Can the Choice Behavior and Fitness of Tamarixia radiata (Hymenoptera: Eulophidae) be Affected by the Citrus (Sapindales: Rutaceae) Variety Used to Rear the Asian Citrus Psyllid (Hemiptera: Liviidae)?

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Can the choice behavior and fitness of *Tamarixia radiata* (Hymenoptera: Eulophidae) be affected by the citrus (Sapindales: Rutaceae) variety used to rear the Asian citrus psyllid (Hemiptera: Liviidae)?

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**Abstract**

Several studies have shown that the host plant influences the biocological parameters of both pest insects and their natural enemies; however, few studies have evaluated the effect of varieties of the same plant species. This study evaluated the host-choice behavior (by a free-choice test) of *Tamarixia radiata* (Waterston) (Hymenoptera: Eulophidae) on nymphs of *Diaphorina citri* Kuwayama (Hemiptera: Liviidae) reared on 4 sweet orange (Sapindales: Rutaceae) varieties (Hamlin, Pêra, Natal, and Valencia), and its development (biology) in nymphs reared on these same varieties, on a mandarin (cv. Ponkan), and on orange jasmine. The host-choice behavior was not affected by the host on which *D. citri* was reared, showing that *T. radiata* has a degree of plasticity in interpreting the cues for host location. In the free-choice test, the hosts did not affect the percentage of parasitism. The emergence parameter, regardless of the host used, showed viability (egg to adult) above 80% for all varieties, with the highest level for Pêra sweet orange (90.06%). The parasitoid’s development period in nymphs reared on Ponkan (12.4 d) was statistically similar to the period in nymphs reared on orange jasmine (11.80 d) but statistically longer than in nymphs reared on other citrus varieties. No significant difference in the sex ratio was observed. *Tamarixia radiata* as a biological control agent of *D. citri* can be an additional component in integrated pest management in citrus groves. It can be used regardless of the citrus variety, because its behavior and biology are similar for the main commercial varieties of citrus grown in São Paulo.

**Key Words:** biological control; insect–plant interaction; free-choice test; parasitoid; HLB

**Resumen**

Distintos estudios han mostrado la influencia de la planta hospedera en los parámetros biocológicos, no solamente en insectos plaga, sino también en sus enemigos naturales. Sin embargo, pocos han evaluado el efecto de diferentes variedades de la misma especie de planta. Este estudio evaluó el comportamiento de elección del hospedero (por la prueba de libre elección) de *Tamarixia radiata* (Waterston) (Hymenoptera: Eulophidae) en ninñas de *Diaphorina citri* Kuwayama (Hemiptera: Liviidae) criadas en cuatro variedades de naranja dulce (Hamlin, Pêra, Natal y Valencia) y su desarrollo (biología) en ninñas criadas en estas mismas variedades además de mandarina (cv. Ponkan) y naranja jazmín. El comportamiento de elección no fue afectado por el huésped donde *D. citri* fue criada, mostrando que *T. radiata* posee plasticidad en la interpretación de señales para la localización del huésped. En cuanto a la prueba de libre elección, los diferentes huéspedes no afectaron el parasitismo en el ensayo biológico. En el parámetro de emergencia, independientemente del huésped utilizado, todos presentaron viabilidad (huevo-adulto) mayor que 80%, con el mayor valor obtenido para la naranja dulce Pêra (90.06%). Un tiempo de desarrollo más largo fue observado en la mandarina Ponkan (12.4 días) que no difirió estadísticamente de la naranja jazmín (11.80 días), pero fue diferente de las otras variedades de cítricos. No fue observada diferencia significativa en la proporción sexual. El uso de *T. radiata* como agente de control biológico de *D. citri* puede ser un componente adicional en el manejo integrado de plagas en plantaciones de cítricos, porque su uso es posible independientemente de la variedad utilizada, ya que su comportamiento y biología son similares en las principales variedades de cítricos utilizadas en São Paulo.

**Palabras Clave:** control biológico; interacciones insecto-planta; prueba de libre elección; parasitoide; HLB

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"Tamarixia radiata" (Waterston) (Hymenoptera: Eulophidae) is the most important parasitoid of *Diaphorina citri* Kuwayama (Hemiptera: Liviidae), the vector of the bacterium associated with the citrus disease huanglongbing (HLB) (Chen & Stansly 2014). Some studies have found that the development of *D. citri* varies on different host species (Tsai & Liu 2000; Nehru et al. 2004; Na- va et al. 2007; Tsagkarakis & Rogers 2010; Teck et al. 2011; Westbrook et al. 2011) or on different varieties of the same plant species (Alves et al. 2014). Several studies have shown that not only herbivorous insects but also their natural enemies are influenced by the first trophic level (host plant) (Price 1980; Orr & Boethel 1985; Kester & Barbosa 1991; Moraes et al. 2000; Hunter 2003; Kagata & Ohgushi 2006; Malinga et al. 2014).

Tritrophic interactions, which involve plants, herbivores, and natural enemies, are basically determined by 2 factors: 1) the direct effect
of the plant on the behavior or biology of the natural enemy (e.g., the presence or absence of trichomes); and 2) the influence of the plant on the herbivore, also affecting its biology and behavior, which in turn indirectly affects the natural enemy (Bottrell & Barbosa 1998; Legrand & Barbosa 2003; Ode 2006; Bukovinszky et al. 2008). Among the indirect effects on the natural enemy, a major factor is the quality of the host plant, which often affects the size or nutritional quality of the herbivore (Legrand & Barbosa 2003; Harvey 2005; Ode 2006; Bukovinszky et al. 2008). Qualitative and quantitative differences in an herbivore’s diet can affect the performance of the organisms in a food chain (bottom-up effect), mediating interactions involving plants, herbivores, and parasitoids, and even hyperparasitoids (Harvey et al. 2003).

Variations in the quality, composition of secondary defense compounds, volatiles released after herbivory, or even morphological characteristics can differ significantly among plant species as well as among varieties of the same species (Kauffman & Flanders 1985; Hare & Luck 1991; Ode 2006; Ballhorn et al. 2008), and this could change the control efficiency of a natural enemy (Harvey 2005). Also, according to Bukovinszky et al. (2009), variations in the nutritional quality of the plant may affect the immune response of herbivores to parasitoids. These differences increase the complexity of the foraging dynamics and the ability of parasitoids to interpret these signals. However, in some cases, natural enemies show wide behavioral plasticity, especially with respect to learning based on previous experience (Moraes et al. 2000).

Detailed studies on the interactions among T. radiata, D. citri, and citrus varieties are important in order to increase the efficiency of strategies for using this natural enemy as a component of integrated pest management in citrus groves. This study evaluated the host-choice behavior and biology of T. radiata on D. citri reared on several plant species and citrus varieties.

Materials and Methods

INSECT REARING AND PLANT MAINTENANCE

The insects used in this study were obtained from the maintenance rearing colony of the Laboratory of Insect Biology, Department of Entomology and Aacarology, “Luiz de Queiroz” College of Agriculture, University of São Paulo, Brazil.

To rear the psyllids and subsequently their parasitoid T. radiata, we used orange jasmine plants (Murraya paniculata [L.] Jacq.) because this species has been reported to be the preferred host of D. citri (Halbert & Manjunath 2004; Nava et al. 2007; Teck et al. 2011). The plants were maintained in a climate-controlled chamber at a temperature of 25 ± 2 °C, RH of 60 ± 10%, and a photoperiod of 14:10 h L:D. After this period, the parasitoids were removed and the plants maintained in climate-controlled chambers at a temperature of 25 ± 2 °C, RH of 60 ± 10%, and a photoperiod of 14:10 h L:D. To obtain the exact number of nymphs, the same method as in the previous experiment was used. The following parameters were evaluated: parasitism, development time (egg to adult), adult emergence (viability), and sex ratio.

BIOLOGY OF T. RADIATA IN D. CITRI ON VARIOUS HOSTS

For this study, the sweet orange varieties Hamlin, Pêra, Natal, and Valencia, the mandarin variety Ponkan, and orange jasmine were used. Each plant contained fifty 5th instar nymphs of D. citri reared previously on the same host. The nymphs were offered to a pair of T. radiata adults (2 d old) for a period of 24 h in mesh sleeve cages maintained in climate-controlled chambers at a temperature of 25 ± 2 °C, RH of 60 ± 10%, and a photoperiod of 14:10 h L:D. After this period, the parasitoids were removed and the plants maintained under the same conditions.

To obtain the exact number of psyllid nymphs, the same method as in the previous experiment was used. The following parameters were evaluated: parasitism, development time (egg to adult), adult emergence (viability), and sex ratio.

STATISTICAL ANALYSES

Data for viability and development time were analyzed for normality, homoscedasticity, and the presence of outliers by optimal Box-Cox transformation; then, the data were subjected to analysis of variance (ANOVA), and the means were compared with the Tukey test (P ≤ 0.05). The nonparametric chi-squared (χ²) test was used to evaluate the sex ratio.

The data for parasitism were analyzed using generalized linear models (GLM) (Nelder & Wedderburn 1972) through a quasi-Poisson distribution; the F value was calculated by ANOVA of the model. The quality of fit was determined using a half-normal graph of probabilities with simulation envelope (Demétrio & Hinde 1997; Hinde & Demétrio 1998). All analyses were conducted with the aid of SAS® version 9.1 (SAS Institute 2003).

Results

HOST-CHOICE BEHAVIOR OF T. RADIATA FOR D. CITRI NYMPHS REARED ON FOUR CITRUS VARIETIES (FREE-CHOICE TEST)

We used cages (40 × 120 × 40 cm) covered with voile fabric. Each cage contained 1 plant of each sweet orange variety (Hamlin, Natal, Pêra, and Valencia), arranged in a randomized design in the corners of the cage (equidistant from each other). Each plant contained 50 nymphs (5th instar) of D. citri, previously rear on the same variety.
The host-choice behavior of female adults of *T*.* radiata* is directly associated with the release of volatile compounds from the plants that is induced by nymphs of *D. citri* (Mann et al. 2010). According to these authors, the female parasitoids are more strongly attracted to citrus plants infested with nymphs (rather than to plants or nymphs alone), and are attracted by the presence of the greening pathogen (Martini et al. 2014). Variations in several factors, for example volatiles, may show different profiles in varieties of the same plant species (Ballhorn et al. 2008), making foraging and particularly the control exerted by a natural enemy even more complex (Harvey 2005).

The results obtained in this study demonstrated that *T. radiata* has a high plasticity and is able to recognize the induced volatiles released by plants attacked by *D. citri* nymphs, independently of the variety on which the nymphs were reared. The volatile compounds are perceived by different types of antennal sensilla found in *T. radiata*. The number of each type of sensillum differs in males and females, and the most abundant type of sensilla in females is associated with host choice (Onagbola et al. 2009).

In a recent study, Khan et al. (2014) observed that the parasitism level of *T. radiata* was similar between 2 host plant species (on average 26%, for both species), which were the Kinnow tangerine variety and sweet orange. According to Wang & Messing (2004), for parasitoids, the success of the offspring development is strongly influenced by the female’s choice of the most suitable host, especially for idiobiont ectoparasitoids such as *T. radiata*.

Results differing from those of the present study were reported by Paiva & Parra (2012) in field conditions, with respect to the 4 citrus varieties most commonly planted in São Paulo. They observed the highest parasitism on Hamlin (35.6%), followed by Pêra (19.2%), Valencia (8.6%), and Natal (7.3%). These differences may be related to the initial populations of *D. citri* in various areas of the state, or to the large number of volatile compounds in the environment.

**BIOLOGY OF *T. RADIATA* IN *D. CITRI* ON VARIOUS HOSTS**

Artificial selection for new varieties may have changed the chemistry of crop plants, and some cases may alter the performance not only of the herbivores but also of their parasitoids (Gols & Harvey 2009). Therefore, varieties of the same species may also affect parasitoids, either directly or indirectly, in plant-herbivore-parasitoid interactions (Soglia et al. 2006).

On different host plant species or varieties, the performance of a host and its parasitoid can be positive (Harvey et al. 2003; Sznajder & Harvey 2003) or negative (Bottrell & Barbosa 1998; Legrand & Barbosa 2003; Ode 2006), although the adverse effects of food-plant characteristics are usually less pronounced on the parasitoid performance than on the herbivore (Gols & Harvey 2009). This may explain the present

**CHOICE BEHAVIOR OF *T. RADIATA* FOR *D. CITRI* NYMPHS REARED ON FOUR CITRUS VARIETIES (FREE-CHOICE TEST)**

The reproductive success of a parasitoid is defined by its ability to find sexual partners and hosts (Dicke & Grostal 2001). Therefore, knowledge of the factors that influence the host search is important. The host-choice behavior of female adults of *T. radiata* is directly associated with the release of volatile compounds from the plants that is induced by nymphs of *D. citri* (Mann et al. 2010). According to these authors, the female parasitoids are more strongly attracted to citrus plants infested with nymphs (rather than to plants or nymphs alone), and are attracted by the presence of the greening pathogen (Martini et al. 2014). Variations in several factors, for example volatiles, may show different profiles in varieties of the same plant species (Ballhorn et al. 2008), making foraging and particularly the control exerted by a natural enemy even more complex (Harvey 2005).

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**Discussion**

**Table 1.** Mean (± SD) of parasitism rate, survival, development time, and sex ratio of *Tamarixia radiata* reared on *Diaphorina citri* on various host plants (temperature: 25 ± 2 °C; RH: 60 ± 10%; photoperiod: 14:10 h L:D).

| Host          | Parasitism (%) | Survival: egg to adult (%) | Development time: egg to adult (d) | Sex ratio |
|---------------|----------------|-----------------------------|-----------------------------------|-----------|
| Hamlin        | 24.94 ± 2.59 a | 85.04 ± 3.04 a              | 11.52 ± 0.11 b                     | 0.69 ± 0.03 |
| Pêra          | 19.38 ± 2.45 a | 90.06 ± 2.10 a              | 11.37 ± 0.11 b                     | 0.66 ± 0.05 |
| Natal         | 24.25 ± 1.40 a | 85.81 ± 2.58 a              | 11.41 ± 0.09 b                     | 0.74 ± 0.04 |
| Valencia      | 21.87 ± 2.36 a | 88.58 ± 2.75 a              | 11.42 ± 0.14 b                     | 0.68 ± 0.04 |
| Ponkan        | 18.12 ± 1.25 a | 80.75 ± 3.53 a              | 12.04 ± 0.16 a                     | 0.77 ± 0.03 |
| Orange jasmine| 22.75 ± 2.29 a | 85.47 ± 2.47 a              | 11.80 ± 0.12 ab                    | 0.68 ± 0.03 |

Means followed by the same letter in a column do not differ by Tukey’s test (*P* > 0.05).

*non-significant by χ² test.*

**Fig. 1.** Mean percentage (± SE) of parasitism of *Tamarixia radiata* on nymphs of *Diaphorina citri* reared on 4 citrus varieties. Means do not differ by Tukey’s test (*P* > 0.05).
results obtained, that different citrus hosts had no effect on parasitism, viability, or sex ratio.

The effects on biological parameters of the parasitoid *Aphytis melinus* DeBach (Hymenoptera: Aphelinidae) on the California red scale (*Aonidiella aurantii* [Maskell]; Hemiptera: Diaspidae) reared on several cultivars of citrus were very noticeable in the study of Hare & Luck (1991). Among the hosts used, tangerine leaves (*Citrus unshiu* Marco-vicz) were the least suitable for both parasitoid and pest development (Hare & Luck 1991).

The effect of the host plant on the biology of parasitoids was al-
sos observed for other eulophids. Kauffman & Flanders (1985) found reduced egg-to-adult viability of the parasitoid *Pediobius foveolatus* (Crawford) (Hymenoptera: Eulophidae) on larvae of the Mexican bean beetle, *Epilachna varivestis* Mulsant (Coleoptera: Coccinellidae), on certain soybean cultivars. In addition to the egg-to-adult viability, the hosts also affected the insect development time. Similar results were obtained recently for the same parasitoid, *P. foveolatus*, on larvae of *Hemosepilachna vigintioctopunctata* F. (Coleoptera: Coccinellidae) on several eggplant and tomato varieties (Wang et al. 2013). These effects may be due mainly to differences in nutritional requirements and the presence of secondary plant metabolites, which may affect some aspects of the biology of the host and its parasitoid (e.g., parasitism and viability) (Ballhorn et al. 2008; Gols & Harvey 2009; Bukovinsky et al. 2009), altering the control efficiency of the parasitoid (Harvey 2005).

According to Gols & Harvey (2009), adverse effects on the natural enemies may not be directly related only to the quality of the host plant. The effects of trophic interactions on plants are strongly associated with the specificity of the parasitoid (van der Meijden 1996; Szajner & Harvey 2003; Harvey 2005). In specific parasitoids such as *T. radiata*, the biological parameters are little affected by the host herbivore’s diet, be it different plant species or different varieties that may contain secondary compounds (Szajner & Harvey 2003) or be nutritionally inadequate.

Unlike *D. citri*, whose development is affected by citrus species (Tsai & Liu 2000; Nava et al. 2007; Tsagarakis & Rogers 2010; Westbrook et al. 2011) or varieties (Alves et al. 2014), its parasitoid *T. radiata* is not affect-
ed by the host plant, according to the present study. These results may indicate that these parasitoids are able to select those hosts, among the several nymphs (50) offered in this study, that are most suitable for the development of their offspring. This selection occurs because, in insect parasitoids, the fitness of the offspring is affected by the host chosen by the female, particularly in idiobiont ectoparasitoids.

In summary, the results obtained in this study show that only the parasitoid development time was influenced by the host on which *D. citri* was reared. These results are promising because they establish that *T. radiata* can be used to control the Asian citrus psyllid regardless of the variety of citrus, as its host-choice behavior and biology are similar on the main commercial varieties of citrus grown in São Paulo State. *Tamarixia radiata* can be an additional component of integrated pest management in citrus groves. Focusing the releases of the para-
sitoid on organic citrus areas, on urban areas with large populations of an alternate psyllid host (*M. paniculata*), or on abandoned groves can increase the population of the parasitoid for subsequent dispersal to commercial citrus areas (Parra et al. 2010).

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References Cited

Alves GR, Diniz AJF, Parra JRP. 2014. Biology of the huanglongbing vector *Diaphorina citri* (Hemiptera: Liviidae) on different host plants. *Journal of Economic Entomology* 107: 691–696.

Aubert B. 1987. *Triaez eretreae* Del Guercio and *Diaphorina citri* Kuwayama (Ho-

mopteridae: Psyllidae), the two vectors of citrus greening disease: biological aspects and possible control strategies. *Fruits* 42: 149–162.

Ballhorn DJ, Kautz S, Lion U, Heil M. 2008. Trade-offs between direct and indirect defenses of lima bean (*Phaseolus lunatus*). *Journal of Ecology* 96: 971–980.

Bottrell DG, Barbosa P. 1998. Manipulating natural enemies by plant variety selection and modification: a realistic strategy? Annual Review of Entomol-
yogy 43: 347–367.

Bukovinsky T, Van Veen FJ, Jongema RY, Dicke M. 2008. Direct and indirect effects of resource quality on food web structure. *Science* 319: 804–807.

Bukovinsky T, Poelman EH, Gols R, Prekatsakis G, Vet LEM. 2009. Consequences of constitutive and induced variation in plant nutritional quality for immune defence of a herbivore against parasitism. *Oecologia* 160: 299–308.

Chen X, Stanisly P. 2014. Biology of *Tamarixia radiata* (Hymenoptera: Eulophi-
daee), parasitoid of the citrus greening disease vector *Diaphorina citri* (He-

moptera: Psyllidae); a mini review. *Florida Entomologist* 97: 1404–1413.

Demétrio CGB, Hinde J. 1997. Half-normal plots and overdispersion. Glim News-
letter 27: 19–26.

Dicke M, Groatal P. 2001. Chemical detection of natural enemies by arthropods: an ecological perspective. Annual Review of Ecology and Systematics 32: 1–23.

Diniz AJF. 2013. Otimização da criação de *Diaphorina citri* Kuwayama, 1908 (He-

moptera: Liviidae) e de *Tamarixia radiata* (Waterston, 1922) (Hymenoptera: Eulophidae), visando a produção em larga escala do parasitoide e avaliação do seu estabelecimento em campo. Ph.D. thesis, Universidade de São Paulo, Piracicaba, Brazil.

Etienne J, Quilici S, Marvival D, Franck A. 2001. Biological control of *Diaphorina citri* (Hemiptera: Psyllidae) in Guadeloupe by imported *Tamarixia radiata* (Hymenoptera: Eulophidae). *Fruits* 56: 307–315.

Gols R, Harvey JE. 2009. Plant-mediated effects in the Brassicaceae on the performance and behaviour of parasitoids. *Phytochemistry Reviews* 8: 187–206.

Gómez-Torres ML. 2009. Estudios bioecológicos de *Tamarixia radiata* (Water-

ston, 1922) (Hymenoptera: Eulophidae) para el control de *Diaphorina citri* Kuwayama, 1908 (Hemiptera: Psyllidae). Ph.D. thesis, Universidade de São Paulo, Piracicaba, Brazil.

Halbert SE, Manjunath KL. 2004. Asian citrus psyllids (*Stenorrhyncha: Psyllidae*) and greening disease of citrus: a literature review and assessment of risk in Florida. *Florida Entomologist* 87: 330–353.

Hare JD, Luck RF. 1991. Indirect effects of citrus cultivars on life history param-
eters of a parasitic wasp. *Ecology* 72: 1576–1585.

Harvey JA. 2005. Factors affecting the evolution of development strategies in parasitoid wasps: the importance of functional constraints and incorporat-
ing complexity. *Entomologia Experimentalis et Applicata* 117: 1–13.

Harvey JA, Van Dam NM, Gols R. 2003. Interactions over four trophic levels: herbivore quality affects development of a hyperparasitoid as mediated through a herbivore and its primary parasitoid. *Journal of Animal Ecology* 72: 520–531.

Hinde J, Demétrio CGB. 1998. Overdispersion: models and estimation. *Computa-
tional Statistics and Data Analysis* 27: 151–170.

Hunter MD. 2003. Effects of plant quality on the population ecology of parasit-
oids. *Agricultural and Forest Entomology* 5: 1–8.

Kataga H, Ohgushi T. 2006. Bottom-up trophic cascades and material transfer in terrestrial food webs. *Ecological Research* 21: 26–34.

Kauffman WC, Flanders V. 1985. Effects of variably resistant soybean and lima bean cultivars on *Pediobius foveolatus* (Hymenoptera: Eulophidae), a para-
sitoid of the Mexican bean beetle, *Epilachna varivestis* (Coleoptera: Cocc-
inellidae). *Environmental Entomology* 14: 678–682.

Kester KM, Barbosa P. 1991. Behavioral and ecological constraints imposed by plants on insect parasitoids: implications for biological control. *Biological Control* 1: 94–106.

Khan SZ, Arif MJ, Hoddle CD, Hoddle MS. 2014. Phenology of Asian citrus psyllid (*Hemiptera: Liviidae*) and associated parasitoids on two species of *Citrus*, Kinnow mandarin and sweet orange, in Punjab Pakistan. *Environmental Ento-

mology* 43: 1145–1156.

Legrand A, Barbosa P. 2003. Plant morphological complexity impacts foraging efficiency of adult *Coccinella septempunctata* L. (Coleoptera: Coccinellidae). *Environmental Entomology* 32: 1219–1226.

Malinga GM, Valtonen A, Nyeko P, Vesterinen EJ, Roininen H. 2014. Bottom-up impact on the cecidomyid leaf galler and its parasitism in a tropical rainfor-
est. *Oecologia* 176: 511–520.
Mann RS, Qureshi J, Stansly PA, Stelinski LL. 2010. Behavioral response of Tamarixia radiata (Hymenoptera: Eulophidae) to volatiles emanating from Diaphorina citri Kuwayama (Hemiptera: Psyllidae) and citrus. Journal of Insect Behavior 23: 447–458.

Martini X, Pelz-Stelinski KS, Stelinski LL. 2014. Plant pathogen-induced volatiles attract parasitoids to increase parasitism of an insect vector. Frontiers in Ecology and Evolution 29: 2–8.

Moraes CM, Lewis WJ, Tumlinson JH. 2000. Examining plant–parasitoid interactions in tritrophic systems. Anais da Sociedade Entomológica do Brasil 29: 189–203.

Nava DE, Gómez-Torres ML, Rodrigues MDL, Bento JMS, Parra JRP. 2007. Biology of Diaphorina citri (Hemiptera, Psyllidae) on different hosts and at different temperatures. Journal of Applied Entomology 129: 370–384.

Nehru RK, Bhagat KC, Kouli VK. 2004. Influence of citrus species on the development of Diaphorina citri. Plant Protein Science 12: 436–438.

Nelder JA, Wedderburn RWM. 1972. Generalized linear models. Journal of the Royal Statistical Society 135: 370–384.

Ode PJ. 2006. Plant chemistry and natural enemy fitness: effects on herbivore and natural enemy interactions. Annual Review of Entomology 51: 163–185.

Onagbola EO, Boina DR, Herman NSL, Stelinski LL. 2009. Antennal sensilla of Tamarixia radiata (Hymenoptera: Eulophidae), a parasitoid of Diaphorina citri (Hemiptera: Psyllidae). Annals of the Entomological Society of America 102: 523–533.

Paiva PEB, Parra JRP. 2012. Natural parasitism of Diaphorina citri Kuwayama (Hemiptera, Psyllidae) nymphs by Tamarixia radiata Waterston (Hymenoptera, Eulophidae) in São Paulo orange groves. Revista Brasileira de Entomologia 56: 499–503.

Parra JRP, Lopes JRS, Gómez-Torres ML, Nava DE, Paiva PEB. 2010. Bioecologia do vetor Diaphorina citri e transmissão de bactérias associadas ao huan-g longbing. Citrus Research and Technology 31: 37–51.

Price PW, Bouton CE, Gross P, McPherson BA, Thompson JN, Weis AE. 1980. Interactions among three trophic levels: influence of plants on interactions between insect herbivores and natural enemies. Annual Review of Ecology and Systematics 11: 41–65.

Sas Institute. 2003. SAS System: SAS/STAT® Version 9.1. SAS Institute, Inc., Cary, North Carolina.

Soglia MCM, Bueno VHP, Sampaio MV, Rodrigues SM, Ledo CAS. 2006. Desenvolvimento e parasitismo de Lysiphlebus testaceipes (Cresson) e Aphidius colemani Viereck (Hymenoptera: Braconidae) em Aphis gossypii Glover (Hemiptera: Aphididae) em duas cultivares de crisântemo. Neotropical Entomology 35: 364–370.

Teck SL, Fatimah A, Beattie A, Heng RKL, King WS. 2011. Influence of host plant species and flush growth stage on the Asian citrus psyllid, Diaphorina citri Kuwayama. American Journal of Agricultural and Biological Sciences 6: 536–543.

Tsagkarakis AE, Rogers ME. 2010. Suitability of ‘Cleopatra’ mandarin as a host plant for Diaphorina citri (Hemiptera: Psyllidae). Florida Entomologist 93: 451–453.

Tsai JH, Liu YH. 2000. Biology of Diaphorina citri (Homoptera: Psyllidae) on four host plants. Journal of Economic Entomology 93: 1721–1725.