Effect of Host Plants on Developmental Time and Life Table Parameters of *Carposina sasakii* (Lepidoptera: Carposinidae) Under Laboratory Conditions

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ABSTRACT Studies were designed to examine the effects of host plants (apricot, *Prunus armeniaca* L.; plum, *Prunus salicina* L.; peach, *Prunus persica* L.; jujube, *Zizyphus jujuba* Will.; apple, *Malus domestica* Mill.; and pear, *Pyrus sorotina* Will) on the development and life table parameters of the peach fruit moth, *Carposina sasakii* Matsumura (Lepidoptera: Carposinidae) under laboratory conditions. Peach fruit moth developed faster (12.48 d) and had the highest preimaginal survival rate (50.54%) on plum compared with the other host plants. Adult longevity was significantly longer on jujube for both female and male moths. Adult females from larvae reared on jujube and peach laid significantly greater numbers of eggs (214.50 and 197.94 eggs per female, respectively) compared with those reared on the other four host plants. Life-table parameters were calculated for each host plant and compared by jackknife procedures. The intrinsic rate of natural increase (r_m) was significantly greatest on plum (0.1294 eggs per female per d), followed by jujube and apricot (0.1201 and 0.1128 eggs per female per d), respectively. Implications of the various measures of population performance are discussed.

KEY WORDS *Carposina sasakii*, duration, fecundity, host plant, survival rate

The peach fruit moth, *Carposina sasakii* Matsumura, is a quarantine pest for Europe (CABI/EPPO 1990) and is widely distributed in northeast Asia including China, Japan, Korea, and the Russian Far East (Hwang et al. 1958, Liu et al. 1997, Kim et al. 2000, Ishiguri and Toyoshima 2006). In Northern China, this pest regularly causes economic damage to deciduous fruit trees such as apple (*Malus domestica* Mill), pear (*Pyrus sorotina* Will), and jujube (*Zizyphus jujuba* Will) (Hwang et al. 1958, Tung et al. 1964, Chang et al. 1977, Hua 1993, Liu et al. 1997). Generally, *C. sasakii* infests fruit trees by laying eggs on the calyx end, stalk cavity of fruits, or both. On hatching, the larva bores into a fruit, then feeds on the fruit flesh and moves deeply into the core. The mature larva emerges from the fruit and drops onto the ground where it pupates or enters a larval diapause to overwinter (Hwang et al. 1958, Toshima et al. 1961, Kim et al. 2000). At high population densities, it regularly causes substantial fruit losses (Chang et al. 1977, Liu et al. 1997, Hua et al. 1998b, Ling et al. 2010).

Since the beginning of this century, apple production in most growing areas of China has decreased, whereas production of stone fruit such as peach (*Prunus persica* L.), plum (*Prunus salicina* L.), and apricot (*Prunus armeniaca* L.) has increased (Li 2003). These stone fruit trees commonly are intercultivated or mix-cultivated with apple, thus facilitating emigration of *C. sasakii* onto the different host plants and changing the ecological environment inhabited by this pest. Previous studies about *C. sasakii* focused mainly on the effects of apple on larval development and survival (Hua et al. 1996, Kim et al. 2001, Ishiguri and Toyoshima 2006, Li et al. 2010a, Toyoshima et al. 2010); impacts of several host plants on diapause status (Hua et al. 1996, Hua et al. 1998a); host-driven biotype (Hua 1993, Hua and Hua 1995); and genetic diversity (Xu and Hua 2004). However, relatively few studies have been conducted to compare the effects of different host plants on development rate and population dynamics of the pest (Chang et al. 1977, Kim and Lee 2002).

To improve our understanding of *C. sasakii*-host interactions, which have an important influence on the dynamics and management of pest populations (Myers et al. 2007), we investigated the effects of several stone and pome fruit host plant on the survivorship and reproduction of *C. sasakii* by examining duration of each developmental stage and fecundity, as well as life table parameters on six species of host

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Table 1. Durations (d ± SE) of each stage of *C. sasakii* on various host plants

Host plants	Egg	Larva	Pre-cocoon	Pupa	Female longevity	Male longevity
Apricot	6.61 ± 0.03a	15.21 ± 0.08c	0.47 ± 0.02c	11.11 ± 0.05c	6.52 ± 0.14bc	6.30 ± 0.19b
Plum	6.63 ± 0.06a	12.48 ± 0.10e	0.56 ± 0.03c	10.96 ± 0.05c	5.63 ± 0.44c	5.82 ± 0.61b
Peach	6.60 ± 0.05a	13.50 ± 0.12d	0.76 ± 0.05b	11.43 ± 0.08b	6.76 ± 0.46bc	6.38 ± 0.78b
Jujube	6.62 ± 0.13a	15.47 ± 0.10c	0.80 ± 0.02ab	11.68 ± 0.07b	11.02 ± 0.68a	10.30 ± 0.72a
Apple	6.81 ± 0.91a	18.13 ± 0.22b	0.90 ± 0.07a	12.19 ± 0.15a	6.75 ± 0.34bc	6.80 ± 0.51b
Pear	6.60 ± 0.08a	19.15 ± 0.44a	0.78 ± 0.04b	11.56 ± 0.14b	7.60 ± 0.46b	5.84 ± 0.86b

Note: values within the same column followed by the same letter are not significantly different ($P > 0.05$, Fisher's LSD).

plants, which would not only enhance our biological knowledge of the insect, but would be integral for developing efficient integrated pest management programs for controlling *C. sasakii.*

Materials and Methods

Host Plants. The plants evaluated are common fruit trees in Northern China: apricot (*Prunus armeniaca* L. 'Golden sun'), plum (*Prunus salicina* L. 'Oishi wase'), peach (*Prunus persica* L. 'Beijing-2'), jujube (*Zizyphus jujuba* Will. 'Candied'), apple (*Malus domestica* Mill. 'Golden delicious'), and pear (*Pyrus sorotina* Will. 'Mengjinsu'). Untreated fruit were collected on 7 June, 21 June, 28 June, 20 July, 23 July, and 26 July 2010, respectively, based on previous field observation (Hwang et al. 1958, Chang et al. 1977) and recent pheromone trapping captures of *C. sasakii* males in different orchards (Hua 1993, Hua et al. 1998b, Li et al. 2010b, Ling et al. 2010). Samples of 60–100 unripened but approximately equal size fruits were used for each host plant evaluation.

Insect Source. The colony of *C. sasakii* used in this study was initiated using individuals collected from an apple orchard in Luoyang, Henan province, in Northern China in August 2009. After a larva emerged from its fruit, it was placed on soil (sand type with moisture: 10%) within a glass vial (18 mm in diameter, 120 mm in height) for pupation and emergence. Newly emerged females and males were paired in Perspex cages (100 mm in diameter, 100 mm in height) covered with absorbent gauze, and 10% (wt:vol) sugar water was provided for food. Two pieces of corrugated filter paper (30 mm by 50 mm) were placed on the bottom of each cage for egg laying. The progeny were reared on apples (*M. domestica* Mill. 'Fuji') for successive generations in the laboratory under conditions of 23 ± 1°C, 80 ± 7% RH, and a photoperiod of 15:9 (L: D) h in a climatic chamber (Li et al. 2010a).

Development and Survival. Eggs laid within 12 h were collected on the filter paper substrate from the colony, and was cut into pieces with 1–2 eggs. Each egg paper was maintained on a 3-mm layer of agar (1% wt:vol) inside a petri dish (90 mm in diameter) under the colony conditions. Upon hatching, each egg paper was attached onto the calyx end (apple and pear) or stalk cavity (apricot, plum, peach, and jujube) of one fruit with agar (1% wt:vol), and kept in a covered plastic cup (90 mm in diameter, 100 mm in height). All the cups were maintained in climatic chambers set at the same conditions as the colony and checked every 4 h from 900 to 2100 hr to determine the hatch, boring time, and emergence time. When mature larvae emerged from the fruit, they were weighed using a Mettler XS104 balance of precision ± 0.1 mg (Mettler-Toledo Inc. Shanghai, China), and transferred individually into a vial for pupation and emergence. Duration of larval stage was measured as the time from hatching to emergence from fruit, and the pupal stage from cocooning to adult emergence.

Longevity and Reproduction. Newly emerged females and males from each host plant were paired as previously stated and maintained in another climatic chamber set at the colony conditions. Eggs were collected twice daily until the adults died. Data obtained from unmated female as indicated by the shape of copulatory pouch (Li et al. 2010a) were excluded from the analyses.

Statistical Analyses. Effect of host plant on the duration of each stage was analyzed with one-way analysis of variance (ANOVA) followed by Fisher least significant difference test (PROC ANOVA, SAS Institute 1999). We used an arcsine square-root transformation for hatching rate, boring rate and exiting rate data, before performing the ANOVA. Population growth rates in each treatment were estimated from life tables (Birch 1948) using the equation:

$$1 = \sum e^{-rm \cdot x} \cdot l_x \cdot m_x$$

Where l_x is age-specific survival, and m_x the number of total reproductive output per female for each age interval (x). From these data, the intrinsic rate of natural increase (r_m = egg/female/d), net reproduction (R_0 = egg per female per generation), mean generation time ($T = \ln(R_0)/r_m$, in days), finite rate of growth ($\lambda = \exp r_m$), and doubling time ($Dt = \ln2/r_m$) were estimated. After r_m was computed from the original data (r_{all}) the differences in r_m-values were tested for significance by estimating the variance using the jackknife method (Meyer et al. 1986, de Maia et al. 2000). Each parameter was considered significantly different among host plants if there was no overlap of the 95% CL.

Results

Duration on Various Host Plants. The duration of each *C. sasakii* stage reared on the six host plants is shown in Table 1. There was no variation in the incubation period of the eggs in each trial, but significant

Table 2. Survivorship (% ± SE) of *C. sasakii* on various host plants

Host plants	Hatching rate	Boring rate	Exiting rate	Body wt	Cocooning rate	Emergence rate	Preimaginal survival rate
Apricot	93.63 ± 0.91a	54.09 ± 1.66b	77.93 ± 2.42a	25.49 ± 0.31c	93.82 ± 0.73a	94.51 ± 1.00a	35.00
Plum	94.89 ± 1.37a	73.99 ± 2.05a	79.46 ± 1.58a	23.15 ± 0.31d	94.49 ± 0.64a	95.87 ± 1.52a	50.54
Peach	94.58 ± 0.71a	30.60 ± 2.01d	82.49 ± 5.35a	25.62 ± 0.58c	91.99 ± 0.19a	94.66 ± 2.68a	20.79
Jujube	94.49 ± 1.43a	78.66 ± 1.84a	78.42 ± 2.08a	19.48 ± 0.26e	92.14 ± 1.92a	92.19 ± 2.21a	49.51
Apple	94.00 ± 2.00a	73.84 ± 5.76a	62.90 ± 5.26b	26.98 ± 0.71b	93.38 ± 0.61a	95.58 ± 2.29a	38.97
Pear	94.22 ± 1.43a	40.78 ± 2.39c	52.60 ± 5.29b	28.50 ± 0.63a	93.31 ± 0.10a	94.99 ± 1.68a	17.91

Note: values within the same column followed by the same letter are not significantly different (*P* > 0.05, Fisher's LSD).

differences were observed in the larval period ($F = 228.49$; df = 5, 702; $P < 0.0001$), precocoon period ($F = 30.83$; df = 5, 681; $P < 0.0001$), and pupal stage ($F = 24.46$; df = 5, 517; $P < 0.0001$) on the various host plants. Larval duration was the longest on pear followed by apple, and the shortest on plum. Precocoon periods on apricot and plum were significantly shorter than that of those on other four species of hosts, while the longest was on apple which was not significantly different from jujube. Pupal periods on apricot and plum were significantly shorter than that of those on other tested hosts, whereas the longest was on apple. Adult longevity for females ($F = 20.28$; df = 5, 178; $P < 0.0001$) and males ($F = 10.88$; df = 5, 142; $P < 0.0001$) were longest on jujube.

Survivorship on Various Host Plants. Significant differences were observed in body weight among mature larvae fed on the different host plants ($F = 72.58$; df = 5, 704; $P < 0.0001$; Table 2). The heaviest were those reared on pear, and the lightest were reared on jujube. No significant differences were found in hatching rate ($F = 0.11$; df = 5, 26; $P = 0.9881$), cocooning rate ($F = 0.63$; df = 5, 23; $P = 0.6786$), and emergence rate ($F = 0.53$; df = 5, 26; $P = 0.7519$) among the host plants. However, the boring rates of neonatal larvae were significantly different ($F = 58.51$; df = 5, 26; $P < 0.0001$), with the lowest rate observed on peach. Exiting rates (percentage of larvae emerging from fruit among those penetrated) on pear and apple were significantly lower compared with the other four hosts ($F = 10.32$; df = 5, 26; $P < 0.0001$). Survival rates from egg to adult were calculated highest on plum, and lowest on pear.

Age-specific Survivorship and Fecundity. Daily age-specific survivorship and fecundity curves are shown in Fig. 1 (A≈F). High mortality occurred during boring periods on peach and pear. The earliest reproduction peak appeared on plum on day 33 (45.15 eggs/female), followed by peach on the day 36 (61.11 eggs per female), whereas the latest was on apple on day 42 (32.20 eggs/female).

Reproduction. Mating rate of adult *C. sasakii* was not significantly influenced by host plant ($F = 2.64$; df = 5, 12; $P = 0.0783$; Table 3), though Fisher least significant difference test indicated that the highest rate was on jujube, which was not significantly different from peach and plum. There was no variation in preoviposition period ($F = 0.30$; df = 5, 171; $P = 0.9114$), but the duration of oviposition was significantly affected by host plant ($F = 14.77$; df = 5, 173;

$P < 0.0001$), the longest being on jujube. Fecundity also was significantly influenced by the different host plants upon which larvae were reared ($F = 4.14$; df = 5, 183; $P = 0.0014$); females from larvae reared on jujube and peach laid a significantly greater number of eggs compared with those from the other four host plants.

Life Table Parameters. Host plants also played a role in affecting the population growth parameters of *C. sasakii* (Table 4). The highest R_0 occurred on jujube which was not significantly different from plum, and no significant differences were found among peach, apple and pear based on the 95% jackknife estimates. The longest mean generation time (T) was observed on apple and this was approximately the same time as on pear, and the shortest on plum. Consequently, the highest r_m was calculated for plum followed by jujube and apricot, and the lowest r_m was on pear albeit not significantly different from apple.

Discussion

Host plant quality can affect life history characteristics of herbivores by impairing growth, lowering resistance to disease, and reducing fecundity (Price et al. 1980). The current results demonstrated that host plants did have a direct affect on *C. sasakii* larval development, acted indirectly on longevity and reproduction, and life table parameters of *C. sasakii* were also affected (Tables 1, 3, and 4). Indeed, the results show that the host plants had substantial effects on net reproduction rate (R_0) and intrinsic rate of increase (r_m).

Data on development and reproduction of *C. sasakii* on different host plants provide a valuable insight into ecological attributes of these hosts, such as the anticipated population growth parameters relative to a particular host. The current study has shown that the larval development and preimaginal survival rates varied among the different host plants (Tables 1 and 2). For example, larvae reared on plum developed faster (12.48 d) and had a higher preimaginal survival rate (50.54%) than those reared on any of the other host plants in our study. Larval duration on Golden delicious apple at 23°C (18.13 d) was similar to that reported by Li et al. (2010a) and to that on Fuji apple at 22.5°C (16.8–16.9 d) (Toyoshima et al. 2010). It is difficult to compare development on other host plants because of a lack of reported data. In addition, mature larvae attained various body weights on the different
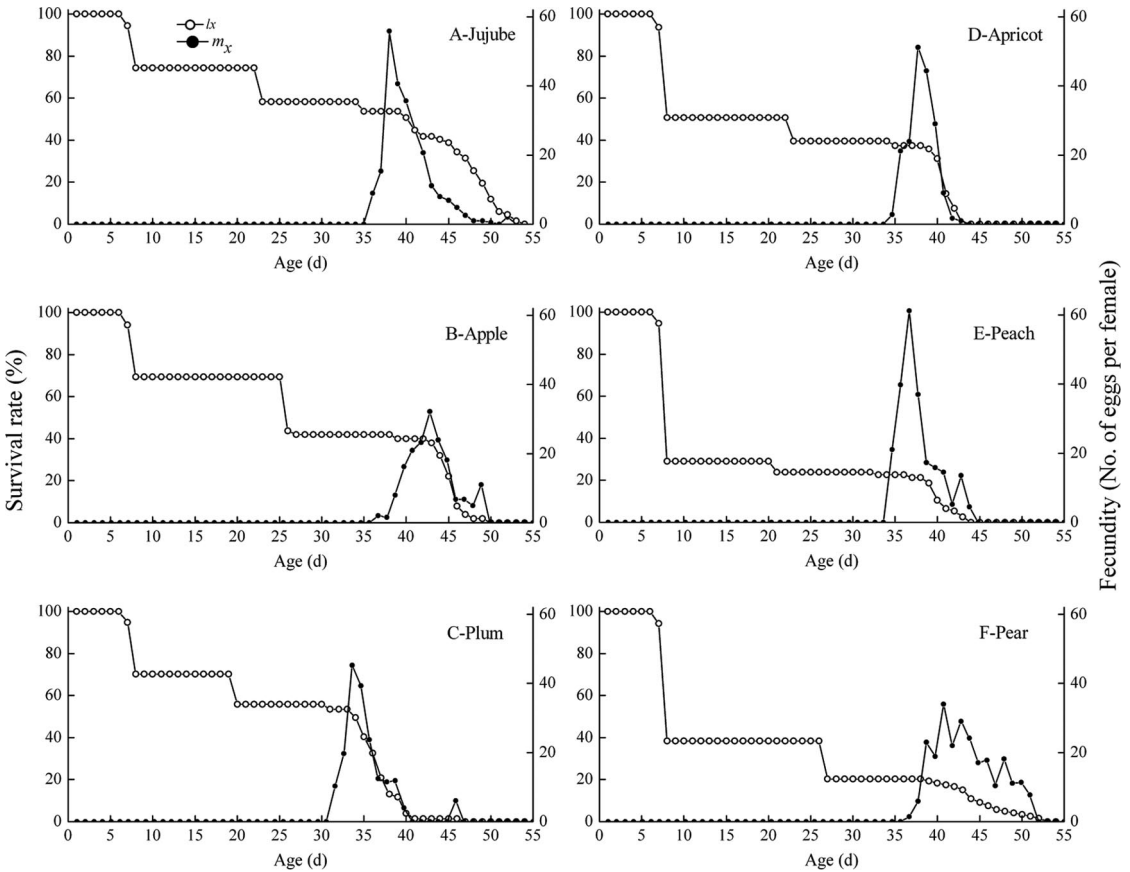
Fig. 1. Age-specific survival (l_x) and fecundity (m_x) of *C. sasakii* on various host plants: (**A**) Jujube, (**B**) Apple, (**C**) Plum, (**D**) Apricot, (**E**) Peach, (**F**) Pear.

host plants as well (Table 2). This variability may be because of nutritional and phago-stimulants of the fruit in our study.

The intrinsic rate of population increase (r_m) is the most important parameter of population dynamics under specific climatic and food conditions (Varley and Gradwell 1970, Southwood and Henderson 2000). Rapid population increase can be achieved by a high reproduction rate, short developmental time, or both, but the relative contribution of these parameters in population increase is not equal (Krips et al. 1998). In current study, for example, the shorter development time was responsible for the highest r_m, which was calculated on plum, whereas higher net reproduc-

tion rate (R_0) should be ascribed to the greater r_m on jujube. The higher r_m values on jujube and plum might imply higher infestation level on these host plants. In fact, severe field infestations of *C. sasakii* have well been confirmed on jujube in Northern China (Hwang et al. 1958, Tung et al. 1964, Liu et al. 1997), but, to our knowledge, data about *C. sasakii* infestation level on plum fruit is unavailable. Thus, more attention might be paid to plum in the intercropping or mixed-cropping orchards, although further investigations of *C. sasakii* under field conditions were needed.

Because *C. sasakii* larvae rely entirely on fruit for food, fruit quality could directly affect larval devel-

Table 3. Effects of host plants on the reproduction of *C. sasakii*

Host plants	Mating rate (%)	Preoviposition (d)	No. eggs per female	Duration of oviposition (d)
Apricot	82.44 ± 2.12b	2.31 ± 0.13a	179.51 ± 9.43ab	3.84 ± 0.20b
Plum	83.84 ± 1.88ab	2.16 ± 0.11a	142.51 ± 12.38b	3.50 ± 0.33b
Peach	84.92 ± 0.79ab	2.16 ± 0.19a	197.94 ± 21.65a	4.59 ± 0.49b
Jujube	91.67 ± 2.08a	2.30 ± 0.12a	214.50 ± 12.39a	7.43 ± 0.51a
Apple	80.09 ± 3.79b	2.25 ± 0.15a	150.21 ± 14.44b	4.65 ± 0.41b
Pear	80.36 ± 3.72b	2.36 ± 0.21a	171.68 ± 18.80ab	4.52 ± 0.48b

Note. Values (means ± SE) within the same column followed by the same letter are not significant difference ($P > 0.05$, Fisher's LSD).

Table 4. Life table parameters of *C. sasakii* on various host plants

Host plants	Intrinsic rate of increase (r_m)	Net reproduction rate (R_0)	Mean generation time (T)	Finite rate of increase (λ)	Doubling time (Dt)
Apricot	0.1128	67.07	37.29	1.1194	6.15
	$0.1105 \approx 0.1151$	$60.99 \approx 72.25$	$37.20 \approx 37.38$	$1.1168 \approx 1.1220$	$6.01 \approx 6.26$
Plum	0.1294	77.78	33.65	1.1381	5.37
	$0.1269 \approx 0.1322$	$56.40 \approx 98.48$	$33.32 \approx 33.98$	$1.1290 \approx 1.1476$	$5.01 \approx 5.68$
Peach	0.1044	44.73	36.42	1.1100	6.64
	$0.1008 \approx 0.1097$	$37.62 \approx 52.12$	$36.24 \approx 36.62$	$1.1060 \approx 1.1159$	$6.27 \approx 6.85$
Jujube	0.1201	117.49	39.70	1.1276	5.77
	$0.1140 \approx 0.1265$	$88.14 \approx 146.81$	$39.36 \approx 40.05$	$1.1207 \approx 1.1349$	$5.46 \approx 6.06$
Apple	0.0987	59.22	41.37	1.1037	7.03
	$0.0891 \approx 0.1089$	$36.16 \approx 81.84$	$40.65 \approx 42.09$	$1.0931 \approx 1.1150$	$6.27 \approx 7.69$
Pear	0.0860	34.92	41.31	1.0898	8.06
	$0.0826 \approx 0.0899$	$29.53 \approx 39.63$	$41.02 \approx 41.68$	$1.0861 \approx 1.0940$	$7.65 \approx 8.35$

Note: data in each cell consist of original parameters, and associated 95% CL of Jackknife estimates.

opment in various ways including physical condition, nutrition, and toxic substances (Kim and Lee 2002, Ishiguri and Toyoshima 2006). Our study demonstrated that there were no variation in hatching rates, cocooning rates and emergence rates of *C. sasakii* reared on the host plants evaluated. Therefore, the variable survival reported in the present paper may mainly attribute to the boring and exiting rates. Our results indicated that high mortality occurred during boring period when the pest fed on peach, but a high exiting rate was also observed on this host. We presume that the boring rates were directly affected by physical characteristics such as hardness or hairiness of fruit. However, Ishiguri and Toyoshima (2006) reported that most newly hatched *C. sasakii* larvae could successfully penetrate young apple fruit which are harder than more mature fruit. Thus, fruit firmness might be inconclusive as a cause of the different boring rates; the low boring rate found on peach in our study might be because of the long and dense hair, which would make it more difficult for larvae to penetrate peach fruit. However, the highly variable exiting rates of larvae in current study might be a reflection of nutrition or toxic substances in the fruit. This suggestion is supported by Kim and Lee (2002), who found that concentrations of the phenolic compounds that changed seasonally in growing fruit could affect larval survivorship of *C. sasakii*, larval survival in growing apple could be low. Ishiguri and Toyoshima (2006) also reported that the larval survival rate of *C. sasakii* differed significantly depending on whether the apple was picked from the tree. Thus, interpretation of our data on impacts of host plants on *C. sasakii* in orchards may be somewhat limited in that we used excised fruit, although a large portion of larvae may develop in fruits that have prematurely dropped from trees because of *C. sasakii* damage or other factors such as early season thinning or harvesting, future studies need to be carried out at field conditions by using wild populations and growing fruits to evaluate the exact effects of various host plants on the pest. Moreover, in our study the exact cause of the variations in larval growth rates, mortality, and adult fecundity among host plants remains unknown, further work is required to investigate possible biochemical reasons for these differ-

ences (e.g., nutrient availability of the host plant species) (Hwang et al. 2008).

Acknowledgments

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