesola *et al.* (2020); Gamarra *et al.* (2020); Khanh and Giang (2021) and Alvarez *et al.* (2025).

Interpretation of biological control results by a parasitoid

The total parasitism rate of *B. tabaci* larvae and pupae by *E. formosa* females during the 2023/2024 growing season was calculated by dividing the number of parasitized pupae by the total number of pupae (healthy + parasitized). This rate reached 76.6%, corresponding to a substantial reduction in *B. tabaci* populations compared with the control greenhouse, which was not equipped with insect-proof nets and did not receive parasitoid releases (Fig 4). This seems to be due to the strong attacks by *B. tabaci* and the temperatures around 28°C during the spring period. Romba *et al.* (2018) reported a significant relationship between parasitism rate and *B. tabaci* larval density. These findings are consistent with those reported by Nunes *et al.* (2006), who observed parasitism rates of 57% by *E. pergandiella* and *E. nigricephala* on squash during the dry season. In tomato crops, the parasitism rate by *E. pergandiella* was approximately 58%. The peak of the numbers is reached in April when there is an increase in the uncontrolled numbers. In contrast, *Eretmocerus mundus* is the most frequently encountered native parasitoid, accounting for approximately 76% of parasitism of the B biotype of *B. tabaci* (Bel Kadhi, 2014). Finaly we can say that temperature also influences insect parasitism, which is a key indicator of the biological control potential of natural enemies (Li *et al.*, 2023). However, the average numbers compared to the control experienced a significant decrease throughout the growing cycle of the tomato crop (Fig 4).

The t-test analysis revealed statistically significant differences between the control group and the group treated with releases of the parasitoid *E. formosa* ($p \leq 0.05$) (Table 2).

A t-test comparing the mean adult *B. tabaci* populations before and after the release of *E. formosa* revealed a statistically significant difference ($p \leq 0.05$). This is consistent with the statements of several authors who have stated that there are decreases in numbers due to parasitoid attacks (Kumar *et al.*, 2021; Nzi *et al.*, 2010; Xiao *et al.*, 2011). These results are consistent with Al-Zyoud (2013) who announced that the correlation between treatments (control, release of *S. parcesetosum* after one

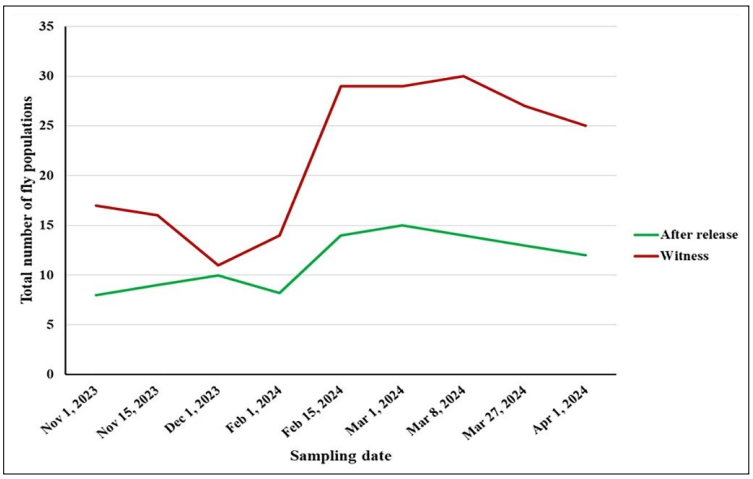


Fig 4: Total number of adults of *B. tabaci* captured during the sampling period (2023/2024), at the control greenhouse and after release of *E. formosa*, in the treated greenhouse at the djamaa site.

Table 2: Equality of expectations test: Paired observations.

	Witness	After release
Moyenne	20,21	7,27
Variance	93,59	6,53
Observations	19,00	19,00
Coefficient de corrélation de pearson	0,76	
Différence hypothétique des moyennes	0,00	
Degré de liberté	18,00	
Statistique t	7,12	
P(T<=t) unilatéral	0,00	
Valeur critique de t (unilatéral)	1,73	
P(T<=t) bilatéral	0,00	
Valeur critique de t (bilatéral)	2,10	

week or two weeks) within each density of *B. tabaci* was calculated by the Pearson correlation method.

Evolution of the parasitism rate

The total number of parasitized during the vegetative cycle of tomato crops recorded a rate of 76.6% at the end of March (Fig 4). This is consistent with the results recorded by Nzi *et al.* (2010) in Ivory Coast where he indicated that the rate of presence of the pest also depends on the variety cultivated and sometimes even on the weeds surrounding these crops (Kumar *et al.*, 2021; Nzi *et al.*, 2010).

Predator abundance at each site influences infestation rates and the percentage of parasitism is not independent but rather associated with predator presence (Álvarez *et al.*, 2021; Wassouf *et al.*, 2022). Similarly, Romba *et al.* (2018) found that whitefly abundance, diversity and parasitism rates varied spatially and temporally, with parasitism which showing a strong density-dependent relationship with whitefly abundance. Similarly, Wang *et al.* (2016) reported that *E. formosa* successfully oviposited and fed on all nymphal stages of *Trialeurodes ricini*. However, in the present study, the hyperparasitoid showed a strong preference for the L3 and L4 larval stages (Fig 5).

Average number of parasitic larvae according to stages

According to Fig 5, we see that the most attacked stages are the last two, the third and the fourth stage, apparently due to the short cycle of *E. formosa*. These results, confirmed by Gnankiné *et al.* (2005) and Sadok (2019), the best rates of parasitism are recorded in the third and fourth larval stages for which the durations of pre-imaginal development are the shortest.

However, these results do not agree with those of Abu-awad and Hamdan (2008) who reported that *B. tabaci* eggs are more attacked than other larval stages. In this case, we note that factors such as high summer temperatures, elevated greenhouse temperatures and extremely low winter temperatures may adversely affect the survival and reproductive capacity of *E. formosa*, thereby influencing its effectiveness in controlling *B. tabaci* (Li *et al.*, 2023). Furthermore, Wassouf *et al.* (2022) demonstrated in their study that a greater abundance of predators was associated with a lower infestation of the olive fly, highlighting the regulatory effect of the predator on the pest.

The importance of abiotic factors

The biplot accounts for 83.03% of the total variability (F1: 45.02% and F2: 38.01%), clearly demonstrating the influence of temperature and humidity on parasitism (Fig 6). Principal Component Analysis (PCA) identified humidity as a key environmental factor affecting parasitic activity. This finding is consistent with conditions in the Mediterranean region characterized by a Saharan bioclimate, where humidity plays a critical role due to low evapotranspiration "ETP" (Zedam *et al.*, 2022). Peak emergence of adult whiteflies occurred between March 15 and April 1, coinciding with favourable bioecological conditions, particularly increased relative humidity typical of the spring season (Aregbesola *et al.*, 2020). In addition, the number of eggs laid and larvae hatched was consistent with the observed parasitism rates and showed a positive correlation with rising temperatures during the period from February 15, to March 1, corresponding to the onset of spring in the Saharan zone (Felicio *et al.*, 2019). This period reflects enhanced insect development under improving climatic conditions. The humidity levels recorded throughout the observed situation shows that there is no correlation with the parasitism rate where this correlation is very weak indicating an R = 0.0101. While the total duration of pre-adult development of *B. tabaci* decreased with increasing temperature, reaching 24.6 and 21.8 days at average temperatures of 21.4°C and 24.6°C according to (Güz *et al.*, 2016).

These results do not agree with those of Hoddle *et al.* (1997) that showed a correlation with temperatures and no correlation with ambient humidity. Temperature has

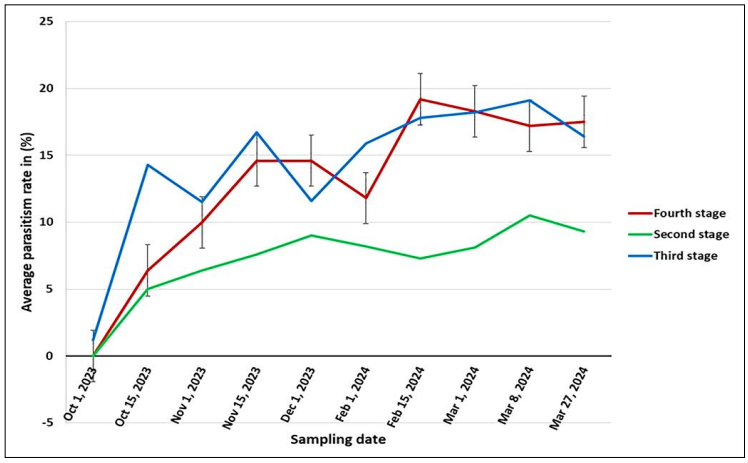


Fig 5: Evolution of the parasitism rate as a percentage of *B. tabaci* larvae and pupae by *E. formosa*, during the 2023-2024 agricultural season.

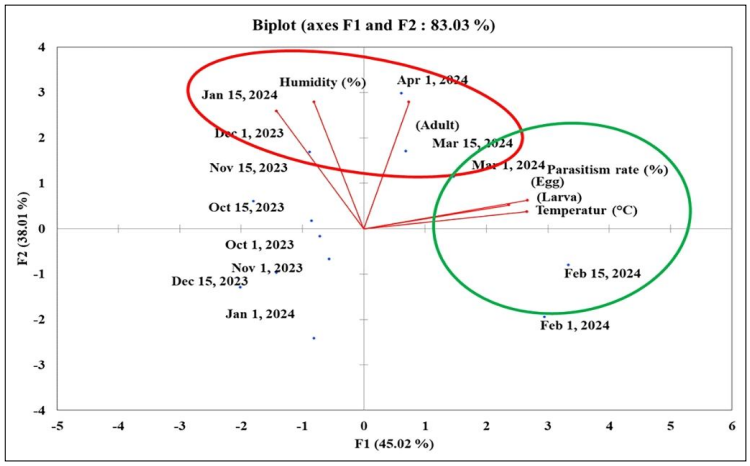


Fig 6: Biplot of the different quantitative variables and the insect stages during the agricultural season: 2023-2024.

significant effects on the development of immature stages and mortality of *B. tabaci* and an inverse relationship between development time and the observed temperature (Güz *et al.*, 2016). Between the development time which would be shorter if observed temperatures were higher In summary, *E. formosa* exhibited early parasitic activity against *B. tabaci* in greenhouse-grown tomato crops under forced agrosystem conditions in the Saharan zone. This activity was strongly associated with environmental factors, particularly humidity and temperature, which played a decisive role in regulating pest parasitism.

CONCLUSION

Integrated biological control using insect-proof nets and E. formosa effectively reduced *B. tabaci* in greenhouse tomatoes. Five releases resulted in an average of 11.55 parasitoids.plant^{-1} which decreased whitefly populations by up to 76.6%. Parasitism was statistically significant, lowering egg, larval and adult densities. Temperature showed a significant positive relationship with parasitism levels. Peak parasitism coincided with major adult whitefly emergence periods. Early parasitoid release is essential to suppress larvae before population outbreaks. Third and fourth larval stages were the most frequently parasitized. Varietal differences were not significant, though 'Tofan' and 'Sahra' showed lower infestation than 'Tavira' and 'Zahra'.

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Conflict of interest

The authors declare that they have no conflict of interest.

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