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Scientific Article

Comparative biology of mediterranean fruit fly in star fruit and mango

Biologia comparativa da mosca do mediterrâneo em frutos de carambola e manga

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ABSTRACT - *Ceratitis capitata* is a polyphagous species adapted to the most diverse hosts. The life cycle of *C. capitata* is influenced by the host species in which it develops, and information about its biological data in star fruit is scarce. This study aimed to characterize the biological cycle of *C. capitata* in star fruit and mango. Portions of 20 g were offered in Petri dishes lined with moistened filter paper to 20 first-instar larvae up to three hours of age. Evaluations were performed daily, quantifying the period and larval survival, pupal viability and mass (puparia weighed at 24 hours of age), longevity, egg-adult period, and fecundity. Larval survival ranged from 89.75% in star fruit to 94.25% in mango. Pupal viability and mass were higher in larvae fed mango. The length of the larval period was not affected by the food substrate. Total and daily fecundities were higher in females from larvae fed mango. Both fruits allowed the complete development of *C. capitata*, but mango is the most suitable host for its development.

Keywords: *Averrhoa carambola*. *Ceratitis capitata*. Fruit flies. *Mangifera indica*.

RESUMO - *Ceratitis capitata* é uma espécie polífaga, adaptando-se aos mais diversos hospedeiros. O ciclo de vida de *C. capitata* é influenciado pelas espécies hospedeiras em que se desenvolve, e informações sobre seus dados biológicos em carambola são escassas. Este estudo teve como objetivo caracterizar o ciclo biológico de *C. capitata* nas frutas carambola e manga. Porções de 10 g foram oferecidas em placas de Petri forradas com papel filtro umedecido para 20 larvas de primeiro ínstar com até três horas de idade. As avaliações foram realizadas diariamente, quantificando-se o período e sobrevivência larval, viabilidade e massa pupal (pupários pesados às 24 horas de idade), longevidade, período ovo-adulto e fecundidade. A sobrevivência larval variou de 89,75% em carambola a 94,25% em manga, a viabilidade e a massa pupal foram maiores em larvas alimentadas com manga. A duração do período larval não foi afetada pelo substrato alimentar. As fecundidades total e diária foram maiores nas fêmeas de larvas alimentadas com manga. Ambas as frutas testadas permitiram o desenvolvimento completo de *C. capitata*, mas a manga é o hospedeiro mais adequado para seu desenvolvimento.

Palavras-chave: *Averrhoa carambola*. *Ceratitis capitata*. Moscas-das-frutas. *Mangifera indica*.

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INTRODUCTION

Brazil is the third largest fruit producer, with a production of more than 40 million tons, behind only China and India (FAO, 2021). Favorable climate conditions and the availability of areas for cultivation are among the main factors that contribute to the development of fruit trees in Brazil. However, fruit tree orchards can be affected by pests, including fruit flies (Diptera: Tephritidae), which cause direct and indirect losses of approximately US$ 2 billion/year (MACEDO et al., 2017). Direct losses are caused by larvae that feed on the fruit pulp, making them unsuitable for fresh consumption and even industrialization (BADII et al., 2015).

Tephritids are phytophagous insects that can be classified as specialists or generalists. The species *Ceratitis capitata* (Wiedemann, 1824) and some species of the genus *Anastrepha* Schiner (1868) are considered generalists or polyphagous because they present a wide diversity of host fruits, and the geographic distribution and dispersion of these insects are related to the host distribution (DIAS et al., 2013). Thus, a polyphagous insect, with high flexibility of behavior, can maintain a vast number of hosts, including *C. capitata*, which is highly polyphagous (ZUCCHI, 2015).

Discrimination and selection of the appropriate host is an unpredictable behavior in polyphagous and multivoltine insects, such as *C. capitata*. These insects infest other plants when their primary hosts are not available (PEÑARRUBIA-MARÍA et al., 2014).

Adaptation to hosts of the most varied botanical families has been observed for *C. capitata*, according to recent records of its association with quiabento (*Rhodocactus bahiensis* Gürke), forage palm [*Opuntia ficus-indica* (L.) Mill.], and banana (*Musa* spp.), among others (LEITE et al., 2017; SÁ et al., 2019). The association of *C. capitata* with star fruit (*Averrhoa carambola*) is recent in Bahia (SANTOS, 2016; LEITE et al., 2017). Studies on the biology of fruit flies in star fruits are scarce and despite the study by Costa et al. (2011), some aspects of the biology of this host still need to be elucidated and reinforced.

The star fruit tree has been cultivated in many tropical and subtropical countries as a cash crop. Star fruit is widely used in the food industry (instant beverages, jellies, or fresh fruits) and in medicine (LE; PHAM, 2018). Star fruit was introduced in Brazil in 1817 and, currently, the country is one of the main producers in the world, with a production of 1,726 tons, cultivated in approximately 424 hectares, with the states of São Paulo, Paraná, Rio Grande do Sul, Amazonas, and Bahia being the main producers (NATALE et al., 2008, IBGE, 2017).

Mango is the tropical fruit tree that most contributes to Brazilian fresh fruit exports, with 270 thousand tons, and the Sub-Middle region of the São Francisco Valley was responsible for 90% of this production (ABRAFRUTAS, 2022). It is consumed both as fresh fruits and processed as juice, nectar, canned, dried, paste, and flour (LIU et al., 2013; NAMBI; THANGAVEL; JESUDAS, 2015). The state of Bahia is the largest national producer, with 633.151 tons (IBGE, 2021).

Ceratitis capitata has the adaptive capacity to different hosts and, in the absence of the primary host, uses secondary hosts, favoring its maintenance in the available hosts (LEITE et al., 2019). The Mediterranean fly may have different biological characteristics, which are influenced by the host. Therefore, studies on the biology of *C. capitata* in the different available hosts are necessary to establish the best management strategies for this pest. In this context, this study aimed to characterize the biological cycle of *C. capitata* in star fruit and mango.

MATERIAL AND METHODS

The studies were conducted from July to December 2019 at the Laboratory of Fruit Flies of the State University of Southwestern Bahia, under conditions of 25±2 °C, 65±10% relative humidity, and 12 h photophase.

The fruit flies of the species *C. capitata* used in the bioassays came from a hybrid population maintained at the Laboratory of Fruit Flies for 13 years, receiving periodic releases of wild individuals. The adults were kept in acrylic cages (30x30x30 cm), and fed daily a diet based on beer yeasts + sugar and water. *C. capitata* larvae were obtained through the distribution of *C. capitata* eggs in closed plastic containers containing an artificial larval diet kept at a temperature of 25±2 °C, where they remained until the larva reached the desired age.

The experimental design was completely randomized, with two treatments (star fruit and mango) and 20 replications. The biological cycle assessment was performed according to the methodology by Leite et al. (2019). Ripe fruits were peeled, cut, had the seeds removed, and portions of 20 g were offered to 20 first-instar larvae of *C. capitata* (totaling 400 larvae) with up to 3 hours of emergence from the rearing in the laboratory. The fruit portions were placed in Petri dishes (12 cm Ø) lined with moistened filter paper.

The larvae were removed every two days for a new portion of fruit and, after six days, the pieces of fruit containing the larvae were placed in plastic pots with a capacity of 100 mL, containing a thin layer of vermiculite, serving as a substrate for pupation. Daily evaluations were performed to quantify the larval period and survival, viability and pupal mass (puparia weighed at 24 hours of age), larval-adult period, adult longevity, and fecundity.

The longevity of newly emerged fruit flies from each treatment was determined by separating them by treatment and sex into groups of five individuals, with five replications for each sex and treatment, totaling 20 cages and 100 fruit flies. The insects were placed in cages containing moistened cotton and a diet based on sugar and yeast extract (Biones®) at a proportion of 3:1, changed every two days, with daily observations until their death.

Fruit fly fecundity was evaluated in cages (20x10x10 cm), in which 10 couples of each treatment were kept, with 10 replications, totaling 200 fruit flies. In each cage, four grapes (neutral substrate) of the variety Itália were placed in paper cups, arranged in Petri dishes (9 cm Ø) so that the females could lay eggs. The grapes were changed daily until the natural mortality of the fruit flies. Grape sorting was performed daily to count eggs per female.

The results of larval survival, pupal viability, pupal mass, larval and pupal period, and longevity were subjected to normality and homoscedasticity tests and the means were compared by the F-test at a 5% probability. The relationship between the emergence of females and males of *C. capitata* and the food source at the larval stage (mango or star fruit) was tested by regression analysis ($p<0.05$), with the curve-fitting procedure of Table Curve 2D (Systat, San Jose, CA). Model selection was based on parsimony, high values of F (and reduced error), and R^2 (steep), which increased with model complexity. All analyses were performed using the statistical software R Development Core Team version 3.5 (2015).

RESULTS AND DISCUSSION

Larval survival in star fruit and mango was not affected by the food substrate (F-test = 0.05, p = 0.05) (Figure 1A). Two substrates allowed for the development of the larval stage of *C. capitata*. A significant difference was observed for pupal viability. Pupae from mango (90.75% viability) were 13.77% more viable than those from star fruit (78.25% viability) (Figure 1B). In contrast, Costa et al. (2011) reported pupal viability of 60.7% for star fruit as a host. The mean pupal viability of *C. capitata* using grapes ranged from 50 to 60% (CORRÊA et al., 2018; GÓMEZ et al., 2019) and differences observed in the pupal mass of insects that used mango as food during the larval stage and those that used star fruit may be related to variations in *C. capitata* populations, such as nutritional and physicochemical characteristics of the hosts. According to Plácido-Silva, Zucoloto and Joachim-Bravo (2005), foods with low protein content, such as star fruit, reduce the larval size and, consequently, pupal mass. In general, the puparium or mass size is an indication of adult size (LEITE et al., 2019).

Pupal mass was influenced by the food substrate, as the insects that used mango as food during the larval stage presented higher pupal mass, differing from those that used star fruit (Figure 1C). The differences observed in these parameters may be related to variations in *C. capitata* populations, such as the nutritional and physicochemical characteristics of the hosts. In general, the puparium or mass size is an indication of adult size, as observed by Leite et al. (2019).

No significant difference was observed for larval period length (F-test = 0.05, p>0.05) between the two types of fruits (Figure 1D). Both larvae fed mango and those fed star fruit had a mean length of 6.0 days, considering the three larval instars. The pupal stage length ranged from 9.5 to 10.7 days, with a significant difference (F-test = 0.05, p>0.05) between hosts (Figure 1E). Mango was the host that provided the shortest pupal stage length for *C. capitata*. The differences observed in the pupal period length relative to the studied hosts may be associated with the nutritional quality of their fruits. Mango may have provided resources for pupal development in more adequate and sufficient amounts to complete this stage shortly.

The longevity between females and males in both fruit species showed no difference, varying between 40.38 and 52.32 days in star fruit and mango, respectively (F-test = 0.05, p>0.05) (Figures 2A and 2B). The mean longevity of females and males of *C. capitata* was 41.58 and 52.32 days in mango, respectively, and 40.38 and 48.68 days in star fruit, respectively (Figures 2A and 2B).

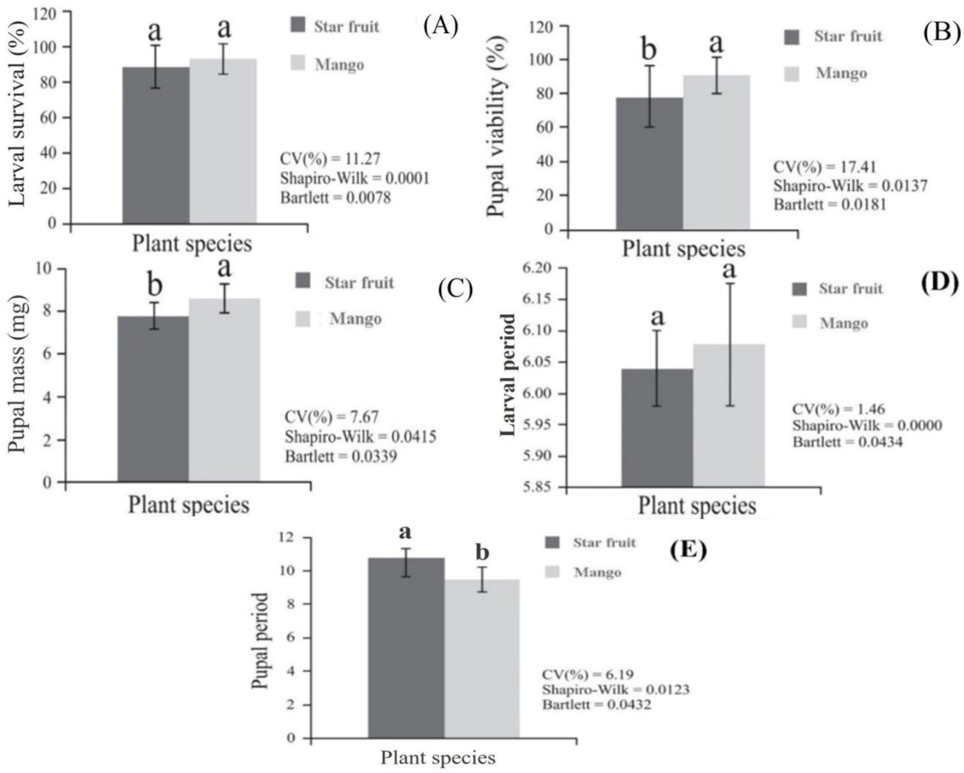

Figure 1. Larval survival (A), pupal viability (B), pupal mass (C), larval period (D), and pupal period (E) of *Ceratitis capitata* in star fruit and mango. Means followed by the same letter in the bars do not differ from each other by the F-test (p<0.05).

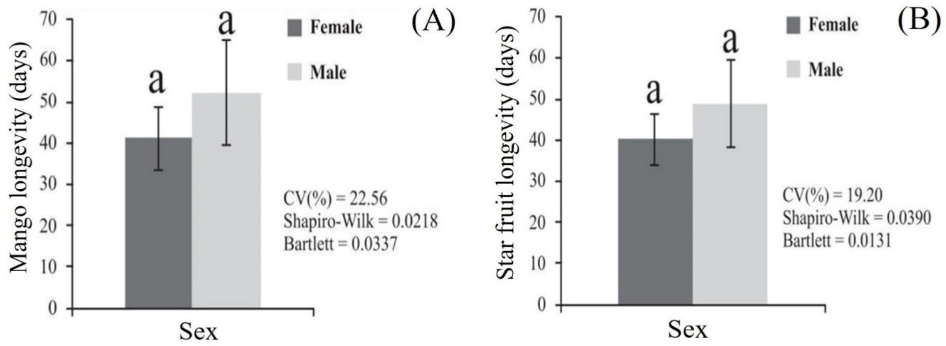

Figure 2. Longevity of *Ceratitis capitata* adults fed mango (A) and star fruit (B) at the larval stage. Means followed by the same letter in the bars do not differ from each other by the F-test (p<0.05).

The cubic model best fitted the emergence curves of females and males in mango ($p<0.05$) (Figures 3A and 3B) and star fruit ($p<0.05$) (Figures 3C and 3D). The largest number of emerged adults, females and males, was verified on the second day after emergence, when star fruit was the host, while the highest number of adults emerged in mango, both females and males, was verified on the third day after emergence. The emergence of females and males in both hosts was similar. The results point to a difference of one day at the peak of emergence. Thus, mango showed the maximum number of adults emerged one day before star fruit and it may have favored a higher number of copulations.

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Total fecundity (eggs/female) and daily fecundity (eggs/female) of *C. capitata* were affected by the host species used during the larval stage, with higher fecundity for females whose larvae fed mango ($p<0.05$) (Table 1).

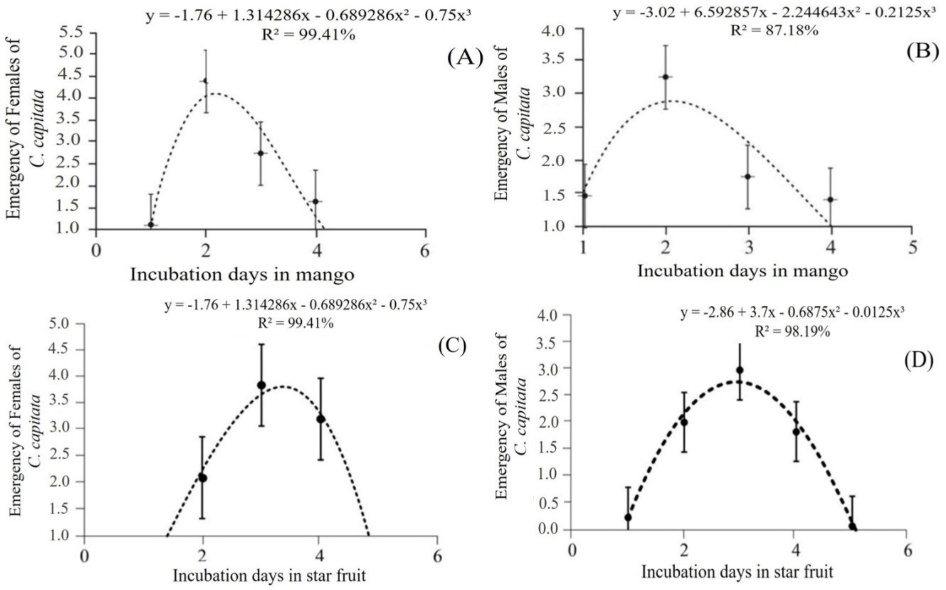

Figure 3. Emergence curves of females and males of *Ceratitis capitata* fed mango (A and B) and star fruit (C and D) at the larval stage ($p<0.05$).

Table 1. Fecundity of females and oviposition period of *C. capitata* fed star fruit and mango at the larval stage.

Host	Total fecundity (eggs/female)	Day fecundity (eggs/female)	Oviposition period (days)
Star fruit	341.31b±55.43	11.30 b	28.25a±2.4
Mango	508.83a±40.81	15.90 a	29.50a±3.0
CV (%)	11.45	41.88	9.35
Shapiro-Wilk	0.0238	0.0000	0.0055
Bartlett	0.0261	0.0237	0.0242

*Means followed by the same letter in the columns do not differ from each other by the F-test ($p<0.05$).

In both cases, the oviposition of females throughout life began on the fifth day after the emergence of adults. The reproductive period (oviposition) varied between 28.25 and 29.5 days, not differing between hosts.

The cubic model best fitted the oviposition data of *C. capitata* from star fruit and mango over 32 days (Figures 4A and 4B). The results show that both fruit species allow the complete development of *C. capitata*, but mango is the most suitable host for its development.

Ceratitis capitata completes the development in mango and star fruit. Mango is one of the preferred hosts by *C. capitata* for oviposition (DIAS et al., 2018; LEITE et al., 2019).

The values observed in this study were higher (larval survival reached 89.75% in star fruit and 94.25% in mango) than those reported by Leite et al. (2019), who verified mean larval survivals of 6.67, 45.83, 64.17, and 82.50% in fruits of quiabento, forage palm, grape, and mango, respectively, while Pacheco (2016) found a mean larval survival of 40.3% for *C. capitata* in grape varieties.

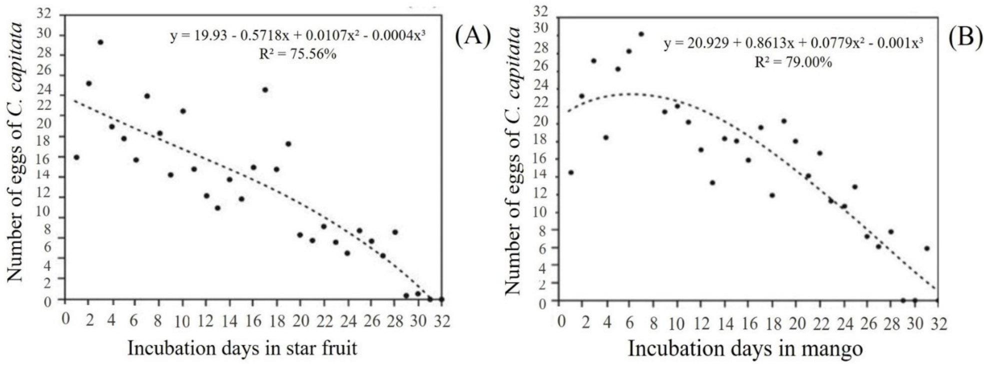

Figure 4. Number of eggs of *Ceratitis capitata* fed star fruit (A) and mango (B) at the larval stage.

A pupal viability from mango of 90.75% was 13.77% more viable than those from star fruit of 78.25% viability, differing from the results observed by Costa et al. (2011), who reported pupal viability of 60.7% for star fruit as a host. The mean pupal viability of *C. capitata* using grapes ranged from 50 to 60% (CORRÊA et al., 2018; GÓMEZ et al., 2019). According to Plácido-Silva, Zucoloto and Joachim-Bravo (2005), foods with low protein content, such as star fruit, reduce the larval size and, consequently, pupal mass. In general, the puparium or mass size is an indication of adult size, as observed by Leite et al. (2019).

Both larvae fed mango and those fed star fruit had a mean length of 6.0 days, considering the three larval instars. Studies evaluating the biological cycle of *C. capitata* in star fruit are scarce, but Leite et al. (2019) reported a mean larval stage length of 8.08 days in mango of the cultivar Palmer, which is longer than that observed in this study.

The difference between hosts in the pupal stage length ranged from 9.5 to 10.7 days. Mango was the host that provided the shortest pupal stage length for *C. capitata*. The differences observed in the length of the pupal period relative to the studied hosts may be associated with the nutritional quality of their fruits. Mango fruit may have provided resources for pupal development in more adequate and sufficient amounts to complete this stage shortly. Kaspi et al. (2002) found that the higher the protein content present in the food ingested during the immature stage, the shorter the insect development time. The pupal stage length of *C. capitata* may vary according to the host. Thus, the quality of food ingested during the larval development period directly influences the insect’s biological cycle, which may result in variations in the number of annual generations, population density, and insect quality (PLÁCIDO-SILVA; ZUCOLOTO; JOACHIM-BRAVO, 2005).

The mean longevity of females and males of *C. capitata* was 41.58 and 52.32 days in mango, respectively, and 40.38 and 48.68 days in star fruit, respectively. However, Costa et al. (2011) reported lower values in star fruit, with mean longevity of females and males of 26.3 and 27.8 days, respectively. Similarly, Leite et al. (2019) observed the mean longevity of adults ranging from 16.92 to 19.67 days in biology studies with quiabento, forage palm, mango, and grape.

Pacheco (2016) evaluated the longevity of males and females in four table grape varieties and observed that the food substrate affected their longevity, with males being longer-lived than females, with values of 55.03 days for females and 111.52 days for males in the Benitaka variety.

The reproductive period (oviposition) varied between 28.25 and 29.5 days, not significantly differing between hosts. Corrêa et al. (2018) observed an oviposition period of 23.9 days when working with “Moscato” grapes.

CONCLUSION

Mango and star fruit allow the complete development of *C. capitata*. The mango tree is the most suitable host for *C. capitata* development.

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