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# Comparative assessment of red and white cabbage resistance against diamondback moth (*Plutella xylostella* L.)

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## Abstract

Cabbage defense against diamondback moth (DBM, *Plutella xylostella* L.) is primarily influenced by various factors, particularly the leaf anatomical traits and phytochemical composition. Four cabbage varieties were assessed for resistance to DBM during the 2020 and 2021 growing seasons at the Agricultural Research Station, University of Basrah (Basra, Iraq). The results indicated that the red cabbage (*Brassica oleracea* var. *capitata* f. *rubra*) varieties Hanar and Kirmizi exhibited low infestation by DBM (1.06 and 1.24 larvae/plant, respectively). However, white cabbage (*Brassica oleracea* var. *capitata* f. *alba*) varieties Dalal and Ortus showed the highest infestation levels (11.18 and 9.74 larvae/plant, respectively). The cuticles, epidermal layers, and parenchymal cells of red cabbage were thicker than those of the white cabbage. The tested varieties varied in their contents of pigments, proteins, carbohydrates, phenols, and glucosinolates. These variations were associated with different levels of DBM infestation. The red cabbage Kirmizi and Hanar showed low infestation, which was likely related to their higher contents of anthocyanins, carotene, phenols, and the glucosinolates progoitrin, goitrin, sinigrin, glucoraphanin, and total glucosinolates. In contrast, the white cabbage varieties, particularly the susceptible cultivar Dalal, had the lowest values of these compounds and consequently showed higher infestation. This study demonstrates that anatomical traits and phytochemical composition are key determinants of cabbage resistance to DBM. Therefore, cultivation of resistant red cabbage varieties offers a promising approach for integrated pest management programs.

**Keywords** Anatomical traits, Cabbage, Diamondback moth, Phytochemical traits, Resistance

## Introduction

Diamondback moth (DBM, *Plutella xylostella* L., Plutellidae: Lepidoptera) is a destructive insect pest responsible for significant crop losses in the mustard family, Brassicaceae, worldwide (Divekar et al. 2024; Philips et al. 2014). DBM larvae harm cabbage by feeding on both sides of the leaves before and after the head forms. As the larvae

grow, the damage worsens as they move into the cabbage crown and bore into the head, reducing marketable yield. Additionally, insect debris can lessen product attractiveness (Furlong et al. 2013).

Various reports have shown that DBM can cause serious damage to cabbage crops, despite the routine use of insecticides (Sharma et al. 2024). This pest is widely recognized for its rapid evolution of resistance, which has been documented across multiple classes of pesticides (Shen et al. 2023; Wang et al. 2021; Banazeer et al. 2022). Regular application of the pesticides also has a devastating influence on the beneficial insects in the cabbage fields' ecosystem (Firake et al. 2017; Ikram et al. 2026).

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The development of insecticide resistance has intensified the search for alternative control methods that are environmentally safe (Siddiqui et al. 2023). IPM provides the most sustainable approach for regulating this pest and mitigating its impact (Asante et al. 2025). A major management strategy is the use of resistant varieties as a part of the cultural control program, which is used to maintain pest densities below economic threshold levels (Sarfraz et al. 2007; Ullah et al. 2025; Tamang and Singh 2025). Host-plant resistance (HPR) contributes to plant protection through one or different tools, antibiosis, antixenosis, and/or tolerance (Mani et al. 2022; Xu et al. 2025). Plant resistance traits can deter the pests by limiting host preference and decreasing suitability for feeding or oviposition. It can also have toxic effects that increase the development time, raise mortality, and reduce the body mass of herbivores (Atee et al. 2025; Bandoly et al. 2016; Kaur et al. 2025).

Morphological traits associated with resistance in Brassicaceae crops have been examined for their effects on Lepidopteran pests, including *P. xylostella* (Ulmer et al. 2002). Traits such as wax content and leaf color have been applied in plant protection to decrease insect infestation and the associated injury (Eigenbrode et al. 1991). Leaf color, in particular, can play a significant role, acting as a repellent to specific pests. For instance, Lepidoptera worms are less attracted to red leaves (Colares et al. 2013; Ide 2022; Xu et al. 2025). Cabbage varieties vary in their susceptibility to damage from DBM. A key factor of this resistance mechanism is the availability of leaf surface wax (Hariprasad and van Emden 2010; Lee et al. 2025). Glossy varieties, which lack the normal waxy coating, are resistant to pest infestation. The larvae obviously invest more time and energy searching and a shorter period feeding on the glossy varieties (Stoner 1990; Zhu et al. 2022).

Additionally, secondary metabolites such as phenols and volatiles have been linked to resistance in varieties against pest herbivores (Khan et al. 2025; Anton and Cortesero 2022). Cabbage plants exhibit varying responses to different herbivore species (Mattiacci et al. 2001; Karmakar et al. 2022). In these plants, some phytochemicals may serve as active defenses against generalists (Malik et al. 2025). However, specialist insects may exploit specific phytochemicals to locate and select their host plants (Grosjean et al. 2024; Piersanti et al. 2020). Crucifers, such as cabbage, canola, Kale, and mustard, vary

relatively in their resistance to infestation by *P. xylostella* (Hasan et al. 2025; Philips et al. 2014). DBM infestation is primarily restricted to Brassicaceae plants, which are distinguished by glucosinolate compounds (Badenes-Pérez et al. 2020; Robin et al. 2017; Davosir et al. 2025). These compounds are a major factor of resistance, acting as a chemical defense. They can negatively affect the performance and fitness of specialist herbivores and serve as a feeding deterrent (Siemens and Mitchell-Olds 1996; Ewunsoh 2023). The objective of this study aimed to evaluate the resistance of red and white cabbage varieties against DBM infestations.

## Materials and methods

### Trial site, experimental design, treatments

The study evaluated four cabbage varieties (two red and two white; Table 1) for resistance to DBM. The experiment was carried out at the Agricultural Research Station of University of Basrah, in the Quarmatt Ali region, Basra, over the 2020–2021 season. The 450 m<sup>2</sup> field was arranged in a randomized complete block design (RCBD) with three replicates. Each experimental unit (30 m<sup>2</sup>) contained three rows planted on 15 November 2019. Rows were set 50 cm apart, and plants within each row were spaced at 30 cm intervals. Routine crop management practices were applied, and the first appearance of DBM larvae was observed on 9 January 2020.

### Host plant effect on diamondback moth densities

Weekly random sampling was used to estimate DBM larval populations, based on three plants per experimental unit. Adult specimens were identified at the Museum of Natural History, University of Baghdad. Environmental data (temperature and relative humidity) were sourced from the Weather Forecasting Station, Basra Province.

### Anatomical and biochemical properties of cabbage varieties

#### Anatomical study

A paraffin method for serially sectioning the leaves was used to prepare permanent microscopic slides from the desiccated cabbage varieties' leaves. The leaves were sectioned using sliding microtome according to the method of Fowke and Rennie (1995); the procedure details the careful handling of minute tissues during the process of fixation, washing, dehydration, clearing, and embedding. Next, the cross-sectional area was determined by measuring the areas of cuticle epidermal layers and Parenchymal cells for each variety.

#### Biochemical properties

Plant leaves were collected randomly from cabbage varieties. The samples were washed, oven-dried at 70 °C, and

**Table 1** Cabbage varieties used in the experiment

| Company/country          | Color | Variety | Scientific name                      |
|--------------------------|-------|---------|--------------------------------------|
| Huizer Zaden/Netherlands | Red   | Hanar   | <i>Brassica oleracea</i>             |
| Sun'Agri/India           | Red   | Kirmizi | var. <i>capitata</i> f. <i>rubra</i> |
| Winseed/New Zealand      | White | Dalal   | <i>Brassica oleracea</i>             |
| Seednet/Greek            | White | Ortus   | var. <i>capitata</i> f. <i>alba</i>  |

ground into a fine powder. Subsequently, they were used for the following biochemical analyses:

#### Chlorophyll, carotene, and anthocyanin

The contents of total Chlorophyll, Chlorophyll *a*, Chlorophyll *b*, carotene, and Anthocyanin in each cabbage variety were quantified according to the procedure described by Asare-Boamah et al. (1986). A sample tissue (200 g) was finely homogenized in 8 mL of 80% acetone. The extract was centrifuged at 30,000 rpm; absorbance was measured at wavelengths 470, 520, 663, and 645 nm by using a UV-9200 spectrophotometer (UK). Concentration of chlorophyll, carotene, and Anthocyanin (mg/g of fresh weight) was calculated using the following equations:

$$\text{Chlorophylla}$$

$$= 12.7(D663) - 2.69(D645) \times (V/1000 \times W)$$

$$\text{Chlorophyllb}$$

$$= 22.9(D645 - 4.68(D663)) \times (V/1000 \times W)$$

$$\text{TotalChlorophyll} = 20.2(D645 + 8.02 \times D663) \times (V/1000 \times W)$$

$$\text{Carotene}$$

$$= ((470(OD - 17.1))(\text{chlorophylla} + \text{chlorophyllb}) - (9.47(\text{anthocyanine}))/119.26$$

$$\text{Totalanthocyanincontent} \left( \frac{\text{mg}}{100\text{g}} \right)$$

$$= (OD661) - 0.002423(OD645)0.0439 - (OD534)0.0821$$

OD (Optical density): absorption value at a wavelength.

V: sample volume.

W: leaves weight (1) g.

#### Total phenolic

The ground powder (2.5 g) from each cabbage variety was boiled in 200 ml of distilled water for 1 h using a water bath. The samples were then soaked for 24 h. From the filtrate, 1 ml was combined with 1.5 ml of 10% Folin–Denis reagent and left for 5 min. After that, 1.5 ml of 6% anhydrous sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) was added. The mixture was kept at room temperature for 40 min. Phenolic content was determined by a Spectrophotometer at a wavelength of 760. The device was calibrated with a blank solution of distilled water, Folin reagent, and  $\text{Na}_2\text{CO}_3$  (Waterhouse 2001).

#### Protein

Protein content was quantified using the Kjeldahl procedure as described by Cresser and Parsons (1979). Ground leaves (0.2 g) were transferred into a 100 ml flask and treated with 5 ml of concentrated sulfuric acid. The samples were left for the next day. The next day, 3 ml of a mixture (4% perchloric acid + 96% concentrated sulfuric acid) was added to the digest. The solution was heated until it became clear, then the volume adjusted to 50 ml with distilled water. The total nitrogen was estimated following the method outlined by Page et al. (1982).

$$\% \text{Nitrogen} = \text{acidvolumeHCL} \times 0.02 \times 14 \times 50 \times 100 \div 1000 \times 0.2 \times 10$$

$$\% \text{Protein} = \% \text{Nitrogen} \times 6.25$$

#### Carbohydrates

Total soluble carbohydrates were quantified according to the phenol–sulfuric acid procedure described by DuBois et al. (1956). Ground leaves (0.5 g) of each variety were added to 75 ml of distilled water in a 100 ml flask. The suspension was incubated in a water bath at 70 °C for an hour. The solution was filtered by filter papers; next, 5 ml of the filtrate was diluted with 25 ml of distilled water. Then, 1 ml of phenol and 5 ml of concentrated sulfuric acid were added to the mixture. The absorbance was recorded at 490 nm using a spectrophotometer. Total soluble carbohydrate contents were calculated from the standard glucose calibration curve using the following equation:

$$TSC = \frac{C \times V \times D}{W}$$

TSC: Total soluble carbohydrates (mg/100 g).

C: concentration of carbohydrate in the standard curve.

V: final volume of the extract (ml).

D: dilutions.

W: sample weight (g)

#### Glucosinolates

Extraction was performed following the protocol described by Van Dam and Oomen (2008) at the Biotechnology Research Center /Al-Nahrain University. Ground leaves (1 g) of each variety were transferred into a 20 ml plastic tube; then, 10 ml of 70% methanol was added to each tube. The solutions were mixed by using a shaker (Vortex) and incubated in a water bath for 5 min. They were then placed in an ultrasonic device for 15 min. The samples were then centrifuged at 10,000 rpm for 10 min. The filtrate was separated and stored at 20 °C until HPLC analysis.

### Detection of glucosinolate by HPLC

Samples were analyzed by an HPLC device. The analysis conditions were fixed according to Graser et al. (2000). The mobile phase consisted of a water-acetonitrile (ACN) mixture. It applied in a gradient program as follows: 4–96% at 0.01 min, 20–80% at 4 min, 50–50% at 7 min, 10–10% at 10 min, and 4–96% at 15 min, followed by a stop at 15.01 min. The stationary phase was a stainless-steel column packed with silica particles (ODSc18, 5  $\mu$ m, 250  $\times$  4.6 mm, LD). The flow rate was maintained at 1.0 ml/min, with an injection volume of 20  $\mu$ L. Detection was performed using a UV detector set at 226 nm under laboratory temperature. For each sample, three replicates were prepared and sequentially injected into the HPLC system. The sample concentration was calculated using the following equation.

$$\text{Sample concentration (parts per million)} \\ = \frac{\text{concentration of the standard substance} \times \text{area in the sample}}{\text{area in the standard substance} \times \text{concentration factor}}$$

To evaluate the relationships, the correlation between the studied physiological and biochemical traits and the insect population density was calculated.

### Statistical analysis

The collected data were statistically analyzed using ANOVA with the IBM SPSS statistical program (version 24). Treatment means were compared using the Least Significant Difference (LSD) test at the 0.05 probability level.

### Results

The results in Table 2 showed that the highest densities of the DBM larvae were recorded on the varieties Dalal and Ortus, with an average of 11.18 and 9.74 larvae/plant, respectively. In contrast, the lowest larval densities were reported on the varieties Hanar and Kirmizi with an average of 1.06 and 1.24 larvae/plant, respectively.

Larvae of the diamondback moth were first detected during the first week of December (14.65 °C and 65.5% RH), with an average density of 1.44 larvae per plant. The larval population increased a maximum of 11.44 larvae/plant in the fourth week of February (19.62 °C and 46.08% RH); then, the density declined to 5.18 larvae/plant, in the fourth week of March (24.13 °C and 39.35% RH).

The results indicated significant differences in larval density among the cabbage cultivars throughout the 2020/2021 season. The highest average of larval density (21.86 larvae/plant) was recorded on the variety Dalal during the fourth week of February, while the lowest density (0.39 larvae/plant) was observed on variety Kirmizi in the second week of December.

**Table 2** Larval density of diamondback moth on cabbage variety at the Quarmatt Ali region, Basra Province, during the growing season of 2020/2021

| Mean                | Population of DBM (larvae/plant) ± SE |                          |                            |                           | Week            |
|---------------------|---------------------------------------|--------------------------|----------------------------|---------------------------|-----------------|
|                     | Red cabbage                           |                          | White cabbage              |                           |                 |
|                     | Kirmizi                               | Hanar                    | Ortus                      | Dalal                     |                 |
| 1.44 <sup>A**</sup> | 0.83 ± 0.08 <sup>a</sup>              | 0.86 ± 0.07 <sup>a</sup> | 1.94 ± 0.09 <sup>ab</sup>  | 2.14 ± 0.09 <sup>b*</sup> | 1 (7/12/2020)   |
| 1.55 <sup>A</sup>   | 0.39 ± 0.08 <sup>a</sup>              | 0.53 ± 0.06 <sup>a</sup> | 2.72 ± 0.12 <sup>b</sup>   | 2.58 ± 0.13 <sup>b</sup>  | 2 (14/12/2020)  |
| 2.49 <sup>B</sup>   | 0.67 ± 0.19 <sup>a</sup>              | 0.42 ± 0.1 <sup>a</sup>  | 4.11 ± 0.12 <sup>c</sup>   | 4.78 ± 0.2 <sup>c</sup>   | 3 (21/12/2020)  |
| 4.01 <sup>C</sup>   | 0.89 ± 0.09 <sup>a</sup>              | 0.64 ± 0.12 <sup>a</sup> | 6.39 ± 0.15 <sup>d</sup>   | 8.14 ± 0.24 <sup>e</sup>  | 4 (28/12/2020)  |
| 4.97 <sup>D</sup>   | 0.67 ± 0.07 <sup>a</sup>              | 0.69 ± 0.06 <sup>a</sup> | 8.53 ± 0.32 <sup>ef</sup>  | 10.00 ± 0.32 <sup>g</sup> | 5 (04/01/2021)  |
| 5.94 <sup>E</sup>   | 1.03 ± 0.10 <sup>a</sup>              | 0.58 ± 0.07 <sup>a</sup> | 10.53 ± 0.26 <sup>g</sup>  | 11.61 ± 0.29 <sup>h</sup> | 6 (11/01/2021)  |
| 5.98 <sup>E</sup>   | 1.00 ± 0.09 <sup>a</sup>              | 0.94 ± 0.08 <sup>a</sup> | 9.91 ± 0.36 <sup>fg</sup>  | 12.06 ± 0.35 <sup>h</sup> | 7 (18/01/2021)  |
| 6.87 <sup>F</sup>   | 2.50 ± 0.19 <sup>b</sup>              | 2.42 ± 0.20 <sup>b</sup> | 10.91 ± 0.32 <sup>g</sup>  | 11.64 ± 0.45 <sup>h</sup> | 8 (25/01/2021)  |
| 6.86 <sup>F</sup>   | 1.58 ± 0.15 <sup>a</sup>              | 1.28 ± 0.13 <sup>a</sup> | 11.22 ± 0.24 <sup>h</sup>  | 13.36 ± 0.45 <sup>i</sup> | 9 (01/02/2021)  |
| 6.50 <sup>F</sup>   | 1.58 ± 0.14 <sup>a</sup>              | 1.14 ± 0.10 <sup>a</sup> | 10.28 ± 0.29 <sup>g</sup>  | 13.00 ± 0.39 <sup>i</sup> | 10 (08/02/2021) |
| 7.80 <sup>G</sup>   | 1.61 ± 0.10 <sup>a</sup>              | 1.36 ± 0.09 <sup>a</sup> | 12.17 ± 0.46 <sup>hi</sup> | 16.02 ± 0.58 <sup>j</sup> | 11 (15/02/2021) |
| 11.44 <sup>H</sup>  | 3.14 ± 0.09 <sup>b</sup>              | 3.14 ± 0.09 <sup>b</sup> | 17.61 ± 0.40 <sup>k</sup>  | 21.86 ± 0.51 <sup>l</sup> | 12 (22/02/2021) |
| 8.41 <sup>I</sup>   | 1.33 ± 0.05 <sup>a</sup>              | 1.19 ± 0.07 <sup>a</sup> | 15.19 ± 0.39 <sup>j</sup>  | 15.92 ± 0.44 <sup>j</sup> | 13 (01/03/2021) |
| 7.43 <sup>G</sup>   | 0.72 ± 0.08 <sup>a</sup>              | 0.61 ± 0.07 <sup>a</sup> | 13.94 ± 0.32 <sup>i</sup>  | 14.42 ± 0.36 <sup>i</sup> | 14 (08/03/2021) |
| 6.00 <sup>E</sup>   | 1.06 ± 0.09 <sup>a</sup>              | 0.61 ± 0.05 <sup>a</sup> | 10.89 ± 0.16 <sup>g</sup>  | 11.44 ± 0.18 <sup>h</sup> | 15 (15/03/2021) |
| 5.18 <sup>D</sup>   | 0.81 ± 0.09 <sup>a</sup>              | 0.58 ± 0.05 <sup>a</sup> | 9.44 ± 0.11 <sup>f</sup>   | 9.89 ± 0.10 <sup>fg</sup> | 16 (22/03/2021) |
|                     | 1.24 <sup>A</sup>                     | 1.06 <sup>A</sup>        | 9.74 <sup>D</sup>          | 11.18 <sup>C***</sup>     | Mean            |

\*Means (week  $\times$  variety) with the same uppercase letters are not statistically significant

\*\*Means (week) with the same lowercase letters are not statistically significant

\*\*\*Means (variety) with the same uppercase letters are not statistically significant

**Table 3** Anatomical characteristics of the leaf of different cabbage varieties and their correlation with DBM larval density

| Thickness (µm) ± SE       |                           |                           | Variety    | Cabbage |
|---------------------------|---------------------------|---------------------------|------------|---------|
| Cuticle layer             | Epidermal layer           | Parenchyma cells          |            |         |
| 630.0 ± 20.2 <sup>a</sup> | 120.0 ± 10.4 <sup>a</sup> | 180.0 ± 15.6 <sup>a</sup> | Dalal      | White   |
| 746.7 ± 23.1 <sup>b</sup> | 176.0 ± 8.7 <sup>b</sup>  | 264.0 ± 13.1 <sup>b</sup> | Ortus      |         |
| 910.0 ± 22.2 <sup>c</sup> | 190.0 ± 20.0 <sup>b</sup> | 285.0 ± 30.0 <sup>b</sup> | Hanar      | Red     |
| 863.3 ± 15.4 <sup>c</sup> | 180.0 ± 21.1 <sup>b</sup> | 270.0 ± 31.6 <sup>b</sup> | Kirmizi    |         |
| −0.96                     | −0.77                     | −0.77                     | <i>r</i> * |         |

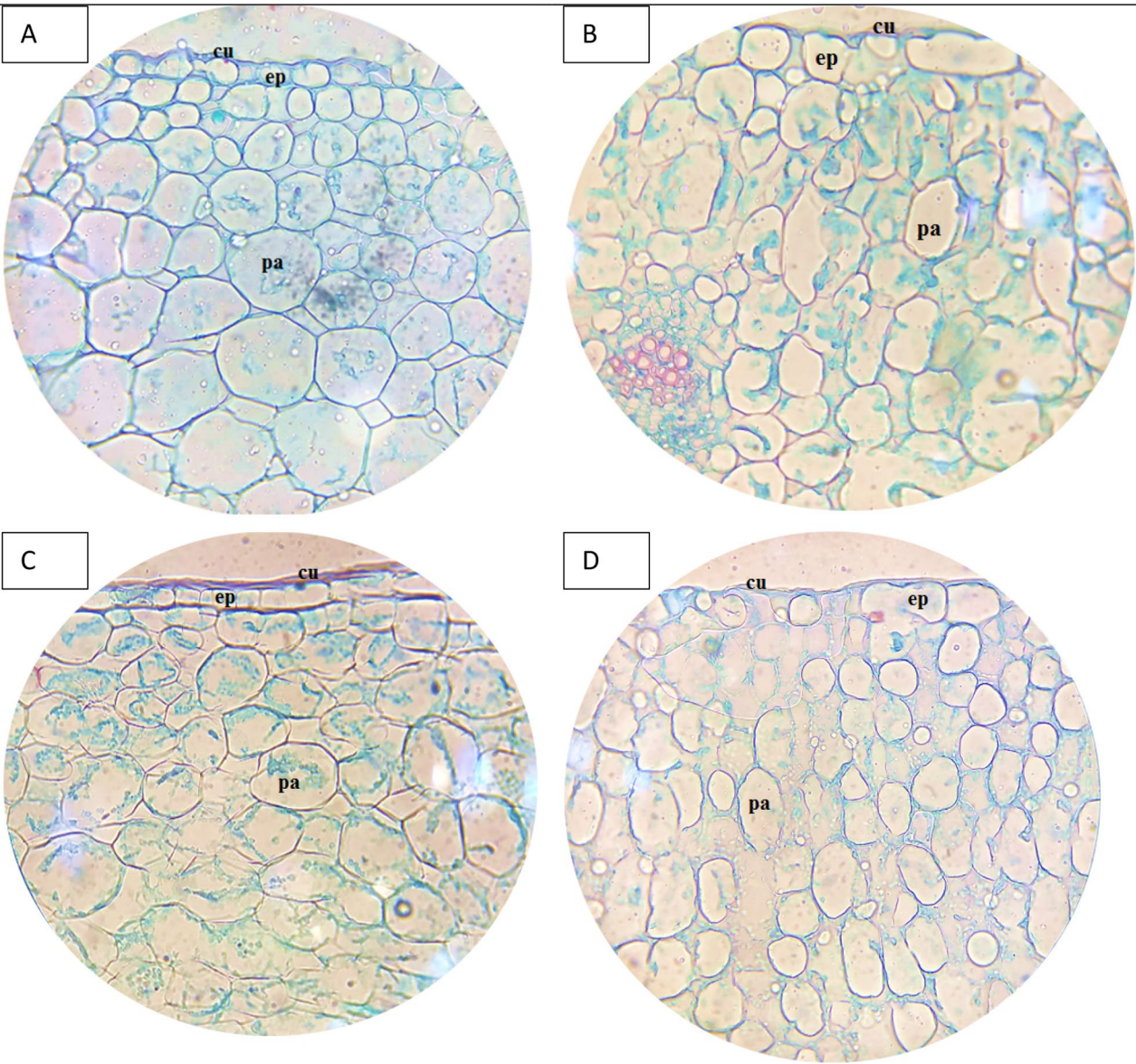
Means in the same column with the same lowercase letters are not statistically significant

\*The correlation coefficient between the anatomical characteristics of the leaf and the larval density of the DBM

**Relationship between Morphological and biochemical traits of diamondback moth infested cabbage varieties**

**Cuticle layer**

The results of Table 3 and Fig. 1 indicated significant differences in the cuticle thickness layers of the leaves among the tested varieties. The maximum cuticle thickness was 910.0 and 863.3 µm in the varieties Hanar and Kirmizi, respectively, while Ortus exhibited a thickness of 746.7 µm. The lowest thickness was recorded in the Dalal variety (630 µm). The results of the statistical analysis indicated a strong negative correlation between the thickness of the cuticle layer and the larval population, where the correlation coefficient = −0.96.



**Fig. 1** Cross-sectional areas of cuticle (Cu) and Epidermal layers (Ep), and Parenchymal cells (Pa) in the cabbage varieties: Ortus (A), Dalal (B), Hanar (C), and Kirmizi (D); at × 40 magnification (200 µm)

**Table 4** Quantity of chlorophyll, carotene, and anthocyanin pigments of some cabbage varieties' leaves (mg/g) and their correlation with DBM larval density

| Leaf content (mg/g) ± SE |                |                  | Variety    | Cabbage |
|--------------------------|----------------|------------------|------------|---------|
| Total chlorophyll        | Carotene       | Anthocyanins     |            |         |
| 0.926 ± 0.064ab          | 0.077 ± 0.007a | 0.008 ± 0.005a   | Dalal      | White   |
| 0.501 ± 0.035a           | 0.118 ± 0.01a  | 0.0027 ± 0.0017a | Ortus      |         |
| 1.246 ± 0.086b           | 0.329 ± 0.028b | 0.0103 ± 0.0005a | Hanar      | Red     |
| 0.877 ± 0.061ab          | 0.28 ± 0.048b  | 0.247 ± 0.024b   | Kirmizi    |         |
| -0.57                    | -0.98          | -0.57            | <i>r</i> * |         |

Means in the same column with the same lowercase letters are not statistically significant

\*Correlation coefficient between the pigmentation of the leaves and the larval density of the DBM

### Epidermal layer

The results also indicated significant variation in the thickness of the epidermal layer among the studied varieties. The greatest average epidermal thickness was recorded in the Hanar variety (190 µm), whereas the lowest average was observed in the Dalal variety (120 µm). Statistical analysis revealed a negative correlation between epidermal layer thickness and larval density ( $r = -0.77$ ).

### Parenchymal cells

The findings also revealed significant differences in the thickness of the parenchymal cells among the four studied varieties. The highest average thickness of cells was found in Hanar variety (285 µm); Kirmizi and Ortus showed an average cell thickness of 270 and 264 µm, respectively. However, the lowest thickness of parenchymal cells was recorded in the Dalal variety (180 µm). Parenchymal cell thickness was associated with lower larval density, with a correlation coefficient of  $-0.77$ .

### Chlorophyll

The analysis of plant pigments (Table 4) revealed that the content of chlorophyll was significantly higher in the Hanar variety, reaching 1.246 mg/g, while the lowest value was recorded in the Ortus variety (0.501 mg/g). Chlorophyll contents of 0.926 mg/g and 0.877 mg/g were recorded in the varieties Dalal and Kirmizi, respectively. The results of the statistical analysis indicated that there is an inverse correlation between the amount of chlorophyll concentration and the larval density population (correlation factor =  $-0.59$ ).

### Carotene

The highest value of carotene was detected in leaves of Hanar variety (0.329 mg/g), while the lowest content was found in Dalal variety (0.077 mg/g). The results of the relationship indicated a strong inverse correlation

**Table 5** Chemical composition of cabbage leaves (mg/g) and their correlation with DBM larval density

| Leaf content (mg/g) ± SE |               |              | Variety    | Cabbage |
|--------------------------|---------------|--------------|------------|---------|
| Proteins                 | Carbohydrates | Phenols      |            |         |
| 12.78 ± 0.6b             | 6.05 ± 0.42b  | 107.7 ± 3.0a | Dalal      | White   |
| 9.3 ± 0.34a              | 4.14 ± 0.29a  | 128.7 ± 3.5b | Ortus      |         |
| 13.13 ± 0.32b            | 3.89 ± 0.27a  | 329.7 ± 5.5d | Hanar      | Red     |
| 19.18 ± 0.14c            | 3.69 ± 0.26a  | 214 ± 3.1c   | Kirmizi    |         |
| -0.65                    | 0.78          | -0.89        | <i>r</i> * |         |

Means in the same column with the same lowercase letters are not statistically significant

\*Correlation coefficient between the chemical content and the larval density of the DBM

between larval population density and carotene ( $r = -0.98$ ).

### Anthocyanins

Significant differences were also observed in the rates of anthocyanins among the varieties. The highest anthocyanin content was found in Kirmizi variety with an average of 0.247 mg/g, while the lowest value was recorded in the Ortus variety (0.0027 mg/g). The content of anthocyanins in Dalal and Hanar varieties was 0.0080 and 0.0103 mg/g, respectively. Anthocyanin content was negatively correlated with DBM larval population ( $r = -0.57$ ).

### Proteins

Table 5 indicated significant differences in the content of protein among the cabbage varieties. The highest content was found in the Kirmizi variety (19.18 mg/g), while the lowest value was in the Ortus variety (9.3 mg/g). Protein content did not differ significantly between Dalal (12.78 mg/g) and Hanar (13.13 mg/g). Protein content was negatively correlated with larval density ( $r = -0.65$ ).

### Carbohydrates

The highest content of carbohydrates was recorded in the Dalal variety (6.05 mg/g), followed by the Ortus variety, with an average of 4.14 mg/g. The lowest carbohydrates were recorded in Kirmizi and Hanar varieties, at 3.69 and 3.89 mg/g, respectively (Table 6). There is a direct relationship between carbohydrates and the density of larvae ( $r = 0.78$ ).

### Phenols

The cabbage varieties exhibited clear differences in phenolic content. Hanar recorded the highest content of phenols (329.7 mg/g), followed by Kirmizi (214 mg/g). However, the lowest value was recorded in the Dalal variety (107.7 mg/g) (Table 6). Statistical analysis showed an inverse relationship between phenol levels and larval density, with a correlation coefficient of  $-0.89$ .

**Table 6** Presence of several compounds of glucosinolates on different cabbage varieties and their correlation with DBM larval density

| Glucosinolate content (ppm) $\pm$ SE |                    |                   |                   |                   | *r    |
|--------------------------------------|--------------------|-------------------|-------------------|-------------------|-------|
| Profile                              | White cabbage      |                   | Red cabbage       |                   |       |
|                                      | Dalal              | Ortus             | Hanar             | Kirmizi           |       |
| Sulforaphane                         | 0.05 $\pm$ 0.04a   | 0.4 $\pm$ 0.02 b  | 0.25 $\pm$ 0.05b  | 0.35 $\pm$ 0.01b  | −0.4  |
| Goitrin                              | 0.01 $\pm$ 0.01a   | 0.12 $\pm$ 0.04a  | 1.8 $\pm$ 0.4b    | 1.62 $\pm$ 0.06b  | −0.94 |
| Glucoalyssin                         | 0.1 $\pm$ 0.02a    | 0.56 $\pm$ 0.04b  | 0.48 $\pm$ 0.04b  | 0.48 $\pm$ 0.05b  | −0.55 |
| Glucoberveroin                       | 0.06 $\pm$ 0.05 a  | 0.28 $\pm$ 0.03 b | 0.2 $\pm$ 0.01ab  | 0.18 $\pm$ 0.05ab | −0.26 |
| Glucoberverin                        | 0.09 $\pm$ 0.03 a  | 0.3 $\pm$ 0.01c   | 0.23 $\pm$ 0.01b  | 0.3 $\pm$ 0.01c   | −0.52 |
| Gluconapin                           | 0.18 $\pm$ 0.06a   | 0.1 $\pm$ 0.02a   | 0.09 $\pm$ 0.01a  | 0.16 $\pm$ 0.05a  | 0.31  |
| Sinigrin                             | 1.88 $\pm$ 0.44a   | 23.92 $\pm$ 0.6b  | 23.02 $\pm$ 0.1b  | 26.46 $\pm$ 1.02c | −0.65 |
| Glucoraphanin                        | 0.07 $\pm$ 0.05a   | 0.25 $\pm$ 0.03b  | 0.27 $\pm$ 0.04b  | 0.22 $\pm$ 0.04ab | −0.65 |
| progoitrin                           | 0.005 $\pm$ 0.005a | 0.06 $\pm$ 0.04a  | 0.21 $\pm$ 0.005b | 0.23 $\pm$ 0.005b | −0.96 |
| Total Glucosinolate                  | 2.445 $\pm$ 0.71a  | 25.99 $\pm$ 0.54b | 26.55 $\pm$ 0.54b | 30 $\pm$ 1.17b    | −0.75 |

Means in the same column with the same lowercase letters are not statistically significant

\*Correlation coefficient between the Glucosinolates and the larval density of the DBM

### Glucosinolate

The results of the glucosinolate profile of the studied cabbage varieties (Table 6) showed the presence of several glucosinolate compounds: Progoitrin, glucoraphanin, sinigrin, gluconapin, glucoiberverin, glucoberveroin, glucoalyssin, goitrin, and sulforaphaneolate. These nine compounds are among the 120–130 known glucosinolates identified in various plants (Fahey et al. 2001; Nguyen et al. 2020; Li et al. 2024a). The concentration of progoitrin was found significantly higher in Kirmizi variety (0.235 ppm) compared to other varieties. Whereas the lowest concentration was recorded in Dalal variety (0.005 ppm). Glucoraphanin had the highest concentration in the Hanar variety (0.27 ppm), and the lowest concentration was recorded in the Dalal variety (0.07 ppm). The concentration of sinigrin was found significantly higher in the Kirmizi variety (26.46 ppm). However, the lowest concentration was recorded in the Dalal variety (1.88 ppm).

The highest concentration of gluconapin was recorded in Dalal (0.18 ppm), and the lowest concentration of 0.09 ppm was found in Hanar. While glucoiberverin had the highest concentration in the two varieties Kirmizi and Ortus, reaching 0.3 ppm, and the lowest concentration was found in the variety Dalal (0.09 ppm). Glucoberveroin had the highest concentration of 0.28 ppm in the variety Ortus, and the lowest concentration in the variety Dalal (0.06 ppm). The concentration of glucoalyssin was found significantly higher in variety Ortus (0.56 ppm), and the lowest concentration was recorded in variety Dalal (0.10 ppm). Goitrin concentration was highest in Hanar (0.8 ppm) and lowest in Dalal (0.01 ppm). The Ortus variety exhibited the highest sulforaphane level (0.4 ppm), whereas Dalal had the lowest (0.05 ppm). Overall, the concentration of total glucosinolate was recorded higher in Kirmizi variety, reaching 30.01 ppm with significant

differences compared to others; whereas, the lowest concentration was found in Dalal variety (2.46 ppm).

Correlation analysis revealed a strong negative relationship between the glucosinolates progoitrin and goitrin and DBM larval density, with correlation coefficients of −0.97 and −0.94, respectively. Moderate negative correlations were observed for glucoraphanin, sinigrin, glucoiberverin, and glucoalyssin ( $r = -0.65$ ,  $-0.71$ ,  $-0.52$ , and  $-0.55$ , respectively). Weak negative correlations were found for glucoberveroin and sulforaphane ( $r = -0.26$  and  $-0.40$ , respectively), while gluconapin showed a weak positive correlation with larval density ( $r = 0.31$ ). Overall, total glucosinolate content was inversely correlated with DBM larval density ( $r = -0.75$ ).

### Discussion

Diamondback moth (DBM) infestation rate varied among cabbage varieties (Table 2). The results of sampling for the DBM population density reflecting damage on cabbage leaves area, caused by feeding of the larvae, showed significant differences among varieties. The red cabbage varieties (Hanar and Kirmizi) had significantly fewer larvae. Conversely, the white variety Dalal exhibited a significantly higher density of larvae.

The present research investigated the role of morphological and phytochemical properties of cabbage varieties on DBM infestation.. Plant resistance to insect herbivory depends on various factors, including the production of secondary metabolites and leaf anatomy. The cabbage varieties varied in anatomical and biochemical characteristics of the leaves. Red cabbage (Hanar and Kirmizi), which exhibited low DBM infestation, had thick cuticle, epidermal layers, and parenchymal cells compared to the susceptible cabbage variety “Dalal”.

Leaf thickness contributes to plant resistance by preventing newly hatched Lepidoptera larvae from feeding (Zalucki et al. 2002). Plant defense against herbivores is

associated with leaf surface and morphological characteristics, such as trichome type, size, and density, cuticle thickness, cell wall thickness, and leaf color (Kaur et al. 2022; Ueno et al. 2025). Wax layers affect DBM larval feeding by influencing larval behavior (Zhu et al. 2022). Glossy-leaved cabbage varieties showed resistance to the DBM, with the waxy layer affecting the foraging and feeding behavior (Philips et al. 2014). Plant wax, composed mainly of fatty compounds, acts as a hydrophobic layer covering the outer surface of leaf tissues (Han et al. 2026). This wax layer, which forms the first line of defense against pathogens, plays a crucial role in defense mechanisms (Han et al. 2026; Wei et al. 2024).

Resistance can also be influenced by biochemical features and secondary plant metabolites that affect the biology of herbivores. In this study, all tested varieties showed different amount of the pigments, proteins, carbohydrates, phenols, and Glucosinolates, which corresponded to varying levels of DBM infestation. For instance, variety 'Kirmizi' showed low infestation that seemed to be related to the high content of the anthocyanin, carotene, phenols, and Glucosinolate (Progoitrin and Goitrin). Cruciferous vegetables contain high levels of carotenoids (Wang et al. 2022). These pigments play important roles not only in plant growth and development, but also in plant defense (Fernández-García et al. 2012). Red pigment has anthocyanins at levels up to 10 times higher than those found in the green pigment (Yuan et al. 2009). The red leaf anthocyanin pigment usually works as a visible warning signal that deters herbivores and reduces their attraction to the plant (Chen et al. 2021; Lev-Yadun 2023).

The highest protein content was found in the resistant variety 'Kirmizi'. In general, the protein content is an important factor in determining the quality of the host herbivorous plant. Some protein levels are beneficial to insects (Li et al. 2024a, b); on the other hand, a higher nitrogen level in leaves may accelerate the development time of herbivorous insects, such as DBM (Nikooei et al. 2015). The highest content of carbohydrates was recorded in the susceptible variety 'Dalal'. Marchioro and Foerster (2013) revealed that adults of the DBM moth need foods rich in carbohydrates as a basis for their energy source, longevity, fertility, and mobility.

The cabbage varieties varied in their phenolic content. Hanar recorded the highest content of phenols. The phenolic content is a crucial factor in determining the suitability of a host plant for herbivorous insects, as high levels of phenols are detrimental to insects and prevent feeding (Li et al. 2024b). Peres et al. (2017) used aqueous extracts of the leaves of *Alibertia edulis* and *A. intermedia* containing phenolic compounds that negatively affected the development of DBM throughout the life cycle, prolonging their duration in the larval stage

and causing death in the larval or pupal stage. Phenolic compounds have multiple roles in plants and are part of a natural defense system against insects, fungi, and bacteria (Khanday et al. 2024; Kumar et al. 2020; Xu and Wang 2025).

The results of the determination of glucosinolates showed that high concentration of some glucosinolates was related to the low density of DBM. Robin et al. (2017) mentioned several glucosinolates appeared, including glucoibererin, glucoerucin, gucoraphanin, glucobras-sicin, progoitrin, and glucoiberin and hydroxyglucobras-sicin-4, which had a role of defense against the injury DBM. The glucosinolates found in cruciferous plants affect herbivorous insects (Magnin et al. 2026). Numerous studies have shown that glucosinolate not only acts in defense against generalist herbivores, but also plays a major role in the host recognition of cross-specialized insects (Badenes-Pérez et al. 2020; Siemens and Mitchell-Olds 1996).

## Conclusions

The anatomical traits and phytochemical composition are key determinants of red and white cabbage resistance to DBM within IPM programs. Our study demonstrated that the red cabbage cultivars Hanar and Kirmizi were most effective in maintaining low DBM populations. Comparative analysis of the studied cultivars showed that leaf morphological and anatomical characteristics are related to their resistance to DBM. The enhanced resistance of red cabbage may be related to the structure of the cuticle, epidermal layers, phenolic compounds, and specific glucosinolates.

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## Author contributions

Aqeel A. Alyousuf: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing—review and editing Rabeaah T. Abdullah: Conceptualization, Data curation, Formal analysis, Investigation [equal], Writing—original draft.

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## Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

## Declarations

## Ethics approval and consent to participate

Ethics approval is not required for this study.

**Consent for publication**

Not applicable.

**Competing interests**

The authors declare no competing interests.

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