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Population dynamics, economic injury levels and life table construction of mealybugs: A review

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Abstract

Mealybugs are one of the most destructive pests in agriculture, affecting a wide range of crops globally. Their ability to adapt to different environmental conditions, reproduce rapidly, and cause extensive damage makes them a significant challenge for farmers and agricultural managers. The management of mealybug populations requires an understanding of their ecology and the integration of various control strategies, including biological, chemical, and cultural methods. According to Borkakati *et al*. (2024), a comprehensive approach to mealybug management is essential to minimize economic losses and ensure sustainable agricultural practices. The population dynamics of mealybugs, particularly *Phenacoccus solenopsis*, have been widely studied due to their significant impact on various crops. This review explores key studies on mealybug population trends, environmental influences, economic injury levels (EIL), and life table constructions for effective pest management. Research by Suroshe *et al*. (2019) and Shah *et al*. (2015) indicates that mealybug populations are positively correlated with temperature and humidity, though variability exists in different regions. Natural enemies like parasitoids and hyperparasitoids also influence mealybug populations, presenting potential for biological control. Charles (1982) and Haviland *et al*. (2015) assess yield losses and establish economic thresholds, highlighting the critical importance of early intervention to prevent crop damage. Life table studies, such as those by Nisha and Kennedy (2017a) and Sahito *et al*. (2017), provide insights into the population growth, mortality, and reproductive rates of mealybugs and their natural enemies. These studies underscore the role of ecological, biological, and environmental factors in managing mealybug populations. Future research should focus on field-based long-term studies to refine pest management models and improve the efficacy of integrated pest management (IPM) programs.

Keywords: Population dynamics, *Phenacoccus solenopsis*, mealybug, natural enemies, economic injury level (EIL), life table, biological control, integrated pest management (IPM), crop damage, parasitoids, yield loss

Introduction

Mealybugs (Hemiptera: Pseudococcidae) are among the most destructive pests that impact agriculture, causing widespread damage to a variety of crops around the globe. These soft-bodied, sap-feeding insects extract nutrients directly from the plant's phloem, leading to reduced growth, vigor, and overall productivity of the host plants. In severe cases, mealybug infestations can result in the death of the plant, causing significant economic losses. A notable secondary issue caused by mealybugs is the secretion of honeydew, a sugary substance that encourages the growth of sooty mold. This mold can cover leaves and fruit, further reducing the quality and marketability of agricultural produce. The wide range of host plants and the ability to reproduce quickly in different environmental conditions make mealybugs highly adaptable pests that are challenging to manage. The economic consequences of mealybug infestations are especially serious in major cash crops like cotton, papaya, grapes, and various horticultural plants. For example, in cotton-producing regions, the cotton mealybug, *Phenacoccus solenopsis*, has emerged as a significant pest, reducing both yield and quality. Similarly, the papaya mealybug, *Paracoccus marginatus*, has caused considerable damage in papaya and other tropical fruit crops, spreading across regions due to its invasive nature. The polyphagous behavior of many mealybug species, meaning they can feed on multiple plant species, further complicates their management, as infestations can spread easily from one crop to another. The rise in mealybug infestations and the subsequent economic damage has driven a need for better understanding of their population dynamics, which are influenced by factors such as climate, natural predators, and plant host availability. Researchers have focused on studying these dynamics to develop effective pest control strategies that go beyond traditional chemical control methods. Although chemical insecticides have been commonly used to manage mealybug populations, their excessive use can lead to resistance development, environmental degradation, and harm to non-target species, including beneficial insects. Thus, there is a growing shift toward integrated pest management (IPM) strategies that combine chemical, biological, and cultural practices to achieve sustainable control. One of the key aspects in understanding mealybug infestations is the construction of life tables, which provide insights into the mortality rates, reproductive potential, and population growth rates of mealybugs under different conditions. Life table analyses can help predict outbreaks and identify critical life stages that are most vulnerable to control measures. Additionally, the relationship between mealybugs and their natural enemies, such as parasitoids and predators, is a crucial area of study. For instance, natural enemies like the parasitoid *Aenasius bambawalei* and predatory ladybird beetles have shown potential in managing mealybug populations effectively. Understanding the interaction between mealybugs and these biological control agents can provide a foundation for developing more sustainable management programs.

The goal of this review is to synthesize the current research on mealybug population dynamics, assess the economic impacts of mealybug infestations on crop yields, and examine the effectiveness of various management strategies, particularly the role of life table construction and IPM programs. By focusing on the interplay between environmental factors, biological control agents, and pest populations, this paper highlights the need for comprehensive pest management strategies that minimize the reliance on chemical pesticides and promote long-term agricultural sustainability.

Population dynamics of mealybug

Suroshe *et al*. (2019) [2] studied the population dynamics of cotton mealybug, *Phenacoccus solenopsis* Tinsley and its natural enemies. From their studies it was revealed that mealy bug population was positively correlated with temperature, RH and RF. Moreover, the population of mealy bugs was positively correlated also with parasitoid, *Aenasius bambawalei* Hayat; and hyper parasitoid, *Promuscideaun fasciativentris* Girault and *Aprostocetus purpureus.*

Shah *et al*. (2015) [3] conducted studies in population dynamic of CMB, *Phenacoccus solenopsis* Tinsley. In field survey, the highest CMB mean population of 99.8±7.8 per plant twig was observed from Shadadpur. Throughout the cotton growing season, the highest CMB mean population of 222.3±22.8 was observed in second fortnight visit of September. The results regarding the population dynamics of *P. solepnosis* showed comparatively similar trend in all talukas. The effect of environmental factors on CMB population was observed through correlation. However, there was no significant effect of relative humidity on the CMB population in all talukas. The maximum damage percentage of cotton crop was observed at first fortnight visit of October and such results remained constant until second fortnight visit in all talukas.

Assessment of yield loss and Economic Injury Level (EIL)

Charles (1982) [4] estimated the economic damage and preliminary economic thresholds for *Pseudococcus longispinus*. The population level (economic injury level) of mealybug required to cause sooty mould formation was found to be about 20 mealybugs of all stages per bunch at harvest. Economic thresholds of less than 0.8 and 34 mealybugs/leaf respectively in the first and second generations resulted in economic injury. Sampling for mealybugs in vineyards to determine economic thresholds is considered to be time-consuming for feasibility of the method. However, the development of the mealybug population can be related to vine development, with the first generation beginning at bud-burst and the second during December before bunch closure. Because of the very low mealybug numbers initially required to lead to economic loss, it was recommended that insecticides could be applied at bud-burst and before Christmas if any mealybugs were reported in the vineyard during the previous harvest or pruning.

Haviland *et al.* (2015) [5] studied the crop loss relationships and EIL for *Ferrisia gilli* (Hemiptera: Pseudococcidae) infesting Pistachio in California. They conducted a 3-year field study to determine the type and amount of damage caused by *F. gilli*. By spraying of pesticides, they established gradients of *F. gilli* densities in a commercial pistachio orchard near Tipton, CA, from 2005 to 2007. Each year, mealybug densities on pistachio clusters were recorded from May through September and cumulative mealybug-days were determined. At harvest time, nut yield per tree (5% dried weight) was determined, and subsamples of nuts were evaluated for market quality. Linear regression analysis of cumulative mealybug-days against fruit yield and nut quality measurements showed no relationships in 2005 and 2006, when mealybug densities were moderate. However, in 2007, when mealybug densities were very high, there was a negative correlation with yield (for every 1,000 mealybug-days, there was a decrease in total dry weight per tree of 0.105 kg) and percentage of split unstained nuts (for every 1,000 mealybug-days, there was a decrease in the percentage of split unstained nuts of 0.560%), and a positive correlation between the percentage of closed kernel and closed blank nuts (for every 1,000 mealybug-days, there is an increase in the percentage of closed kernel and closed blank nuts of 0.176 and 0.283%, respectively). The data were used to determine economic injury levels, showing that for each mealybug per cluster in May there was a 4.73% reduction in crop value associated with quality and a 0.866 kg reduction in yield per tree (4.75%).

Construction of life history and life table

Life table study is very useful to analyse the mortality of insect population, to determine key factors responsible for the highest mortality within population. It is determined by constructing two types of life table *viz.*, Age Specific (or Horizontal) and Stage Specific (or Vertical) life table. Moreover, various mathematical formulas are also indicated for the appropriate evaluation of life fecundity tables, stable age distribution and life expectancy. Life expectancy of beneficial insects can be calculated and used for biological control program by predicting natural factors in a particular instar within which the maximum mortality of the pests is obtained and plan for managing pests can be prepared in time (Kakde *et al*., 2014) [8].

Nisha and Kennedy (2017a) [6] studied using Age Specific (or Horizontal) and Stage Specific (or Vertical) life table for *P. marginatus*. The net reproductive rate of papaya mealybug was observed to be higher in papaya (559.48 females/female) and least in tapioca (282.53). The capacity for increase (rc) was minimum (0.324) in tapioca and maximum in papaya (0.512). Intrinsic rate of increase (rm) has increased with the increase in the rate of capacity for increase as it was maximum in papaya (0.570 increase per day), minimum in tapioca (0.342/day). The cumulative K value, total generation mortality was observed to be minimum in female than male. It was minimum in papaya (0.0325 for female and 0.0587 for male mealybug), while tapioca recorded the highest K value among the host plants (0.1405 in female and 0.1799 in male). However, the study on life cycle of encyrtid parasitoid *Acerophagus papayae* Noyes and Schauff was conducted for IPM programme with laboratory host *P. marginatus* raised in different host plants. From the investigation it was revealed that the host plants induced changes in the behavior and physiology of mealybug that indirectly influenced the efficiency of parasitoids. In case of age specific life table of the parasitoid, the net reproductive rate NRR of *A. papayae* was observed to be higher in papaya (559.48 females/female) and lower in tapioca (282.53 females/female). The net reproductive rate (NRR) of *A. papayae* was changed in accordance with NRR of *P. marginatus* on different host plants. Intrinsic rate of increase (r_m) was maximum in papaya (0.570 increase per day) and minimum in tapioca (0.342/day). Moreover, the host induced life cycle of parasitoid *A. papayae;* and the information gathered from this study will be important in the management of this host papaya mealybug *P. marginatus* (Nisha and Kennedy, 2017b) [9].

Kece (2019) [10] conducted an experiment for the determination of life table parameters of *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) on four different host plants, *viz.*, eggplant, cotton, tomato, and pepper. The study revealed that eggplant was the most suitable host plants and values of life table parameters obtained from eggplant were R_0=184.36 nymphs/female, r=0.269 d^{-1}, λ=1.309 d^{-1}, GRR=264.18 nymphs/female.

Payandeh and Dehghan (2011) [11] constructed a life table of the dubas bug, *Ommatissus lybicus* (Hem: Tropiduchidae) at three constant temperatures. It is one of the major pests of date palm in Bam region, Iran. In this study, life table parameters of *O. lybicus* were studied at 25, 30 and 35 °C. The experiments were conducted in a leaf cage at 60 ± 5% RH and a photoperiod of 16:8 (L: D) h. The survival rate (xl) of individuals developed to adults from the initial cohort stages was estimated and these were 0.78, 0.84 and 0.43 at 25, 30 and 35 °C, respectively. The longest and shortest life expectancy (xe) of the pest was 91.9 and 62.5 days at 25 and 35 °C, respectively at the beginning of life. These results indicated that 30 °C could be the optimum temperature for the biological activities of *O. lybicus*.

Much of the confusion and controversy surrounding the regulation of insect populations may be traced to the lack of adequate field data. The classical interpretation of regulatory mechanisms has been largely based on a assumptions using models derived from controlled laboratory experiments or fragments of disconnected field data. Such theories, although stimulating, are essentially deductive in that they have not had the benefit of precise long-term data from carefully planned population studies in which all of the relevant factors have been measured accurately (90, 105, 107). The inherent weakness in deductive reasoning is that the conclusions reached are no better than the basic assumptions made. It is now apparent that many of the assumptions underlying our population models are oversimplified or do not relate to biological reality, and it follows that a number of our ecological concepts are actually untested. Hence, it is not surprising that the discipline of population dynamics has for the past three or four decades been so heavily overclouded by semantics and preoccupied with debate (Harcourt, 1967) [12].

Sahito *et al.* (2017) [7] constructed a stage specific life table of invasive mealybug, *P. solenopsis* under cotton field conditions. For this study there were 200 eggs kept for each replication on cotton plants grown in large pots. When eggs hatched, the life table parameters such as; apparent mortality, survival fraction, mortality survivor ratio, indispensable mortality and k-value were studied. Natural enemies such as, *Chrysoperla carneae*, lady bird beetles, Spiders and *Anasius bambawallae* were found active on the potted and surrounding cotton plants in the field conditions. The total mortality in egg stage went to 19.00%. The mortality percentages of 1st instars due to natural enemies recorded was 18.73% while, in 2nd instars 13.13% mortality was recorded. The total combined mortality recorded in 1st and 2nd instars was 26.34% and 15.64%, respectively. However, the mortality of 3rdinstars and pupae due to parasitoids were 7.28% with the total mortality of 10.26% and the total mortality in cotton potted plants was 54.83 percent recorded. Consequently, 45.17% of adults survived with male and female ratio as ♂1:6.52♀. The highest apparent mortality was 26.34%, indispensable mortality 96.89 and k-value recorded was 0.13 in 1st instar. The maximum survival fraction recorded was 0.90 in third instars/pupae with the total k-value generations of 0.35. The study revealed that the predators and parasitoids should be encouraged in cotton field when mealybugs appear, because predators are highly voracious feeders of 1st and 2nd instars whereas; the parasitoid, *A. bambawallae* is known as the main controlling natural enemy of cotton mealybug.

Mastoi *et al.* (2014) [13] constructed the life table and demographic parameters of papaya mealybug, *P. marginatus*, an imperative insect pest because of its invasive and polyphagous nature. Age-specific life and fertility tables of *P. marginatus* were constructed in laboratory conditions (27±2 °C, 60±5% RH). Survival and fertility characteristics of *P. marginatus* were observed with provision of unlimited food source (Fresh hibiscus leaves); and under pesticide and natural enemy free environment. The highest apparent mortality (20.1%) was observed in the 1st instar nymphs with k-value of 0.097 indicating the key factor in regulating pest population size. The proportion of female to male was 1.09:1. The values for net reproductive rate (Ro), mean generation time (Tc), intrinsic rate of increase (rc), innate capacity of increase (rm), finite rate of increase (I»), and doubling time were recorded as 43.36 female offsprings per female, 30.73 days, 0.1248/day, 0.1227/day, 1.1329 female offsprings/female and 5.65 days, respectively.

Life tables provide a means of measuring the schedules of birth and death from populations over time. They can be used to quantify the sources and rates of mortality in populations, which has a variety of applications in ecology, including agricultural ecosystems. Horizontal, or cohort-based, life tables provide for the most direct and accurate method of quantifying vital population rates because they follow a group of individuals in a population from birth to death. Naranjo and Ellsworth (2017) [14] presented the cohort-based life tables in the field that takes advantage of the sessile nature of the immature life stages of a global insect pest, *Bemisia tabaci*. Individual insects are located on the underside of cotton leaves and are marked by drawing a small circle around the insect with a non-toxic pen. This insect can then be observed repeatedly over time with the aid of hand lenses to measure development from one stage to the next and to identify stage-specific causes of death associated with natural and introduced mortality forces. Analyses explain how to correctly measure multiple mortality forces that act contemporaneously within each stage and how to use such data to provide meaningful population dynamic metrics. The method does not directly account for adult survival and reproduction, which limits inference to dynamics of immature stages. An example is presented that focused on measuring the impact of bottom-up (plant quality) and top-down (natural enemies) effects on the mortality dynamics of *B. tabaci* in the cotton system.

Farhadi *et al.* (2019) [15] constructed the life history and carried out life table analysis of the predator *Hyperaspis polita* (Coccinellidae) on the mealybug *Nipaecoccus viridis* (Pseudococcidae). *H. polita* is one of the important predatory coccinellids in southern Iran including Khuzestan Province. In this study, they examined life history traits and life table parameters of *H. polita* fed on the important citrus pest *Nipaecoccus viridis* (Pseudococcidae) in the laboratory, using the age-stage, two-sex life table. Experiments were performed under controlled conditions (25 °C and 30 ± 1 °C, 65 ± 5% RH and 14:10 h, L: D). Total preadult developmental period was significantly shorter at 30 (30.5 d males, 30.1 d females) compared to 25 °C (40.0 d males, 40.4 d females). The oviposition period was not significantly different at both these temperatures. However, the mean female fecundity for the total life span ranged from 180 to 368 eggs at 25 °C and 30 °C, respectively. The values for the intrinsic rate of increase ($r = 0.089\ d^{-1}$), finite rate of increase ($\lambda = 1.093\ d^{-1}$), and net reproductive rate ($R_0 = 102.6$) were higher at 30 °C. On the other hand, the mean generation time (T) was shorter for the cohort reared at 30 °C (51.9 d) than at 25 °C (86.2 d).

Construction of life history and life table of hemipteran and others

Ning *et al.* (2017) [16] developed a life table of two demographic methods of onio maggot, *Delia antiqua* (Meigen) on different hosts. In this study, they first constructed an age-stage, two-sex life table for onion maggot, *Delia antiqua*, grown on three host plants: onion, scallion, and garlic. They found that onion was the optimal host for this species and populations grown on onion had maximum fecundity, longest adult longevity and reproduction period, and the shortest immature developmental time. In contrast, the fecundity on other hosts was lower, particularly on garlic, but these crops can also serve as important secondary hosts for this pest. They also compared the demographic analyses of using individually-reared and group-reared methods. These two methods provided similar accurate outcomes for estimating insect population dynamics for this species. However, for gregarious species, using the individually-reared method to construct insect life tables produces inaccurate results, and researchers must use group-reared method for life table calculations. When studying large groups of insects, group-reared demographic analysis for age-stage, two-sex life table can also simplify statistical analysis, save considerable labor, and reduce experimental errors.

Mounica *et al.* (2018) [17] studied the life table parameters of maize aphid, *Rhopalosiphum maidis* (Aphididae: Hemiptera) at elevated and ambient concentrations of CO_2 (550 and 380ppm + 25 ppm at six temperatures (20, 25, 27, 30, 33 and 35 °C) for understanding the population dynamics of insect pests. The life table parameters of *R. maidis*, *viz.*, intrinsic rate of increase (r_m), finite rate of increase (λ), net reproductive rate (R_o) and gross reproductive rate (GRR) were increased with increase in temperatures from 20 °C to 27 °C further declining from 30 °C to 35 °C under both ambient and elevated CO_2 conditions. Generation time (T) was reduced with an increase of temperature from 20 °C to 35 °C. The upper temperature threshold for r_m, λ, R_o, GRR and T required 26.6, 30.1, 24.9, 25.0 and 34.6 °C under *e*CO_2 conditions whereas it was 29.8, 30.5, 25.7, 25.4 and 34.9^{o}C under *a*CO_2 conditions, respectively. The increased r_m, λ, R_o, GRR and decreased T showed the non-linear relationship and this can be used for the status of future insect populations.

Rode *et al.* (2020) [18] constructed a field life table of *Earias vittella, which* revealed that egg stage contributed 20 percent mortality mainly due to egg sterility. Younger and older larval group contributed 25.94 and 8.73 percent mortality, respectively. Viral, bacterial, fungal infection, *Cotesia sp., etc.* were key mortality factors operating under field conditions. The value of generation survival and trend index were found 0.44811 and 0.0166, respectively. In immature stages the maximum mortality was recorded during pupal stage which recorded 0.1637 value of 'K's while, less mortality was observed in the older larval group with a 0.0645 'K's value.

Win *et al.* (2011) [19] investigated the life table and population parameters of *Nilaparvata lugens* Stal. (Homoptera: Delphacidae) on rice. They constructed the life tables and population parameters of the BPH with unlimited food supply and free of natural enemies. The highest mortality occurred in the immature stages, especially in the first and second instars with gradual decrease of population density. The survival ratio of male to female was 0.512:0.488. The females lived for a maximum of 20 days. The trend of oviposition showed a peak at around the tenth day of the female life. The highest number of eggs produced per female per day was 9.63. The intrinsic rate of increase (rm) in egg production per female per day was 0.0677 and the daily finite rate of increase (λ) was 1.0688 females per female per day, with a mean generation time (T) of 34.05 days. The net reproductive rate (Ro) of the population was 10.02. The population doubling time (DT) was 10.42 days.

Conclusion

In conclusion, a comprehensive understanding of mealybug population dynamics, economic injury thresholds, and life history traits is essential for developing precise and effective pest control strategies. Integrating life table construction with field data offers valuable insights into pest population growth and mortality, enabling more efficient pest management techniques. By incorporating biological control methods and considering economic injury levels, Integrated Pest Management (IPM) programs can be optimized to reduce dependency on chemical pesticides and promote sustainability. Moreover, leveraging traditional knowledge, such as that highlighted by Borkakati *et al.* (2023) [20], allows for the integration of organic farming practices, enhancing pest control efforts through sustainable means. The natural enemy fauna in agricultural ecosystems, as documented by Borkakati *et al.* (2018) [21], further emphasizes the importance of biodiversity in maintaining ecological balance. Additionally, research on farmer participation and the evaluation of ICAR schemes demonstrate the significance of aligning agricultural initiatives with local practices (Barman *et al.*, 2022) [22]. Studies on crop performance and nutrient management, such as garlic germplasm trials (Rahman *et al.*, 2022) [23] and integrated nutrient management for Rajmah (Nath *et al.*, 2023) [24], highlight the role of research in driving productivity and resilience in agricultural systems. Collectively, these approaches contribute to the development of more sustainable and productive farming systems, ensuring long-term agricultural success.

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