

Suitability as Medfly *Ceratitis capitata* (Diptera, Tephritidae) hosts, of seven fruit species growing on the island of São Miguel, Azores

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Medeiros, A., L. Oliveira & P. Garcia 2007. Suitability as Medfly *Ceratitis capitata* (Diptera, Tephritidae) hosts, of seven fruit species growing on the island of São Miguel, Azores. *Arquipélago. Life and Marine Sciences* 24: 33-40.

Seven species of fruit were selected to study their suitability as hosts to *Ceratitis capitata* (Wiedemann). Suitability was determined by evaluating field infestation rates of different host-fruit and by studying the performance of *C. capitata* reared on these hosts. We sampled old regional cultivars of hot pepper (*Capsicum annum*), loquat (*Eriobotrya japonica*), cattley guava (*Psidium littorale*), sweet orange (*Citrus sinensis*) and mandarin (*Citrus reticulata*); and two introduced fruit plants, feijoa (*Feijoa sellowiana* cultivar Sellwiana) and peach (*Prunus persica* cultivar Robidoux). Of the latter, except for mandarin, fruit contained larvae that pupated and yielded viable adults. In the case of mandarins, larvae were detected but none was able to pupate. The percentage of infested fruit was similar among peach, feijoa, sweet orange and hot pepper and, significantly higher than the other hosts (>60%). The highest mean number of pupae and adults per fruit was observed in peach (18.30 and 17.17, respectively) and the lowest in loquat (4.62 and 3.68, respectively). Host-fruit significantly influenced pupal weight, with heavier pupae (0.0124 g) observed in sweet orange. The shortest pupal development time (9.31 days) was observed in hot pepper, whereas the longest (11.99 days) was in feijoa. Adult emergence rates were generally high (>80%), except for sweet orange. Results showed the most suitable host-fruit for *C. capitata* was peach, followed by cattley guava and feijoa; although loquat and sweet orange were shown to be the less suitable hosts they seem to have an important role as alternative hosts between January and June, allowing the continuous development of *C. capitata* throughout the year.

Key words: Azores, infestation, Mediterranean fruit fly, pupae development

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INTRODUCTION

The Mediterranean fruit fly *Ceratitis capitata* (Wiedemann) (Diptera, Tephritidae), also designated as “medfly”, it is one of the world’s most well-known and damaging pests of fruit crops. It is considered one of the most important fruit pests because it develops in fruit species, most with high commercial value (Liquido et al.

1991). Originally from Africa (White & Elson-Harris 1992), this species extended first to the Mediterranean region during the early 19th century, and from there to the rest of World (Headrick & Goeden 1996). In 1829, MacLeay referred to the presence of *C. capitata* in oranges produced in the Azores and exported to England (Piedade-Guerreiro 1987). *Ceratitis capitata* is a highly polyphagous species, having more than

300 host fruits (Liquido et al. 1990). Among the most frequent host fruit species of the medfly, the following stand out: from Rosaceae, plums (*Prunus domestica*), peaches (*Prunus persica*), apples (*Malus sylvestris*); from Rutaceae, oranges (*Citrus sinensis*), sweet lime (*Citrus aurantifolia*), grapefruit (*Citrus paradisi*); from Rubiaceae, coffee (*Coffea arabica*); from Anacardiaceae, mango (*Mangifera indica*); from Myrtaceae, feijoa (*Feijoa sellowiana*); from Lauraceae, avocado (*Persea americana*); and, from Caricaceae, papaya (*Carica papaya*) (Krainacker et al. 1987; Fimiani 1989; Zucoloto 1993a; Carvalho & Aguiar 1997; Papadopoulos et al. 2002; Ovruski et al. 2003; Medeiros 2005).

The nutrition of tephritid fruit flies in the larval stage is considered very important, since nutrients are required, qualitatively and quantitatively, not only to provide energy and building material for survival, growth and development, but also for stored nutrients to be utilized in the pupal stage (Tsitsipis 1989). Insect diets can affect their performance, either when provided during the pre-imaginal stages (adult emergence, female size, pre-oviposition period, larval development time) and adult stages (oviposition period, egg production, sexual acceptance, adult longevity), as observed by Tsitsipis (1989), Chan et al. (1990), Zucoloto (1991; 1993a, b) and Cangussu & Zucoloto (1997), among others.

In this study the suitability of seven species of fruit as hosts to *C. capitata* was evaluated by comparing the infestation rates under field conditions and by studying the performance of *C. capitata* (pupal weight, pupal development, pupae and adults per fruit, adult emergence and sex ratio) when reared on these hosts.

MATERIAL AND METHODS

Studies were carried out during 2003 on São Miguel Island (37°42', 37°55'N latitude, 25°09', 25°41'W longitude and 58 - 140 m altitude), Azores. Seven fruit species were selected by their economic importance and damage potentially caused by *C. capitata* to: cattley guava (*Psidium littorale* old regional cultivar, Myrtaceae), feijoa (= pineapple guava) (*Feijoa sellowiana* cultivar

Sellwiana, Myrtaceae), loquat (*Eriobotrya japonica* old regional cultivar, Rosaceae), peach (*Prunus persica* cultivar Robidoux, Rosaceae), hot pepper (*Capsicum annuum* old regional cultivar, Solanaceae), sweet orange (*Citrus sinensis* old regional cultivar, Rutaceae) and mandarin (*Citrus reticulata* old regional cultivar, Rutaceae). Every week, in insecticide free orchards and during fruit harvest (see Table 1), samples of ripe and semi-ripe fruit were randomly taken from trees, as well as of some fruit that had recently fallen, to determine infestation by allowing the medflies to develop. Sweet orange fruit were only collected during the last three weeks of fruit maturity, i.e., May-June. For each species, fruit were always collected from the same orchard and immediately brought to the laboratory. The number of fruit collected each week per host, depended on their size and their production on the trees (see Table 2). A random sample taken from the harvested fruit was weighted using a scale Precisa 404 M SCS (see Table 2). In the laboratory, each fruit was placed in a plastic container on a 3 cm layer of dry sand, to hold the exudates dripping from the rotting fruit and to serve as pupation area for mature larvae as they leave the fruit. Fruit were held inside a climatic chamber at 25±2 °C, with a photoperiod of 14L: 10D, while humidity was kept at 70±5 %. Each day, all fruits were checked to collect and count the emerging mature larvae and pupae by sieving the sand. Then, insects were placed in small plastic containers on a 3 cm stratum of dry sand, in which larvae pupated. Each plastic container was covered by a nylon cloth and checked every day until adults emerged. This methodology was adapted from Papadopoulos et al. (2001a, b). Pupae less than 24 hours old were weighed using a precision scale MOD. 40 SM - 200 A.

The following parameters were recorded: pupal weight, pupal development times (male and female), number of pupae per fruit, number of adults per fruit, adult emergence rate and sex ratio (number of females/total number of adults).

STATISTICAL ANALYSIS

Samples were first described with regular averages and standard errors. To homogenize the variances, data concerning the percentages of

fruit infestation (i.e., fruit with larvae of *C. capitata* that pupated) and adult emergence were transformed by $\arcsin\sqrt{x}$ and, fruit weight, pupal weight, pupal development times, number of pupae per fruit, number of adults per fruit and sex ratio were transformed by $\sqrt{x+0.5}$ (Zar 1996). Analyses of variance (ANOVA) were conducted on all data regarding performance parameters, followed by Scheffé tests with $P<0.05$, except for comparisons between pupal development times of each sex for each host-fruit, which were analyzed using *t*-tests. Percentage of infested fruit was analyzed using a Multiple Comparison test for Proportions (Zar 1996). A Pearson correlation was performed between mean fruit weight and mean number of pupae per fruit. All analyses were performed using SPSS 10.0 Windows (SPSS Inc. 1999). Using PRIMER 5 for Windows (Clarke & Warwick 2001), a hierarchical analysis was performed to compare host suitability using group-average clustering from Bray-Curtis similarities on square root transformation data corresponding to pupal weight, pupal development times, number of pupae per fruit, number of adults per fruit, adult emergence rate and sex ratio.

RESULTS

The production times of the seven fruit species examined in this study covered almost the entire year (Table 1). This fact, associated to the temperate climate of the Azorean islands allows *C. capitata* to be present year-round in the archipelago.

Our results demonstrated that all fruit species were infested by *C. capitata*. However, larvae

that pupated and yielded viable adults were only observed in six (hot pepper, loquat, feijoa, peach, guava and sweet orange); in the case of mandarins, larvae were detected but none was able to pupate.

The percentage of fruit infestation was similar for peach, feijoa, sweet orange and hot pepper. This was significantly higher (over 60 %) than for the other hosts; significantly lower infestation rates were recorded in loquat and cattley guava ($P<0.05$) (Table 2).

The mean number of pupae per fruit was very irregular, differing significantly ($F=48.03$; $df=5, 992$; $P<0.00$) between host-fruit species (Table 3). The highest mean number of pupae per fruit was observed in peach (the heaviest fruit, Table 2). Significantly fewer pupated from the other hosts, cattley guava, feijoa, sweet orange and hot pepper (Table 3). The lowest mean number of pupae per fruit, and significant different from the others, was observed in loquat, one of the two lightest fruit (Table 2 and 3). However, no significant correlation was observed between mean fruit weight and mean number of pupae per fruit ($R^2=0.75$; $df=6$; $P=0.09$). Similar results were observed when regarding the highest and lowest mean numbers of adults per fruit ($F=58.05$; $df=5, 992$; $P<0.00$) (Table 3). In general, adult emergence rates were high (over 80%), except in sweet orange where the emergence was significantly lower (i.e. 53.92%). Nevertheless, significant differences ($F= 41.37$; $df=5, 992$; $P<0.00$) were observed among the remaining host fruit, with feijoa, peach and cattley guava having the higher emergences of fruit flies (Table 3). The sex ratio of *C. capitata* was similar among all host-fruit species

Table 1. Ripening periods (shaded areas) of the studied host fruit of *C. capitata* in S. Miguel island.

Fruit fly host plant species	Months											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
<i>Citrus</i> spp	■	■	■	■	■	■	■	■	■	■	■	■
<i>Eriobotrya japonica</i>			■	■	■	■	■	■	■	■	■	■
<i>Prunus persica</i>								■	■	■	■	■
<i>Capsicum annuum</i>								■	■	■	■	■
<i>Psidium littorale</i>										■	■	■
<i>Feijoa sellowiana</i>										■	■	■

Table 2. Number of collected fruit, number of sampled weeks and percentage of fruit infestation (with larvae that pupated) by *C. capitata* in six host fruit species.

Fruit fly host plant species	No. of collected fruits	No. of weeks collected	Fruit mean weight (g) a	% of fruits yielding pupae b
<i>Capsicum annuum</i>	326	7	51.95c	61.96a
<i>Citrus sinensis</i>	59	4	159.32b	66.10a
<i>Eriobotrya japonica</i>	502	8	20.29de	40.84b
<i>Feijoa sellowiana</i>	1027	11	28.43d	68.74a
<i>Prunus persica</i>	240	5	250.70a	69.17a
<i>Psidium littorale</i>	669	13	14.18e	24.96c

Values in the column that are followed by a different letter are significantly different (^a $P < 0.05$, Scheffé tests; ^b $P < 0.05$, Multiple Comparison test for Proportions).

($F=0.43$; $df=5,959$; $P=0.83$), with like percentages of females and males (Table 3).

Host fruit species also significantly influenced the pupal weight of *C. capitata* ($F=838.87$; $df=5, 294$; $P < 0.00$), with significantly heavier pupae when the host was sweet orange followed by feijoa and peach (Table 3).

Pupal development time also depended on host fruit species, but varied significantly ($F= 102.18$; $df=5, 1631$; $P < 0.00$). The shortest pupal development time was observed for *C. capitata* grown on hot pepper and, the longest on feijoa, followed by sweet orange (Table 4). No differences were observed for pupal development times between males and females developing in each host fruit species, except when the hosts were feijoa or loquat ($t=-2.290$; $df=223$; $P=0.023$ and $t=-2.691$; $df=345$; $P=0.007$), where female pupae developed slower than males (Table 4).

The hierarchical analysis showed a high similarity between feijoa and cattley guava (86.5 %) and, hot pepper and loquat (86.0 %); peaches were separated from the other five fruit-host species, with only 80.3 % of similarity (Figure 1).

Table 3. Mean (\pm SE) number of pupae and adults obtained per fruit, emergence rate and sex ratio of the adults, and pupal weight of *C. capitata* observed in six host fruit species.

Fruit fly host plant species	N	Mean no. of pupae per fruit	Mean no. of adults per fruit	Emergence rate	Sex ratio	Pupal	
						N	weight (mg)
<i>Capsicum annuum</i>	202	7.11 \pm 0.41b	5.85 \pm 0.35c	83.81 \pm 0.2b	49.39 \pm 0.02a	50	10.79 \pm 0.19c
<i>Citrus sinensis</i>	39	7.15 \pm 0.78bc	4.00 \pm 0.49cd	53.92 \pm 4.24c	49.17 \pm 4.63a	50	12.39 \pm 0.10a
<i>Eriobotrya japonica</i>	205	4.62 \pm 0.24c	3.68 \pm 0.20d	80.82 \pm 0.02b	47.92 \pm 0.02a	50	9.05 \pm 0.21d
<i>Feijoa sellowiana</i>	220	9.24 \pm 0.51b	8.87 \pm 0.49b	95.60 \pm 0.01a	48.58 \pm 0.02a	50	12.15 \pm 0.15b
<i>Prunus persica</i>	166	18.30 \pm 1.31a	17.17 \pm 1.28a	93.20 \pm 0.01a	49.08 \pm 1.75a	50	11.62 \pm 0.16b
<i>Psidium littorale</i>	166	9.42 \pm 0.55b	8.94 \pm 0.55b	94.44 \pm 0.02a	52.24 \pm 0.02a	50	10.51 \pm 0.15c

Means in each column that are followed by a different letter are significantly different ($P < 0.05$, Scheffé tests).

DISCUSSION

Ceratitis capitata was able to complete the preimaginal development in hot pepper, loquat, feijoa, peach and cattley guava. Although *C. capitata* is reported as a key pest of citrus in tropical production areas (Dolinski & Lacey 2007), the absence of pupae in mandarin fruit may be due to the mesocarp and flavedo thickness of the varieties produced in Azores. According to Papadopoulos et al. (2002), fruit mesocarp thickness affects the larval developmental duration and survival of *C. capitata*. Aluja et al. (2003) showed that when *Anastrepha fraterculus* (Diptera, Tephritidae) oviposited into two citrus fruit no larvae developed in oranges or, of the few that developed or pupated in grapefruit very few adults survived. According to these authors the latter facts could be explained by the thickness of the flavedo of studied fruit varieties. Loquat has been described as a host for *C. capitata* in the tropics (Eskafi & Kolbe 1990; Liquido et al. 1990), Madeira Island (Pereira et al. 2000), northwestern Argentina (Ovruski et al. 2003) and, as shown in this study, in Azores. However, in other localities as Algarve (south Portugal; Entrudo-Fernandes et al. 2000) and Thessaloniki (northern Greece; Papadopoulos et al. 2001a), no infestation by medfly were observed in this fruit. Papadopoulos et al. (2001a) suggested that differences in loquat infestation may be due to the low adult population densities of *C. capitata* at the time when loquats ripen, the particular characteristics of the varieties cultivated in an

Table 4. Mean (\pm SE) pupal development time (M+F) and, male and female pupal development times of *C. capitata* grown in six host fruit species.

Fruit fly host plant species	N	Pupae develop. time	N (males)	Pupae dev. time (males)	N (females)	Pupae dev. time (females)
<i>Capsicum annuum</i>	348	9.31 \pm 1.81e	180	7.22 \pm 1.77A	168	9.44 \pm 1.77A
<i>Citrus sinensis</i>	154	11.37 \pm 0.04b	75	11.36 \pm 0.04A	79	11.38 \pm 0.04A
<i>Eriobotrya japonica</i>	347	10.52 \pm 0.73c	179	10.42 \pm 0.73A	168	10.63 \pm 0.71B
<i>Feijoa sellowiana</i>	225	11.99 \pm 0.99a	128	11.87 \pm 0.93A	97	12.16 \pm 1.05B
<i>Prunus persica</i>	309	10.16 \pm 1.99d	160	9.98 \pm 1.99A	149	10.36 \pm 1.99A
<i>Psidium littorale</i>	254	10.48 \pm 1.79cd	117	10.41 \pm 1.82A	137	10.54 \pm 1.77A

Means followed by different letters within a column (a-e) or within a row (A-B) are significantly different ($P < 0.05$, Scheffé tests and *t*-tests, respectively).

area, and the presence or absence of other preferred host fruit. According to Ovruski et al. (2003) loquat seems to play a critical role as alternative host between May and September, which is the time of the year when the preferred hosts are not available in Northwestern Argentina as happens in Azores between Mars and June.

Results showed that host fruit species can influence the number of pupae and adults per fruit, pupal weight, pupal development times and adult emergence rate of *C. capitata*. In this study, the most suitable host for *C. capitata* was peach (the heaviest fruit of this study), which presented the maximum number of pupae per fruit and a considerable pupal weight. Similar results were observed in other countries as in Hawaii (Nishida

et al. 1985), south Portugal (Entrudo-Fernandes et al. 2000) and north of Greece (Papadopoulos et al. 2001a). According to Fitt (1989), the number of larvae of tephritid flies that survive until maturity in a given fruit will be a function of fruit size, nutritional quality and conditions, as well as larval density. McDonald & McInnis (1985) showed that the number of eggs laid by *C. capitata* was higher in fruit with a larger diameter. However in our study this fact was only observed for peach, since cattley guava, the lightest fruit came in second place when considering the mean number of pupae per fruit. Loquat was the host in which the smallest number of *C. capitata* pupae and adults per fruit was observed as well the lighter pupae. Such results

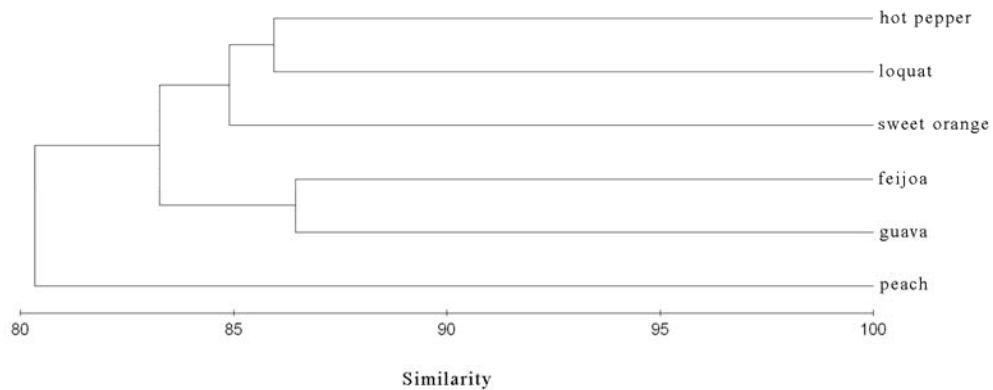


Figure 1. Dendrogram for hierarchical clustering of the six host fruit species, using group-average clustering from Bray-Curtis similarities on square root transformation.

can be due to the fact that loquat is a small fruit with a large seed.

The differences observed in pupal weight and pupal development times can be related to variations in the quantity or quality of the food ingested by insects (Chan et al. 1990; Chapman 1998; Nylin & Gotthard 1998; Honek et al. 2002). Chapman (1998) also stated that as food intake decreases, the duration of development is extended and the insect becomes smaller and lighter in weight. Krainacker et al. (1987) noted that in general, there is considerable variation in development time, growth, and survival of larvae of *C. capitata* on different host fruit, and Papadopoulos et al. (2002) affirm that nutritional contents of the different fruit might greatly affect larval development time. According to our results, the longest pupal development time was observed in feijoa, particularly that of female pupae, indicating that this fruit is probably of inferior nutritional quality.

The emergence rate of the adults of *C. capitata* was quite variable from one host fruit species to another or among fruit of the same species. Comparing *C. capitata* emergence rates obtained in the present analysis with data reported in other similar studies, some results are contradictory. For example, in peach, Carey (1984) found that 64% of the fruit flies emerged, and Zucoloto (1993a) observed only 54% of emergence, while in this study the adult emergence rate was superior to 93%. According to Zucoloto (1993a) differences in adult emergence rates can be due to variations in the populations of *C. capitata* used in the different studies, or caused by the fruit themselves, that can have different nutritive values depending of environmental factors.

Finally, results showed that the most suitable host fruit for *C. capitata* was peach, followed by cattley guava and feijoa; although loquat and sweet orange were found to be the less suitable hosts they seem to have an important role as alternative hosts between January and June, allowing the continuous development of *C. capitata* throughout the entire year.

ACKNOWLEDGEMENTS

We thank Roger Williams for his generous help in correcting the English writing.

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*Braslian Journal of Medical and Biological
Research 53: 611-618.*

Accepted 21 December 2007