

Biophysical and biochemical mechanism of plant resistance in *Brassica juncea* (L.) Czern & Cross against *Lipaphis erysimi* (Kalt.) (Homoptera: Aphididae)

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Abstract

The mustard aphid (*Lipaphis erysimi* Kaltenbach) is a major limiting factor in the production of rapeseed-mustard, causing significant yield and quality losses. Host plant resistance offers a sustainable and eco-friendly alternative to chemical control within integrated pest management (IPM) frameworks. The present investigation was carried out during the Rabi seasons of 2023–24 and 2024–25 to evaluate the resistance potential of diverse *Brassica juncea* genotypes against *L. erysimi*. Resistance was assessed using the Aphid Population Index (API), Aphid Damage Index (ADI), and Aphid Resistance Index (ARI). Among the genotypes evaluated, TARAMIRA and LACMA-SP523N5 were the most susceptible, while KRANTI, PM-25, and PDL-1 showed the highest levels of resistance. Significant correlations were observed between aphid resistance and key biochemical markers, including elevated levels of glucosinolates, total phenols, tannins, and antioxidant enzymes such as peroxidase, phenylalanine ammonia-lyase (PAL), and tyrosine ammonia-lyase (TAL). Conversely, increased total sugar content was associated with greater aphid susceptibility. Morphological traits such as stem thickness and surface wax deposition, particularly in PM-25, also contributed to aphid deterrence. These findings demonstrate that a combination of biochemical and morphological traits underpins resistance to *L. erysimi* in mustard. The identified resistant genotypes and associated defense mechanisms provide valuable insights for breeding programs aimed at developing aphid-resistant *Brassica* cultivars, contributing to sustainable pest management in oilseed crops.

Introduction

Rapeseed-mustard is cultivated globally for its food and oil value, owing to its nutritional, medicinal, bio-industrial, and crop rotation benefits. Among the various oilseed *Brassica* species, *Brassica juncea* (L.) Czern & Coss. is the most widely preferred, accounting for over 90% of the total cultivated area in India. India is one of the leading mustard-producing countries in the world, where mustard ranks as the second most important edible oilseed crop after groundnut in terms of acreage and production. The crop's significance is further underscored by its potential to bridge the widening demand–supply gap of edible oil in India. Globally, rapeseed-mustard is the third most important source of edible oil after soybean and oil palm. Every part of the plant holds value in human livelihoods, having been traditionally used for flavoring, medicinal, and preservative purposes since ancient times. India ranks third in global rapeseed-mustard production, following Canada and China, contributing approximately 11% to the world's total production (Rathore et al., 2022).

Among the various pests affecting rapeseed-mustard, the mustard aphid, *Lipaphis erysimi* (Kaltenbach) (Homoptera: Aphididae), is a major yield-reducing factor, causing preventable yield losses ranging from 10.2–61.1% (Dhillon et al., 2022). Several studies have reported variable damage levels, with plant injury ranging from 10–90% and yield losses between 65% and 96% in different *Brassica* species. These variations are influenced by crop growth stage, aphid population dynamics, and agro-climatic conditions (Bakhetia and Sekhon, 1989; Yue and Liu, 2000; Patel et al., 2004; Ahuja et al., 2010). Aphids derive nutrition by extracting phloem sap through their piercing-sucking mouthparts and stylets, which they use to probe plant tissues (Fritz et al., 2023). Their ability to feed on intracellular compartments without causing cellular damage enables efficient nutrient extraction. *L. erysimi* exhibits both sexual and asexual reproduction, resulting in a short life cycle and rapid population buildup under favorable conditions (Matis et al., 2007). The species' reproductive efficiency, widespread distribution, and phloem-feeding behavior, particularly through parthenogenesis and vivipary, have elevated its status as a globally significant pest. Infestations lead to stunted plant growth, poor seed formation, and reduced oil content (Malik and Rohilla, 2004). Management decisions depend on several factors including the economic threshold level, the speed of population increase, and the severity of infestation. With climate change altering insect–plant interactions, there is a pressing need to update our understanding of aphid-induced damage, yield loss, and effective management options suited for currently cultivated varieties (Sharma and Dhillon, 2020).

Although chemical control using two insecticidal sprays is the predominant strategy, it poses several ecological and health concerns. These include negative impacts on beneficial insects (e.g., pollinators and natural enemies), environmental contamination, and residue accumulation in mustard oil due to the lipophilic nature of many insecticides (Dhillon et al., 2022). Thus, the development of environmentally sustainable, economically viable, and effective pest control strategies is imperative. Among the alternatives, host plant resistance has emerged as a cornerstone of integrated pest management (IPM).

Although extensive efforts to identify resistance within *Brassica* germplasm, no genotype has demonstrated complete resistance to mustard aphid in India (Dhillon et al., 1993). In this context, a standardized field-based artificial infestation technique has been developed for screening mustard genotypes against *L. erysimi* (Dhillon et al., 2018). A thorough understanding of host–plant interactions, including plant metabolic responses and aphid adaptation strategies, is vital for developing resistant cultivars (Kumar et al., 2017). Plant resistance mechanisms involve antixenosis, antibiosis, and tolerance each governed by complex phenological, morphological, and biochemical traits. In *B. juncea*, morphological features such as leaf color, shape, size, cuticle thickness, trichome density, surface wax deposition, pod size, and number of seeds per pod contribute to physical defense barriers that reduce aphid colonization (Rahman et al., 2022).

Biochemical traits also play a pivotal role in influencing aphid herbivory (Bhoi et al., 2020). Compounds such as total antioxidants, tannins, and phenols have been shown to negatively impact aphid fecundity, reproductive period, and survival in *B. juncea* (Samal et al., 2021). Among these, glucosinolates, sulfur-containing secondary metabolites typical of Brassicaceae are especially significant. These compounds affect aphid feeding, establishment, and population development (Kumar and Sangha, 2017). Furthermore, antioxidant enzymes such as ascorbate oxidase, ascorbate peroxidase, and catalase contribute indirectly to plant defense (Harish et al., 2021). The hydrolysis of glucosinolates by myrosinase upon herbivore attack produces bioactive compounds that deter aphids (Andreasson et al., 2001). Additionally, insect feeding may induce broader changes in biochemical profiles, secondary metabolite biosynthesis, and physical plant characteristics.

Despite the widespread cultivation of high-yielding mustard varieties, it remains unclear whether their adoption is based solely on productivity or also on aphid tolerance. While the role of phytochemicals in defense against other insect pests is well documented, studies on the defensive role of these compounds in *B. juncea* against *L. erysimi* are relatively limited. This gap in understanding the biochemical basis of resistance poses a major constraint to

breeding aphid-tolerant cultivars. Therefore, the present study aims to assess the level of aphid resistance and elucidate the underlying biochemical and morphological mechanisms in widely cultivated genotypes of *Brassica juncea*.

Materials and Methods

Study Area and Field Screening

The field experiments were conducted during the Rabi seasons of 2023–24 and 2024–25 at the Student's Instructional Farm, Acharya Narendra Deva University of Agriculture and Technology (ANDUAT), Kumarganj, Ayodhya, India. A total of 20 *Brassica juncea* germplasms, including one susceptible check (Giriraj), were evaluated under open field conditions to assess their resistance to mustard aphid (*Lipaphis erysimi* Kalt.). Seeds were obtained from the Department of Genetics and Plant Breeding, ANDUAT, Kumarganj. Two to three seeds per hill were sown at a depth of 4–5 cm, maintaining a spacing of 30 × 15 cm (row × plant). After germination and seedling establishment, thinning was performed to retain one to two plants per hill. Each genotype was grown in five rows, each 4 meters long. All recommended agronomic practices were followed, except for the application of insecticides.

Monitoring of Mustard Aphid Infestation

The test genotypes were observed daily to monitor aphid infestation. Once the *L. erysimi* population reached the economic threshold level (ETL), five randomly selected plants from each genotype were tagged. Observations were recorded 21 days after the population reached ETL. The number of aphids present on the apical 10 cm of the main shoot of each plant was counted and expressed as aphids per plant. The Aphid Population Index (API), Aphid Damage Index (ADI), and Aphid Resistance Index (ARI) were calculated following the methodology of Dhillon et al. (2018) (Table 1).

Morphological Characterization of *B. juncea* Genotypes

Surface Wax Estimation

Surface wax content was determined according to the method of Ebercon et al. (1977). Fresh, healthy leaves were cleaned, air-dried, and immersed in 20 mL of chloroform for 30 seconds to 1 minute to dissolve the waxes. The chloroform extract was filtered and evaporated to dryness in a pre-weighed vial. The residue was weighed, and surface wax content was expressed as mg/cm² or mg/g fresh weight.

Stem Diameter Measurement

Stem diameter was measured using a Vernier caliper with 0.01 mm precision. Three plants per genotype were randomly selected. The apical 10 cm portion of the main shoot was identified, and stem diameter was measured at a representative point within this section. The mean of three measurements was recorded for each genotype.

Biochemical Characterization of *B. juncea* Genotypes

Sample Collection and Preparation

Healthy leaves from five randomly selected plants per genotype were collected 48 hours after exposure to field conditions. Approximately 2 g of leaf tissue was frozen in liquid nitrogen and homogenized in 10 mL of phosphate buffer (50 mM, pH 7.8). The homogenate was centrifuged at 12,000–20,000 rpm for 20–30 minutes at 4°C. The supernatant was collected and stored at –20 °C for further biochemical analysis.

Total Sugar Estimation

Total sugar content was estimated using the phenol-sulfuric acid method (Dubois et al., 1956) with glucose as the standard. 500 µL of plant extract was mixed with 0.5 mL of 5% phenol, followed by the addition of 2.5 mL of concentrated H₂SO₄. Absorbance was measured at 490 nm using a UV-spectrophotometer. Sugar content was calculated based on a glucose standard curve and expressed in mg/g of tissue.

Total Phenol Estimation

Total phenolic content was measured following the method of Singleton and Rossi (1965), using gallic acid as the standard. Each sample consisted of 200 µL of plant extract and 300 µL of water, followed by the addition of 0.1 mL of Folin–Ciocalteu reagent. After 15 minutes, 2.5 mL of saturated sodium carbonate was added and incubated for 30 minutes. Absorbance was recorded at 760 nm, and values were expressed as mg/g of tissue.

Total Tannin Estimation

Tannin content was determined using the method of Amorim et al. (2008). 500 mg of plant tissue was extracted in 25 mL of 80% ethanol and filtered after 30 minutes. The final volume was adjusted with ethanol. Absorbance of 200 µL of each sample was measured at 760 nm, and tannin content was calculated using a gallic acid standard curve.

Total Glucosinolate Estimation

Glucosinolate content was estimated as per Mawlong et al. (2017). Dried leaf samples (0.3 g) were extracted with 300 mL of 80% methanol at 70°C for 5 minutes. After cooling and centrifugation at 15,000 rpm for 15 minutes, 100 µL of the supernatant was mixed with 4 mL of 0.2 mM sodium tetrachloropalladate and incubated for 1 hour. Absorbance was measured at 425 nm, and glucosinolate content was calculated using the formula: $y = 1.40 + 118.86 \times A_{425}$, and expressed as µmol/g of tissue.

Total Chlorophyll Estimation

Chlorophyll content was estimated using the DMSO method (Nayek et al., 2014). Fresh leaf tissue (50 mg) was incubated in 10 mL DMSO at 65°C for 1 hour. Absorbance was recorded at 645 and 663 nm, and total chlorophyll was calculated using the equation:

$$\text{Total chlorophyll} = (20.2 \times A_{645} + 8.02 \times A_{663}) \times (V / 1000 \times W)$$

where V = volume of extract (mL), and W = weight of fresh tissue (g).

Enzymatic Assays

Ascorbate Peroxidase (APX) Activity

APX activity was determined using the method of Ali et al. (2005). The reaction mixture (1 mL) consisted of 100 mM Tris-acetate buffer (pH 7.0), 2 mM ascorbic acid, 2 mM H₂O₂, and 20 µL enzyme extract. Absorbance was recorded at 290 nm for 3 minutes. Activity was expressed as U/mg protein.

Phenylalanine Ammonia-Lyase (PAL) Activity

PAL activity was measured according to Fritz et al. (1976). The reaction mixture (1 mL) contained 0.1 mM Tris-acetate buffer (pH 8.5), 0.833 mM L-phenylalanine, and 50 µL enzyme extract. Absorbance was monitored at 290 nm over 10 minutes and expressed as U/mL of protein.

Tyrosine Ammonia-Lyase (TAL) Activity

TAL activity was estimated as per Thorpe and Beaudoin-Eagan (1985). The reaction mixture (1 mL) contained 0.1 mM Tris-acetate buffer (pH 8.5), 0.833 mM L-tyrosine, and 50 µL enzyme extract. Absorbance was recorded at 290 nm for 10 minutes and activity was expressed as U/mL of protein.

Statistical Analysis

Data on aphid infestation, morphological, and biochemical parameters were subjected to one-way analysis of variance (ANOVA). Differences among treatment means were evaluated using the F-test and compared using the least significant difference (LSD) at $P = 0.05$. Pearson correlation coefficients and principal component analysis (PCA) were computed to assess the relationships between plant traits and aphid resistance using SPSS® version 27.0 software.

Results

Response of divers *Brassica* germplasms against mustard aphid infestation

The mustard aphid infestation during the *Rabi* 2023-2024 season recorded significant results and revealed that the total number of mustard aphids (*Lipaphis erysimi*) found on the top 10 cm of the central shoot of various *Brassica juncea* germplasm was ranged from about 21.7 to 782.9 aphids per 10 cm of the top shoot, wherein none of mustard germplasms found free from mustard aphid infestation (Table 4). The germplasm TARAMIRA had recorded the highest number aphid population (782.9 nos.), indicating it was highly susceptible against mustard aphid infestation, followed by LACMA-SP523N5 (272.3 nos.), SHIVANI (186.4 nos.) and BRIJRAJ (194.2 nos.) also supported relatively high aphid populations, suggesting they are more prone to mustard aphid infestation. On the other hand, germplasm such as PM-25 (21.7 nos.) and KRANTI (22.9 nos.) had observed fewer aphids and showing better resistance to mustard aphid attacks. Besides, the study measured different indices aphid population index, damage index, and resistance index that varied considerably across the germplasm. Meanwhile, TARAMIRA, RH-725, LACMA-SP523N5, CS-56, and SHIVANI showed higher values, indicating greater vulnerability. Conversely, germplasm such as PM-25, KRANTI and PDL-1 had lower scores, reflecting stronger resistance against mustard aphid infestation.

As per scale of resistance category, we grouped the germplasm into five categories: resistant, moderately resistant, tolerant, susceptible, and highly susceptible, based on how many mustard aphids were found on each plant. None of the germplasm fell into the resistant category with aphid numbers between 0.0-1.0 Germplasm in the 1.1-2.0 range, like PM-25 (1.5), KRANTI (1.5), and PDL-1 (1.7), were considered moderately resistant. Those with 2.1-2.5 aphids namely MASC-1 (2.3), EC-399301 (2.1), PUSA BAHAR (2.2), and RH-406 (2.3) were classified as tolerant. The susceptible group includes plants like GIRIRAJ (2.6), PUSA TARAK (2.6), and PM-22 (2.7), which had aphid counts between 2.6 and 3.5. Finally, the two germplasm LACMA-SP523N5 (3.6) and TARAMERA (4.8) supported the highest number of aphids, in the 3.6 to 5.0 range, making them highly susceptible.

Similarly, during the *Rabi* season of 2024-2025 ranged from as low as 20.1 to as high as 444.4 aphids per 10 cm of the top shoot. This variation emphasizes major differences in how susceptible or resistant these germplasms are (Table 2). Notably, the germplasm TARAMIRA experienced the highest average aphid population with 444.4 aphids per 10 cm of the top shoot, indicating very high susceptibility, followed by RH-725 (181.1 nos.) and LACMA-SP523N5 (170.2 nos.). Conversely, the lowest populations were observed in PM-25, with an average of 20.1 nos., followed by KRANTI (20.68 nos.) both maintaining minimal aphid counts throughout the observation period even during peak infestation periods demonstrating their strong resistance (Table 1).

The total aphid count, along with indices such as the aphid population index, damage index, and resistance index, ranged from 20.1 to 444.4, 2.0 to 4.3, 1.0 to 3.4, and 1.5 to 3.9 respectively (Table 1). Major variation among these indices was evident, with TARAMERA, RH-725, and LACMA-SP523N5 showing notably higher aphid populations. In contrast, PM-25, KRANTI, and PDL-1 exhibited considerably lower aphid population, indicating superior resistance. In particular, the aphid population index, damage index, and resistance index were considerably enhanced in TARAMERA, RH-725, GIRIRAJ, and LACMA-SP523N5, whereas these were markedly lower in PM-25, KRANTI, PUSA BAHAR, CS-60, PDL-1, RADHIKA, and SHIVANI. These findings suggest that the latter germplasm demonstrate a degree of tolerance against *Lipaphis erysimi*.

Plant morphological characterization of *B. juncea* genotypes

Stem diameter

Stem diameter among the germplasm ranged between 2.1 and 3.1 mm (Table 3). The maximum stem thickness was observed in SHIVANI (3.1 mm), followed by TARAMERA (3.1 mm), PUSA TARAK (3.0 mm), PM-29 (2.9 mm) and RH-725 (2.9 mm). Thicker stems may act as a physical barrier against aphid infestation. The minimum stem diameter was recorded in RADHIKA (2.1 mm), followed by CS-60 (2.5 mm) and PDL-1 (2.6 mm).

Surface wax content

The surface wax content varied significantly among the germplasm, ranging from 3.1% to 5.1% (Table 3). The highest wax deposition was found in PM-25 (5.1%), followed by KRANTI (4.8 %), MASC-1 (4.6 %) and PDL-1 (4.3 %), which may hinder aphid adhesion and feeding. However, the lowest surface wax content was observed in TARAMERA (3.1 %), followed by EC-399301 (3.2 %) and PUSA TARAK (3.3 %).

Biochemical characterization of *B. juncea* genotypes

Total chlorophyll content in leaves

The total chlorophyll content among different *Brassica juncea* germplasm varied significantly, ranging from 3.7 to 9.6 mg/g in the leaves of different *Brassica* germplasm (Table 4). The highest chlorophyll content was observed in PUSA TARAK (9.6 mg/g), followed by RH-725 (9.3 mg/g), PM-22 (8.8 mg/g), PDL-1 (8.5 mg/g), GIRIRAJ (7.9 mg/g), and PM-25 (7.9 mg/g) indicating better photosynthetic capacity. Whereas, the lowest values were recorded in BRIJRAJ (3.7 mg/g), followed by CS-60 (4.2 mg/g), RH-406 (4.6 mg/g), JM-3 (4.6 mg/g), CS-56 (4.7 mg/g), and TARAMERA (4.9 mg/g) as compared to other *Brassica juncea* germplasm.

Total sugar content in leaves

The total sugar content of different germplasm was observed to be ranged from 1.4 to 17.6 mg/g in the leaves of different *Brassica* germplasm (Table 4). The highest sugar accumulation was recorded in TARAMERA (17.6 mg/g), followed by RH-725 (14.2 mg/g), LACMA-SP523N5 (12.1 mg/g), PUSA TARAK (11.1 mg/g) and GIRIRAJ (10.6 mg/g). While the lowest sugar content was found in KRANTI (1.4 mg/g), followed by PM-25 (1.7 mg/g), PUSA BAHAR (4.1 mg/g), SHIVANI (4.7 mg/g), RADHIKA (6.2 mg/g), and CS-56 (mg/g).

Total phenols content in leaves

The data on the total phenols content showed significant variation, observed to be in the rang from 1.5 to 6.4 mg/g in the leaves of different *Brassica* germplasm (Table 4). The amount of total phenols was observed to be maximum in KRANTI (6.4 mg/g), PM-25 (5.2 mg/g), followed by SHIVANI (4.9 mg/g), CS-60 (4.8 mg/g) and RADHIKA (4.2 mg/g), which are known to enhance insect resistance. While the minimum total phenols content was found in GIRIRAJ (1.5 mg/g), followed by TARAMERA (2.2 mg/g), PUSA TARAK (2.4 mg/g), EC-399301 (2.5 mg/g) and JM-3 (2.8 mg/g) as compared to other *Brassica juncea* germplasm.

Peroxidase activity in leaves

The data of Peroxidase activity among the germplasm ranged between 777.2 and 1399.5 U/mg in the leaves of different *Brassica* germplasm (Table 4). The maximum peroxidase activity was found in KRANTI (1399.5 U/mg), followed by MASC-1 (1210.5 U/mg). While the lowest Peroxidase activity was observed in RH-725 (777.2 U/mg) and GIRIRAJ (986.2 U/mg).

Tannin content in leaves

Data of Tannin content was ranged from 0.1 to 3.6 mg/g across germplasm in the leaves of different *Brassica* germplasm (Table 4). The highest tannin content values were noted in KRANTI (3.6 mg/g), followed by PDL-1 (3.1 mg/g), TARAMERA (3.1 mg/g) and PM-25 (2.8 mg/g). The lowest tannin content was recorded in PUSA TARAK (0.1 mg/g), followed by PM-22 (0.1 mg/g) and EC-399301 (0.1 mg/g).

Total glucosinolate content in leaves

The data of total glucosinolate content ranged from 13.7 to 108.2 $\mu\text{mol/g}$ in the leaves of different *Brassica* germplasm (Table 4). The highest glucosinolate levels were recorded in PM-25 (108.2 $\mu\text{mol/g}$), followed by KRANTI (103.6 $\mu\text{mol/g}$), RADHIKA (92.4 $\mu\text{mol/g}$), MASC-1 (86.0 $\mu\text{mol/g}$) and PDL-1 (82.4 $\mu\text{mol/g}$), indicating potential aphid resistance. While the lowest total glucosinolate content was recorded in JM-3 (13.7 $\mu\text{mol/g}$), followed by RH-725 (24.2 $\mu\text{mol/g}$), LACMA-SP523N5 (26.7 $\mu\text{mol/g}$) and PUSA TARAK (27.8 $\mu\text{mol/g}$).

Total Phenylalanine ammonia-lyase (PAL) activity in leaves

PAL activity among the *Brassica juncea* germplasm ranged from 551.6 to 1998.8 u/ml in the leaves of different *Brassica* germplasm (Table 4). The highest PAL activity was recorded in KRANTI (1998.8 u/ml), followed by SHIVANI (1888.0 u/ml), MASC-1 (1867.9 u/ml), JM-3 (1757.4 u/ml) and BRIJRAJ (1782.7 u/ml) indicating stronger phenolic biosynthesis pathways and potential resistance. The lowest activity was observed in PM-25 (551.6 u/ml).

Total Tyrosine ammonia-lyase (TAL) activity in leaves

TAL activity in the leaves of different germplasm varied from 508.8 to 1619.8 u/ml in the leaves of different *Brassica* germplasm (Table 4). The highest TAL activity was observed in KRANTI (1619.8 u/ml), followed by PUSA BAHAR (1540.3 u/ml), CS-60 (1441.6 u/ml), BRIJRAJ (1419.5 u/ml), PDL-1 (1366.5 u/ml), and RADHIKA (1322.4 u/ml) suggesting efficient biosynthesis of defense metabolites. The lowest TAL activity was found in PM-25 (508.8 u/ml), followed by PUSA TARAK (559.2 u/ml), PM-29 (666.4 u/ml) and GIRIRAJ (774.7 u/ml).

Correlation of plant morphological and biochemical parameters with aphid population

Mean No. of Aphid Population X_1 exhibited a highly significant positive correlation with aphid population index (X_2 ; $r = 0.847$, $p < .001$), aphid damage index (X_3 ; $r = 0.648$, $p < .01$) and aphid resistance index (X_4 ; $r = 0.772$, $p < .001$) indicating (Table 5) that higher aphid counts were directly associated with greater levels of infestation and visual damage symptoms. Among biochemical traits, X_1 showed a significant positive correlation with total sugar content (X_6 ; $r = 0.87$, $p < .01$), suggesting that germplasm with higher sugar content tend to support larger aphid population. X_1 had significant negative correlations with total phenols (X_7 ; $r = -0.583$, $p < .01$) and total glucosinolates (X_9 ; $r = -0.523$, $p < .05$), both of which are known secondary metabolites involved in plant defense. Morphological traits like surface wax content (X_{14} ; $r = -0.574$, $p > .01$) showed surface wax shows negative correlation. The present correlation analysis highlights that the mean number of aphid population per plant is strongly associated with several biochemical and morphological parameters in mustard germplasm. The highly significant positive correlations with aphid population index, aphid damage index and aphid resistance index, reaffirm that these indices accurately reflect field infestation levels and can be reliably used in resistance screening. Among biochemical traits, the strong positive correlation between aphid population and total sugar content suggests that elevated sugar levels may favour aphid multiplication. High sugar availability might enhance the nutritional quality of phloem sap, making the host plant more suitable for aphid feeding and reproduction. This observation is consistent with earlier findings where susceptible germplasm often showed higher sugar content. Conversely, significant negative correlations of aphid population with total phenols and total glucosinolates support the defensive roles of these secondary metabolites. Phenolic compounds are known to deter insect feeding by affecting palatability and digestibility, while glucosinolates play a critical role in Brassicaceae defense by producing toxic breakdown products that inhibit herbivore performance. Additionally, surface wax content exhibited a significant negative correlation with aphid population, suggesting that higher wax deposition may act as a physical barrier against aphid colonization and movement. Surface waxes have previously been reported to interfere with aphid probing behaviour and settlement. Although not all parameters showed statistically significant correlations, the overall trend indicates that secondary metabolites and surface waxes are closely linked with aphid resistance, whereas traits like sugar content may contribute to susceptibility. These findings provide useful insights for breeding programs aiming to develop mustard germplasm with durable aphid resistance through enhanced biochemical defense and structural traits.

The current study used Principal Component Analysis (PCA) to assess the relationship among different characteristics, including morpho-biochemical traits and aphid infestation parameters in mustard germplasm for *Lipaphis erysimi* preference. Four principal components (PCs) were extracted, with four components (PC1, PC2, PC3 and PC4) having eigenvalues greater than 1.0 and explaining the majority of the total variance. Figure 1 displays a wide range of morphological and biochemical parameters. As shown in Table 4.10, PC1 accounted for 49.9% of the total variability, PC2 contributed 14.9%, PC3 contributed 9.8% and PC4 contributed 9% together explaining 83.6% of the cumulative variance. The PCA loading matrix indicated that aphid infestation related parameters including aphid population (AP), aphid population index (API), aphid damage index (ADI), and aphid resistance index (ARI) had high positive loadings on PC1, suggesting a strong influence on the primary component. In contrast, key biochemical defense traits such as total phenols (TP), total glucosinolates (TG), surface wax (SW), ascorbate peroxidase (PA), and total sugar (TS) loadings on PC1, Phenylalanine ammonia lyase activity (PAL), Tyrosine ammonia lyase activity (TAL) and Total Chlorophyll Content (TCC) loading on PC2, stem diameter (SD) comes on PC3 and the total tannin (TN) loading on PC4. Regarding the strength of their relationship, the Pearson correlation matrix (Table 6) confirmed the previous statement.

Discussion

The current study revealed notable differences in aphid (*Lipaphis erysimi*) infestation levels among *Brassica juncea* germplasm under natural field conditions during the *rabi* seasons of 2023-24 and 2024-25. Germplasm such as TARAMIRA, LACMA-SP523N5, and RH-725 consistently supported higher aphid populations, indicating greater susceptibility. In contrast, PM-25, KRANTI, and PDL-1 exhibited lower aphid counts, demonstrating strong resistance. The current study's findings were in accordance with those of Madhukar (2012) who evaluated various germplasm and identified KRANTI as the least susceptible, with an infestation level of 1.59. Dwivedi et al. (2019) also observed the highest aphid populations on the variety PDL-1 (285.7 aphids per 10 cm of the top shoot) and the lowest on Rohini (110.5 aphids per 10 cm of the apical shoot). The present findings are also similar to the results reported by Tripathi et al. (2025), who screening of 50 *Brassica* genotypes, observed the KRANTI (*Brassica juncea*) exhibited the lowest aphid population among the genotypes.

Across the 2023-24 and 2024-25 cropping seasons, *Brassica juncea* germplasm displayed significant disparities in aphid population index (API: 2.0-5.8 and 2.0-4.3), aphid damage index (ADI: 1.0-4.7 and 1.0-3.4), and aphid resistance index (ARI: 1.5–5.3 and 1.5–3.9). Germplasm TARAMIRA, RH-725, and LACMA-SP523N5 exhibited persistently high API and ADI, but low ARI, flagging them as highly susceptible to *Lipaphis erysimi*. Conversely, PM-25, KRANTI, and PDL-1 consistently had low API and ADI and high ARI, confirming their stable resistance. The consistency of the present findings with those reported by Kumar et al. (2025); Samal et al. (2023) and (Dhillon et al. 2018) further reinforces the reliability of the identified resistant and susceptible germplasm. These previous studies also documented significant genotypic differences in aphid resistance and highlighted the importance of multi-seasonal evaluation for the identification of stable sources of resistance. Previous findings were not much comparable to the current findings since the screening was done with different *Brassica juncea* germplasms in the current study, which were not included in earlier research. The geographical variable also affects the insect population.

The results reported here show that mustard aphid had a variable response to selected Brassica germplasms. This was most likely attributed to the plants range of physical, and biochemical properties. Stem thickness affects the aphid infestation, highly infested germplasms SHIVANI, TARAMERA, and PUSA TARAK having thicker stems, while RADHIKA, CS-60, and PDL-1 had thinner stems. Although not a biochemical trait, stem diameter may provide mechanical

resistance to aphid penetration and movement. Samal (2021) noticed thicker stems can deter aphid colonization by stylet penetration and delaying phloem access. The highest surface wax deposition was found in PM-25, KRANTI, and MASC-1, and the lowest in TARAMERA, EC-399301, and PUSA TARAK. Waxes serve as a physical barrier, interfering with aphid landing, probing, and feeding behavior. The results are in agreement with findings by Kumar et al. (2017) and Pippal et al. (2022), who documented the significant role of epicuticular wax in pest resistance across *Brassica species*.

The biochemical compounds of mustard leaves significantly differed among the tested mustard germplasms. The total chlorophyll content among the germplasm ranged significantly, with higher values observed in resistant germplasm such as PUSA TARAK and RH-725. Increased chlorophyll may enhance photosynthetic efficiency and plant vigor, indirectly contributing to stress tolerance, although it may not directly influence aphid resistance. Chandrakumara et al. (2024) found in his research the total chlorophyll content in of *Brassica juncea* cultivars ranged from 5.5 to 9.1 mg/g of tissue. However, he suggested that healthy foliage can delay aphid colonization by improving plant defense signalling. Similar trends were recorded by Ipsita et al. (2021), who indicated a moderate association between chlorophyll content and aphid suppression under early infestation stages.

Sugar content varied markedly across germplasm, with the highest levels observed in TARAMIRA, RH-725, and LACMA-SP523N5. Elevated sugar levels are positively correlated with aphid population, as sugars enhance the palatability and nutritive value of phloem sap, promoting aphid feeding and reproduction. Similarly, Kumar et al. (2017) reported that sugar content significant and positive correlation with aphid population. Ahmed et al. (2022) also reported that high sugar content in plants was associated with susceptibility to aphid infestation and provided better nutrients for the growth and development of aphids. This results also supports the findings of Pippal et al. (2022) and Samal et al. (2021), who confirmed that susceptible germplasm often accumulates higher sugar content, resulting in increased aphid multiplication.

Higher phenol levels were consistently recorded in resistant germplasm such as KRANTI, PM-25, and RADHIKA. Phenolic compounds function as natural antifeedants by disrupting aphid digestion and reducing palatability. A significant negative correlation between phenol content and aphid population was also reported in the present study. Yadav and Rana (2018) reported that the correlation coefficient between phenol content and aphid infestation index was significantly negative. Kumar and Singh (2012) reported significant negative correlation between phenolics content and aphid infestation. Some other findings align with those of Chandrakumara et al., (2024); Mishra et al., (2019) and Pippal et al., (2022), who have emphasized the defensive roles of phenolics in plant resistance mechanisms.

Peroxidase activity, an indicator of oxidative stress response, ranged from 777.2 to 1399.5 U/mg among the germplasm. Maximum activity was observed in KRANTI and MASC-1, while the minimum was recorded in RH-725 and GIRIRAJ. Peroxidase enzymes play a vital role in strengthening cell walls through lignification and in detoxifying reactive oxygen species during pest attack. These results align with earlier findings by Samal (2021) and are further supported by Xu et al. (2021), who observed peroxidase activity higher in susceptible germplasm.

Tannin levels were notably higher in germplasm such as KRANTI and PDL-1. Tannins have been reported to act as feeding deterrents by forming complexes with insect digestive enzymes. However, the role of tannins in aphid resistance is complex, as seen in TARAMIRA, which, despite high tannins, was highly susceptible indicating that tannins alone may not confer resistance. Samal et al. (2021) also reported greater quantity of total tannins in the resistant germplasm of *B. juncea* further supported by Chandrakumara et al. (2023).

Glucosinolates were highly concentrated in resistant germplasm like PM-25, KRANTI, and RADHIKA, while susceptible lines like LACMA-SP523N5 recorded the lowest levels. These sulphur-containing compounds degrade into toxic isothiocyanates upon aphid feeding, thereby impairing insect physiology. Bakhetia (1989) who reported a negative correlation between aphid population and total glucosinolate content. Similarly, findings of Viswakannan (2000) are also in support of present findings as they observed a negative correlation between total glucosinolate content and aphid population. The findings align with Samal et al. (2021) and Kumar et al. (2017), who confirmed that glucosinolates are critical biochemical markers for resistance in Brassicaceae. Rask et al. (2000) suggested that on one side, the glucosinolate-myrosinase system provides resistance against many generalist insect-pests, and on the other hand, it makes plants vulnerable to attack by specialist insects such as *L. erysimi*.

PAL is a key enzyme in the biosynthesis of phenolic compounds. Its activity ranged between 551.6 and 1998.8 u/ml, with the highest values recorded in KRANTI, SHIVANI, and MASC-1, indicating enhanced activation of the phenylpropanoid pathway. Increased PAL activity has been correlated with reduced aphid colonization and feeding damage. These findings corroborate with the Chandrakumara et al. (2024) similarly found in his study the PAL activity in healthy tissue range from 642.7 to 1900.5 u/ml. The constitutive PAL activity in RH-725 displayed highest upsurge in the PAL activity, while Pusa Tarak exhibited lowest surge in the activity of PAL. who emphasized the defensive role of PAL in secondary metabolite production. Also, the findings align with Samal et al. (2021). TAL activity ranged from 508.8 to 1619.8 u/ml, with maximum levels found in KRANTI, PUSA BAHAR, and CS-60. TAL, like PAL, is involved in the phenylpropanoid pathway and contributes to the synthesis of antimicrobial compounds and cell wall fortification. Elevated TAL levels suggest a heightened defense readiness in this germplasm. Kumar et al. (2020) and Ipsita et al. (2021) support the association between TAL activity and aphid resistance in mustard. These findings were consistent with the findings of the current investigation.

The correlation analysis clearly establishes that the mean number of aphids per plant is strongly associated with several physiological, biochemical, and morphological traits in *Brassica juncea* germplasm. These results support the use of visual rating and index-based metrics for effective resistance screening, as also emphasized by Samal (2021). Biochemically, a strong positive correlation between aphid population and total sugar content indicates that higher sugar levels enhance aphid proliferation. Increased sugar concentration in plant tissues may improve phloem sap palatability, promoting feeding and reproductive success of *Lipaphis erysimi*. Also, the results are in agreement with findings by Kumar et al. (2020), who observed significantly positively correlated with total sugar content with aphid population. Conversely, significant negative correlations with total phenols and total glucosinolates highlight the defensive function of these secondary metabolites. Glucosinolates crucial allelochemicals in Brassicaceae release toxic isothiocyanates upon hydrolysis, deterring aphid colonization and growth by Chandrakumara et al. (2024). In terms of morphology, surface wax content showed a moderate negative correlation with aphid population indicating that higher wax deposition may hinder aphid movement and settling. This aligns with previous studies

demonstrating that epicuticular wax acts as a physical barrier, disrupting aphid probing and stylet insertion Pippal et al. (2022). Also, the findings align with Ipsita *et al.* (2021), who suggest that resistance to mustard aphid is a multifaceted trait influenced by both biochemical defenses (e.g., phenols, glucosinolates) and morphological barriers (e.g., wax content). Incorporating these traits in breeding programs could lead to the development of aphid-resistant cultivars with reduced reliance on chemical control.

Conclusion

The exploration into the biophysical and biochemical mechanisms of plant resistance in against *Brassica juncea* germplasms against mustard aphid *Lipaphis erysimi* (Kalt.) infestation sheds light on crucial aspects of insect-plant interactions. Through this study, we have gained insights into the intricate defense strategies employed by mustard plants, which involve both morphological and biochemical components. The biophysical barriers biochemical defenses collectively contribute to the resistance observed in mustard plants against the *L. erysimi*, biophysical and biochemical mechanisms underlying plant resistance in mustard plant against the *L. erysimi* represents a significant step towards developing resilient and eco-friendly pest management strategies, thereby ensuring the productivity and sustainability of mustard cultivation in the face of pest challenges.

Declarations

The authors want to say that no conflict of interest exists.

Authors contribution

HM: Conceptualization, Methodology, Investigation, Writing - original draft, KRS: Supervision, Data curation, Writing - review & editing, Writing - original draft. SKS: Writing - review & editing, Formal analysis, Conceptualization.

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Tables

Table 1: Aphid Population Index (API), Aphid Damage Index (ADI), Aphid Resistance Index (ARI) and Resistance category

Aphid Population Index (API)	Aphid Damage Index (ADI)	Aphid Resistance Index (ARI)	Resistance category
1 = No or less than 20 aphids on the inflorescences of test plants.	1 = Normal plant growth, no symptoms of injury, no curling or yellowing of leaves.	(API+ADI/2)	0.1-1.0 = Resistance
2 = Up to 25% of inflorescences have 21-100 aphids on the test plants.	2 = Average plant growth, curling and yellowing of few leaves, flowering and fruiting.	(API+ADI/2)	1.1-2.0 = Moderately resistance
3 = Upto 50% of inflorescences have 101-250 aphids across test plants.	3 = Poor plant growth, curling and yellowing of leaves on some branches, drying of few flowers and poor pod setting.	(API+ADI/2)	2.1-3.0 = Tolerant
4 = Upto 75% inflorescences have 251-500 aphids across test plants.	4 = Stunted plant growth, heavy curling and yellowing of leaves all through the plant, drying and curling of almost half the inflorescence with poor flowering and rare pod setting.	(API+ADI/2)	3.1-4.0 = Susceptible
5 = 100% of inflorescences have more than 500 aphids across test plants.	5 = Severe stunting and ragged plant appearance, yellowing and curling of almost all the leaves, complete drying of inflorescence without any flower and immature drying of pods if any.	(API+ADI/2)	4.1-5.0 = Highly susceptible

Table 2: Population build-up and resistance indices of *Lipaphis erysimi* on different *Brassica* germplasm under natural conditions during *Rabi* 2023-24 and 2024-25

Germplasm	Aphids/10 cm top shoot portion		API		ADI		ARI	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
BRIJRAJ	194.2±42.6	115.5±21.0	3.8±0.4	3.1±0.2	2.1±0.2	2.8±0.2	3.0±0.1	3.0±0.3
PDL-1	30.8±4.1	41.0±8.1	2.0±0.1	2.1±0.1	1.0±0.3	1.2±0.3	1.5±0.2	1.7±0.1
RH-725	162.6±31.1	181.1±34.4	3.5±0.2	3.7±0.3	2.0±0.4	3.4±0.2	2.8±0.3	3.6±0.2
LACMA-SP523N5	272.3±57.1	170.2±34.1	4.1±0.3	3.3±0.3	3.1±0.3	3.1±0.2	3.6±0.3	3.2±0.2
GIRIRAJ	127.9±30.5	157.3±29.2	3.3±0.2	3.3±0.2	1.8±0.2	3.7±0.2	2.6±0.1	3.5±0.3
PUSA TARAK	135.8±28.8	125.7±24.5	3.2±0.1	3.1±0.2	2.0±0.1	3.0±0.1	2.6±0.1	3.1±0.2
PM-29	146.5±31.2	102.6±19.0	3.4±0.3	3.0±0.2	2.1±0.3	2.4±0.3	2.8±0.3	2.7±0.2
PM-22	140.2±28.1	115.1±20.0	3.4±0.3	3.0±0.1	2.0±0.2	2.6±0.1	2.7±0.2	2.8±0.3
EC-399301	84.7±16.1	118.6±21.1	2.7±0.2	3.1±0.1	1.6±0.1	2.6±0.2	2.1±0.3	2.9±0.2
SHIVANI	186.4±40.0	93.3±16.3	3.8±0.3	2.6±0.3	2.4±0.3	1.7±0.2	3.1±0.1	2.1±0.3
KRANTI	22.9±3.8	20.7±3.3	2.0±0.2	2.0±0.2	1.0±0.2	1.0±0.1	1.5±0.2	1.5±0.1
PM-25	21.7±3.3	20.1±2.9	2.0±0.1	2.0±0.1	1.0±0.1	1.0±0.3	1.5±0.3	1.5±0.2
JM-3	133.4±29.3	118.9±25.3	3.2±0.1	3.1±0.3	2.2±0.3	1.2±0.3	2.7±0.2	2.2±0.2
CS-56	166.0±36.8	121.3±28.7	3.7±0.2	3.2±0.3	2.5±0.3	1.0±0.1	3.1±0.3	2.1±0.2
MASC-1	96.5±21.1	95.0±21.2	2.6±0.2	2.4±0.1	2.0±0.2	1.8±0.2	2.3±0.2	2.1±0.3
RH-406	103.3±22.9	114.7±27.1	3.0±0.2	3.2±0.2	1.6±0.2	2.0±0.2	2.3±0.3	2.6±0.3
TARAMERA	782.9±126.3	444.4±85.4	4.8±0.4	4.3±0.4	4.7±0.4	3.4±0.3	4.8±0.1	3.9±0.4
RADHIKA	113.5±26.6	85.6±17.3	3.1±0.3	2.6±0.2	2.2±0.2	1.6±0.2	2.7±0.2	2.1±0.2
CS-60	177.8±43.7	87.0±19.0	3.7±0.1	2.2±0.3	2.8±0.3	1.1±0.1	3.3±0.2	1.7±0.3
PUSA BAHAR	96.2±18.9	74.0±15.6	2.7±0.4	2.1±0.2	1.8±0.1	1.0±0.2	2.2±0.2	1.6±0.2
F-probability	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
LSD (P=0.05)	78.635	53.675	0.706	0.841	0.987	0.651	0.759	0.658

API = Aphid Population Index, ADI = Aphid damage Index, ARI = Aphid Resistance Index

Table 3: Evaluation of mustard germplasm based on aphid resistance-related biochemical parameters

Germplasm	Total Chlorophylls	Total Sugar	Total Phenols	Peroxidase Activity	Tannin Estimation	Total Glucosinolates	PAL	TAL
BRIJRAJ	3.7±0.1	8.6±0.1	2.8±0.1	1076.0±0.9	2.4±0.1	37.9±0.8	1782.7±13.8	1419.5±17.6
PDL-1	8.5±0.1	3.4±0.1	4.2±0.1	1035.9±1.7	3.1±0.1	82.4±1.6	1276.2±9.5	1366.5±20.5
RH-725	9.3±0.1	14.2±0.1	3.1±0.1	777.2±0.9	1.5±0.1	24.2±0.4	1042.5±19.5	1221.7±12.1
LACMA-SP523N5	5.4±0.1	12.1±0.1	3.0±0.1	1017.4±1.2	1.1±0.1	26.7±0.2	807.4±9.0	1050.8±9.6
GIRIRAJ	7.9±0.3	10.6±0.1	1.5±0.1	986.2±1.9	0.4±0.1	56.0±1.1	1154.3±20.3	774.7±12.1
PUSA TARAK	9.6±0.1	11.1±0.1	2.4±0.1	1120.4±3.1	0.1±0.1	27.8±0.9	1160.1±2.2	559.2±7.4
PM-29	7.3±0.3	8.7±0.2	2.8±0.1	1123.5±1.6	0.5±0.1	43.9±1.1	1274.6±5.8	666.4±7.9
PM-22	8.8±0.3	9.8±0.1	2.8±0.1	1075.8±1.7	0.1±0.1	38.4±1.0	1460.8±17.7	778.5±7.7
EC-399301	5.4±0.2	6.7±0.1	2.5±0.1	1107.8±4.5	0.1±0.1	51.3±1.0	1679.7±19.3	884.6±6.0
SHIVANI	5.7±0.2	4.7±0.1	4.9±0.1	1075.0±0.8	1.7±0.1	63.7±0.8	1888.0±4.1	994.1±10.5
KRANTI	6.3±0.1	1.4±0.1	6.4±0.1	1399.5±59.3	3.6±0.1	103.6±2.1	1998.8±39.7	1619.8±14.6
PM-25	7.9±0.1	1.7±0.1	5.2±0.1	1125.1±2.0	2.8±0.1	108.2±2.0	551.6±11.5	508.8±21.2
JM-3	4.6±0.1	7.9±0.1	2.8±0.1	1082.6±0.9	0.3±0.1	13.7±0.2	1757.4±32.4	1294.0±20.0
CS-56	4.7±0.1	6.7±0.1	3.1±0.1	1117.1±1.8	1.7±0.1	36.1±1.4	1650.8±27.1	922.6±10.6
MASC-1	6.9±0.1	5.9±0.1	4.3±0.1	1210.5±1.2	2.1±0.1	86.0±1.6	1867.9±32.4	797.1±54.3
RH-406	4.6±0.3	9.2±0.1	4.9±0.1	1089.9±4.0	0.6±0.1	34.2±1.5	1529.7±16.3	1096.4±6.3
TARAMERA	4.9±0.1	17.6±0.1	2.2±0.1	1107.0±4.7	3.1±0.1	38.4±1.6	1407.7±13.8	1210.4±4.3
RADHIKA	5.7±0.4	6.2±0.1	4.2±0.1	1037.1±3.7	1.8±0.1	92.4±1.6	1231.0±13.2	1322.4±6.7
CS-60	4.2±0.2	5.5±0.1	4.8±0.1	1067.8±2.1	2.1±0.1	81.0±1.5	1042.4±4.4	1441.6±6.0
PUSA BAHAR	6.7±0.1	4.1±0.1	3.9±0.1	1120.0±4.5	1.5±0.1	75.7±0.8	974.5±7.1	1540.3±5.6
C.D.	0.513	0.222	0.137	38.715	0.107	3.646	54.238	48.564
SE(m)	0.179	0.077	0.048	13.495	0.037	1.271	18.907	16.929
SE(d)	0.253	0.11	0.067	19.085	0.053	1.797	26.738	23.941
C.V.	4.831	2.125	2.196	2.149	3.835	3.369	2.378	2.731

Table 4: Evaluation of mustard germplasm based on aphid resistance-related plant morphological parameters

Germplasm	Stem Diameter	Surface Wax
BRIJRAJ	2.8±0.19	3.4±0.05
PDL-1	2.6±0.19	4.3±0.05
RH-725	2.9±0.15	3.6±0.05
LACMA-SP523N5	2.6±0.20	3.7±0.05
GIRIRAJ	2.6±0.17	3.8±0.04
PUSA TARAK	3.0±0.00	3.3±0.05
PM-29	2.9±0.08	3.6±0.04
PM-22	2.6±0.18	3.5±0.06
EC-399301	2.7±0.18	3.2±0.07
SHIVANI	3.1±0.15	3.3±0.04
KRANTI	2.6±0.08	4.8±0.06
PM-25	2.8±0.17	5.1±0.06
JM-3	2.4±0.13	3.4±0.04
CS-56	2.9±0.17	3.7±0.04
MASC-1	2.6±0.17	4.6±0.10
RH-406	2.8±0.14	4.3±0.09
TARAMERA	3.1±0.22	3.1±0.04
RADHIKA	2.1±0.17	3.9±0.08
CS-60	2.5±0.08	3.6±0.07
PUSA BAHAR	2.6±0.15	4.1±0.03
C.D.	0.452	0.168
SE(m)	0.157	0.059
SE(d)	0.222	0.083
C.V.	9.766	2.222

Table 5: Correlation matrix among biochemical, morphological, and resistance traits in mustard germplasm

Parameters	(X ₁)	(X ₂)	(X ₃)	(X ₄)	(X ₅)	(X ₆)	(X ₇)	(X ₈)	(X ₉)	(X ₁₀)	(X ₁₁)	(X ₁₂)	(X ₁₃)	(X ₁₄)
Mean No. of Aphid Population (X ₁)	1.000	0.847***	0.648**	0.772***	-0.170	0.870***	-0.583**	-0.020	-0.523*	-0.285	-0.020	-0.036	0.000	0.000
Aphid Population Index (X ₂)		1.000	0.792***	0.922***	-0.087	0.930***	-0.743***	-0.358	-0.833***	-0.433	0.049	-0.250	0.000	0.000
Aphid Damage Index (X ₃)			1.000	0.966***	0.251	0.850***	-0.74***	-0.384	-0.593**	-0.464*	-0.143	-0.299	0.000	0.000
Aphid Resistance Index (X ₄)				1.000	0.119	0.932***	-0.785***	-0.391	-0.728***	-0.487*	-0.070	-0.284	0.000	0.000
Photosynthetic pigments (X ₅)					1.000	0.047	-0.126	-0.165	0.089	-0.226	-0.381	-0.504*	0.000	0.000
Total Sugar Estimation (X ₆)						1.000	-0.724***	-0.335	-0.757***	-0.522*	-0.136	-0.224	0.000	0.000
Total Phenols Estimation (X ₇)							1.000	0.573**	0.707***	0.471*	0.116	0.250	0.000	0.000
Tannin Estimation (X ₈)								1.000	0.619**	0.315	0.053	0.410	0.000	0.000
Total glucosinolates (X ₉)									1.000	0.455*	-0.094	0.240	0.000	0.000
Ascorbate peroxidase activity (X ₁₀)										1.000	0.464*	0.196	0.000	0.000
Phenylalanine ammonia lyase activity (X ₁₁)											1.000	0.241	0.000	0.000
Tyrosine ammonia lyase activity (X ₁₂)												1.000	0.000	0.000
Stem Diameter (X ₁₃)													1.000	0.000
Surface wax (X ₁₄)														1.000

***, **, * Correlation coefficients significant at P = 0.001, 0.01, 0.05 level, respectively

Table 6: Principal components (PCs) with eigen values and variances in germplasm preference by *Lipaphis erysimi* in mustard

PCs	Variables	Eigen value	% Variance	Cumulative % of Variance
1	AP, API, ADI, ARI, TS, TP, TG, PA, SW	6.983	49.877	49.877
2	PAL, TAL,	2.079	14.851	64.728
3	SD	1.377	9.833	74.562
4	TN	1.255	8.962	83.524

AP Aphid population, API Aphid population index, ADI Aphid damage index, ARI Aphid resistance Index, TCC Total Chlorophyll Content, TS Total Sugar Estimation, TP Total Phenols Estimation, TN Tannin Estimation, TG Total glucosinolates, PA Ascorbate peroxidase activity, PAL Phenylalanine ammonia lyase activity, TAL Tyrosine ammonia lyase activity, SD Stem Diameter, SW Surface wax.

Figures

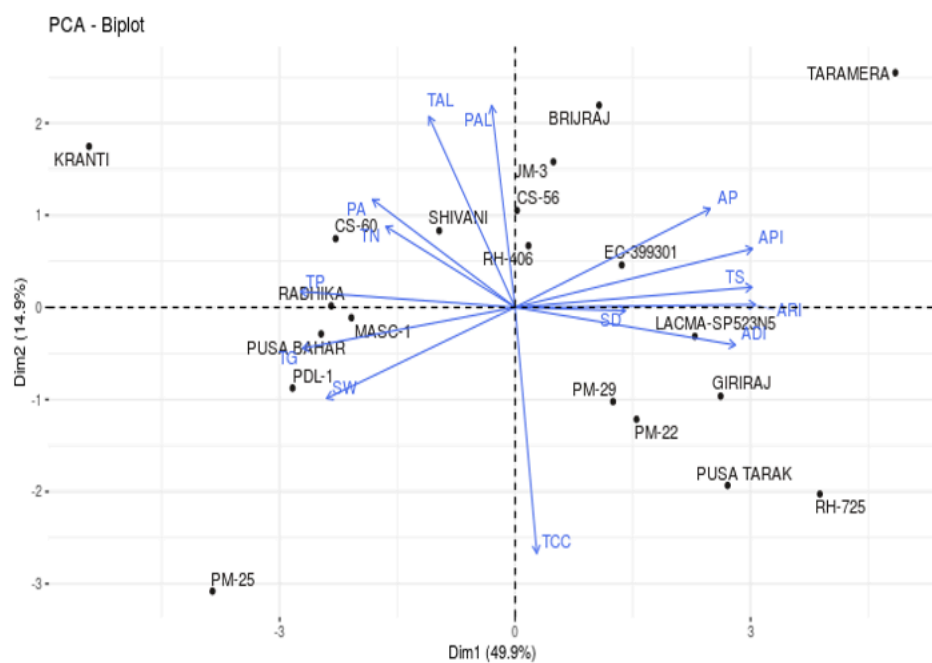


Figure 1

Principal component analysis (PCA) bi-plot of various morpho-biochemical constituents of mustard germplasm biochemical traits in the red rice germplasm preference by *Lipaphis erysimi* in mustard: a grouping of the variables into two main principal components.