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Development and Survival of the Whitefly under Contrasting Conditions in a Semiarid Environment

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Abstract

The whitefly *Bemisia tabaci* (Gennadius) Middle East-Asia Minor 1 (MEAM1) (formerly known as biotype B) (Hemiptera: Aleyrodidae) is an economically important pest affecting several crops worldwide. However, information on its biological traits under semiarid conditions remains scarce. This study aimed to assess the developmental duration and survival of the immature stages of *B. tabaci* MEAM1 on melon plants (*Cucumis melo* L.) under contrasting meteorological conditions (dry and rainy periods) in the semiarid region of northeastern Brazil. Melon plants were infested with *B. tabaci* under laboratory conditions and subsequently transferred to the field, where the immature stages developed under natural conditions. The embryonic period lasted an average of 6.6 days during the dry period and 6.9 days during the rainy period. Total nymphal development lasted an average of 12.8 days in the dry period and 14.7 days in the rainy period. Egg hatching did not differ between periods, whereas survival responses during the nymphal stages varied according to developmental transition. Overall, *B. tabaci* developed more rapidly during the dry period, indicating that contrasting meteorological conditions in a semiarid environment can influence immature development and stage-specific survival.

Keywords: bioecology, insect pest, environmental factors, *Cucumis melo*, whitefly

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Desarrollo y supervivencia de la mosca blanca *Bemisia tabaci* bajo condiciones contrastantes en un ambiente semiárido

Resumen

La mosca blanca *Bemisia tabaci* (Gennadius) Middle East-Asia Minor 1 (MEAM1) (anteriormente conocida como biotipo B) (Hemiptera: Aleyrodidae) es una plaga de importancia económica que afecta diversos cultivos en todo el mundo. Sin embargo, la información sobre sus características biológicas bajo condiciones semiáridas sigue siendo escasa. Este estudio tuvo como objetivo evaluar la duración del desarrollo y la supervivencia de las fases inmaduras de *B. tabaci* MEAM1 en plantas de melón (*Cucumis melo* L.) bajo condiciones meteorológicas contrastantes (períodos seco y lluvioso) en la región semiárida del nordeste de Brasil. Las plantas de melón fueron infestadas con *B. tabaci* bajo condiciones de laboratorio y posteriormente transferidas al campo, donde las fases inmaduras se desarrollaron bajo condiciones naturales. El período embrionario duró en promedio 6,6 días durante el período seco y 6,9 días durante el período lluvioso. El desarrollo ninfal total duró en promedio 12,8 días en el período seco y 14,7 días en el período lluvioso. La eclosión de los huevos no difirió entre los períodos, mientras que las respuestas de supervivencia durante las fases ninfales variaron según la transición del desarrollo. En general, *B. tabaci* se desarrolló más rápidamente durante el período seco, indicando que las condiciones meteorológicas contrastantes en un ambiente semiárido pueden influir en el desarrollo de las fases inmaduras y en la supervivencia específica de cada fase.

Palabras clave: bioecología, insecto plaga, factores ambientales, *Cucumis melo*, mosca blanca

Desenvolvimento e sobrevivência da mosca-branca *Bemisia tabaci* sob condições contrastantes em um ambiente semiárido

Resumo

A mosca-branca *Bemisia tabaci* (Gennadius) Middle East-Asia Minor 1 (MEAM1) (anteriormente conhecida como biótipo B) (Hemiptera: Aleyrodidae) é uma praga de importância econômica que afeta diversas culturas em todo o mundo. No entanto, informações sobre suas características biológicas sob condições semiáridas ainda são escassas. Este estudo teve como objetivo avaliar a duração do desenvolvimento e a sobrevivência das fases imaturas de *B. tabaci* MEAM1 em plantas de meloeiro (*Cucumis melo* L.) sob condições meteorológicas contrastantes (períodos seco e chuvoso) na região semiárida do Nordeste do Brasil. As plantas de meloeiro foram infestadas com *B. tabaci* em condições de laboratório e posteriormente transferidas para o campo, onde as fases imaturas se desenvolveram sob condições naturais. O período embrionário durou em média 6,6 dias durante o período seco e 6,9 dias durante o período chuvoso. O desenvolvimento ninfal total durou em média 12,8 dias no período seco e 14,7 dias no período chuvoso. A eclosão dos ovos não diferiu entre os períodos, enquanto as respostas de sobrevivência durante as fases ninfais variaram conforme a transição de desenvolvimento. Em geral, *B. tabaci* apresentou desenvolvimento mais rápido durante o período seco, indicando que condições meteorológicas contrastantes em um ambiente semiárido podem influenciar o desenvolvimento das fases imaturas e a sobrevivência específica de cada fase.

Palavras-chave: bioecologia, inseto-praga, fatores ambientais, *Cucumis melo*, mosca-branca

1. Introduction

In the Brazilian semiarid region, melon [*Cucumis melo* L.] cultivation is an important economic activity, especially in the states of Rio Grande do Norte and Ceará (Gazzola et al., 2020). In 2025, the planted area of melon in this region was approximately 17,200 hectares in Rio Grande do Norte and Ceará, and 1,700 hectares in the Vale do São Francisco. Between August and November, about 121,000 tons of melon were exported. In terms of revenue, exports amounted to US$ 105 million (FOB) ("Anuário 2025-2026", 2026).

One of the main phytosanitary problems in melon-growing areas is the attack of the whitefly (Macêdo et al., 2019). This species is considered a pest of economic importance for several crops in different regions of the world (Abubakar et al., 2022; Yamamoto-Kihara et al., 2025). In melon crops, the damage caused by this pest is associated with sap sucking and virus transmission, compromising photosynthetic processes and resulting in adverse effects on plant development (Abubakar et al., 2022).

The development of the whitefly begins with oviposition on the abaxial surface of the leaves. After hatching, first-instar nymphs are mobile, whereas subsequent instars remain sessile. Adult emergence occurs through a longitudinal opening on the dorsal surface of the last nymphal instar (Gangwar & Gangwar, 2018). Knowledge of the biological cycle of this pest under different climatic conditions throughout the year is essential for the adoption of integrated pest management strategies, as it enables the prediction of the number of generations throughout the crop cycle (Khanh et al., 2021). Under warm climatic conditions, high temperatures tend to accelerate the life cycle of the insect (Chandi et al., 2021). In addition, host plant suitability and environmental variations directly influence pest development and emergence, reinforcing the importance of continuous monitoring (Alvarez et al., 2025; Hyvönen et al., 2021).

The semiarid climate predominates over most of the Northeast region of Brazil and is considered one of the most complex climates in the world due to irregular rainfall (Gomes & Zanella, 2023). This region presents severe climatic conditions, characterized by recurrent drought periods, average annual precipitation equal to or below 800 mm, and high water deficit throughout the year. Mean annual temperatures range from 26 to 28 °C, associated with high solar radiation and low relative humidity, resulting in aridity indices between 0.21 and 0.50 (P/ETP) (Gomes & Zanella, 2023; Lucena et al., 2024; Zanella, 2014). The rainy season generally lasts three to five months, beginning between February and March, while the dry season may last seven to nine months, starting between August and September (Zanella, 2014).

Understanding the influence of climatic factors on insect pest populations provides relevant information on their population dynamics and supports the development of integrated pest management programs (Farias et al., 2020; Khanh et al., 2021). Despite the recognized economic importance of whiteflies for several crops, information on the influence of environmental factors on the biological aspects of this pest is still scarce, especially under Brazilian semiarid conditions. Therefore, the objective of this study was to evaluate the influence of two contrasting meteorological periods (dry and rainy periods) on the duration and survival of the immature stages of *B. tabaci* on melon plants in the semiarid region of northeastern Brazil.

2. Materials and Methods

2.1 Study Area and Climatic Characterization

This study was conducted at the experimental agricultural area of the Federal Rural University of the Semi-Arid (UFERSA) (5°11'15" S, 37°20'39" W), in Mossoró, Rio Grande do Norte, Brazil. The region has a semiarid climate, characterized by hyperxerophytic Caatinga vegetation, high solar radiation levels, maximum temperatures above 30 °C, and low annual precipitation (700-800 mm), concentrated over three to four months of the year (Gomes & Zanella, 2023; Lucena et al., 2024). Rainfall is primarily concentrated in the first half of the year. During the dry period, high temperatures and low relative humidity levels are observed (Zanella, 2014).

The biology of *Bemisia tabaci* was evaluated during two contrasting meteorological periods, hereafter referred to as the dry and rainy periods. The dry-period experiments were conducted from October to December 2019 (egg evaluation: October 27 to November 7; nymphal evaluation: November 19 to December 3), whereas the

rainy-period experiments were conducted from July to August 2020 (egg evaluation: July 9 to 21; nymphal evaluation: July 22 to August 4).

Meteorological data were obtained from automatic weather stations of the Brazilian National Institute of Meteorology (INMET) located in the study region. Hourly records of air temperature, relative humidity, precipitation, and global solar radiation were used to characterize the meteorological conditions of the study periods. Air temperature and relative humidity were expressed as means calculated from the hourly records, precipitation was expressed as accumulated precipitation, and global solar radiation was expressed as the mean of the hourly records. During the dry period, mean air temperature was 27.8 °C, mean relative humidity was 64.5%, accumulated precipitation was 0.2 mm, and mean hourly global solar radiation was 1071.4 kJ m^{-2}. During the rainy period, mean air temperature was 25.8 °C, mean relative humidity was 66.9%, accumulated precipitation was 38.0 mm, and mean hourly global solar radiation was 885.4 kJ m^{-2}.

2.2 Melon Plant Production

Seeds of yellow-type melon of the cultivar Goldmine (Seminis, Campinas, SP, Brazil) were sown in 162-cell polyethylene trays containing coconut fiber substrate (Golden Mix, Amafibra, Ananindeua, PA, Brazil). Seedlings at the two-cotyledon-leaf stage were transplanted into polyethylene pots (10 cm in diameter × 10 cm in height), using the same substrate combined with an organic matter source, Pole (Nibrafértil, Mossoró, RN, Brazil), at a proportion of 75% and 25%, respectively. Irrigation was carried out in the morning and late afternoon. Plants were fertilized three times per week with a mineral fertilizer (nitrogen, phosphorus, and potassium formulation 06-24-12) at a concentration of 5 g L^{-1}, with 40 mL of solution applied per pot.

2.3 Plant Infestation and Experimental Setup

Plant infestation was carried out using a reared population of *B. tabaci* originating from individuals collected in the Mossoró region, Rio Grande do Norte, Brazil. The population was maintained in rearing cages, which, before the experiment, were kept in an area near the greenhouse under local environmental conditions. The population was considered to belong to the Middle East-Asia Minor 1 (MEAM1) group, formerly referred to as biotype B. Twelve-day-old melon seedlings were placed in whitefly rearing cages (61 × 64 × 80 cm) for oviposition for a period of 24 hours.

After oviposition, eggs were marked and counted using a stereomicroscope by examining the abaxial surface of the melon leaves. A total of 390 eggs were marked by circling each egg with a black, permanent, non-toxic marker. Of these, 208 eggs were evaluated on 12 plants during the dry period and 182 eggs on 7 plants during the rainy period. Subsequently, the same procedure was performed to locate and mark the position of first-instar nymphs (newly hatched). A total of 342 first-instar nymphs were initially evaluated, comprising 205 nymphs on 9 plants during the dry period and 137 nymphs on 7 plants during the rainy period. The nymphal evaluation was conducted independently on different plants. The lower number of plants evaluated during the rainy period resulted from plant losses during the experiment. Because these nymphs are initially mobile, they were observed 1 to 2 hours after marking to confirm their presence within the marked area. Eggs and first-instar nymphs were marked on different plants. On each plant, only one leaf was selected for evaluation. The plant was considered the experimental unit for the survival analyses.

To monitor the development of the immature stages of the whitefly under ambient conditions, immediately after egg and nymph marking and counting, the melon plants were transferred to the experimental area. Evaluations of developmental characteristics and final outcomes were conducted until adult emergence, using a stereomicroscope. For this purpose, the plants were transported daily to the laboratory, where they remained for approximately one hour for assessment, and were then returned to the field. The transition between different nymphal instars was identified based on changes in body color, body size, and mycetome size, or by the presence of

exuviae (Figure 1). Individuals that did not complete development or were lost due to displacement were recorded according to their final observed outcome.



Figure 1. *Bemisia tabaci*. (A) Eggs; (B) first-instar nymph; (C) red-eyed nymphs (pupal stage); and (D) puparium/exuvia with an inverted T-shaped opening

2.4 Biological Parameters and Statistical Analysis

The biological parameters evaluated included the developmental time (in days) of the egg and the nymphal stages, the survival rates of each developmental stage, and the total survival rate (%). Developmental time was determined as the number of days spent in each specific stage. For nymphal developmental time, 82 individuals with complete developmental records were included in the analysis, comprising 37 individuals from the dry period and 45 from the rainy period. Nymphal survival was determined for each developmental transition based on the 342 first-instar nymphs initially evaluated, comprising 205 individuals during the dry period and 137 during the rainy period, and survival proportions were calculated for each plant. The ratio between the number of marked eggs and the number of hatched nymphs determined egg survival.

Final outcomes of the initially marked first-instar nymphs were classified as adult, when individuals completed nymphal development and emerged as adults; nonviable nymphs, when individuals remained at the marked location but did not continue development; parasitized, when parasitism was identified; displaced/lost, when individuals disappeared from the marked location; and no determined outcome, when the final outcome of the individual could not be established.

Data normality was assessed using the Shapiro-Wilk test, and homogeneity of variances was assessed using Levene's test. The dry and rainy periods were considered independent groups. Differences between periods were evaluated using the Mann-Whitney U test. All tests were conducted at a 95% confidence level using R software.

3. Results

3.1 Duration of Immature Stages

During the dry period, the mean duration of the egg stage of *B. tabaci* was 6.6 ± 0.7 days, with a median of 7.0 days (Q1-Q3: 6.0-7.0), whereas in the rainy period it was 6.9 ± 0.7 days, with a median of 7.0 days (Q1-Q3: 6.0-7.0). Egg-stage duration differed significantly between the dry and rainy periods (P < 0.001) (Table 1).

The complete nymphal stage mean duration was 12.8 ± 1.4 days during the dry period, with a median of 13.0 days (Q1-Q3: 12.0-14.0), and 14.7 ± 1.6 days during the rainy period, with a median of 14.0 days (Q1-Q3: 14.0-16.0) (P < 0.001) (Table 1).

Table 1. Developmental duration (days) of *B. tabaci* eggs and nymphs on melon plants during the dry and rainy periods in a semiarid environment

Developmental interval	Dry period	Rainy period	P-value
Egg	n = 182	n = 161	<0.001
Mean (SD), days	6.6 (0.7)	6.9 (0.7)	
Median (Q1-Q3), days	7.0 (6.0-7.0)	7.0 (6.0-7.0)	
N1 to adult	n = 37	n = 45	<0.001
Mean (SD), days	12.8 (1.4)	14.7 (1.6)	
Median (Q1-Q3), days	13.0 (12.0-14.0)	14.0 (14.0-16.0)	

Note. For developmental time, n represents individuals with complete records for the corresponding interval. Mann-Whitney U test; significance level α = 0.05.

3.2 Survival of Immature Stages

The survival rate of the egg stage was 87.8 ± 14.6% and 87.9 ± 8.2% during the dry and rainy periods, respectively, with no significant difference (P = 0.500) (Table 2). Survival differed between the dry and rainy periods for the N1→N2 (80.2 ± 8.7% and 43.2 ± 13.5%, respectively; P = 0.001), N2→N3 (91.7 ± 8.4% and 100%, respectively; P = 0.005), N3→N4 (80.2 ± 14.6% and 100%, respectively; P < 0.001), and N4→adult transitions (29.9 ± 26.6% and 79.5 ± 35.9%, respectively; P = 0.012) (Table 2).

Table 2. Plant-level survival (%) across developmental transitions of *B. tabaci* during the dry and rainy periods

Developmental transition	N (plants; individuals: initial → final)	Dry period	Rainy period	P-value
N1 → N2	16; 342 → 222	80.2 ± 8.7	43.2 ± 13.5	0.001
N2 → N3	16; 222 → 208	91.7 ± 8.4	100.0 ± 0.0	0.005
N3 → N4	16; 208 → 178	80.2 ± 14.6	100.0 ± 0.0	<0.001
N4 → Adult	16; 178 → 82	29.9 ± 26.6	79.5 ± 35.9	0.012
Eggs → Hatched	19; 390 → 343	87.8 ± 14.6	87.9 ± 8.2	0.5

Note. N indicates the number of plants and individuals at the beginning and end of each developmental transition. The plant was considered the experimental unit for statistical analysis. Values are mean ± standard deviation. P-values were obtained using the Mann–Whitney U test; significance level α = 0.05.

Regarding the final outcomes of the initially marked first-instar nymphs, the proportion reaching adulthood did not differ significantly between the dry and rainy periods (19.9 ± 19.3% and 33.3 ± 17.5%, respectively; P = 0.150). The proportion of individuals with no determined outcome was higher during the rainy period (66.1 ± 17.9%) than during the dry period (14.9 ± 20.2%; P = 0.003) (Table 3).

Table 3. Final outcomes (%) of initially marked first-instar nymphs (N1) of *B. tabaci* during the dry and rainy periods

Final outcome of N1 nymphs	Dry period (n = 9 plants; N = 205 nymphs)	Rainy period (n = 7 plants; N = 137 nymphs)	P-value
Adult	19.9 ± 19.3	33.3 ± 17.5	0.15
Nonviable nymphs	29.2 ± 18.6	0.6 ± 1.7	0.003
Parasitized	3.1 ± 9.3	0.0 ± 0.0	0.4
Displaced/lost	32.8 ± 14.3	0.0 ± 0.0	<0.001
No determined outcome	14.9 ± 20.2	66.1 ± 17.9	0.003

Note. n indicates the number of plants (experimental units), and *N* indicates the number of first-instar nymphs initially evaluated. Values are mean ± standard deviation of the proportions calculated per plant. P-values were obtained using the Mann–Whitney U test; significance level α = 0.05.

4. Discussion

The variation in egg-stage development time of *B. tabaci* between the dry and rainy periods is likely driven by differences in climatic conditions, particularly temperature, in the semiarid environment. Thus, under Brazilian semiarid conditions, shorter embryonic development of the whitefly can be expected during the dry period, mainly due to higher temperatures during this period. Similarly, the duration of nymphal development was influenced by temperature. Total nymphal development was shorter during the dry period than during the rainy period. Other studies have shown that the development time of immature *B. tabaci* decreases with increasing temperature, ranging from 59.3 days at 16 °C to 16.3 days at 28 °C under constant temperature conditions (Aregbesola et al., 2020).

The shorter total nymphal development observed during the dry period reinforces the influence of temperature on the developmental rate of *B. tabaci*. Higher temperatures can increase insect metabolic activity and consequently accelerate developmental rates. The egg-to-adult cycle of *B. tabaci* reared on melon at 25 °C and 70% relative humidity ranged from 20.2 to 22.1 days (Baldin et al., 2012). However, it is important to note that extreme temperatures exceeding the optimal threshold can slow down or disrupt the life cycle of *B. tabaci*. For instance, Chandi et al. (2021) reported a prolonged life cycle of 30 days at 32 °C and 63 days at 17 °C due to thermal stress.

Although the Brazilian semiarid region is located close to the equator and exhibits limited seasonal temperature variation, the higher mean temperatures during the dry period may contribute to faster development of the whitefly. There is also an optimal range of relative humidity for growth and development, as water is essential for maintaining physiological processes such as digestion, nutrient transport, and temperature regulation. Extremes of humidity have a strong impact, particularly on survival or reproduction. A mean relative humidity of approximately 65% is considered favorable for reproduction, whereas 75% relative humidity is more conducive to adult survival and longevity in whiteflies (Liu et al., 2020). It is essential to note that climatic conditions, including temperature, humidity, and light intensity, are also key factors influencing species distribution and abundance. Although climatic stress generally tends to negatively affect life-history traits, its effects vary according to species adaptation, resulting in different responses depending on the tolerance of whiteflies (Aregbesola et al., 2019).

The survival of the *B. tabaci* egg stage was similar during both dry and rainy periods, with no detectable difference between periods. Buckner et al. (2002) reported that whitefly eggs are attached to leaves by means of a pedicel, allowing them to obtain water or water vapor from the plant to survive. Thus, this protective physiological mechanism likely operated under the field conditions of the present study.

Nymphal survival differed between the dry and rainy periods according to the developmental stage. These differences may be related not only to the direct influence of meteorological conditions, but also to the conditions provided by each period, which may favor different factors affecting survival throughout nymphal development.

The final outcomes of the first-instar nymphs also varied between periods. During the dry period, nonviable nymphs and displacement/loss were more frequently recorded. Displacement/loss may have been associated with factors such as wind, detachment from leaves, and predation by chewing arthropods, whereas during the rainy period a higher proportion of individuals had no determined outcome. Parasitism represented a small proportion of the recorded outcomes. The high proportion of individuals without a determined outcome during the rainy period limits the interpretation of nymphal survival, as their final condition could not be confirmed.

Due to its high thermotolerance, as demonstrated by Muñoz-Valencia et al. (2013), *B. tabaci* is capable of developing under high-temperature conditions typical of hot semiarid regions. This physiological tolerance may contribute to its ability to develop under the environmental conditions observed in the present study. However, the present results are based on one dry and one rainy experimental period at a single location and should not be generalized to population persistence or long-term adaptation in semiarid environments.

In the present study, it was observed that the developmental time of the immature stages of the whitefly was shorter during the dry period than during the rainy period, whereas survival responses varied among developmental stages. These findings should be interpreted within the temporal and spatial limits of the experiment. Future studies should evaluate *B. tabaci* over longer periods under dry and rainy conditions, at additional locations, and under commercial production conditions to determine whether the patterns observed here are consistent across environments and years.

5. Conclusions

Contrasting meteorological conditions influenced the immature development of *B. tabaci* on melon plants. Development was faster during the dry period, whereas survival responses varied according to developmental transition.

Egg hatching was similar between periods, while nymphal transitions showed different responses under dry and rainy conditions. These findings highlight the importance of considering stage-specific responses when evaluating the effects of environmental conditions on whitefly biology in semiarid agroecosystems.

Because some initially marked nymphs were classified as nonviable, displaced/lost, or had no determined final outcome, these categories were analyzed separately. This distinction limits inference about cumulative field survival but provides a more transparent representation of the observed outcomes.

Overall, the study demonstrates that contrasting meteorological conditions can affect developmental rate and stage-specific survival of immature *B. tabaci*. Further studies conducted over longer periods, at different locations, and under commercial production conditions are recommended to confirm the patterns observed in this study.

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Transparency of Data

Available data: The entire data set that supports the results of this study was published in the article itself.

Author Contribution Statement

	JAM Rodrigues	RSM da Cunha	MM de Sousa	EL Araujo
Conceptualization	■			■
Data curation	■			
Formal analysis	■	■	■	
Funding acquisition				■
Investigation	■	■	■	
Methodology	■			■
Project administration				■
Resources				■
Software	■			
Supervision				■
Validation				■
Visualization	■			
Writing – original draft	■			
Writing – review and editing	■	■	■	■

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