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Pink bollworm (*Pectinophora gossypiella*) movement with respect to rosette flowers in cotton: Novel insights for integrated pest management

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Abstract

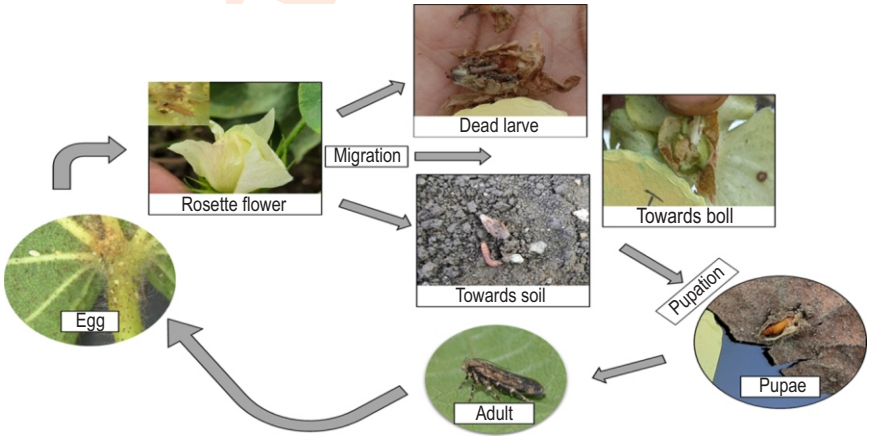
Aim: This preliminary study aimed to investigate the movement patterns of *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae) larvae in the rosette flowers.

Methodology: Field experiments conducted on the migration behavior of pink bollworm larvae with respect to rosette flowers in cotton fields. Observations included monitoring infested flowers, larval stage duration within rosette flowers, and larval movement to soil for pupation, larval mortality post-drop, and larval migration to early bolls, all conducted without insecticide application to reflect natural conditions.

Results: The movement of the larvae was tracked and recorded from the start of flowering to the boll formation stage. Nearly, 44.88% of the larvae present on the infested flowers had moved to the soil for pupation, while 14.29% had moved to newly formed bolls on the same rosette flower. Additionally, 30.90% of the larvae had moved to dry leaf debris on the soil, and the remaining 9.93% either escaped or died due to environmental factors such as damp soil. Notably, the study showed that dry soils or light debris accumulation were the most favorable environments for pink bollworm larvae.

Interpretation: The present study has generated useful information regarding the movement of PBWs larvae from rosette flowers to bolls that contribute to infestation. Hence, by implementing integrated pest management strategies during the early crop periods between 60 and 100 DAS, green boll infestations can be avoided and economic yields improved.

Key words: Larval movement, Pest carryover, Pest management, Rosette flower



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Introduction

The pink bollworm, *Pectinophora gossypiella* (Lepidoptera: Gelechiidae), poses a major threat to cotton crops globally, inflicting substantial economic losses by burrowing into cotton bolls and feeding on seeds during its larval stages. This pest can reduce cotton quality and yield, affecting both farmers and the textile industry (Fand *et al.,* 2019; Naik *et al.,* 2019, 2021). However, in India, the pink bollworm has become an increasing concern for cotton growers due to its widespread occurrence and growing resistance to transgenic cotton, particularly in major cotton of southern and central zones of India (Najork *et al.,* 2021; Naik *et al.,* 2018; Rao *et al.,* 2022). Historically, *P. gossypiella* has presented significant challenges to cotton cultivation, with early documentation of its detrimental effects on cotton production (Noble, 1969; Gutierrez *et al.,* 1977; Bhute *et al*., 2023).

Various control measures, including chemical, biological, and integrated pest management strategies, have been extensively studied to mitigate its impact (Naranjo *et al.,* 2002; Parmar and Patel, 2016). The concealed feeding habits of pink bollworms make them difficult to manage using chemical insecticides (Dhurua and Gujar, 2011). Recent research underscores the persistent challenges presented by the pink bollworm and emphasizes the need for sustainable pest management practices to prevent resistance and maintain effective control.Recent observations indicate a shift in the pest's behavior, with infestations occurring earlier in the growing season, targeting squares and flowers shortly after their emergence, rather than being an end-of-season pest (Slosser and Watson, 1972; Kranthi, 2021). Pink bollworm larvae feed on cotton flowers, creating "rosetted blooms" by webbing and tying petals together (Noble and Watson, 1964). The larvae undergo short and long diapause periods, ranging from 42 to 180 days, as they pupate on bolls and in the soil (Khalifa *et al.,* 1975). However, soil disturbance during cultivation and natural predation can increase larval mortality (Fye and Brewer, 1975).

Previous studies on the biology and movement of *P. gossypiella* have been conducted in North America (Loftin *et al.,* 1921; Ohlendorf, 1926; Owen and Calhoun, 1932; Fenton and Owen, 1953), where it was found that larvae prefer loose, cultivated soils for pupation, with most pupation occurring within the top 0.5 to 1.25 cm of soil, and that light soils are more suitable for larval movement (Richmond and Clark, 1961). Pink bollworms complete four to five generations after emerging in the spring (Henneberry and Naranjo, 1998), with exponential population growth in both Bt and non-Bt cotton fields (Naik *et al.,* 2018). Therefore, the first and second generations are crucial for integrated pest management to prevent increased infestation, which leads to green boll damage. This study aims to understand the movement, survival, and pupation sites of pink bollworm larvae within rosette blooms, along with the percentage of rosette and boll infestation and locule damage. It distinguishes itself from previous research by focusing on the early-season behavior of *P. gossypiella* larvae in cotton crops, particularly within rosette blooms, providing critical insights into initial infestation stages that are often overlooked. Unlike other studies that generalize larval movement and survival, this research offers a detailed examination of their ecological preferences and pupation sites within rosette blooms, revealing specific vulnerabilities that can be exploited for precise pest management.

Additionally, the study highlights the superior effectiveness and economic benefits of targeted management strategies compared to traditional farmer practices, emphasizing the importance of early and short-duration cotton varieties in disrupting the pest's life cycle and reducing the window for peak infestation. This approach not only minimizes pest damage but also promotes sustainable integrated pest management (IPM) practices by reducing reliance on chemical controls, making it a valuable contribution to developing effective early intervention strategies for managing pink bollworm infestations.

Materials and Methods

Field experiments were conducted during the Kharif season (2021-2022) in a cotton field at ICAR-CICR, Nagpur, where both Bt and non-Bt cotton had previously been cultivated without insecticide application. The experiment began with scouting for rosette flowers soon after the onset of flowering in the field. Infested flowers were tagged and observed regularly. The dates of rosette appearance and infestation were recorded on the tags. At the end of the flower development period, squares were dropped at the base of the plant, creating a small mesh in the soil to prevent larvae from escaping. The duration of the larval stage in the rosette flower was calculated as the period from the date the larva was observed in the flower until it emerged from the rosette flower. Daily observations were made of larval movement on the rosette flowers. Larval movement into the soil or debris was confirmed by the presence of pupae near the tagged plant (Noble and Robertson, 1964).

The field was managed according to the standard practices, with no insecticides applied during the observation period (Loftin *et al.,* 1921; Ohlendorf, 1926; Owen and Calhoun, 1932; Fenton and Owen, 1953). Primary observations focused on identifying rosette flowers, where larvae were fed on developing anthers, styles, and occasionally on the ovary. All rosette flowers in the experimental field were visually examined on each tagging date. The number of infested flowers that developed into bolls was recorded. Additionally, the number of pink bollworm larvae that moved into soil and debris for pupation, the number that died after dropping from rosette flowers, and the number that moved to early bolls were also recorded.

Per cent Rosette Infestation: The occurrence of rosette infestation in the field was calculated by dividing the total number of flowers on the plant by the number of rosette flowers.

Statistical analysis: The mean and standard errors were estimated for the recorded observations by MS-Excel, and Tukey

post-hoc tests were performed by SPSS Statistical Package.

Results and Discussion

The population of pink bollworms that overwintered in the previous crop from the same field or a nearby field was emerged during the first rainfall. These populations were attracted to cotton flowers for egg-laying. The larvae hatched from the eggs early in the morning, and findings were aligning with Noble and Watson, 1964. In some cases, the first instar larvae spin a web that ties the flower petals together, which makes the flower appear closed. Fig. 1 shows the percent of cotton flowers infested by pink bollworm larvae at intervals of 60, 70, 80, 90 and 100 days after sowing (DAS). The highest mean rosette infestation was observed at 90 DAS, with 25% of the flowers infested (Late formed squares), and the lowest infestation at 60 DAS, with only 8.8% of the flowers infested (Early formed squares).

After 90 DAS, the infestation decreased as the larvae began feeding on the newly formed bolls. The infestation rate increased as the number of flowers increased, with a greater number of rosette flowers observed at 60 DAS than at 100 DAS. Following decrease in rosette infestation, a simultaneous increase in green boll damage was observed. In Fig. 1, the shift of infestation from squares to bolls could be seen clearly. The data showed a direct correlation between increase in moth catches and subsequent rise in boll damage. The number of moths caught started to increase significantly around 90 DAS, peak at 130 DAS, which corresponds with the sharp rise in boll damage. This correlation suggests that moth activity is a key driver of boll damage, emphasizing the need for timely and effective pest control measures targeting moth populations to protect the developing bolls. These findings corroborates with Raju *et al.* (2020) who found that flower damage (*P. gossypiella*) in Bt cotton increased progressively with crop maturity, with peak at around 120 days after sowing. Similar to the results of this study, Shrilakshmi and Udikeri (2021) conducted an extensive surveys across Karnataka during 2017-18 and 2018-19, revealing that *P. gossypiella* infestations in Bt cotton progressively increased over time, with rosette flowers emerging as significant hotspots for pest aggregation and damage. Narayanamma *et al.* (2022) demonstrations revealed that over 10% of rosette flowers were damaged by pink bollworm during flowering period. Lakshmi Narayanamma *et al.* (2023) revealed that a minimum 10 % flowers were infested with *P. gossypiella* during peak crop periods. Recently, Rao *et al.* (2023) reported rosette damage of more than 10 per cent in Ananthapur while compared with IPM practices the damage was reduced to 3.92%. Similar to our findings Kranthi (2021), reported that early-formed squares were less susceptible to infestation compared to late-formed squares. Retaining these early-formed squares is crucial for achieving high yields, as they contribute significantly to the harvestable crop. Shedding of these early squares leads to increased plant stress and reduced yield potential. This finding is pivotal for improving pink bollworm management in India. Effective management practices, such as ensuring proper nutrition and timely pest control, can minimize the shedding of early squares and bolls, enhancing crop yield and quality.

The durations of the larval stage in rosette flowers are shown in Table 1, where it was found that the larval stages lasted approximately 10-12 days and were non-significant without diapause. Out of 75 rosette flowers that were infested, 15% of the larvae left the flower after 5th day of flowering, 55% left on 10th day after flowering, and 30% left on 15th day after flowering. These findings suggest that nearly 75% of the larvae left the flowers at

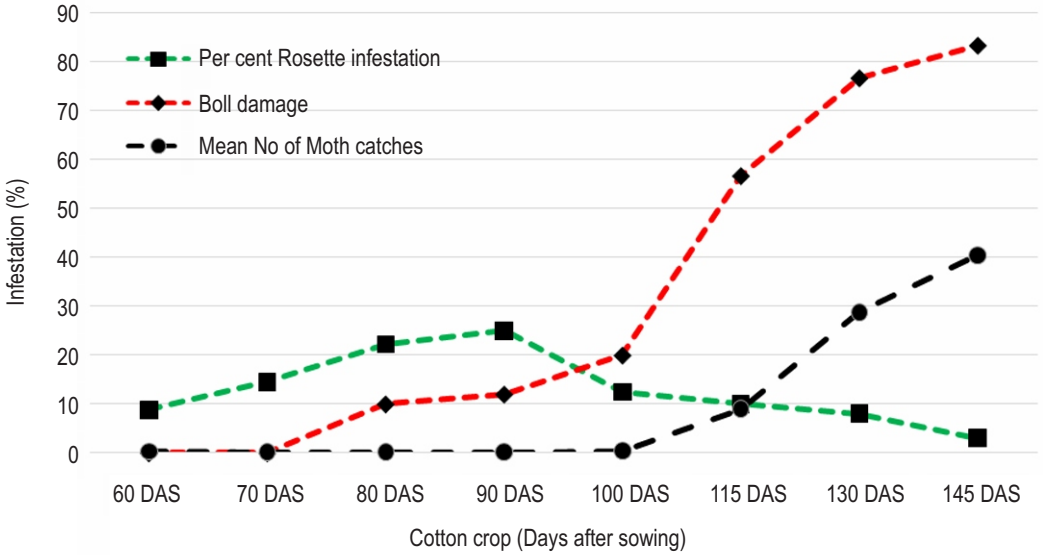

Fig. 1: Per cent rosette infestation, boll damage and moth catch*. *Correlation of percent rosette infestation and boll damage with moth catches.

Table1: Mean larval development in rosette flowers

Crop stage (Days after sowing)	No. of larvae observed	Mean development period (days) of larvae with rosette flower
60	15	11.46±0.55^{ab}
70	11	12.27±0.61^{a}
80	16	10.12±0.54^{c}
90	15	11.06±0.77^{b}
100	18	12.72±0.78^{a}

Values are mean ±S.E. The letters (a, b, c) indicate the significance grouping based on Tukey's test. Means with same letter are not significantly different from each other whereas means with different letters are significantly different ($p < 0.05$).

Table 2: Movement of pink bollworm larvae into soil, debris and bolls

Days after sowing	Soil (%)	Bolls (%)	Debris (%)
60	50.26^{a}	5.74^{a}	41.23^{a}
70	41.26^{a}	7.85^{a}	33.29^{c}
80	45.67^{a}	16.80^{b}	23.21^{a}
90	42.42^{a}	18.93^{bc}	30.60^{bc}
100	44.78^{a}	22.15^{c}	26.17^{ab}
Overall mean	44.88	14.29	30.90
S.D.	3.49	7.14	6.96
C.D	9.23	6.35	5.10

The letters (a, b, c) indicate the significance grouping based on Tukey's test. Means with same letter are not significantly different from each other whereas means with different letters are significantly different ($p < 0.05$).

midday, when soil temperature rose and the larvae could reach cooler temperatures below the plants in the afternoon before they entered the pupal stage and became inactive. Table 2 presents the results of pink bollworm larvae movement, and Fig. 2 shows a series of events with larval movement in flowers tagged for 10-day interval. Of the larvae that completed development in the rosette flower, 44.88% moved to the soil for pupation, 30.90% moved to debris for pupation, and 14.29% moved to bolls after boll formation. The remaining larvae escaped and likely died. Once the bolls were set, subsequent fruit development was found to be independent of the previous infestation of the bloom. Tukey's post hoc test results shed light on the movement of the pest under field conditions. The movement of larvae into the soil was similar on different days. However, the movement of larvae into bolls was significantly greater at 90 and 100 DAS, and the lowest movement of larvae occurred during the initial period (*i.e.,* 60 DAS). Regarding the movement of larvae onto debris, peak movement was observed at 60 DAS, and the lowest movement was observed at 80 DAS.

The emergence of pink bollworm populations during the first rainfall, followed by their attraction to cotton flowers for egg laying, presents a significant challenge for pest management. The larvae hatch early in the morning, between 7 and 8 am, and complete this process within 2 to 3 hrs, indicating a critical window for intervention. Notably, some first-instar larvae exhibit a behavior of spinning webs to close the flower petals, potentially as a defense against pesticides, as observed by Willcocks (1916). This behavior complicates control efforts, suggesting that integrated pest management strategies should focus on timely interventions and possibly incorporate systemic insecticides or biological controls to effectively target the larvae. Understanding these behavioral patterns is crucial for developing effective pest management practices in cotton cultivation. Larvae are more likely to complete feeding by the flowering stage, after which they drop to ground from either fresh or dried flowers. A few larvae may also feed on young bolls that are just beginning to form and damage them. Therefore, measures to control late populations during the flag end stage of the crop are necessary to reduce the potential population that might attack the crop in the next season (Nagrare *et al.,* 2023). The pink bollworm prefers to feed on squares, flowers, and tender green bolls on the cotton plant. Our findings suggest that the first generation of pink bollworms in the field may complete their development on flowers. Additionally, we observed that first-generation larvae may also feed on 2-3-day-old bolls when larval development has not yet been completed in the flower or square.

Butler and Hamilton (1976) equation used for estimating the timing of first-instar larvae entering flower buds provides valuable insights into the developmental progression of pink bollworm populations within cotton plants. This analysis reveals a

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Fig. 2: Sequence of events recorded between rosette flower and larval leaving from rosette flower: (a) Rosette flower, (b) Dried Rosette flower, (c) PBW larvae in rosette bloom, (d) and (e) are the same PBW larvae protuding out from the newly formed bolls, (f) PBW larvae moved to soil, (g) PBW dead larvae, (h) and (i): pupae were found on dried leaves.

consistent pattern, with an initial 3-to-5-day egg stage followed by an 18-to-22-day larval stage prior to flowering, contributing to a relatively uniform age distribution of larvae within rosette flowers. Moreover, observations by Lukefahr and Griffin (1962) regarding accelerated larval development as flowers age underscore the synchronized maturation dynamics within flower buds, further emphasizing the importance of understanding these developmental processes for effective pest management strategies. Recently, there has been an increase in the incidence of pink bollworms on flowers, which is likely due to factors such as cotton cultivation during summer months by a larger number of farmers, as well as long-term storage of raw cotton in ginning mills and market yards. Based on the findings of this study, it is presumed that the increased incidence of PBWs on flowers may contribute to a greater population of second-generation PBWs.

After completing development within the flowers, the larvae drop to the ground and are assumed to feed on green bolls during the second generation (Ellsworth *et al.,* 2006). Similar events are believed to occur during subsequent generations, during which the PBWs feed on green bolls instead of squares and flowers (Sevacherian and El Zik, 1983; Ellsworth *et al.,* 2006). The findings presented are consistent with earlier research of Butler and Henneberry (1976) and Pinter and Jackson (1976), which elucidate the influence of environmental factors on pink bollworm behavior. Understanding the interplay between biological development and environmental cues, particularly regarding larval departure from flowers during midday hours and in response to specific soil temperatures, provides valuable insights for the development of targeted pest control interventions. These observations collectively highlight the complex yet predictable nature of pink bollworm behavior, informing more strategic and sustainable approaches to pest management in cotton cultivation. Mushtaq *et al.* (2017) observed that pink bollworm life cycle on cotton starts with the appearance of rosettes on cotton flowers, first observed on June 15th and peaking at the end of the season. Boll infestation began on 15th July and reached peak on 15th October. Their life cycle is completed in approximately 54.775 days. Gergis *et al.* (2001) observed PBW survival rates ranging from 48% to 99% in field conditions, highlighting their resilience and potential to cause economically significant infestations in subsequent years.

However, the reproductive success of emerging moths and the survival of F1 generation eggs and larvae are significantly affected by diverse biological and environmental factors. Mohan (2017) and Sarwar (2017) concluded that timely management practices can effectively reduce pest populations. Additionally, an area-wide approach to pink bollworm management on Bt cotton in India is deemed a dire necessity, requiring community participation.

Taken together, the results of our study led to the conclusion that the first generation of PBWs, which emerges from diapause, may complete their life cycle on flowers due to the initial availability of squares and flower buds. Our results also indicate that 44.88% of PBW larvae moved to the soil, and 14.29% moved to bolls, which suggests that these larvae may have given rise to the second generation. The shift in the population from flowers to bolls accounts for the increase in infestation levels. This is an essential ecological aspect that could be explored for PBW management. The transformation of infestations from flowers to bolls occurred between 60 DAS and 100 DAS. By applying efforts during this critical stage, we have a plausible opportunity to avoid infestations and improve economic yields. This weak link presents ample opportunity for exploration in pest management, as later stages become internal feeders, making management more cumbersome. We can conclude that the movement of the PBW from flowers to soil results in better pest survival, during a transition stage between the first and second generations. Timely management practices applied at this stage increase the chances of restricting further population build-up in the field.This information could be useful in determining the benefits of cultural practices in reducing pink bollworm populations during the soil-inhabiting phases of the seasonal cycle.

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