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Decoding Aphid Outbreaks: Impact of sowing windows and mustard varietal diversity on the population fluctuations of Mustard Aphid (Lipaphis erysimi)

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Abstract

Mustard aphid (*Lipaphis erysimi* Kalt.) is a key insect pest of mustard, causing heavy losses by sap-sucking and transmitting viral diseases. The present study was conducted to investigate the influence of sowing dates and mustard varieties on aphid population build-up under field conditions at the research farm of Lovely Professional University, Jalandhar, Punjab, during the Rabi season of 2023–2024. The experiment was conducted in FRBD (Factorial randomized block design) with three replications having two factors. First factor comprised of three dates of sowing: Early sowing-D_1 (15th October), Mid sowing-D_2 (30th October) and Late sowing- D_3 (15th November). whereas the second factor consists of five Indian mustard varieties viz; {V_1 (GSC-07), V_2 (Laxmi-846), V_3 (Durgamani), V_4 (Gujarat Mustard-2), and V_5 (RH-119)}. Aphid populations were recorded at regular intervals from initiation (52nd SMW) (Standard meteorological week) until decline (15th SMW). Results revealed significant differences among varieties and sowing dates. Early-sown crops (D_1) generally escaped severe infestation, while late-sown crops (D_3) harboured the highest aphid populations. Resistant/tolerant varieties, Durgamani(V_3) and RH-119 (V_5) showed consistently lower infestation compared to susceptible ones Gujarat-Mustard 2 (V_4), GSC-07 (V_1) and Laxmi-846 (V_2). The study revealed that both sowing time and varietal differences significantly affected aphid incidence. Early sowing consistently resulted in lower aphid populations, whereas delayed sowing encouraged higher infestations due to synchronization with favorable environmental conditions. Resistant varieties showed markedly lower aphid loads compared to susceptible types, suggesting the role of inherent morphological and biochemical defense mechanisms. These results highlight the importance of timely sowing and selection of tolerant varieties as vital agronomic strategies to suppress aphid incidence naturally and ensure sustainable mustard production under changing environmental conditions.

Introduction

Rapeseed (*Brassica spp.)* is a major oilseed crop cultivated globally for edible oil, vegetables, condiments, medicinal uses, and various bio-industrial purposes, ranking third in production after soybean and palm oil. In India, Brassica species cover about 6.13 million hectares with a production of 7.38 million tonnes. Among these, Brassica *juncea* (L.) Czern & Coss. is the predominant species, accounting for over 90% of the cultivated area (A.S.G, 2018; Directorate of Economics & Statistics, 2019). Mustard holds the second position among edible oilseeds in India after groundnut, contributing nearly 27.8% to the national oilseed economy. However, the average productivity of mustard in India (1511 kg/ha) remains lower than the global average (1980 kg/ha), representing only about three-fourths of the world's productivity, much lower compared to countries such as Sweden, Canada, Germany, and the United Kingdom (Dhillon et al., 2022).

Among the several factors contributing to low productivity, insect pests are particularly important. Nearly three dozen insect species attack rapeseed–mustard, but the mustard aphid (*Lipaphis erysimi* Kalt.) is considered the most serious. The aphids' ability to feed on phloem sap and their capacity for rapid reproduction have made them a significant yield-reducing factor worldwide, which causes the plant to grow more slowly, produce fewer seeds, and have a lower oil content (Dhillon et al., 2022). *Lipaphis erysimi* poses a major constraint to mustard production, with reported yield losses varying from 35.4% to as high as 96% under favorable conditions, along with a concomitant decline of 5–6% in seed oil content (Geethanjali et al., 2024). Abiotic factors significantly influence aphid infestation, as variation in sowing dates affect the initiation and progression of population build-up under favorable weather conditions (Narjary et al., 2013). The period of sowing exerts a critical influence on the level of aphid infestation. Several studies have demonstrated that early planting facilitates the crop in escaping the peak activity of aphids, thereby substantially minimizing yield losses (Kumar et al., 2024). Early-sown crops generally establish vigorous growth and exhibit greater tolerance, whereas delayed sowing often coincides with severe aphid colonization during sensitive phenological stages such as flowering and pod formation, which are decisive for seed development (Chattopadhyay et al., 2005; Sanp et al., 2016). In addition to sowing dates, host plant resistance among mustard varieties serves as an essential factor in reducing aphid-induced yield reduction. While complete immunity has not been identified in any variety, several genotypes demonstrate moderate to high levels of tolerance, which can be ascribed to specific morphological attributes or underlying biochemical mechanisms (Bhat *et al*.,2004; Tripathi *et al*.,2025). Thus, examining the interactive effects of sowing dates and genotypic variation on the population dynamics of *Lipaphis erysimi* is imperative, not only for identifying resistant sources and understanding pest ecology, but also for developing eco-friendly and cost-effective management strategies to mitigate yield and oil losses in mustard cultivation. These investigations will improve decision support for efficient *Lipaphis erysimi* management and have consequences for the production of sustainable rapeseed and mustard.

Materials and Methodology

A field experiment was carried out during the Rabi season of 2023–24 at the Research Farm of Lovely Professional University, Jalandhar, Punjab, India. The trial was arranged in a Factorial Randomized Block Design (FRBD) with two factors and three replications. The treatments comprised of three dates of sowing treated as a main factor and five different varieties treated as sub-factor. Five varieties namely GSC-07 (V_1), Laxmi-846 (V_2), Durgamani (V_3), Gujarat Mustard-2 (V_4) and RH-119 (V_5) were sown at three planting dates, early (15th October), mid (30th October) and late (15th November). A total of 45 plots were established, each with a net plot size of 5 × 4 m². The crop was sown at a row spacing of 30 cm and plant spacing of 10 cm, using a seed rate of 4–6 kg ha^{-1} at a depth of 3–4 cm.

Standard agronomic practices and intercultural operations, including gap filling, thinning, and hand weeding, were carried out in the experimental plots. The crop was maintained under natural infestation conditions, without any insecticidal intervention. Monitoring of mustard aphid infestation commenced three weeks after germination and continued until crop maturity. Observations on aphid appearance and subsequent population dynamics were recorded at weekly intervals from the 10 cm terminal portion of the central shoot of five randomly selected plants in each plot and the data were averaged to obtain mean values.

Statistical Analysis

Data on aphid population were recorded from five randomly selected plants per plot during each observation. The mean values thus obtained were subjected to statistical analysis to determine the effects of sowing dates, varieties, and their interactions on the population dynamics of *Lipaphis erysimi* (Kalt.). The data were analyzed using Analysis of Variance (ANOVA) following the procedures described by Panse and Sukhatme (1957). The significance of differences among treatment means was tested using the Critical Difference (CD) test at the 5% level of probability (P = 0.05). Pooled analysis over the Standard Meteorological Weeks (SMWs) was conducted to obtain a comprehensive understanding of treatment effects and to draw logical inferences about the influence of environmental and varietal factors. Where necessary, data were transformed to stabilize variances before analysis. To further explore multivariate relationships, Principal Component Analysis (PCA) was carried out using GRAPES software to identify and visualize the major components contributing to the variability in aphid population across sowing dates, varieties, and meteorological weeks. The PCA biplot helped in understanding the degree of association among variables and the clustering pattern of treatments based on aphid infestation intensity.

Results and Discussion

The seasonal incidence of mustard aphid, *Lipaphis erysimi*, showed marked variation across sowing dates and varieties, reflecting the combined influence of crop phenology, prevailing weather, and host plant characteristics. Early and late-sown crops presented contrasting environments for aphid multiplication, while genotypic differences further contributed to variability in infestation levels. The following results are presented under three headings: effect of sowing dates, effect of varieties, and their interaction, to provide a clear understanding of treatment influences on aphid population dynamics.

Effect of sowing dates on aphid population

Sowing date exerted a significant influence on the population build-up of *Lipaphis erysimi*. Aphid infestation increased consistently with delayed sowing (Fig.1). Aphids appeared during the 52nd SMW (late December) in the early (D_1) and mid-sown crop (D_2) and during the 1st SMW (early January) in the late-sown one (D_3). Late-sown crops (D_3) exhibited the highest aphid infestation with the population peaking during the 8th SMW (139.987) and 9th SMW (150.427) followed by mid-sown crops (D_2) with the population peaking during the 8th SMW (136.560). On the other hand, the lowest aphid counts were recorded in D_1 sowing with the population peaking during the 7th SMW (113.173) before declining sharply. In the early sown crop (D_1), the initial incidence of mustard aphid (*Lipaphis erysimi* Kalt.) was recorded in the 52nd SMW with a very low population of 0.200 aphids per 10 cm central twig, indicating the onset of infestation at the vegetative stage of the crop. The aphid population showed a gradual and continuous increase from the 1st to the 7th SMW, attaining its peak density of 113.173 aphids per 10 cm twig during the 7th SMW when the crop was at the flowering stage. Thereafter, the population started declining steadily from the 8th to the 12th SMW (Table 2). attributed to the senescence of the crop and the dispersal of aphids to other host plants. The mid-sown crop (D_2) recorded a higher and more sustained aphid infestation than the early-sown crop (D_2). The initial appearance of *Lipaphis erysimi* was observed during the 52nd SMW (0.107), and the population gradually increased, reaching its maximum density (136.560) during the 8th SMW. Thereafter, the aphid population showed a gradual decline but persisted up to the 14th SMW (6.347). In contrast, the early-sown crop (D_1) matured earlier, leading to a reduction in the availability of succulent plant parts suitable for aphid feeding. Consequently, the aphid population in the early-sown crop (D_1) declined sharply after the 7th SMW and completely disappeared by the 13th SMW. The longer persistence of aphids in the mid-sown crop (D_2) is therefore associated with the delayed maturity and prolonged availability of tender plant tissues, coupled with favorable temperature and humidity during the 8th to 12th SMWs. In the late-sown crop (D_3), the initial incidence of mustard aphid (*Lipaphis erysimi* Kalt.) was recorded during the 1st SMW. The aphid population increased progressively, attaining its peak during the 9th SMW (150.427), followed by slightly lower populations in the 8th SMW (139.987). The intensity of infestation was the highest in the late-sown crop (D_3) compared to both early (D_1) and mid-sown (D_2) crops. This may be attributed to the coincidence of the crop's flowering and pod formation stages with the period of congenial weather conditions, such as moderate temperature and relatively high humidity, during the 7th to 9th SMWs. Thereafter, the aphid population declined gradually from the 10th SMW (129.453) onwards but continued to persist up to the 15th SMW (2.28). The prolonged survival of aphids in the late-sown crop (D_3) was likely due to the delayed crop maturity and extended availability of tender plant tissues favorable for feeding and multiplication. Similar findings were reported by (Patel and Singh, 2018), who observed that late-maturing mustard crops supported aphid populations for a longer duration due to extended availability of suitable host stages. Early sowing thus allowed the crop to escape the peak period of aphid multiplication, while delayed sowing coincided with congenial weather conditions, leading to greater infestation. These results suggest that early sowing allowed the crop to escape the peak aphid multiplication period, whereas delayed sowing coincided with congenial weather conditions, thus favouring pest proliferation. The current findings are in line with previous results (Mishra and Gaurav, 2022), who reported reduced aphid incidence in early-sown mustard. These observations confirm the importance of sowing time in pest avoidance. However, irrespective of sowing window, genotypic differences also played a critical role, as described below. During the course of the investigation, meteorological parameters such as maximum and minimum temperature, relative humidity (maximum and minimum), rainfall, wind speed, and sunshine hours were recorded weekly across the 52nd to 15th SMWs (Table 1). The data revealed considerable fluctuations in temperature and humidity, which coincided with the changing trend of aphid population on mustard. Such variations in weather conditions played a significant role in determining the onset, build-up, and decline of aphid infestation.

Effect of varieties on aphid population

The tested varieties exhibited significant differences in their susceptibility to aphid infestation. The infestation of mustard aphid (*Lipaphis erysimi* Kalt.) was observed on all the tested varieties beginning from the 52nd SMW. The mean aphid population varied significantly among the varieties throughout the cropping period. The highest population (216.667) was recorded on Gujarat Mustard-2(V_4) (Fig.2), which was followed by GSC-07(V_1) (179.156) and Laxmi-846(V_2) (167.378). The peak infestation (216.667) in Gujarat Mustard-2(V_4) was observed during the 8th SMW, indicating its high susceptibility to aphid attack under prevailing weather conditions. GSC-07(V_1) and Laxmi-846(V_2) also exhibited a similar trend but with comparatively lower mean populations. The **lowest aphid population** was consistently recorded on *Durgamani*(V_3) across all SMWs. In this variety, the population attained its **peak (28.644) during the**

8th SMW, which, however, remained **significantly lower** than that observed on the other varieties. Thereafter, the aphid population in *Durgamani (V_3)* **declined gradually from the 9th SMW** and **completely disappeared by the 15th SMW**.A **similar trend** was observed in *RH-119(V_5)*, wherein the aphid population peaked (36.644) around the 7th SMW and started declining thereafter. However, *RH-119(V_5)* **harbored comparatively higher populations** than *Durgamani(V_3)* throughout the observation period (Table 2). The comparatively lower population in Durgamani(V_3) and RH-119(V_5) suggests their relative tolerance or resistance to aphid infestation which may be attributed to their inherent **morphological or biochemical traits**, which possibly make these varieties **less conducive for aphid multiplication and feeding** under the present field conditions (Samal *et al*.,2021). These findings are consistent with the reports of (Chand *et al*.,2023; Sinha *et al*., 2024), who demonstrated that varietal resistance offers a sustainable means of aphid management. The varietal resistance may be attributed to morphological and biochemical traits such as thicker cuticle layers, higher glucosinolate contents, and reduced phloem sap palatability that adversely affect aphid colonization and feeding rates (Chandrakumara *et al*.,2023; Loitongbam *et al*.,2024). Since both sowing date and variety significantly affected aphid infestation individually, their combined effect was further examined.

Interaction effect of sowing dates and varieties

A significant interaction between date of sowing and variety was observed with respect to aphid population (Fig.3). The data (Table 2) indicated that the **late-sown crop of Gujarat-Mustard 2 (D_3V_4)** recorded the **highest aphid infestation (256.800)** among all combinations, reaching its **peak during the 9th SMW.** Similar trends were evident for the other sowing dates, where **variety V_4 (Gujarat-Mustard 2)** consistently maintained higher aphid populations compared to the rest. Varieties **V_1 (GSC-07)** and **V_2 (Laxmi-846)** followed Gujarat-Mustard 2(V_4) in infestation intensity across all sowing dates. Conversely, the **lowest (0.067) aphid population** was recorded in **D_1V_3 (early-sown Durgamani),** followed by **D_1V_5 (early-sown RH-119) (0.133)**, suggesting their **comparative tolerance** to aphid attack under early-sown conditions. These results imply that **late sowing enhanced aphid susceptibility**, particularly in **highly susceptible genotypes** such as Gujarat- Mustard 2, whereas **early sowing** coupled with **tolerant varieties** reduced infestation levels. This indicates that varietal performance is influenced by sowing window, and the right combination can effectively minimize aphid incidence. Such interactions were also reported by (Khan and Jha,2010; Ahlawat *et al*., 2021), who observed that delayed sowing exposed the crop to favorable temperature and humidity regimes for aphid multiplication, thereby intensifying infestation in susceptible genotypes, highlighting that both agronomic and genetic factors must be considered simultaneously in aphid management. The combined evidence from sowing date, varietal differences, and their interaction emphasizes that integration of cultural practices with host plant resistance can serve as an effective, eco-friendly approach to suppress aphid infestation in mustard.

Principal Component Analysis (PCA)

Principal Component Analysis (PCA) was employed to analyse the relationship between aphid population and Standard Meteorological Weeks (SMWs) across different sowing dates and mustard varieties. The PCA biplot (Fig.4) provides a visual summary of the variation explained by the first two principal components (PC_1 and PC_2). The centre of the biplot represents the origin, indicating neutral association, whereas points positioned nearer to the circumference exhibit stronger correlations with the principal components. The **length of the arrows** signifies the magnitude of each SMW's contribution to the overall variation, while their **direction** depicts the nature of association. Arrows pointing in similar directions represent positively correlated SMWs, whereas those oriented oppositely reflect negative associations. The clustering pattern of SMWs revealed that those corresponding to the peak aphid infestation period (around 7□□ to 9□□ SMW) showed strong association with PC_1, indicating their major role in influencing population dynamics. In contrast, early (52nd - 1□□ SMW) and late (12□□ -15□□ SMW) periods were positioned closer to the origin, suggesting minimal contribution to overall variability. The PCA thus effectively differentiated critical infestation phases and validated the seasonal influence of meteorological conditions on aphid build-up. It also revealed the clear temporal segregation of weeks based on aphid incidence. The vectors corresponding to the **8th and 9th SMWs** were closely aligned with the positive side of PC_1, indicating that these weeks contributed most strongly to the **peak aphid population period.** In contrast, the vectors representing the **52nd, 1st, and 2nd SMWs** were oriented along a different axis, reflecting the **initial phase of aphid colonization** with lower population densities. The **later weeks (13th to 15th SMWs)** showed negative loading values, indicating the **declining phase** of aphid infestation as the crop approached maturity and environmental conditions became less favorable for aphid multiplication. Thus, the PCA clearly differentiated the **onset, build-up, and decline** phases of aphid infestation during the crop season, demonstrating that maximum variation in aphid abundance occurred during the 7th to 9th SMWs. Similar use of PCA has been reported in mustard aphid research to summarize multivariate relationships between infestation levels, weather parameters, and genotypic traits. **Shukla *et al*. (2023)** used PCA and PLSR to distinguish aphid-infested and healthy mustard crops using hyperspectral data. Furthermore, JAMES ***et al*. (2024)** applied PCA in the evaluation of yield and aphid resistance of Indian mustard genotypes under acidic soil conditions of Meghalaya, identifying distinct genotype clusters based on resistance indices and yield traits. Collectively, these findings substantiate the present PCA results, confirming that principal component analysis is a robust tool to decipher key temporal and varietal factors influencing mustard aphid dynamics.

Conclusion

Overall, the study revealed that sowing time and varietal selection significantly influenced mustard aphid (*Lipaphis erysimi* Kalt.) incidence. Early-sown crops (D_1) recorded the lowest aphid population, while late-sown crops (D_3) had the highest, coinciding with favourable weather for aphid build-up. Among varieties, Gujarat-Mustard 2(V_4) showed maximum infestation, whereas Durgamani(V_3) and RH-119(V_5) were relatively tolerant. The late-sown Gujarat-Mustard 2 (D_3V_4) combination exhibited the highest aphid density, highlighting the effect of sowing–variety interaction. These findings underscore the importance of optimizing sowing windows and selecting tolerant varieties as integral components of Integrated Pest Management (IPM) in mustard ecosystems. Adoption of early sowing schedules, coupled with tolerant cultivars, can substantially suppress aphid incidence, reduce the need for chemical interventions, and promote environmentally sustainable and economically viable mustard production systems under changing climatic conditions.

Declarations

We confirm that all the authors have read and approved the final version of the manuscript. Furthermore, we affirm that the manuscript has not been published elsewhere, in whole or in part, and is not currently under consideration by any other journal. We also confirm the following:

• No funds, grants, or other support was received.

• The authors declare that they have no relevant financial or non-financial interests to disclose.

• We also confirm that there are no competing interests related to the content of this article.

• All authors certify that they have no affiliations with, or involvement in, any organization or entity with any financial or non-financial interest in the subject matter or materials discussed in this manuscript.

• Additionally, the authors have no financial or proprietary interests in any material presented in this article.

Ethics approval

This article does not contain any studies with human participants or animals performed by any of the authors. All procedures involving fieldwork and data collection compiled with relevant institutional, national, and international guidelines and legislation were applicable, permission was obtained from relevant authorities to conduct the research.

Clinical trial number

Not applicable

Author Contribution

We confirm that all the authors have read and approved the final version of the manuscript. Furthermore, we affirm that the manuscript has not been published elsewhere, in whole or in part, and is not currently under consideration by any other journal. We also confirm the following:- No funds, grants, or other support was received.- The authors declare that they have no relevant financial or non-financial interests to disclose.- We also confirm that there are no competing interests related to the content of this article.- All authors certify that they have no affiliations with, or involvement in, any organization or entity with any financial or non-financial interest in the subject matter or materials discussed in this manuscript.- Additionally, the authors have no financial or proprietary interests in any material presented in this article.

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Tables

Table 1. Weekly meteorological parameters recorded during the experimental period (from 52nd SMW to 15th SMW) at Research Farm during Rabi [2023–2024]

SMW	Temperature (°C)		Relative Humidity (%)		Rainfall (mm)	Windspeed (Km/hr)	Sunshine (hrs)
	Max.	Min.	Max.	Min.			
52	18	7.45	94.26	70.63	0.05	2.68	2.55
1	12.4	6.6	95	85.9	0	3.1	5.7
2	11.8	6.4	94.3	78.3	0	2.9	7.4
3	13.1	5.6	94.6	78.9	0	3.2	7
4	14.1	5.6	93.6	75	0	4.9	3.5
5	17.70	9.00	93.40	72.90	1.30	5.10	1.90
6	20.20	3.50	93.50	54.40	0.00	5.30	8.70
7	23.30	5.60	94.00	54.10	0.00	4.40	7.10
8	22.80	7.50	89.30	47.00	0.10	10.10	9.60
9	22.00	9.90	85.40	54.70	8.00	8.40	6.40
10	23.20	7.50	91.10	55.60	0.00	6.00	9.10
11	26.90	8.90	91.70	52.90	0.00	6.40	9.40
12	29.71	13.80	91.40	49.50	0.00	7.41	9.83
13	30.54	16.50	87.10	52.13	2.00	6.54	5.30
14	32.90	12.85	90.40	33.04	0.00	7.60	10.04
15	34.20	16.50	79.00	34.30	0.00	5.50	10.10

SMW = Standard Meteorological Week

Table 2. Effect of dates of sowing and varieties of mustard on aphid intensity and their amalgamation

Treatments	SMW 52	SMW 1	SMW 2	SMW 3	SMW 4	SMW 5	SMW 6	SMW 7	SMW 8	SMW 9	SMW 10	SMW 11
Sowing Dates												
D_1(15th Oct.)	0.200^{a}	4.440^{a}	6.787^{b}	10.547^{b}	13.013^{b}	18.013^{b}	28.16^{b}	113.173^{c}	99.200^{c}	84.596^{c}	71.380^{c}	57.55
D_2 (30th Oct.)	0.107^{ab}	4.267^{a}	8.293^{a}	11.733^{a}	13.693^{a}	20.293^{a}	34.84^{a}	119.827^{b}	136.560^{b}	115.108^{b}	92.507^{b}	64.42
D_3 (15th Nov.)	0.000^{b}	1.000^{b}	3.373^{c}	8.640^{c}	11.253^{c}	16.307^{c}	35.76^{a}	122.893^{a}	139.987^{a}	150.427^{a}	129.453^{a}	86.88
CD (P = 0.05)	0.126	0.209	0.4	0.247	0.374	0.548	1.434	2.122	2.723	4.623	2.831	2.488
SEM	0.043	0.072	0.138	0.085	0.129	0.189	0.495	0.732	0.94	1.596	0.977	0.859

Treatments	SMW 52	SMW 1	SMW 2	SMW 3	SMW 4	SMW 5	SMW 6	SMW 7	SMW 8	SMW 9	SMW 10	SMW 11
Variety												
GSC-07(V_1)	0.156	5.022^{b}	8.289^{b}	13.311^{b}	16.133^{b}	23.178^{b}	44.067^{b}	177.356^{b}	179.156^{b}	168.771^{b}	144.022^{b}	99.34
Laxmi-846(V_2)	0.089	4.511^{c}	7.356^{c}	11.956^{c}	14.511^{c}	20.556^{c}	37.178^{c}	166.867^{c}	167.378^{c}	153.067^{c}	128.533^{c}	93.71
Durgamani(V_3)	0.022	0.533^{d}	2.133^{e}	5.244^{e}	6.667^{e}	9.022^{e}	12.444^{e}	26.044^{e}	28.644^{e}	27.378^{d}	20.189^{e}	12.60
Gujarat Mustard-2(V_4)	0.200	5.511^{a}	9.800^{a}	14.956^{a}	17.489^{a}	26.800^{a}	53.911^{a}	186.244^{a}	216.667^{a}	201.987^{a}	169.000^{a}	121.4
RH-119(V_5)	0.044	0.600^{d}	3.178^{d}	6.067^{d}	8.467^{d}	11.467^{d}	17.000^{d}	36.644^{d}	34.400^{d}	32.349^{d}	27.156^{d}	21.05
CD (P = 0.05)	NS	0.269	0.517	0.318	0.483	0.708	1.852	2.739	3.515	5.968	3.655	3.212
SEM	0.056	0.093	0.178	0.11	0.167	0.244	0.639	0.946	1.213	2.06	1.262	1.109

Sowing Date × Variety	SMW 52	SMW 1	SMW 2	SMW 3	SMW 4	SMW 5	SMW 6	SMW 7	SMW 8	SMW 9	SMW 10	SMW 11
D_1V_1	0.267	6.667^{c}	9.600^{c}	13.400	16.733	23.267^{d}	39.000^{d}	170.267^{de}	149.267^{f}	123.933^{f}	107.333^{f}	87.29
D_1V_2	0.200	6.400^{cd}	8.133^{d}	12.333	15.067	20.333^{e}	29.800^{e}	161.933^{f}	147.067^{f}	120.667^{f}	102.133^{f}	86.13

D_1V_3	0.067	0.800^{gh}	2.600^{hi}	5.600	6.800	8.267^{i}	11.533^{h}	24.333^{i}	17.267^{i}	14.467^{j}	8.167^{k}	2.800
D_1V_4	0.333	7.400^{a}	10.200^{bc}	15.333	17.600	26.467^{b}	44.333^{bc}	174.933^{cd}	160.133^{e}	143.933^{e}	121.667^{e}	97.33
D_1V_5	0.133	1.200^{fg}	3.400^{fgh}	6.067	8.867	11.733^{g}	16.133^{fg}	34.400^{h}	22.267^{i}	19.980^{ij}	17.600^{j}	14.23
D_2V_1	0.200	6.800^{bc}	11.000^{b}	15.000	16.933	25.200^{c}	46.267^{b}	178.933^{bc}	190.867^{c}	167.513^{d}	133.400^{d}	92.60
D_2V_2	0.067	6.133^{d}	10.333^{bc}	13.533	15.667	23.133^{d}	40.533^{d}	167.467^{e}	175.733^{d}	144.267^{e}	120.733^{e}	89.60
D_2V_3	0.000	0.667^{hi}	2.800^{ghi}	6.667	7.800	10.200^{h}	12.800^{h}	25.867^{i}	33.600^{h}	28.333^{i}	21.400^{ij}	14.93
D_2V_4	0.267	7.400^{a}	13.400^{a}	16.067	18.733	30.467^{a}	57.200^{a}	190.667^{a}	244.200^{a}	205.227^{b}	159.867^{c}	103.7
D_2V_5	0.000	0.333^{ij}	3.933^{f}	7.400	9.333	12.467^{g}	17.400^{f}	36.200^{gh}	38.400^{gh}	30.200^{hi}	27.133^{hi}	21.26
D_3V_1	0.000	1.600^{ef}	4.267^{f}	11.533	14.733^{d}	21.067^{e}	46.933^{b}	182.867^{b}	197.333^{b}	214.867^{b}	191.333^{b}	118.1
D_3V_2	0.000	1.000^{gh}	3.600^{fg}	10.000	12.800	18.200^{f}	41.200^{cd}	171.200^{de}	179.333^{d}	194.267^{c}	162.733^{c}	105.4
D_3V_3	0.000	0.133^{j}	1.000^{j}	3.467	5.400	8.600^{i}	13.000^{gh}	27.933^{i}	35.067^{h}	39.333^{gh}	31.000^{gh}	20.06
D_3V_4	0.000	2.000^{e}	5.800^{e}	13.467	16.133	23.467^{d}	60.200^{a}	193.133^{a}	245.667^{a}	256.800^{a}	225.467^{a}	163.1
D_3V_5	0.000	0.267^{ij}	2.200^{i}	4.733	7.200	10.200^{h}	17.467^{f}	39.333^{g}	42.533^{g}	46.867^{g}	36.733^{g}	27.66
CD (P = 0.05)	NS	0.467	0.895	NS	NS	1.226	3.207	4.744	6.088	10.336	6.331	5.564
SEM	0.097	0.161	0.309	0.19	0.289	0.423	1.107	1.638	2.102	3.568	2.185	1.921
CV	164.62	8.623	8.7	3.2	3.952	4.026	5.825	2.391	2.906	5.295	3.871	4.778

Values in a column having different letter (s) differ significantly at 5% level of probability according to CD, NS, not significant, P < 0.05 by analysis of variance with randomized complete block

Figures

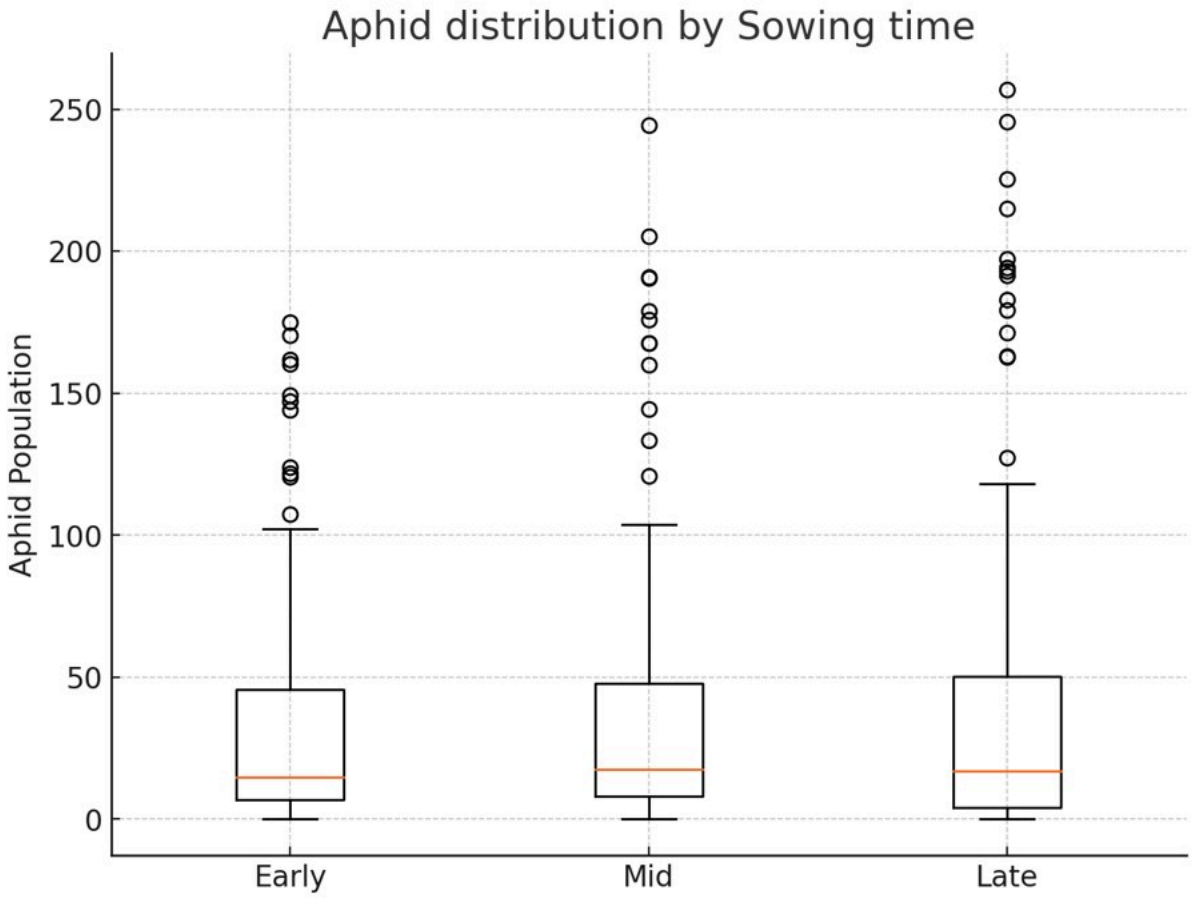


Figure 1

Box plot showing the distribution of aphid population under early, mid, and late sowing

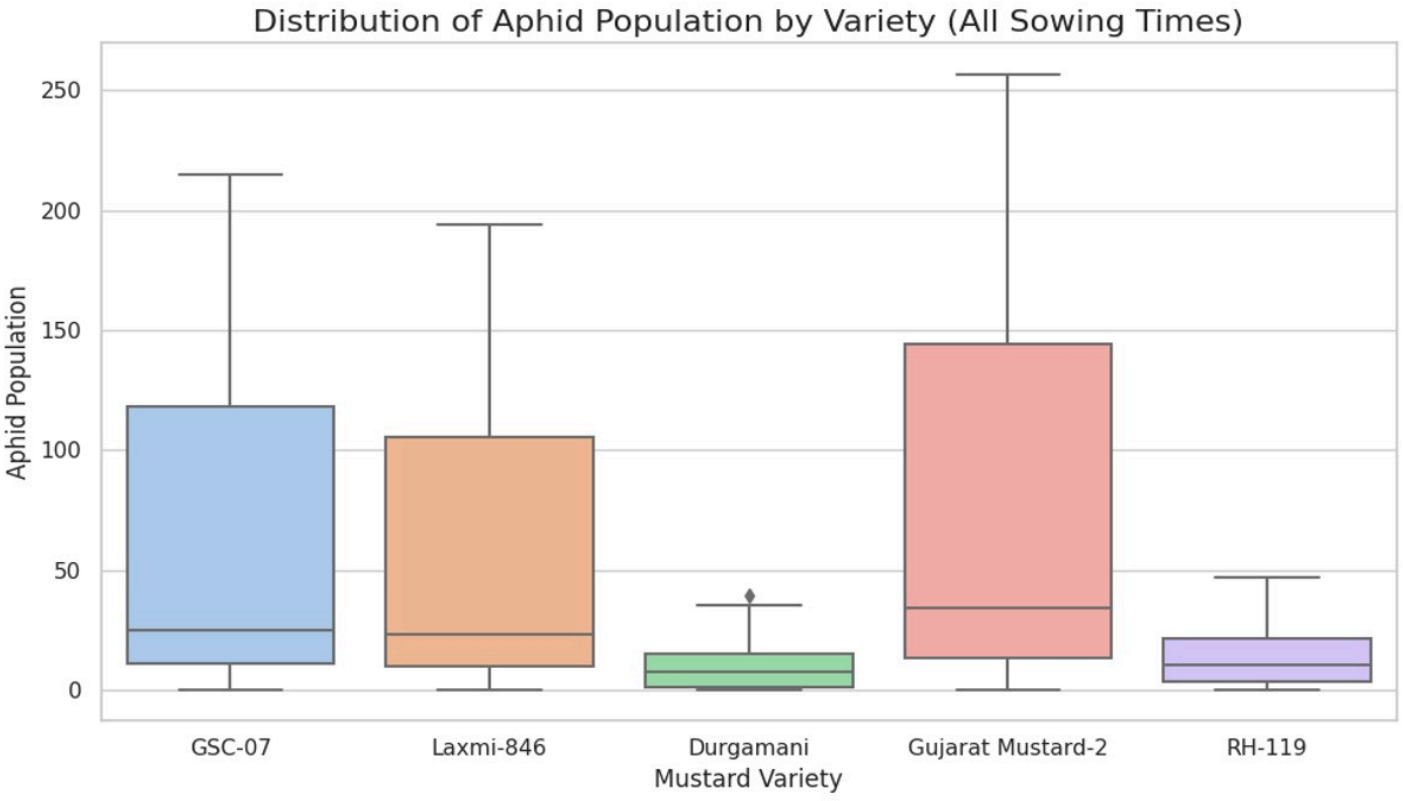


Figure 2

Box plot showing aphid population distribution across mustard varieties

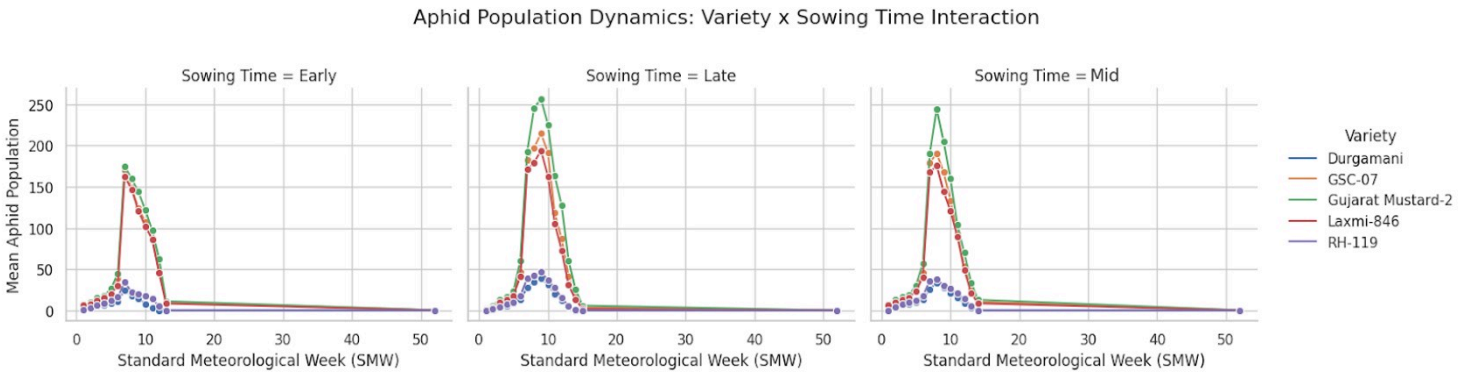


Figure 3

Interaction effect of sowing time and mustard variety on mean aphid population observed across Standard Meteorological Weeks.

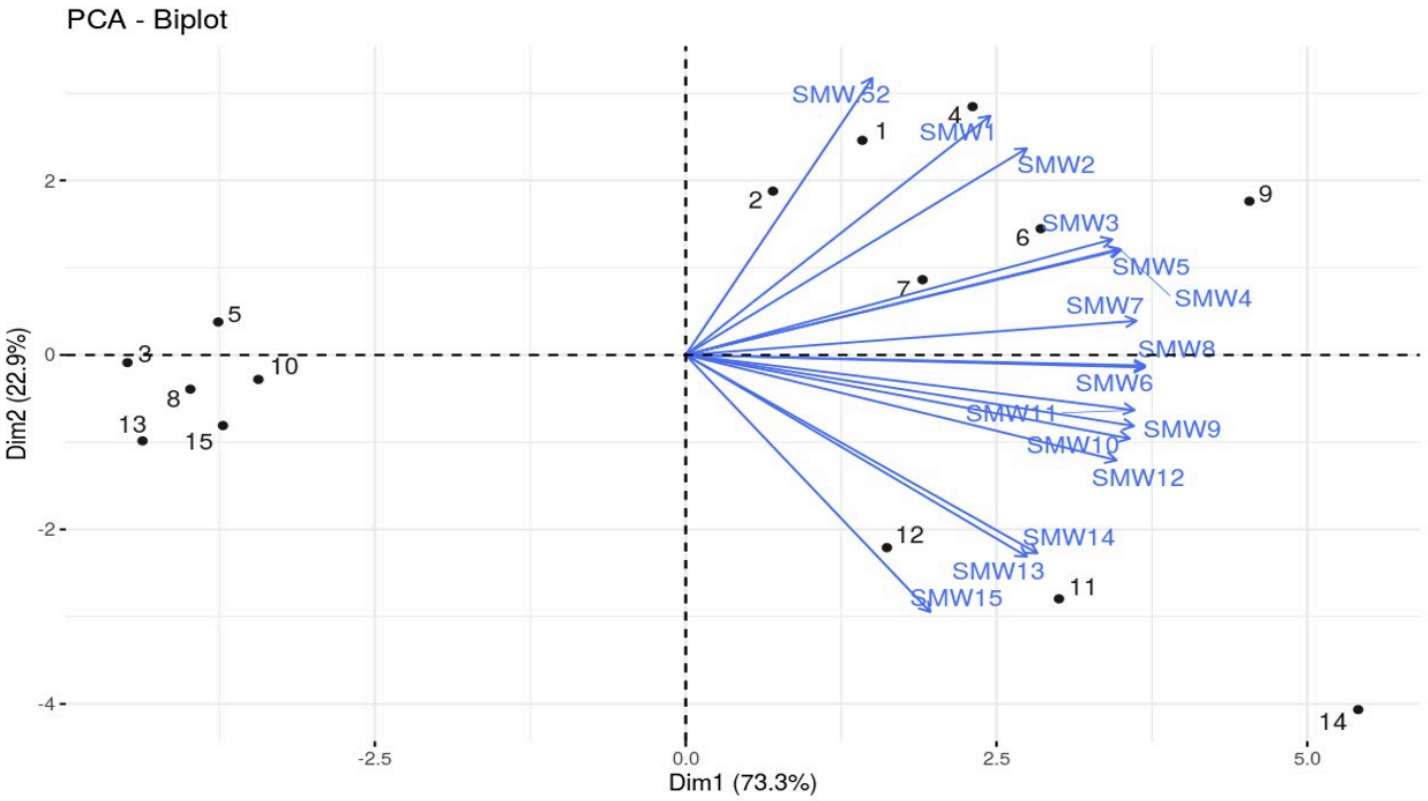


Figure 4

Principal Component Analysis (PCA) biplot showing the relationship between aphid population and Standard Meteorological Weeks (SMWs). The length of the arrows represents the strength of each SMW's contribution to total variation, while their direction indicates the degree of association among SMWs—arrows pointing in similar directions denote positive correlation, and those in opposite directions indicate negative correlation.