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Full Length Article

Elucidating a Synergistic Influence of Mustard Resistance and Chemical Control for the Management of *Lipahis eyrsimi*

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Abstract

Oilseed cultivation is the major source of energy that fulfills the cooking oil requirements of large masses across the globe. Mustard is one of the important members of the brassica family, which is attacked by an aphid, *Lipaphis erysimi.* This research investigated the field population fluctuations of *L. erysimi* on different mustard varieties for two growing years. *L. erysimi* population reached to peak (171.3 nymphs and 141.6 adults) in the Mustard-early variety in early March. Based on Mustard Resistance Index (MRI), the Mardan-Local variety is highly resistant having an Aphid Population Score (APS) and Leaf Damage (LD) of 1 with a pooled annual mean of 1.85 aphids. The varietal preference test results indicated that the highest *L. erysimi* (8.0 adults) were attracted to the Mustard-early variety while the least (2.80 adults) were attracted to Mardan-local. In the *In-vitro* bioassay, Lefenuron and Pyriproxyfen caused 100 and 70.4% mortality, respectively. In the field, synchronized experiment, Imidochloprid (control positive) and Lefenuron showed the highest mortalities (100%), respectively. The Pyriproxefen and Runner (Methoxyfenoxid) treated plots had caused 77 and 70.3% mortalities, respectively. The present research is the first attempt to investigate the synchronized effects of Host Plant Resistance and Insect Growth Regulators for the *L. erysimi* management in Mustard. It is concluded that Mardan-Local variety alongside lefenuron application provides an effective IPM for *L. erysimi*. These outcomes will help the farmers better understand and manage aphids; it will help the researcher to explore further management tools of Aphids in oilseed crops.

Keywords: *Lipahis eyrsimi* (Kalt.); Mustard; Host plant resistance; Population fluctuations; Chemical control

Introduction

Mustard (*Brassica* spp.) is one of the most significant members of the brassicas and has been grown throughout the world in both tropic and sub-tropic regions for many decades as an oilseed crop (Poveda 2020). It's a winter season crop and is considered as an important source of vegetable oil (Akhatar *et al.* 2021). Mustard is a nutritious food that comprises different bioactive components such as polyphenols (flavonoids and anthocyanins, glucosinolates and their degradation products, as well as a high amount of dietary fiber, Beta carotene, chlorophylls, ascorbic acid, volatile components and minerals (Tian and Deng 2020).

The total area under mustard cultivation for the growing season of 2019/20 in Pakistan was 349000 Hectares, while the total production was 302000 tonnes (PBS 2020). The total production of mustard is very low as compared to other countries. The mustard crop is highly susceptible to various biotic and abiotic stresses that significantly affect the production and productivity of the mustard crop (Akhatar *et al.* 2021). Biotic stresses include insect pests and diseases. Important insect pests of the mustard are, *Bemesia tabaci* (Gennedius), *Lipaphis erysimi* (Kalt.), *Chromatomyia horticola* (Goureau) cabbage butterfly, *Pieris brassicae* (Linn), Thrip, *Thrip tabaci*, and *Brevicoryne brassica* (L.) (Shah *et al.* 2020). Aphid *Lipahis eyrsimi* Kalt. causes up to a 90% reduction in the yields of mustard in severe infestation (Pradhan *et al.* 2020).

Farmers are mostly relying on heavy broad-spectrum pesticide application for the management of *L. erysimi*. But, the environmental aspects of pesticides are disturbing and thus scientists are constantly working on an alternate way of management of this obnoxious pest. An integrated approach known as Integrated Pest Management (IPM) is adopted by entomologists in the field of pest management. This approach works by implementing various control methods for a single pest species (Dedryver *et al.* 2010). Some of the important management strategies are 1) the use of resistant varieties

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(Host Plant Resistance, HPR) (Straub *et al.* 2020) and 2) Insect Growth Regulators (IGR) (Apolinário and Feder 2021).

HPR is a practical approach in which host plants withstand/tolerate the infestation caused by insect pests, it may have biochemical (antibiosis) and physical (antixenosis) barriers (Wiseman 1985). Ahmad *et al.* (2015) conducted an experiment on the resistance of different mustard varieties against aphids and concluded that mustard varieties induce physical/antixenotic resistance in great variety.

Insect Growth Regulators provide a stage-specific control of the target insect pest. It is comparatively safer than broad-spectrum insecticides (Apolinário and Feder 2021). It acts on the juvenile hormones/chitin synthesis inhibition to stop the normal metamorphosis of the target insect.

Both HPR and IGR could be synchronized at a time to enhance the IPM strategy, as both these methods don't have any ill effects on one another. These methods are cheaper and environmentally friendly as compared to other control methods (Gajger and Dar 2021). Keeping in view the significance of HPR and IGRs, this research work was conducted to evaluate the field resistance in mustard varieties and the management of *L. eyrsimi.* This work will provide key information to the farmers and entomologists to better understand and plan strategies for *L. eyrsimi* management.

Materials and Methods

Experiment 1: population dynamics of *L. erysimi* on three different mustard varieties

The present research was carried out at the Agriculture Research Farm, Abdul Wali Khan University Mardan (AWKUM), Khyber Pakhtunkhwa Pakistan. Three different mustard varieties, *viz*., Hasnain-13, Mustard early, and Mardan-local were studied for their resistance against the natural field infestation of *L. eyrsimi* for two growing seasons *i.e*., 2018/19 and 2019/2020.

Population dynamics of *L. eyrsimi* were recorded on three different mustard varieties mentioned above. Sowing was done on the 8th of October 2019 and the 22nd of October 2020. The treatments were laid out in a Randomized Complete Block Design (RCBD) having five replications. Each plot consisted of five rows. The size of each plot was 4.5 m^2. The distance among plots was 60cm while row to row distance was 45 cm while plant to plant distance was kept at 10cm. *L. eyrsimi*, nymph and adult populations were recorded from randomly selected three plants from the upper, middle and lower parts of the plant per row (Amer *et al.* 2009). The mustard aphid resistance index of Dhillon *et al.* (2018) was adopted with slight modifications based on the threshold level. The details are given in Table 1.

Experiment 2: Varietal preference test

Rearing of *L. erysimi*: Apterous female adults were collected from the garden campus of AWKUM before the rearing of *L. eyrsimi. L. eyrsimi* was identified following the keys provided by National Insect Museum (NIM) Islamabad, Pakistan. The major keys were the antenna six segments and the winged aphid's abdominal dorsum was without an abdominal patch. The aphids were reared on a susceptible variety *i.e*., Mustard-Early (based on field infestation resistance). When the plant reached the two-leaf stage, they were infested with the *L. eyrsimi* female adults. The aphids were reared for three generations and were kept under anti-aphid cages to avoid the escape of aphids.

Varietal preference test: A varietal preference test was carried out in controlled conditions at the Lab of Botany Department AWKUM. Treatments was laid out in Completely Randomized Design (CRD) having 10 replicates {Temperature = 25 ± 5°C, 60 ± 10% Relative Humidity, and 16: 8 Light: Dark (L:D) photoperiod}. Leaves were placed equidistantly in a circular tray. 90 *L. eyrsimi* adults were released in the center of the tray. Data on adult attractiveness (no. of adults settled on each variety) towards each variety was recorded after 6, 12, and 24 h (Raeyat *et al.* 2021).

Experiment 3: *In-vitro* bioassay of the selected chemicals against *L. erysimi*

An *in-vitro* bioassay of the selected chemicals was carried out under the controlled lab conditions at Temperature = 25 ± 5°C, 60 ± 10% Relative Humidity, and 16: 8 Light: Dark (L: D) photoperiod. The experimental treatments included three IGRs (Lefenuron, Pyriproxyfen, and Runner {Methoxyfenoxide}). Imidochloprid was applied as a positive standard while negative control received simple distelled water. Treatments were laid out in Completely Randomized Design (CRD) having 05 replicates.

The selected insecticides were evaluated against *L. erysimi* adults. The mortality was assessed on a comparatively more resistant and susceptible variety (based on field infestation level). A leaf disc of a comparatively more resistant and susceptible variety was sprayed with the respective concentration (10000, 15000 and 20000 ppm respectively) of the selected insecticides. The leaf disc was placed in a plastic vial and each vial contained 30 ± 2 *L. erysimi* adults. The data was recorded after 24, 48 and 72 h of post exposure (Kalasariya 2016).

Experiment 4: synchronization of the selected insecticides and host plant resistance (HPR) against *L. erysimi*

An integrated Pest Management (IPM) strategy was implemented against *L. erysimi* for the field management. Comparatively more resistant variety *i.e.,* Mardan-local was sown in the year 2020/2021 following the same methodology for experiment 1. A recommended dose (Lufenuron and Pyriproxyfen @ 200 mL/acre respectively, Methoxyfenozide @180 mL/acre while imidacloprid

@65g/acre) of all the selected IGRs was applied when the *L. eryismi* population reached the Economic Threshold Level (ETL). A pre-data was recorded 24 h before the spray while post-spray data was recorded after 1, 2, 3, 7 and 14 days. A second spray decision was made based on the population of *L. erysimi* infestation surpassing the ETL.

Statistical analysis

The data were subjected to statistical software (Statistix 8.0 FL USA). The adults and nymphs data was polled and mean values were taken for finding the MRI. The data regarding *in-vitro* and field study was corrected *via* Abbots's formula and then one-way ANOVA was performed. A field reduction in population was analyzed and means were separated by Tukey's mean comparison test. A GraphPad (prism version 8) was utilized for the graphical depiction.

Results

Mustard varietal screening against *L. erysimi* for the growing season of 2018/19 under field conditions

Comparing means of aphid population on different mustard varieties revealed that the highest aphid population (adult 40.1 and nymph 69.2) were recorded in Mustard early followed by Hasnain-13 (adult 8.5 and nymph 14.2) while the least aphid population (adult 1.5 and nymph 1.3) was recorded in Mardan-Local as shown in Fig. 1.

Comparing means of aphid population on different weeks revealed that the highest aphid adult population 58.6 was recorded in the ninth week (14 Mar) and the highest nymph population (71.8 and 71.7) was recorded in the tenth (21 Mar) and ninth week (14 Mar) respectively. A least adult (1.4) and nymph (0.9) population was recorded in the first week (22 Jan).

Comparing interactions of the week into varieties revealed that the highest aphid population (adult 141.6 and nymph 171.3) was recorded in the ninth week in the Mustard-early variety while the least population (adult 0.1 and nymph 0) was recorded in Mardan-local in the first week (22 Jan) as shown in Fig. 1.

Mustard varietal screening against *L. erysimi* for the growing season of 2019/20 under field conditions

Comparing means of aphid population on different mustard varieties revealed that the highest aphid population (adult 55 and nymph 72.8) were recorded in Mustard early followed by Hasnain-13 (adult 11.1 and nymph 19) while the least aphid population (adult 1.8 and nymph 2.8) was recorded in Mardan-Local as shown in Fig. 2.

Comparing means of aphid population on different weeks revealed that the highest aphid adult population 71.7 was recorded in the tenth week (17 Mar) and the highest nymph population (85.3) was recorded in the ninth week (11 Mar). A least adult (2.1) and nymph population (0.9) was recorded in the first week (16 Jan).

Comparing interactions of the week into varieties revealed that the highest aphid population, adult 176.6 and nymph 199.6 was recorded in the tenth and ninth week in the Mustard-early variety respectively while no population was present in the Mardan-local variety in the twelve-week (29 Mar) as shown in Fig. 2.

Characterization of mustard varieties' resistance against *L. erysimi* based on mustard resistance index (MRI)

A pooled mean of adults and nymphs on different varieties revealed that Hanain-13 was the most resistant variety while Mustard early and Mardan local were susceptible and highly resistant respectively as shown in Table 2.

Evaluation of mustard resistance based on varietal preference

The varietal preference test results revealed that a maximum (8.0 adults) were attracted towards mustard early followed by Hasnain-13 (5.2) and Mardan local had the least aphids (2.8). Initially, the aphids were moving in circles for 12 h and after 24 h maximum adults settled on their preferred variety as shown in Table 3.

Mean mortality of *L. erysimi* at different time intervals on comparatively more resistant mustard variety

The mortality of *L. erysimi* increased with the exposure time and concentrations. Comparing means of the different concentrations of the treatments revealed that the highest mortality (45.3) was achieved with Imidacloprid and then followed by Lefenuron (44) with 20000 ppm. Then followed treatment was Pyriproxyfen having 38.6 mean mortality. All the treatments had significantly caused mortality as compared to Control negative as shown in Fig. 3A.

The mortality of *L. erysimi* increased with the exposure time and concentrations. Comparing means of the different concentrations of the treatments revealed the highest mortality (100) at Conc. 2000 ppm, was achieved with Imidacloprid and then followed by Lefenuron (85), while the treatment Pyriproxyfen had (63) mean mortality. All the treatments had significantly caused mortality as compared to Control negative as shown in Fig. 3B.

The mortality of *L. erysimi* increased with the exposure time and concentrations. Comparing means of the different concentrations of the treatments revealed the highest mortality (100) at conc. 2000 ppm, was achieved with Imidacloprid and then followed by Lefenuron (100), while the treatment Pyriproxyfen had (70.4) mean mortality. All the treatments had significantly caused mortality as compared to Control negative as shown in Fig. 3C.

Table 1: Mustard Aphid resistance index based on population score

Aphid population score (APS)	Leaf damage (LD)	Mustard Aphid Resistance Index	Resistance category
1 means ≤ 5	1 means Healthy leaves	0.1-1 (APS + LD/2)	Highly Resistant
2 means 6-20	2 means slight curling and yellowing	1.1-2 (APS + LD/2)	Resistant
3 means 21-70	3 means curling yellowing followed by drying of the branches	2.1-3 (APS + LD/2)	Tolerant
4 means 71-100	4 means stunted plant growth having 50% drying of the branches	3.1-4 (APS + LD/2)	Susceptible
5 means 100 >	5 means extreme curling, yellowing, and drying of the whole plant	4.1 > (APS + LD/2)	Highly Susceptible

Table 2: Mustard Aphid Resistance Index (MARI) for determining varietal resistance

Varieties	Aphid population score (AP)	Leaf damage (LD)	Mustard Aphid Resistance Index (AP + LD/2)	Resistance category	Spectrum (RBG)[2]
Hasnain-13	2 (8.3)[1]	2	2	Resistant	114,168,80
Mustard Early	3 (59.2)	4	3.5	susceptible	161,195,109
Mardan Local	1 (1.85)	1	1	Highly Resistant	174,203,173

[1] A pooled mean of adult and nymph of two growing seasons are in the parenthesis [2] Red, Blue and Green spectrum in foliage

Table 3: Mean *L. erysimi* attractiveness towards mustard varieties at different time intervals

Varieties	12 h	24 h	48 h	Mean
Hasnain-13	2.6 d	7.0 b	6.0 bc	5.2 b
Mustard Early	2.6 d	10.6 a	10.6 a	8.0 a
Mardan-Local	0.3 e	3.0 d	5.3 c	2.8 c
Mean	1.8 b	6.8 a	7.3 a	

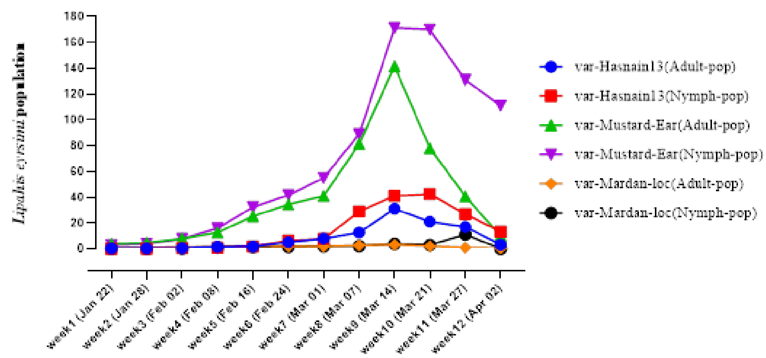

Fig. 1: Mean adult and nymph population of *L. erysimi* at different time intervals on Mustard varities for the growing season of 2018/19 under field conditions

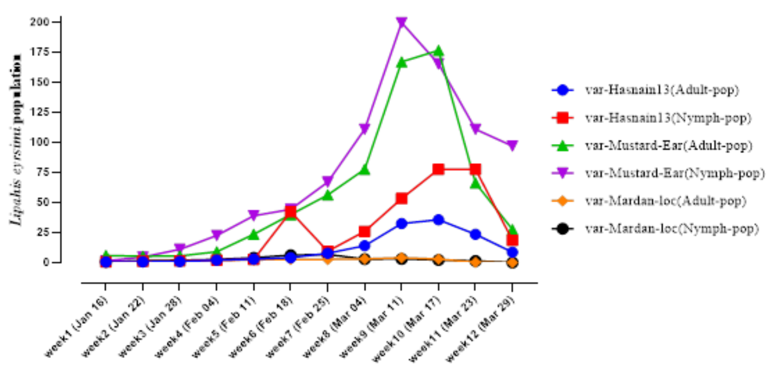

Fig. 2: Mean adult and nymph population of *L. erysimi* at different time intervals on Mustard varieties for the growing season of 2019/20 under field conditions

Mean mortality of *L. erysimi* at different time intervals on comparatively more susceptible mustard variety

The mortality of *L. erysimi* increased with the exposure time and concentrations. Comparing means of the different concentrations of the treatments revealed the highest mortality (100) at conc. 2000 ppm, was achieved with Imidacloprid and then followed by Lefenuron (100), while

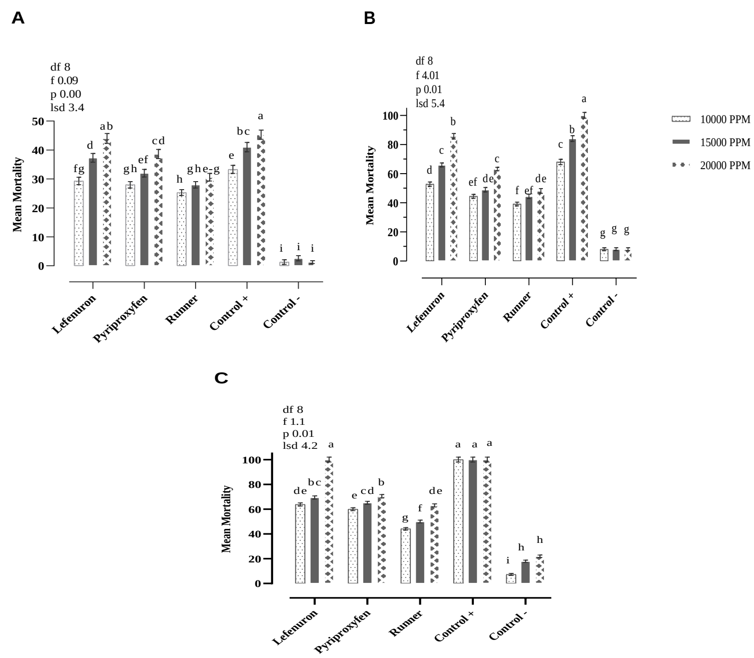

Fig. 3: Fractional *In-vitro* bioassay of different Insect Growth Regulators (IGRs) against *L. erysimi* mean mortality after 24 h (A), 48 h (B) and 72 h (C) on comparatively more resistant mustard variety

the treatment Pyriproxyfen had (70.4) mean mortality. All the treatments had significantly caused mortality as compared to Control negative as shown in Fig. 4A.

The mortality of *L. erysimi* increased with the exposure time and concentrations. Comparing means of the different concentrations of the treatments revealed the highest mortality (92) at conc. 2000 ppm, was achieved with Imidacloprid and then followed by Lefenuron (63.2), while the treatment Pyriproxyfen had (57.7) mean mortality. All the treatments had significantly caused mortality as compared to Control negative as shown in Fig. 4B.

The mortality of *L. erysimi* increased with the exposure time and concentrations. Comparing means of the different concentrations of the treatments revealed the highest mortality (100) at conc. 2000 ppm, was achieved with Imidacloprid and then followed by Lefenuron (83.3), while the treatment Pyriproxyfen had (72.6) mean mortality. All the treatments had significantly caused mortality as compared to Control negative as shown in Fig. 4C.

The mean population and reduction of *L. erysimi* after the first spray in the comparatively more resistant mustard variety

Comparing means of aphid population after treatments revealed that control negative had the highest aphids population (11.5) while the least population was recorded in control positive (imidacloprid) (5.4) followed by Lefenuron (6.3) as shown in Table 4.

Comparing means of aphid population in different time intervals revealed that the highest population was found one day before spray (10.8) followed by one day after the treatment (8.6) while the least population was recorded after 14 days (6.3).

All the treatments caused a significant reduction over control negative. The highest reductions 75, 71.3 and 69.3% were achieved with control positive (imidacloprid) on days three, seven, and fourteen respectively followed by Lefenuron having a 64.6% reduction on day fourteen and 62.6% reduction on the third day. The least reduction was achieved with Runner (27%) on day second as shown in Table 4.

The mean population and reduction of *L. erysimi* after second spray in the comparatively more resistant mustard variety

Comparing means of aphids population after treatments revealed that control negative had the highest aphids population (9.7) while the least population was recorded in control positive (imidacloprid) (2.2) followed by Lefenuron (3.3) Table 5. Comparing means of aphid population in different time intervals revealed that the highest population was found one day before spray (11.8) followed by one day after the treatment (6.8) while the least population was recorded after 14 days (5.6).

All the treatments caused a significant reduction over control negative. The highest reduction, 100%, was achieved with control positive (imidacloprid) on days seven and fourteen respectively. Lufenuron followed next by causing a 100% reduction on day fourteen. The

Table 4: The percent reduction of *L. erysimi* after the first spray at various time intervals caused by Insect Growth Regulators (IGRs) in the comparatively more resistant mustard variety

Treatments	1 DBT[2]	1 DAT[3]	2 DAT	3 DAT	7 DAT	14 DAT	Mean
Lefenuron	(11.3) c-e[1]	39.3 (7.3) jk	48.3 (5.6) l	62.6 (4) mn	58 (5.3) l	64.6 (4.6) lm	6.3 d
Pyriproxyfen	(11) c-f	34 (8) h-k	33.6 (7.3) jk	34.6 (7) k	45.3 (7) k	41.3 (7.6) i-k	8 c
Runner	(11.6) b-d	28.3 (8.6) hi	27 (8) h-k	31.6 (7.3) jk	34.6 (8.3) h-j	30.6 (9) gh	8.8 b
Control +	(10.3) ef	39.3 (7.3) jk	56 (5) lm	75 (2.6) o	71.3 (3.3) no	69.3 (4) mn	5.4 e
Control -	(10) fg	(12) a-c	(11) c-f	(10.6) d-f	(12.6) ab	(13) a	11.5 a
Mean	10.8 a	8.6 b	7.6 c	7.4 c	7.3 c	6.3 d	

*Data in parenthesis is the mean population of each plot
[1]Mean followed by the same letter don't differ significantly, [2]Day before treatment (Blank spray data),
[3]Day after treatment.
Each value is the mean of five replications

Table 5: The percent reduction of *L. erysimi* after the second spray at various time intervals *caused by* Insect Growth Regulators (IGRs) in the comparatively more resistant mustard variety

Treatments	1 DBT[2]	1 DAT[3]	2 DAT	3 DAT	7 DAT	14 DAT	Mean
Lefenuron	(11.6) bc[1]	66 (4) j	79 (2.3) k	85.3 (1.3) k-m	91 (0.6) l-n	100 (0) n	3.3 d
Pyriproxyfen	(12.6) b	37.6 (7.3) gh	41.6 (6.3) hi	59 (3.6) j	69.3 (2.3) k	77 (1.3) k-m	5.6 c
Runner	(11) cd	23.3 (9) ef	19.3 (8.3) fg	41 (5.3) i	53 (3.6) j	70.3 (1.6) kl	6.5 b
Control +	(10) de	80.3 (2.3) k	90.3 (1) l-n	96.6 (0.3) mn	100 (0) n	100 (0) n	2.2 e
Control -	(14) a	(11.6) bc	(10.3) d	(9) ef	(7.6) g	(5.6) i	9.7 a
Mean	11.8 a	6.8 b	5.6 c	3.9 d	2.8 e	1.7 f	

*Data in parenthesis is the mean population of each plot
[1]Mean followed by the same letter don't differ significantly, [2]Day before treatment (Blank spray data),
[3]Day after treatment
Each value is the mean of five replications

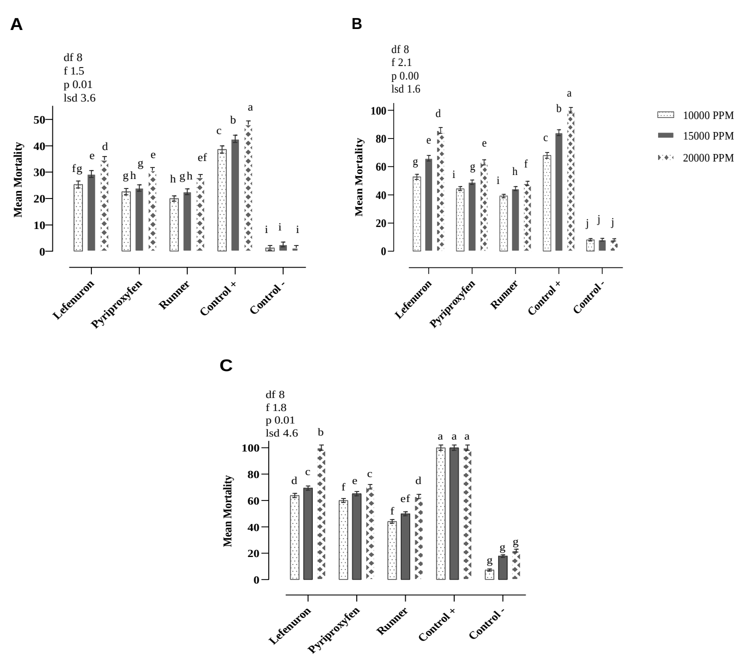

Fig. 4: Fractional *In-vitro* bioassay of different Insect Growth Regulators (IGRs) against *L. erysimi* mean mortality after 24 h (**A**), 48 h (**B**) and 72 h (C) on comparatively more susceptible mustard variety

least reduction was achieved with Runner (23.3%) on day first as shown in Table 5.

Discussion

Lipaphis erysimi (Kalt.) is a major threat to the production of mustard alongside other biotic and abiotic stresses. In Pakistan, its production declined drastically over the past few decades due to the attack of *L. erysimi* (Solangi *et al.* 2020). The conventional management methods require a lot of sum as well as it has drastic effects on the environment like bio-magnification and bio-accumulation. Scientists and naturalists are in keen search for finding either alternative or to minimize the dependency on these broad-spectrum pesticides. Two of the methods include Host Plant Resistance (HPR) and target-specific Insect Growth Regulators (IGRs). The HPR provides preemptive management against an intruding insect pest due to either physical barrier (antixenosis) or biochemical resistance (antibiosis) (Ninkovic *et al.* 2021). Contrary to HPR, IGRs have a direct effect on the stage and site-specific targeted action (Hafez and Abbas 2021). The current research was set up to explore the varietal resistance and evaluation of IGRs in the *in-vitro* as well as field levels.

A peak of *L. erysimi* was observed in March and declined in April. The highest population mean (adult 176.6 adults and 199.6 nymphs) in March could be related to the abiotic factors like ambient temperature (T) (28°C) and relative humidity (RH) (40%). The abiotic factors play a key role in the survivorship of *L. erysimi* as reported by Sridhar *et al.* (2022) that temperature had a positive correlation with the aphid abundance. However, RH had a negative correlation with the aphid abundance. The mean comparison of different mustard varieties revealed that the highly resistant variety was the local one (Mardan-Local) having a mean of 1.5 adults and 1.3 nymphs while the most susceptible variety was Mustard early having a mean of 55 adults and 72.8 nymphs. The resistance in any variety is either due to the physical barriers (antixenosis) and biochemical (antibiosis) or a combination of both (tolerance) (Natukunda and MacIntosh 2020). The resistance in the Mardan-local variety could be due to the inability of the *L. erysimi* to break its resistance. This inability could be 1) the *L. erysimi* is somehow not able to assimilate genetic pathways 2) an inability to perform normal activities like a) a variety color does not prefer by the aphid, b) unsuitability of the landing site c) volatiles ill effects d) inability to establish feeding site, 3) qualitative and quantitative availability of diet metabolites for the aphid (Åhman *et al.* 2019).

The resistance exhibited by the Mardan-Local variety in the free-choice test may be due to the presence of waxy contents on a leaf, availability of spines, fingernail skin hardness, and trichomes that affect aphids for selection of the target portion of the plant. Furthermore, leaves with different metabolites and healthy fluid content of the plant section serve as a target host for plant lice as described by Dwivedi *et al.* (2021).

The field resistance of mustard was aided by the application of Insect Growth Regulators (IGRs). The excess and unjustified use of the insecticides leads the ecosystem toward destruction. Many efforts had been drawn for the safe management of the insect pest. The IPM was introduced with the hope to utilize all the possible methods for the management of insect pests (Trapero *et al.* 2016). Several authors (Nderitu *et al.* 2020; Fakhouri *et al.* 2021) had previously reported the combination of HPR and IGRs. The *in-vitro* bioassay revealed that mortality increased in the resistant variety (Mardan-Local) as compared to the susceptible variety. The mortality increased with the increasing concentration of all the tested IGRs and standards (Imidochloprid). Lufenuron caused maximum mortality (77.7%) followed by Pyriproxyfen (65.2%) as compared to check (15.7%). Significant effects of the Lefenuron could be due to the inhibition of chitin biosynthesis (Merzendorfer and Zimoch 2003; Xin *et al.* 2021). Shonga and Getu (2021) reported that lufenuron caused 71.94% mortality of aphids. The results insinuate the inhibition of the hormone necessary for chitin synthesis. The current results of pyriproxyfen exhibit that it affected the hormone that mimics the growth of the apterous and does not allow them to adulthood.

Combination of both, resistant variety and chemical control aids for the management of *L. erysimi*. The field trials revealed that insecticide efficacy gave the best results while spraying on the resistant variety. The first spray reduced the population of *L. erysimi* but the second spray was needed to bring the population to the Threshold level. On the initial days of both the sprays, the effect of all the treatments was low that increased with time. The initial slow response could be due to the cuticle thickening (Xu *et al.* 2022). Lufenuron caused 100% mortality after the 2nd spray alongside control + (Imidochloprid).

Conclusion

L. erysimi can cause 81% damage to the mustard. It reaches to peak in late February and early March. Proper monitoring needs to be carried out for timely management. The resistant variety (Mardan-Local) provides a natural barrier to stop the population buildup of this insect. The *In-vitro* and field experiments provided evidence that Lefenuron could be used in the IPM package as over 70% mortality was achieved in the *In-vitro* bioassay and 100% mortality in the field was achieved. These findings lay a foundation for the future exploration of HPR and IGR against *L. erysimi*. The application of Bio degree days and molecular mechanisms need further investigation to better understand the mechanism of HPR in mustard against aphids.

Acknowledgments

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Author Contributions

SA and IU planned the experiments, MK interpreted the results, NM, AA and AH did the write up, RZK and MA statistically analyzed the data and made illustrations.

Conflicts of Interest

All authors declare no conflict of interest.

Data Availability

Data presented in this study will be available on a fair request to the corresponding author.

Ethics Approval

Not applicable to this paper

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