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Biological performance and biochemical interactions of mustard aphid (*Lipaphis erysimi*) in *Brassica juncea*

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ABSTRACT

Present studies were carried out on development and survival of *Lipaphis erysimi* (Kaltenbach) on diverse *Brassica juncea* (L.) Czern. & Coss. genotypes, and decipher the role of certain biochemical compounds in plant defense against mustard aphid. There were significant differences among test *B. juncea* genotypes for total nymphal duration, reproductive period, total developmental period, fecundity and survival of *L. erysimi*. The development period was significantly longer on PDZM 31, NRCHB 101, RP 7-3-2-2-1, TS 18-5124, RP 11-2-1-3-1, YSG, RLC 3, NPJ 50, IC 355399, MSTWR 17-1, EC 61-9-2-2-2, GP 454 and Kranti, while fecundity and survival were significantly lower on RLC 3, Kranti, IC 355399, Rohini, GP 454, NPJ 50 and TS 18-5124 as compared to other *B. juncea* genotypes. The biochemical constituents like, total antioxidants, tannins, phenols and FRAP were also significantly higher in RLC 3, Kranti, IC 355399, Rohini, GP 454, NPJ 50 and TS 18-5124 as compared to other *B. juncea* genotypes, except in a few cases. The total antioxidants and total tannins had significant and negative association, and explained 78.5% and 91.3% variability for fecundity and survival of *L. erysimi*, indicating their detrimental effects on progeny production and survival of mustard aphid on *B. juncea*. Present studies suggest that the *B. juncea* genotypes RLC 3, IC 355399, Rohini, GP 454, NPJ 50, TS 18-5124 and Kranti have higher amounts of test defense biochemicals and impart adverse effects on the reproductive period, fecundity and survival of *L. erysimi*.

Keywords: Biochemicals, Biology, *Brassica juncea*, *Lipaphis erysimi*, Mustard aphid, Rapeseed-Mustard

Rapeseed-mustard is one of the most important edible oilseed crops, which occupies second position after groundnut contributing to about 27.8% of the Indian oilseed economy. Among different rapeseed-mustard species, *Brassica juncea* (L.) Czern. & Coss. occupies >80% of the mustard area in India, and is grown on 6.13 million ha with production of 7.38 million tonnes (ASG 2018). In India, average productivity of rapeseed-mustard is 1150 kg/ha, which is about 56% lower than the world (2047 kg/ha) average (Jat *et al.* 2019). Several biotic factors contribute to reduction in productivity of rapeseed-mustard, of which mustard aphid, *Lipaphis erysimi* (Kaltenbach) causes 10–90% damage under different agro-climatic conditions (Ahuja *et al.* 2009). Both adults and nymphs suck sap at vegetative, flowering and pod formation stages, which inhibits plant growth resulting in poor pod formation, less seed set, low oil content, and reduced seed yield (Dhillon *et al.* 2018).

The aphids are currently being managed by insecticides and to reduce the insecticidal load, there is a need to find genetic solutions. An insect resistant cultivar fits well in integrated pest management module as it provides ecologically sound, effective and economical option to the farmers. Under such situations, host plant resistance could be one of the most effective mean of minimizing losses due to this pest. Plant defense against insects negatively affect the preference, development and survival resulting in increased plant fitness, which is a function of initial selection process, i.e. regulated by different olfactory and visual cues of the plant parts mainly leaves in case of aphids (Carrasco *et al.* 2015). Plants produce specialized defense compounds that have anti-nutritional effects to overcome the pest attack (Stahl *et al.* 2018). Certain plant chemicals like constitutive and induced compounds regulate the plant-herbivore interaction (Holopainen and Blande 2013). However, little is known about role of different biochemical compounds in *B. juncea* to impart defense against *L. erysimi.* Therefore, present studies were conducted to know the variation in development and survival of *L. erysimi* on diverse *B. juncea* genotypes, and understand the role and contribution of certain biochemical compounds in plant defense against mustard aphid.

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MATERIALS AND METHODS

Plant material: Thirty *B. juncea* genotypes possessing

different morpho-physiological traits like variation in flower colour, vegetation colour, plant height, siliquae density and orientation, glucosinolates and erucic acid contents were used in the present studies. The test genotypes were grown in 4 row plots of 5 m length, with rows 30 cm apart and 15 cm plant to plant spacing in experimental plots of Division of Entomology, Indian Agricultural Research Institute, New Delhi during 2018–20 cropping seasons. All recommended agronomic practices, except insecticide use were followed to raise the *B. juncea* genotypes. Ten randomly selected plants of each test *B. juncea* genotype were tagged for biological and biochemical studies.

Developmental biology and reproductive performance of L. erysimi *on diverse* B. juncea *genotypes*: The biological studies of *L. erysimi* on test *B. juncea* genotypes were carried out at 17±3°C temperature, 60–70% relative humidity and 12L:12D photoperiod under controlled conditions in the laboratory. The mustard aphid, *L. erysimi* were collected from the field and reared on mustard leaves in the glass Petri dishes measuring 10 cm height and 2 cm diameter under laboratory conditions. The Petri dishes were provided with moistened filter paper over which leaf disc were placed to keep them turgid for longer duration. The newly hatched nymphs obtained from the laboratory reared aphids were collected and transferred to leaf disc of each test *B. juncea* genotype (top third leaf) with the help of fine moist camel hair brush. The leaf discs were changed daily till the completion of studies. There were 10 replications for each test *B. juncea* genotype in a completely randomized design. The observations were recorded on total nymphal period, reproductive period, total developmental period, fecundity and offspring survival. The growth of nymphs, moulting and passing into next instar and the number of nymphs laid per female were recorded at 12 h interval. Total nymphal period was calculated on the basis of birth of first instar to the end of fourth instar and expressed in hours. The duration from birth of first nymph to last nymph was recorded as reproductive period, and expressed in hours. The duration from first instar nymph to death of the female was recorded as total developmental period, and expressed in hours. The fecundity of the adult females were recorded by counting the number of individuals produced by each female during its reproductive period. Total offsprings produced were observed and survival of nymphs was calculated after 48 h of emergence and expressed as survival (%) per female.

Estimation of biochemical constituents in the leaves of test B. juncea *genotypes*: The top third leaves of earlier tagged three plants of each test *B. juncea* genotype were collected in polythene zip bags separately and brought to laboratory. Two-gram tissues from these leaves of aforesaid test *B. juncea* genotypes were crushed in liquid nitrogen separately, and added with 10 ml phosphate buffer 50 Mm *p*H 7.8. After that the slurry was transferred to centrifuge tubes and centrifuged at 12000 rpm for 20 min at 4°C. The supernatant was collected and stored in 2.5 ml Eppendorf tubes at -20°C in the refrigerator for estimation of various biochemical constituents. Four important biochemical constituents, viz. total antioxidants, total tannins, total phenols and ferric ion reducing antioxidant power (FRAP) were analysed in the leaves of test *B. juncea* genotypes. There were three replications for each test biochemical constituent in a completely randomized design. Total antioxidant content was estimated by total antioxidant reagent method (Prieto *et al.* 1999), tannin content by Folin-Ciocalteu method (Amorim *et al.* 2008), total phenol content by Folin-Ciocalteau reagent method (Singleton and Rossi 1965), and ferric ion reducing antioxidant power was estimated by FRAP reagent method (Benzie and Strain 1999), and were expressed in mg/g of plant tissue.

Statistical analysis: The data on various biological parameters and biochemical constituents were subjected to analysis of variance using completely randomized design. The significance of differences in the test genotypes were tested by *F*-test, and the treatment means were compared by least significant differences at P=0.05 using the statistical software SAS® version 9.2. The Pearson correlation, multiple linear and stepwise regression analysis was carried out to understand the association of plant biochemical constituents with *L. erysimi* biological parameters.

RESULTS AND DISCUSSION

Developmental biology and reproductive performance of L. erysimi *on diverse* B. juncea *genotypes*: The studies on developmental biology of *L. erysimi* on different *B. juncea* genotypes revealed that the total nymphal durations varied between 74.3–101.2 h (Table 1). The total nymphal duration of *L. erysimi* was significantly longer (F=2.76; df=29, 299; P<0.001) on RP 7-3-2-2-1, TN 3, PDZM 31, NRCHB 101, RLC 3, TS 18-5124 and EC 62-46-1 as compared to other *B. juncea* genotypes (Table 1). (Jana and Pal 2008) reported larger nymphal size and shorter nymphal period of *L. erysimi* on Varuna, B-9 and Jhumka, where Varuna was also found most preferred host for mustard aphid.

The reproductive period, total developmental period, fecundity and survival of *L. erysimi* on the test *B. juncea* genotypes varied between 120.6–173.5 h, 240.6–364.4 h, 41.2–76.6%, and 39.5–82.8%, respectively (Table 1). The reproductive period was significantly longer (F=4.99; df=9,299; P<0.001) on PDZM 31, NRCHB 101 and RP 7-3-2-2-1 as compared to other *B. juncea* genotypes (Table 1). The total development period was significantly longer (F=7.23; df=9,299; P<0.001) on PDZM 31, NRCHB 101, TS 18-5124, YSG, RLC 3, NPJ 50, IC 355399, MSTWR 17-1, EC 61-9-2-2-2, GP 454 and Kranti compared to other *B. juncea* genotypes (Table 1). Earlier studies reported significant variation in developmental periods and reproductive capacity of *L. erysimi* which were higher on Varuna as compared to B-9 and Jhumka (Jana and Pal 2008). The fecundity (F=30.33; df=29,299; P<0.001) and survival (F=100.49; df=29,299; P<0.001) were significantly lower on RLC 3, Kranti, IC 355399, Rohini, GP 454, NPJ 50 and TS 18-5124 as compared to other *B. juncea* genotypes. Further, the *L. erysimi* fed on Pusa 119-1-1, PM 26, PM 30, PM 25, RP 7-3-2-2-1 and RH 749 although

Table 1 Developmental biology and reproductive performance of *Lipaphis erysimi* on diverse *Brassica juncea* genotypes

Genotype	Total nymphal duration (h)	Reproductive period (h)	Total developmental period (h)	Fecundity (nymphs/ female)	Survival (%)
RBJ 11 (Resynthesized)	76.9± 6.4	126.6± 7.7	264.0± 10.2	68.8± 1.7	80.2± 1.5
RBJ 77 (Resynthesized)	76.0± 4.2	141.0± 5.5	254.9± 7.4	73.8± 2.6	80.9± 0.8
RBJ 49 (Resynthesized)	77.7± 6.0	129.0± 4.2	240.7± 6.6	76.6± 0.9	82.7± 1.0
NPJ 161	78.6± 4.3	125.4± 5.5	245.4± 10.3	68.4± 1.7	77.6± 1.0
PDZ 6	81.4± 5.1	120.6± 6.3	245.4± 8.9	61.2± 1.0	82.9± 1.3
Pusa 119-1-3	75.4± 5.2	124.2± 5.5	242.5± 7.9	60.6± 0.6	79.9± 0.3
EC 62-46-1	90.5± 1.2	137.8± 5.4	269.2± 7.1	61.7± 0.7	80.6± 0.2
Pusa 119-1-2	76.7± 4.8	137.4± 5.6	259.5± 8.8	62.7± 1.4	77.5± 0.9
Pusa 119-1-1	81.6± 4.6	135.4± 4.7	262.9± 4.6	58.4± 0.7	73.6± 0.3
Pusa Tarak	87.8± 3.0	136.2± 5.9	264.9± 6.0	61.7± 1.1	73.3± 0.5
PM 26	86.6± 3.3	130.2± 4.1	261.4± 6.8	58.9± 0.6	72.1± 0.3
PM 30	87.6± 4.9	124.2± 5.5	261.0± 8.3	58.0± 0.6	71.6± 0.3
PM 25	85.8± 3.3	130.8± 2.9	262.0± 5.3	55.7± 1.1	70.4± 0.6
RH 749	87.5± 3.4	137.2± 4.9	263.6± 6.9	58.5± 0.7	71.9± 0.3
RP 7-3-2-2-1	101.2± 6.0	155.2± 3.2	313.0± 8.3	57.2± 0.8	71.2± 0.4
PDZM 31	96.6± 6.3	173.5± 2.1	326.4± 8.4	64.4± 1.5	74.3± 0.7
NRCHB 101	93.1± 2.0	165.8± 5.5	322.7± 6.4	72.6± 0.8	77.3± 0.2
YSG (Resynthesized)	87.6± 3.3	130.1± 7.7	284.2± 8.4	67.2± 0.6	75.5± 0.2
TS 18-5124	90.0± 5.0	144.4± 5.4	285.2± 8.3	54.8± 2.5	66.3± 1.8
TS 18-5050 (Multiple cross)	86.4± 4.1	132.0± 4.2	265.1± 6.8	73.3± 2.3	72.6± 1.0
MSTWR 17-1	89.8± 3.5	128.4± 5.5	271.4± 9.4	66.9± 2.7	69.7± 1.5
TN 3 (Resynthesized)	99.3± 5.7	127.2± 5.1	281.2± 8.8	66.0± 0.9	75.4± 0.4
RP 11-2-1-3-1	91.3± 2.5	140.8± 5.4	284.8± 6.9	60.6± 1.7	71.9± 0.8
EC 61-9-2-2-2	74.3± 4.9	140.4± 5.6	271.8± 8.7	60.3± 1.7	70.8± 1.4
NPJ 50	81.4± 4.3	138.4± 4.7	277.4± 5.7	58.0± 0.7	59.8± 0.8
GP 454 (Non-waxy mutant)	78.7± 3.0	139.2± 5.9	270.5± 5.3	57.7± 0.5	56.8± 0.4
Rohini	76.8± 5.0	133.2± 4.1	266.3± 7.6	57.1± 0.5	60.4± 0.6
IC 355399	85.9± 4.2	127.2± 5.5	274.0± 6.1	55.3± 0.9	56.4± 0.9
RLC 3	92.1± 2.8	133.8± 2.9	283.0± 2.8	41.2± 2.0	39.6± 1.9
Kranti	82.4± 3.0	140.2± 4.9	273.3± 6.9	45.2± 1.6	42.4± 1.2
F-probability	<0.001	<0.001	<0.001	<0.001	<0.001
LSD (P=0.05)	12.19	14.52	21.35	3.91	2.96

yielded less number of offsprings, the survival in their offsprings was significantly higher as compared to other *B. juncea* genotypes (Table 1). The differential effects on developmental duration, reproduction and survival of the insects could be due to variation in genetic makeup and/ or expression of defense biochemical compounds in the host plants (Kumar *et al.* 2011, Dhillon and Chaudhary 2015). Similar deleterious effects of *B. juncea* genotype purple mutant were reported on lifespan and fecundity of *L. erysimi*, which were significantly high on BSH-1 as compared to purple mutant (Rana 2005). Singh *et al.* (2006) also reported higher fecundity of *L. erysimi* fed on BSH-1 as compared to those fed on PCR-7. Present study suggest that the *L. erysimi* fed on RLC 3, IC 355399, Rohini, GP 454, NPJ 50, TS 18-5124 and Kranti imparted deleterious effects on their reproductive period, fecundity and survival of the offsprings produced, and thus these genotypes can be used in breeding program.

Biochemical constituents in the leaves of diverse B. juncea *genotypes*: The biochemical factors of host plant play major role in feeding, survival, development, growth and oviposition preference in phytophagous insects and determines the resistance/susceptibility reaction of the host plant (Awmack and Leather 2002). The biochemical constituents, viz. total antioxidants, total tannins, total phenols and FRAP in the leaves of test *B. juncea* genotypes varied between 1.6 to 6.4, 0.1 to 3.4, 1.6 to 6.1 and 0.6 to 1.9 mg/g, respectively (Table 2). Total antioxidants were

Table 2 Amounts of different biochemical constituents in diverse *Brassica juncea* genotypes

Genotype	Total antioxidants (mg/g)	Total tannins (mg/g)	Total phenols (mg/g)	FRAP (mg/g)
RBJ 11 (Resynthesized)	1.6± 0.3	0.6± 0.2	1.6± 0.3	0.7± 0.2
RBJ 77 (Resynthesized)	1.8± 0.2	0.4± 0.3	2.9± 0.9	0.6± 0.3
RBJ 49 (Resynthesized)	1.8± 0.1	0.5± 0.2	3.4± 0.2	0.8± 0.2
NPJ 161	1.6± 0.3	0.7± 0.2	3.5± 0.3	1.0± 0.2
PDZ 6	2.6± 0.1	0.3± 0.1	4.4± 0.4	1.2± 0.2
Pusa 119-1-3	4.7± 0.3	0.2± 0.3	4.6± 0.5	1.4± 0.2
EC 62-46-1	3.7± 0.2	0.2± 0.3	4.9± 0.6	1.4± 0.3
Pusa 119-1-2	3.8± 0.3	1.0± 0.2	4.2± 0.4	1.5± 0.2
Pusa 119-1-1	3.7± 0.2	0.4± 0.4	5.2± 0.4	1.8± 0.2
Pusa Tarak	3.7± 0.3	0.6± 0.3	6.1± 0.5	1.7± 0.2
PM 26	3.7± 0.3	0.5± 0.2	5.4± 0.4	1.9± 0.3
PM 30	4.3± 0.3	0.4± 0.3	2.7± 0.5	1.0± 0.2
PM 25	4.5± 0.2	1.1± 0.3	2.1± 0.4	0.7± 0.2
RH 749	3.4± 0.1	0.3± 0.2	4.0± 0.4	0.9± 0.3
RP 7-3-2-2-1	3.7± 0.2	1.7± 0.2	3.7± 0.5	1.1± 0.2
PDZM 31	3.4± 0.4	0.3± 0.3	3.9± 0.4	1.1± 0.2
NRCHB 101	5.0± 0.3	0.4± 0.3	4.3± 0.3	1.3± 0.3
YSG (Resynthesized)	5.0± 0.1	0.2± 0.2	5.1± 0.4	1.5± 0.2
TS 18-5124	5.0± 0.2	0.4± 0.2	4.5± 0.3	1.5± 0.3
TS 18-5050 (Multiple cross)	4.4± 0.3	0.3± 0.3	4.7± 0.4	1.8± 0.2
MSTWR 17-1	4.6± 0.3	0.1± 0.2	6.0± 0.3	1.8± 0.2
TN 3 (Resynthesized)	3.8± 0.3	0.3± 0.2	3.4± 0.2	1.6± 0.2
RP 11-2-1-3-1	4.3± 0.1	0.4± 0.3	2.2± 0.4	0.7± 0.3
EC 61-9-2-2-2	4.8± 0.1	0.3± 0.3	3.9± 0.3	0.8± 0.3
NPJ 50	5.0± 0.1	1.0± 0.2	4.1± 0.4	1.0± 0.3
GP 454 (Non-waxy mutant)	5.6± 0.1	0.2± 0.2	4.4± 0.3	1.1± 0.3
Rohini	5.8± 0.2	0.5± 0.2	4.1± 0.2	1.3± 0.2
IC 355399	5.8± 0.3	2.5± 0.3	5.1± 0.3	1.5± 0.3
RLC 3	6.4± 0.2	3.4± 0.4	4.6± 0.2	1.5± 0.2
Kranti	6.2± 0.3	3.1± 0.3	4.8± 0.3	1.8± 0.2
F-probability	<0.001	<0.001	<0.001	<0.001
LSD (P=0.05)	0.66	0.63	1.11	0.94

significantly higher (F=32.125, df=29,58 P<0.001) in the leaves of RLC 3, Kranti, IC 355399, Rohini, GP 454, NPJ 50, TS 18-5124, NRCHB 101, YSG, EC 61-9-2-2-2, Pusa 119-1-3, MSTWR 17-1, TS 18-5050, PM 30 and PM 25 as compared to other genotypes (Table 2). Barbehenn *et al.* (2005) found that the higher levels of antioxidant activity decrease availability of ascorbate in plant tissues, leading to increase in oxidative stress resulting in reduced growth and development of the insect. Total tannins were significantly higher in the leaves of RLC 3, Kranti, IC 355399, NPJ 50, RP 7-3-2-2-1, PM 25 and Pusa 119-1-2 (F=330.5, df=29,58 P<0.001) as compared to other *B. juncea* genotypes (Table 2). The total phenol content was significantly higher (F=7.546, df=29,58 P<0.001) in Pusa Tarak, PM 26, MSTWR 17-1, IC 355399 and YSG as compared to other *B. juncea* genotypes (Table 2). The phenolic compounds provide structural support, pigmentation, signaling and defense against herbivory (Felton *et al.* 1992, Barbehenn *et al.* 2005). Similarly, Sarwan and Sangha (2013) found that the biochemical constituents namely glucosinolates, total phenols and ortho-dihydroxy phenols in the mustard genotypes provide defense against aphids. The content of FRAP was significantly higher (F=7.613, df=29,58 P<0.001) in PM 26, Kranti, TS 18-5050, MSTWR 17-1 and Pusa 119-1-1 as compared to other test *B. juncea* genotypes (Table 2). Bhoi *et al.* (2021) reported that the antioxidant scavenging activity of FRAP is higher in resistant plants, which further increases in response to damage by the insects.

Association of B. juncea *biochemicals with biological performance of* L. erysimi: The antioxidants, tannins,

phenols and FRAP in *B. juncea* leaves showed positive correlation with total nymphal period (r = 0.18, 0.12, 0.11 and 0.25, respectively) and total developmental period (r = 0.35, 0.14, 0.04 and 0.09, respectively), while negative correlation with fecundity (r = -0.66**, -0.68**, -0.19 and -0.23, respectively) and offspring survival (r = -0.78**, -0.77**, -0.24 and -0.30, respectively) of *L. erysimi*. However, only antioxidants and tannins in *B. juncea* leaves showed significant and negative association with fecundity and offspring survival of *L. erysimi*. Earlier studies also reported negative correlation of phenols in different rapeseed-mustard genotypes with aphid multiplication and survival (Dilawari and Atwal 1987). The multiple linear regression analysis of antioxidants (X_1), tannins (X_2), phenols (X_3) and FRAP (X_4) in *B. juncea* leaves indicated that these compounds contribute to 33.4, 36.5, 78.8 and 91.3% variability in total nymphal period ($80.49 + 0.54X_1 + 0.14X_2 – 2.19\ X_3 + 8.99X_4$; $R^2 = 33.4$), total developmental period ($254.95 + 6.52\ X_1 – 0.91X_2 – 2.68X_3 + 1.21X_4$; $R^2 = 36.5$), fecundity ($74.61 – 2.82X_1 – 4.39X_2 – 0.19X_3 + 1.90X_4$; $R^2 = 78.8$) and survival ($92.80 – 4.65X_1 – 6.\ 70X_2 – 0.37X_3 + 2.61X_4$; $R^2 = 91.3$) of *L. erysimi*. However, the stepwise regression analysis suggested that the total antioxidants (X_1) explained 33.7% and 32.4% variability for total nymphal period ($72.34 + 0.41X_1$; $R^2 = 30.7$) and total developmental period ($239.65 + 4.61X_1$; $R^2 = 32.4$), while the total antioxidants (X_1) and tannins (X_2) explained 78.5% and 91.3% variability for fecundity ($75.49 – 2.63\ X_1 – 4.37X_2$; $R^2 = 78.5$) and survival ($93.71 – 4.44X_1 – 6.66X_2$; $R^2 = 91.1$) of *L. erysimi*, suggesting that that the antioxidants and tannins result in detrimental effects on developmental period, progeny production and survival of aphid, *L. erysimi* on *B. juncea*.

Present studies revealed that the *B. juncea* genotypes, viz. RLC 3, IC 355399, Rohini, GP 454, NPJ 50, TS 18-5124 and Kranti had higher amounts of antioxidants, tannins, phenols and FRAP, and resulted in adverse effects on reproductive period, fecundity and survival of *L. erysimi*, thus can be used in breeding program for selecting aphid tolerant Indian mustard.

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REFERENCES

Ahuja I, Rohloff J and Bones A M. 2009. Defence mechanisms of Brassicaceae: Implications for plant-insect interactions and potential for integrated pest management-A review. *Agronomy for Sustainable Development* **30**: 311–48.

Amorim L C, Nasciment J E, Monteiro J M, Sobrinho J S, Araujo A S and Albuquerque U P. 2008. A simple and accurate procedure for the determination of tannin and flavonoid levels and some applications in ethnobotany and ethoparmocology. *Functional Ecosystems and Communities* **2**: 88–94.

Agricultural Statistics at a Glance (ASG). 2018. *Agricultural Statistics at a Glance -2018*. Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Govt. of India, New Delhi.

Awmack C S and Leather S R. 2002. Host plant quality and fecundity in herbivorous insects. *Annual Review of Entomology* **47**: 817–44.

Barbehenn R, Cheek S, Gasperut A, Lister E and Maben R. 2005. Phenolic compounds in red oak and sugar maple leaves have prooxidant activities in the midgut fluids of *Malacosoma disstria* and *Orgyia leucostigma* caterpillars. *Journal of Chemical Ecology* **31**(5): 969–88.

Benzie I F F and Strain J J. 1999. Ferric reducing /antioxidant power assay: Direct measure of total antioxidant activity of biological fluids and modified version for simultaneous measurement of total antioxidant power and ascorbic acid concentration. *Methods in Enzymology* **299**: 15–27.

Bhoi, T K, Trivedi N, Kumar H, Tanwar A K and Dhillon M K. 2021. Biochemical defense in maize against *Chilo partellus* (Swinhoe) through activation of enzymatic and nonenzymatic antioxidants. *Indian Journal of Experimental Biology* **59**(1): 54–63.

Carrasco D, Larsson M C and Anderson P. 2015. Insect host plant selection in complex environments. *Current Opinion in Insect Science* **8**: 1–7.

Dhillon M K and Chaudhary D P. 2015. Biochemical interactions for antibiosis mechanism of resistance to *Chilo partellus* (Swinhoe) in different maize types. *Arthropod-Plant Interactions* **9:** 373–82.

Dhillon M K, Singh N, Tanwar A K, Yadava D K and Vasudeva S. 2018. Standardization of screening techniques for resistance to *Lipaphis erysimi* (Kalt.) in rapeseed-mustard under field conditions. *Indian Journal of Experimental Biology* **56**: 674–85.

Dilawari V K and Atwal A S 1987. Effect of cruciferous glucosinolates on probing pattern and feed uptake by mustard aphid, *Lipaphis erysimi* (Kaltenbach). *Proceedings: Animal Sciences* **96**(6): 695–703.

Felton G W, Donato K K, Broadway R M and Duffey S S. 1992. Impact of oxidized plant phenolics on the nutritional quality of dietary protein to a noctuid herbivore, *Spodoptera exigua*. *Journal of Insect Physiology* **38**(4): 277–85.

Holopainen J K and Blande J D. 2013. Where do herbivore-induced plant volatiles go? *Frontiers in Plant Science* **4**: 185.

Jana K and Pal S. 2008. Biology of mustard aphid, *Lipaphis erysimi* (Kalt.) on certain *Brassica* genotypes. *Journal of Applied Zoological Researches* **19**(2): 145–46.

Jat R S, Singh V V, Sharma P and Rai P K. 2019. Oilseed brassica in India: Demand, supply, policy perspective and future potential. *Oilseeds & Fats Crops and Lipids* **26**: 8.

Kumar S, Atri C, Sangha M K and Banga S S. 2011. Screening of wild crucifers for resistance to mustard aphid, *Lipaphis erysimi* (Kaltenbach) and attempt at introgression of resistance gene(s) from *Brassica fruticulosa* to *Brassica juncea*. *Euphytica* **179**: 461–70.

Prieto P, Pineda M and Aguilar M. 1999. Spectrophotometric quantitation of antioxidant capacity through the formation of a phosphor molybdenum complex: specific application to the determination of vitamin E. *Analytical Biochemistry* **269**(2): 337–41.

Rana J S. 2005 Performance of *Lipaphis erysimi* (Homoptera: Aphididae) on different Brassica species in a tropical environment. *Journal of Pest Science* **78** (3): 155–60.

Sarwan K and Sangha M K. 2013. Biochemical mechanism

of resistance in some brassica genotypes against *Lipaphis erysimi* (Kaltenbach) (Homoptera: Aphidiae). *Vegetos* **26** (2): 387–95.

Singh A P, Singh P P and Singh Y P. 2006. Biology of mustard aphid, *Lipaphis erysimi* (Kalt). *Indian Journal of Entomology* **68**(2): 144–47.

Singleton V L and Rossi J A. 1965. Colorimetry of total phenolics with phosphomolybdic- phosphotungestic acid reagents. *American Journal of Enology and Viticulture* **16**: 144–58.

Stahl E, Hilfiker O and Reymond P. 2018. Plant–arthropod interactions: who is the winner? *The Plant Journal* **93**(4): 703–28.