Journal of Agrometeorology

ISSN : 0972-1665 (print), 2583-2980 (online)
Vol. No. 26 (2) : 238 - 242 (June - 2024)
https://doi.org/10.54386/jam.v26i2.2405
https://journal.agrimetassociation.org/index.php/jam

Research Paper

Influence of weather factors on population dynamics of major insect pests in Moringa (*Moringa oleifera Lam.*) in south Tamil Nadu

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ABSTRACT

The field experiments were conducted to study the relationship of major Moringa pests infesting buds (budworm), flowers(ants) and pods (podfly) with weather factors (maximum and minimum temperature and relative humidity and rainfall) during the *rabi*-summer and *kharif* seasons of 2021 and 2022 in Dindigul district, Tamil Nadu. The pest population data indicated that the infestations were found to vary with the seasons as well as years. The correlation with weather parameters revealed that the budworm infestation was significant and positively correlated with maximum temperature (r= 0.459***) and negatively correlated with morning relative humidity (r= -0.277*), evening relative humidity (r= -0.584***) and rainfall (r= -0.459***). While in infestation by ants, it was positively correlated with the maximum temperature (r=0.42**) and minimum temperature (r= -0.296*), relative humidity (evening) (r= -0.649***) and negatively correlated with rainfall (r= -0.382**). The moringa pod fly infestation had a strong significant positive correlation with relative humidity (evening) (r= 0.7***) and rainfall (r= 0.517***) and a negative correlation (r= -0.518***) with maximum temperature. The stepwise linear regression showed that all the weather factors collectively influenced the budworm infestation by up to 60.7 %, ants infestation by 50.5 % and up to 60.7 % in podfly infestation.

***Keywords*:** Moringa, Insect pest, Weather, Ant, Budworm, Podfly

Moringa (*Moringa oleifera* Lam.) is an important perennial/semi-perennial vegetable crop, rich in nutrients; vitamins A, C, D and E, Calcium, Protein, Iron and antioxidants (Mutiara *et al.,* 2013) popularly known as "Miracle tree" and is predominantly cultivated for its green pods and leaves in tropical and subtropical regions, and its pod production influenced by diversity and abundance of insect pollinators (Dhandapani *et al.,* 2024). In India, it covers an area of 43,600 ha with an annual production of 2.2 million tonnes of tender pods, with Tamil Nadu alone contributing 13,042 ha and 6.71 lakh tonnes annually (Venkatesan *et al.,* 2018). The Dindigul region in Tamil Nadu, comprising the Theni, Karur and Dindigul districts, is a significant Moringa cultivation cluster, covering 3600 ha (50% of the area under Moringa in Tamil Nadu). The pods produced here are marketed domestically and exported to Gulf and Southeast Asian countries.

Pest infestation is a significant challenge affecting pod productivity and quality, with over 30 insect species identified as pests of Moringa (Mahesh and Kotikal, 2014). Among these, budworm (*Noorda moringae* Tams.,), chafer beetle (*Holotrichia serrata* F.), red ant and pod/fruit fly (*Gitona distigma* (Meigen) (Manikandan and Rengalakshmi, 2023) cause considerable economic losses from flowering to maturity stages. For instance, budworm infestation can lead to 78 per cent of flower shedding (Saha *et al.,* 2014). Pod fly infestation during pod initiation and formation stages can result in yield loss of up to 75 per cent (Honnalingappa, 2001). Insect pest infestation intensity varies in different geographical conditions and seasons due to the changes in local weather conditions (Manikandan *et al.,* 2020 and 2021; Elango *et al.,* 2021; Khokhar and Rolania, 2021; Borkakati *et al.,* 2021; Reddy *et al.,* 2022). The notable differences in the Moringa pest infestation were recorded over the cultivation seasons (Honnalingappa, 2001). Understanding these variations is crucial for effective pest management strategies tailored to specific locales (Mahesh *et al*., 2018). However, such location-based studies are lacking in major Moringa cultivation zones in Tamil Nadu.

In this backdrop, to design a location-specific integrated pest management strategy, a field experiment was conducted to comprehend the population dynamics of these important pests of

***Article info - DOI*:** https://doi.org/10.54386/jam.v26i2.2405
Received:13 October 2023; Accepted: 26 April 2024; Published online : 1 June 2024

Moringa with prevailing weather conditions.

MATERIALS AND METHODS

The experiment was conducted in ten farmers' fields in the Dindigul district of Tamil Nadu during the "*rabi*-summer" (Feb - May) and "*kharif*" (June – September) seasons of 2021 to 2022. Ten well-established moringa (cv. Karumbu) fields with three to four-year-old plantations were selected for the experiment. The trees were pruned in November 2020 and the practices of irrigation, manuring and weeding were uniformly followed and no pesticide application was done during the study period. The data was collected from the standard Meteorological week (SMW) of flower initiation to the harvest of both "*rabi*-summer" (8th to 25th SMW) (February to June) and "*kharif*" (33rd to 42nd SMW) (August to October) seasons of 2021 to 2022. In each field, 10 trees were randomly selected from all the directions of the field and the pest population was recorded in weekly intervals. The trees were not the same for all the weekly observations for the pest infestation. In each selected tree, observations were made from all four directions: east, south, west and north. The infestation of moringa budworm and ants was observed on two inflorescences from each of four directions, the total number of infested buds/flowers was counted and the mean number of infested buds/flowers per inflorescence was calculated. Similarly, moringa pod fly infestation was recorded on two inflorescences in each direction of the selected trees and the total number of pods infested with pod fly was counted and the mean number of infested pods per inflorescence was calculated.

The weather parameters such as temperature (maximum and minimum), relative humidity, rainfall and wind speed were collected from the records of the office of B-type Agro-meteorological field unit, located at Kannivadi, Reddiyarchatram, Dindigul (10^{o}23' N, 77^{o}49' E, 293 m altitude). The selected fields were spread within a 0.5 to 4 km radius of the observatory. The relationship between the pests and weather factors was analysed by Pearson correlation coefficient, regression and principal component analysis (PCA) using IBM SPSS and the PCA plotted in R.

RESULTS AND DISCUSSION

Population dynamics of budworm

The Moringa budworm infestation was first observed during the 3rd week of February (8th SMW) in the *rabi*-summer season and the infestation showed an increasing trend in subsequent weeks and reached a peak in the 1st week of April (14th SMW) recorded with the following weather factors maximum temperature (36.7°C), and minimum temperature (19.6°C), morning RH (83.7 %), evening RH (42.5 %), wind speed (1.3 km hr^{1}) and rainfall (0.0 mm) (Table 1). During the *kharif* season, the infestation was first observed in 2nd week of August (33rd SMW) and with a gradual increase, the maximum population was observed during 2nd week of September (37th SMW) recorded with weather factors maximum temperature (32.5°C), and minimum temperature (18.4°C), morning RH (86.5 %), evening RH (60.2 %), wind speed (1.9 km hr^{1}) and rainfall (0.0 mm) (Table 2). The trend was analogous in both 2021 and 2022. A similar observation was reported by Mahesh *et al*. (2013) in *rabi* summer (8th SMW) at Baglkote district of Karnataka and *kharif* season in Rajnandgaon district of Chhattisgarh (36th SMW) by Chandrakar and Gupta (2020). Besides, the study of Chandrakar and Gupta (2020) reported a complete disappearance of the budworm population from November to January months. Manikandan and Selvanarayanan (2020) reported less leaf caterpillar infestation during *kharif* than the *rabi*-summer in groundnut.

Population dynamics of ants

The infestation of ants was observed only in the *rabi-summer* season. The infestation started from the 3rd week of February (8th SMW) with the prevailing weather factors such as maximum temperature (31.4°C), minimum temperature (16.0°C), morning RH (89.4 %), evening RH (55.3 %), wind speed (0.4 km hr^{1}) and rainfall (0.6 mm) and the maximum infestation was recorded during the 3rd week of March (13th SMW) in 2021 with the following weather condition, maximum temperature (35.9°C), and minimum temperature (19.8°C), morning RH (84.2 %), evening RH (45.9 %), wind speed (1.8 km hr^{1}) and rainfall (0.0 mm). In 2022, the infestation started six weeks later, 1st week of April (14th SMW) 2022 and a considerable infestation of ants was recorded up to the 4th week of April (17th SMW) in 2022 the range of weather parameters from 14th to 17th SMW was the maximum temperature (33.3°C to 36.7°C), and minimum temperature (19.2°C to 20.6°C), morning RH (82.1 % to 88.9 %), evening RH (42.5 % to 58.1 %), wind speed (1.3 to 2.1 km hr^{1}) and rainfall (0.0 to 4.1 mm) (Table 1 and 2).

Population dynamics of podfly

The first infestation of moringa pod fly was observed in the 3rd week of April (16th SMW) and increased in the subsequent weeks and the maximum infestation was observed during 1st week of June (23rd SMW) with the prevailing weather factors such as maximum temperature (34.4°C), minimum temperature (19.6°C), morning RH (88.6 %), evening RH (60.8 %), wind speed (1.6 km hr^{1}) and rainfall (7.8 mm) in the *rabi*-summer season 2021. Infestation started from 1st week of March (10th SMW) and a considerable infestation was recorded in 1st week of May (18th SMW) and increased in the subsequent weeks. The maximum infestation was observed during 2nd week of June 2022 (24th SMW) with the prevailing weather factors such as maximum temperature (33.5°C), minimum temperature (19.4°C), morning RH (86.2 %), evening RH (58.4 %), wind speed (1.4 km hr^{1}) and rainfall (3.4 mm) (Table 1). During the *kharif* season, the pod fly infestation was observed from the 2nd week of August (33rd SMW). An extensive infestation was observed throughout the season (Table 2) in both 2021 and 2022, which was comparatively higher than during the rabi-summer season. These results are in agreement with the study of Mahesh *et al.,* (2018) which also reported the first appearance of the pod fly in August 2021 and 2022 and their presence continued throughout the season.

Correlation of pest population with weather parameters

Moringa budworm infestation showed a highly significant positive correlation with maximum temperature ($r= 0.459^{***}$) whereas negatively correlated with morning relative humidity ($r= -0.277^{*}$), evening relative humidity ($r= -0.584^{***}$) and rainfall ($r= -0.459^{***}$) (Table 3). The influence of weather factors on ant infestation

Table 1: Population dynamics of insect pests on moringa during *rabi*-summer, 2021 and 2022 (pooled)

SMW	Mean number of buds/pods infested			Weather parameters					
	Budworms	Ants	Pod fly	Temperature (°C)		RH (%)		Wind speed (km hr^1)	Rainfall (mm)
				Tmax	Tmin	Morning	Evening		
8	0.33	0.34	0.00	31.4	16.0	89.4	55.3	0.4	0.6
9	0.85	0.61	0.00	33.1	13.8	88.1	47.4	1.2	0.0
10	0.96	0.70	0.02	32.7	15.4	88.9	50.4	1.6	0.3
11	1.32	0.82	0.03	34.4	15.4	86.9	44.1	1.1	0.0
12	1.52	0.96	0.03	35.0	17.8	87.4	45.2	1.3	0.0
13	1.98	1.00	0.00	35.9	19.8	84.2	45.9	1.8	0.0
14	2.26	0.78	0.00	36.7	19.6	83.7	42.5	1.3	0.0
15	1.01	0.32	0.00	33.3	19.2	88.9	58.2	1.5	4.1
16	0.67	0.25	0.10	35.6	20.2	86.8	47.6	2.1	0.6
17	0.48	0.25	0.17	35.9	20.6	82.1	48.4	1.7	1.1
18	0.05	0.00	0.34	35.7	20.5	85.2	51.0	2.2	5.8
19	0.00	0.19	0.41	33.4	20.4	86.5	59.2	2.6	2.5
20	0.00	0.00	0.54	32.3	19.7	87.4	65.6	2.2	1.7
21	0.20	0.00	0.63	33.5	19.5	88.1	59.4	1.6	4.7
22	0.62	0.00	0.71	34.1	19.5	85.6	56.7	1.4	1.5
23	0.23	0.00	0.92	34.4	19.6	88.6	60.8	1.6	7.8
24	0.93	0.11	0.90	33.5	19.4	86.2	58.4	1.4	1.9
25	0.70	0.00	0.75	33.0	18.5	89.4	58.8	1.8	3.4

Table 2: Population dynamics of insect pests on moringa during *kharif*, 2021 and 2022 (pooled)

SMW	Mean number of buds/pods infested			Weather parameters					
	Budworms	Ants	Pod fly	Temperature (°C)		RH (%)		Wind speed (km hr^1)	Rainfall (mm)
				Tmax	Tmin	Morning	Evening		
33	0.77	0.00	0.39	34.1	18.9	84.0	52.5	3.3	1.1
34	0.23	0.00	0.65	33.0	18.4	89.1	57.1	2.5	3.0
35	0.00	0.00	0.92	32.0	18.4	88.3	63.5	2.1	10.0
36	0.93	0.00	1.03	31.0	17.9	88.2	66.4	1.7	6.4
37	1.30	0.00	1.04	32.5	18.4	86.5	60.2	1.9	0.0
38	0.84	0.00	1.15	33.3	18.6	85.4	57.8	2.0	0.2
39	0.39	0.00	1.32	33.8	18.4	83.0	53.4	2.6	1.7
40	0.00	0.00	1.39	32.5	18.2	87.3	63.2	2.2	10.0
41	0.00	0.00	1.29	30.9	17.7	89.0	68.1	1.2	11.7
42	0.00	0.00	1.49	30.6	17.8	90.0	70.9	1.3	7.3

also followed a similar trend of budworm, the ant infestation was increased with a temperature rise ($r=0.42^{**}$). However, other weather parameters such as minimum temperature ($r= -0.296^{*}$), relative humidity (evening) ($r= -0.649^{***}$) and rainfall ($r= -0.382^{**}$) had a significant negative correlation with ant infestation (Table 3).While the moringa pod fly infestation had a strongly significant positive correlation with relative humidity (evening) ($r= 0.7^{***}$) and rainfall ($r= 0.517^{***}$) whereas the maximum temperature had a strong significant negative correlation ($r= -0.518^{***}$) with moringa podfly infestation. The results were supported by the findings of Mahesh *et al*., (2013) who reported a highly significant and negative correlation between the maximum temperature and pod fly infestation ($r = -0.8713$) and a positive correlation with evening relative humidity ($r = 0.0422$) and rainfall ($r = 0.0171$) (Table 3).

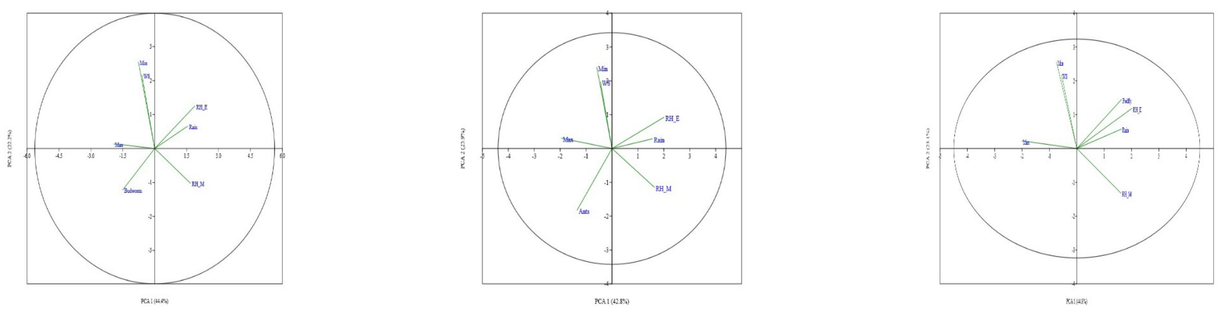
Principal component analysis

In addition to correlation, a principal component analysis (PCA) is done to capture the nature of relationships between the pests and different weather parameters, as additional supportive evidence to the correlation analysis. Khokhar and Rolania (2021) also plotted the PCA to reveal the relationship between the aphids and their natural enemies and the weather parameters. The PCA plotted for budworm and weather factors showed the variability in the data viz., PC1 (44.4 %) and PC2 (22.2 %). A significant positive relationship between the budworm and maximum temperature and a significant negative relationship between the budworm and rainfall and relative humidity (evening) was revealed by direction and the distance between the vectors (Fig 1a). Data variability in the PCA of ants and the weather factors viz., PC1 (42.8 %) and PC 2 (25.9 %), negative relationship between ant population and relative humidity (evening), Rainfall revealed by the opposite direction and maximum distance of the vectors (Fig 1b). The positive strong relationship of the pod fly with relative humidity (evening), and rainfall and the negative relationship with maximum temperature was indicated by

Table 3: Correlation between weather factors and insect pests of moringa

Weather factors	Budworm	Ants	Podfly
Maximum temperature	0.459***	0.42**	-0.518***
Minimum temperature	-0.02	-0.296*	0.026
Relative humidity (morning)	-0.277*	-0.141	0.142
Relative humidity (evening)	-0.584***	-0.649***	0.7***
Wind speed	0.031	-0.184	0.005
Rainfall	-0.459***	-0.382**	0.517***

*** Correlation is significant at 0.001 level (two-tailed); ** Correlation is significant at 0.01 level (two-tailed); * Correlation is significant at 0.05 level (two-tailed)



(a) Budworm (b) Ant (c) Podfly

Fig 1: Principal component analysis of insect pest with weather parameters

Table 4: Stepwise linear regression of insect pests of moringa and weather parameters

Pest	Regression model	R^2
Moringa budworm (Y1)	$Y1= 0.33+0.33x_1-0.05x_2+0.01\ x_3-0.03x_4+0.01x_5-0.02x_6$	0.607
Ants (Y2)	$Y2=0.06+0.33x_1-0.05x_2+0.01x_3-0.01x_4-0.01x_5$	0.505
Moringa podfly (Y3)	$Y3=4.15+0.04x_1-0.07x_2-0.07x_3+0.05x_4-0.00x_5+0.02x_6$	0.607

x1= Maximum temperature, x2= Minimum temperature, x3= Relative humidity (morning), x4= Relative humidity (evening), x5= Wind speed, x6= Rainfall.

the distance and direction of the vectors (Fig 1c).

Impact of specific weather parameters on pests

The linear regression model showed the effect of individual weather factors on moringa pests and the results suggested the strong positive impact of maximum temperature (R^2= 0.21; F1,7= 14.46, p= 0.00) and strong negative impact of rainfall (R^2= 0.21; F1,7= 14.42, p= 0.00) on Moringa budworm also revealed that there was no significant relationship between Moringa budworm with minimum temperature, humidity and wind speed. The significant influence of individual weather factors on ant infestation viz., maximum temperature (R^2= 0.17; F1,7= 11.66, p= 0.00) had a significant positive relationship whereas minimum temperature (R^2= 0.08; F1,7= 5.22, p= 0.03) and rain (R^2= 0.14; F1,7= 9.19, p= 0.00), and had a significant negative relationship. The relationship between maximum temperature and pod fly infestation was significantly negative (R^2= 0.27; F1,7= 19.95, p= 0.00) and rainfall (R^2= 0.26; F1,7= 19.70, p= 0.00) had a significant positive impact on pod fly infestation other factors such as relative humidity, minimum temperature and wind speed had no significant relationship.

The stepwise linear regression showed that all the weather factors collectively influenced the budworm infestation by up to 60.7 %, ants infestation by 50.5 % and it was up to 60.7 % in podfly infestation (Table 4). The equation can predict the pest infestation based on the prevailing weather.

In summary, the analysis pointed out that different weather factors have varying relationships with the population of budworms, ants and podflies. The maximum temperature, evening relative humidity, and rainfall are shown as significant factors influencing these insect pest populations, while, other factors like minimum temperature, morning relative humidity, and wind speed do not show strong associations with these populations.

CONCLUSION

The observations pointed out that the infestation of pests in Moringa was strongly influenced by weather factors along with seasonal impacts. The weather prevailing in the *"rabi*-summer*"* season favours ants and budworm infestation, whereas the weather of the *"kharif"* season favours the pod fly infestation. The budworm infestation is positively related to the rise in maximum temperature whereas infestation has a negative relationship with morning relative humidity, evening relative humidity and high rainfall. The ant infestation is also higher when the maximum temperature is high, on the contrary, ant infestation is very low when the rainfall is high. The high relative humidity (evening) and high rainfall favour the moringa pod fly infestation whereas the high maximum temperature suppresses the podfly infestation. A clear understanding of the weather and pest population dynamics are the basic inputs to designing a locale-specific Integrated Pest Management strategy.

ACKNOWLEDGEMENT

The authors thank M S Swaminathan Research Foundation, Chennai for granting permission to conduct this research work and IMD, MoES for funding through its GKMS project.

Conflict of Interests: The authors declare that there are no conflicts of interest related to this article.

Data availability: Cannot be shared

Authors contribution: **P.Manikandan**: Conceptualization, Methodology, Data collection and analysis, Writing original draft; **R.Rengalakshmi**: Super vision, Editing

Disclaimer: The contents, opinions, and views expressed in the research article published in the Journal of Agrometeorology are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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