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Research Article

Comparative toxicity of insecticides and botanical extracts against canola aphids and associated predators under field conditions

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ABSTRACT

Canola aphid (*Lipaphis erysimi*) is a major insect pest that significantly reduces canola productivity. This study evaluated the efficacy of three insecticides (acetamiprid, profenofos, and diafenthiuron) and two botanical extracts (*Matricaria chamomilla* and *Citrullus colocynthis*) against aphid populations and their effects on associated bio-control agents in two canola varieties, Rainbow and Oscar. Pre-treatment observations revealed no significant differences in aphid or bio-control agent populations among treatments, confirming uniform pest infestation and predator distribution before application. Following treatment, all insecticides and botanical extracts significantly reduced aphid populations compared with the untreated control. In both varieties, diafenthiuron consistently exhibited the highest efficacy, achieving aphid reductions of up to 86.12% and 91.85% at 4 days after treatment in Rainbow and Oscar, respectively. Profenofos and acetamiprid also provided substantial aphid suppression, whereas the botanical extracts were comparatively less effective. Among the botanicals, *C. colocynthis* showed greater aphid reduction than *M. chamomilla* throughout the study. Mean aphid suppression was significantly higher in insecticide-treated plots than in botanical treatments. Assessment of bio-control agent populations indicated that synthetic insecticides adversely affected beneficial insects. Diafenthiuron caused the greatest reduction in bio-control agents, reaching 94.44% and 100% mortality in Rainbow and Oscar varieties, respectively. In contrast, botanical extracts exhibited comparatively lower toxicity, particularly *M. chamomilla*, which preserved a greater proportion of beneficial organisms. In conclusion, diafenthiuron provided the highest aphid control in both canola varieties but significantly reduced bio-control agent populations. In contrast, *C. colocynthis* offered moderate aphid suppression with comparatively lower adverse effects on beneficial arthropods.

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Introduction

Agriculture is a cornerstone of Pakistan's economy, contributing significantly to national income, employment, and food security. Despite its substantial

agricultural base, Pakistan remains heavily dependent on the import of edible oils. According to Ahmed et al. (2013), a considerable proportion of the country's import expenditure is allocated to edible oil imports due to

insufficient domestic production. Pakistan Oilseed Products (2010) reported that local production fulfills only about 20% of the national edible oil demand, while the remaining 80% is met through imports.

Among the major oilseed crops cultivated in Pakistan, canola, rapeseed, and mustard (genus *Brassica*) are important sources of edible oil and have been grown in the subcontinent for centuries. Rapeseed and mustard seeds contain approximately 44-46% high-quality oil and 38-40% protein, along with essential amino acids such as lysine, cysteine, and methionine.

Canola was developed through breeding programs in Canada to reduce undesirable compounds, namely erucic acid in the oil and glucosinolates in the meal (Abbas et al., 2017). These improvements enhanced its suitability for human consumption and animal feed, particularly in the poultry industry. Consequently, canola oil is now regarded as one of the most important vegetable oils worldwide, second only to soybean oil.

Brassica napus L. (canola) is recognized as one of the most important oilseed crops and is currently the third-largest source of vegetable oil globally (Miri, 2007; Kandil and Gad, 2012). In Pakistan, canola is cultivated extensively, particularly in Punjab and Sindh provinces (Anonymous, 2015). Canola oil is highly nutritious, providing approximately 884 kcal per 100 g and containing a favorable fatty acid composition, including 61% monounsaturated, 31% polyunsaturated, and 8% saturated fats. Young canola leaves are also consumed as a vegetable, while the crop serves as a valuable source of green fodder for livestock. The seeds contain approximately 40% oil, which is widely used for cooking, frying, pickling, flavor enhancement, and food preservation. In addition, canola oil has several industrial applications, including leather processing, pharmaceutical products, and livestock feed production through oilseed cake utilization (Arain, 2013).

Canola production is constrained by numerous insect pests throughout its growth cycle, from seedling emergence to maturity. Among these pests, aphids are particularly destructive and can cause yield losses ranging from 700 to 900 kg ha⁻¹ under severe infestations (Mahmoud and Shebl, 2014). Aphid infestations significantly reduce canola productivity (Lamb, 1989), with three species being especially important: *Lipaphis erysimi* (turnip aphid), *Myzus persicae* (green peach aphid), and *Brevicoryne brassicae* (cabbage aphid). Aslam and Razaq (2007) identified

cabbage and turnip aphids as major pests of canola in southern Punjab. The cabbage aphid, *B. brassicae*, is particularly damaging during the flowering and pod formation stages (Aslam et al., 2007; Sayed and Teilep, 2013). Aphids cause damage by extracting plant sap, excreting honeydew that promotes sooty mold growth, and transmitting plant viruses (Berlandier et al., 2010). Under severe infestations, yield losses may exceed 75% (Abbas et al., 2012).

Various management strategies have been employed to suppress aphid populations, including cultural, biological, botanical, and chemical control methods. Intercropping has been reported as an effective approach for increasing crop productivity while reducing losses caused by insect pests, weeds, and diseases (Vandermeer, 1989). Non-chemical management practices are generally considered environmentally safe and less hazardous to human health. However, many commercially cultivated canola varieties exhibit inadequate resistance to aphid infestations, making insecticide applications necessary for effective pest management (Amer et al., 2009). Akbar et al. (2016) reported that chemical insecticides remain the most widely adopted aphid control method among farmers. Nevertheless, excessive reliance on insecticides can lead to environmental contamination, pesticide residues, adverse effects on human health, and disruption of beneficial arthropod populations (Hill, 1989).

Currently, insect pest management in many cropping systems relies heavily on chemical insecticides. According to Nault et al. (2004), systemic insecticide seed treatments represent an important component of integrated pest management because they are relatively economical, selective, environmentally safer, and capable of maintaining ecological balance compared with repeated foliar applications.

Considering the economic importance of canola and the significant losses caused by aphid infestations, the present study was conducted to evaluate the efficacy of selected botanical extracts and chemical insecticides against aphid populations and their associated natural enemies in canola agroecosystems.

Materials and Methods

Experimental site

The field experiment was conducted during the 2020 and 2021 growing seasons at the research farm of the

Airport Campus, Ghazi University, Dera Ghazi Khan, Pakistan. The study aimed to evaluate the population dynamics of aphids and their natural enemies (predators) on canola and to assess the efficacy of selected insecticides and botanical extracts for aphid management under field conditions.

Sowing of canola varieties

Two commercially cultivated canola varieties, namely Oscar and Rainbow, were used in the experiment. Healthy and certified seeds of each variety were sown separately using a seed drill at a seed rate of 2 kg per acre. All recommended agronomic practices, including land preparation, irrigation, fertilization, and weed management, were uniformly adopted throughout the experimental period to ensure optimal crop growth.

Experimental design and plot layout

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Each experimental plot measured 2.5 m². A plant-to-plant spacing of 10 cm and the recommended row-to-row spacing were maintained across all plots. To minimize treatment interference, a buffer distance of 1 m between treatment plots and 2 m between replications was maintained.

Treatments

A total of six treatments were evaluated, including an untreated control. The treatments consisted of three synthetic insecticides, two botanical extracts, and one untreated control. Details of the treatments and their application rates are presented in Tables 1.

Preparation and application of treatments

Before treatment application, the experimental area was calibrated to determine the volume of spray solution required per plot. Treatments were applied separately to both canola varieties using a calibrated knapsack sprayer. The insecticides were applied at the manufacturers' recommended field rates. For the preparation of botanical extracts, fresh leaves of chamomile and bitter apple were collected from surrounding areas of Dera Ghazi Khan. The leaves were shade-dried, ground into powder, and 50 g of each powdered plant material was soaked separately in 1 L of water for 24 h to obtain a 5% (w/v) extract. The extracts were subsequently filtered through muslin cloth before application.

Aphid population assessment

Aphid populations were monitored at two-week intervals in both canola varieties to determine infestation levels. Treatments were applied when the aphid population reached the Economic Threshold Level (ETL).

For population assessment, five plants were randomly selected from each plot, and aphids were counted from the upper 10 cm portion of each plant. A white collection sheet was used to facilitate accurate counting of dislodged aphids. Observations were recorded one day before treatment application (pre-treatment) and at 1, 2, 3, and 4 days after treatment application (post-treatment).

The percentage reduction in aphid population was calculated using the following formula:

$$\text{Percent reduction} = \frac{\text{Pre-treatment population} - \text{Post-treatment population}}{\text{Pre-treatment population}} \times 100$$

Table 1. Details of insecticidal and botanical treatments evaluated for aphid management in canola.

Treatment	Trade name/ Botanical name	Common name	Dose per Acre/Family name
T ₁	Acetamiprid	Mospilan/Rani 20 SP	125 mL
T ₂	Profenofos	Curacron 500 EC	1000 mL
T ₃	Diafenthiuron	Polo 500 SC	200-250 mL
T ₄	<i>Matricaria chamomilla</i>	Chamomile	Asteraceae
T ₅	<i>Citrullus colocynthis</i>	Kortumma/bitter apple	<i>Cucurbitaceae</i>
T ₆	Control	Control	

Assessment of predator population

The abundance of predatory natural enemies associated with canola was recorded in each plot before treatment application. Similar observations were taken after

spraying to evaluate the impact of treatments on beneficial arthropods. The percentage reduction in predator populations was calculated using the same formula employed for aphid population reduction.

Statistical analysis

The collected data on aphid and predator populations, recorded before and after treatment application, were subjected to analysis of variance (ANOVA) using an appropriate statistical software package. Treatment means were separated using the Least Significant Difference (LSD) test at the 5% probability level ($P \leq 0.05$). Data were presented as mean values $\pm$ standard error where applicable.

Results

Aphid population in the rainbow variety

Aphid population before treatment application

The pre-treatment assessment revealed no significant differences among treatments with respect to aphid population, indicating a uniform infestation level before the application of insecticides and botanical extracts (Table 2). Numerically, the highest aphid population was recorded in the *C. colocynthis* treatment (T5) with 113.33 aphids per plant, followed by Acetamiprid (T1; 110.00), Profenofos (T2; 105.00), Control (T6; 103.33), and Diafenthiuron (T3; 102.66). The lowest aphid population (98.66) was observed in the *M. chamomilla* treatment (T4).

Percentage reduction in aphid population one day after treatment application

One day after treatment application, significant reductions in aphid population were observed across all treated plots compared with the untreated control (Table 2). Diafenthiuron (T3) exhibited the highest aphid reduction (56.10%), whereas no reduction was recorded in the control treatment (T6). Statistically similar reductions were observed between Acetamiprid (T1; 42.37%) and Profenofos (T2; 48.69%), as well as between *M. chamomilla* (T4; 25.79%) and *C. colocynthis* (T5; 28.02%).

Percentage reduction in aphid population two days after treatment application

At 2 DAT, Diafenthiuron (T3) remained the most effective treatment, achieving 68.12% aphid reduction, followed by Profenofos (T2; 62.27%) and Acetamiprid (T1; 56.36%). The botanical extracts also reduced aphid populations, with *C. colocynthis* (T5) and *M. chamomilla* (T4) recording reductions of 42.42% and 35.38%, respectively. However, their efficacy was considerably lower than that of the synthetic insecticides (Table 2).

Percentage reduction in aphid population three days after treatment application

Three days after treatment application, all treatments significantly reduced aphid populations relative to the control (Table 2). Diafenthiuron (T3) achieved the highest aphid reduction (82.80%), whereas *M. chamomilla* (T4) exhibited the lowest reduction among the treated plots (47.43%). Acetamiprid (T1) and Profenofos (T2) produced statistically comparable results. No reduction was observed in the untreated control.

Percentage reduction in aphid population four days after treatment application

At 4 DAT, all treatments demonstrated significant differences in aphid suppression (Table 2). Among the botanical extracts, *C. colocynthis* (T5) resulted in greater aphid reduction (60.35%) than *M. chamomilla* (T4; 54.65%). Among the insecticidal treatments, Diafenthiuron (T3) remained the most effective, followed by Profenofos (T2) and Acetamiprid (T1).

Mean percentage reduction in aphid population

The overall mean aphid reduction differed significantly among treatments. Insecticide-based treatments produced substantially higher aphid suppression than botanical extracts. Diafenthiuron exhibited the greatest mean reduction, whereas no reduction was observed in the untreated control (Table 2).

Table 2. Effect of synthetic insecticides and plant extracts on aphid population reduction (%) at different intervals after treatment application in the Rainbow canola variety.

Treatments	Pre-Treatment	1 DAT	2 DAT	3 DAT	4 DAT	% Mean reduction
T ₁ = Acetamiprid	110 a	42.37 b	56.36 b	73.24 b	86.12 b	64.52 b
T ₂ = Profenofos	105 a	48.69 b	62.27 ab	74.86 b	87.97 ab	68.44 b
T ₃ = Diafenthiuron	102.66 a	56.10 a	68.12 a	82.8 a	92.57 a	74.9 a
T ₄ = <i>M. chamomilla</i>	98.66 a	25.79 c	35.38 c	47.43 d	54.65 d	40.81 d
T ₅ = <i>C. colocynthis</i>	113.33 a	28.02 c	42.42 c	54.29 c	60.35 c	46.27 c
T ₆ = Control	103.33 a	0.0 d	0.0 d	0.0 e	0.0 e	0.0 e

Bio-control agent population before treatment application

No significant differences were observed among treatments in the pre-treatment population of bio-control agents (Table 3). The highest mean population was recorded in Profenofos-treated plots (T2; 5.66), followed by Acetamiprid (T1) and the control (T6), each with 5.33 individuals. The lowest population was observed in Diafenthiuron-treated plots (T3; 4.00). Among the botanical treatments, *C. colocynthis* (T5) and *M. chamomilla* (T4) recorded mean populations of 5.00 and 4.66, respectively.

Bio-control agent population after treatment application

Post-treatment observations revealed significant reductions in bio-control agent populations. The highest reduction was recorded in Diafenthiuron-treated plots (T3; 94.44%), followed by Profenofos (T2; 90.47%) and Acetamiprid (T1; 86.66%). The botanical extracts caused comparatively lower reductions, with *C. colocynthis* (T5) and *M. chamomilla* (T4) reducing bio-control agent populations by 60.00% and 50.00%, respectively. No reduction was observed in the untreated control (Table 3).

Table 3. Pre- and Post-treatment population dynamics of bio-control agents in the canola variety 'Rainbow' following application of insecticides and botanical extracts.

Treatments	Bio-control agent Population (Pre-Treatment)	Bio-control agent Population (Post-Treatment)
T ₁	5.33 a	86.66 a
T ₂	5.66 a	90.47 a
T ₃	4.00 a	94.44 a
T ₄	4.66 a	50.0 b
T ₅	5.00 a	60.0 b
T ₆	5.33 a	0.00 c

Aphid population in the Oscar variety

Aphid population before treatment application

The pre-treatment aphid population did not differ significantly among treatments (Table 4). Numerically, the highest aphid population was recorded in Diafenthiuron-treated plots (T3; 106.66), followed by Profenofos (T2; 106.33), *C. colocynthis* (T5; 101.33), and the control (T6; 100.00). The lowest populations were

observed in Acetamiprid (T1; 98.33) and *M. chamomilla* (T4; 93.33) plots.

Percentage reduction in aphid population one day after treatment application

At 1 DAT, all insecticidal treatments exhibited statistically similar performance. Diafenthiuron (T3) achieved the highest aphid reduction (56.49%), followed by Profenofos (T2; 51.50%) and Acetamiprid (T1; 49.69%). Among the botanical treatments, *C. colocynthis* (T5) recorded greater aphid suppression (31.37%) than *M. chamomilla* (T4; 28.51%). No reduction was observed in the control treatment (Table 4).

Percentage reduction in aphid population two days after treatment application

Highly significant differences were observed among treatments at 2 DAT. Acetamiprid (T1) and Profenofos (T2) produced statistically similar results, whereas the remaining treatments differed significantly (Table 4). Diafenthiuron (T3) exhibited the highest aphid reduction among the insecticides, while *C. colocynthis* (T5) was the most effective botanical treatment. The lowest reduction among treated plots was recorded for *M. chamomilla* (T4), whereas the control showed no reduction.

Percentage reduction in aphid population three days after treatment application aphid

At 3 DAT, all treatments significantly reduced aphid populations compared with the control (Table 4). Diafenthiuron (T3) remained the most effective treatment, followed by Profenofos (T2) and Acetamiprid (T1). The botanical extracts also demonstrated notable efficacy, with aphid reductions of 56.57% and 51.85% for *C. colocynthis* (T5) and *M. chamomilla* (T4), respectively. No reduction was recorded in the untreated control.

Percentage reduction in aphid population four days after treatment application aphid

Four days after treatment application, insecticide-based treatments provided the highest levels of aphid suppression. Acetamiprid (T1) and Profenofos (T2) produced statistically similar reductions of 85.57% and 82.85%, respectively, while Diafenthiuron (T3) achieved the highest reduction (91.85%). Significant differences were observed between the botanical treatments, with *C. colocynthis* (T5) and *M. chamomilla* (T4) reducing aphid populations by 65.26% and 59.07%, respectively. No aphid reduction was observed in the untreated control (Table 4).

Table 4. Effect of synthetic insecticides and plant extracts on aphid population reduction (%) at different intervals after treatment application in the Oscar canola variety.

Treatments	(Pre-Treatment)	(1DAT)	(2DAT)	(3DAT)	(3DAT)	% Mean reduction
T ₁ = Acetamiprid	98.33 ab	49.69 a	60.00 b	72.87 b	85.57 b	67.03 b
T ₂ = Profenofos	106.33 a	51.50 a	60.91 b	73.44 b	82.85 b	67.17 b
T ₃ = Diafenthiuron	106.66 a	56.49 a	71.35 a	81.86 a	91.85 a	75.39 a
T ₄ = <i>M. chamomilla</i>	93.33 b	28.51 b	37.59 d	51.85 d	59.07 d	44.25 d
T ₅ = <i>C. colocynthis</i>	101.33 ab	31.37 b	45.68 c	56.57 c	65.26 c	49.72 c
T ₆ = Control	100.00 ab	0.0 c	0.00 e	0.00 e	0.00 e	0.00 e

Mean percentage reduction in aphid population

The overall mean aphid reduction differed significantly among treatments (Table 4). Acetamiprid (T₁) and Profenofos (T₂) produced statistically comparable reductions, whereas Diafenthiuron (T₃) exhibited significantly greater efficacy than all other treatments. Among the botanical extracts, *C. colocynthis* (T₅) achieved a mean reduction of 49.72%, followed by *M. chamomilla* (T₄) with 44.25%. No aphid mortality was recorded in the control treatment.

Bio-control agent population before treatment application

No significant differences were observed among treatments regarding bio-control agent populations before treatment application (Table 5). The highest mean population was recorded in *M. chamomilla* plots (T₄; 5.66), followed by Diafenthiuron (T₃; 5.33), Acetamiprid (T₁; 5.00), and the control (T₆; 5.00). The lowest populations were observed in Profenofos (T₂; 4.33) and *C. colocynthis* (T₅; 4.66) plots.

Table 5. Pre- and Post-treatment population dynamics of bio-control agents in the canola variety 'Oscar' following application of insecticides and botanical extracts.

Treatments	Bio-control agent Population (Pre-Treatment)	Bio-control agent Population (Post-Treatment)
T ₁	5.00 a	87.77 a
T ₂	4.33 a	86.66 a
T ₃	5.33 a	100.0 a
T ₄	5.66 a	46.66 b
T ₅	4.66 a	58.88 b
T ₆	5.00 a	6.66 c

Bio-control agent population after treatment application

Following treatment application, substantial reductions

in bio-control agent populations were observed. Diafenthiuron (T₃) caused complete mortality (100%) of bio-control agents, followed by Acetamiprid (T₁; 87.77%) and Profenofos (T₂; 86.66%). In contrast, the botanical extracts exhibited lower toxicity, with reductions of 58.88% and 46.66% in *C. colocynthis* (T₅) and *M. chamomilla* (T₄) treatments, respectively. The control treatment showed only a minimal reduction (6.66%), which was significantly lower than all other treatments (Table 5).

Discussion

The present trial demonstrated that insecticidal treatments caused a highly significant reduction in aphid populations in both canola varieties within four days of exposure. Among the synthetic insecticides, diafenthiuron exhibited the highest efficacy, recording mean aphid population reductions of 74.90% and 75.39% in the 'Rainbow' and 'Oscar' varieties, respectively. It was followed by profenofos (68.44% and 67.17%) and acetamiprid (64.52% and 67.03%) in Rainbow and Oscar, respectively. After four days of exposure, diafenthiuron achieved maximum aphid suppression, with reductions of 92.57% and 91.85% in Rainbow and Oscar varieties, respectively, followed by profenofos (87.97% and 82.85%) and acetamiprid (86.12% and 85.57%).

These findings are consistent with Arif et al. (2012), who reported 82-94% aphid reduction in canola following insecticide application over a 7-day period. Similarly, Ahmad et al. (2007) also observed superior aphid control in *Brassica campestris* using synthetic insecticides compared with untreated controls. Comparable trends were reported by Lashkari et al. (2007) and Saljoqi et al. (2009), who found that insecticides such as imidacloprid and monocrotophos effectively suppressed aphid populations, although their efficacy declined over time. In

the present study, sustained reduction from day 1 to day 4 indicates comparatively prolonged residual activity of the tested insecticides.

However, contrasting results were reported by Arshad et al. (2016), who observed higher mortality of *Lipaphis erysimi* with acetamiprid (up to 98.7%) compared to diafenthiuron (53.52%) in *Camelina sativa*, suggesting that insecticide efficacy may vary with host plant, aphid species, and environmental conditions. Similarly, Zafar et al. (2016) and Khan et al. (2017) reported high aphid mortality (up to 96.7%) with various insecticides, supporting the overall superiority of chemical control under field conditions.

Among botanical treatments, *C. colocynthis* exhibited considerable insecticidal activity, causing aphid mortality of 60.35% in Rainbow and 65.26% in Oscar after four days. These results are supported by Pravin et al. (2013), who reported that *C. colocynthis* possesses bioactive compounds with insecticidal, antifeedant, and growth-regulating properties. Gurdeeban et al. (2010) further confirmed the presence of cucurbitacins, alkaloids, flavonoids, and terpenoids responsible for insecticidal activity. Similarly, Ibrahim (2015), Khalid (2015), and Alanazi (2019) reported strong insecticidal potential of different plant parts and solvent extracts of *C. colocynthis* against aphid species, supporting the present findings. Rahuman et al. (2008) also highlighted its larvicidal properties due to the presence of toxic fatty acids such as oleic and linoleic acid.

M. chamomilla leaf extract also showed moderate aphid mortality, causing 54.65% and 59.07% reduction in Rainbow and Oscar varieties, respectively. These results are supported by Padin et al. (2013), who reported 57% aphid mortality with *M. chamomilla* extracts under laboratory conditions. Biniaś and Gospodarek (2017) also demonstrated its efficacy against aphid larvae and wingless females, particularly at higher concentrations. The insecticidal activity is attributed to sesquiterpenes and other volatile compounds present in *M. chamomilla* (Slavik et al., 2021), which contribute to toxicity and repellency against insect pests.

The present study further evaluated the impact of treatments on bio-control agents (predators). Pre-treatment observations showed non-significant differences among all plots. However, post-treatment results revealed that insecticidal applications significantly reduced predator populations compared with botanical extracts. Diafenthiuron caused the highest reduction in

predator populations (94.44% in Rainbow and complete or near-complete reduction in Oscar), followed by profenofos and acetamiprid. In contrast, botanical treatments caused comparatively lower reductions, with *C. colocynthis* resulting in 60% and 58.88% reduction, while *M. chamomilla* caused 50% and 46.66% reduction in Rainbow and Oscar, respectively. The control plots exhibited minimal changes in predator populations.

These findings are consistent with Yazdanpanah et al. (2013) and Atta et al. (2019), who reported that insecticide applications significantly reduced natural enemy populations in canola ecosystems. Elliott et al. (2014) and Sayed et al. (2020) also emphasized the positive association between aphid density and predator abundance, indicating that insecticide-induced aphid suppression indirectly affects predator dynamics. Abbas et al. (2017) further reported that ladybird beetles, chrysopids, and syrphid flies are the dominant aphid predators in *Brassica* ecosystems.

Overall, the results indicate that while chemical insecticides provide rapid and high aphid suppression, they also exert substantial negative effects on beneficial insect populations. In contrast, botanical extracts offer moderate pest control with comparatively lower disruption of natural enemies, highlighting their potential role in integrated pest management (IPM) strategies.

Conclusion

It is concluded that synthetic insecticides, particularly diafenthiuron, were highly effective in reducing aphid populations in both canola varieties within four days of application. Botanical extracts, especially *C. colocynthis*, also demonstrated appreciable insecticidal activity, though at a comparatively lower level than synthetic insecticides.

However, insecticidal treatments caused significant reductions in bio-control agent populations, whereas botanical extracts had a comparatively lesser negative impact on natural enemies. Therefore, although chemical insecticides provide rapid and effective aphid suppression, their adverse effects on beneficial insects limit their sustainability in agroecosystems.

In contrast, plant-based extracts, particularly *C. colocynthis* and *M. chamomilla*, may serve as safer and more environmentally compatible alternatives within integrated pest management (IPM) programs for sustainable canola production.

Author Contributions

MSN and GM conceived and designed the study. GM conducted the field investigations and experimental work. MSN supervised the research and ensured methodological and analytical rigor throughout the study. AKK and GF provided critical input on experimental design, data interpretation, and overall research development. MSN, GM, GF, and AKK contributed to drafting the manuscript, including data compilation, result presentation, and interpretation. All authors critically reviewed the manuscript, verified the data and analyses, contributed to its intellectual refinement, and approved the final version for submission.

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Conflict of Interest

The authors declare no conflict of interest.

Sustainable Development Goals Targeted

SDG 2: Zero Hunger

SDG 12: Responsible Consumption and Production

SDG 15: Life on Land

Policy Addressed

The findings support Pakistan's National Food Security Policy (2018), National IPM initiatives, and the FAO International Code of Conduct on Pesticide Management by demonstrating that botanical extracts can suppress aphids while conserving beneficial arthropods. The results align with IPM principles and biodiversity conservation objectives, promoting reduced reliance on synthetic pesticides.

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