Print ISSN : 0972-8813
e-ISSN : 2582-2780

[Vol. 23(2) May-August 2025]

Pantnagar Journal of Research

(Formerly International Journal of Basic and Applied Agricultural Research ISSN : 2349-8765)

G.B. Pant University of Agriculture & Technology, Pantnagar

PANTNAGAR JOURNAL OF RESEARCH

Vol. 23(2) May-August, 2025

CONTENTS

Influence of weather parameters on the population dynamics of Papaya mealybugs, *Paracoccus marginatus* and its natural enemies in Pantnagar, Uttarakhand

DIPTI JOSHI* and POONAM SRIVASTAVA

Department of Entomology, College of Agriculture, G. B. Pant University of Agriculture and Technology, Pantnagar-263145 (U. S. Nagar, Uttarakhand)
**Corresponding author's email id: diptiento@gmail. com*

ABSTRACT: The papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink, is a small hemipteran pest that attacks important tropical fruits, vegetables and ornamentals. In the present study, the population dynamics of *P. marginatus* and its natural enemies, were carried out in randomly selected papaya trees in Pantnagar from August 2023 to July 2024. Study revealed that infestations began in the second fortnight of August 2023, with the pest infestation (1.8 mealybugs/5cm^2/leaf/plant). The population was low during the first fortnight of January but peaked during the first fortnight of April 2024. During the second fortnight of May, the highest level of *P. marginatus* infestation was noticed (147.40 mealybugs/5cm^2/leaf/plant), but the population declined during July. The study also examined the relationship between weather parameters and insect population, indicating a significant positive correlation between maximum, minimum temperature, sunshine hours, and the pest. The peak population of coccinelid predators like *Scymnus frontalis*, *Brumoides suturalis,* and *Cryptolaemus montrouzeiri* with 7.0, 3.6, and 3.8 adults/leaf/plant population were noticed in between second fortnight of April to second fortnight of June. Thereafter, a gradual decline in the population of all three natural enemies was noticed in July. Weather parameters like maximum, minimum temperature and sunshine hours exhibited a positive correlation with the natural enemies, while the morning, evening relative humidity and rainfall showed a negative correlation. On correlating the natural enemies with the population of *P. marginatus*, all three coccinellids exhibited a positive correlation, displaying a substantial positive connections with the population of *P. marginatus.*

Key words: Natural enemies, papaya, *Paracoccus marginatus*, population dynamics, weather parameters

Being a tropical fruit tree, Papaya (*Carica papaya* L.), which is known to have originated from America, grows quickly and is quite popular for its fruit, papain, pectin, and antibacterial properties. Papaya ranks third among commercially grown fruit crops in lowland tropical and subtropical areas worldwide. Papayas are long berries with varying diameters, smooth, thin skin, and a greenish-yellow color. They are a year-round climacteric fruit (Nandini *et al.,* 2021). Brazil and India are the world's top producers of papayas, but Mexico is the main exporter. Cultivated papaya trees prove their quick development, reaching maturity 9–12 months after planting. Rich with flavonoids, saponins, papain, and other vitamins, papaya has a variety of medical applications, such as antioxidant qualities and the treatment of cancers like breast cancer and others like colorectal, prostate, and cervical cancer (Jiao *et al.,* 2022). Papaya is also used in the production of cleaning paper and adhesives for clothing and textiles, medications and sewage disposal (Banerjee *et al.,* 2025). Papaya, a super delicious and nutritional fruit belongs to the family Caricaceae and holds crucial economic importance. It is predicted in a forecasting study that the area under cultivation and production of papaya will reach 1538 hectares and 6,384,220 metric tons, respectively, by 2030 (Sharma *et al.,* 2024). However, this prediction may be challenged by multiple biotic and abiotic influences. Among the biotic factors, the papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink (Hemiptera:Pseudococcidae) is a polyphagous pest which is also a major pest of papaya and causes a high level of yield loss. In India, agricultural losses due to papaya mealybug were estimated to be 10-60%, depending on the crop and in some cases even higher (Watson, 2022). Some studies recorded a yield loss of 91% of affected farms in Kenya

(Macharia *et al.,* 2017). The first infestation of papaya mealybug was detected on July 10, 2008 in the campus orchard of Tamil Nadu Agricultural University (TNAU) by Muniappan and his team, during IPM CRSP project network visit. This was the first report of the papaya mealybug in India and South Asia (Muniappan *et al.,* 2008). The infestation of mealybug appears as clusters of cotton like mass on the above ground portion of plants with long waxy filaments. Immature and adult stages of *P. marginatus* sucks the sap of the plant and weaken it. Heavy infestations can render fruit inedible due to the buildup of thick white waxy coating. The leaves become crinkled, yellowish and wither. The honeydew excreted by the bug and the associated black sooty mould formation impair photosynthetic efficiency of the affected plant (Tanwar *et al.,* 2010; Khan and Hossain, 2021). Clearly specify the rationale behind undertaking this study and explain how your research is relevant to papaya cultivation in the current context.

MATERIALS AND METHODS

In order to study the seasonal incidence of papaya mealybug on papaya, the observations were recorded at a weekly interval from August 2023 to July, 2024. The population counts of *P. marginatus* and its natural enemies (predators) were carried out on ten randomly selected Papaya plants infested with mealybugs (Fig.1.). The leaves in the selected papaya trees were tagged (5 leaves per tree) in the Pantnagar region for collecting data. Observations on number of live mealybugs per 5cm^2 leaf area from each tagged leaf were taken with the help of a scale (fig.2). The average number of mealybugs per 5cm^2 leaf areas was worked out (Aditi *et al.,* 2025). In case of natural enemies, complete leaf was considered for counting the adult stage of predator. While the investigation was done, crop was kept unprotected by any control measures. The average mealybugs and natural enemy population per plant was calculated and the correlation and regression were analysed.

Meteorological Observations

The weekly meteorological data related to the abiotic factors *viz*., temperature (maximum and minimum), relative humidity (morning and evening) recorded at 0712 and 1412 hours, sunshine hours and total rainfall (in mm) were obtained throughout the year from the Department of Meteorology, G. B. P. U. A. T., Pantnagar and the monthly averages and correlation coefficients were determined.

Statistical analysis

The data was analyzed for correlation between weather parameters such as minimum and maximum temperature, Morning, evening relative humidity, Sunshine hours and rainfall with insect populations and natural enemies by using SPSS software 16.0.

RESULTS AND DISCUSSION

Seasonal incidence of papaya mealybug with weather parameters

The data on the incidence of *P. marginatus* during 2023-2024 in papaya is reflected in Table 1. The build-up of *P. marginatus* population was observed from 35th SMW 2023 (1.8 mealybugs/5cm^2/leaf/plant). The incidence of papaya mealybug increased gradually and reached its maximum (29.8 mealybugs/5 cm2/leaf/plant) during 42nd SMW. The incidence of *P. marginatus* in 1st SMW, 2024 was initially low (9.6 mealybugs/5cm^2/leaf/plant). The population of the pest was observed to increase steadily during 11th SMW (35.60 mealybugs/5cm^2/leaf/plant) as the maximum, minimum temperature rose to 29°C and 11.3°C, while the rainfall and sunshine hours were observed to be 0.00mm and 9.5hrs. The population continued to increase until it reached on peak in the 21st SMW (147.40 mealybugs/5cm^2/leaf/plant), but it started declining from the 23rd SMW onwards, coinciding with the increase in rainfall. The population was observed to be (0.0 mealybugs/5cm^2/leaf/plant) on 27th SMW as the rainfall was at its peak (331.8mm), and no mealybug activity was recorded till the 31st SMW.

Seasonal incidence of natural enemies with weather parameters

From the observed data in Table 1., it is evident that

Table 1: Seasonal incidence of Papaya mealybug, *Paracoccus marginatus* on papaya during (August, 2023 to July, 2024)

SMW	Date	Weather parameters (Average of last 7 days weather conditions)						Mean population of natural enemies		
		Temperature (^{0}C)		RH (%)		RF (mm)	SH	Number of mealybug	*S. frontalis*	*B. suturalis*	*C. montrouzeiri*
		Max	Min	Mor	Eve			5cm^2/leaf/plant			
32.	06/08/23	32.2	25.7	92.4	76.0	251.2	6	0.0	0.0	0.0	0.0
33.	13/08/23	32.4	26.1	89.7	69.4	11.8	1	0.0	0.0	0.4	0.0
34.	20/08/23	30.6	25.5	91.6	80.1	110.0	5	0.0	0.6	0.0	0.0
35.	27/08/23	34.0	25.6	91.3	62.1	0.0	0	1.8	0.0	0.6	0.4
36.	03/09/23	34.3	25.4	88.4	67.6	42.0	0	0.0	0.0	0.0	0.0
37.	10/09/23	31.0	25.4	91.1	74.6	152.2	2	2.6	0.2	0.6	0.0
38.	17/09/23	32.6	24.6	90.4	69.7	47.4	4	1.4	1.2	1.2	1.6
39.	24/09/23	32.9	23.5	88.6	57.9	60.2	1	0.0	0.0	0.2	0.4
40.	01/10/23	33.6	22.8	88.7	51.7	0.0	0	4.2	0.0	0.4	0.2
41.	08/10/23	33.0	19.3	79.6	46.7	0.0	0	1.4	0.4	1.6	1.2
42.	15/10/23	30.2	16.3	84.1	48.6	7.4	1	29.8	1.6	0.8	0.6
43.	22/10/23	30.9	14.3	88.9	36.9	0.0	0	29.2	1.0	1.2	1.4
44.	29/10/23	30.4	15.2	86.4	40.7	0.0	0	25.8	0.6	1.0	2.2
45.	05/11/23	28.7	13.8	89.6	41.7	0.0	0	20.0	0.8	1.0	0.4
46.	12/11/23	28.5	12.7	87.1	40.7	0.0	0	18.6	1.2	2.0	1.2
47.	19/11/23	27.4	11.3	91.6	42.3	0.0	0	17.8	1.0	1.2	1.6
48.	26/11/23	26.2	13.0	84.7	49.6	0.0	0	20.4	1.0	1.8	1.8
49.	03/12/23	26.5	10.9	85.3	42.4	1.0	0	13.4	0.6	0.6	1.8
50.	10/12/23	22.8	5.9	93.6	47.0	0.0	0	9.8	0.4	0.6	0.2
51.	17/12/23	22.9	6.0	92.0	41.6	0.0	0	4.4	0.4	0.4	1.2
52.	24/12/23	22.0	8.4	93.1	59.3	0.0	0	1.4	0.2	0.0	0.4
1.	01/01/24	17.52	7.9	94.7	69.7	0.0	2.2	9.60	0.0	0.0	0.0
2.	08/01/24	14.1	7.7	93.7	79.4	0.0	0.2	4.00	0.0	0.0	0.0
3.	15/01/24	13.4	6.8	95.7	85.7	0.0	1.2	7.40	0.0	0.0	0.0
4.	22/01/24	13.6	4.6	96.0	77.4	0.0	1.4	7.80	0.0	0.0	0.0
5.	29/01/24	20.3	7.4	94.3	55.7	10.0	3.8	2.80	0.0	0.0	0.0
6.	05/02/24	20.9	6.9	93.6	51.9	1.6	5.8	1.60	0.0	0.0	0.0
7.	12/02/24	25.4	8.0	92.1	38.1	0.0	7.4	4.20	0.0	0.0	0.0
8.	19/02/24	25.4	8.7	86.6	31.3	2.6	7.3	1.60	0.0	0.0	0.0
9.	26/02/24	24.2	10.4	88.5	52.8	60.8	5.3	0.20	0.4	0.0	0.0
10.	05/03/24	24.5	9.3	92.3	44.7	0.0	9.2	5.80	0.0	0.0	0.0
11.	12/03/24	29.0	11.3	87.1	32.6	0.0	9.5	35.60	1.0	0.0	0.0
12.	19/03/24	29.1	12.2	85.7	41.6	0.0	7.9	46.20	2.6	0.0	0.0
13.	26/03/24	33.3	16.9	76.9	40.6	0.0	8.6	31.40	5.6	1.6	3.6
14.	02/04/24	34.5	13.2	71.6	16.1	0.0	9.3	70.40	3.6	2.2	3.8
15.	9/04/24	35.5	16.2	58.4	22.1	0.0	8.3	74.20	4.2	1.8	1.4
16.	16/04/24	37.0	18.7	57.4	18.4	0.0	9.0	101.00	2.8	1.4	1.6
17.	23/04/24	38.4	18.2	61.4	14.1	0.0	10.3	137.20	4.2	1.6	2.2
18.	30/04/24	37.7	17.8	55.1	17.4	0.0	9.6	129.40	7.0	2.2	1.8
19.	7/05/24	35.5	23.1	61.7	40.3	0.8	7.3	84.80	3.8	1.2	2.8
20.	14/05/24	39.9	24.1	52.2	24.7	0.0	9.2	79.20	1.2	2.2	3.4
21.	21/05/24	38.9	27.4	54.7	35.9	0.0	8.9	147.40	1.8	1.8	1.6
22.	28/05/24	41.7	27.9	51.4	30.6	0.0	9.7	141.20	2.8	1.4	1.6
23.	04/06/24	39.5	24.0	56.1	27.1	1.6	9.7	25.80	4.6	1.6	1.4
24.	11/06/24	42.6	26.6	54.1	26.0	0.0	10.6	120.80	6.4	1.6	1.4
25.	18/06/24	39.5	27.8	66.9	44.1	4.4	7.5	21.60	2.8	3.6	1.2
26.	25/06/24	34.1	27.1	80.7	65.0	58.0	2.9	8.80	1.4	2.2	1.6
27.	02/07/24	29.5	25.0	90.9	89.1	331.8	1.4	0.00	0.0	0.0	1.0
28.	9/07/24	33.1	25.1	87.3	67.6	62.0	3.4	0.00	0.0	0.8	0.4
29.	16/07/24	33.9	27.3	85.4	69.0	75.4	6.9	0.00	0.0	0.0	0.0
30.	23/07/24	34.4	22.8	87.3	70.4	58.6	6.0	0.00	0.0	0.0	0.0
31.	30/07/24	32.9	26.3	86.7	74.6	110.0	4.5	0.00	0.0	0.0	0.0

SMM- Standard Meteorological Week, Max. - Maximum, Min. - Minimum, RF- Rainfall, SH-Sunshine, Mor. RH- Morning Relative Humidity, Eve. RH- Evening Relative Humidity

Table 2: Correlation between the population dynamics of *Paracoccus marginatus*, natural enemies and weather factors during 2023-24

Variable	Temp.		RH		RF	SH
	Max.	Min.	Mor.	Eve.		
Paracoccus marginatus	0.568**	0.223	-0.870**	-0.697**	-0.294*	0.631**
Scymnus frontalis	0.573**	0.205	-0.794**	-0.668**	-0.272	0.629**
Brumoides suturalis	0.607**	0.327*	-0.709**	-0.580**	-0.295*	0.289*
Cryptolaemus montrouzeiri	0.491**	0.171	-0.640**	-0.593**	-0.229	0.304*

**Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed).
Max temp= maximum temperature; Min. temp= minimum temperature; RH mor. = Relative Humidity Morning, RH eve. = Relative Humidity evening, RF=Rainfall, SH= Sunshine Hours

Table 3: Correlation between the population dynamics of *Paracoccus marginatus*, and natural enemies during 2023-24

Variable	*Scymnus frontalis*	*Brumoides suturalis*	*Cryptolaemus montrouzeiri*
Paracoccus marginatus	0.76*	0.70*	0.82*

**Correlation is significant at the 0.01 level (2-tailed).

Fig 1: Papaya plants selected for the study

Fig 2: Counting of mealybugs for population dynamics

Fig 3: Heavy infestation of papaya mealybug

Fig 4: Predator *Scymnus frontalis*

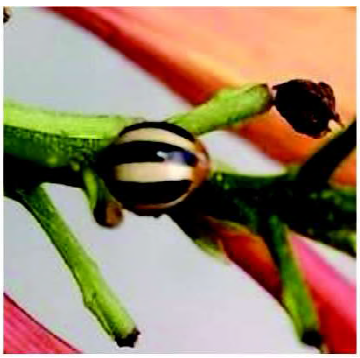

Fig 5: Predator *Brumoides suturalis*

Fig 6: Predator *Cryptolaemus montrouzeiri*

the maximum, minimum temperature and Sunshine hours were beneficial for the development of all three predatory beetles *Scymnus frontalis*, *Brumoides suturalis,* and *Cryptolaemus montrouzeiri*. The peak incidence of *S. frontalis*, *B. suturalis*, and *C. montrouzeiri* with 7.0, 3.6, and 3.8 adults/leaf/plant

population was recorded in the 18th, 25th and 14th SMW, respectively. Thereafter, a gradual decline in the population of all three natural enemies *i. e. S. frontalis*, *B. suturalis, and C. montrouzeiri* from 27th, and 29th SMW, respectively, were noticed.

Seasonal incidence of natural enemies with papaya mealybugs

During the experiment, it was clear that the population of coccinellid predators increased along with the population of their prey, and that the subsequent predator and prey population fluctuations occurred at the same time. The peak period of *S. frontalis* fell in between 13th to 18th SMW, while the population of *B. suturalis* hiked up between 14th to 25th SMW and the peak population of C. *montrouzeiri* was measured in the period between 13th to 20th SMW, precisely corresponded with *P. marginatus*.

Correlation of mealybug population with weather parameters

Data on mealybugs for the year 2023-2024 (Table 2), when analysed against weather parameters, was found to be positively correlated with maximum temperature, minimum temperature, and sunshine hours, exhibiting Pearson's correlation coefficients (r values), r=0.568**, r=0.223, and r=0.631 respectively, all at a significance level of p=0.01. Whereas, the population was significant and negatively correlated with morning RH (r=-0.870) and evening RH (r=-0.697), and rainfall (r=-0.294*).

Correlation of natural enemies with the population of P. marginatus and weather parameters

The coccinellid predators, *Scymnus frontalis*, *Brumoides suturalis*, and *Cryptolaemus montrouzeiri*, are always connected to the population of *P. marginatus*. It is clear from the Table 3 that the populations of all three coccinelids displayed a substantial positive connection with the population of *P. marginatus.* The correlation coefficients for *S. frontalis, B. suturalis*, and *C. montrouzeiri* were found to be significantly positively correlated as r= 0.76*, r=0.70 and r= 0.82 respectively. The data on correlation of natural enemies with weather parameters (Table 2) showed that the occurrence of predator *S. frontalis* was positively correlated with maximum (r=0.573), minimum temperature (r= 0.205), and sunshine hours (r= 0.629) during the year 2023-2024. Morning, evening relative humidity and rainfall showed significantly negative correlation exhibiting Pearson's correlation coefficients (r = 0.794), (r=-0.668), and (r= -0.272), respectively. Another predator, *B. suturalis,* when correlated with weather parameters, showed a significant positive correlation with maximum temperature (r=0.607), minimum temperature (r=0.327) and sunshine hours (r=0.289). Whereas, significantly negative correlations were recorded with morning RH (r=-0.709), evening RH (r=-0.580) and rainfall (r=-0.295). Weather parameters significantly influenced the development of the *C. montrouzeiri* population on papaya and showed significant positive correlation with maximum (r = 0.491), minimum temperature (r =0.171) and sunshine hours (r = 0.304*). On the other hand, the morning relative humidity, evening relative humidity and rainfall showed highly significant negative correlation, (r =-0.640), (r =-0.593) and (r =-0.229), respectively.

The buildup of *P. marginatus* began from 34th SMW 2023 (1.8 mealybugs/5 cm^2/leaf/plant), gradually the population reached to its maximum by the 42nd SMW 2023 (29.8 mealybugs/5 cm^2/leaf/plant) during 42nd SMW and gave a strong significant positive correlation with max., min. temperature, and sunshine hours aligning somewhat with Aditi *et. al.* (2025), who observed the peak activity of *P. marginatus* on papaya (91.5 mealybugs/5 cm^2/leaf/plant) during 40th SMW, also showed significant positive correlation with maximum temperature (r = 0.392) and sunshine hours (r = 0.436). Baidya and Chatterjee (2020) also observed the peak population of papaya mealy bug in between 31st and 35th SMW, respectively with 61.9 and 164.9 number of nymph and adult per 10 cm twig. The continuous increase and sudden decline of pest population is also supported by the reports by Khan and Hossain (2021) who recorded the highest number of papaya mealybugs (128 mealybugs/leaf), during 26th SMW. Similarly, the experimental results by Hazarika and Dutta (2020) revealed

that the first peak population of the mealybugs was recorded on 18-19th SMW with a mean population of 138.00 mealybugs per leaf on papaya.

In case of predators, we observed the peak incidence of all three coccinelids, *S. frontalis*, *B. suturalis*, and *C. montrouzeiri* during 18th, 25th and 14th SMW which were 7.0, 3.6, and 3.8 adults/leaf/plant, respectively. These findings were seen to be in conformity with the results reported by Gurung *et al.* (2018) who observed the highest population of *C. septempunctata* on wheat in 11th SMW (1.72/plant) when temperatures were slightly higher and humidity was lower. In present study, the data on natural enemies was found to be positively correlated with max. temp., min. temp. and sunshine hours during the year 2023-2024. *S. frontalis* was positively correlated with maximum (r= 0.573), minimum temperature (r= 0.205), and sunshine hours (r= 0.629) while morning, evening relative humidity and rainfall showed significantly negative correlation exhibiting Pearson's correlation coefficients (r = -0.794), (r=-0.668), and (r= -0.272), respectively. *B. suturalis* exhibited positive correlation with the maximum temperature (r=607), min. temperature (r=0.327) and sunshine hours (r=0.289), whereas, significantly negative correlations were recorded with morning RH (r=-0.709), evening RH (r=-0.580) and rainfall (r=-0.295). Dhaka and Pareek (2007) revealed a significantly negative correlation of coccinellid beetles with evening RH (r = –0.320) and rainfall (r = –0.390). In present study, the weather parameters significantly influenced the development of the *C. montrouzeiri* population on papaya and showed significant positive correlation with maximum (r = 0.491), minimum temperature (r =0.171) and sunshine hours (r = 0.304) while, the negative correlation was found with morning relative humidity (r =-0.640), evening relative humidity (r =-0.593) and rainfall (r =-0.229) as shown in the Table 2. The present study indicates that the population of coccinellid predators increased in parallel with the population of mealybugs. Similar results were recorded by Singh and Kumar (2012), whose results indicated the average maximum population of Coccinellids at peak when the mealybug population was also at its peak i. e., 120.20 mealybugs/plant. The correlation coefficients were found to be significantly positively correlated with mealybugs for *S. frontalis* (r= 0.76*), *B. suturalis* (r=0.70), and *C. montrouzeiri* (r= 0.82) which partially aligns with Saikia *et al.* (2023), who reported a significant strong positive correlation between coccinellid predators and *P. marginatus*, for *Coccinella septempunctata* (r=0.70) and for *Coccinella transversalis* (r=0.82) and *Micraspis discolour* (r=0.82). Srija *et. al.* (2024) revealed that the population of coccinellids was non-significantly positively correlated with the temperature maximum (r = 0.288), sunshine hours (r = 0.158) and negatively correlated with morning RH (r = -0.023) and evening RH (r = -0.396), these results support the findings of our study. Baidya *et al.* (2020) also observed positive correlation between the population of *C. septempunctata* and maximum temperature (r= 0.057), while negative correlation with morning RH (r= -0.002). A study by Dhaka and Pareek (2007) revealed a significantly negative correlation of coccinellid beetles with evening RH (r= –0.320) and rainfall (r = –0.390). The present studies are in agreement to that of Gaikwad *et al.* (2018) who claimed that in their study, highly significantly positive correlation was noticed with maximum temperature (r=0.280) and sunshine hours (r=0.316), Whereas it correlated non-significantly negative with rainfall (r=-0.112) and morning (r=-0.595) and evening (r=-0.453) relative humidity.

CONCLUSION

The incidence of mealybugs was supported by the increasing temperature and sunshine hours. Before managing any pest, it's important to analyse the correlation between pest occurrence and weather factors, it becomes easier to identify the climatic conditions that affect pest populations. For a non-manageable pest like *P. marginatus*, the study of natural enemies has an impact, as the synchronization of the natural enemies with the pest would help in keeping the pest in control. Farmers can control the pest only when they are aware of the weather factors that help the pest to prevail. Our study will encourage farmers to adopt effective crop management strategies based on the crop's growth stage and prevailing weather factors.

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Received: July 10, 2025
Accepted: July 21, 2025