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ZOOLOGY

Impact of weather parameters on the seasonal incidence of *Helopeltis antonii* (Miridae: Hemiptera) on neem

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ABSTRACT. Neem (*Azadirachta indica* A. Juss.), known for its extensive therapeutic properties, is susceptible to various pests, notably the tea mosquito bug (*Helopeltis antonii* Signoret). This study investigates the seasonal incidence of *H. antonii* on neem across different age classes and explores the correlation between meteorological factors and pest infestation. The survey monitored sixty neem trees categorized into three age groups: Category I (less than 2 years), Category II (2-6 years), and Category III (more than 6 years). Peak nymphal populations occurred in November for Categories I (12.70 nymphs/branch) and III (13.35 nymphs/branch), while Category II peaked in October (12.80 nymphs/branch). Complete drying (100% infestation) was observed from late January to mid-February for Categories I and III, and from early December to mid-February for Category II. Correlation analysis revealed a significant negative relationship between infestation levels and minimum temperature, while maximum relative humidity and sunshine hours positively correlated with pest abundance. Multi-linear regression indicated that over 90% of the variation in infestation rates could be attributed to meteorological factors. This study highlights the persistent threat of *H. antonii* to neem trees, regardless of age and is the first study to look at the seasonal incidence of *H. antonii* on different age classes of neem. Further research is required to assess the long-term implications of climate variability on *H. antonii* dynamics and its broader ecosystem effects.

Keywords: *Azadirachta indica*; *Helopeltis antonii*; weather parameters; infestation; seasonal incidence; correlation.

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Introduction

Neem (*Azadirachta indica* A. Juss.), commonly referred to as 'Indian Lilac' or 'Margosa', is a significant tropical evergreen tree belonging to the family Meliaceae (Chaitanya et al., 2024). It is native to the Indian subcontinent, where it has played a vital role in traditional medicine and sustainable agricultural practices for centuries. With a rich history of use in Ayurvedic medicine spanning over 4,000 years, neem is highly regarded for its diverse therapeutic properties, which include antifungal, antibacterial, antiviral, and anti-inflammatory effects. Its multifaceted uses extend beyond medicinal applications; neem is also utilized as a natural pesticide, a soil conditioner, and a means of pest management in organic farming systems. The phenology of the neem tree includes the flushing of new leaves with panicles occurring in February and March, followed by the ripening of fruits from June to July. After the fruiting season, new leaf flushes persist until September, creating a vital habitat for various insects and contributing to biodiversity. Currently, neem is flourishing in 72 countries around the world, with an estimated population of 25 million trees in India alone. Karnataka, a state in southern India, ranks third in neem cultivation, accounting for 5.5% of the total neem population, following Uttar Pradesh (55.7%) and Tamil Nadu (17.8%). The wide distribution of neem reflects its adaptability to different climatic conditions and its importance as a multipurpose tree species.

Despite its extensive benefits, neem is not immune to the pressures exerted by various insect pests. Reports indicate that neem is vulnerable to attacks by over 110 different insect species, highlighting the need for effective pest management strategies (Boa, 1995). Among these pests, the tea mosquito bug (*Helopeltis antonii* Signoret) emerges as a significant sucking pest, specifically targeting the tender shoots of neem. The feeding behavior of *H. antonii* results in severe damage, affecting not only the growth of the tree but also its overall health and productivity (Murthy et al., 2023; Rao, 1915). India is home to four recognized species of

Helopeltis, including *H. antonii*, *H. theivora* Waterhouse, *H. bradyi* Waterhouse, and *H. cinchonae* Mann (Firake et al., 2021). Among these, *H. antonii* is the most prevalent, thriving on more than 35 plant species across 24 families, with neem considered its primary host in southern India (Raviprasad & Vanitha, 2020; Srikumar & Bhat, 2012). Both the nymphs and adults of *H. antonii* feed by sucking sap from the tender shoots, leading to the formation of lesions that can coalesce and necrotize, often resulting in gummosis. Affected shoots eventually wilt, causing the tree to present a burnt appearance, which can severely impact its aesthetic and functional value (Murthy et al., 2023). The first documented identification of *H. antonii* as a pest of neem in southern India dates back to Rao (1915), who highlighted its prevalence in the Coimbatore region. Subsequent research by Murthy et al. (2023) corroborated its status as a prominent sucking pest in both southern and northern Karnataka. Additionally, Kalloor et al. (2020) investigated the seasonal abundance of *H. antonii* infesting neem in Mettupalyam, contributing to the growing body of knowledge regarding this pest's impact on neem trees. *Helopeltis* species exhibit a continuous cycle of generations throughout the year, with their populations fluctuating in response to various climatic events. These fluctuations can be influenced by environmental factors such as heavy rainfall, high winds, or low relative humidity, which may hinder the pests' survival and reproduction (Lever, 1949; Miller, 1941; Pillai et al., 1976; Stonedahl, 1991). The susceptibility of neem to *H. antonii* infestations raises concerns about the tree's survival, particularly in light of the growing host range and increasing pest pressures worldwide.

Given the significance of neem as a multipurpose tree species and its relevance in sustainable agriculture, understanding the factors influencing *H. antonii* infestations becomes paramount. However, there is a notable gap in the literature regarding the relationship between meteorological factors and the infestation levels of this pest across different age classes of neem. Therefore, the current study aims to examine the abundance and percentage infestation of *H. antonii* on various age classes of neem trees and correlating these findings with relevant meteorological data. By elucidating the impact of environmental conditions on pest dynamics, this research contributes to valuable insights to the development of effective pest management strategies for neem cultivation.

Material and methods

Study location

The study was conducted at the College of Agriculture (CoA), University of Agricultural Sciences (UAS), Raichur, India. This location is characterized by a tropical climate, conducive to the growth of neem (*A. indica*), which is prevalent in the region. The objective was to determine the seasonal incidence of the tea mosquito bug (*H. antonii*) on neem trees of varying ages.

Selection of neem trees

A total of sixty neem trees were randomly selected from the study area. The trees were categorized into three distinct age groups based on their growth stages: Category I (< 2 years), Category II (2–6 years), and Category III (> 6 years). Each age category consisted of twenty tagged plants, ensuring an equal distribution of sample size across age groups. This stratified sampling approach was adopted to accurately assess the impact of tree age on the abundance and percentage infestation of *H. antonii*.

Monitoring of pest infestation

Weekly monitoring of the trees was carried out from October 2021 to September 2022. For each selected tree, four uniform tender shoots from the cardinal directions (North, East, South, and West) were chosen to ensure representativeness in sampling. The shoots were tagged and observed for the presence and absence of nymphs and adults of *H. antonii*. The number of nymphs and adults was counted directly from the marked shoots and expressed as the average number of nymphs per shoot and their infestation rates were calculated.

Calculating infestation rates

The percentage infestation of TMB was calculated using the formula:

$$Per\ cent\ infestation = \frac{Infested\ branches}{Total\ number\ of\ branches\ observed} \times 100$$

This calculation provided a quantitative measure of infestation levels across different tree categories and allowed for a comparative analysis.

Meteorological data collection

Weekly meteorological data were gathered from the Department of Agrometeorology at UAS, Raichur to evaluate the influence of environmental factors on the infestation levels of *H. antonii*. Rainfall was measured in millimeters (mm) to assess moisture availability and sunshine was recorded in hours to evaluate light exposure. Maximum and minimum temperature was recorded in degrees Celsius (°C) to gauge thermal conditions, while, maximum and minimum relative humidity was expressed in percentage (%) to assess humidity levels. The collected meteorological data was aligned with the pest monitoring observations, for thorough analysis of their relationship with TMB infestation.

Statistical analysis

Data analysis was conducted to determine correlations between meteorological factors and the incidence of *H. antonii*. The relationships between the monthly mean percentage infestation of *H. antonii* and each of the meteorological variables were assessed using Pearson's correlation coefficient and Multiple Linear Regression (MLR). The model fit was evaluated using the coefficient of determination (R^2), indicating the percentage of variation in infestation explained by the independent variables. Statistical analyses was performed using R (v4.2.0) and SPSS (v16.0) software with significance at $p < 0.05$ to determine the statistical significance of the results.

Ethical considerations

All procedures performed in this study were in accordance with relevant guidelines and regulations. The research was designed to minimize harm to the neem trees and surrounding ecosystem while providing valuable insights into pest management strategies.

Results and discussion

Seasonal incidence of *H. antonii* on neem

The seasonal incidence of the tea mosquito bug (*H. antonii*) on neem (*A. indica*) was systematically monitored throughout the period from October 2021 (40th Standard Meteorological Week, SMW) to September 2022 (39th SMW). The findings indicate that *H. antonii* was actively infesting neem trees from October 2021 through February 2022, highlighting the pest's sustained presence during these months. Notably, the peak nymphal populations were recorded in the first fortnight of November 2021, where Category I trees exhibited an average of 12.70 nymphs per branch, while Category III trees showed a slightly higher infestation rate of 13.35 nymphs per branch. Conversely, Category II neem trees reached their peak in the second fortnight of October 2021, recording 12.80 nymphs per branch.

As the season progressed into February, the observations indicated the least populations recorded during the first fortnight across all age classes of neem trees. This decline in population is significant, suggesting environmental factors may play a crucial role in the pest's lifecycle and distribution. Complete drying of the affected trees, indicative of 100% infestation, was noted between the second fortnight of January and the second fortnight of February 2022 for both Category I and III trees. In contrast, Category II trees displayed a complete infestation period from the first fortnight of December through the second fortnight of February. The observed nymphal populations per branch showed a broad range: from 0.10 to 12.70 in Category I, 0.10 to 12.80 in Category II, and 0.15 to 13.35 in Category III. This variability suggests differing susceptibility levels among age classes to *H. antonii* infestations. Additionally, the percentage of infestation varied significantly across the categories: Category I trees experienced infestations ranging from 7.50 to 96.25%, Category II from 50 to 90%, and Category III from 48.75 to 92.50% (Table 1).

The month-wise pooled mean data from the fixed plot survey elucidated that Category III neem trees consistently harboured the highest average nymphal populations, recorded at 10.89 nymphs per branch in November 2021. Category II followed closely with an average of 10.43 nymphs per branch, while Category I trees showed an average of 9.55 nymphs per branch. The patterns observed reveal an alarming trend in *H. antonii* infestation, which may have implications for neem management practices in the region. In February 2022, however, the lowest nymphal counts were observed in Category I trees at just 0.05 nymphs per branch, while Category II and III trees recorded 0.11 and 0.18 nymphs per branch, respectively. Moreover, the least percentage infestation was documented in October 2021 across all age classes, with Category I trees at 32.50%, Category II at 51.88%, and Category III at 55% (Table 2).

Table 1. Seasonal incidence of *Helopeltis antonii* on different age classes of neem during 2021-22 (weekly interval).

SMW	Mean no. of nymphs/branch			Per cent infestation			Temperature (°C)		Rainfall (mm)	Relative humidity (%)		Sunshine hours (h day^{-1})
	Category of neem trees			Category of neem trees			Max	Min		Max	Min	
	I	II	III	I	II	III						
40	2.65	4.05	5.80	7.50	50.00	48.75	33.1	23.3	4.0	84	54	7.3
41	6.90	6.95	7.85	22.50	50.00	50.00	31.7	22.4	105.8	92	60	5.2
42	10.70	12.25	12.40	50.00	52.50	58.75	32.1	21.6	0.0	88	50	4.6
43	11.25	12.80	12.35	50.00	55.00	62.50	32.3	17.4	0.0	77	42	4.7
44	12.00	12.15	13.35	53.75	62.50	67.50	30.8	20.2	0.2	85	56	2.9
45	12.70	11.30	12.90	60.00	72.50	75.00	31.0	19.1	0.0	78	42	6.25
46	7.15	10.90	9.40	68.75	75.00	75.00	30.1	20.9	23.6	88	65	25.7
47	6.35	7.35	7.90	77.50	82.50	83.75	30.0	21.1	15.8	92	63	3.4
48	3.75	3.85	4.85	78.75	85.00	81.25	29.4	19.4	2.4	90	55	2.8
49	3.15	5.45	4.65	80.00	90.00	86.25	31.5	18.9	0.0	85	43	7.3
50	2.60	3.35	3.65	88.75	100	86.25	30.3	18.5	0.0	80	45	3.4
51	2.50	2.75	3.40	92.50	100	90.00	29.9	12.9	0.0	81	29	5.3
52	0.65	3.00	2.20	92.50	100	92.50	31.5	14.8	0	82	35	7
1	0.75	1.15	2.70	96.25	100	86.25	30.5	16.4	0.0	85	36	5.9
2	0.15	0.70	2.45	100	100	91.25	30.8	16.6	1.6	84	38	4.3
3	0.30	0.45	1.85	100	100	88.75	31.3	16.3	0.0	79	33	6.6
4	0.15	0.35	0.55	100	100	100	31.3	14.6	0.0	68	30	5.9
5	0.10	0.20	0.35	100	100	100	32.9	13.1	0.0	68	24	8.4
6	0.10	0.15	0.20	100	100	100	32.7	16.0	0.0	76	31	9.2
7	0	0.10	0.15	100	100	100	31.6	15.5	1.6	77	32	6.7
8	0	0	0	100	100	100	35.1	18.5	0.0	65	19	8.2
9	0	0	0	0	0	0	32.6	17.4	0.0	59	16	9.6
10	0	0	0	0	0	0	36.1	19.2	0.0	58	21	8.4
11	0	0	0	0	0	0	38.1	20.1	0.0	49	17	7.7
12	0	0	0	0	0	0	40.0	24.0	10.6	69	23	6.7
13	0	0	0	0	0	0	42.0	24.5	0.0	55	19	6.8
14	0	0	0	0	0	0	39.0	24.1	0.0	57	31	7.5
15	0	0	0	0	0	0	38.1	24.1	0.0	64	34	4.5
16	0	0	0	0	0	0	38.8	23.4	12.2	62	33	4.6
17	0	0	0	0	0	0	39.7	24.3	0.0	60	32	8.5
18	0	0	0	0	0	0	40.7	1.5	1.2	60	20	8.25
19	0	0	0	0	0	0	38.8	1.3	0.0	67	30	2.7
20	0	0	0	0	0	0	36.8	23.3	85.2	78	50	3.0
21	0	0	0	0	0	0	39.2	22.4	0.0	71	33	6.25
22	0	0	0	0	0	0	38.1	22.8	8.2	67	27	7.3
23	0	0	0	0	0	0	37.9	21.9	2.8	75	34	4.4
24	0	0	0	0	0	0	36.2	22.1	2.2	76	40	5.9
25	0	0	0	0	0	0	34.9	21.4	0.8	79	42	3.2
26	0	0	0	0	0	0	35.1	21.8	2.0	76	41	25.5
27	0	0	0	0	0	0	32.7	21.2	47.0	86	63	0.6
28	0	0	0	0	0	0	27.3	20.2	42.6	89	78	0.25
29	0	0	0	0	0	0	32.8	20.7	16.6	85	52	4.8
30	0	0	0	0	0	0	33.8	21.3	114.0	81	50	2.9
31	0	0	0	0	0	0	32.1	20.7	76.6	91	62	5.7
32	0	0	0	0	0	0	29.7	20.5	23.2	87	65	1.5
33	0	0	0	0	0	0	30.7	20.1	40.0	85	62	5.4
34	0	0	0	0	0	0	31.9	20.1	2.2	85	56	5.1
35	0	0	0	0	0	0	31.5	20.7	37.4	88	62	4.5
36	0	0	0	0	0	0	31.6	21.0	147.6	90	65	5.5
37	0	0	0	0	0	0	31.6	20.6	441.0	87	60	4.4
38	0	0	0	0	0	0	31.3	20.5	768.0	87	62	4.6
39	0	0	0	0	0	0	31.2	20.5	1459.4	87	62	4.4

Table 2. Seasonal incidence of *Helopeltis antonii* on different age classes of neem during 2021-22 (monthly interval).

Month	Mean no. of nymphs/branch			Per cent infestation			Temperature (°C)		Rain fall (mm)	Relative humidity (%)		Sunshine hours (h day^{-1})
	Category of neem trees			Category of neem trees			Max	Min		Max	Min	
	I	II	III	I	II	III						
Oct	7.88	9.01	9.60	32.50	51.88	55.00	32	21	110.0	85	52	5.3
Nov	9.55	10.43	10.89	65.00	73.13	75.31	30	20	41.8	87	56	3.3
Dec	2.53	3.68	3.75	86.50	95.00	87.25	31	16	0.0	83	39	5.6
Jan	0.28	0.66	1.89	99.06	100	91.56	31	16	1.6	77	33	5.9

Feb	0.05	0.11	0.18	100	100	100	33	17	0.0	69	24	8.2
Mar	0	0	0	0	0	0	38	21	10.6	59	19	7.7
Apr	0	0	0	0	0	0	39	24	12.2	60	31	6.4
May	0	0	0	0	0	0	39	24	86.4	68	33	5
June	0	0	0	0	0	0	36	22	16.0	76	38	4
July	0	0	0	0	0	0	31	21	184.4	87	62	3
Aug	0	0	0	0	0	0	31	20	160	88	62	3.9
Sep	0	0	0	0	0	0	31	20	206.6	88	64	4.6

Correlation between weather parameters and seasonal incidence of *Helopeltis antonii* on neem

Correlation analysis clearly indicated that minimum temperature was the most influential factor affecting *H. antonii* incidence. For Category I neem trees, infestation was significantly and negatively correlated with minimum temperature ($r = –0.85$, $p < 0.01$), while maximum relative humidity ($r = 0.69$, $p < 0.05$) and sunshine hours ($r = 0.83$, $p < 0.01$) showed significant positive correlations. Similar patterns were recorded for Category II (minimum temperature: $r = –0.88$, $p < 0.01$; sunshine hours: $r = 0.90$, $p < 0.01$) and Category III trees (minimum temperature: $r = –0.88$, $p < 0.01$; sunshine hours: $r = 0.90$, $p < 0.01$). In all cases, rainfall, maximum temperature, and minimum relative humidity exhibited weak or non-significant associations with infestation (Tables 3, 4, 5).

Multiple Linear Regression (MLR) analysis further confirmed the influence of climatic variables on pest incidence. The regression models explained 90.2% ($R^2 = 0.902$), 91.2% ($R^2 = 0.912$), and 91.7% ($R^2 = 0.917$) of the variation in infestation for Categories I, II, and III respectively (Table 6). Among the predictors, minimum temperature consistently showed the largest negative regression coefficients (–15.23 to –20.06), highlighting its strong suppressive role on *H. antonii* populations, while, sunshine hours (coefficients ranging from +6.33 to +12.90) and maximum relative humidity (+1.51 to +3.26) contributed positively to infestation. These statistical results indicate that *H. antonii* thrives under conditions of moderate to high relative humidity and extended sunshine hours but declines sharply when minimum temperatures fall below threshold levels.

Table 3. Relationship between the meteorological variables and infestation of *Helopeltis antonii* on category I (1-2 years age) neem trees.

Parameters	X_1	X_2	X_3	X_4	X_5	X_6
Y = Per cent infestation	-0.47	-0.85**	-0.54	0.11	-0.27	0.35
X_1 = Maximum temperature	1	0.69**	-0.37	-0.88**	-0.68**	0.45
X_2 = Minimum temperature		1	0.25	-0.32	0.06	-0.20
X_3 = Rainfall			1	0.62**	0.83**	-0.60**
X_4 = Maximum relative humidity				1	0.90**	-0.75**
X_5 = Minimum relative humidity					1	-0.84**
X_6 = Sunshine hours						1

* Significant at $p \leq 0.05$; ** Significant at $p \leq 0.01$.

Table 4. Relationship between the meteorological variables and infestation of *Helopeltis antonii* on category II (2-6 years age) neem trees.

Parameters	X_1	X_2	X_3	X_4	X_5	X_6
Y = Per cent infestation	-0.49	-0.82**	-0.52	0.15	-0.22	0.32
X_1 = Maximum temperature	1	0.69**	-0.37	-0.88**	-0.68**	0.45
X_2 = Minimum temperature		1	0.25	-0.32	0.06	-0.20
X_3 = Rainfall			1	0.62**	0.83**	-0.60**
X_4 = Maximum relative humidity				1	0.90**	-0.75**
X_5 = Minimum relative humidity					1	-0.84**
X_6 = Sunshine hours						1

* Significant at $p \leq 0.05$; ** Significant at $p \leq 0.01$

Table 5. Relationship between the meteorological variables and infestation of *Helopeltis antonii* on category III (more than 6 years age) neem trees.

Parameters	X_1	X_2	X_3	X_4	X_5	X_6
Y = Per cent infestation	-0.49	-0.80**	-0.51	0.16	-0.21	0.32
X_1 = Maximum temperature	1	0.69**	-0.37	-0.88**	-0.68**	0.45
X_2 = Minimum temperature		1	0.25	-0.32	0.06	-0.20
X_3 = Rainfall			1	0.62**	0.83**	-0.60**
X_4 = Maximum relative humidity				1	0.90**	-0.75**
X_5 = Minimum relative humidity					1	-0.84**
X_6 = Sunshine hours						1

* Significant at $p \leq 0.05$; ** Significant at $p \leq 0.01$.

Table 6. Multiple regression analysis showing meteorological variables against the per cent infestation of *Helopeltis antonii* on different age classes of neem.

Age class of neem	Constant	X_1	X_2	X_3	X_4	X_5	X_6	R^2	F value	S.E.	Multiple regression equation
Category I	410.20	-15.23	5.16	-0.22	1.51	-2.49	6.33	0.902	7.66	19.98	$Y_1 = 410.20-15.23X_1+5.16X_2-0.22X_3+1.51X_4-2.49X_5+6.33X_6$
Category II	268.11	-17.52	10.23	-0.27	3.09	-3.07	11.34	0.912	8.67	19.80	$Y_2 = 268.11-17.52X_1+10.23X_2-0.27X_3+3.09X_4-3.07X_5+11.34X_6$
Category III	271.82	-20.06	13.84	-0.26	3.26	-3.41	12.90	0.917	9.15	18.61	$Y_3 = 271.82-20.06X_1+13.84X_2-0.26X_3+3.26X_4-3.41X_5+12.90X_6$

X_1 - Maximum temperature; X_2 - Minimum temperature; X_3 - Rainfall; X_4 - Maximum relative humidity; X_5 - Minimum relative humidity; X_6 - Sunshine hours; R^2 – Co-efficient of Determination; Y_1 - Per cent infestation on category I neem trees; Y_2 - Per cent infestation on category II neem trees; Y_3 - Per cent infestation on category III neem trees; S.E. -Standard Error

Implications of findings

The current study reveals that *H. antonii* infests neem trees across all age, with visible damage noted on the tender shoots of both younger and older trees. Both adult and nymph stages were found feeding on these vulnerable shoots, causing significant stress and potential long-term damage to the trees. Historical literature supports this observation, indicating that *Helopeltis* populations fluctuate in response to localized climatic conditions, exhibiting a tendency to struggle in environments characterized by heavy rainfall, high winds, or low relative humidity. The drastic reduction in *H. antonii* populations might also relate to the non-availability of food resources, as damaged shoots dry out rapidly, prompting the pest to migrate to alternative hosts. By the end of February, the visual assessment of the neem trees revealed widespread damage, presenting a burnt appearance indicative of severe stress. Consequently, the population of *H. antonii* declined sharply and was virtually absent from March to August.

The implications of these results are two-fold. First, they provide strong experimental evidence that *H. antonii* infestations can be forecasted with considerable accuracy using key weather variables. By monitoring minimum temperature, sunshine hours and relative humidity, it is possible to predict periods of high pest risk. Second, the findings suggest that pest outbreaks are more likely in years or seasons characterized by warmer nights, higher humidity, and abundant sunshine — conditions expected to become more frequent under climate change scenarios. Practically, this means that neem growers should intensify pest surveillance during October–November, when weather conditions favour pest multiplication. Integration of meteorological monitoring with pest management strategies could reduce losses by enabling timely interventions. Moreover, these insights support the development of weather-based forecasting models and decision support systems for *H. antonii* management.

These statistical insights imply that the fluctuations in minimum temperature act as a primary suppressor of pest incidence, explaining why populations collapse during cooler months (December–February), and increased sunshine and relative humidity significantly promote pest outbreaks, highlighting October–November as the critical window for pest monitoring and intervention. Weather-based forecasting models for *H. antonii* are feasible, since over 90% of infestation variability is explained by meteorological parameters. Thus, the findings provide a robust quantitative basis for developing early warning systems and climate-informed Integrated Pest Management (IPM) strategies for neem.

This study serves as a pioneering effort in systematically examining the seasonal incidence of *H. antonii* across different age classes of neem. The findings are consistent with earlier reports by Murthy et al. (2023), who also noted a peak incidence of *H. antonii* on neem during October. Supporting this observation, Sundararaju and Sundarababu (1996) documented peaks in November and December. However, these findings diverge from those of Kalloor et al. (2020), who reported peak infestations occurring in January, 2020. Such discrepancies may arise from variations in local environmental conditions, highlighting the importance of localized studies to inform pest management. Since reports on the correlation between weather parameters and the incidence of *H. antonii* on neem are limited, comparisons were made with existing literature on other host plants. The current investigation results align with findings Damasia et al. (2020), who reported that relative humidity exhibited a positive association while temperature and rainfall had a negative correlation with the incidence of *H. antonii* on cashew trees. Furthermore, Srinivasnaik et al. (2019) documented a positive relationship between *H. antonii* incidence and relative humidity in cocoa, reinforcing the notion that environmental conditions play a pivotal role in the population dynamics of this pest across various host plants.

Conclusion

The current study represents the first comprehensive investigation on the seasonal incidence of *H. antonii* on various age classes of neem (*A. indica*). The *H. antonii* infests neem trees regardless of their age, size, or growth stage, indicating the pests broad host range and adaptability and exhibits peak activity in October–November. Infestation showed a strong negative correlation with minimum temperature and positive associations with maximum relative humidity and sunshine hours. Regression models confirmed that over 90% of infestation variability could be explained by meteorological parameters, underscoring the pivotal role of climatic factors in shaping pest dynamics. These insights emphasize the importance of timely monitoring and integrated pest management strategies aligned with seasonal climatic conditions. Future research should focus on the development of predictive forecasting models integrating real-time meteorological data for early warning of *H. antonii* outbreaks, explore climate-resilient management strategies, particularly under scenarios of rising temperatures and shifting rainfall patterns, identify and deploy biocontrol agents and botanicals as eco-friendly alternatives to chemical pesticides ultimately safeguarding neem trees and their ecological and economic significance.

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