International Journal of Plant & Soil Science

Volume 38, Issue 8, Page 499-510, 2026; Article no.IJPSS.163895
ISSN: 2320-7035

Seasonal Population Dynamics of Major Insect Pests of *Moringa oleifera* Lam. in Relation to Weather Variables

M. Mamatha [a], T. Pavani [b], N. Jemimah [c] and P. Neelima [d*]

[a] *Department of Entomology, College of Agriculture, Rajendranagar, Telangana, India.*
[b] *Krishi Vigyan Kendra, Wyra, Khammam, Telangana, India.*
[c] *Department of Entomology, Agricultural College, Aswaraopet, Telangana, India.*
[d] *Department of Horticulture, Agricultural College, Aswaraopet, Telangana, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijpss/2026/v38i86236

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/163895

Original Research Article

Received: 09/06/2026
Accepted: 29/07/2026
Published: 31/07/2026

Abstract

A single-season field study was conducted from standard meteorological week (SMW) 40 of 2025 to SMW 15 of 2026 in an established PKM-1 moringa plantation at Agricultural College, Aswaraopet, Telangana, India. Five plants were sampled weekly, with one branch selected in each cardinal direction on every plant. The abundance of the leaf-eating caterpillar (*Noorda blitealis*), bud worm (*Noorda moringae*), hairy caterpillar (*Eupterote mollifera*), grasshoppers, and two ash weevils (*Myllocerus viridanus* and *M. discolor*) was recorded together with visible shoot damage and five weather variables. The leaf-eating caterpillar was the most abundant pest and reached 4.60 larvae per branch in SMW 10; shoot damage reached 48% in the same week. After Benjamini-Hochberg correction for multiple correlation tests, maximum temperature was positively associated with leaf-eating caterpillar, bud worm, and *M. discolor* abundance, whereas evening relative humidity was negatively associated with leaf-eating caterpillar, shoot damage, bud worm, hairy

**Corresponding author: E-mail: neelimapalagani@pjtau.edu.in;*

Cite as: *Mamatha, M., Pavani, T., Jemimah, N., & Neelima, P. (2026). Seasonal Population Dynamics of Major Insect Pests of Moringa oleifera Lam. in Relation to Weather Variables. International Journal of Plant & Soil Science, 38(8), 499–510. https://doi.org/10.9734/ijpss/2026/v38i86236*

caterpillar, *M. viridanus*, and *M. discolor*. Multiple linear regression models explained 27.24-71.77% of the observed weekly variation. All overall models except the grasshopper model were statistically significant, although the independently significant predictors differed among taxa. Maximum temperature was independently associated with leaf-eating caterpillar, bud worm, and *M. discolor* abundance, while evening relative humidity was independently associated with shoot damage and hairy caterpillar abundance. The findings identify locally relevant seasonal windows for field surveillance, but the single-site, single-season design does not establish causality or provide an externally validated forecasting model. Multi-season studies incorporating plant-level repeated measures, crop phenology, natural enemies, and lagged weather effects are required before operational prediction is attempted.

Keywords: Abiotic factors; ash weevils; integrated pest management; Moringa oleifera; Noorda blitealis; seasonal incidence; weather-pest association.

1. Introduction

Moringa oleifera Lam. is a fast-growing perennial tree cultivated in tropical and subtropical regions for its edible leaves, flowers, and pods. Its leaves contain proteins, minerals, vitamins, and diverse phytochemicals, and the crop also has commercial value in food, feed, and value-added products (Gopalakrishnan et al., 2016; Islam et al., 2021; Leone et al., 2015). The expanding cultivation of moringa increases the need for locally appropriate crop-protection programmes that preserve marketable foliage and pods while limiting unnecessary pesticide use.

A diverse complex of arthropods can infest moringa at different phenological stages. Important pests reported from India include the leaf-eating caterpillar *Noorda blitealis*, bud worm *Noorda moringae*, hairy caterpillars, aphids, whiteflies, tea mosquito bugs, pod flies, stem borers, and several beetles and weevils (Duvaraga Devi et al., 2024; Math & Kotikal, 2014; Prasannakumar et al., 2024). Defoliating larvae can reduce functional leaf area and damage tender shoots, while bud-feeding insects may interfere with flowering and subsequent pod development. Because the crop may retain foliage and reproductive structures over extended periods, pest occurrence can vary substantially across weeks and seasons.

Temperature, humidity, and rainfall influence insect development, survival, feeding, movement, and host-plant quality. The direction and strength of these effects are species-specific and may change across geographic regions and host phenological stages (Bale et al., 2002). At broader scales, warming can increase metabolic demand or population growth in some agricultural pests, but local field responses remain contingent on thermal limits, moisture, crop management, and biotic interactions (Deutsch et al., 2018). Consequently, weather-pest relationships derived at one location should be interpreted as local associations rather than universal biological constants.

Moringa-specific studies have demonstrated pronounced geographic and seasonal variation. Chandrakar and Gupta (2020) observed comparatively high leaf-caterpillar abundance during February-April in Chhattisgarh, whereas Yadav et al. (2024) reported a July-August peak in Rajasthan. Wayal et al. (2025) recorded important peaks during October and December in Maharashtra. A two-year investigation in southern Tamil Nadu also found that bud-worm abundance varied between seasons and was associated with maximum temperature and humidity (Manikandan & Rengalakshmi, 2024). These differences reinforce the need for location-specific monitoring before pest-management calendars are recommended.

Weather-informed surveillance can contribute to integrated pest management by directing field scouting towards periods of elevated risk; however, operational forecasting requires multi-year data, suitable models for count outcomes, assessment of lagged effects, and independent validation (Naranammal & Krishna Priya, 2024). Such monitoring should complement, rather than replace, crop inspection, biological-control conservation, economic thresholds, and other components of integrated pest management (Stenberg, 2017).

The present study therefore characterised the weekly incidence of major insect pests in a moringa plantation at Aswaraopet, Telangana, and examined their statistical associations with temperature, relative humidity, and rainfall. The objectives were to identify the principal pest taxa and their seasonal peaks, quantify contemporaneous weather-pest associations, and generate an exploratory local evidence base for more comprehensive multi-season monitoring.

2. Materials and Methods

2.1 Study Site and Crop

The investigation was conducted during the 2025-2026 rabi season at the College Farm, Agricultural College, Aswaraopet, Telangana, India (17.245106 degrees N, 81.108338 degrees E; approximately 166 m above mean sea level). The site has a semi-arid tropical climate. Observations were made in an established plantation of *Moringa oleifera* cv. PKM-1 grown on black soil at a spacing of 2 x 2 m.

Before observations began, plants were pruned uniformly to approximately 90 cm above ground level, with three healthy primary branches retained per plant to encourage comparable canopy development. Standard crop-management practices used at the farm were followed during the observation period.

2.2 Insect and Damage Observations

Five apparently healthy plants were selected at random. On each plant, one branch was selected from each cardinal direction, providing 20 branch observations per weekly assessment. The terminal 60 cm of each selected branch was examined from SMW 40 of 2025 through SMW 15 of 2026, giving 28 weekly observations. Counts were recorded for the leaf-eating caterpillar (*Noorda blitealis*), bud worm (*Noorda moringae*), hairy caterpillar (*Eupterote mollifera*), grasshoppers, *Myllocerus viridanus*, and *Myllocerus discolor*. Weekly abundance was expressed as the mean number of larvae or adults per branch. The examined terminal portions were also assessed for visible shoot damage associated with leaf-eating caterpillar feeding, expressed as a percentage.

Weekly meteorological data for maximum temperature, minimum temperature, morning relative humidity, evening relative humidity, and rainfall were obtained from the Agro-Meteorological Observatory at Agricultural College, Aswaraopet. Weather values were aligned with the corresponding standard meteorological week.

2.3 Statistical Analysis

The analytical unit was the weekly mean record ($n = 28$). Pearson product-moment correlation coefficients were calculated between each of seven response variables (six pest-abundance measures and shoot damage) and the five weather variables. All tests were two-sided. To limit the false-discovery rate across the 35 correlation tests, P values were adjusted using the Benjamini-Hochberg procedure; adjusted $q < .05$ was considered statistically significant.

Separate multiple linear regression models were fitted for each response variable. Maximum temperature (X1), minimum temperature (X2), morning relative humidity (X3), evening relative humidity (X4), and rainfall (X5) were entered simultaneously as predictors. Unstandardised equations were retained for direct comparison with the measured units, while standardised coefficients were used for graphical comparison of predictor magnitudes. Model R2, adjusted R2, overall F tests, coefficient estimates, 95% confidence intervals, and P values were examined. Calculations and graphical outputs were verified in Python 3.13 using SciPy 1.17.0, statsmodels 0.14.6, pandas 2.2.3, NumPy 2.3.5, and Matplotlib 3.10.8.

The analyses were considered exploratory. Because the dataset comprised weekly means from one plantation and one season, the models were used to describe contemporaneous associations; they were not interpreted as causal effects or as externally validated forecasting tools.

3. Results

3.1 Seasonal Incidence of Major Insect Pests

The leaf-eating caterpillar was the most abundant pest throughout the observation period. Its incidence began in SMW 41 at 1.50 larvae per branch and exhibited local maxima in SMWs 46, 52, 10, and 14. The highest abundance, 4.60 larvae per branch, occurred in SMW 10. Visible shoot damage was first recorded in SMW 42 and rose to 48% in SMW 10 before declining to 28% by SMW 15.

Bud worm was absent until SMW 6 and then increased from 0.50 larvae per branch to a maximum of 1.20 larvae per branch in SMW 10. Hairy caterpillar appeared earlier, in SMW 44, and reached 2.50 larvae per branch in SMW 13. Grasshopper abundance fluctuated markedly, with peaks of 2.00 adults per branch in SMW 47, 2.40 in SMW 2, and 2.15 in SMW 13. *Myllocerus viridanus* and *M. discolor* were first recorded in SMW 42 and both reached their highest abundance in SMW 13, at 2.20 and 2.50 adults per branch, respectively. The complete weekly observations and corresponding weather conditions are presented in Table 1, and pest trajectories are shown in Fig. 1.

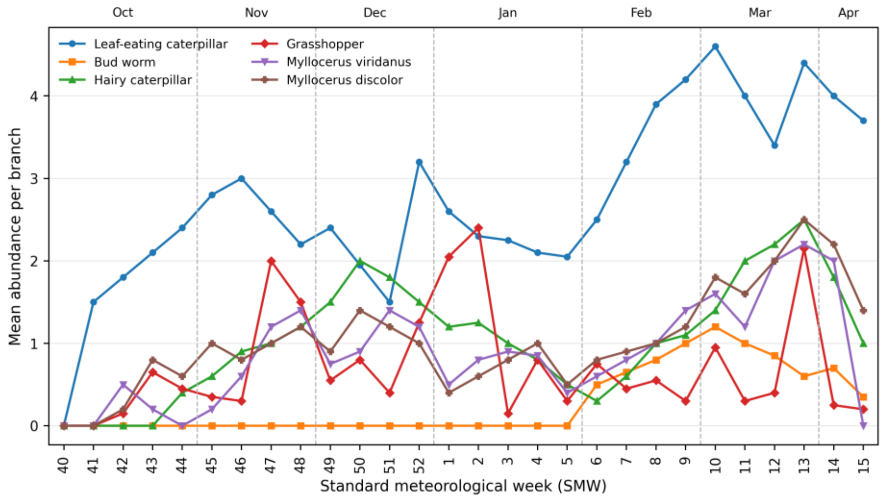

Fig. 1. Seasonal abundance of major insect pests in moringa from SMW 40 of 2025 to SMW 15 of 2026

3.2 Associations between Pest Incidence and Weather Variables

Correlation coefficients are shown in Fig. 2. After adjustment for multiple testing, leaf-eating caterpillar abundance was positively associated with maximum temperature (r = .587, q = .009) and negatively associated with evening relative humidity (r = -.475, q = .042). Shoot damage was negatively associated with evening relative humidity (r = -.599, q = .009); its nominal positive correlation with maximum temperature did not remain significant after false-discovery-rate correction (r = .418, q = .073).

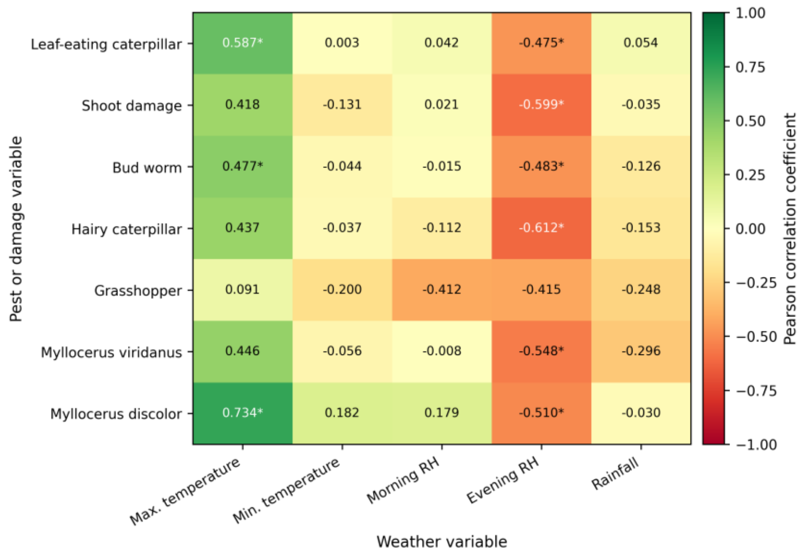

Fig. 2. Pearson correlation coefficients between weather variables and weekly pest or damage records
Note. An asterisk denotes Benjamini-Hochberg adjusted q < .05 across the 35 correlation tests.

Table 1. Weekly incidence of major insect pests and weather conditions in moringa during the 2025-2026 rabi season

Panel A. Pest abundance and shoot damage

No.	Month	SMW	Leaf-eating caterpillar (larvae/branch)	Shoot damage (%)	Bud worm (larvae/branch)	Hairy caterpillar (larvae/branch)	Grasshopper (adults/branch)	M. viridanus (adults/branch)	M. discolor (adults/branch)
1	Oct	40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2		41	1.50	0.00	0.00	0.00	0.00	0.00	0.00
3		42	1.80	6.00	0.00	0.00	0.15	0.50	0.20
4		43	2.10	9.00	0.00	0.00	0.65	0.20	0.80
5		44	2.40	19.00	0.00	0.40	0.45	0.00	0.60
6	Nov	45	2.80	22.00	0.00	0.60	0.35	0.20	1.00
7		46	3.00	29.00	0.00	0.90	0.30	0.60	0.80
8		47	2.60	33.00	0.00	1.00	2.00	1.20	1.00
9		48	2.20	30.00	0.00	1.20	1.50	1.40	1.20
10	Dec	49	2.40	27.00	0.00	1.50	0.55	0.75	0.90
11		50	1.95	28.00	0.00	2.00	0.80	0.90	1.40
12		51	1.50	31.00	0.00	1.80	0.40	1.40	1.20
13		52	3.20	26.00	0.00	1.50	1.25	1.20	1.00
14	Jan	1	2.60	24.00	0.00	1.20	2.05	0.50	0.40
15		2	2.30	27.00	0.00	1.25	2.40	0.80	0.60
16		3	2.25	22.00	0.00	1.00	0.15	0.90	0.80
17		4	2.10	26.00	0.00	0.80	0.80	0.85	1.00
18		5	2.05	20.00	0.00	0.50	0.30	0.40	0.50
19	Feb	6	2.50	19.00	0.50	0.30	0.75	0.60	0.80
20		7	3.20	30.00	0.65	0.60	0.45	0.80	0.90
21		8	3.90	33.00	0.80	1.00	0.55	1.00	1.00
22		9	4.20	36.00	1.00	1.10	0.30	1.40	1.20
23	Mar	10	4.60	48.00	1.20	1.40	0.95	1.60	1.80
24		11	4.00	44.00	1.00	2.00	0.30	1.20	1.60
25		12	3.40	42.00	0.85	2.20	0.40	2.00	2.00
26		13	4.40	38.00	0.60	2.50	2.15	2.20	2.50
27	Apr	14	4.00	36.00	0.70	1.80	0.25	2.00	2.20
28		15	3.70	28.00	0.35	1.00	0.20	0.00	1.40

Panel B. Weekly weather variables

No.	Month	SMW	Maximum temperature (degrees C)	Minimum temperature (degrees C)	Morning relative humidity (%)	Evening relative humidity (%)	Rainfall (mm)
1	Oct	40	29.59	22.60	83.71	67.14	0.00
2		41	29.51	22.67	83.00	74.86	0.00
3		42	31.16	21.31	90.43	82.29	1.45
4		43	31.87	23.03	87.00	71.29	1.57
5		44	31.16	23.24	93.14	74.86	7.73
6	Nov	45	32.30	23.17	90.00	67.14	4.36
7		46	31.59	23.24	90.43	85.29	5.93
8		47	30.94	22.53	89.29	66.29	0.83
9		48	31.73	21.31	87.43	58.86	0.00
10	Dec	49	29.44	18.74	83.00	50.17	0.00
11		50	31.16	19.74	86.00	65.71	0.00
12		51	28.94	19.39	84.86	60.14	0.00
13		52	28.51	17.31	83.00	60.29	0.00
14	Jan	1	29.51	15.89	75.00	43.57	0.00
15		2	29.73	16.39	74.57	52.00	0.00
16		3	29.30	15.81	91.00	54.43	0.00
17		4	28.73	15.74	87.71	61.00	0.00
18		5	29.30	15.24	86.00	50.86	0.00
19	Feb	6	30.44	15.96	85.29	62.14	0.00
20		7	29.59	16.74	82.29	57.14	0.00
21		8	30.30	18.89	81.57	63.86	0.00
22		9	31.30	18.17	85.00	49.43	0.00
23	Mar	10	31.73	18.46	87.86	43.86	0.00
24		11	33.09	20.10	87.43	48.57	0.99
25		12	32.94	21.67	87.86	53.53	3.97
26		13	36.59	22.67	87.14	39.00	0.00
27	Apr	14	34.30	23.03	83.71	57.71	0.00
28		15	32.94	22.60	86.71	60.29	2.54

Note. SMW = standard meteorological week. Pest-abundance values in Panel A are weekly means per sampled branch.

Bud-worm abundance was positively associated with maximum temperature (r = .477, q = .042) and negatively associated with evening relative humidity (r = -.483, q = .042). Hairy-caterpillar abundance was negatively associated with evening relative humidity (r = -.612, q = .009), whereas its positive correlation with maximum temperature did not remain significant after adjustment (r = .437, q = .064). None of the grasshopper correlations remained statistically significant after correction.

Myllocerus viridanus abundance was negatively associated with evening relative humidity (r = -.548, q = .018). *Myllocerus discolor* showed the strongest positive association with maximum temperature (r = .734, q < .001) and a negative association with evening relative humidity (r = -.510, q = .033). Minimum temperature, morning relative humidity, and rainfall were not significantly associated with any outcome after adjustment.

3.3 Multiple Linear Regression

The overall multiple regression models were statistically significant for leaf-eating caterpillar abundance, shoot damage, bud-worm abundance, hairy-caterpillar abundance, *M. viridanus* abundance, and *M. discolor* abundance, but not for grasshopper abundance (Table 2). The proportion of weekly variation explained by the five weather variables ranged from 27.24% for grasshopper to 71.77% for *M. discolor*. Adjusted R2 values were lower, ranging from 10.71% to 65.36%, reflecting the modest number of weekly observations relative to the five-predictor models.

Within the full models, maximum temperature was an independently significant positive predictor of leaf-eating caterpillar abundance (B = 0.467, 95% CI [0.174, 0.759], P = .003), bud-worm abundance (B = 0.140, 95% CI [0.008, 0.273], P = .039), and *M. discolor* abundance (B = 0.220, 95% CI [0.080, 0.359], P = .004). Evening relative humidity was an independently significant negative predictor of shoot damage (B = -0.592, 95% CI [-1.145, -0.040], P = .037) and hairy-caterpillar abundance (B = -0.039, 95% CI [-0.073, -0.005], P = .026). Although the overall *M. viridanus* model was significant, no individual weather coefficient reached P < .05, indicating that the overall fit should not be attributed to a single independently established predictor. Evening relative humidity in the *M. discolor* model was borderline (P = .057).

Standardised coefficients are displayed in Figs. 3 and 4. These figures describe the conditional direction and magnitude of the coefficients within each model and should not be interpreted as causal effects.

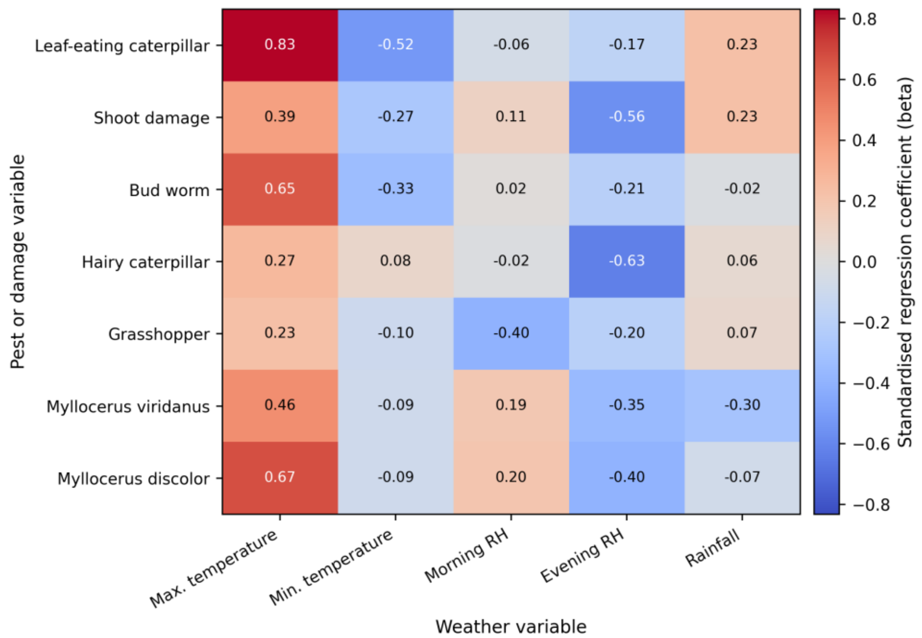

Fig. 3. Heatmap of standardised multiple regression coefficients for weather variables and weekly pest or damage records

Table 2. Multiple linear regression models relating weekly pest incidence to weather variables

Response	Regression equation	F	P	R2	Adjusted R2	Independently significant coefficient(s)
Leaf-eating caterpillar	Y = -5.956 + 0.467X1 - 0.190X2 - 0.014X3 - 0.016X4 + 0.119X5	6.067	.001	0.5796	0.4841	Maximum temperature: B = 0.467, P = .003
Shoot damage (%)	Y = -21.637 + 2.474X1 - 1.109X2 + 0.319X3 - 0.592X4 + 1.339X5	4.955	.003	0.5297	0.4228	Evening RH: B = -0.592, P = .037
Bud worm	Y = -2.850 + 0.140X1 - 0.047X2 + 0.002X3 - 0.007X4 - 0.005X5	3.249	.024	0.4247	0.2940	Maximum temperature: B = 0.140, P = .039
Hairy caterpillar	Y = 0.039 + 0.102X1 + 0.019X2 - 0.003X3 - 0.039X4 + 0.020X5	4.274	.007	0.4927	0.3774	Evening RH: B = -0.039, P = .026
Grasshopper	Y = 4.818 + 0.085X1 - 0.025X2 - 0.065X3 - 0.012X4 + 0.023X5	1.648	.189	0.2724	0.1071	None
Myllocerus viridanus	Y = -4.645 + 0.154X1 - 0.019X2 + 0.028X3 - 0.020X4 - 0.091X5	4.199	.008	0.4883	0.3720	None
Myllocerus discolor	Y = -6.530 + 0.220X1 - 0.018X2 + 0.028X3 - 0.021X4 - 0.021X5	11.188	< .001	0.7177	0.6536	Maximum temperature: B = 0.220, P = .004

Note. Y = predicted pest abundance or shoot damage; X1 = maximum temperature; X2 = minimum temperature; X3 = morning relative humidity; X4 = evening relative humidity; X5 = rainfall. Coefficient significance was evaluated within each full five-predictor mode

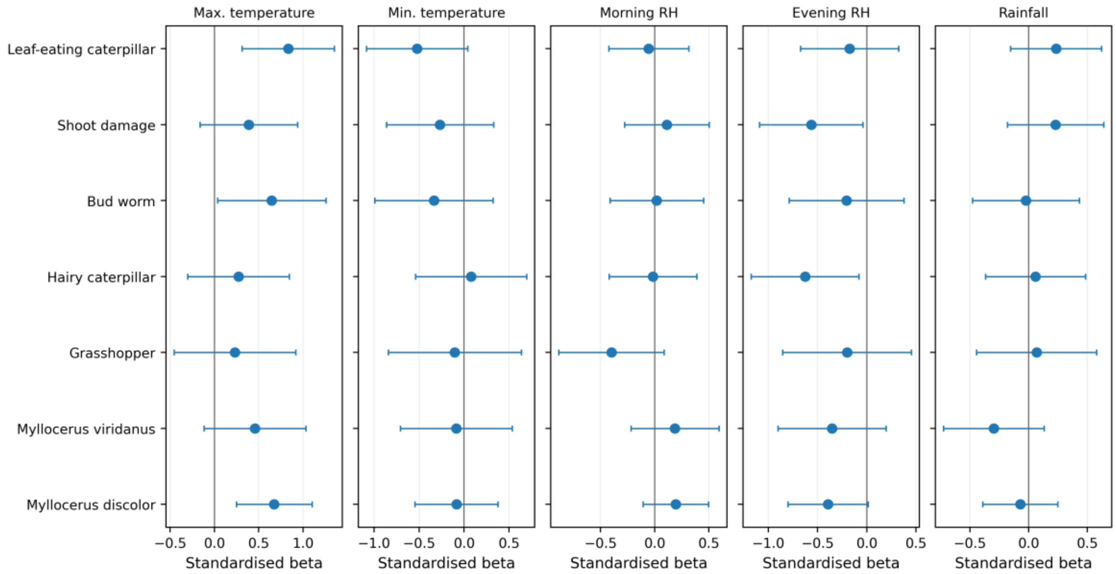

Fig. 4. Standardised regression coefficients and 95% confidence intervals for weather variables in the seven multiple regression models

Note. Confidence intervals crossing zero indicate that the corresponding coefficient was not statistically distinguishable from zero at the 5% level

4. Discussion

4.1 Seasonal Composition and Peak Incidence

The leaf-eating caterpillar was the dominant pest during the study and remained present for most of the season. Its highest abundance and the greatest recorded shoot damage occurred in SMW 10, followed by continued comparatively high abundance through SMW 15. This late-season concentration is broadly consistent with the February-April activity reported by Chandrakar and Gupta (2020) in Chhattisgarh. Math and Kotikal (2014), Duvaraga Devi et al. (2024), and Prasannakumar et al. (2024) likewise identify *N. bliteali*s as an important foliage-feeding pest of moringa in India.

Nevertheless, the timing of peak abundance is not uniform across regions. Yadav et al. (2024) reported a leaf-caterpillar peak during August in Rajasthan, whereas Wayal et al. (2025) recorded peaks during October and December in Maharashtra. Differences in rainfall regime, pruning and flush development, planting system, local pest phenology, and natural-enemy activity may contribute to this variation. The Aswaraopet pattern should therefore be used to guide local scouting rather than transferred directly to other production zones.

Bud worm appeared only from SMW 6 onwards and peaked in SMW 10, indicating a relatively restricted late-season occurrence during the sampled period. Hairy caterpillar and both Myllocerus species reached their maxima in SMW 13. Grasshopper abundance was more irregular, with several sharp peaks separated by low counts. Such fluctuations may reflect movement between the plantation and surrounding vegetation in addition to local weather conditions.

4.2 Weather Associations

Maximum temperature and evening relative humidity were the weather variables most consistently associated with pest incidence. The positive association between maximum temperature and leaf-eating caterpillar abundance remained significant after correction for multiple testing and within the full regression model. Temperature can influence insect development and feeding within species-specific thermal ranges, but a positive field association does not by itself demonstrate a direct physiological mechanism because temperature also covaries with crop stage and season (Bale et al., 2002).

The negative association between evening relative humidity and shoot damage remained significant in both the adjusted correlation analysis and the multiple regression model. Evening humidity was also an independently significant negative predictor of hairy-caterpillar abundance. These results suggest that comparatively dry evening conditions coincided with greater damage or abundance during this season. They should not be interpreted to mean that humidity universally suppresses these insects; moisture responses may vary among species, developmental stages, and locations.

For bud worm, maximum temperature remained independently significant in the full model, while both maximum temperature and evening relative humidity were significant in the adjusted pairwise analysis. This pattern is directionally compatible with the positive maximum-temperature and negative humidity associations reported in the two-year Tamil Nadu study by Manikandan and Rengalakshmi (2024). Agreement across studies provides useful biological context, although differences in crop stage, season, sample size, and analytical method preclude direct comparison of coefficient magnitudes.

Myllocerus discolor showed the strongest model fit and the largest adjusted positive correlation with maximum temperature. By contrast, the *M. viridanus* model was significant overall but contained no independently significant weather coefficient. The latter result may arise when several moderately correlated predictors contribute jointly, or when limited sample size reduces coefficient precision. The moderate variance-inflation factors observed for the temperature and humidity variables did not indicate extreme collinearity, but the estimates should still be interpreted cautiously.

No grasshopper association remained significant after false-discovery-rate correction, and the overall regression model was not significant. This finding supports the interpretation that same-week weather variables alone were insufficient to describe the observed grasshopper fluctuations. Mobility, vegetation outside the sampled plantation, species composition within the grasshopper category, and local disturbance may all be relevant.

4.3 Implications for Monitoring and Integrated Pest Management

The weekly pattern identifies February-March as a particularly important scouting period for leaf-eating caterpillar, bud worm, hairy caterpillar, and ash weevils in the sampled plantation. Monitoring should begin earlier, however, because leaf-eating caterpillar was already present in SMW 41 and visible damage followed in SMW 42. Regular inspection of newly developing foliage and buds after pruning may permit intervention before damage reaches the highest levels observed in SMW 10.

The weather associations may be used to prioritise surveillance when maximum temperature rises and evening humidity declines, but they do not define an action threshold. Integrated pest management requires confirmation of pest identity and density, assessment of crop stage and damage, conservation of natural enemies, and selection of proportionate control measures (Stenberg, 2017). Local economic thresholds and treatment efficacy were not evaluated in this study and should not be inferred from the reported correlations.

Operational forecasting would require data from multiple seasons and preferably multiple sites, together with lagged weather variables, crop phenology, natural-enemy abundance, and management records. Count-oriented models, including negative-binomial or zero-inflated approaches when supported by the data, may be preferable for sparse pest counts, and predictive performance should be tested on independent observations (Naranammal & Krishna Priya, 2024).

5. Limitations

The study was conducted at one site during one season and involved five repeatedly sampled plants. Consequently, the findings describe local temporal associations and cannot establish regional generalisability or causal effects of weather. Plant-level and branch-level variability was not available in the analytical dataset, so weekly means were treated as the units of analysis and uncertainty associated with repeated sampling could not be modelled directly.

The models used same-week weather values and did not evaluate biologically plausible lag periods. Pest responses may occur after weather exposure during egg, larval, pupal, or adult stages. Crop phenology, tender-foliage availability, natural enemies, surrounding vegetation, and management operations were not included as covariates. These omitted factors may account for part of the unexplained variation and may also confound apparent weather relationships.

Linear regression was used to preserve comparability with the original agronomic analysis, although several response variables were low counts with zeros. The results should therefore be regarded as exploratory. Future studies should retain plant-level repeated observations and evaluate generalised mixed, time-series, or count models with appropriate diagnostics and independent validation.

6. Conclusion

In the Aswaraopet moringa plantation, *Noorda blitealis* was the predominant insect pest and attained its highest weekly abundance and associated shoot damage in SMW 10. Bud worm, hairy caterpillar, and both Myllocerus species also increased during the later part of the observation period, whereas grasshopper abundance fluctuated irregularly. After adjustment for multiple correlation testing, maximum temperature was positively associated with several pests and evening relative humidity was negatively associated with multiple pest or damage outcomes. The full regression models indicated that the independently supported weather predictors differed among taxa: maximum temperature was associated with leaf-eating caterpillar, bud worm, and *M. discolor*, while evening relative humidity was associated with shoot damage and hairy caterpillar. These results support intensified field surveillance during the late winter and early summer transition under local conditions. They do not constitute a causal or externally validated forecast. Multi-season, multi-location studies using plant-level repeated observations and validated count or time-series models are needed before weather-based decision rules are incorporated into operational moringa pest management.

Acknowledgements

The authors acknowledge the guidance and support of the advisory committee and the facilities provided by Professor Jayashankar Telangana Agricultural University, Rajendranagar, Hyderabad, and Agricultural College, Aswaraopet.

Declaration of AI Use

This manuscript was prepared through the combined contributions of all author(s), including contributions to the study design, data, content development, results, interpretation, and related scholarly work. The author(s) acknowledge the use of Grammarly and ChatGPT to assist with grammar checking, language refinement, reference formatting. These AI-assisted tools were not used as authors and did not replace the intellectual contributions or scholarly judgment of the author(s). All AI-assisted outputs, including content, references, and interpretations, were carefully reviewed, revised, verified, and approved by the author(s). The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that no competing interests exist.

References

Bale, J. S., Masters, G. J., Hodkinson, I. D., Awmack, C., Bezemer, T. M., Brown, V. K., Butterfield, J., Buse, A., Coulson, J. C., Farrar, J. F., Good, J. E. G., Harrington, R., Hartley, S., Jones, T. H., Lindroth, R. L., Press, M. C., Symrnioudis, I., Watt, A. D., & Whittaker, J. B. (2002). Herbivory in global climate change research: Direct effects of rising temperature on insect herbivores. *Global Change Biology, 8*(1), 1–16. https://doi.org/10.1046/j.1365-2486.2002.00451.x

Chandrakar, T., & Gupta, A. K. (2020). Seasonal incidence of insect pests on drumstick (*Moringa oleifera* Lamk.). *Journal of Entomology and Zoology Studies, 8*(4), 1384–1387. https://www.entomoljournal.com/archives/?ArticleId=7323&issue=4&vol=8&year=2020

Deutsch, C. A., Tewksbury, J. J., Tigchelaar, M., Battisti, D. S., Merrill, S. C., Huey, R. B., & Naylor, R. L. (2018). Increase in crop losses to insect pests in a warming climate. *Science, 361*(6405), 916–919. https://doi.org/10.1126/science.aat3466

Duvaraga Devi, M., Muthuswami, M., Suganthi, A., Indu Rani, C., & Manikanda Boopathi, N. (2024). Insights into arthropod pests of *Moringa oleifera*: Emerging threats and management strategies. *The Journal of Animal & Plant Sciences, 34*(6), 1340–1354. https://doi.org/10.36899/JAPS.2024.6.0815

Gopalakrishnan, L., Doriya, K., & Kumar, D. S. (2016). *Moringa oleifera*: A review on nutritive importance and its medicinal application. *Food Science and Human Wellness, 5*(2), 49–56. https://doi.org/10.1016/j.fshw.2016.04.001

Islam, Z., Islam, S. M. R., Hossen, F., Mahtab-ul-Islam, K., Hasan, M. R., & Karim, R. (2021). *Moringa oleifera* is a prominent source of nutrients with potential health benefits. *International Journal of Food Science, 2021*, Article 6627265. https://doi.org/10.1155/2021/6627265

Leone, A., Spada, A., Battezzati, A., Schiraldi, A., Aristil, J., & Bertoli, S. (2015). Cultivation, genetic, ethnopharmacology, phytochemistry, and pharmacology of *Moringa oleifera* leaves: An overview. *International Journal of Molecular Sciences, 16*(6), 12791–12835. https://doi.org/10.3390/ijms160612791

Manikandan, P., & Rengalakshmi, R. (2024). Influence of weather factors on population dynamics of major insect pests in moringa (*Moringa oleifera* Lam.) in south Tamil Nadu. *Journal of Agrometeorology, 26*(2), 238–242. https://doi.org/10.54386/jam.v26i2.2405

Math, M., & Kotikal, Y. K. (2014). Studies on insect pests of drumstick, *Moringa oleifera* Lam. *Indian Journal of Plant Protection, 42*(4), 461–464. https://epubs.icar.org.in/index.php/IJPP/article/view/106819

Naranammal, N., & Krishna Priya, S. R. (2024). Weather-based forewarning model for cotton pests using zero-inflated and hurdle regression models. *Journal of Agrometeorology, 26*(4), 485–490. https://doi.org/10.54386/jam.v26i4.2744

Prasannakumar, N. R., Bhat, P. S., Jyothi, N., & Saroja, S. (2024). Current scenario of insect pests and mite on drumstick (*Moringa oleifera*) in south India and their management. *The Indian Journal of Agricultural Sciences, 94*(2), 156–160. https://doi.org/10.56093/ijas.v94i2.117500

Stenberg, J. A. (2017). A conceptual framework for integrated pest management. *Trends in Plant Science, 22*(9), 759–769. https://doi.org/10.1016/j.tplants.2017.06.010

Wayal, D. T., Bharati, M. S., Shinde, H. S., Avhad, P. S., & Kuldharan, P. V. (2025). Seasonal incidence of major insect pests of drumstick along weather parameters with natural enemies. *International Journal of Advanced Biochemistry Research, 9*(8), 510–513. https://doi.org/10.33545/26174693.2025.v9.i8g.5239

Yadav, A., Kumawat, M. M., Ram, D., Pradhan, P., & Yadav, T. (2024). Insects associated with moringa and their correlation with abiotic parameters. *International Journal of Environment and Climate Change, 14*(11), 595–604. https://doi.org/10.9734/ijecc/2024/v14i114571

Peer-review history:
The peer review history for this paper can be accessed here:
https://pr.sdiarticle5.com/review-history/163895