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Pheno-morphological traits of diverse *Brassica juncea* (L.) genotypes determining variability in *Lipaphis erysimi* (Kaltenbach) population build-up

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Abstract

Role of *Brassica juncea* pheno-morphological variation in imparting resistance to *Lipaphis erysimi* was studied. There was significant variation for most phenotypic and yield attributing traits, and aphid resistance indices on the test genotypes, across seasons, and for genotype × season interactions. Genotype RBJ 49 with longer siliquae, greater number of siliquae and seeds per siliqua was found with moderate aphid resistance. Taller genotypes PDZ 6 and RBJ 11 with small siliquae although took longer time to flower and mature, aphid resistance indices were lower than on other genotypes. Genotype IC 355399 having bunchy inflorescence, dark yellow flowers and higher siliquae, harboured greater aphids, while GP 454 and RP 11-2-1-3-1 having cream colour petals displayed opposite reaction towards aphids. In spite of significant variability in test genotypes for seedling colour, petal colour and siliquae orientation, their regression coefficients were nonsignificant with number of aphids and aphid resistance indices. However, path coefficient analysis revealed that number of aphids, aphid population and damage indices, point to first branch and siliqua, seeds per siliqua, total siliquae and siliquae length have significant association with aphid resistance index, indicating that these traits directly or indirectly contribute to differential reaction against *L. erysimi* in *B. juncea*.

Keywords: *aphid resistance, Brassica juncea, insect-plant interaction, Lipaphis erysimi, morphological traits*

Introduction

Brassicas are predominantly cultivated for edible oil and vegetable purposes in different parts of the world (Singh *et al*., 2022). Among different oleiferous rapeseed-mustard group of crops, *Brassica juncea* (L.) Czern & Coss., commonly called as Indian mustard, being relatively better tolerant to abiotic stresses occupies significantly large area in stress prone arid and semi-arid regions. Productivity of this oilseed crop is always challenged by different biotic factors including aphids. Among different aphid species that infest oilseed Brassicas, the turnip/ mustard aphid, *Lipaphis erysimi* (Kaltenbach) infestation causes 11.4 to 71.0% seed yield losses, and its management can prevent 10.2 to 61.1% losses in seed yields of *B. juncea* (Dhillon *et al*., 2022). Sustained feeding and insertion of toxic saliva by both nymphs and adults in plant tissue results in manifestation of yellowing, curling and crumpling of shoots, pods and leaves, and indirect damage by transmitting viruses. Plants respond to herbivory through various morphological, biochemical and molecular mechanisms to counter the effects of herbivore attack. The key plant traits that drive the plant-herbivore interactions are either physical or biochemical or their interactions (Pegadaraju *et al*., 2005; Munzbergova and Skuhrovec, 2020). To overcome insect attacks, plants either have specialized morphological structures or secondary metabolites that have anti-nutritional effect on the insect pests (Usha Rani and Jyothsna, 2010). Resistance factors in the plants direct the defence system against herbivorous insects by negatively affecting insect preference and/or performance (Van Lenteren and De Ponti, 1990). The suitability of a host plant is determined initially by host habitat finding. Aphids use both visual and chemical cues to select the host plants for landing on the host. During this process, insects encounter many morphological barriers that affect their survival and development. The suitability of host plants can also be determined by the deterrent/ stimulant effects of their pheno-morphological traits on the intensity of insect infestation. Furthermore, the plant phenological state such as flowering time, and days to maturity can be used to track degree day accumulation and predict insect activity (Sridhar and Reddy, 2013). Many genotype-specific morphological characters are known to influence plant-insect interactions across the crops. However, such information on the influence of quantitative and qualitative morphological traits of the host plant *B. juncea* on *L. erysimi* interaction is still limited. Therefore, the present study was planned to decipher the role and contribution of pheno-morphological variation in *B. juncea* genotypes in imparting resistance and regulating population build-up of *L. erysimi*.

Materials and Methods

Thirty morphologically diverse *B. juncea* genotypes (Table 1) were raised in the experimental field of ICAR-Indian Agricultural Research Institute, New Delhi. The experiment was laid in four replications in a randomised complete block design keeping 4-row plots of 5 m length. The row-to-row and plant-to-plant spacing were kept at 30 cm and 15 cm, respectively. Test *B. juncea* genotypes were sown in the last fortnight of November during 2018-2019 and 2019-20 cropping seasons to synchronize the flowering with peak activity of aphids. All recommended agronomic practices, except insecticide use were followed to raise the genotypes.

Phenotypic traits recorded on *Brassica juncea* genotypes

Data were recorded on different pheno-morphological characters of *B. juncea* genotypes such as plant height (cm), point to first branch (cm), total number of branches, main shoot length (cm), days to 50% flowering and days to maturity. Furthermore, descriptive characters such as seedling colour, petal colour and siliqua orientation of the test *B. juncea* genotypes were scored during the crop growth period, as described in Table 1.

Yield attributing traits of diverse *Brassica juncea* genotypes

The observations on test *B. juncea* genotypes for yield attributing traits like point to the first siliqua on main shoot (cm), number of siliquae on main shoot, average siliqua length (cm), number of seeds/siliquae and total siliquae/plant were recorded at crop maturity.

Evaluation of test *Brassica juncea* genotypes for resistance against *Lipaphis erysimi*

The test *B. juncea* genotypes were monitored daily to track the mustard aphid, *L. erysimi* infestation and population reaching economic threshold level (ETL: 15 *aphids* on top 10 cm twig in 10% of plants). Five randomly selected plants of each test genotype were tagged for recording the observations, thus making five replications in a completely randomized block design. The observations were recorded on the number of aphids, aphid population index (API on a rating scale of 1-5) and aphid damage index (ADI on a rating scale of 1-5) of all the test genotypes as described by Dhillon *et al.* (2018). At two weeks after *L. erysimi* population reaching ETL, number of aphids on the apical 10 cm main shoot of each selected plant was counted and expressed as aphids/ plant. At three weeks after the aphid population reached ETL, aphid population index, aphid damage index and aphid resistance index (ARI) for each tagged plant of the test *B. juncea* genotypes were recorded as described by Dhillon *et al.* (2018).

Statistical analysis

The data on plant phenotypic and yield attributing traits, aphid population and different resistance indices in different *B. juncea* genotypes raised during different seasons, and genotype × season interactions were analysed in factorial design using statistical software SPSS version 22. The significance of differences was tested by *F*-test, and the genotypes and season means, and their interactions were compared using LSD values at P = 0.05. The correlation coefficients and path coefficient analysis were used to assess the direct and indirect effects of aphid population, aphid damage and population indices, and pheno-morphological traits of *B. juncea* genotypes on aphid resistance index. The square plot regression analysis was used to assess the effect of seedling color, petal color and siliquae orientation in test *B. juncea* genotypes on number of aphids, and aphid damage, population and resistance indices.

Results and Discussion

Descriptive traits of test *Brassica juncea* genotypes

The test *B. juncea* genotypes selected for the present studies were highly diverse in their phenological and morphological traits such as seedling colour, siliqua orientation, petal colour, siliqua length, branching pattern, plant height, seed glucosinolates content, proportion of fatty acids in oil, seed coat colour, plant surface wax, pattern of inflorescence, origin of the genotypes etc. as described in Table 1.

Phenotypic traits of diverse *Brassica juncea* genotypes

Plant morphological traits act as a primary cue for orientation and establishment behavior, however plant quality determines survival and performance of the insects (Schoonhoven *et al*., 2005; Barton and Koricheva, 2010). Present studies found significant variation in test *B. juncea* genotypes for various phenotypic traits *viz.*, point to first branch, total branches, main shoot length, plant height, days to 50% flowering and days to maturity across the seasons (Table 2). However, the genotype × season interactions were significant only for total branches, plant height and days to 50% flowering (Table 2). The point to first branch was shorter in genotypes NPJ 161, RBJ 77, RBJ 49, RBJ 11 and RP 11-2-1-3-1, and total number of branches were significantly higher in RBJ 49, NPJ 161, RBJ 77, Rohini, NRCHB 101 and RBJ 11 as compared to

Table 1. Pheno-morphological description of *Brassica juncea* genotypes

Genotypes	Seedling colour score (1-3)	Siliqua orientation score (1-3)	Petal colour score (1-4)	Additional descriptor traits
RBJ 11	Light green (3)	Intermediate (2)	Yellow (2)	Small siliqua (2.7 cm), synthetic *B. juncea* genotype
RBJ 77	Green (2)	Open (3)	Pale yellow (3)	Small siliqua (2.74 cm), synthetic *B. juncea* genotype
RBJ 49	Green (2)	Open (3)	Yellow (2)	Long siliqua (6-5 cm), synthetic *B. juncea* genotype
NPJ 161	Light green (3)	Intermediate (2)	Dark yellow (1)	Long siliqua, high glucosinolate content and bold seeded
PDZ 6	Light green (3)	Intermediate (2)	Yellow (2)	Low erucic acid and intermediate glucosinolate content (~70 ppm)
Pusa 119-1-3	Green (2)	Open (3)	Yellow (2)	Long siliqua, open siliqua arrangement
EC 62-46-1	Light green (3)	Intermediate (2)	Dark yellow (1)	High branching
Pusa 119-1-2	Green (2)	Open (3)	Yellow (2)	Long siliqua, open siliqua arrangement
Pusa 119-1-1	Green (2)	Intermediate (2)	Yellow (2)	Long siliqua, open siliqua arrangement
Pusa Tarak	Green (2)	Appressed (1)	Dark yellow (1)	Appressed siliqua arrangement, bold seeded
PM 26	Green (2)	Intermediate (2)	Dark yellow (1)	Short duration
PM 30	Dark green (1)	Open (3)	Dark yellow (1)	Low erucic acid content and bold seeded
PM 25	Green (2)	Intermediate (2)	Yellow (2)	Short duration
RH 749	Dark green (1)	Intermediate (2)	Dark yellow (1)	Tall plant height, high biomass and takes longer duration to mature
RP 7-3-2-2-1	Green (2)	Intermediate (2)	Dark yellow (1)	-
PDZM 31	Dark green (1)	Intermediate (2)	Yellow (2)	Yellow seed coat colour, Low in erucic acid and total glucosinolates (double zero)
NRCHB 101	Dark green (1)	Intermediate (2)	Pale yellow (3)	Thick siliqua and bold seeded
YSG	Green (2)	Intermediate (2)	Pale yellow (3)	High biomass, synthetic *B. juncea* genotype
TS 18-5124	Green (2)	Appressed (1)	Pale yellow (3)	*Brassica carinata* derived *B. juncea* introgression line
TS 18-5050	Dark green (1)	Open (3)	Yellow (2)	*Brassica carinata* derived *B. juncea* introgression line
MSTWR 17-1	Light green (3)	Intermediate (2)	Yellow (2)	White rust resistant
TN 3	Green (2)	Intermediate (2)	Pale yellow (3)	Synthetic *B. juncea*, high biomass, takes longer duration to mature
RP 11-2-1-3-1	Dark green (1)	Intermediate (2)	Pale yellow (3)	-
EC 61-9-2-2-2	Dark green (1)	Intermediate (2)	Dark yellow (1)	Yellow seed coat colour
NPJ 50	Light green (3)	Open (3)	Pale yellow (3)	-
GP 454	Light green (3)	Open (3)	Creamish (4)	Little wax on stem and leaves (Non-waxy mutant)
Rohini	Light green (3)	Intermediate (2)	Yellow (2)	-
IC 355399	Dark green (1)	Appressed (1)	Dark yellow (1)	Bunchy inflorescence
RLC 3	Green (2)	Intermediate (2)	Yellow (2)	Low erucic acid and low glucosinolate content
Kranti	Green (2)	Intermediate (2)	Yellow (2)	Purple stem pigmentation

Table 2. Diverse phenotypic characters of different *Brassica juncea* genotypes

Genotypes	Plant height (cm)		Point to first branch (cm)		Total no. of branches		Main shoot length (cm)		Days to 50% flowering		Days to maturity	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
RBJ 11	206.5	209.4	2.6	3.0	198.2	210.2	54.8	49.7	38.4	41.4	126.8	132.0
RBJ 77	253.4	232.4	1.4	1.5	220.8	232.8	76.2	60.4	33.2	29.8	125.4	129.2
RBJ 49	189.5	178.9	2.0	2.3	232.6	247.8	71.1	58.5	34.4	31.8	124.0	127.0
NPJ 161	169.3	153.6	1.2	1.4	230.4	246.4	76.8	65.0	34.8	29.6	115.8	118.8
PDZ 6	280.2	288.4	75.7	76.5	28.0	45.0	93.4	84.9	35.8	30.0	123.2	126.2
Pusa 119-1-3	218.1	232.3	19.0	21.6	28.4	45.4	91.1	78.8	32.8	29.6	123.8	126.8
EC 62-46-1	220.9	229.1	39.3	42.3	27.4	39.6	97.0	84.7	30.6	30.2	123.8	126.8
Pusa 119-1-2	220.8	220.2	19.9	22.0	25.6	37.4	87.0	74.7	31.4	29.6	124.0	127.0
Pusa 119-1-1	268.0	280.3	22.0	24.9	74.6	85.6	77.8	65.5	31.4	30.2	127.4	130.4
Pusa Tarak	182.4	192.1	44.9	47.8	25.0	36.0	83.1	70.8	32.8	30.6	116.6	119.6
PM 26	178.7	189.0	15.9	18.8	26.4	37.4	81.6	69.3	36.4	30.8	115.0	118.0
PM 30	139.3	151.6	24.4	27.3	28.6	39.6	77.0	64.7	33.2	32.8	123.2	126.2
PM 25	188.1	200.4	30.6	33.5	29.2	39.4	97.7	87.4	30.6	28.6	113.4	116.4
RH 749	248.3	260.5	42.9	45.8	32.6	42.6	87.5	75.2	30.8	35.4	122.6	125.6
RP 7-3-2-2-1	209.4	218.5	42.1	45.0	29.0	39.0	89.7	77.4	32.8	25.0	116.8	119.8
PDZM 31	237.7	248.0	32.8	35.7	38.0	48.0	83.5	71.2	25.6	24.0	123.2	126.2
NRCHB 101	268.5	272.8	2.8	4.0	222.0	232.0	82.1	69.8	27.2	23.4	120.6	123.6
YSG	230.4	242.6	23.3	26.2	45.2	55.2	83.7	71.4	35.0	30.6	124.4	127.4
TS 18-5124	258.8	275.1	22.0	24.9	30.0	40.0	78.4	64.7	41.2	41.6	125.0	128.0
TS 18-5050	263.5	275.8	23.6	26.5	32.4	42.4	71.6	59.3	31.2	29.0	124.0	127.0
MSTWR 17-1	227.9	240.1	22.0	24.9	37.8	47.8	76.6	64.3	26.4	20.4	117.2	120.2
TN 3	261.7	270.0	31.9	34.8	30.2	40.2	82.9	70.6	27.4	20.4	125.6	128.6
RP 11-2-1-3-1	174.4	186.6	20.1	23.0	27.8	37.8	75.9	63.6	26.8	21.4	121.8	124.8
EC 61-9-2-2-2	184.2	209.5	5.2	5.7	126.2	136.2	45.5	41.1	26.4	20.4	119.0	122.0
NPJ 50	224.9	237.2	21.8	24.7	31.8	41.8	71.7	59.4	34.6	30.0	125.8	128.8
GP 454	232.9	245.2	25.0	27.9	31.2	41.4	76.1	57.8	26.8	22.6	126.0	129.0
Rohini	243.3	255.5	65.0	69.0	213.6	225.2	77.8	61.5	32.0	26.0	122.4	125.4
IC 355399	161.3	173.6	72.0	75.0	37.4	51.4	25.0	26.0	31.8	34.8	126.8	131.8
RLC 3	227.1	241.1	22.0	22.4	30.4	44.4	70.7	63.8	30.0	22.2	123.0	128.0
Kranti	257.3	272.3	23.4	23.8	32.2	46.2	77.9	68.9	31.2	26.2	117.8	122.8
For comparing	LSD	F-p	LSD	F-p	LSD	F-p	LSD	F-p	LSD	F-p	LSD	F-p
Genotype (G)	9.91	<0.001	2.97	<0.001	5.65	<0.001	5.27	<0.001	1.32	<0.001	2.50	<0.001
Season (S)	2.56	<0.001	0.77	<0.001	1.46	<0.001	1.36	<0.001	0.34	<0.001	0.64	<0.001
G × S	14.01	<0.001	4.20	1.00	7.99	<0.001	7.45	0.96	1.86	<0.001	3.53	1.00

LSD = Least significant differences at P = 0.05. F-p = F-probability.

Table 3. Different yield attributing traits of *Brassica juncea* genotypes

Genotypes	Point to first siliqua on main shoot (cm)		Siliquae on main shoot (no)		Siliqua length (cm)		Seeds/siliqua		Total siliquae/plant	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
RBJ 11	5.9	5.8	61.4	53.4	2.3	2.6	14.1	12.1	2160.0	2020.0
RBJ 77	7.9	7.4	48.8	36.8	3.5	3.8	11.0	13.9	1290.0	1190.0
RBJ 49	5.9	6.2	35.2	24.4	5.9	6.4	17.3	20.5	1280.0	1180.0
NPJ 161	6.9	6.1	45.2	54.2	4.0	4.3	16.4	18.5	630.0	530.0
PDZ 6	13.3	14.2	36.2	40.6	4.7	5.2	10.7	12.5	559.0	563.0
Pusa 119-1-3	14.1	14.6	42.2	41.6	5.0	5.6	11.4	13.2	680.0	710.0
EC 62-46-1	13.0	13.9	40.8	41.8	3.1	4.1	11.3	13.1	616.0	646.0
Pusa 119-1-2	9.7	10.2	23.2	29.2	4.8	5.3	14.7	16.5	510.0	540.0
Pusa 119-1-1	18.5	18.1	65.6	74.6	4.9	5.8	16.6	18.4	674.0	708.0
Pusa Tarak	12.2	12.8	57.2	66.2	5.0	5.7	16.4	18.2	578.0	618.0
PM 26	13.1	13.6	55.2	64.2	4.8	5.2	17.1	18.9	668.0	708.0
PM 30	12.2	12.8	54.4	63.4	4.4	4.7	16.6	18.4	644.0	702.0
PM 25	11.1	11.6	30.6	39.6	3.8	4.1	16.1	17.9	734.0	804.0
RH 749	13.5	14.1	42.8	51.8	4.3	4.6	12.0	13.8	528.0	598.0
RP 7-3-2-2-1	8.1	9.1	40.0	49.0	3.9	4.2	10.5	12.3	538.0	612.0
PDZM 31	15.4	14.4	24.6	33.6	2.8	3.2	10.8	12.6	622.0	702.0
NRCHB 101	24.1	24.8	27.8	36.8	2.9	3.3	12.6	14.4	980.0	1060.0
YSG	17.4	20.9	25.0	34.0	3.3	3.6	15.0	16.8	670.0	750.0
TS 18-5124	21.2	24.7	26.2	35.2	3.9	4.2	17.7	19.5	678.0	778.0
TS 18-5050	22.9	26.4	24.8	33.8	4.0	4.3	19.0	20.8	510.0	610.0
MSTWR 17-1	23.0	26.5	32.8	41.8	4.0	4.3	15.6	17.4	686.0	778.0
TN 3	22.4	25.9	35.2	44.2	4.0	4.1	19.0	20.8	582.0	662.0
RP 11-2-1-3-1	24.5	28.0	28.2	37.2	4.0	4.0	15.4	17.2	496.0	476.0
EC 61-9-2-2-2	6.8	9.9	38.0	51.0	4.0	4.3	15.7	17.5	1144.0	1124.0
NPJ 50	15.8	19.3	37.4	46.4	3.9	4.2	19.3	21.1	680.0	660.0
GP 454	14.4	17.9	39.4	48.4	3.8	4.1	18.3	20.1	578.0	558.0
Rohini	8.3	11.8	49.0	58.0	3.3	3.7	11.7	13.5	756.0	736.0
IC 355399	7.7	11.2	69.2	72.2	3.2	3.6	19.8	21.6	634.0	514.0
RLC 3	15.1	17.3	33.4	42.4	3.3	3.6	16.8	18.6	632.0	512.0
Kranti	15.6	19.1	38.8	47.8	3.4	3.8	17.0	18.8	606.0	486.0
For comparing	LSD	F-p	LSD	F-p	LSD	F-p	LSD	F-p	LSD	F-p
Genotype (G)	1.68	<0.001	5.05	<0.001	0.28	<0.001	1.43	<0.001	121.44	<0.001
Season (S)	0.43	<0.001	1.30	<0.001	0.07	<0.001	0.37	<0.001	31.36	0.69
G × S	2.37	<0.001	7.13	<0.001	0.39	0.77	2.03	0.96	171.75	0.78

LSD = Least significant differences at P = 0.05. F-p = F-probability.

other *B. juncea* genotypes (Table 2). Further, the main shoot was significantly longer in Pusa Mustard 25, EC 62-46-1, PDZ 6, Pusa 119-1-3 and RP 7-3-2-2-1, while shorter in IC 355399 as compared to other test *B. juncea* genotypes. Genotypes PDZ 6, TN3, Kranti, Pusa 119-1-1, RH 749, NRCHB 101, TS 18-5050, TS 18-5124 were significantly taller as compared to other test *B. juncea* genotypes across the seasons (Table 2). Genotype PDZ 6 having tallest plant height was recorded with lower aphid infestation as compared to other *B. juncea* genotypes. Conversely, earlier studies found that the shorter varieties receive severe aphid attack than the taller varieties (Mamun *et al*., 2010). Late maturing genotype RBJ 11, with shorter siliqua observed the least number of aphids and lower aphid resistance indices. Genotypes TS 18-5124 and RBJ 11 longer time to flower, while RBJ 11, Pusa 119-1-1, IC 355399 and GP 454 took longer time to mature across the seasons (Table 2).

Yield attributing traits of diverse *Brassica juncea* genotypes

The yield attributing traits viz., point to first siliqua on main shoot, number of siliquae on main shoot, length of siliquae, seeds per siliqua and total siliquae per plant significantly varied among the test *B. juncea* genotypes across the seasons (Table 3). However, the genotype × season interactions were significant only for point to first siliqua and number of siliquae on the main shoot among the test *B. juncea* genotypes (Table 3). Point to first siliqua on the main shoot was shorter in RBJ 11, RBJ 77, RBJ 49, NPJ 161, EC 61-9-2-2-2 and RP 7-3-2-2-1 as compared to other *B. juncea* genotypes across seasons (Table 3). The numbers of siliquae on main shoot were higher in Pusa 119-1-1, IC 355399, RBJ 11, Pusa Tarak, Pusa Mustard 26 and Pusa Mustard 30 as compared to other *B. juncea* genotypes across seasons (Table 3). Genotypes RBJ 49, Pusa 119-1-3, Pusa 119-1-1, Pusa 119-1-2, Pusa Tarak, Pusa Mustard 26, Pusa Mustard 30 and RH 749 has significantly longer siliquae, while relatively shorter siliquae were recorded in RBJ 11, PDZM 31 and NRCHB 101 genotypes across seasons (Table 3). Earlier studies reported that the genotypes having longer siliquae have greater aphid population build-up on *B. juncea* (Khan and Jha, 2010; Khayat *et al*., 2012). Genotypes IC 355399 bearing the siliquae in bunches, was found with greater total number of siliquae on main shoot as well as higher total number of aphids per plant and aphid resistance indices. This clearly indicates that close arrangement of siliquae on the inflorescence harbour higher number of aphids. Reddall *et al*. (2004) reported that the plant morphological traits adversely influence the pest population build-up. The seeds per siliqua were significantly greater in NPJ 50, TN 3, IC 355399, RBJ 49, TS 18-5050 and TS 18-5124, while number of siliquae per plant were significantly greater on RBJ 11, RBJ 77, RBJ 49 and EC 61-9-2-2-2 as compared to other *B. juncea* genotypes across the seasons (Table 3).

Population build-up and resistance indices of *Lipaphis erysimi* on *B. juncea* genotypes

The numbers of aphids per plant, aphid population index, aphid damage index and aphid resistance index significantly varied among the test *B. juncea* genotypes across seasons, and for genotype × season interactions (Table 4). The *B. juncea* genotypes viz., Pusa Mustard 30, RBJ 11, PDZ 6, Pusa Mustard 25, GP 454 and RLC 3 were found with significantly lower numbers of aphids per plant, and aphid population, damage and resistance indices as compared to other test *B. juncea* genotypes across seasons (Table 4). Furthermore, genotypes RBJ 49, Pusa 119-1-3, Pusa 119-1-1, Pusa 119-1-2, Pusa Tarak, Pusa Mustard 26, Pusa Mustard 30 and RH 749 having longer siliquae, NPJ 50, TN 3, IC 355399, RBJ 49, TS 18-5050 and TS 18-5124 with higher number of seeds per siliqua, and RBJ 11, RBJ 77, RBJ 49 and EC 61-9-2-2-2 with higher number of siliquae per plant, were found to harbor significantly lower numbers of aphids per plant, and aphid resistance indices (Table 4). However, earlier studies reported that the length of siliquae had a positive impact on build-up of aphid population on *B. juncea* (Khan and Jha, 2010).

Direct and indirect effects of *Lipaphis erysimi* infestation and *B. juncea* traits for aphid resistance index

Plant resistance in most of the cases is determined by various morphological and biochemical traits governing different resistance mechanisms in plants against insects, which also varies across genotypes and seasons (Kher and Rataul, 1991). The number of aphids, aphid population index, aphid damage index, total number of siliquae on main shoot, point to first siliqua on main shoot and seeds per siliqua had significant and positive, while point to first branch, siliqua length and total number of siliquae per plant negative correlation with aphid resistance index (Table 5). Earlier studies reported a negative correlation between plant height and aphid incidence as the shorter varieties observed severe aphid attack than the taller varieties (Mamun *et al*., 2010). The path coefficient analysis showed that the numbers of aphids, aphid population index, aphid damage index, point to first branch, total number of branches, point to first siliqua on main shoot, seeds per siliqua, total siliquae per plant, days to 50% flowering and days to maturity had direct effects on

Table 4. Population build-up and resistance indices of *Lipaphis erysimi* on diverse *Brassica juncea* genotypes

Genotypes	Aphids/plant (top 10 cm)		Aphid population index		Aphid damage index		Aphid resistance index	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
RBJ 11	95.0	178.0	2.4	3.0	1.4	2.6	1.9	2.8
RBJ 77	217.0	198.0	3.0	3.0	3.0	2.6	3.0	2.8
RBJ 49	159.0	194.0	3.0	3.0	2.4	2.4	2.7	2.7
NPJ 161	125.0	136.0	3.0	2.8	2.2	2.2	2.6	2.5
PDZ 6	172.0	62.0	3.0	2.0	2.6	1.0	2.8	1.5
Pusa 119-1-3	219.0	146.0	3.0	3.0	2.8	2.2	2.9	2.6
EC 62-46-1	230.0	252.0	4.0	3.2	3.8	2.6	3.9	2.9
Pusa 119-1-2	213.0	194.0	3.0	2.8	3.0	2.0	3.0	2.4
Pusa 119-1-1	161.2	166.0	3.0	3.0	2.8	2.2	2.9	2.6
Pusa Tarak	220.0	206.0	3.0	3.0	2.8	2.4	2.9	2.7
PM 26	152.0	162.0	3.0	3.0	2.8	2.4	2.9	2.7
PM 30	120.0	114.0	3.0	1.6	2.2	1.0	2.6	1.3
PM 25	161.0	140.0	3.0	2.2	2.4	2.0	2.7	2.1
RH 749	241.0	211.0	3.4	3.0	3.4	2.2	3.4	2.6
RP 7-3-2-2-1	248.0	226.0	3.6	3.0	3.4	2.4	3.5	2.7
PDZM 31	234.0	236.0	3.2	3.2	3.2	2.4	3.2	2.8
NRCHB 101	237.4	252.0	3.4	3.0	3.4	2.0	3.4	2.5
YSG	336.2	302.0	3.8	4.0	3.4	3.4	3.6	3.7
TS 18-5124	350.0	324.0	4.0	4.0	3.8	3.6	3.9	3.8
TS 18-5050	338.4	272.0	4.0	3.8	3.4	3.0	3.7	3.4
MSTWR 17-1	148.2	133.0	3.0	3.0	2.8	1.8	2.9	2.4
TN 3	185.4	158.0	3.0	3.0	2.6	2.2	2.8	2.6
RP 11-2-1-3-1	354.8	316.0	4.4	3.8	4.6	3.0	4.5	3.4
EC 61-9-2-2-2	335.0	354.0	4.0	3.8	4.6	3.2	4.3	3.5
NPJ 50	253.8	266.0	3.6	3.6	3.2	3.0	3.4	3.3
GP 454	126.0	142.0	3.0	2.8	2.2	2.0	2.6	2.4
Rohini	260.0	232.0	4.0	3.0	4.4	2.4	4.1	2.7
IC 355399	450.0	436.0	4.0	4.0	4.6	4.6	4.3	4.3
RLC 3	114.0	132.0	2.8	2.6	1.8	1.6	2.3	2.1
Kranti	178.2	156.0	3.0	2.8	2.6	2.2	2.8	2.5
For comparing	LSD	F-p	LSD	F-p	LSD	F-p	LSD	F-p
Genotype (G)	15.80	<0.001	0.28	<0.001	0.45	<0.001	0.31	<0.001
Season (S)	4.08	<0.001	0.07	<0.001	0.12	<0.001	0.08	<0.001
G × S	22.35	<0.001	0.39	<0.001	0.64	<0.001	0.44	<0.001

Table 5. Direct and indirect effects of 14 independent variables of *Lipaphis erysimi* infestation and *Brassica juncea* traits on aphid resistance index

Plant/aphid traits	Path coefficients														
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	r
Number of aphids (X_1)	**0.44**[#]	0.53	0.98	-0.05	-0.32	-0.23	-0.62	0.01	-0.03	0.04	0.02	0.02	0.04	0.01	0.84**
Aphid population index (X_2)	0.40	**0.54**	0.96	-0.04	-0.09	-0.21	-0.07	-0.08	-0.04	-0.06	-0.04	0.25	-0.29	-0.26	0.97**
Aphid damage index (X_3)	0.41	0.56	**0.89**	-0.06	-0.09	-0.23	-0.09	-0.04	-0.05	-0.04	-0.06	0.21	-0.23	-0.21	0.97**
Plant height (X_4)	0.05	-0.13	0.01	**-0.06**	-0.13	0.17	0.01	0.09	0.05	-0.02	-0.02	0.02	-0.02	0.01	0.03
Point to first branch (X_5)	0.02	-0.39	0.08	-0.24	**-0.09**	0.08	0.02	0.10	0.29	-0.01	0.01	-0.15	-0.11	-0.18	-0.57**
Total number of branches (X_6)	0.00	0.28	-0.11	0.17	-0.02	**-0.14**	0.01	0.08	-0.38	0.02	0.00	-0.09	-0.05	-0.12	-0.35
Main shoot length (X_7)	0.01	-0.25	0.05	-0.39	-0.01	0.03	**0.02**	0.13	0.32	0.01	0.01	-0.07	-0.04	-0.09	-0.27
Total number of siliquae on main shoot (X_8)	-0.02	0.10	0.01	0.02	0.37	-0.08	0.00	**-0.11**	0.04	0.03	-0.01	-0.35	0.23	0.32	0.55**
Point to first siliqua on main shoot (X_9)	0.03	-0.09	0.05	-0.04	-0.09	0.35	0.01	-0.11	**0.23**	-0.06	-0.01	-0.21	0.09	0.26	0.41*
Siliqua length (X_{10})	-0.01	-0.09	0.02	-0.07	-0.04	-0.04	0.02	-0.08	0.15	**0.02**	0.01	-0.11	-0.07	-0.11	-0.40*
Seeds per siliqua (X_{11})	-0.01	0.10	0.02	0.13	0.11	0.09	0.01	-0.40	0.13	0.00	**0.00**	0.18	0.08	0.17	0.61**
Total siliquae per plant (X_{12})	0.00	0.20	-0.07	0.21	-0.02	-0.13	-0.01	0.38	-0.59	0.06	-0.01	**-0.28**	-0.14	-0.29	-0.69**
Days to 50 % flowering (X_{13})	-0.01	0.02	-0.01	-0.02	0.07	-0.12	0.01	0.00	-0.19	0.18	-0.01	-0.08	**-0.04**	-0.09	-0.29
Days to maturity (X_{14})	0.02	0.05	0.00	0.09	0.09	0.03	0.00	-0.03	-0.13	0.04	-0.06	0.10	0.05	**0.10**	0.35

[#]The diagonal values in bold are the direct effects, while rest of the values are indirect effects. The correlation coefficients (r) marked with *,** are significant at P = 0.01 and 0.05, respectively.

Path coefficient equation: Aphid Resistance Index = "2317 + $0.44X_1 + 0.54X_2 + 0.89X_3 - 0.06X_4 - 0.09X_5 - 0.14X_6 + 0.02X_7 - 0.11X_8 + 0.23X_9 + 0.02X_{10} + 0.00X_{11} - 0.28X_{12} - 0.04X_{13} + 0.10X_{14}$ (residual variance = 0.0).

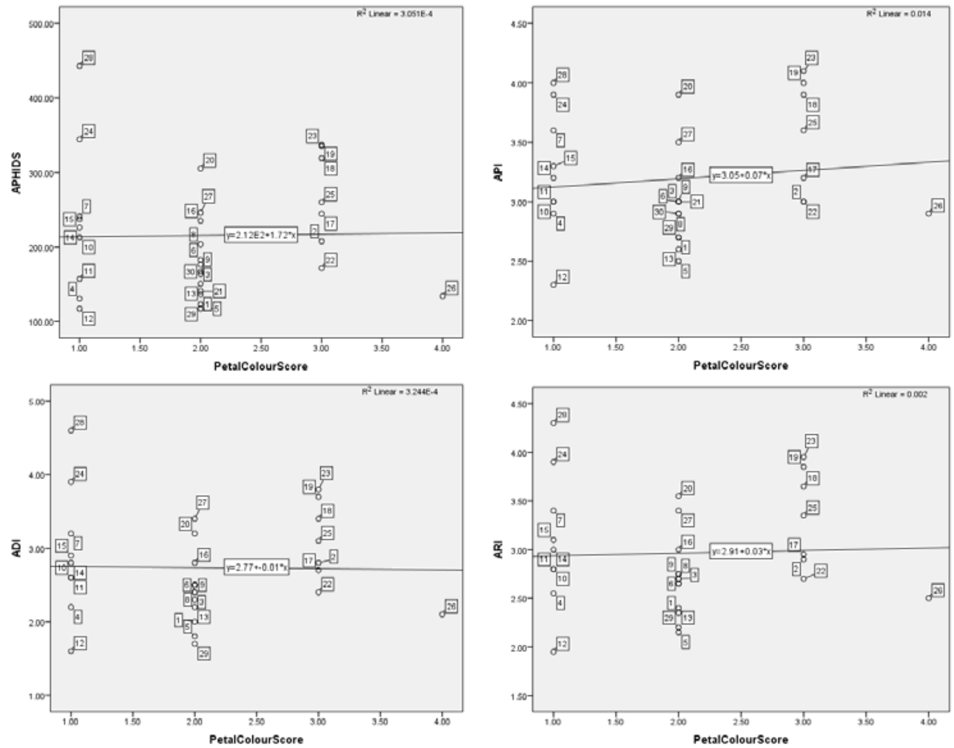

Figure 1. Regression of seedling colour score of different *Brassica juncea* genotypes with numbers of *Lipaphis erysimi*, and population, damage and aphid resistance indices

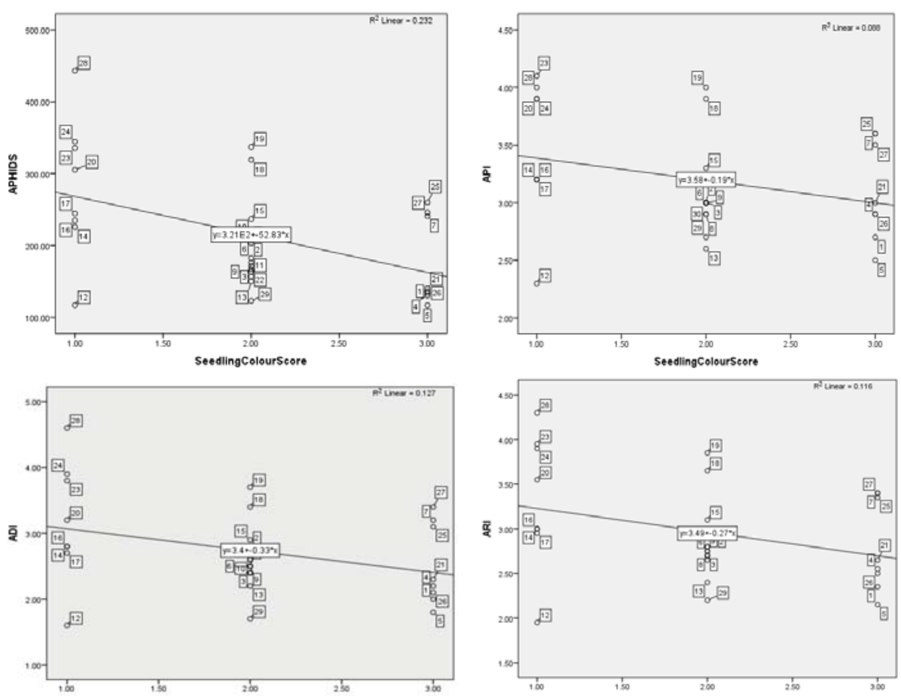

Figure 2. Regression of petal colour score of different *Brassica juncea* genotypes with numbers of *Lipaphis erysimi*, and population, damage and aphid resistance indices

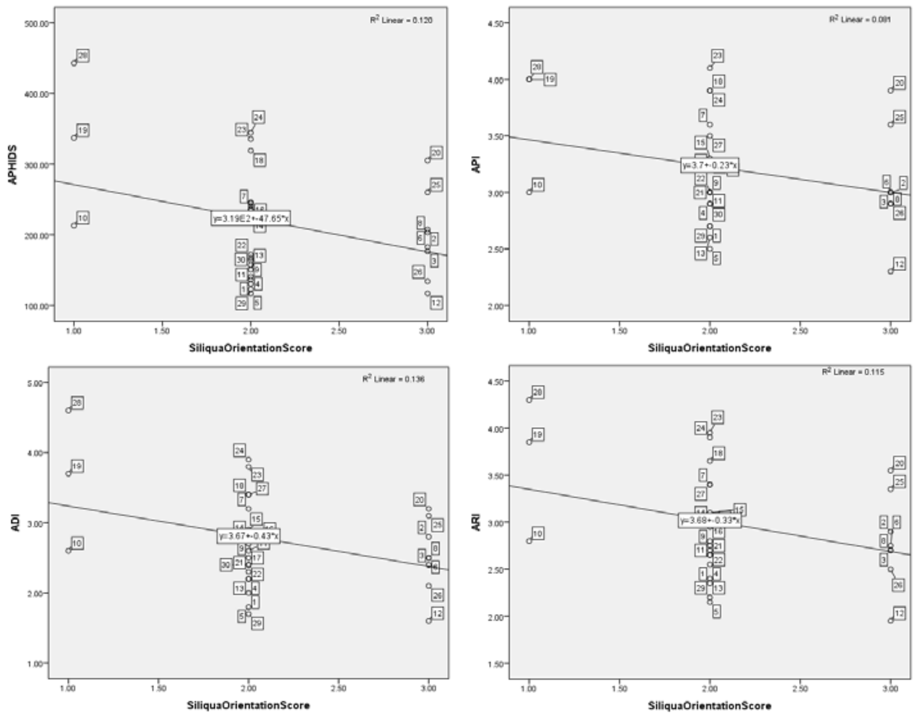

Figure 3. Regression of siliquae orientation of different *Brassica juncea* genotypes with numbers of *Lipaphis erysimi*, and population, damage and aphid resistance indices

aphid resistance index (+ve or -ve) in the same direction (Table 5). Conversely, direct effects of plant height, main shoot length, total number of siliquae on main shoot and siliqua length on aphid resistance index were in the opposite direction. The indirect effects of numbers of aphids, aphid population index, aphid damage index, total number of siliquae on main shoot, point to first siliqua on main shoot and seeds per siliqua on aphid resistance index were largely through point to first branch, siliqua length and total number of siliquae per plant and days to maturity (Table 5).

Present studies revealed significant variability among the test *B. juncea* genotypes for seedling colour score, petal colour and siliqua orientation (Figs. 1 to 3). Genotype IC 355399 bearing flowers and siliquae in bunches with dark yellow petals harboured a greater number of aphids per plant, while GP 454 possessing cream colour petals recorded lower number of aphids as compared to other *B. juncea* genotypes. Earlier studies also reported that the *L. erysimi* were more attracted towards yellow as compared to other inflorescence colours and green pods (Dilawari and Dhaliwal, 1988; Dilawari and Atwal, 1989; Rajesh *et al*., 2010). Conversely, RP 11-2-1-3-1 having cream colour petals recorded higher number of aphids and aphid resistance indices as compared to other *B. juncea* genotypes. The correlation and path coefficient analysis indicated that the numbers of aphids, aphid population index and aphid damage index were significantly and positively associated, and indirectly contributed to aphid resistance index in the test *B. juncea* genotypes. However, present studies showed non-significant effects of seedling colour score (Fig. 1), petal colour score (Fig. 2) and siliqua orientation (Fig. 3) on number of aphids per plant, aphid population index, aphid damage index and aphid resistance index of *L. erysimi* on the test *B. juncea* genotypes. These findings also indicate that the intraspecific trait variability in genotypes for plant colour, architecture and phloem sap quality differs not only at the population but also at individual level, leading to differential herbivory by the sap feeders (Albert *et al*., 2011; Jakobs *et al*., 2019). Hence, biochemical profiling along with pheno-morphological traits is needed to identify appropriate morphological and biochemical markers for the selection of sources of resistance against *L. erysimi* in *B. juncea*.

Conclusion

Present studies recorded significant variation in test *B. juncea* genotypes for phenotypic and yield attributing traits, number of aphids per plant, and resistance indices of mustard aphid, *L. erysimi*. The pheno-morphological traits like point to first branch, siliqua length and total siliquae per plant observed significant and negative, while total number of siliquae per plant, point to first siliqua on the main shoot and seeds per siliqua observed positive association with *L. erysimi* resistance index in the test *B. juncea* genotypes. However, in spite of having significant variability among the test *B. juncea* genotypes for seedling colour, petal colour and siliqua orientation, their regression coefficients with numbers of aphids per plant, aphid population index, aphid damage index and aphid resistance index were nonsignificant, indicating that the pheno-morphological plant traits differentially affect the population build-up and resistance reaction against *L. erysimi* in *B. juncea*.

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