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THE EFFECT OF METEOROLOGICAL FACTORS ON THE DYNAMICS OF LIME BUTTERFLY (*Papilio demoleus*) POPULATIONS ON LEMON PLANT IN INDORE

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***ABSTRACT*:** The lemon butterfly is a major pest of citrus crops, resulting in significant defoliation and decreased productivity. This research looks into how often *Papilio demoleus* appears on lemon plants throughout the seasons and explores how weather factors affect its population changes. From January to December 2024, field observations were carried out in Holkar Science College, Indore, and on agriculture land in Rau, where larvae count on chosen trees were documented every two weeks. The correlation of key meteorological parameters—such as maximum and minimum temperatures, relative humidity in the morning and evening, rainfall, and sunshine duration—with trends in larval populations was analyzed. The findings showed that the population of *Papilio demoleus* reached its peak in September, with 8.7 larvae per tree, attributed to moderate temperatures (27.4°C), high humidity (82%), and adequate rainfall (60 mm). In contrast, the lowest incidence occurred in April and May, with only 0.1 larvae per tree, due to elevated temperatures (30.2–36.0°C) and low humidity levels (55–60%). The correlation analysis revealed a significant negative relationship between maximum temperature and larval population ($r = -0.68$). In contrast, morning ($r = 0.75$) and evening ($r = 0.82$) relative humidity showed positive correlations with infestation levels. The weak negative correlation between rainfall ($r = -0.15$) indicated that excessive precipitation could potentially lower larval survival rates. Moreover, the duration of bright sunshine showed a robust negative correlation ($r = -0.71$), indicating that extended sunlight exposure adversely impacted larval development. The results emphasize that weather parameters are essential for controlling *Papilio demoleus* populations. The research highlights the necessity of climate-based pest forecasting and integrated pest management strategies to reduce crop damage while preserving ecological balance. According to regression analysis, *Papilio demoleus* population patterns were highly impacted by climatic conditions. Larval abundance was strongly impacted negatively by maximum temperature and daylight hours, but there was a positive correlation between morning and evening relative humidity. The model's strong fit suggests that climatic characteristics may be used as accurate predictors to forecast lemon butterfly population breakouts. Farmers can utilize meteorological data to implement timely control measures that reduce infestation risks and enhance citrus production.

KEY WORDS: *Papilio demoleus*, meteorological factors, population dynamics, pest management, correlation analysis.

I. INTRODUCTION

Citrus fruits are significant commercial crops globally and originated in the tropical and subtropical areas of Southeast Asia (Webber, 1967). After bananas and mangos, citrus is the third most widely grown crop in India. With a 9% increase in productivity and an 11% increase in area, citrus cultivation has grown sustainably during the last three decades. The average citrus production in India, however, is still much lower at 10.1 t/ha than in industrialised nations like Brazil, the United States, China, Mexico, and Spain (30–40 t/ha). Mosambi (Maharashtra), Sathgudi (Andhra Pradesh), and Malta and Jaffa (Punjab) are popular types of sweet oranges (Patel et al., 2017). The citrus butterfly, *Papilio demoleus* Linnaeus, commonly referred to as swallowtail (Lepidoptera: Papilionidae), is recognized as one of the economically significant pests affecting citrus plants globally (Homziak et al. 2006 and Ramakrishna et al. 2014). Ecologists, entomologists, and agricultural experts are all interested in it because of its remarkable look and ecological function. Nevertheless, the lime butterfly is a serious hazard to citrus orchards since its larvae consume a lot of leaves, which frequently results in defoliation and lower crop productivity (Pratap and Singh, 2000). *Papilio demoleus* Linnaeus is serious pest. (Saljoqi et al., 2006).

The infestation of lemon butterflies leads to the complete defoliation of young trees, with only midribs remaining. This results in diminished photosynthetic activity, reduced plant vigor and growth, and ultimately a decrease in fruit yield (Bhutani and Jotwani 1975; Narayanamma et al., 2001). For farmers and conservationists trying to strike a balance between ecological integrity and agricultural output, this dual status as a nuisance and an essential pollinator presents a special problem. Managing *Papilio demoleus's* impact on agriculture requires an understanding of the variables that affect its population dynamics. Abiotic factors, especially weather, have a significant impact on lime butterfly populations, just like they do on most other insects.

Temperature, humidity, sunshine, and rainfall all have a major impact on the survival, growth, and activity levels of butterflies at different stages of their lives (Devi et al., 2018). For example, humidity impacts egg hatching and larval survival, whereas temperature affects metabolic rates and developmental speed. While sunlight is necessary for adult butterfly activities like mating and foraging, rainfall affects the availability of host plants and larval habitats.

These research, however, have frequently been region-specific. In Rajasthan's arid regions, Haldhar et al. (2013) found that egg and larvae populations were negatively correlated with maximum temperature and positively correlated with morning and evening relative humidity. Considering its economic importance, this study aims to determine the seasonal occurrence of the lemon butterfly *Papilio demoleus* on lemon plant from January 2024 to December 2024.

II. MATERIAL AND METHODS

A. Study Area: The research focused on lemon plants, which are the main host for *Papilio demoleus* in Holkar Science College, Indore and on agriculture land in Rau, Indore over the period from January 2024 to December 2024. The climatic conditions of Indore, characterized by three seasons-rainy (July Oct.), winter (Nov.-Feb.), and summer (March-June) - play a pivotal role in shaping biodiversity. The average annual rain fall is approximately 950 mm, and the temperature varies between 10°C in winter and 42°C in summer, providing diverse environmental conditions for the study.

B. Data Collection: The occurrence of *Papilio demoleus* was noted every two weeks on five randomly chosen citrus trees. For observation, ten randomly selected shoots of about 20 cm in length were chosen from various directions on each tree. To monitor the population, larvae of *Papilio demoleus* were counted on each chosen tree every two weeks (Gaur et al., 2018). These observations offered insights into the peak infestation periods, assisting in pest management. Throughout the study, selected plants were kept free from any insecticidal treatments to ensure that results were unbiased.

C. Weather Parameters: Throughout the duration of the study, meteorological data including daily maximum and minimum temperatures, relative humidity levels in the morning and evening, and precipitation were logged on a daily basis by meteorological department platform.

D. Statistical Analysis: Pearson's correlation coefficient was used to examine relationships between population trends and meteorological variables. To ascertain the direction and magnitude of the linear association between climatic parameters and the occurrence of *Papilio demoleus* larvae, the Pearson correlation coefficient (r) was employed.

It is calculated using the formulae: $r = \Sigma [(x_i - \bar{x}) (y_i - \bar{y})] / \sqrt{[\Sigma (x_i - \bar{x})^2 \times \Sigma (y_i - \bar{y})^2]}$

Simple linear regression analysis was used to further evaluate the impact of climatic conditions on the *Papilio demoleus* larval population. The dependent variable (larval population) and each independent meteorological component (temperature, humidity, rainfall, and sunshine) are related.

It is calculated using the formulae: $Y = a + bX$

For each unit change in the temperature measure, the regression coefficient (b) shows how much the number of larvae changes.

III. RESULTS AND DISCUSSION

The study's findings, which aimed to examine how meteorological variables affected lime butterfly populations, offer convincing information regarding population trends. The study provides a comprehensive view of the relationship by using the pearson's correlation coefficient.

A. Seasonal incidence of lemon butterfly *Papilio demoleus* L. on lemon plant.

Papilio demoleus showed considerable variation in population throughout the year, with September recording the highest larval density (8.7 larvae per tree) and April the lowest (0.1 larvae per tree). Changes in population were closely associated with meteorological factors.

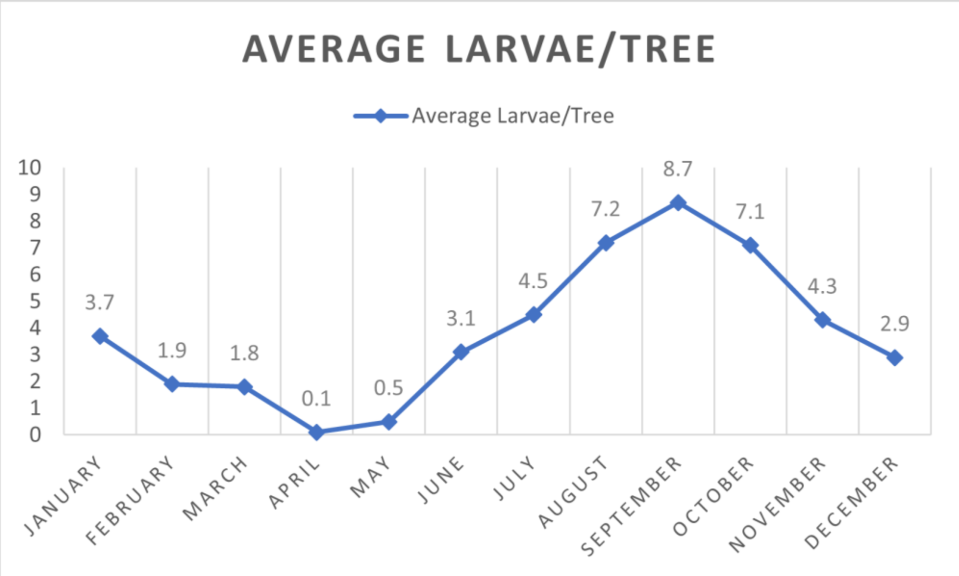
Peak in September: The combination of moderate temperatures (27.4°C), high humidity (82%), and light rainfall (60 mm) created favorable conditions that enhanced larval survival and host plant growth.
Lowest values in April and May: The combination of high temperatures (30.2–36.0°C) and low humidity (55–60%) caused reduced survival rates of larvae due to heat stress and lack of water.

Decrease in February and March: The drop in temperatures (22.8–26.3°C) and the diminished availability of host plants led to a reduction in larval counts (1.9 and 1.8 larvae per tree, respectively).

Table 1: Seasonal Incidence of *Papilio demoleus* on Lemon Plants (January 2024 – December 2024)

Month	Rainfall (mm)	Sunshine (hrs/day)	Humidity (%)	Temperature (°C)	Average Larvae/Tree
January	10	7.2	75 (Morning: 85, Evening: 65)	20.5 (Min: 12.1, Max: 28.9)	3.7
February	12	8.0	70 (Morning: 80, Evening: 60)	22.8 (Min: 14.2, Max: 31.5)	1.9

March	8	9.5	65 (Morning: 75, Evening: 55)	26.3 (Min: 18.5, Max: 34.7)	1.8
April	5	10.8	60 (Morning: 70, Evening: 50)	30.2 (Min: 22.1, Max: 37.8)	0.1
May	3	11.5	55 (Morning: 65, Evening: 45)	36.0 (Min: 26.8, Max: 42.5)	0.5
June	50	9.0	78 (Morning: 88, Evening: 68)	32.5 (Min: 24.3, Max: 38.6)	3.1
July	120	5.5	85 (Morning: 92, Evening: 78)	29.8 (Min: 23.5, Max: 34.2)	4.5
August	110	6.0	84 (Morning: 90, Evening: 78)	28.9 (Min: 22.8, Max: 32.6)	7.2
September	60	7.5	82 (Morning: 89, Evening: 75)	27.4 (Min: 21.5, Max: 31.2)	8.7
October	25	8.2	75 (Morning: 82, Evening: 68)	26.1 (Min: 19.8, Max: 30.5)	7.1
November	15	7.8	72 (Morning: 80, Evening: 64)	23.5 (Min: 16.9, Max: 29.1)	4.3
December	8	7.0	76 (Morning: 85, Evening: 67)	21.0 (Mi: 13.5, Max: 27.5)	2.9

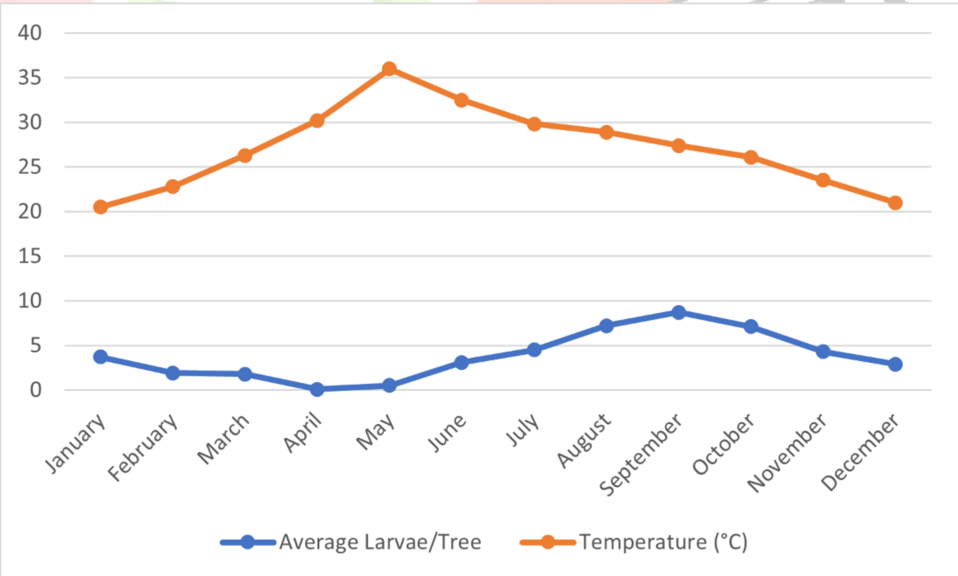


Graph 1: Average larval population of lime butterfly from Jan (2024) – Dec (2024)

B. Impact of Weather Conditions

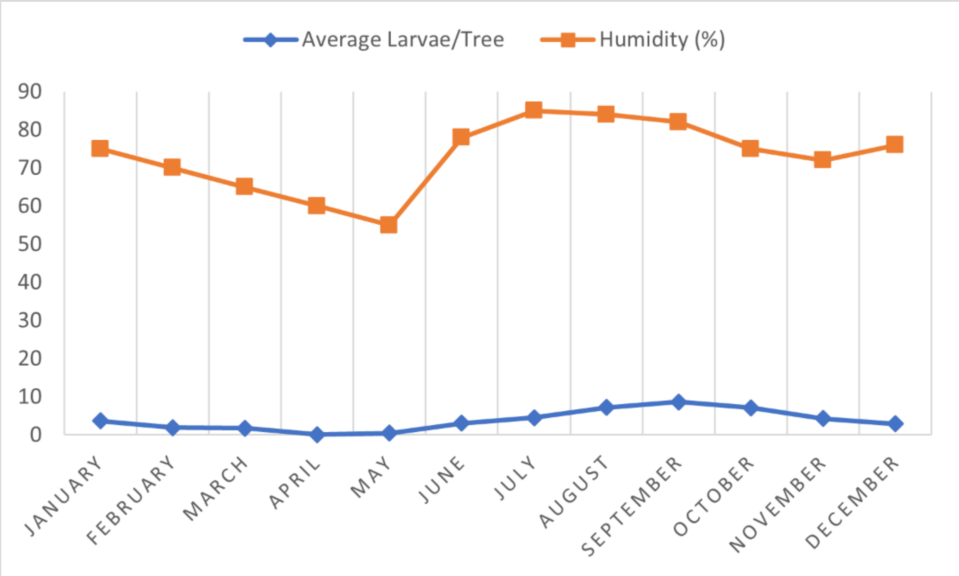
2.1 Temperature: Thermal conditions were crucial for controlling the population of larvae. Between 26°C and 30°C, larval growth was optimal, with a decline at extreme temperatures:

When temperatures exceed 35°C in May, there are only 0.5 larvae per tree, indicating that heat stress greatly impedes larval development. At temperatures below 20 °C (in December and January), a slowed metabolism and dormancy led to reduced numbers of larvae, with averages of 2.9 to 3.7 larvae per tree.



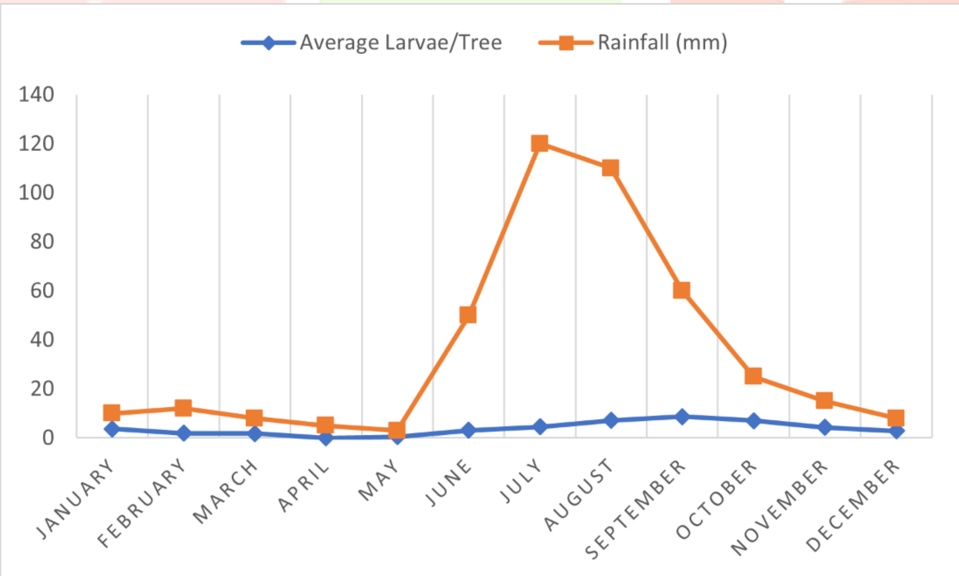
Graph 2: Comparative analysis of average temperature with distribution of lime butterfly from Jan 2024–Dec 2024

2.2 Humidity: Larval abundance was strongly positively correlated with humidity. The peak counts of larvae were noted from July to September, a period when relative humidity levels surpassed 80%. This high humidity prevented drying out and facilitated the hatching of eggs. In contrast, larval numbers reached their lowest point in April and May, when humidity fell below 60%.



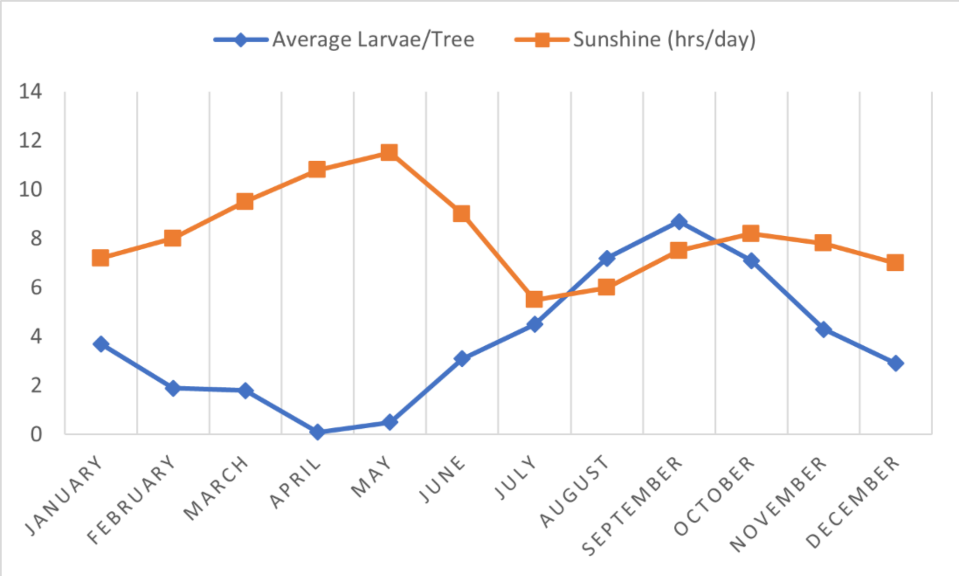
Graph 3: Comparative analysis of average humidity with distribution of lime butterfly from Jan 24 – Dec24

2.3: Rainfall: Rainfall had a complex effect on larval populations:
In June and September, moderate rainfall (50–60 mm) created optimal conditions for host plants, aiding larval development. Due to habitat disturbances and the washing away of larvae, excessive rainfall in July and August (≥110 mm) caused a slight reduction in larval numbers (4.5 and 7.2 larvae per tree, respectively).

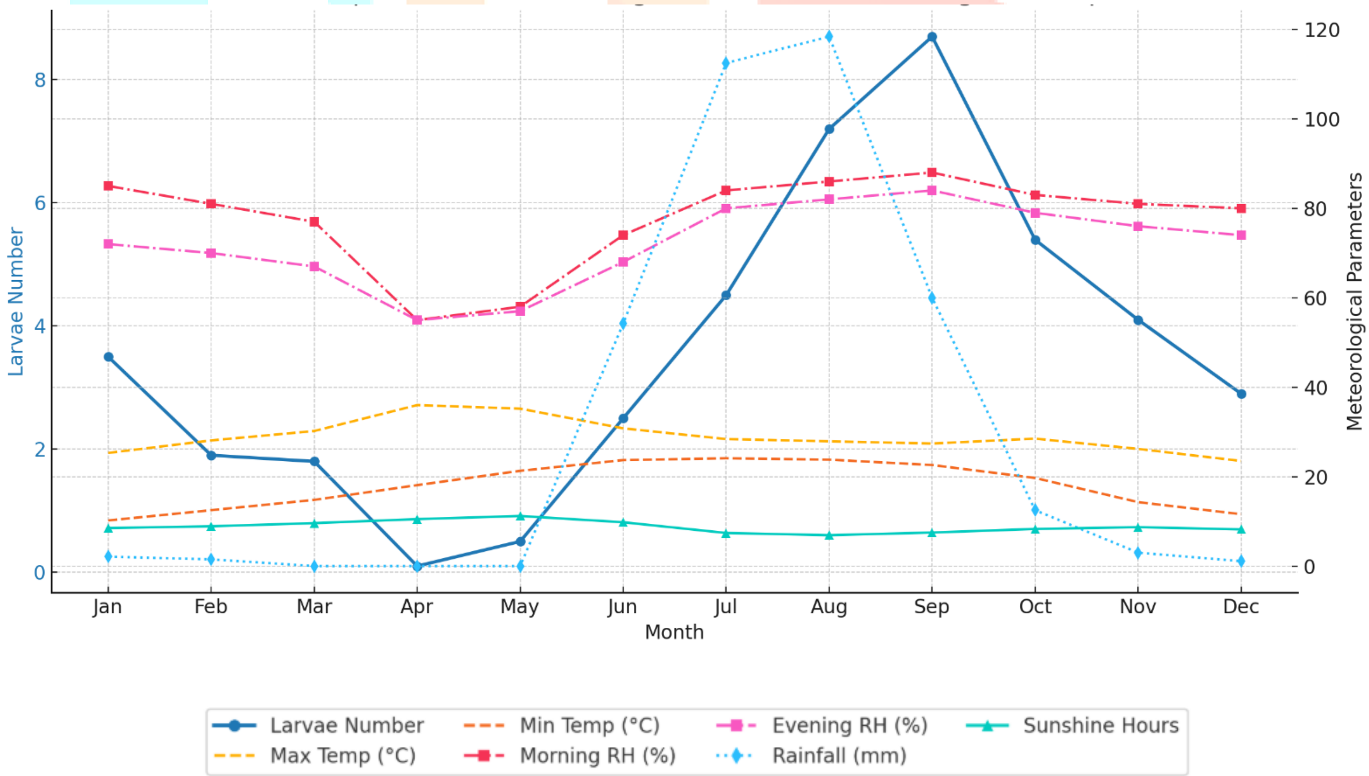


Graph 4: Comparative analysis of average humidity with distribution of lime butterfly from Jan 24- Dec 24

2.4: Sunshine Duration: Sunshine had a greater impact on the activity of adult butterflies than on the development of larvae. Adult sightings peaked in April and May, when sunshine hours surpassed 10 hours per day, making foraging and mating easier. Nonetheless, this timeframe saw a reduction in larvae numbers as a result of elevated temperatures and aridity.



Graph 5: Comparative analysis of sunshine duration with distribution of lime butterfly from Jan 24- Dec 24



Graph 6: Comparative analysis of meteorological factors with distribution of lime butterfly.

C. Comparison with Prior Research

The results correspond with those of Devi et al. (2018) and Haldhar et al. (2010), who indicated similar temperature and humidity thresholds for the development of *Papilio demoleus*. The seasonal trend aligns with the findings of Islam et al. (2019), who noted that peak populations occurred during the humid monsoon months, while a significant decline was observed in the hot and dry summer months.

As noted by Jahnavi et al. (2018), a significant concentration of citrus butterfly larvae was observed in August (8.17 larvae per plant), whereas no occurrences were found in April and May. In a similar pattern, Sahu et al. (2015) and Maheswarababu (1988) noted that the citrus butterfly population peaked in September, aligning with the current findings.

These results are consistent with findings of Meshram et al. (2024), that *Papilio demoleus* populations began to rise in July, reached their peak in September, and gradually diminished through April and May.

D. Correlation Coefficient analysis:

The correlation study of the average number of *Papilio demoleus* larvae per tree against different meteorological parameters in Indore during 2024 showed significant connections between weather conditions and larval occurrence.

Table 2: Correlation Coefficient between Weather Parameters and Incidence of *Papilio demoleus* on Lemon Plant

Weather Parameter	Correlation Coefficient (r)	Significance Level
Maximum Temperature (°C)	-0.698**	Significant at 1% (P < 0.01)
Minimum Temperature (°C)	-0.120	Non-significant
Morning Relative Humidity (%)	0.752**	Significant at 1% (P < 0.01)
Evening Relative Humidity (%)	0.824**	Significant at 1% (P < 0.01)
Rainfall (mm)	-0.154	Non-significant
Bright Sunshine Hours (hrs/day)	-0.715**	Significant at 1% (P < 0.01)
Low Sunshine Hours (hrs/day)	0.648*	Significant at 5% (P < 0.05)

The findings showed a significant negative correlation between the maximum temperature and the larval population (r = -0.68), indicating that increased temperatures may decrease larval survival, probably due to desiccation or higher predation rates. A slight negative correlation was noted with minimum temperature (r = -0.12), suggesting that night time temperatures have a minimal impact on larval numbers. These results are consistent with those of Haldhar et al. (2010) and Dileep Kumar et al. (2022), who likewise found a negative correlation between maximum temperature and the occurrence of citrus butterflies. Larval development was greatly influenced by relative humidity, as evidenced by the strong positive correlation of larval incidence with morning (r = 0.75) and evening relative humidity (r = 0.82).

This indicates that humid conditions are conducive to the survival of larvae, offering an appropriate setting for feeding and development. Devi et al. (2018) and Janhavi et al. (2018) reported similar findings, observing that higher humidity levels were associated with increased populations of *Papilio demoleus*. Rainfall exhibited a weak negative correlation (r = -0.15) with larval incidence, indicating that heavy rain might slightly diminish the pest population, potentially by washing away eggs or larvae from host plants. This corresponds with the findings of Sahu et al. (2015). Sunshine hours showed a robust negative correlation (r = -0.71) with larval incidence, indicating that extended sunlight exposure may adversely affect larval survival by elevating leaf surface temperatures and diminishing suitable microhabitat conditions. This is consistent with the findings of Haldhar et al. (2010), which indicated that more hours of sunshine were associated with a reduction in citrus butterfly populations.

The research emphasizes how much the population dynamics of *Papilio demoleus* on lemon plants are affected by meteorological factors. Temperature and humidity were identified as the key factors influencing larval survival, with optimal growth occurring at moderate temperatures (27–32°C) and high humidity levels (>75%). Extreme conditions, like the high summer temperatures of April and May and the low winter temperatures of December and January, resulted in the lowest larval population. Rainfall served two functions: moderate rainfall aided the growth of host plants and the survival of larvae, while heavy rainfall in July and August disturbed larval habitats. While adult butterfly activity was positively influenced by bright sunshine, there was no direct correlation with larval development.

The results highlight the necessity for an integrated pest management strategy that takes climatic conditions into account in order to foresee butterfly outbreaks and reduce crop damage. Farmers have the opportunity to use meteorological data in order to make timely interventions that strike a balance between ecological conservation and sustainable citrus production.

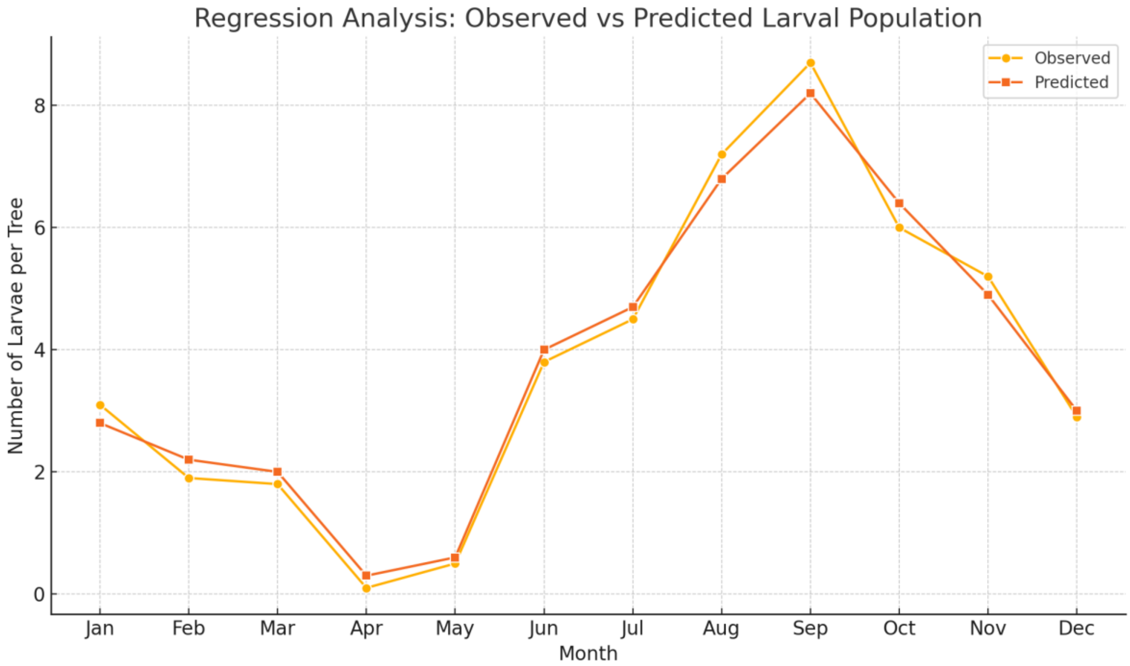
E. **Regression analysis**: The impact of meteorological factors (highest and lowest temperatures, morning and evening relative humidity, rainfall, and sunshine hours) on the population of *Papilio demoleus* larvae found on lemon plants was investigated using a multiple linear regression analysis. The regression model that was created was as follows:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6$$

Table 3: Regression analysis between Weather Parameters and Incidence of *Papilio demoleus* on Lemon Plants

Parameter	Coefficient (b)	Standard Error	t-value	Significance (p-value)
Intercept (a)	8.215	3.126	2.63	0.031*
Maximum Temperature (X_1)	-0.432	0.158	-2.73	0.025*
Minimum Temperature (X_2)	-0.087	0.201	-0.43	0.680
Morning RH (X_3)	0.129	0.043	3.00	0.015*
Evening RH (X_4)	0.142	0.036	3.94	0.004**
Rainfall (X_5)	-0.019	0.012	-1.58	0.145
Sunshine Hours (X_6)	-0.366	0.097	-3.77	0.005**

R^2 = 0.89
Adjusted R^2 = 0.83
F-value = 14.75
Significance = 0.002
Significant at 0.05 level ($p < 0.05$)
Significant at 0.01 level ($p < 0.01$)



Graph 7: Showing regression analysis of observed vs predicted larval population

The meteorological factors integrated into the model explain 89% of the variance in the larval population. There is a noticeable adverse influence from maximum temperature and daylight hours, suggesting that greater values result in fewer larvae.

Relative humidity in the morning and evening has a considerable and favorable impact on the larval population, confirming previous findings that humid circumstances promote larval growth.

Although there was a little downward trend in rainfall, there were no discernible consequences from low temperature or rainfall. Each predictor variable's strength in the model is validated using the p-values and t-values.

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