



Host-dependent Life Cycle Variations in Papaya Mealybug *Paracoccus marginatus* and Their Implications for Divergent Natural Selection

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ABSTRACT

Background: This study was undertaken to understand how host plant variations influence the life cycle and adaptability of *Paracoccus marginatus*. It aims to reveal how such host-dependent differences drive divergent natural selection and pest evolution.

Methods: *Paracoccus marginatus* life cycle on different host plants was investigated utilizing both stage-specific (vertical) and age-specific (horizontal) life tables. These studies revealed significant biological variation in PMB performance across different hosts.

Result: Among the tested host plants viz. papaya, cotton, tapioca mulberry, brinjal and hibiscus, papaya supported the highest net reproductive rate, reaching 559.48 females per female, whereas the lowest was recorded in tapioca at 282.53. The capacity for population growth (r_c) also varied, being highest in papaya (0.512) and lowest in tapioca (0.324). Correspondingly, the intrinsic rate of increase (r_m), which reflects the potential for population expansion per day, peaked in papaya at 0.570 and dropped to 0.342 in tapioca. Analysis of cumulative K values, representing total generation mortality, showed lower values in females than in males across all hosts. In papaya, the K value was the lowest for both sexes 0.0325 in females and 0.0587 in males indicating lower mortality. Conversely, tapioca showed the highest K values, with 0.1405 in females and 0.1799 in males. These results demonstrate how host plants have a major impact on papaya mealybug population dynamics and survival rates.

Key words: Generation mortality, Host plant influence, Intrinsic rate of increase, Life table analysis, Papaya mealybug, *Paracoccus marginatus*.

INTRODUCTION

A life table is a valuable analytical tool used by ecologists to monitor and document stage-specific mortality within a population. It offers a systematic framework for recording data across successive age intervals, including the number of deaths, surviving individuals, mortality rates and life expectancy (Chi *et al.*, 2023). In entomology, life tables are particularly important due to the distinct developmental stages of insects, each of which may experience significantly different mortality rates. This method allows researchers to assess population dynamics and identify critical stages where mortality is most pronounced, thereby highlighting the key factors influencing population decline (Majd-Marani *et al.*, 2023). Life tables also facilitate the application of various mathematical models to evaluate fecundity, stable age distribution and overall life expectancy. Such analyses are instrumental in understanding the reproductive potential and survival trends of insect populations. Furthermore, constructing multiple life tables under different conditions can help in developing predictive models that can be validated against real-world population changes, aiding in forecasting and pest management planning (Cao *et al.*, 2023).

In addition to these benefits, life tables contribute to determining the distribution patterns, age structure and survival probabilities of organisms. These insights are essential for designing targeted interventions in pest management strategies. The polyphagous papaya mealybug (PMB), *Paracoccus marginatus*, infests a variety of host plants, each of which has a distinct impact on the pest's development and bioecological characteristics

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(Borkakati *et al.*, 2024). Despite its wide host range, comprehensive life table analyses on PMB across various host plants have been limited. Therefore, the current investigation was undertaken to examine the life cycle and population dynamics of *P. marginatus* on different host species. This study represents the first detailed attempt to construct life tables for PMB across multiple host plants, providing new insights into how host selection influences pest biology and survival patterns, which is crucial for effective pest management strategies.

MATERIALS AND METHODS

The study was carried out in the Under Graduate Laboratory, Department of Entomology and farm area at

SRM College of Agricultural Sciences, Chengalpattu, Tamil Nadu India.

***Paracoccus marginatus* collection and mass rearing**

Papaya mealybugs were raised using potato sprouts as an alternate food source. Potato sprouts were produced in large quantities using the procedure described in a prior work. A camel hair brush was used to transport mealybugs from a variety of host plants, including papaya, tapioca, cotton, mulberry, brinjal and hibiscus, to potato sprouts at a rate of three to five ovisacs per sprout. Within 25 to 30 days of inoculation, a large number of mealybugs were successfully cultured. Additionally, mass rearing was simultaneously performed on the respective host plants mentioned above and used in subsequent experimental work (Amarasekare *et al.*, 2008). All essential observations related to life cycle parameters were systematically recorded and analyzed.

Description of life table statistics

A life table outlines the survival and death trends within a population. By analyzing mortality rates across different age groups, it offers key insights into the number of individuals surviving, those that perish and the expected lifespan, helping to understand population dynamics effectively (Dublin and Lotka, 1937). A life table is an organized depiction of a population's mortality and survival rates at various stages of life. The organism's chronological age from birth to death is recorded in the first column of the table. The survivorship at each age is listed in the second column, starting with all people alive at birth (age 0) and gradually decreasing as mortality happens. This column, which shows the percentage of the original cohort that survived to each age, is represented by the symbol l_x . The survival fraction between age intervals, denoted as S_x , is shown in the third column. It is computed by dividing the present age's survivorship by that of the next age. The age-specific mortality rate, or the likelihood of dying within a given time frame, is shown in the fourth column and is typically denoted by q_x . Columns five and six provide reproductive data: the total number of female progenies produced by the population and the number of female offspring per female insect, respectively. These values are crucial in understanding reproductive capacity and population growth.

The expectation of life, which appears in column nine, is calculated using the intermediate values in columns seven and eight. The average number of people alive at each age range is shown in column nine. It can alternatively be understood as the total number of days that the cohort at each age lived. The values in column seven are added up in reverse order, beginning with the final step, to get column eight. The life expectancy at each age is calculated in column nine by dividing the cumulative total in column eight by the corresponding number of survivors in column two. This gives an estimate of the average remaining lifespan for individuals at a given age. Finally, columns ten

and eleven are supporting data points used to estimate the intrinsic rate of natural increase (r_m), presented in the twelfth column, which quantifies the population's growth potential (Dublin and Lotka, 1937).

Creation of a life table by age and stage

To construct life tables for the papaya mealybug, its life cycle was divided into distinct developmental stages such as eggs, nymphs and adults. For each stage, data on development duration, survival and mortality were carefully recorded. In the case of females, age-specific fecundity *i.e.*, the total number of eggs laid over time was also assessed to determine reproductive potential.

Various life table parameters were calculated based on standard procedures followed in earlier studies. These included survivorship (k value) (Amarasekare and Sifuentes, 2012), survivorship curves (Gotelli, 2007), standardization of survivorship patterns (Ralston and Jennrich, 1978), apparent mortality, survival fraction (S_x), indispensable mortality (IM), generation mortality expressed as K -values and mortality survivor ratio (MSR) (Southwood, 1978). Additionally, population growth metrics such as net reproductive rate (R_0), intrinsic rate of natural increase (r_m), finite rate of increase (λ), mean generation time (T) and population doubling time (t) were determined according to methodologies established in previous research (Arshad Ali and Rizvi, 2007).

RESULTS AND DISCUSSION

Survival, mortality and reproductive data were collected for *Paracoccus marginatus* across various host plants. These observations included total female emergence and fecundity. Using these records, age-specific life tables were developed and stage-specific life tables were subsequently derived from this information for each host, allowing detailed analysis of developmental stage performance.

***Paracoccus marginatus*'s age-specific life table on various host plants**

Age-specific life table data of papaya mealybug *P. marginatus* across various host crops are presented in Fig 1. The findings showed noticeable variation in the adult lifespan and reproductive performance depending on the host plant. The shortest adult life span was observed on papaya, lasting 28 days, whereas the longest was on tapioca, extending to 42 days. On papaya, reproduction began on the 8th day with 56 offspring and continued until the 18th day, concluding with 26 females per female. In cotton, reproduction started on the 9th day with 65 offspring and ended on the 19th day with 21 females, with adults living for 30 days. Mealybugs reared on potato sprouts initiated reproduction on the 9th day (56 offspring) and ceased by the 19th day (22 females), with a total lifespan of 31 days.

In mulberry, egg-laying commenced on the 10th day with 49 offspring and concluded on the 21st day with 10 females, with adult longevity of 32 days. Brinjal supported

reproduction from the 10th to 22nd day, starting with 44 and ending with 11 offspring, across a 35-day life span. Hibiscus and tapioca supported delayed and lower reproduction. In hibiscus, offspring production started on the 11th day (31 females) and stopped on the 23rd day (5 females), while in tapioca it began on the 13th day with 21 females and ended on the 26th day with just 2 females. The adult longevity was 36 days in hibiscus and 42 days in tapioca. Overall, papaya, cotton and potato sprouts supported early and higher reproduction with shorter life

spans. Mulberry showed comparable trends. Conversely, brinjal, hibiscus and tapioca supported lower fecundity with longer life spans and extended reproductive periods.

A summary of *P. marginatus*'s age-specific life table properties on different host plants is provided in Fig 2 and Fig 3. Comprehending the life cycle of insects is crucial for researching their growth, population dynamics and patterns of dispersal. In polyphagous species like *P. marginatus*, the life cycle often varies depending on the host plant. The present study is the first to report the complete life

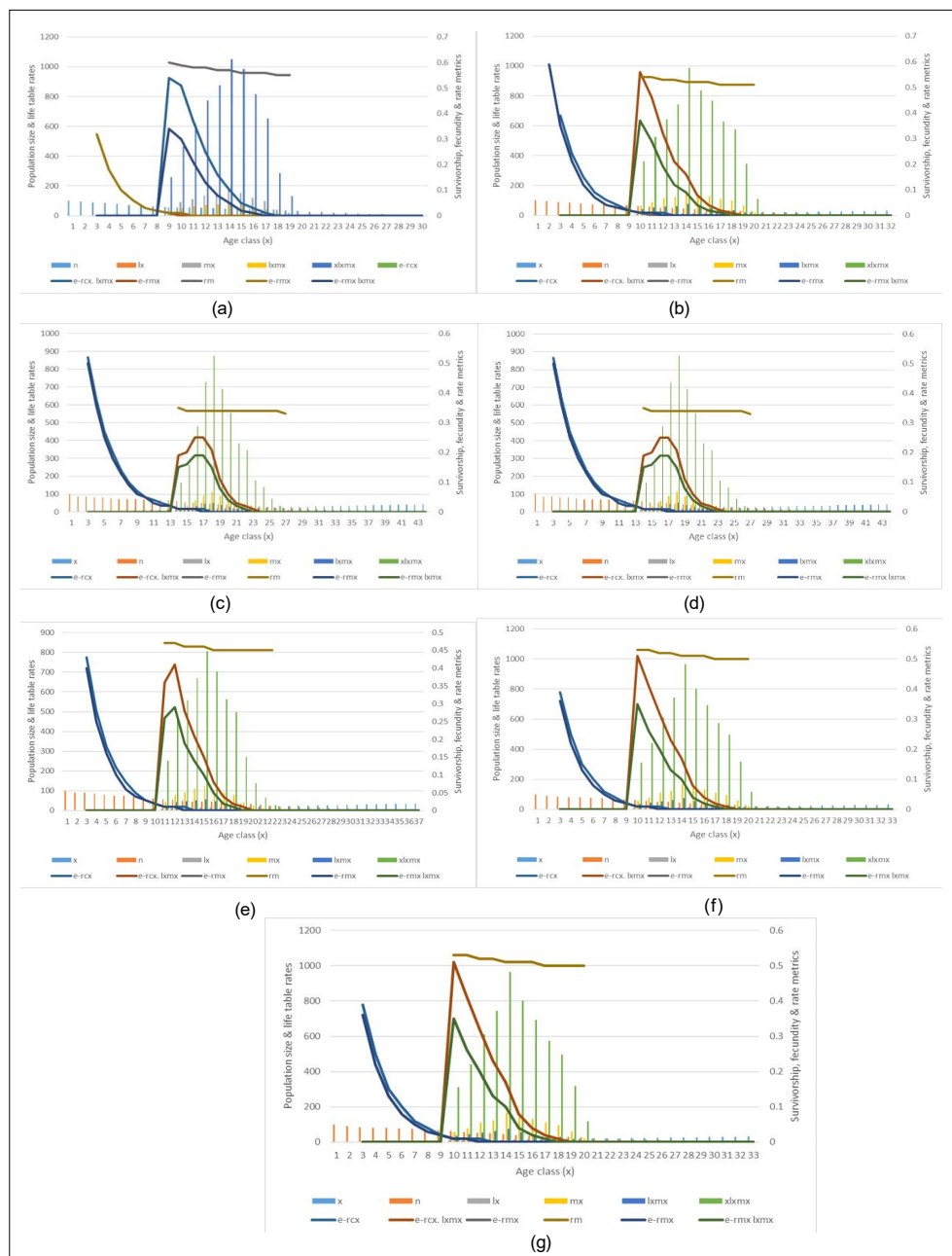


Fig 1: Papaya mealybug *Paracoccus marginatus* age specific life table parameters on papaya (a), cotton (b), tapioca (c), mulberry (d), brinjal (e) hibiscus (f) and potato sprouts (g) respectively.

cycle of this pest on different hosts and the results demonstrated significant variations in its biological performance. The significance of variations in biological parameters among different host plants was determined through one-way analysis of variance (ANOVA), followed by Duncan's Multiple Range Test (DMRT) at a 5% level of significance to separate the means. All reported values for net reproductive rate, intrinsic rate of increase and other life table parameters represent mean values $\pm$ standard deviation (SD) obtained from the analysis. Each treatment or host plant group consisted of a sample size of 30 adult females and all experiments were conducted under controlled laboratory conditions to ensure uniformity and reproducibility of the results. Among the tested hosts, papaya supported the highest net reproductive rate, with 559.48 females per female, followed by cotton at 498.28. The lowest net reproductive rate was recorded in tapioca,

with only 282.53 females per female. Similarly, the capacity for population increase (r_c) was greatest in papaya (0.512), followed by cotton (0.474) and potato sprouts (0.427), while the lowest was observed in tapioca (0.324). The intrinsic rate of increase (r_m), which closely followed the trend of r_c , was highest in papaya at 0.570 per day and lowest in tapioca at 0.342 per day. The doubling time of the population also varied with the host plant. The shortest doubling time was recorded in papaya (1.216 days), indicating rapid population growth, while the longest was in tapioca (2.028 days), followed by hibiscus (1.696 days). These differences reflect the adaptability of *P. marginatus* to certain host plants where it could complete its life cycle quickly and reproduce more effectively. These findings contrast with the results of Amarasekare *et al.* (2008), who reported similar egg survival across four hosts plumeria, acalypha, hibiscus

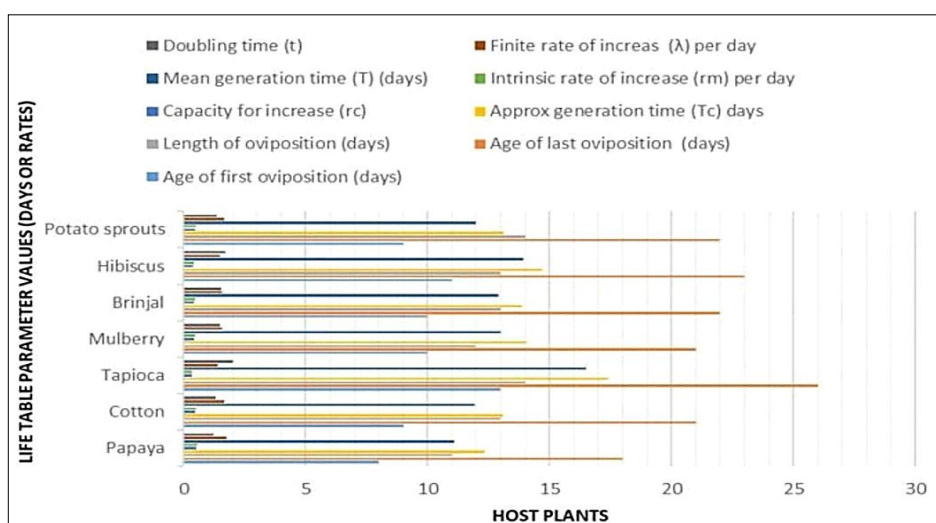


Fig 2: *Paracoccus marginatus* life table criteria for several host plants.

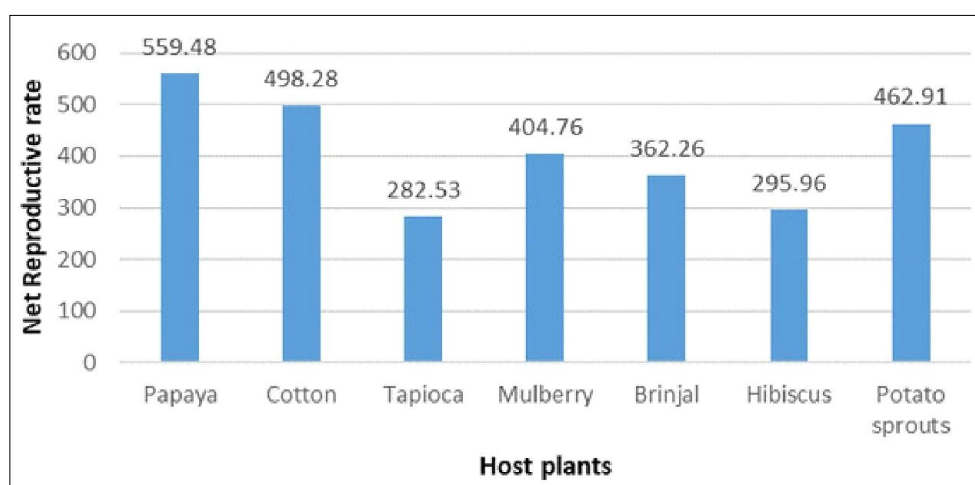


Fig 3: Net reproductive rate (RO) of *Paracoccus marginatus* in different host plants.

and parthenium. However, they observed reduced survival in early instars on plumeria and a higher proportion of female emergence on that plant compared to the others, highlighting species-specific host interactions (Ramzan *et al.*, 2021).

***Paracoccus marginatus* life table by stage on various host plants**

The stage-specific life table data of *Paracoccus marginatus* across different host plants are presented in Fig 4 and Fig 5. The results indicated a female-biased sex ratio in the offspring. This ratio was initially determined during the second instar stage and then back-calculated for the earlier

stages, including eggs and first instars. Fig 3 and Fig 4 show the detailed survival and mortality rates at each developmental stage for both male and female mealybugs on papaya. On papaya, the study began with 890 female and 175 male eggs, resulting in 660 females and 89 males reaching adulthood. In cotton, 760 female and 205 male eggs were recorded, with successful adult emergence noted accordingly. For tapioca, the initial count included 299 female and 246 male eggs, with only 82 females and 31 males maturing into adults, indicating higher mortality. On mulberry, 610 female and 315 male eggs were observed, from which 356 females and 85 males developed successfully. In brinjal, hibiscus and potato sprouts, the



Fig 4: Stage wise life cycle of papaya mealybug *Paracoccus marginatus* on papaya, cotton, tapioca and mulberry in female and male insects respectively.

number of eggs in female mealybugs was 526, 399 and 708 respectively, while corresponding male egg counts were 309, 296 and 242. These results highlight significant variations in survival across host plants and between sexes.

Papaya had the highest survival percentage and survival fraction (S_x) of female mealybugs (74.16% and 0.91, respectively), whereas tapioca had the lowest (27.42% and 0.76, respectively). Similarly, male mealybugs showed higher survival on papaya (50.86%, S_x 0.74) and the lowest on tapioca (12.60%, S_x 0.75). Tapioca also exhibited the greatest apparent mortality for both sexes. Among female instars, the lowest mortality occurred during

the first instar (23.65%), whereas the second instar had the highest (30.32%). For males, the fourth instar showed the highest mortality (50.00%). Specifically on papaya, female mortality ranged from 6.14% in the first instar to 9.14% in the third, while in males, it was lowest in the first instar (5.14%) and peaked in the fourth instar (26.45%).

To determine the possible population growth at a particular stage if mortality had not occurred during that stage, the Mortality Survivor Ratio (MSR) was computed. MSR values for tapioca at the egg stage were almost the same for both sexes: 0.48 for males and 0.47 for females. During the second instar, MSR was 0.31 in females and



Fig 5: Stage wise life cycle of papaya mealybug *Paracoccus marginatus* on brinjal, hibiscus and potato sprouts in female and male insects and k value respectively.

slightly higher at 0.34 in males. Male mealybugs exhibited greater MSR in later stages, recording 0.18 and 0.36 in the third and fourth instars, respectively, while females showed a lower MSR of 0.10 in the third instar. Similar patterns were also observed in other host plants. Indispensable Mortality (IM), indicating the portion of mortality that could be avoided if the responsible factor were eliminated, was consistently higher in females across all stages. In papaya, female IM ranged from 47.71 to 67, whereas in tapioca it was lower, between 25.39 and 38.78. In males, the highest IM occurred in tapioca (10.50 to 31.00) and the lowest in papaya (2.08 to 2.24).

The stage-specific life table analysis revealed significant differences among host plants in survival proportion, survival fraction (Sx), apparent mortality, mortality-survivor ratio (MSR), indispensable mortality (IM) and K-values. Although differences existed among hosts, all plants consistently showed a female-biased sex ratio, albeit with varying proportions, as also noted by earlier researchers (Atanu Seni and Chongtham, 2013). A notable decline in first instar *P. marginatus* was observed, likely due to the active movement of crawlers away from leaf surfaces, leading to their accidental fall from the plant. This behavior was evident across all tested plants. Similar findings were reported previously, where approximately 17-18% of first instar mortality occurred on hibiscus, acalypha and parthenium due to such displacement (Silva, 2023). Early observations confirmed that dislodged crawlers could not survive unless they were able to return to or were manually repositioned onto the leaf, indicating their vulnerability during the initial mobile stage of development. Early instars of scale insects and mealybugs are generally highly susceptible to displacement, with survival dependent on quick resettlement—a pattern noted across several mealybug species (e.g., citrus mealybug and cotton mealybug; Rao *et al.*, 2006; Joshi *et al.*, 2010). Ecological studies of mealybug pests highlight that early mobile stages often exhibit high mortality unless they effectively settle on host tissue, underscoring the vulnerability of crawlers and first instars (Basavaraju *et al.*, 2013).

The current study revealed variations in adult longevity of mealybugs across different host plants, contrasting with earlier findings (Subramanian *et al.*, 2021) that reported no such differences between males and females across hosts. Survival proportion and survival fraction were highest in papaya, while the lowest values were noted in tapioca and hibiscus. Conversely, mortality was most pronounced in tapioca and hibiscus, with papaya showing the least. Total generation mortality, expressed as the K-value, was consistently lower in females compared to males (Fig 4). In papaya, K-values were 0.0325 for females and 0.0587 for males the lowest among all hosts. Tapioca showed the highest K-values (0.1405 in females, 0.1799 in males), followed by hibiscus (0.0959 and 0.1478, respectively).

Tapioca and hibiscus had the greatest finite mortality rates in both the egg and first instar stages of *Paracoccus marginatus* among the six host plants that were assessed.

These elevated mortality levels could be attributed to differences in nutritional content, developmental suitability and the susceptibility of early instars. It is well established that host plant species can significantly influence the life history traits of various mealybug species. For example, a longer pre-reproductive time and higher progeny output were noted in *Rastrococcus invadens* raised on several *Mangifera indica* types. The variability in *P. marginatus* performance across hosts in this study may be linked to differences in nutrient composition, presence of allelochemicals, or structural properties of the leaves.

A similar trend has been documented in the citrus mealybug, *Planococcus citri*, where mortality was higher on green *Coleus blumei* plants compared to red or yellow variegated ones. Moreover, development was faster and fecundity greater on red-variegated plants (Bibi *et al.*, 2022). Environmental factors like food quality and availability also play crucial roles in shaping life history traits, regardless of whether such traits are influenced by natural selection in a particular environment (Rodrigues-Silva *et al.*, 2021). Overall, while *P. marginatus* can survive and reproduce on a range of host plants, its life history is notably affected by host-specific characteristics (Alfayo *et al.*, 2024).

CONCLUSION

The findings from the life history study of *Paracoccus marginatus* are valuable in understanding its development, survival and reproduction across various host plants that provides essential insights into its biology and adaptability. Such knowledge is crucial for designing integrated pest management (IPM) programs tailored to reduce the impact of this pest. The pest's ability to complete its life cycle on multiple host species highlights its potential to spread, colonize and establish in new environments. This adaptability increases the risk of infestation in diverse cropping systems, making early detection and preventive strategies vital. The data generated will help in identifying vulnerable life stages for targeted interventions, optimizing control efforts while minimizing environmental harm. Moreover, the study emphasizes the need to monitor alternative host plants that may serve as reservoirs, facilitating the movement and expansion of *P. marginatus*. This comprehensive understanding supports sustainable and strategic pest control planning.

Conflict of interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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