

Article

Demographic Characteristics of *Novius penicillioides* (Coleoptera, Coccinellidae) in Relation to *Icerya jacobsoni* (Hemiptera, Monophlebidae) Reared on Different Host Plants

Jing Peng ^{1,2,†}, Jianfeng Liang ^{1,2,†}, Siqin Zheng ^{1,2}, Muhammad Hamid Bashir ³, Shaukat Ali ^{1,2} and Xingmin Wang ^{1,2,*}

¹ College of Plant Protection, South China Agricultural University, Guangzhou 510642, China; pengjing17@scau.edu.cn (J.P.); jmx02@stu.scau.edu.cn (J.L.); zhengsiqin77@stu.scau.edu.cn (S.Z.); aliscou@scau.edu.cn (S.A.)

² Engineering Research Center of Biological Control, Ministry of Education and Guangdong Province, South China Agricultural University, Guangzhou 510642, China

³ Department of Entomology, University of Agriculture, Faisalabad 38000, Pakistan; h.bashir@uaf.edu.pk

* Correspondence: wangxmcn@scau.edu.cn

† These authors contributed equally to this work.

Abstract

The cottony cushion scale, *Icerya jacobsoni* (Hemiptera: Monophlebidae), is a highly polyphagous pest inflicting significant damage to multiple crops and ornamental plants across the globe. The study investigates the impact of four distinct host plants (*Macaranga tanarius* L., *Magnolia denudata* L., *Ficus microcarpa* L., and *Psidium guajava* L.) on the biological traits and life table metrics of *I. jacobsoni* and *Novius penicillioides* Tao & Wang (Coleoptera: Coccinellidae) feeding on *I. jacobsoni*, under controlled laboratory conditions. The results showed that host plants significantly influenced the growth period, survival rate, fecundity, and life table parameters of all *I. jacobsoni* stages. *I. jacobsoni* performed best on *M. tanarius*, exhibiting the shortest growth period, highest fecundity, and highest intrinsic rate of increase. In contrast, *F. microcarpa* was the most unsuitable host, resulting in delayed growth, lower survival, and reduced fecundity. Furthermore, this host-mediated effect propagated up the food chain, significantly impacting the performance of the natural enemy, *N. penicillioides*. Ladybirds feeding on *I. jacobsoni* (reared on *M. tanarius*) developed faster, exhibited higher fecundity, longer longevity, and greater population growth potential. Conversely, those feeding on prey grown on *F. microcarpa* had suppressed growth and life history parameters. These findings highlight the critical role of host plants in *I. jacobsoni* population dynamics and *N. penicillioides* biocontrol efficacy, providing insights for integrated pest management strategies.

Keywords: ladybird; prey quality; host plants; intrinsic rate of increase; biological characteristics



Academic Editor: Fajun Chen

Received: 12 September 2025

Revised: 15 October 2025

Accepted: 20 October 2025

Published: 22 October 2025

Citation: Peng, J.; Liang, J.; Zheng, S.; Bashir, M.H.; Ali, S.; Wang, X. Demographic Characteristics of *Novius penicillioides* (Coleoptera, Coccinellidae) in Relation to *Icerya jacobsoni* (Hemiptera, Monophlebidae) Reared on Different Host Plants.

Agronomy **2025**, *15*, 2457. <https://doi.org/10.3390/agronomy15112457>

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1. Introduction

Coccids or scale insects are recognized as major pests of agriculture, horticulture, and forestry [1]. In recent years, *Icerya* spp. have posed serious threats to various crops and ornamental plants worldwide, with particularly severe impacts in forestry [2,3]. In China, 30 species of scale insects have been listed among the first catalog of threatening forest pests [4]. The nymphs and adult females of *Icerya* species often infest plant shoots in clusters. They damage host plants primarily by sucking sap, which weakens the plants. Furthermore,

their honeydew secretions promote the growth of sooty mold fungus ultimately impairing photosynthetic. These combined stresses can lead to serious consequences including leaf yellowing, defoliation, and in extreme cases, plant mortality [5–8].

Icerya jacobsoni Green (Hemiptera: Monophlebidae) is currently distributed in eight countries, including China, India, and the Philippines. It was first reported in Hong Kong, China, by Tao [9] as *Crypticerya jacobsoni* (a synonym), with recorded hosts spanning 22 genera across 17 families [10]. In Guangdong province, its host plants include species from Magnoliaceae, Moraceae, Euphorbiaceae, Verbenaceae, Myrtaceae, Rutaceae, Elaeocarpaceae, Lauraceae, Ulmaceae, and others [11,12]. As one of the major forest pests in China, both nymphs and adults of *I. jacobsoni* damage a wide range of plants. Being an ovoviparous species, the females directly give birth to nymphs rather than laying eggs. They form dense colonies on the undersides of leaves and young shoots, primarily sucking sap. This feeding causes direct injury, leading to leaf yellowing and premature abscission [13].

Although chemical insecticides have historically been the primary method for controlling *Icerya* pests. This over-reliance on synthetic chemicals has raised concerns due to their harmful effects on human health and the environment [7]. Consequently, there is growing interest in exploring alternative pest management strategies, particularly biological control [6,14]. In this study, we found that *Novius penicillioides* Tao & Wang [15] (Coleoptera: Coccinellidae) acts as an effective natural enemy of *I. jacobsoni*. We observed that its larvae prefer feeding on second-instar nymphs, consuming them until only the empty shell remains. Adults were seen to bite and feed on the pests, often causing body fluid outflow and coagulation, though not always resulting in immediate death. Particularly during their larval stage, individuals can consume between 25 and 40 eggs or nymphs of *I. jacobsoni* per day. These findings demonstrate its significant potential for use in biological control programs.

The nutritional quality and chemical composition of host plants can significantly influence the biology of insect pests as well as their natural enemies [16]. Variations in these plant characteristics can lead to differences in the growth, survival, and reproductive success of these insects [17]. Therefore, understanding how different host plants affect the life history traits of both *I. jacobsoni* and its predators is essential for effective pest management.

This study aimed to explore the growth, survival, and reproduction of *I. jacobsoni* and its predator, the ladybird *N. penicillioides*, on four host plants: *Macaranga tanarius* L., *Magnolia denudata* L., *Ficus microcarpa* L., and *Psidium guajava* L. These plants are common hosts for *Icerya* spp. in Southern China, encompassing significant ecological and economic value. The main objective of this study was to provide comprehensive data on the biology and population dynamics of *I. jacobsoni* and its natural enemies, with the ultimate objective of improving pest management strategies. By constructing life tables and demographic models, this research will provide valuable insights into the ecology of *I. jacobsoni* and inform more effective and sustainable pest control methods.

2. Materials and Methods

2.1. Host Plants

Four host plants used in this study (*M. tanarius*, *M. denudata*, *F. microcarpa*, and *P. guajava*) were sourced from the greenhouse at South China Agricultural University. All plants were carefully examined to ensure that they were free of insect pests prior to experiments.

2.2. Insects

The *I. jacobsoni* utilized in this study were obtained from colonies maintained at the Engineering Research Center of Biological Control, South China Agricultural University. To initiate the colonies, approximately 100 reproductively active females of *I. jacobsoni* were

collected and cultured on red pumpkin in a controlled laboratory environment at 26 ± 1 °C; 75–90% R.H; and a photoperiod of 14 h of light and 10 h of darkness [18]. The colonies were allowed to develop for two generations on each host plant. *I. jacobsoni* females from the final generation were then selected for the experimental procedures. Approximately 100 gravid females were housed in small rearing boxes ($9.0 \times 6.3 \times 5.0$ cm) to produce the nymphs used in the following experiments.

Additionally, *N. penicillioides* (a natural predator of *I. jacobsoni*) was obtained from an existing greenhouse colony at the same institute, maintained on croton plants (*Codiaeum variegatum* (L.)). The potting regime for these plants involved 15 cm diameter containers and a nutrient regime supplemented with a balanced N:P:K (13:7:15) fertilizer applied weekly at a dilution ratio of 1:500 to promote optimal health. The *N. penicillioides* colonies were maintained for several generations on *C. variegatum* before being used in this study.

2.3. Growth and Survival of *I. jacobsoni*

To assess the growth periods of *I. jacobsoni* on different host plants, newly emerged nymphs (less than 24 h old) were placed on a leaf of each host plant. The leaves (approximately 2.5 cm at the base and 10.0–15.0 cm in length) were transferred to glass tubes (2.5 cm in diameter and 25 cm in length) open at both ends. The ends of the tubes were sealed with polyethylene sheet secured by rubber bands. After 3 days, one nymph was marked, and its feeding behavior was monitored. All unmarked nymphs were removed, retaining solely the marked one for individual rearing. Growth stages were recorded at half-day intervals using a stereomicroscope, and molting events were observed to ascertain the instar number. Dietary replenishment with fresh leaves occurred every 7 to 10 days. Observations were performed on groups of 100 nymphs for each plant species. The entire experiment was conducted in a laboratory setting with controlled parameters: temperature at 26 ± 1 °C, relative humidity between 75% and 90%, and a light-dark cycle of 14:10 h.

2.4. Longevity and Reproduction of *I. jacobsoni*

For the assessment of longevity and reproductive success, 15 newly emerged virgin *I. jacobsoni* female were isolated on their respective host plants. Each female was individually placed in separate tubes and paired with two males after their final molt to ensure mating. The lifespan of each female was recorded, along with the number of nymphs produced. The nymphs laid each day were removed from the leaves. The experimental conditions were the same as those described for the growth study.

2.5. Growth and Survival of *N. penicillioides* Immatures

The growth periods of *N. penicillioides* on various host plants were assessed by placing adult beetles on four different host plants that were infested with *I. jacobsoni* eggs. Leaves having 12 h-old beetle eggs were excised and transferred to Petri dishes (9 cm in diameter), which were lined with moistened filter paper. The dishes were placed in growth chambers (PXY-300QA, Shaoguan Keli Experimental Instrument Co., Shaoguan, China) set at a temperature of 26 ± 1 °C, $75 \pm 10\%$ relative humidity, and a photoperiod of 14 h of light and 10 h of darkness. For each host plant treatment at least 60 eggs were used, and three replicates were performed per treatment. The eggs were monitored daily until hatched. Newly emerged larvae were carefully transferred to fresh leaf disks ($10\text{--}15\text{ cm}^2$) from the respective host plants. Fresh leaf disks were replaced daily, except during the pupal stage. Growth periods and stage-specific mortality were monitored daily till adult emergence.

2.6. Longevity and Fecundity of *N. penicillioides* Adults

Newly emerged *N. penicillioides* adults were individually placed on fresh leaf disks (5–8 cm in width) infested with *I. jacobsoni* eggs. After mating, 15 pairs were selected and

placed in separate Petri dishes lined with moistened filter paper. Fresh leaf disks containing *I. jacobsoni* eggs were supplied daily as food. The number of eggs laid, the survival rate of the adults, and the longevity of each pair were recorded until all adults perished. After death, the sex of each adult was determined through dissection to expose the reproductive organs. The female-to-male sex ratio was calculated based on the numerical count of female and male adults.

2.7. Life Table Analysis

Life table parameters for both *I. jacobsoni* and *N. penicillioides* were computed using the method described by Birch [19], described as:

$$R_0 = \sum l_x m_x, \quad (1)$$

$$T = \sum l_x m_x / R_0, \quad (2)$$

$$r_m = \ln R_0 / T, \quad (3)$$

$$\lambda = \exp(r_m), \quad (4)$$

In this context, X represents the age of *I. jacobsoni* or *N. penicillioides* measured in days, while l_x denotes the survival at a specific time x . m_x refers to the average number of female offspring generated by each surviving female adult within the age interval x . T indicates the mean generation time, which is the average age at which a female produces her offspring. R_0 signifies the net reproductive rate, reflecting the average number of offspring that an individual in the population is expected to produce over its lifetime. The term r_m represents the intrinsic rate of increase, which describes the rate at which a population expands in size in the absence of density-dependent factors that might otherwise regulate it. Lastly, λ denotes the finite rate of increase, indicating the factor by which the population size must be multiplied to project the population size in the subsequent time unit, assuming a stable age distribution.

2.8. Statistical Analysis

The influence of host plants on the growth period and survival of the immature stages, as well as the longevity and reproductive output of adult *I. jacobsoni* and *N. penicillioides*, was analyzed using one-way analyses of variance (ANOVA). If ANOVA results were significant, means were compared using Duncan's multiple range test ($p < 0.05$).

3. Results

3.1. Effect of Host Plants on Growth and Survival

Host plants exerted a significant influence on growth periods of *I. jacobsoni* across various life stages. Specifically, the growth period of first instar nymph differed significantly among host plants ($F_{3, 396} = 59.67, p < 0.0001$), as did the second instar nymph ($F_{3, 396} = 32.21, p < 0.001$), the female third instar nymph ($F_{3, 396} = 57.18, p < 0.0001$), the male pre-pupa ($F_{3, 396} = 48.91, p < 0.001$), and the male pupa ($F_{3, 396} = 45.23, p < 0.001$). Additionally, the transition from nymph to female adult ($F_{3, 396} = 46.32, p < 0.0001$) and from nymph to male adult ($F_{3, 396} = 41.87, p < 0.0001$) also demonstrated significant variations (Table 1). The growth period of females were shortest on *M. tanarius*, averaging 53.0 ± 2.3 days, while the longest duration was recorded on *F. microcarpa*, with a mean of 65.8 ± 7.8 days. For males, the longest growth period (65.0 ± 6.9 days) was also noted on *F. microcarpa*, contrasting with the shortest duration observed on *M. tanarius*. The growth periods across *M. tanarius*, *M. denudata*, and *P. guajava* were statistically similar (Table 1).

Table 1. Growth period of *I. jacobsoni* on different host plants (Mean $\pm$ SE) (d).

Host Plants	1st Instar Nymph	2nd Instar Nymph	Female 3rd Instar Nymph	Male		Nymph to Adult	
				Pre-Pupa	Pupa	Female	Male
<i>M. tanarius</i>	18.1 $\pm$ 2.0 b	17.4 $\pm$ 2.0 b	17.6 $\pm$ 2.4 b	10.3 $\pm$ 0.6 c	7.3 $\pm$ 0.5 b	53.0 $\pm$ 2.3 b	52.8 $\pm$ 1.9 b
<i>M. denudata</i>	18.3 $\pm$ 2.1 b	17.5 $\pm$ 2.0 b	18.1 $\pm$ 2.1 b	11.0 $\pm$ 0.8 b	7.0 $\pm$ 0.8 b	53.9 $\pm$ 4.3 b	53.8 $\pm$ 3.4 b
<i>F. microcarpa</i>	25.4 $\pm$ 4.0 a	19.0 $\pm$ 3.3 a	21.4 $\pm$ 4.0 a	11.6 $\pm$ 2.1 a	9.0 $\pm$ 1.9 a	65.8 $\pm$ 7.8 a	65.0 $\pm$ 6.9 a
<i>P. guajava</i>	18.3 $\pm$ 2.2 b	17.6 $\pm$ 2.2 b	17.9 $\pm$ 1.0 b	11.0 $\pm$ 1.0 b	7.1 $\pm$ 0.9 b	53.8 $\pm$ 1.1 b	54.0 $\pm$ 0.7 b

Different letters within a column indicate samples that differ significantly ($p < 0.05$) from each other based on the test results.

The survival of *I. jacobsoni* was markedly affected by the choice of host plants, with statistical analyses revealing significant differences (for females, $F_{3, 396} = 32.67$, $p < 0.0001$; for males, $F_{3, 396} = 34.18$, $p < 0.0001$) (Table 2). The species exhibited the lowest survival rates on *F. microcarpa*, $41.90 \pm 10.36\%$ for females and $53.0 \pm 8.6\%$ for males. No significant differences were observed among the other host plants. Notably, the survival rates of male pupae was the highest across all growth stages, followed closely by the third instar female nymphs. In contrast, the first instar nymphs demonstrated the lowest survival on *F. microcarpa* ($78.0 \pm 5.3\%$), although survival rates exceeded 90% on the other three host plants. Similarly, the second instar nymphs exhibited their lowest survival ($68.0 \pm 7.6\%$) on *F. microcarpa*, while the third instar nymphs had a survival of $79.9 \pm 9.4\%$ on the same plant; both stages showed survival rates greater than 90% on the alternative host plants. Importantly, all male pre-pupae successfully transitioned to the pupal stage (Table 2).

Table 2. Survival rate of *I. jacobsoni* on different host plants (Mean $\pm$ SE) (%).

Host Plants	1st Instar Nymph	2nd Instar Nymph	Female 3rd Instar Nymph	Male		Nymph to Adult	
				Pre-Pupa	Pupa	Female	Male
<i>M. tanarius</i>	99.0 $\pm$ 1.0 a	99.0 $\pm$ 1.0 a	100.0 $\pm$ 0.0 a	100.0 $\pm$ 0.0 a	100.0 $\pm$ 0.0 a	98.0 $\pm$ 1.5 a	98.0 $\pm$ 1.5 a
<i>M. denudata</i>	99.0 $\pm$ 1.0 a	98.0 $\pm$ 0.0 a	100.0 $\pm$ 2.0 a	98.0 $\pm$ 1.0 a	100.0 $\pm$ 0.0 a	97.0 $\pm$ 1.5 a	97.0 $\pm$ 1.0 a
<i>F. microcarpa</i>	78.0 $\pm$ 5.3 b	68.0 $\pm$ 7.6 b	79.9 $\pm$ 9.4 b	100.0 $\pm$ 0.0 a	100.0 $\pm$ 0.0 a	41.9 $\pm$ 10.4 b	53.0 $\pm$ 8.6 b
<i>P. guajava</i>	92.0 $\pm$ 3.6 a	94.0 $\pm$ 6.8 a	100.0 $\pm$ 0.0 a	100.0 $\pm$ 0.0 a	100.0 $\pm$ 0.0 a	86.5 $\pm$ 8.6 a	86.5 $\pm$ 8.6 a

Different letters within a column indicate samples that differ significantly ($p < 0.05$) from each other based on the test results.

Host plants used to rear *I. jacobsoni* significantly influenced the growth period of *N. penicillioide*s eggs ($F_{3, 236} = 32.74$, $p < 0.0001$), first instar nymphs ($F_{3, 236} = 25.34$, $p < 0.0001$), second instar nymphs ($F_{3, 236} = 43.71$, $p < 0.001$), third instar female nymphs ($F_{3, 236} = 28.75$, $p < 0.0001$), pupae ($F_{3, 236} = 35.42$, $p < 0.001$), and the overall period from egg to adult ($F_{3, 236} = 36.24$, $p < 0.0001$). The shortest duration from egg to adult was recorded for *N. penicillioide*s feeding on *I. jacobsoni* reared on *F. microcarpa* (27.3 ± 0.3 days), while the longest duration was noted for *N. penicillioide*s feeding on *I. jacobsoni* reared on *M. tanarius*, with a mean of 28.8 ± 0.3 days. The growth period of the egg stage and total larval stage of *N. penicillioide*s were not significantly effected by feeding on *I. jacobsoni* reared on different host plants, whereas a significant difference was observed in the pupal stage growth period (Table 3).

The survival rates of *N. penicillioide*s eggs and the overall egg-to-adult were significantly affected by feeding on *I. jacobsoni* reared on different host plants. The survival rates for different larval instars and pupae remained relatively stable (Table 4). The lowest survival percentage ($53.6 \pm 4.0\%$) for *N. penicillioide*s from egg to adult was recorded for *N. penicillioide*s feeding on *I. jacobsoni* reared on *F. microcarpa*, while the highest survival was observed for *N. penicillioide*s feeding on *I. jacobsoni* reared on *M. denudata*, with a mean of $86.8 \pm 6.0\%$. For eggs, the lowest survival was noted for *N. penicillioide*s feeding on *I.*

jacobsoni reared on *F. microcarpa* at $88.0 \pm 3.0\%$, whereas survival rates exceeded 90% on the other three host plants (Table 4).

Table 3. Growth period of *N. penicillioideis* feeding on *I. aegyptiaca* reared on different host plants (Mean $\pm$ SE) (d).

Host Plants	Egg	Larval Instars				Pupa	Egg-Adult
		1st Instar	2nd Instar	3rd Instar	4th Instar		
<i>M. tanarius</i>	5.1 ± 0.0 a	2.1 ± 0.1 a	2.2 ± 0.1 a	2.1 ± 0.0 a	8.8 ± 0.2 a	8.6 ± 0.2 a	28.8 ± 0.3 a
<i>M. denudata</i>	5.1 ± 0.1 a	2.1 ± 0.0 a	2.2 ± 0.1 a	2.1 ± 0.1 a	8.8 ± 0.2 a	7.8 ± 0.3 b	28.0 ± 0.3 b
<i>F. microcarpa</i>	5.2 ± 0.1 a	2.1 ± 0.1 a	2.1 ± 0.1 a	2.1 ± 0.1 a	8.2 ± 0.3 a	7.5 ± 0.2 b	27.3 ± 0.3 b
<i>P. guajava</i>	5.2 ± 0.1 a	2.1 ± 0.3 a	2.2 ± 0.1 a	2.1 ± 0.1 a	8.8 ± 0.2 a	8.6 ± 0.2 a	28.8 ± 0.3 a

Different letters within a column indicate samples that differ significantly ($p < 0.05$) from each other based on the test results.

Table 4. Survival rate of *N. penicillioideis* feeding on *I. aegyptiaca* reared on different host plants (Mean $\pm$ SE) (%).

Host Plants	Egg	Larval Instars				Pupa	Egg-Adult
		1st Instar	2nd Instar	3rd Instar	4th Instar		
<i>M. tanarius</i>	96.0 ± 3.0 a	92.0 ± 4.0 a	99.0 ± 2.0 a	98.0 ± 1.0 a	100.0 ± 0.0 a	100.0 ± 1.0 a	85.7 ± 3.0 a
<i>M. denudata</i>	94.0 ± 3.1 a	93.5 ± 5.2 a	98.8 ± 1.0 a	100.0 ± 0.0 a	100.0 ± 0.0 a	100.0 ± 2.1 a	86.8 ± 6.0 a
<i>F. microcarpa</i>	88.0 ± 3.0 b	90.0 ± 4.0 a	85.0 ± 3.0 b	83.0 ± 4.0 b	100.0 ± 0.0 a	96.0 ± 3.0 a	53.6 ± 4.0 b
<i>P. guajava</i>	92.0 ± 3.0 a	91.0 ± 2.0 a	95.0 ± 2.0 a	95.0 ± 2.0 a	100.0 ± 0.0 a	100.0 ± 0.0 a	75.6 ± 5.0 a

Different letters within a column indicate samples that differ significantly ($p < 0.05$) from each other based on the test results.

3.2. Effect of Host Plants on Longevity and Reproduction

The female to male sex ratio of *I. jacobsoni* exhibited significant variation across the four host plants ($F_{3,56} = 34.72$; $p < 0.001$). The highest female-male sex ratio was recorded on *M. tanarius*, with a mean of 0.6 ± 0.1 , whereas the lowest was found on *F. microcarpa*, which had a mean value of 0.39 ± 0.08 (Table 5). Additionally, the pre-lay period for adult females showed significant differences among the host plants ($F_{3,56} = 39.65$; $p < 0.001$). The longest pre-lay period, averaging 25.5 ± 0.3 days, was noted on *F. microcarpa*, while the shortest duration was observed on *M. denudata*, with a mean of 15.3 ± 0.3 days (Table 5).

Table 5. Longevity and reproduction of *I. jacobsoni* on different host plants (Mean $\pm$ SE).

Host Plants	Sex Ratio	Pre-Lay Period (d)	Fecundity (Nymphs/Female)	Adult Longevity (d)	
				Male	Female
<i>M. tanarius</i>	0.6 ± 0.1 a	15.6 ± 0.5 c	162.7 ± 21.5 a	6.5 ± 1.1 b	40.3 ± 1.1 c
<i>M. denudata</i>	0.6 ± 0.1 a	15.3 ± 0.3 c	134.4 ± 12.3 b	7.5 ± 0.5 a	54.3 ± 1.7 a
<i>F. microcarpa</i>	0.4 ± 0.1 c	25.5 ± 0.2 a	81.6 ± 10.8 c	5.1 ± 0.5 b	52.7 ± 2.5 a
<i>P. guajava</i>	0.5 ± 0.1 b	18.4 ± 0.4 b	93.7 ± 10.0 c	3.2 ± 0.2 c	45.6 ± 3.9 c

Different letters within a column indicate samples that differ significantly ($p < 0.05$) from each other based on the test results.

Fecundity exhibited significant variation across different host plants, with the highest fecundity (162.7 ± 21.5 nymphs per female) recorded on *M. tanarius* followed by *M. denudata*, which averaged 134.4 ± 12.3 nymphs per female (Table 5). Additionally, the longevity of adults varied among the host plants (Table 5). The highest female longevity (54.3 ± 1.7 days) was observed on *M. denudata*, whereas no significant differences were noted among the other three host plants. In contrast, male longevity was shortest on *P. guajava* at 3.2 ± 0.2 days, with the longest lifespan recorded on *M. denudata* at an average of 7.5 ± 0.5 days.

The natality and survival rates of *I. jacobsoni* adult females across four host plants are illustrated in Figure 1. For *M. denudata*, adult females started producing nymphs on day 15 post-adult emergence (Figure 1A). Nymph production fluctuated from days 17 to 36, after which a marked decline was observed. Survival remained high until day 40, at which point it began to decline. In the case of *P. guajava*, nymph production started on the 17th day post-adult emergence (Figure 1B). The highest rates of natality occurred on the 30th and 41st days, subsequently experiencing a sharp decline. The survival of females was also at 100% until the 23rd day, after which a marked decrease began. Nymph production in *F. microcarpa* commenced on the 25th day, with peak natality recorded on the 26th day. This production exhibited fluctuations from the 27th to the 57th day, followed by a significant decline (Figure 1C). The survival rate of adult females remained at 100% until the 35th day, after which a decrease was noted. On *M. tanarius*, adult females commenced nymph production on day 16 post-emergence (Figure 1D). Nymph output varied between days 17 and 29, followed by a sharp decline on day 31. The survival rate remained high and relatively stable until day 34, after which it decreased significantly.

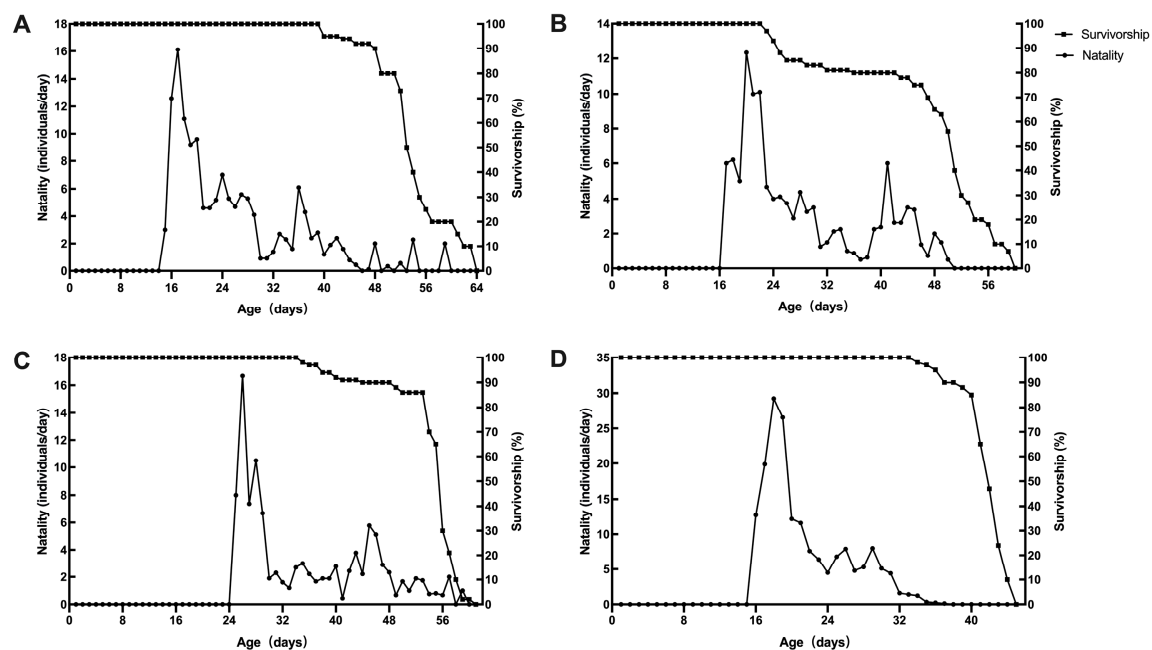


Figure 1. Natality and survival rate of adult females of *I. jacobsoni* on different host plants. (A): *M. denudata*; (B): *P. guajava*; (C): *F. microcarpa*; (D): *M. tanarius*.

The female to male sex ratios of *N. penicillioides* adult females feeding on *I. jacobsoni* reared on four host plants exhibited significant variations ($F_{3,56} = 23.47$; $p < 0.001$). The highest sex ratio was recorded for *N. penicillioides* adult females feeding on *I. jacobsoni* reared on *M. denudata*, with a mean of 0.6 ± 0.1 , while the lowest was found for *N. penicillioides* adult females feeding on *I. jacobsoni* reared on *F. microcarpa*, which had a mean value of 0.3 ± 0.2 (Table 6). Additionally, the pre-oviposition period for *N. penicillioides* adult females feeding on *I. jacobsoni* reared on four host showed significant differences among the host plants ($F_{3,56} = 43.56$; $p < 0.001$). The longest pre-oviposition period was observed for *N. penicillioides* adult females feeding on *I. jacobsoni* reared on *M. denudata* (7.2 ± 0.2 days), whereas the shortest was noted for *N. penicillioides* adult females feeding on *I. jacobsoni* reared on *M. tanarius*, with a mean of 4.9 ± 0.1 days (Table 6).

Table 6. Longevity and reproduction of *N. penicillioidea* feeding on *I. aegyptiaca* reared on different host plants (Mean $\pm$ SE).

Host Plants	Sex Ratio	Pre-Oviposition Period (d)	Fecundity (Eggs/Female)	Adult Longevity (d)
<i>M. tanarius</i>	0.5 $\pm$ 0.2 a	4.9 $\pm$ 0.1 c	199.9 $\pm$ 5.9 a	75.0 $\pm$ 0.9 a
<i>M. denudata</i>	0.6 $\pm$ 0.1 a	7.2 $\pm$ 0.2 a	216.8 $\pm$ 10.5 a	73.4 $\pm$ 0.5 a
<i>F. microcarpa</i>	0.3 $\pm$ 0.2 b	6.9 $\pm$ 0.2 a	68.1 $\pm$ 2.4 c	48.6 $\pm$ 1.0 c
<i>P. guajava</i>	0.4 $\pm$ 0.1 b	5.8 $\pm$ 0.2 b	150.7 $\pm$ 3.9 b	57.6 $\pm$ 0.6 b

Different letters within a column indicate samples that differ significantly ($p < 0.05$) from each other based on the test results.

Fecundity also varied significantly among *N. penicillioidea* adult females feeding on *I. jacobsoni* reared on different host plants, with *N. penicillioidea* adult females feeding on *I. jacobsoni* reared on *M. denudata* yielding the highest average of 216.8 ± 10.5 eggs per female, followed closely by *N. penicillioidea* adult females feeding on *I. jacobsoni* reared on *M. tanarius*, which averaged 199.9 ± 5.9 eggs per female. (Table 6). Furthermore, adult longevity differed among *N. penicillioidea* adult females feeding on *I. jacobsoni* reared on different host plants (Table 6). Female longevity of *N. penicillioidea* adult females feeding on *I. jacobsoni* reared on *M. tanarius* was longest (75.0 ± 0.9 days), while the shortest lifespan was recorded for *N. penicillioidea* adult females feeding on *I. jacobsoni* reared on *F. microcarpa*, with a mean of 48.6 ± 1.0 days.

The natality and survival rates of adult females of *N. penicillioidea* feeding on *I. jacobsoni* reared across the four host plants are illustrated in Figure 2. *N. penicillioidea* adult females feeding on *I. jacobsoni* reared on *M. denudata*, egg laying began on the sixth day post-adult emergence (Figure 2A). Egg production peaked between the sixth and eighteenth days, followed by a gradual decline. Survival was high until the fifty-fourth day, after which it began to decrease. In the case of *N. penicillioidea* adult females feeding on *I. jacobsoni* reared on *P. guajava*, females initiated egg laying on the third day post-emergence (Figure 2B). The highest natality was observed on the twenty-fifth day, after which there was a marked decline. The survival rate was consistently 100% until the fifty-third day followed by a sharp decline across the growth period. In *N. penicillioidea* adult females feeding on *I. jacobsoni* reared on *F. microcarpa*, the onset of egg production occurred on the sixth day, with peak egg laying recorded on the eighteenth day, followed by a significant decrease (Figure 2C). The survival rate of adult females remained at 100% until the fortieth day, after which a decline was noted. For adult females feeding on *I. jacobsoni* reared on *M. tanarius*, commenced laying nymphs on the third day post-emergence (Figure 2D). Egg production fluctuated between the third and twenty-seventh days after emergence, followed by a sharp decline post the twenty-seventh day. survival remained high and relatively stable until the sixty-sixth day, after which it decreased sharply.

3.3. Life Table Parameters

Life table parameters for *I. jacobsoni* exhibited variability across different host plants. The highest recorded values for R_0 (111.48), r_m (0.0642), and λ (1.0663) were observed on *M. tanarius*, while the longest mean generation time (99.53 days) was recorded on *F. microcarpa*. Conversely, the lowest values for R_0 (20.92), r_m (0.0306), and λ (1.0310) were observed on *F. microcarpa*, with *M. tanarius* showing the shortest mean generation time of 73.5 days (Table 7).

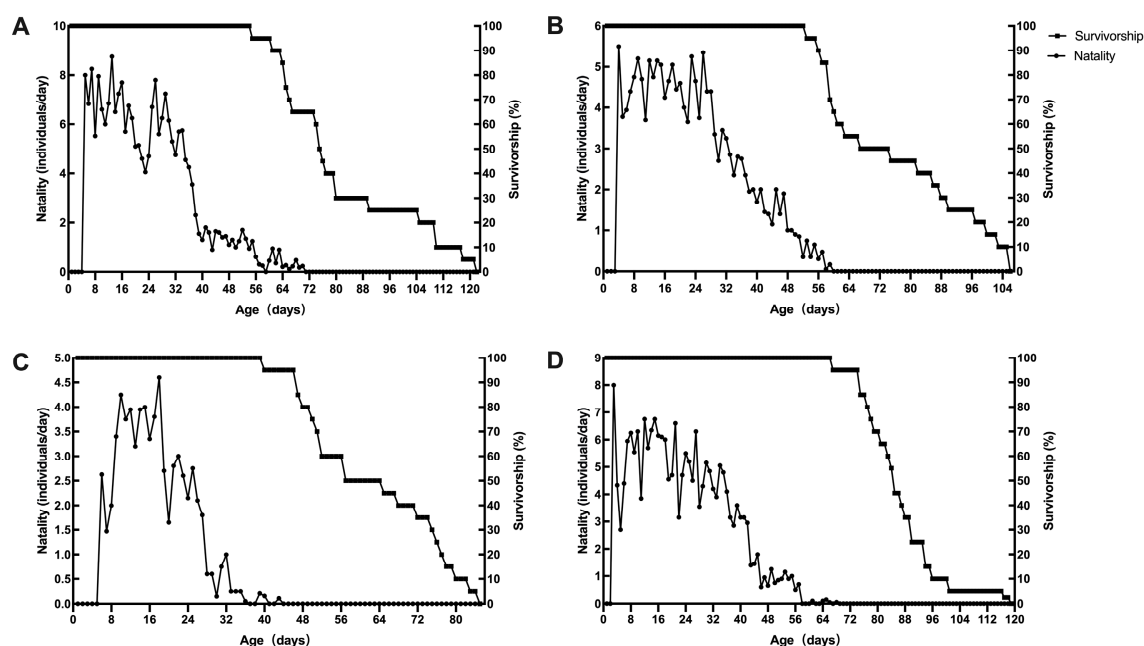


Figure 2. Natality and survival rate of adult females of *N. penicillioides* on different host plants. (A): *M. denudata*; (B): *P. guajava*; (C): *F. microcarpa*; (D): *M. tanarius*.

Table 7. Life table parameters of *I. jacobsoni* on different host plants.

Host Plants	Net Reproductive Rate (R_0)	Generation Time (T)	Intrinsic Rate of Increase (r_m)	Finite Rate of Increase (λ)
<i>M. tanarius</i>	111.48	73.5	0.0642	1.0663
<i>M. denudata</i>	85.74	81.3	0.0548	1.0563
<i>F. microcarpa</i>	20.92	99.5	0.0306	1.0310
<i>P. guajava</i>	46.96	81.2	0.0474	1.0485

The life table parameters for *N. penicillioides* feeding on *I. jacobsoni* reared on different host plants exhibited variability across different host plants. The maximum values for R_0 (86.53), r_m (0.0860), and λ (1.0898) were recorded for *N. penicillioides* adult females feeding on *I. jacobsoni* reared on *M. tanarius*, while the longest mean generation time (53.8 days) was recorded on *N. penicillioides* adult females feeding on *I. jacobsoni* reared on *P. guajava*. Conversely, the minimum values for R_0 (4.36), r_m (0.0294), and λ (1.0299) were found for *N. penicillioides* adult females feeding on *I. jacobsoni* reared on *F. microcarpa* (Table 8).

Table 8. Life table parameters of *N. penicillioides* feeding on *I. aegyptiaca* reared on different host plants.

Host Plants	Net Reproductive Rate (R_0)	Generation Time (T)	Intrinsic Rate of Increase (r_m)	Finite Rate of Increase (λ)
<i>M. tanarius</i>	86.53	51.9	0.0860	1.0898
<i>M. denudata</i>	65.49	51.5	0.0813	1.0847
<i>F. microcarpa</i>	4.36	50.0	0.0294	1.0299
<i>P. guajava</i>	24.15	53.8	0.0592	1.0610

4. Discussion

The choice of host plants plays a pivotal role in shaping the life history traits of herbivorous insects and their natural enemies by altering nutritional availability, chemical composition, and physiological interactions [20,21]. This study demonstrates that both *I. jacobsoni* reared on four different host plants (*M. tanarius*, *M. denudata*, *F. microcarpa*, and *P. guajava*), and its predator *N. penicillioides* feeding on these *I. jacobsoni*, exhibited

significant differences in growth, survival, reproduction, and population growth. These findings align with previous research on polyphagous insects and their predators, underscoring the importance of host plant suitability in pest ecology and biological control strategies [20,22,23].

In this study, the observed differences in the life history of *I. jacobsoni* could be attributed to unknown host plant factors, potentially including their nutritional and chemical properties [20]. Our findings indicated that the growth period and survival rates of *I. jacobsoni* exhibited significant variation among the different host plants. Previous research has also demonstrated that host plants can influence the life history characteristics of various mealybug species [18,24,25]. For instance, the growth time of female *Planococcus kraunhiae* Kuwana was reduced when fed on germinated *Vicia faba* L. seeds compared to leaves of *Citrus* sp. L. and *Cucurbita maxima* Duchesne, with higher survival rates observed on germinated *V. faba* seeds than on citrus leaves [26]. Similarly, the pink hibiscus mealybug, *Maconellicoccus hirsutus* Green, showed comparable growth on *Cucurbita pepo* L. and *C. maxima* [27]. The citrus mealybug, *Planococcus citri* Risso, experienced higher mortality on green than on red or yellow variegated *Coleus blumei* ‘Bellevue’ (Bentham) plants, and exhibited faster growth and greater fecundity on the red variegated plants [28]. Furthermore, the survival and growth of the mealybug *Phenacoccus parvus* Morrison did not vary significantly on *Lantana camara* L., *Lycopersicon esculentum* Miller, and *Solanum melongena* L., while *Gossypium hirsutum* L., *Ageratum houstonianum* Miller, and *Clerodendrum cunninghamii* Benth were found to be less suitable hosts compared to *L. camara* [29]. Previous studies indicated that the efficacy of natural predators of herbivorous insects may be indirectly influenced by the characteristics of host plants [30–33]. For instance, Giles et al. [34] demonstrated that the fatty acid composition of *Acyrtosiphon pisum* varied with its host plant, thereby affecting the performance of its natural enemies. Fukunaga and Akimoto [35] reported increased mortality and reduced growth rates in *Harmonia axyridis* larvae, attributed to the insect host *Aulacrothum magnoliae*’s ability to absorb toxic compounds from its host plant, *Salix sieboldiana*. Our findings indicated that *N. penicilliioides* successfully completed all growth stages when preying on *I. jacobsoni* that had been reared on the various host plants. Furthermore, the host plant of the prey had no significant impact on the growth and survival of the predator’s different immature stages. This aligns with the observations of Fotukiaii et al. [31], who reported similar outcomes for *Serangium montazerii* feeding on *Dialeurodes citri*.

I. jacobsoni exhibited the highest fecundity, the highest female to male sex ratio, and a shorter pre-oviposition period in *M. tanarius*. In contrast, both male and female individuals were also capable of mating and reproducing on the other three host plants examined. The various longevity and reproductive metrics recorded in this investigation align with findings from prior studies on different mealybug species. Lim [36] documented that the pre-lay period, nymph production, and post-reproductive phase for *D. neobrevipes* were 11.6, 9.1, and 4.3 days, respectively. Additionally, the adult lifespan for females and males was reported as 28.1 and 3.3 days, respectively, with females producing between 19 and 137 nymphs. The performance of natural enemies, such as their fecundity and longevity, can be indirectly influenced by the host plant of their prey [37]. Our results showed significant variation in the fecundity and longevity of *N. penicilliioides* when preying on *I. jacobsoni* reared on different host plants. This prey-mediated effect is consistent with observations of *S. montazerii*, whose fecundity and longevity differed when feeding on whiteflies from different citrus varieties [31]. These changes in reproductive parameters can be due to the differences in host plants, prey quality and predator species [37–39].

The intrinsic rate of natural increase (r_m) serves as a significant measure of the cumulative effects on growth, reproduction, and survival [40]. Our data demonstrated that

M. tanarius is the most suitable host plant for the growth of *I. jacobsoni*, as the mealybug's growth on this plant was notably swift, and the intrinsic rate of increase was substantial at 0.0642. Life table analysis revealed that the r_m values for *I. jacobsoni* were lower on the other three host plants, suggesting a greater adaptation of *I. jacobsoni* to *M. tanarius* compared to the other tested plants. Consequently, it is imperative for pest management strategies to focus on *I. jacobsoni* in agricultural settings where *M. tanarius* is cultivated. The populations of *N. penicillioides* feeding on *I. jacobsoni* reared on the four host plants all showed a finite rate of increase (λ) greater than 1 and a positive intrinsic rate of increase (r_m). These results demonstrate that the predator population has the capacity for sustained growth under these conditions, enabling it to complete its life cycle and expand its population, which is a positive indicator of its potential as a biological control agent [40].

The results of the present study indicate that *I. jacobsoni* is capable of developing on all four plant species examined, implying that this pest may establish itself in new regions of Southern China [41]. With its rapid growth, high survival rates, and substantial reproductive potential, populations of *I. jacobsoni* can proliferate significantly, leading to considerable damage to numerous economically vital crops if appropriate management strategies are not adopted [12,13]. The life history data for *I. jacobsoni* will aid in pest management, as this information can facilitate the prediction of early instar emergence in the field and optimize the timing of pesticide applications. Controlling early-instar mealybugs is generally more effective than managing later instars [13,42]. Conversely, our life table data suggest that *N. penicillioides* have a great biocontrol potential when *I. jacobsoni* infests *M. tanarius* or *M. denudata*. This inference is based on the superior host quality of these plants for the scale insect, which likely supports a more robust prey population for the predator. Future research involving paired prey–predator population studies is needed to confirm this.

5. Conclusions

Based on the findings of this study, *M. tanarius* was identified as the most suitable host for *I. jacobsoni*, supporting higher pest growth and reproductive rates, while *F. microcarpa* negatively affected its fitness. The predator *N. penicillioides* performed most effectively when preying on scales from favorable host plants such as *M. tanarius* or *M. denudata*. These results elucidate the tri-trophic interactions among host plants, *I. jacobsoni*, and *N. penicillioides*, providing a foundation for targeted pest management. By leveraging host plant suitability data, agricultural practitioners can enhance both chemical and biological control measures, mitigating the spread of this economically significant pest.

Author Contributions: Conceptualization, J.P. and X.W.; methodology, J.L.; software, J.L.; validation, M.H.B.; formal analysis, M.H.B.; investigation, S.Z. and M.H.B.; resources, X.W.; data curation, S.Z. and M.H.B.; writing—original draft preparation, J.P. and S.A.; writing—review and editing, S.A.; supervision, J.P.; funding acquisition, X.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Modern Agricultural Industry Technology System for Tea in Guangdong Province, grant number 2024CXTD11 and the Key Science and Technology Projects of YNTC, grant number 2023530000241004.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: The authors are thankful to Andrew G. S. Cuthbertson from York, UK for language editing.

Conflicts of Interest: The authors declare no conflicts of interest.

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