



Seasonal incidence of mango stem borer, *Batocera rufomaculata* (Coleoptera: Cerambycidae) in north-western Himalayan region of India

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ABSTRACT

The mango stem borer, *Batocera rufomaculata* De Geer (Coleoptera: Cerambycidae) is a serious pest of concern affecting mango (*Mangifera indica* L.) orchards, causing substantial damage to fruit trees. This study was carried out from June 2020–May 2021 at Regional Horticultural and Forestry Research Station, Bhota, Hamirpur, Himachal Pradesh to evaluate the seasonal incidence patterns of *B. rufomaculata* in relation to key abiotic factors such as temperature, rainfall and relative humidity. Infestation was identified based on visible signs such as fresh frass, oozing gum and larval tunnels which revealed that *B. rufomaculata* was active from June to October with peak incidence in July (43.75%). Statistical analysis revealed a significant positive correlation between pest incidence and both maximum temperature ($r = 0.90$) and minimum temperature ($r = 0.96$), highlighting strong influence of temperature on infestation. Rainfall ($r = 0.71$) and relative humidity ($r = 0.70$) also contributed positively, though to a lesser extent. A multiple regression model incorporating these variables explained 96.95% of the variance in infestation levels ($R^2 = 0.96$), confirming the strong predictive power of these abiotic factors. These findings highlight the strong influence of monsoon-associated temperature and moisture on borer activity and provide baseline information useful for forecasting and timely implementation of management strategies against *B. rufomaculata* in mango orchards of the north-western Himalayas, particularly in the era of shifting climatic conditions.

Keywords: Abiotic factors, *Batocera rufomaculata*, Mango, Pest management, Rainfall, Seasonal incidence, Temperature

Mango (*Mangifera indica* L.) also known as ‘King of Fruits’ is an important tropical fruit crop grown worldwide. The significance of this plant can be perceived from the fact that it has been declared as national fruit of India and Philippines as well as national tree of Bangladesh (Usman *et al.* 2001). India with an annual production of 20,772 thousand Mt in the year 2021–2022, accounts for around 40% of global mango production (Balaganesh and Makarabbi 2022). India is also a leading exporter of fresh mangoes to the world with export of 32,104.09 Mt during FY 2024 (APEDA 2024). Mango is infested by various insect-pests among which mango stem borer, *Batocera rufomaculata* (Coleoptera: Cerambycidae) under the subfamily Lamiinae and tribe Batocerini, is a serious pest causing economic injury (Mitra *et al.* 2016).

It has a polyphagous nature and infests a variety of trees including cashew, jackfruit, mulberry, rubber and fig besides mango. Widespread occurrence of mango stem borer *B. rufomaculata* as a primary pest of mango has been reported from all over India (Beeson and Bhatia 1939, Hussain and Khan 1940, Daniel 1991).

The larvae of insect borers remain cryptic within the trunk or stem and feed primarily on subcortical tissues which usually contain phloem, immature xylem and inner bark (Potter and Potter 2008). They build extensive tunnels or galleries which run through the vascular tissue of the host plant. In general, older trees that are more than 15 years old or those that have already been damaged by other factors, whether pathological or environmental, are more susceptible to attack by stem borers (Waite 2002, Kanan and Rao 2006). The female beetle lays her eggs singly on the main stem of mango trees. After hatching from the egg, the neonate larva feeds initially underneath the bark before tunneling through the sapwood which interferes with sap flow and negatively impacting foliage and productivity. Tunnels can be found in the tree's periphery or deep within the trunk. As the grub develops, the size of the tunnel increasingly expands. The harm is not visible in the early stages, although it can be

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seen from the oozing of sticky fluid from many locations on the tree trunk and branches (Reddy *et al.* 2018). If the tree attacked by *B. rufomaculata* is not treated then the plant dries up in two to three years and which may lead to a loss of estimated one lakh rupees (Shivananda *et al.* 2012). Hence, it becomes pertinent to manage this pest to avoid the huge economic losses to farmers.

Information on the seasonal incidence of insect pests is essential for developing effective management strategies including both chemical and non-chemical approaches. Such studies help identify the period of pest initiation, peak activity and decline, which in turn supports timely interventions. Pest incidence is strongly influenced by environmental conditions and favourable weather can trigger outbreaks. Therefore, understanding the behaviour of *B. rufomaculata* in relation to temperature, rainfall and humidity is particularly important for accurate forecasting and the development of region specific Integrated Pest Management (IPM) strategies. Despite the economic importance of this pest, systematic studies examining its incidence and association with abiotic factors are lacking for the north-western Himalayan region.

Therefore, the present study was carried out to document the seasonal incidence of *B. rufomaculata* in mango orchards of Himachal Pradesh and examine its relationship with key weather parameters, using correlation and regression analysis as this region differs fundamentally in terms of altitude, pronounced winter dormancy, large diurnal and seasonal thermal amplitudes and monsoon dominated precipitation, none of which were addressed in earlier low-altitude studies. The findings provide essential basic information to support forecasting efforts and enhance the timing and effectiveness of IPM interventions in mango growing areas of this region.

MATERIALS AND METHODS

Experimental site: This study was carried out from June 2020 to May 2021 at Regional Horticultural and Forestry Research Station, Bhota, Hamirpur (31° 36' 34" N, 76° 32' 54" E; at an elevation of 847 m amsl), Himachal Pradesh. The average annual rainfall is around 1250 mm with maximum concentration during July and August months. Maximum average temperatures of 38–39°C are experienced during June–July and minimum average temperatures fall to 7–9°C during December–January. The site has a subtropical climate dominated by monsoons and falls under Zone-I of agro-climatic zones of Himachal Pradesh. Mango plants of cultivar 'Dashehri' of age group 15–20 years were utilised for conducting this study. To maintain experimental uniformity the orchards with similar management practices were included. The orchards followed standard cultural operations such as irrigation, pruning, fertilisation and orchard sanitation and none had received any chemical or mechanical control measures targeting trunk or stem borers during the study period. The orchards were kept free from application of insecticidal trunk injections, bark pastes or mechanical removal of grubs to prevent interference with natural pest incidence. This ensured that

the recorded infestation patterns reflected natural field conditions rather than management-induced variation.

Data collection: For studying the seasonal incidence of mango stem borer following observations was recorded monthly from June 2020–May 2021. A total of 30 plants in three orchards were observed randomly every month for infestation. The orchards comprised mango trees of the cv. 'Dashehri' within a uniform age range of 15–20 years, ensuring similarity in host-plant susceptibility and tree architecture. Infested plants were identified based on distinct and standardised visual symptoms that reliably indicate active *Batocera rufomaculata* infestation. Since early stages are cryptic, only confirmed and externally visible indicators of larval or adult activity were used. A tree was recorded as infested if one or more of the following symptoms were observed (Ahmed *et al.* 2013); the presence of fresh yellowish brown chewed sawdust or frass accumulated at the base of the trunk; fresh or old larval entry holes on the trunk or main branches, often accompanied by frass extrusion; oozing of red, sticky sap (gum exudation) from active larval entry points; visible emergence/exit holes indicating adult beetle activity; and accumulation of fresh excreta or wood dust around galleries or openings on the bark.

These criteria ensured that only trees with clear, unambiguous signs of active infestation were counted, minimising the risk of misclassification due to the concealed nature of early larval stages. Number of infested plants was counted as per the method of Ahmed *et al.* (2013) on an interval of one month and incidence of infestation (%) was calculated with the help of formula given below:

$$\text{Incidence of infestation (\%)} = \frac{\text{Number of infested trees}}{\text{Total number of trees observed}} \times 100$$

Meteorological parameters such as maximum temperature (°C), minimum temperature (°C), relative humidity (%) and rainfall (mm) were recorded daily during the study and averaged for each month and obtained from weather station installed at RHFRS, Bhota to find out the correlation and regression between % incidence and meteorological parameters.

Statistical analysis: The data was statistically analysed to find out the correlation of pest incidence with abiotic factors using OPSTAT package (Sheron *et al.* 1998). The data were statistically analysed and determination of 'r' values was carried out. To interpret the correlations, the calculated 'r' values were compared to tables. Simple regression and multiple regression equations were also worked out for *B. rufomaculata* incidence with relation to abiotic factors to access the collective impact of major weather factors.

RESULTS AND DISCUSSION

The seasonal incidence of the mango stem borer (*B. rufomaculata*) exhibited distinct fluctuations over the period from June 2020–May 2021 (Table 1, Fig. 1), correlating with variations in weather parameters such as total rainfall, relative humidity and temperature. It is evident from the Table 1 that incidence of borer was higher during

Table 1 Seasonal incidence of mango stem borer (*Batocera rufomaculata*) with relation to different weather parameters

| Month | Total rainfall (mm) | Average relative humidity (%) | Average maximum temperature (°C) | Average minimum temperature (°C) | Per cent incidence (%) |
|----------------|---------------------|-------------------------------|----------------------------------|----------------------------------|------------------------|
| June 2020 | 80.70 | 68.91 | 38.47 | 27.14 | 31.25 |
| July 2020 | 297.60 | 76.32 | 37.50 | 27.24 | 43.75 |
| August 2020 | 452.81 | 83.39 | 30.07 | 23.87 | 37.50 |
| September 2020 | 33.45 | 71.94 | 30.09 | 22.23 | 25.00 |
| October 2020 | 0.12 | 42.65 | 29.04 | 18.24 | 18.75 |
| November 2020 | 40.78 | 44.52 | 22.27 | 11.96 | 0.00 |
| December 2020 | 26.07 | 45.77 | 19.23 | 8.69 | 0.00 |
| January 2021 | 36.03 | 48.93 | 18.22 | 7.73 | 0.00 |
| February 2021 | 19.24 | 45.64 | 22.25 | 10.94 | 6.25 |
| March 2021 | 31.86 | 37.71 | 27.94 | 15.09 | 12.50 |
| April 2021 | 101.27 | 36.09 | 30.09 | 16.56 | 18.75 |
| May 2021 | 98.82 | 39.63 | 33.02 | 20.94 | 25.00 |

the monsoon season. The highest percent incidence was recorded in July 2020 (43.75%), which corresponded to the highest total rainfall of 297.60 mm and elevated relative humidity of 76.32%. The average maximum and minimum temperatures during this month were 37.50°C and 27.24°C, respectively. This indicates that higher rainfall and relative humidity levels were conducive to the stem borer's activity. The months of June and August 2020 also experienced high incidence rates of 31.25% and 37.50%, respectively. June had moderate rainfall (80.70 mm) and higher temperatures (38.47°C maximum and 27.14°C minimum) while August saw increased rainfall (452.81 mm), the highest relative humidity (83.39%), even though the temperatures fell nominally (30.07°C maximum and 23.87°C minimum). These conditions seemed favourable for *B. rufomaculata* proliferation.

There was a decline in incidence of *B. rufomaculata* after monsoon. The incidence began to decrease in September 2020 (25.00%), coinciding with lower rainfall (33.45 mm) and decreased relative humidity (71.94%). The temperatures also dropped, with an average maximum of 30.09°C and a minimum of 22.23°C. A continued decline was noted in October 2020 (18.75%) as rainfall became negligible (0.12 mm) and relative humidity dropped sharply (42.65%). From November 2020 to January 2021, no incidence of *B. rufomaculata* was observed. These months experienced relatively low temperatures (maximum ranging from 18.22°C–22.27°C and minimum from 7.73°C–11.96°C) and low humidity (44.52–48.93%). This suggests that the colder and drier winter conditions were unsuitable for the borer's activity. In February 2021, there was a slight resurgence with a 6.25% incidence, corresponding to moderate rainfall (19.24 mm), a relative humidity of 45.64% and average temperatures (22.25°C maximum and 10.94°C minimum). The incidence increased to 12.50% in March 2021 as temperatures rose (27.94°C maximum and 15.09°C minimum) and humidity decreased to 37.71%. The incidence climbed again in April 2021 and May 2021 reaching 18.75%

and 25.00%, respectively as the temperatures continued to rise (April: 30.09°C max, 16.56°C min; May: 33.02°C max, 20.94°C min) while relative humidity remained low (April: 36.09%; May: 39.63%). Increased rainfall in April (101.27 mm) and May (98.82 mm) likely contributed to the resurgence of borer activity.

The infestation and incidence of the mango stem borer, *Batocera rufomaculata*, exhibit clear seasonal patterns which are strongly influenced by various abiotic factors. Peak infestations are typically recorded during warmer months, particularly in the monsoon season (June to August), when environmental conditions favour the beetle's life cycle. Our studies are in partial corroboration with findings of Jadhav *et al.* (2015) who reported most severe cumulative incidence of *B. rufomaculata* from summer to rainy season (25–76%) and least incidence in winter season. The incidence of mango stem borer has been observed from various states of India with varying intensity depending upon the varieties and climatic conditions. Reddy *et al.* (2015) reported damage levels ranging between 25–50% in the Langra, Alphonso and Jehangir cultivars in India, which aligns with our findings. Similarly, infestation rates of up to 40% in the alphonso cultivar of mango has been observed across Karnataka (Rakshita 2018). In Punjab, Singh and Kaur (2014) observed an of average 10% damage to mango by *B. rufomaculata* while in Tamil Nadu infestation of 0.80–44.97% by *B. rufomaculata* was recorded by Survilvelu *et al.* (1976). The present study indicated that the incidence of *B. rufomaculata* was closely associated with weather conditions. Higher rainfall and relative humidity during the monsoon season and warmer temperatures favoured increased activity whereas colder, drier winter conditions led to a cessation of borer incidence.

B. rufomaculata is capable of causing significant economic damage in mango as well as other crops of economic importance. The seasonal pattern of its incidence on other crops is closely similar to its incidence on mango. Similar to our results, Ahmed *et al.* (2013) found that

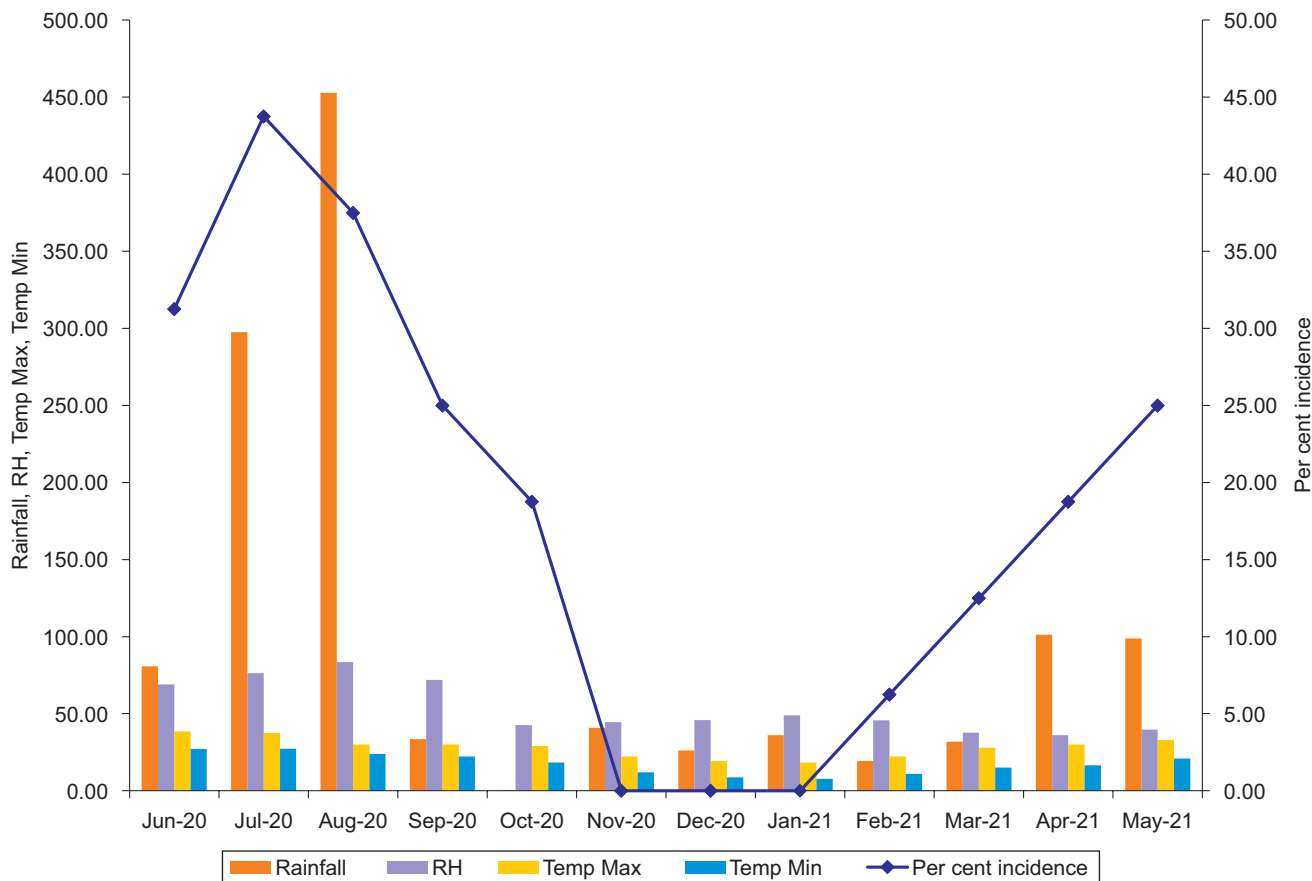


Fig. 1 Graphical representation of seasonal incidence of mango stem borer (*Batocera rufomaculata*) with relation to different weather parameters from June 2020 to May 2021. RH, Relative humidity.

B. rufomaculata exhibited peak infestation in jackfruit plantations in July while the lowest infestation was observed in February with no activity during the colder months of November to January likely due to the insect entering a diapause phase or other forms of dormancy. This aligns with the general observation that many cerambycid borers are less active during colder months as their development slows or halts at low temperatures. In Karnataka, Vasanthi and Raviprasad (2015) observed a pattern similar to our studies, reporting that *B. rufomaculata* reached its highest incidence on cashew plants in August, which coincides with the post-monsoon season. Sudhi-Aromna *et al.* (2008) reported ability of this pest to cause up to 100% damage in durian orchards in Thailand, emphasising the destructive potential of cerambycid borers when conditions are favourable. The presence of adequate moisture coupled with warm temperatures, creates ideal conditions for the emergence of adult beetles and subsequent infestation of host plants. The pest's activity resumed as temperatures rose in the spring with moderate humidity and rainfall supporting the infestation. This seasonal pattern highlights the strong influence of climatic factors on *B. rufomaculata* population dynamics.

Correlation of weather parameters with incidence of B. rufomaculata: The analysis of pest incidence and weather parameters from June 2020 to May 2021 reveals significant

correlations between the % incidence of pests and various climatic factors (Table 2). The strongest correlation was observed with minimum temperature, which showed a highly significant positive correlation ($r = 0.96, p < 0.01$). This suggests that higher minimum temperatures, often associated with warmer nights are a critical factor for pest survival and activity. The consistently elevated minimum temperatures in June and July 2020 (27.14°C and 27.24°C, respectively) coincided with peak pest incidence (31.25% and 43.75%) while the steep drop in minimum temperatures

Table 2 Correlation and multiple regression analysis of weather parameters with mango stem borer incidence

| Weather parameters | Correlation coefficient |
|--|-------------------------|
| Maximum temperature | 0.90** |
| Minimum temperature | 0.96** |
| Rainfall | 0.71** |
| Relative humidity | 0.70** |
| $Y = - 22.34 + 0.55X_1 + 1.22X_2 + 0.03X_3 + 0.008X_4$ | $R^2 = 0.9695$ |

** indicates significant at 1% level of significance. Where X_1 , Maximum temperature; X_2 , Minimum temperature; X_3 , Rainfall; X_4 , Relative humidity; Y, Per cent incidence. Standard error values: X_1 , 0.99; X_2 , 1.15; X_3 , 0.01; X_4 , 0.15.

during the winter months of November 2020 to January 2021 (ranging from 11.96–7.73°C) correlated with a no activity of pests.

Similarly, maximum temperature demonstrated a significant positive correlation with pest incidence ($r = 0.90$, $p < 0.01$). The highest maximum temperatures recorded in June 2020 (38.47°C) and July 2020 (37.50°C) were associated with the highest pest incidences. However, a slight decrease in maximum temperatures during the monsoon period (August 2020: 30.07°C) did not lead to a proportional drop in pest incidence, indicating that other factors such as moisture availability may moderate this relationship.

Rainfall also showed a positive correlation with pest incidence ($r = 0.71$, $p < 0.01$). The peak rainfall during August 2020 (452.81 mm) and July 2020 (297.60 mm) was associated with high pest incidence (37.50% and 43.75%, respectively). Elevated moisture likely creates a conducive environment for pest development, influencing host plant health and providing favourable microhabitats for pests. Conversely, low rainfall in October 2020 (0.12 mm) and November 2020 (40.78 mm) was associated with lower pest activity, indicating that pest outbreaks are more frequent during periods of moderate to high rainfall.

Relative humidity also exhibited a positive correlation with pest incidence ($r = 0.70$, $p < 0.01$). The highest relative humidity values in August 2020 (83.39%) and July 2020 (76.32%) correlated with peak pest incidences. Increased humidity likely prolongs pest longevity and enhances reproductive rates contributing to higher infestation levels. In contrast, low relative humidity during the colder months such as in November 2020 (44.52%) and January 2021 (48.93%), coincided with no pest incidence suggesting that drier conditions inhibit pest survival and reproduction.

Regression analysis of weather parameters on incidence of *B. rufomaculata*: To understand the relationship between various weather parameters and the incidence of *B. rufomaculata*, we applied both simple and multiple regression analysis. Simple regression equation indicated that 81.90, 92.50, 51.60 and 50.10% variability in pest incidence can be explained by maximum temperature (Fig. 2), minimum temperature (Fig. 3), rainfall (Fig. 4) and relative humidity (Supplementary Fig. 1), respectively. This means for every one unit increase in maximum temperature, minimum temperature, rainfall and relative humidity pest incidence increases by approximately 2.05, 2.09, 0.07 and 0.63%, respectively.

To assess the combined effects of each weather parameter, a multiple regression analysis was performed which indicated that the model explains 96.95% variability in pest incidence, demonstrating a strong overall predictive capability (Table 2). The coefficients suggested that minimum temperature had the most significant effect on pest incidence (1.22 ± 1.15) followed by maximum temperature (0.55 ± 0.99), with rainfall (0.03 ± 0.01) and relative humidity (0.008 ± 0.15) contributing less significantly.

The correlation studies establish that the incidence of *B. rufomaculata* is significantly influenced by temperature,

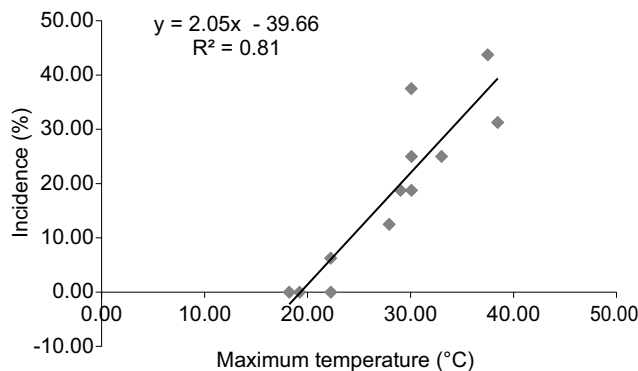


Fig. 2 Linear relationship between seasonal incidence of *Batocera rufomaculata* (%) and average maximum temperature (°C).

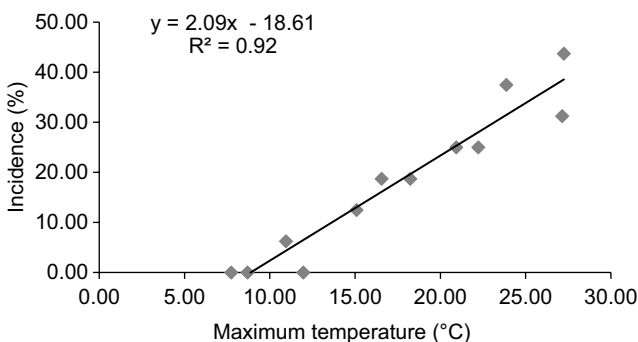


Fig. 3 Linear relationship between seasonal incidence of *B. rufomaculata* (%) and average minimum temperature (°C).

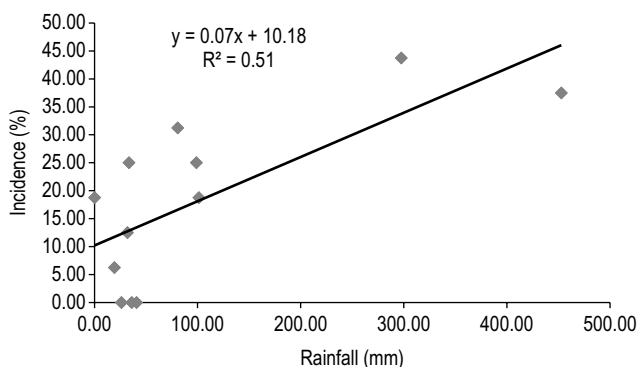


Fig. 4 Linear regression between seasonal incidence of *B. rufomaculata* (%) and total monthly rainfall (mm).

humidity and rainfall. These results are in conformation to Ahmed *et al.* (2013) who observed significant and positive correlation of *B. rufomaculata* infestation with maximum temperature, minimum temperature, average temperature and rainfall. The incidence of many other cerambycids shows a similar pattern with respect to their correlation with weather parameters. Shylesha and Veeresh (1995) demonstrated a significant positive correlation between white borer (*Xyloterchus quadripes*) and minimum temperature, humidity and sunshine hours in coffee plantations, suggesting that these factors provide favourable conditions for the beetles' activity. Reddy *et al.* (2022) further corroborated present finding by showing a positive correlation between both maximum and minimum

temperatures and the emergence of *X. quadripes*, highlighting the critical role of temperature in driving borer activity. Research on cerambycid borers like *Aristobia approximata* supports our findings as Subharani *et al.* (2024) observed significant positive correlations between the infestation of *A. approximata* on *Quercus serrata* and weather parameters, viz. maximum and minimum temperatures and relative humidity. These correlations were particularly strong during years with higher temperatures, underscoring the importance of climatic conditions in influencing borer populations across different regions. Similarly, Red-necked longhorn beetle (*Aromia bungii*) infestations in stone fruits have been shown to positively correlate with tree characteristics and environmental conditions like high temperatures, which enhance beetle activity (Yamamoto and Kaneko 2022, Yamamoto *et al.* 2022).

While every weather parameter positively correlated with pest incidence, minimum temperature emerged as the most influential predictor showing the strongest linear association. This biological pattern aligns with the thermal ecology of cerambycid borers. Larvae of *B. rufomaculata* are wood-boring and rely on continuous metabolic activity to feed and excavate tunnels. At lower night-time temperatures, metabolic processes slow markedly and larvae may enter extended quiescence or diapause (Husain and Khan 1940). Minimum temperatures below 12–14°C inhibit feeding and reduce frass production. This corresponds precisely with the zero-incidence winter months (November–January) observed in the present study, when minimum temperatures dropped to 7–12°C. As temperatures increased above 15°C from February onward, early signs of activity i.e. fresh frass and sap exudation reappeared. Thus, minimum temperature serves as a reliable biological cue controlling larval activity, development rate and population buildup, making it a key driver of seasonal dynamics.

Rainfall and relative humidity also contributed positively to infestation. High moisture levels soften bark tissues, aiding larval penetration and improve survival of both eggs and neonate larvae. Extended monsoon humidity creates ideal microhabitat conditions inside galleries, leading to enhanced larval survival and accelerated growth factors reported for several longhorn beetles (Potter and Potter 2008).

The correlation and regression analysis demonstrates that pest incidence is significantly influenced by weather parameters, particularly temperature and rainfall. The results emphasise the importance of considering climatic conditions in pest management strategies as periods of elevated temperature, humidity and rainfall are likely to trigger pest outbreaks. The multiple regression model serves as a valuable tool for predicting pest outbreaks under varying weather conditions. With input of forecasted weather data into the equation, pest management strategies can be tailored to mitigate risks associated with rising pest populations, especially during warmer months when conditions are more conducive to pest proliferation.

Based on the seasonal incidence patterns observed,

specific monitoring and management interventions can be aligned with high risk periods to improve control of *B. rufomaculata* in mango orchards. Monitoring should begin in February as minimum temperatures rise above 15°C with monthly inspections for fresh frass, sap exudation and early feeding holes. During the high risk months (June–September), monitoring frequency should increase to weekly, especially following rainfall events, which favour larval activity. Management interventions during this period may include mechanical killing of larvae by probing active galleries, removal and destruction of heavily infested branches and the use of recommended trunk injections or insecticidal plugs when larvae are still in accessible early stages. Preventive measures such as maintaining tree vigour, avoiding bark injury and installing light traps to detect adult emergence can further reduce infestation pressure. These recommendations, grounded in the observed seasonal trends provide practical guidance for timely and effective integrated pest management in the region.

The present study documented clear seasonal patterns in the incidence of *B. rufomaculata* in mango orchards of the north-western himalayan region of Himachal Pradesh. Mango stem borer activity was confined primarily to the warm and humid monsoon months with peak incidence in July (43.75%) while no activity occurred during the winter period when temperatures fell below the threshold required for larval development. Among the weather parameters examined, minimum temperature showed the strongest positive association with infestation followed by maximum temperature, rainfall and relative humidity. The multiple regression model demonstrated that these abiotic factors collectively explained most of the variation in monthly pest incidence. These findings provide region specific baseline information on the seasonal behaviour of *B. rufomaculata* and its relationship with key climatic variables. Such insights can support the development of simple, short term forecasting tools and guide the timing of monitoring and management interventions. Although the results suggest that temperature and moisture strongly influence pest activity, the conclusions are based on a small duration dataset and long term studies are required before drawing inferences about broader climatic trends or long term shifts in pest dynamics.

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