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# Effect of weather parameters on population dynamics of pod borer (*Helicoverpa armigera*) of pigeon pea (*Cajanus cajan*) crop in Raipur district of Chhattisgarh

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## Abstract
An investigation was carried out at Department of Agricultural Meteorology, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, to find out the effect of weather parameters on population dynamics of pod borer. With respect to these, correlation analyses were conducted to elucidate the relationships between meteorological factors and the population dynamics of the legume pod borer in pigeon pea crops. The findings indicated a substantial inverse correlation (-0.615) between maximum temperature and the pod borer population was noticed in the 9$^{th}$ standard meteorological week (SMW) of the corresponding week. Conversely, a highly significant positive correlation (0.851) was detected in 37$^{th}$ SMW with a three-week lag. Significant negative correlations (-0.627) and (-0.610) were observed in 49$^{th}$ and 37$^{th}$ SMW of three-week lag. Positive correlations were found between minimum temperature and the pod borer population in 42$^{nd}$ SMW (0.714) of a two-week lag, and with wind speed (0.608) in 38$^{th}$ SMW four-week lag. Whereas, Sunshine hours exhibited significant negative correlations in 48$^{th}$ SMW (-0.804) of a two-week lag.

**Keywords:** Correlation analysis, Pigeonpea pod-borer, population dynamics, weather relationship

## Introduction
Pigeon pea (*Cajanus cajan*), known as tur or arhar dal in India, is a legume with a domestication history exceeding 3500 years (Saxena *et al.*, 2016) [6]. It is agriculturally and economically significant in the Indian subcontinent for its protein-rich seeds, which are a staple in diets and a key protein source in vegetarian meals. Pigeon pea is often intercropped with millet, sorghum, and maize, contributing to farm productivity and resilience against climate variability (Wallis and Byth, 1992; Ariyanayagam and Rao, 1987) [92, 1]. Despite its importance, Pigeon pea suffers from numerous challenges including pests and diseases, the pod borer (*Helicoverpa armigera*) being particularly damaging. This pest attacks during the podding stage, causing yield losses of up to 30% and reducing crop quality and seed viability (Sharma *et al.*, 2017) [2].
This study explored the dynamics of insect pests in relation to weekly meteorological variables, such as maximum and minimum temperatures, rainfall, relative humidity, and sunshine hours, using light trap data. During the study, characterized by significant seasonal variations in temperature and rainfall, researchers employed statistical and computational techniques to examine the correlations between pest population peaks and specific weather patterns. This analysis is vital for refining pest control strategies within integrated pest management programs. It enables the determination of optimal timing for pest interventions based on weather conditions, facilitating the anticipation of insect occurrences and enabling growers to take prompt action for efficient crop management. Keeping in view of above facts the present investigation has been carried out.

## Materials and Methods
The present investigation was conducted at Department of Agriculture Meteorology, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh. Raipur is situated in Eastern Central part of Chhattisgarh at latitude of 21°16’ N, longitudes 81°36’E and altitude 289.5 m above mean sea level and characterized by scorching summers, where temperatures frequently surpass 40 °C

(104°F) in the peak months of April and May. Conversely, winters are relatively gentle, with temperatures hovering around 10-15 °C (50-59°F) from December through February. Long-term weather data (2010-2023) was collected daily from the Department of Agriculture Meteorology, College of Agriculture for Raipur district of Chhattisgarh. And light trap Insect population were collected from Department of Entomology, IGKV, Raipur (C.G.). The dataset includes a comprehensive range of meteorological parameters such as temperature (both maximum and minimum (°C), relative humidity (RH I & RH II (%), rainfall (mm), wind speed (kmph), and sunshine hours.

Correlation coefficients between pod borer light trap catches and each of the weather parameters *viz.*, maximum temperature (T max), minimum temperature (T min), rainfall (mm), morning relative humidity (RH I), evening humidity (RH II), wind speed (WS) and sunshine hours (SSH) of the same year was worked out by taking the dataset in Microsoft Excel spreadsheet and analyzing correlation coefficients by using the data analysis tool. The correlation coefficients so obtained was be considered significance level of 5% and 1%.

Correlation analysis measures the strength and direction of the linear relationship between two variables. The most common method to calculate correlation is the Pearson correlation coefficient (r), given by the formula:

$$r = \frac{n(\sum xy)-(\sum x)(\sum y)}{\sqrt{[n\sum x^2-(\sum x)^2][n\sum y^2-(\sum y)^2]}}$$

Where, n = number of obser
vations

$\sum x$ = Sum of the first variable value

$\sum y$ = Sum of the second variable value

$\sum xy$ = Sum of the product of first and second value

$\sum x^2$ = Sum of the squares of first variable value

$\sum y^2$ = Sum of the squares of second variable value

## Results and Discussion

### Maximum Temperature

The analysis revealed a significant negative correlation (-0.615) between maximum temperature and the population of pod borers in 9th SMW. Conversely, a highly significant positive correlation (0.851) was observed in 37th SMW with a three-week lag. Notably, the 49th SMW showed a significant negative correlation (-0.627), and a highly significant positive correlation was recorded with in 45th SMW of four-week lag. The highest significant negative correlation (-0.735) was observed in 2nd SMW, While, a significant negative correlation (-0.626) was noticed in 48th SMW of a four-week lag (Table 1).

### Minimum Temperature

The study found a significant negative correlation between minimum temperature and pod borer population in 42nd and 44th SMW with a one-week lag. A significant positive correlation (0.714) was observed in 42nd SMW with a two-week lag, and a highly significant positive correlation (0.834) in 37th SMW with a three-week lag. The 44th SMW show a significant positive correlation (0.632) with a three-week lag. A significant Negative correlations were observed in 49th and 3rd SMW with a three-week lag. In four-week lag, a highly significant positive correlation was seen in the 37th and 44th SMW. And a significant negative correlation (-0.651) in 49th SMW (Table 1).

### Rainfall

The analysis of rainfall's impact on the pod borer population revealed various non-significant correlations across different SMWs and lag periods. The highest non-significant positive correlation was observed in the 47th SMW, while the lowest non-significant positive correlation was recorded in the 49th and 52nd SMWs. The highest non-significant negative correlation was found in the 50th SMW, with the lowest non-significant negative correlation in the 40th SMW. These correlations varied across one-week, two-week, three-week, and four-week lag periods, with the significant negative correlation at the 5% level observed only in the 37th SMW with a three-week lag (Table 1).

### Relative Humidity (RH-I)

The analysis indicated a highly significant negative correlation (-0.747) between pod borer population and RH-I in 8th SMW of the corresponding week. Significant negative correlations were also found in the 8th and 50th SMW of one-week lag. The 37th SMW show a significant negative correlation (-0.823) in 37th SMW of three-week lag, and highly significant negative correlations were observed in 37th and 46th SMW of a four-week lag. Significant negative correlations were also noted in 40th and 4th SMW of four-week lag (Table 2).

### Relative Humidity (RH-II)

A significant positive correlation (0.667) was observed between pod borer population and RH-II in 42nd SMW of two-week lag. Conversely, highly significant negative correlations were found in 37th SMW of three-week and four-week lag (Table 2).

### Wind Speed

The analysis shows that the pod borer population of pigeon pea show non-significant correlation across different SMWs and lag periods. The strong non-significant positive correlation was observed in 46th SMW, While the correlation between weather parameter and population was noticed in 44th SMW. The highest non-significant negative correlation was found in the 42nd SMW, Whereas, the week non-significant correlation was noticed lowest in 2nd SMW. Significant positive correlations were noted in 36th and 38th SMWs of four-week lag (Table 2).

### Sunshine Hours

Significant negative correlations were observed between pod borer population and sunshine hours in 48th, 49th, and 51st SMW of the corresponding week lag. While, a significant negative correlation (-0.690) was found in the 42nd SMW of two-week lag and a highly significant negative correlation (-0.804) was observed in 48th SMW of three-week lag. Conversely, strong significant positive correlations were observed in 37th SMW of a three-week and four-week lag (Table 2).

Kumar *et al.* (2016) [3] observed that moderate temperatures are conducive to the growth of the rice leaf folder, a common rice pest. Our findings similarly show that the pod borer population reaches its peak at moderate maximum temperatures between 28 °C and 32 °C, suggesting that this temperature range is ideal for the pest's life cycle, in agreement with Kumar *et al.* (2016) [3]. Tiwari and Singh (2019) [10] noted that heavy rainfall can disrupt pest life cycles, leading to population decreases. Relative humidity also plays a critical role in pest populations. Sharma *et al.* (2018) [7] indicated that high humidity in the morning is associated with increased pest activity, whereas higher afternoon humidity can have a detrimental effect on pest numbers. The significant negative correlation between wind speed and pod borer population suggests that stronger winds can disrupt the pest's ability to thrive, echoing the findings of Singh and Verma (2021) [9]. Gupta *et al.* (2017) [2] reported that some pests favour stable weather conditions with plenty of sunlight for optimal activity. In summary, our study corroborates previous research on the impact of weather parameters on pest populations.

**Table 1:** Correlation coefficient value between pod borer of pigeon pea and maximum & minimum temperature and rainfall in corresponding week, 1st week lag, 2nd week lag, 3rd week lag and 4th week lag (From 40th SMW to 9th SMW)

| Corresponding week | Correlation coefficient | | | 1 Week Lag | Correlation coefficient | | | 2 Week lag | Correlation coefficient | | | 3 Week lag | Correlation coefficient | | | 4 week lag | Correlation coefficient | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $T_{max}$ | $T_{min}$ | Rainfall | | $T_{max}$ | $T_{min}$ | Rainfall | | $T_{max}$ | $T_{min}$ | Rainfall | | $T_{max}$ | $T_{min}$ | Rainfall | | $T_{max}$ | $T_{min}$ | Rainfall |
| 40 | 0.135 | 0.292 | -0.028 | 39 | 0.119 | 0.008 | 0.429 | 38 | 0.010 | 0.359 | -0.062 | 37 | 0.851** | 0.834** | -0.610* | 36 | -0.172 | 0.461 | -0.085 |
| 41 | 0.290 | 0.271 | -0.130 | 40 | 0.403 | 0.583 | -0.312 | 39 | 0.309 | 0.109 | -0.067 | 38 | 0.274 | 0.401 | 0.045 | 37 | 0.851** | 0.911** | -0.282 |
| 42 | 0.109 | -0.249 | 0.022 | 41 | 0.096 | -0.056 | -0.368 | 40 | 0.038 | -0.208 | -0.015 | 39 | -0.068 | -0.011 | 0.030 | 38 | -0.321 | -0.388 | 0.105 |
| 43 | 0.022 | 0.387 | 0.141 | 42 | -0.115 | 0.627* | 0.032 | 41 | 0.349 | 0.323 | -0.190 | 40 | 0.429 | 0.554 | -0.460 | 39 | 0.208 | 0.048 | -0.166 |
| 44 | 0.563 | 0.283 | -0.346 | 43 | 0.189 | 0.313 | -0.054 | 42 | 0.009 | 0.714* | 0.019 | 41 | 0.436 | 0.346 | -0.366 | 40 | 0.463 | 0.642* | -0.379 |
| 45 | 0.179 | -0.064 | -0.111 | 44 | 0.296 | 0.683* | -0.419 | 43 | -0.173 | 0.340 | 0.382 | 42 | -0.041 | 0.397 | -0.086 | 41 | 0.404 | 0.199 | -0.353 |
| 46 | 0.129 | 0.158 | -0.117 | 45 | 0.124 | 0.052 | -0.088 | 44 | 0.247 | 0.584 | -0.451 | 43 | -0.108 | 0.339 | 0.296 | 42 | 0.053 | 0.408 | -0.045 |
| 47 | 0.439 | 0.356 | 0.564 | 46 | 0.133 | 0.079 | -0.211 | 45 | 0.234 | -0.072 | -0.190 | 44 | 0.332 | 0.632* | -0.541 | 43 | -0.117 | 0.299 | 0.369 |
| 48 | -0.201 | 0.183 | 0.374 | 47 | 0.120 | 0.183 | 0.461 | 46 | 0.142 | 0.075 | -0.266 | 45 | 0.210 | 0.213 | -0.479 | 44 | 0.203 | 0.706* | -0.390 |
| 49 | -0.592 | -0.361 | 0.000 | 48 | -0.403 | 0.017 | 0.386 | 47 | 0.180 | 0.040 | 0.464 | 46 | 0.315 | -0.348 | -0.559 | 45 | 0.649* | 0.213 | -0.549 |
| 50 | 0.534 | 0.228 | -0.549 | 49 | -0.579 | -0.521 | 0.000 | 48 | -0.544 | 0.112 | 0.504 | 47 | 0.297 | 0.240 | 0.503 | 46 | 0.309 | -0.342 | -0.457 |
| 51 | -0.298 | 0.221 | 0.451 | 50 | 0.558 | 0.164 | -0.489 | 49 | -0.569 | -0.480 | 0.000 | 48 | -0.578 | -0.051 | 0.190 | 47 | 0.403 | 0.243 | 0.363 |
| 52 | -0.077 | -0.128 | 0.000 | 51 | -0.237 | 0.077 | 0.431 | 50 | 0.555 | -0.217 | -0.601 | 49 | -0.627* | -0.631* | 0.000 | 48 | -0.626* | -0.086 | 0.189 |
| 1 | 0.151 | -0.094 | 0.114 | 52 | 0.010 | -0.061 | 0.000 | 51 | -0.193 | -0.066 | 0.377 | 50 | 0.454 | -0.337 | -0.583 | 49 | -0.584 | -0.651* | 0.000 |
| 2 | 0.434 | 0.455 | 0.145 | 1 | 0.012 | 0.134 | 0.257 | 52 | 0.090 | -0.031 | 0.000 | 51 | -0.017 | 0.164 | 0.167 | 50 | 0.592 | -0.273 | -0.438 |
| 3 | 0.031 | 0.479 | 0.258 | 2 | 0.454 | 0.407 | 0.142 | 1 | 0.116 | 0.117 | 0.309 | 52 | -0.054 | -0.305 | 0.000 | 51 | -0.037 | 0.117 | 0.295 |
| 4 | -0.034 | -0.485 | 0.293 | 3 | -0.027 | -0.361 | 0.129 | 2 | -0.310 | -0.027 | 0.305 | 1 | -0.342 | -0.216 | 0.047 | 52 | -0.276 | -0.171 | 0.000 |
| 5 | -0.162 | -0.162 | 0.118 | 4 | -0.105 | -0.544 | 0.193 | 3 | -0.098 | -0.565 | 0.016 | 2 | -0.566 | -0.264 | 0.001 | 1 | -0.403 | -0.144 | -0.014 |
| 6 | -0.303 | 0.247 | 0.269 | 5 | 0.125 | 0.186 | -0.015 | 4 | -0.024 | -0.400 | -0.024 | 3 | -0.105 | -0.638* | -0.209 | 2 | -0.735** | -0.343 | -0.123 |
| 7 | 0.053 | -0.246 | -0.288 | 6 | -0.144 | 0.244 | 0.149 | 5 | 0.220 | 0.160 | -0.165 | 4 | -0.083 | -0.334 | -0.125 | 3 | -0.187 | -0.582 | -0.219 |
| 8 | 0.329 | 0.420 | -0.144 | 7 | 0.367 | 0.013 | -0.266 | 6 | 0.153 | 0.220 | -0.150 | 5 | 0.276 | 0.074 | -0.244 | 4 | -0.009 | -0.372 | -0.125 |
| 9 | -0.615* | -0.046 | 0.003 | 8 | 0.329 | 0.420 | -0.144 | 7 | 0.367 | 0.013 | -0.266 | 6 | 0.153 | 0.220 | -0.150 | 5 | 0.276 | 0.074 | -0.244 |

* Significant at 5%
** Significant at 1%
$T_{max}$ = Maximum temperature, $T_{min}$= Minimum temperature

**Table 2:** Correlation coefficient value between pod borer of pigeon pea and RH-I&RH-II and Wind speed and Sunshine hours in corresponding week, 1st week lag, 2nd week lag, 3rd week lag and 4th week lag (From 40th SMW to 9th SMW)

| Corresponding week | Correlation coefficient | | | | 1 Week Lag | Correlation coefficient | | | | 2 Week lag | Correlation coefficient | | | | 3 Week lag | Correlation coefficient | | | | 4 week lag | Correlation coefficient | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RH-I | RH-II | WS | SH | | RH-I | RH-II | WS | SH | | RH-I | RH-II | WS | SH | | RH-I | RH-II | WS | SH | | RH-I | RH-II | WS | SH |
| 40 | -0.373 | -0.061 | 0.361 | -0.085 | 39 | 0.216 | 0.195 | -0.202 | -0.203 | 38 | 0.020 | 0.204 | 0.435 | -0.312 | 37 | -0.823** | -0.820** | 0.011 | 0.919** | 36 | -0.576 | 0.379 | 0.606* | -0.260 |
| 41 | 0.117 | 0.118 | -0.111 | -0.414 | 40 | -0.480 | -0.237 | 0.210 | -0.122 | 39 | 0.007 | -0.082 | -0.296 | 0.181 | 38 | 0.254 | 0.095 | 0.105 | -0.208 | 37 | -0.886** | -0.794** | 0.109 | 0.768** |
| 42 | 0.228 | 0.041 | -0.321 | 0.082 | 41 | -0.148 | -0.035 | -0.300 | 0.147 | 40 | -0.245 | -0.022 | 0.414 | 0.228 | 39 | 0.161 | 0.234 | -0.052 | -0.457 | 38 | 0.218 | 0.333 | 0.608* | -0.294 |
| 43 | -0.196 | 0.071 | 0.396 | -0.122 | 42 | -0.160 | 0.667* | 0.542 | -0.728* | 41 | -0.053 | 0.086 | 0.141 | -0.272 | 40 | -0.667* | -0.327 | 0.217 | 0.033 | 39 | 0.027 | 0.014 | -0.128 | 0.099 |
| 44 | -0.140 | -0.287 | 0.089 | -0.413 | 43 | -0.328 | -0.098 | 0.339 | 0.054 | 42 | -0.198 | 0.587 | 0.584 | -0.690* | 41 | -0.012 | 0.070 | 0.102 | -0.321 | 40 | -0.623* | -0.320 | 0.236 | -0.063 |
| 45 | -0.284 | -0.053 | 0.111 | -0.156 | 44 | 0.080 | 0.161 | 0.167 | -0.466 | 43 | -0.136 | 0.226 | 0.514 | -0.315 | 42 | -0.054 | 0.535 | 0.293 | -0.520 | 41 | -0.194 | -0.019 | -0.004 | -0.119 |
| 46 | -0.347 | 0.176 | 0.488 | -0.093 | 45 | -0.323 | 0.063 | 0.329 | -0.211 | 44 | 0.009 | 0.109 | 0.365 | -0.321 | 43 | -0.104 | 0.159 | 0.596 | -0.205 | 42 | -0.231 | 0.419 | 0.271 | -0.395 |
| 47 | 0.307 | 0.277 | 0.429 | 0.070 | 46 | -0.412 | 0.080 | 0.406 | -0.002 | 45 | -0.363 | -0.084 | 0.190 | -0.080 | 44 | -0.006 | 0.090 | 0.222 | -0.458 | 43 | -0.186 | 0.133 | 0.521 | -0.218 |
| 48 | 0.444 | 0.515 | 0.454 | -0.625* | 47 | 0.342 | 0.283 | 0.412 | -0.081 | 46 | -0.317 | 0.079 | 0.360 | 0.001 | 45 | -0.257 | 0.111 | 0.252 | -0.147 | 44 | -0.079 | 0.261 | 0.394 | -0.283 |
| 49 | -0.252 | -0.016 | 0.337 | -0.614* | 48 | 0.404 | 0.316 | 0.388 | -0.683* | 47 | 0.206 | 0.115 | 0.292 | -0.173 | 46 | -0.707* | -0.297 | 0.089 | 0.271 | 45 | -0.571 | -0.125 | 0.046 | 0.184 |
| 50 | -0.404 | -0.124 | -0.091 | -0.194 | 49 | -0.250 | -0.178 | 0.374 | -0.391 | 48 | 0.170 | 0.384 | 0.598 | -0.804** | 47 | 0.100 | 0.227 | 0.472 | -0.303 | 46 | -0.794** | -0.237 | 0.214 | 0.052 |
| 51 | -0.288 | 0.466 | 0.291 | -0.686* | 50 | -0.659* | -0.183 | -0.145 | -0.188 | 49 | -0.066 | -0.165 | 0.164 | -0.386 | 48 | -0.021 | 0.135 | 0.469 | -0.562 | 47 | -0.200 | 0.043 | 0.321 | -0.243 |
| 52 | -0.108 | -0.073 | -0.070 | -0.212 | 51 | -0.165 | 0.336 | 0.275 | -0.552 | 50 | -0.506 | -0.437 | -0.351 | 0.050 | 49 | 0.113 | -0.394 | 0.039 | -0.235 | 48 | -0.360 | 0.061 | 0.435 | -0.475 |
| 1 | 0.195 | 0.047 | -0.239 | -0.335 | 52 | 0.081 | 0.054 | -0.260 | -0.195 | 51 | -0.075 | 0.210 | 0.198 | -0.401 | 50 | -0.325 | -0.487 | -0.382 | 0.142 | 49 | 0.237 | -0.444 | -0.064 | -0.128 |
| 2 | -0.022 | 0.204 | -0.260 | -0.209 | 1 | 0.088 | 0.272 | 0.041 | -0.521 | 52 | -0.038 | -0.005 | -0.091 | -0.341 | 51 | -0.061 | 0.211 | 0.131 | -0.527 | 50 | -0.225 | -0.504 | -0.297 | 0.209 |
| 3 | 0.225 | 0.300 | 0.289 | -0.559 | 2 | -0.068 | 0.104 | -0.219 | -0.145 | 1 | 0.225 | 0.210 | -0.038 | -0.516 | 52 | 0.093 | -0.201 | -0.055 | -0.127 | 51 | -0.161 | 0.154 | 0.115 | -0.502 |
| 4 | -0.058 | -0.107 | 0.150 | 0.207 | 3 | 0.037 | -0.238 | -0.370 | 0.185 | 2 | -0.267 | 0.049 | 0.238 | -0.082 | 1 | -0.286 | 0.008 | 0.352 | -0.122 | 52 | -0.259 | -0.267 | 0.240 | -0.029 |
| 5 | -0.091 | 0.047 | -0.138 | -0.055 | 4 | -0.244 | -0.067 | 0.209 | 0.373 | 3 | 0.029 | -0.313 | -0.386 | 0.391 | 2 | -0.320 | -0.029 | 0.376 | 0.137 | 1 | -0.240 | 0.001 | 0.389 | 0.070 |
| 6 | -0.030 | 0.334 | 0.359 | -0.291 | 5 | -0.115 | 0.152 | -0.161 | 0.027 | 4 | -0.460 | -0.004 | 0.294 | 0.343 | 3 | -0.035 | -0.332 | -0.302 | 0.494 | 2 | -0.372 | -0.090 | 0.584 | 0.159 |
| 7 | 0.239 | -0.258 | -0.095 | 0.346 | 6 | -0.087 | 0.230 | 0.407 | -0.106 | 5 | 0.050 | 0.034 | -0.197 | 0.230 | 4 | -0.520 | 0.007 | 0.334 | 0.396 | 3 | -0.009 | -0.238 | -0.148 | 0.448 |
| 8 | -0.747** | -0.125 | 0.323 | 0.192 | 7 | 0.010 | -0.272 | -0.065 | 0.417 | 6 | -0.262 | -0.009 | 0.207 | 0.166 | 5 | 0.198 | -0.119 | -0.344 | 0.323 | 4 | -0.681* | -0.159 | 0.254 | 0.541 |
| 9 | 0.211 | 0.451 | 0.091 | -0.447 | 8 | -0.747** | -0.125 | 0.323 | 0.192 | 7 | 0.010 | -0.272 | -0.065 | 0.417 | 6 | -0.262 | -0.009 | 0.207 | 0.166 | 5 | 0.198 | -0.119 | -0.344 | 0.323 |

* Significant at 5%
** Significant at 1%
RH-I= Relative humidity I, RH-II= Relative humidity II, WS= Wind speed, SH= Sunshine hours

## Conclusion

The study concludes that weather parameters significantly influence the pod borer's population dynamics in pigeon pea. Sunshine hours and wind speed positively correlate with population of pod borer, indicating favourable conditions for the pest's life cycle. In contrast, relative humidity and rainfall negatively correlate with pest population, especially during early life stages. These insights are crucial for developing targeted pest management strategies, enabling farmers to anticipate and reduce pest outbreaks, thereby promoting sustainable and productive agriculture.

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