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# Seasonal Insect Pest Incidence and Its Impact on Mustard Health and Yield in Kaithal District, Haryana

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## Abstract

*The majority of Haryana's mustard (Brassica juncea L. Czern & Coss.) acres are located in the Kaithal district, making it the state's most important rabi oilseed crop. But a complex of insect pests that colonize the crop from seedling to pod-maturation stage continues to limit productivity. Researchers in this study tracked the rabi seasons (2023–24 and 2024–25) in farmers' fields and a research farm that reflected the agro-climatic conditions of the Kaithal district in Haryana. Their goals were to record the occurrence of the mustard insect pest complex throughout the year, determine the relationship between the accumulation of pest populations and the abiotic factors that were prevalent, and finally, to measure the effects on plant health and seed yield that resulted from this. On a weekly basis, researchers have noticed a succession of pests, the most common of which are mustard aphids, mustard sawflies, painted bugs, leaf miners, cabbage butterflies, mustard leaf webbers, and mustard linnaeus beetles. The first sawfly larvae emerged in the first two or three standard meteorological weeks (SMW), reaching their peak in the third and fourth SMW at the seedling-rosette stage. In contrast, aphid populations began to rapidly increase beginning in the fourth SMW and reached their peak infestation in the sixth to eighth SMW, which coincided with the transition from flowering to pod formation, minimum temperatures of 8 to 14°C, and morning relative humidity of more than 80%. According to multiple regression analysis, aphid population variability was most explained by the combination of minimum temperature and morning relative humidity, with rainfall and wind velocity having a strong negative effect. When comparing protected and unprotected plots, a correlation analysis of pest indices with plant health metrics revealed that the latter had significantly lower levels of chlorophyll content, leaf area index, and pod-bearing capacity. Based on data from paired protected-unprotected plots, the percentage of grain output lost due to the pest complex varied between 26 and 34% over the course of the two seasons, with the biggest contributor being aphid infestation. The proposed practical action point for the district is an economic threshold level of around 10-12 aphids per 10 cm shoot length during the pre-flowering period. The results highlight the importance of a weather-based integrated pest control and location-specific forecasting module for mustard farming in the Kaithal district and other comparable agro-climatic zones of the Trans-Gangetic Plains.*

**Keywords Mustard, Brassica juncea, Lipaphis erysimi, Athalia lugens proxima, Bagrada hilaris, seasonal incidence, integrated pest management**

## 1. INTRODUCTION

India's second-largest source of edible oil is rapeseed mustard, which is the country's most important winter oilseed crop (Brassica juncea L. Czern & Coss.). In Haryana, mustard is one of the most important rabi oilseeds. It is widely grown in the semi-arid and sub-humid regions of the state, including the Kaithal district. In both irrigated and rainfed settings, mustard is grown singly and in combination with wheat and gram. As a result of biotic constraints, such as insect pest infestation, mustard's actual production in the area falls short of its genetic potential, even tho disease-tolerant and high-yielding varieties are available.

Of the forty or so bug species known to attack Brassica crops in India, only a fraction of those actually do economically substantial damage across all agroclimatic tracts. Mustard aphids, scientifically known as Lipaphis erysimi (Kaltenbach), are widely considered the most destructive pests in the Trans-Gangetic Plains region, which includes the Kaithal district. Left unchecked, they can reduce crop yields by as much as 60–90% in fields that are particularly hard hit. While crops are still immature and susceptible to harm, the mustard sawfly (Athalia lugens proxima, Klug) defoliates young plants voraciously, sometimes requiring resowing.

Bagrada hilaris, more often known as Burmeister, is a painted beetle that targets crops from seedlings all the way up to pod maturity. It does this by slicing thru tissue and draining sap, which causes the terminal shoots to wilt and dry up. Pests such as the mustard leaf miner (Phytomyza horticola, Gourie) and the cabbage butterfly (Pieris brassicae, Linnaeus) and the mustard leaf webber (Crocidiolomia binotalis, Zeller) are minor yet significant in their particular areas.

Sowing date, cultivar, and crop phenology are among the many environmental factors that significantly impact the population dynamics of this pest complex. Other important meteorological parameters include minimum and maximum temperatures, relative humidity, rainfall, and wind speed. Since these factors differ across agroclimatic tracts, it is not possible to directly apply pest incidence data from one place to another. Therefore, in order to create accurate pest forecasting models and reasonable, need-based management plans, it is necessary to conduct location-specific seasonal incidence studies. There is a lack of published information related to the Kaithal district of Haryana, even tho the mustard pest complex has been documented from other Indian states. Consequently, the following goals motivated the current investigation:

(i) to catalog the mustard-related insect pest complex in the Kaithal district;

(ii) to analyze the major pests' seasonal occurrence and population dynamics in connection to crop phenology and standard meteorological weeks;

(iii) to link changes in pest populations to abiotic (weather) variables; and

(iv) to determine the complex's effect on plant physiological health and final seed yield in order to establish a preliminary economic threshold level for the district.

## 2. REVIEW OF LITERATURE

### 2.1 Pest complex and their status

In their *1989 study, Bakhetia and Sekhon* examined the rapeseed and mustard insect-pest complex in the context of India's unique agroclimate. Researchers set out to catalog economically significant insect pests and rank them according to how crucial they are at various points in a crop's life cycle. To investigate the prevalence of pests, researchers drew on both experimental data and data collected in the field. Some of the most significant pests of rapeseed-mustard include mustard aphids, mustard sawflies, painted bugs, and cabbage caterpillars (1992). Depending on the crop stage, the season, and the geographical conditions, the study found that mustard supported a complex of insect pests, the relative importance of which changed.

In rapeseed-mustard farming in northern India, *Singh and Sachan (1994)* examined the pest status of the mustard aphid, Lipaphis erysimi. Finding out how significant an aphid infestation is for crop growth and yield was the main goal. At various points in the life cycle of the crops studied, researchers observed naturally occurring aphid populations and documented infestations. The results showed that mustard aphids, when numbers were high throughout the flowering and pod-development stages, were one of the most damaging sucking pests to the crop. Since severe infestations could negatively impact plant development and seed production, the researchers determined that mustard aphid required regular observation.

In their *2010 study, Sharma and Singh* identified the most common insect pests in India's rapeseed mustard crop. Finding major pest species and determining their relative economic importance was the goal of the study. To define the pest complex, researchers drew on data collected from both in-field observations and prior experimental studies. Important parts of the mustard agroecosystem include mustard aphids, mustard sawflies, painted bugs, and other sucking and defoliating pests. The study found that L. erysimi was still one of the most significant commercial pests of mustard, and that the pest complex altered depending on the crop stage and climatic conditions.

Under the conditions of *Punjab, Kular and Kumar (2017)* studied the effects of insect pests on various species of the oilseed Brassica over an extended period of time. The goal was to find out which Brassica crops were more vulnerable to the most common insect pests and how that affected their yields. Over the course of six growing seasons, researchers monitored insect populations weekly and compared protected and unprotected plots. The numbers of mustard aphids and cabbage caterpillars varied greatly between Brassica species. Pest populations were much lower in some species and genotypes than in others. The study found that insect numbers and crop losses were significantly affected by host-plant characteristics.

**2.2 Seasonal Incidence and Population Dynamics**

Based on their observations in North India, *Singh and Malik (1998)* sought to understand the mustard aphid population dynamics throughout the year. The purpose of the study was to track the life cycle of L. erysimi, from initial invasion to population peak and subsequent decline. Over the course of the Rabi season, we tracked the populations of aphids on a few different mustard plants and correlated them to the weather. Aphid populations were low at the start of the crop period, spiked when conditions were good, and then fell as temperatures dropped and crops matured. There was a clear seasonal trend to the mustard aphid population, according to the study, and finding out when to expect an invasion required consistent field monitoring.

The relationship between mustard aphid incidence and climatic variables was investigated by *Vekaria and Patel (2000).* We set out to determine whether and how climatic factors like temperature and relative humidity affected the maturation of aphid populations. The mustard-growing season was observed in the field at regular intervals, and the number of pests was compared to meteorological records. During optimal temperature and humidity conditions, the study found that aphid numbers fluctuated significantly over time. The researchers came to the conclusion that the timing and severity of mustard aphid infection were significantly impacted by weather conditions.

In *2014, Rao et al. created* weather-based warning models after studying mustard aphid infestations in several parts of northern India. We analyzed experimental data from six sites in North India to find out how weather affected the spread and emergence of L. erysimi. It became clear that temperature was a key regulator of aphid emergence and population growth. While aphids tend to emerge within a specific range of cumulative thermal-time, populations tend to peak earlier in warmer and more humid climates. This study found that mustard aphid forecasting systems could benefit from using meteorological and historical pest-population data.

The effectiveness of several management methods for mustard was studied by *Roy, Sarkar, and Sarkar (2018),* as was the seasonal incidence of Lipaphis erysimi. The 2013–14 and 2014–15 harvest seasons in West Bengal were the times when field observations were carried out. Midway thru December saw the beginning of the aphid population boom, which peaked after the middle of January. The amount of rainfall and highest temperature were negatively correlated with the accumulation of aphid populations, while the minimum temperature, relative humidity, and dew point were positively correlated. According to the research, the amount of mustard aphids varied greatly throughout the year and was highly correlated with the weather.

**2.3 Yield Loss Estimation**

In the Tarai region of India, *Singh and Sachan (1994)* measured mustard aphid-induced rapeseed production losses. The goal was to measure how crop development and seed output were affected by varying degrees and lengths of aphid infestation. Plant metrics including height, number of siliquae, major branches, seed yield, and 1000-seed weight were measured under both naturally occurring and intentionally induced aphid infestations. Aphid exposure, both in terms of time and intensity, had a negative impact on various yield-related traits and ultimate seed creation. According to the research, rapeseed-mustard crops could suffer significant economic losses if aphid infestations occur early or last for a long time.

Under field circumstances in India, *Singh and Premchand (1995)* investigated the correlation between mustard aphid infestation and crop yield. We set out to measure how various insect population levels affected yield and key yield-contributing variables. During the reproductive stages, researchers tracked aphid populations and examined the effects of different infestation intensities on crop performance. There was a negative correlation between the density of aphids and seed weight, siliqua development, and overall crop production. The researchers came to the conclusion that the density of mustard aphids was a major factor in the decrease of production and that control methods were necessary to prevent populations from reaching harmful levels.

For various varieties of oilseed Brassica, *Kular and Kumar (2017)* measured the preventable yield losses caused by insect pests. Punjab Agricultural University ran a field trial with both protected and unprotected treatments for six years. At harvest, we calculated the seed yield, and weekly we checked the pest numbers. Permissible yield losses caused by mustard aphids and cabbage caterpillars ranged from 6.5% to 26.4% across different Brassica species. The study found that the amount of yield lost was determined by factors such as host susceptibility and the severity of the pest population.

In their *2019 study, Sharma, Yadav, and Yadav* examined the potential preventable yield losses caused by Lipaphis erysimi in various Brassica species grown in Haryana. This experiment compared aphid infestation and crop production in the field during the 2015–2016 Rabi season in Rohtak, Haryana. The quantity of aphids and the yield decrease that accompanied them varied considerably among Brassica species. Protecting mustard crops from mustard aphids, according to the research, can drastically cut down on needless crop losses. The study's authors came to the conclusion that vulnerable Brassica crop production potential could be better protected with prompt L. erysimi management.

In the Rewari District of Haryana, *Kumar, Singh, and Yadav (2022)* looked at the preventable yield losses in mustard (Brassica juncea) caused by mustard aphids. The impact of aphid infestation on various yield parameters was investigated in field tests conducted throughout the 2019–20 and 2020–21 Rabi seasons. Protection from aphids improved crop performance compared to that of crops infested with the pests, which had a negative impact on key yield-contributing traits and final seed production. The research found that L. erysimi was a major problem for mustard yields in Haryana and that controlling the pests would save a lot of money.

**Natural Enemies and Management**

In their *2013* study, Singh and Singh looked at rapeseed-mustard agroecosystems to investigate if there were any natural adversaries of mustard aphids. The goal was to record key parasitoids and predators of *L. erysimi* and evaluate their possible role in natural pest control. While aphids were active, mustard fields were under constant surveillance. In general, the abundance of predatory coccinellids, syrphid flies, lacewings, and parasitoids rose as aphid populations grew. The study found that natural enemies were a crucial part of mustard agroecosystems and that integrated pest management programs should work to protect them.

To combat the mustard aphid, Lipaphis erysimi, in Indian mustard, *Naga, Rana, Naga, and Lal (2022)* assessed various Integrated Pest Management (IPM) modules. We examined ten different integrated pest management (IPM) modules in the field to see how they affected aphid populations, crop productivity, and financial returns. The various management treatments showed notable variations. Although thiamethoxam and imidacloprid both worked well, the treatment that included two applications of the pesticide resulted in the highest decrease of aphid populations, as well as comparatively high seed production and economic returns. Methodical, need-based pest-management programs could significantly lower mustard aphid numbers and safeguard mustard yields, according to the study.

## 3. MATERIALS AND METHODS

**Study area:** The research took place in the Kaithal district of Haryana, which is in the Trans-Gangetic Plains agro-climatic zone and has a semi-arid, subtropical climate with hot and dry summers, a rainy season caused by the monsoon, and cold winters with mean minimum temperatures dropping to 4-8°C in January. The exact coordinates of the district are approximately 29.8°N, 76.4°E, and the average elevation is about 245 m above sea level. At the Zoology (Entomology) Research Farm and in four randomly chosen farmer's fields spread out over two blocks of the district, we used fixed-plot surveys to get a feel for the local mustard belt's normal planting window, irrigation schedule, and variety mix.

**Crop and experimental layout:** In order to record the incidence of natural pests, the widely-grown variety RH 725 was sown in the observation plots during the last week of October in both the 2023-24 and 2024-25 study years according to recommended agronomic practices for row spacing, fertilizer dose, and irrigation. So that we could compare the two settings side by side in terms of plant health and yield characteristics, we kept an adjacent protected plot at each site that received insecticides according to a need-based timetable.

**Sampling Method:** We started keeping track of things when the seedlings first emerged and kept going every week until the crop was complete. Early in the morning, we counted the larvae, nymphs, and adults of four different species—sawfly, painted bug, leaf miner, and cabbage butterfly—from ten plants marked at random within each plot. Following the usual 10-cm shoot-count approach commonly used in aphid incidence research, the aphid population was recorded as the total number of aphids (all instars) on a 10-cm central shoot/twig of the identical tagged plants. Each standard meteorological week (SMW) had its total counts averaged out to either per plant or per 10-cm shoot.

**Weather data:** From the closest agro-meteorological observatory, we retrieved daily meteorological data including high and low temperatures, relative humidity in the morning and evening, rainfall, and wind speed. We then collected this data on an SMW basis to match the intervals for pest counts.

**Plant health and yield parameters:** Tagging plants in both protected and unprotected plots allowed for the recording of physiologically appropriate crop stages data, including leaf chlorophyll content (SPAD units), plant height, number of siliquae (pods) per plant, and 1000-seed weight. At harvest, we recorded the final seed yield on a whole-plot basis and represented it as quintals per hectare (q/ha). To find the percentage of avoidable yield loss, the formula was: Loss (%) = [(Yield in protected plot − Yield in unprotected plot) / Yield in protected plot] × 100.

**Statistical analysis:** For this study, we first calculated simple correlation coefficients between pest population indices and each weather parameter. Then, we used stepwise multiple linear regression to see how much each weather variable contributed to the fluctuation in the aphid population. Utilizing industry-standard statistical software, we compared data on plant-health and yield parameters between protected and unprotected plots using Student's t-test. We compared treatment/seasonal means for pest incidence using analysis of variance (ANOVA) followed by Duncan's Multiple Range Test (DMRT) at the 5% level of significance.

## 4. RESULTS AND DISCUSSION

### 4.1 Insect pest complex recorded

Insects from six different species were found throughout the inquiry as pests of the mustard crop. From this group, A. lugens proxima, B. hilaris, P. horticola, and L. erysimi were classified as major/regular pests according to their infestation levels and frequency of occurrence, whereas C. binotalis and P. brassicae were classified as minor pests due to their infrequent occurrences (Table 1).

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**Table 1. Insect pest complex recorded on mustard in Kaithal district (pooled data, 2023–24 and 2024–25)**

| Sl. No. | Common name | Scientific name | Order : Family | Status | Damaging stage/part |
|---|---|---|---|---|---|
| 1 | Mustard aphid | Lipaphis erysimi (Kalt.) | Hemiptera: Aphididae | Major (key pest) | Nymph & adult; shoot, inflorescence, pods |
| 2 | Mustard sawfly | Athalia lugens proxima (Klug) | Hymenoptera: Tenthredinidae | Major | Larva; leaves (seedling stage) |
| 3 | Painted bug | Bagrada hilaris (Burm.) | Hemiptera: Pentatomidae | Major | Nymph & adult; leaves, terminal shoot |
| 4 | Leaf miner | Phytomyza horticola (Goureau) | Diptera: Agromyzidae | Major | Larva; leaf mesophyll |
| 5 | Cabbage butterfly | Pieris brassicae (L.) | Lepidoptera: Pieridae | Minor | Larva; leaves |
| 6 | Mustard leaf webber | Crocidolomia binotalis (Zell.) | Lepidoptera: Crambidae | Minor | Larva; leaves, inflorescence |

## 4.2 Seasonal incidence

During the 44th SMW (last week of October), just after seedling emergence, sawfly larvae made their initial appearance on the crop. By the 46th and 47th SMW, at the rosette stage, their incidence peaked at 1.2-1.4 larvae/plant, and then it dropped dramatically as the plants expanded out of the vulnerable period. Painted bug adults and nymphs had a bimodal pattern. During the seedling stage (46th-47th SMW), there was a slight surge, and then, during the 5th-6th SMW, which coincided with the commencement of flowers, there was a more significant peak with 3.1-3.6 bugs/plant. Despite staying relatively low throughout, the incidence of leaf miner did rise gradually from the 48th SMW to a high around the 4th SMW. Based on the data presented in Table 2 and Figure 1, the mustard aphid, which is considered a key pest, began to accumulate slowly during the first seven stages of flowering (SMW), then increased exponentially from the third SMW onward. By the seventh SMW, which corresponds to the mid-flowering to early pod-formation stage, the infestation had reached its peak (357.4 aphids/10 cm shoot, pooled mean). Subsequently, it declined as temperatures rose and pod walls hardened (from the 9th SMW onward).

**Table 2. Mean seasonal incidence (pooled, 2023–24 and 2024–25) of major insect pests of mustard in relation to standard meteorological week (SMW) and crop stage**

| SMW | Crop stage | Sawfly (larvae/plant) | Painted bug (no./plant) | Aphid (no./10 cm shoot) | Leaf miner (mines/plant) |
|---|---|---|---|---|---|
| 44 | Seedling | 0.3 | 0.4 | 0.0 | 0.0 |
| 45 | Seedling | 0.8 | 0.9 | 0.0 | 0.2 |
| 46 | Rosette | 1.2 | 1.6 | 0.6 | 0.5 |
| 47 | Rosette | 1.4 | 1.8 | 2.1 | 0.9 |
| 48 | Vegetative | 0.9 | 1.2 | 6.8 | 1.4 |
| 49 | Vegetative | 0.5 | 0.8 | 14.5 | 1.8 |
| 50 | Pre-flowering | 0.2 | 0.6 | 28.7 | 2.0 |
| 51 | Pre-flowering | 0.1 | 0.5 | 49.3 | 2.3 |
| 52 | Flower initiation | 0.0 | 0.7 | 88.6 | 2.6 |
| 1 | Flowering | 0.0 | 1.1 | 146.2 | 2.9 |
| 2 | Flowering | 0.0 | 1.9 | 212.5 | 3.0 |
| 3 | Flowering | 0.0 | 2.6 | 281.4 | 2.8 |
| 4 | Flowering–pod set | 0.0 | 3.1 | 329.7 | 2.5 |
| 5 | Pod formation | 0.0 | 3.4 | 349.8 | 2.1 |

| SMW | Crop stage | Sawfly (larvae/plant) | Painted bug (no./plant) | Aphid (no./10 cm shoot) | Leaf miner (mines/plant) |
|---|---|---|---|---|---|
| 6 | Pod formation | 0.0 | 3.6 | 353.6 | 1.7 |
| 7 | Pod formation | 0.0 | 3.3 | 357.4 | 1.3 |
| 8 | Pod development | 0.0 | 2.4 | 298.1 | 0.9 |
| 9 | Pod maturation | 0.0 | 1.3 | 162.5 | 0.4 |
| 10 | Maturity | 0.0 | 0.5 | 58.9 | 0.1 |

**4.3 Relationship with weather parameters**

The results of the correlation analysis demonstrated that the aphid population was moderately and negatively correlated with maximum temperature ($r = -0.71$) and morning relative humidity ($r = 0.68$), but moderately and negatively correlated with rainfall ($r = -0.42$) and wind velocity ($r = -0.38$). This is in line with the common belief that precipitation physically displaces aphid colonies and hinders their multiplication. From the low twenties to around 10–12°C, the population increased in a curvilinear fashion, but this trend petered out after the minimum temperature dropped below around 6-7°C. By using a combined coefficient of determination ($R^2$) of 0.79 and five weather parameters as independent variables in a stepwise multiple regression analysis, we found that morning relative humidity and minimum temperature were the two most important predictors of aphid population. Contrary to previous findings in other mustard-growing regions of northern India, sawfly incidence did not show a significant correlation with any one weather parameter (r values ranging from −0.18 to 0.24). This suggests that crop phenological stage, rather than prevailing weather, is the primary determinant of sawfly occurrence.

**4.4 Impact on plant physiological health**

As a result of chlorophyll degradation due to constant phloem-sap withdrawal and honeydew-associated sooty mold formation, the leaf chlorophyll content was considerably lower in protected plots (43.8 SPAD units) compared to unprotected plots (32.6 SPAD units) during the peak aphid infestation. There was a 24% decrease in leaf area index and a 9% drop in plant height at maturity in unprotected plots compared to protected plots at the same growth stage. Table 3 shows that plants with heavy infestations of painted bugs and aphids experienced a stunted canopy, diminished and delayed flowering, and premature wilting of terminal shoots as a result of these physiological impacts.

**Table 3. Effect of unprotected pest infestation on plant-health and yield-attributing parameters of mustard (pooled mean ± SE, 2023–24 and 2024–25)**

| Parameter | Protected plot | Unprotected plot | Per cent reduction | 't' value |
|---|---|---|---|---|
| Chlorophyll content (SPAD units) | 43.8 ± 1.2 | 32.6 ± 1.5 | 25.6 | 6.84** |
| Leaf area index (at 60 DAS) | 3.42 ± 0.11 | 2.61 ± 0.14 | 23.7 | 5.92** |
| Plant height at maturity (cm) | 168.4 ± 3.1 | 153.2 ± 3.6 | 9.0 | 4.15** |
| Siliquae per plant (no.) | 312.6 ± 8.4 | 221.3 ± 9.1 | 29.2 | 8.03** |
| Seeds per siliqua (no.) | 13.8 ± 0.3 | 11.2 ± 0.4 | 18.8 | 5.31** |
| 1000-seed weight (g) | 4.62 ± 0.06 | 4.18 ± 0.08 | 9.5 | 3.72** |

*(** significant at $P < 0.01$)*

**4.5 Yield loss and economic threshold**

The protected plots had an average grain yield of 19.4 q/ha in 2024-25 and 18.9 q/ha in 2023-24, while the unprotected plots averaged 13.6 and 14.1 q/ha, respectively. This resulted in an avoidable yield loss of 27.3% in the first season and 27.4% in the second, for a total of 27.7% over the two seasons. This loss was similar to the 26-34% range calculated across all of the study sites. According to a path analysis that looked at how each pest affected yield loss, mustard aphids were the biggest culprit, responsible for around 60–65 percent of the total avoidable loss. Painted bugs and sawflies combined to cause the second-worst amount of damage. Considering the correlation between pre-flowering aphid density and yield loss across different years and locations, we propose an economic threshold level of around 10-12 aphids per 10 cm central shoot during the pre-flowering to early-flowering stage. This level would serve as a practical guideline for when to intervene in order to prevent economically significant loss under the agro-climatic conditions of the Kaithal district.

**4.6 Discussion**

This study examined the agro-climatic conditions of Kaithal District, Haryana, to determine the seasonal incidence of key insect pests of mustard (Brassica juncea) and their impact on crop health and yield. The results demonstrated that mustard provided a habitat for a variety of insect pests, the frequency and significance of which varied throughout the life cycle of the crop and in response to environmental factors. The most significant and prevalent pest among the recorded pests was mustard aphid (Lipaphis erysimi). Other pests included mustard sawfly (Athalia lugens proxima), painted bug (Bagrada hilaris), leaf miner (Phytomyza horticola), cabbage butterfly (Pieris brassicae), and mustard leaf webber (Crocidolomia binotalis).

There was a distinct pattern of the seasons following one another. During the early vegetative stages, mustard sawflies were most common, whereas painted bugs and leaf miners appeared at various points in the life cycle of crops. Mustard aphids reached their peak population during blooming and early pod development, and their significance began to grow during the flower-initiation stage and continued thereafter. As the crop neared maturity, the aphid population fell from its peak of 357.4 aphids per 10-cm shoot during the 7th Standard Meteorological Week. This proved that the most susceptible times for aphid invasion were during the flowering and early pod development stages.

There was a correlation between weather and the seasonal fluctuations in mustard aphid populations. There was a negative correlation between aphid abundance and maximum temperature ($r = -0.71$) and a positive correlation with morning relative humidity ($r = 0.68$), although there was a negative correlation with rainfall ($r = -0.42$) and wind velocity ($r = -0.38$). Aphid population variance was well-explained by the weather-parameters-involved regression model ($R^2 = 0.79$). According to these results, aphid populations thrive in environments with just the right amount of humidity and temperature, while winds and rain can help keep them in check. You should not take these correlations as proof of direct causality, tho; they were only statistical connections. There was a quantifiable decline in crop health that occurred in conjunction with pest infestation. Chlorophyll content dropped from 43.8 SPAD units in protected plots to 32.6 SPAD units in unprotected plots during peak infestation. Other metrics that showed a decline included plant height and leaf area index. These alterations demonstrated that persistent pest pressure had a negative impact on photosynthesis, vegetative development, and general plant robustness. When the crop needed enough physiological resources for reproductive growth, like during blooming and pod formation, the effects were more essential. Important yield-contributing traits later showed the negative consequences. Along with a fall in seeds per siliqua and 1000-seed weight, the number of siliquae per plant fell from 312.6 in protected plots to 221.3 in unprotected plots. Unprotected plots produced around 13.6–14.1 q/ha, while protected plots produced about 18.9–19.4 q/ha. This means that reproductive efficiency and final seed output were both significantly reduced when insect pressure was high. Previous research out of India has also shown substantial preventable output losses caused by mustard aphid infestation, which is in line with our results.

As a result, the results demonstrated a significant correlation between insect incidence, crop health, and ultimate productivity. Reduced chlorophyll content and leaf area, worse siliqua development, seed formation, and final output occurred in tandem with rising aphid pressure during crucial reproductive stages. There were a number of insect pests in the research region at the same time, but the relative abundance of L. erysimi during blooming and pod development suggested that mustard aphid was the most important pest to control. Meanwhile, the findings highlighted the importance of paying attention to early-season pests including painted bug and mustard sawfly. Aphids may weaken plants and their leaves before the peak of an infestation occurs if they feed on seedlings and young plants while they are still developing. Therefore, rather than focusing just on aphids, mustard pest management should take into account the full seasonal pest complex. The study found that crop phenology, seasonal circumstances, and pest population behavior interacted to affect mustard pest incidence in Kaithal District. As part of an Integrated Pest Management (IPM) strategy, the results backed up routine field surveillance, monitoring of pests depending on weather, preservation of natural enemies, and actions based on needs. Additional multi-location and multi-seasonal studies would further validate pest thresholds and weather-based forecasting models for Kaithal District, however the results did give helpful location-specific information for mustard pest management.

## 5. Conclusion

In this two-season study, researchers in Haryana's Kaithal district characterized the mustard insect pest complex and measured the effect it had on plant health and yield. There were six different species of insects found, with the four most problematic being mustard aphids, mustard sawflies, painted bugs, and leaf miners. In the seedling-rosette stage, sawfly and painted bug damage the crop. In the flower-initiation stage, aphid populations build up sharply and peak during the pod-formation stage (6th-7th SMW), closely tracking the minimum temperature and morning relative humidity. This seasonal succession is clearly visible. An unprotected infestation greatly reduced the levels of chlorophyll, leaf area index, pod number, and seed weight, leading to a total preventable yield loss of 27.7 percent. The aphid was the most responsible pest for this loss. At the pre-flowering stage, the proposed economic threshold for the district is 10–12 aphids per 10-centimeter stalk. In order to reduce the yield gap caused by pests in mustard cultivation in Kaithal district and similar agro-climatic zones of Haryana, these results establish a location-specific empirical basis for weather-based pest forecasting and for scheduling timely, threshold-based interventions. They also support the wider adoption of an integrated pest management strategy that combines tolerant cultivars, conservation of natural enemies like coccinellids and Diaeretiella rapae, and the prudent, threshold-triggered use of selective insecticides or biopesticides.

### 5.1 Recommendations for future work

- Experiments that span multiple locations and years to hone the suggested economic threshold and create a district-wide weather forecasting model that has been officially validated.
- Assessing the tolerance of locally grown mustard genotypes to aphids and sawflies in the specific agroclimatic conditions surrounding Kaithal.
- An integrated pest management (IPM) module's conservation biological control components can be strengthened thru the quantification of natural enemy activity (coccinellids, syrphids, Diaeretiella rapae) in connection to pest build-up.
- Economic (cost-benefit) evaluation of the proposed threshold-based IPM module across typical farmer fields in the district, as well as on-farm demonstration of the module.

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