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Allelochemical resistance traits of muskmelon (*Cucumis melo*) against the fruit fly (*Bactrocera cucurbitae)* in a hot arid region of India

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Abstract Host plant resistance is an important component for management of the melon fruit fly, *Bactrocera cucurbitae* (Coquillett), owing to difficulties associated with its chemical and biological control. Various biochemical traits including total sugar, reducing sugar, non-reducing sugar, tannins, phenols, alkaloids, flavinoid and pH contents of fruit were studied on 11varieties/ genotypes of muskmelon, *Cucumis melo* L., in relation to resistance against *B. cucurbitae* under field conditions. Significant differences were found in tested varieties/ genotypes for fruit infestation and larval density per fruit. AHMM/BR-1, RM-50 and AHMM/BR-8 were the most resistant; MHY-5, Durgapura Madhu and Pusa Sarabati were moderately resistant; AHMM/BR-13, Pusa Madhuras and Arka Jeet were susceptible; whereas Arka Rajhans and GMM-3 were the highly susceptible varieties/ genotypes to fruit fly in both seasons, 2011 and 2012. The larval density per fruit increased with an increase in percent fruit infestation and there was a significant positive correlation (r = 0.97) between percent fruit infestation and larval density per fruit. Total sugar, reducing sugar, non-reducing sugar and pH were lowest in resistant and highest in susceptible varieties/ genotypes, whereas tannins, phenols, alkaloids and flavinoid contents were highest in resistant and lowest in susceptible varieties/ genotypes. Total alkaloid and pH contents explained 97.96% of the total variation in fruit fly infestation and 92.83% of the total variation in larval density per fruit due to alkaloids and total sugar contents.

Keywords Antibiosis · Biochemical traits

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Introduction

Muskmelon (*Cucumis melo* L.) is an important horticultural crop worldwide and plays an important role in international trade. Different forms of melon are known that are morphologically different. It is a species of melon that has been developed into many cultivated varieties. These include smooth skinned varieties such as honeydew, crenshaw and casaba and different netted cultivars (cantaloupe, Persian melon and Santa Claus or Christmas melon). The main plant organ used is the fruit, which is eaten both immature and mature (McCreight & Staub 1993) as desserts and vegetables for salad. Melon seeds may be eaten after being slightly roasted or edible oil can be extracted from them. In addition to their consumption when fresh, melons are sometimes dried. Other varieties are cooked, or grown for their seeds, which are processed to produce melon oil. Still other varieties are grown only for their pleasant fragrance. The Japanese liqueur Midori is flavored with muskmelon. Plants are generally exposed to a variety of biotic and abiotic factors that may alter their genotypic and/or phenotypic properties resulting in different mechanisms of resistance which enable plants to avoid, tolerate or recover from the effects of pest attacks (Gogi *et al.* 2010b; Pedigo 1996; Sarfraz *et al.* 2006). Such mechanisms of plant resistance have been effectively used against insect pests in many field and horticultural crops (Dhillon *et al.* 2005b; Gogi *et al.* 2010a; Kogan 1982; Sarfraz *et al.* 2007). Mechanisms of resistance in plants are either constitutive or induced (Karban & Agrawal 2002; Painter 1951; Traw & Dawson 2002) and are grouped into three main categories: antixenosis, antibiosis and tolerance (Painter 1951). Plants responsible for antibiosis resistance may cause reduced insect survival, prolonged developmental time, decreased size and reduced fitness of new generation adults (Gogi *et al.* 2010b; Painter 1951; Sarfraz *et al.* 2006, 2007).

Insect pests are a major constraint for increasing the production and productivity of muskmelon crops. The melon fruit fly, *Bactrocera cucurbitae* (Coquillett) (Diptera: Tephritidae), is a serious pest of muskmelon in India and its outbreaks cause substantial crop losses to growers. It has been observed on 81 host plants, but muskmelon is one of the most preferred hosts and has been a major limiting factor in obtaining good quality fruits and high yield (Doharey 1983; Nath & Bhushan 2006; Rabindranath & Pillai 1986). The extent of losses varies between 30% and 100%, depending on the cucurbit species and the season. As the maggots damage the fruits internally, it is difficult to control this pest with insecticides. Hence, development of varieties resistant to melon fruit fly is an important component of integrated pest management (Panda & Khush 1995), in particular because of difficulties associated with chemical and biological control. Development of muskmelon varieties/ genotypes resistant to fruit fly has been limited in India owing to inadequate information on the sources of plant traits associated with resistance to pest infestations. The present study was designed to identify various biochemical (allelochemical compounds) fruit traits of muskmelon varieties/ genotypes associated with resistance against melon fruit fly in terms of fruit infestation and larval density under field conditions.

Materials and methods

Preliminary screening of muskmelon varieties/ genotypes (summer 2011) Twenty-four varieties/ genotypes of muskmelon, *viz.,* AHMM/BR-1, AHMM/BR-8, RM-50, MHY-3, MHY-5, Durgapura Madhu, Pusa Sarabati, AHMM/BR-3, AHMM/BR-15, AHMM/BR-14, Pusa Madhuras, AHMM/BR-32, Hara Madhu, Punjab Sunhari, AHMM/BR-25, AHMM/BR-35, AHMM/BR-7, Kashi Madhu, AHMM/BR-4, AHMM/BR-13, RM-43, Arka Jeet, Arka Rajhans and GMM-3, were sown at the experimental farm of the Central Institute for Arid Horticulture (CIAH), Bikaner (28°06’N, 73°21’E). Seeds of the muskmelon crop were soaked in water for 2 h to soften their seed coat. The crop was sown in February 2011 with three replicates (blocks) for each genotype following a randomized block design. The area of each bed was 5 m × 2 m and the plant-to-plant distance was maintained at 50 cm with a drip irrigation system. All the recommended agronomic practices (*e.g.* weeding, fertilization, hoeing, etc.) were performed equally in each experimental bed. Four pickings were done for the entire growing season of muskmelon fruits. Ten fruits were randomly selected from each picking from each experimental bed; a total of 30 fruits were taken from each picking of each genotype and were brought to the laboratory for microscopic examination for fruit infestation. The infested fruits were sorted and the percent fruit infestation was calculated. Ten fruits from all infested fruits from each picking of each genotype were then randomly selected for further examination, and the numbers of larvae were counted in each infested fruit. The varieties/ genotypes were categorized by following the rating system given by Nath (1966) for fruit infestation as: immune (no damage), highly resistant (1–10%), resistant (11–20%), moderately resistant (21–50%), susceptible (51–75%) and highly susceptible (76–100%).

Final screening of the selected muskmelon varieties/ genotypes (rainy season 2011 & summer 2012) Eleven selected varieties/ genotypes from the preliminary screening of muskmelon, *viz.,* AHMM/BR-1, AHMM/BR-8, RM-50, MHY-5, Durgapura Madhu, Pusa Sarabati, Pusa Madhuras, AHMM/BR-13, Arka Jeet, Arka Rajhans and

GMM-3, were sown at the experimental farm of CIAH, Bikaner, in July 2011 and February 2012 following a randomized block design, with three blocks for each genotype and each block representing a replication. The area of each bed was 5 m × 2 m and the plant-to-plant distance was maintained at 50 cm, with a drip irrigation system. All the recommended agronomic practices (*e.g.* weeding, fertilization, hoeing, etc.) were performed equally in each experimental bed. Four pickings were done for the entire growing season of muskmelon fruits. Ten fruits were randomly selected from each picking from each experimental bed; a total of 30 fruits were taken from each picking of each genotype and were brought to the laboratory for microscopic examination for fruit infestation. The infested fruits were sorted and the percent fruit infestation was calculated. Ten fruits from all infested fruits from each picking of each genotype were then randomly selected for further examination, and the numbers of larvae were counted in each infested fruit. The varieties/ genotypes were ranked on the basis of their resistance following the rating system of Nath (1966).

Biochemical fruit traits of the re-evaluated muskmelon varieties/ genotypes Two fresh fruits of each genotype were picked from the field and brought to the Plant Physiology Laboratory of CIAH, Bikaner. The fresh fruits were cut into small pieces for drying. The biochemical contents in dry fruits were determined following protocols of Hedge & Hofreiter (1962) for total sugar, Somogyi (1952) for reducing sugar, Malik & Singh (1980) for phenols content, and Schanderl (1970) for tannins content. Colorimetric aluminum chloride method was used for flavinoid determination (Ebrahimzadeh *et al.* 2008; Nabavi *et al.* 2008). pH was determined at three positions of each fruit using a pH meter (Model PHTEST30, Waterproof pH meter, Eutech Instruments, New Delhi, India) in the Plant Physiology Laboratory of CIAH, Bikaner (30 ± 1°C and 65 ± 5% R.H.)

Statistical analysis Transformations (angular & square root transformed value) were used to achieve normality in the data before analysis (Steel *et al.* 1997), but untransformed means are presented in tables. The data on percentage fruit infestation and larval density per fruit and biochemical fruit traits were analyzed through one-way ANOVA using SPSS 16 software (O'Connor 2000). The means of significant parameters, among tested varieties/ genotypes, were compared using Tukey's honestly significant difference (HSD) test for paired comparisons at the 5% probability level. Correlations between biochemical fruit traits and fruit fly parameters (percent fruit infestation and larval density per fruit) were determined using correlation analysis and backward stepwise multiple regression analysis at the 95% significance level.

Results

Preliminary screening of muskmelon varieties/ genotypes The 24 muskmelon varieties/ genotypes taken for preliminary screening against melon fruit fly showed significant differences in percent fruit infestation and larval density per fruit. The latter had a significant positive correlation with the former (r =0.93; P<0.01). AHMM/BR-1, RM-50 and AHMM/BR-8 were the most resistant; MHY-3, MHY-5, D. Madhu, P. Sarabati, AHMM/BR-3, AHMM/BR-15, AHMM/BR-14, P. Madhuras and AHMM/BR-32 were moderately resistant; Hara Madhu, Punjab Sunhari, AHMM/BR-25, AHMM/BR-35, AHMM/BR-7, K. Madhu, AHMM/BR-4, AHMM/BR-13, RM-43 and Arka Jeet were susceptible; whereas Arka Rajhans and GMM-3 were the highly susceptible varieties/ genotypes (Table 1). The larval density ranged from 11.10 (in AHMM/BR-1) to 23.76 (in genotype Arka Rajhans) larvae per fruit and was significantly lower in resistant varieties/ genotypes than in the susceptible varieties/ genotypes. The percent fruit infestation was highest in Arka Rajhans (79.49%) and lowest in AHMM/BR-1 (12.61%), being significantly lower in resistant varieties/ genotypes and higher in susceptible varieties/ genotypes (Table 1).

Final screening of muskmelon varieties/ genotypes The 11 varieties/ genotypes were selected for final evaluation trials against fruit fly resistance during the 2011 rainy season and the 2012 summer season. AHMM/BR-1, RM-50 and AHMM/BR-8 were the most resistant; MHY-5, D. Madhu and P. Sarabati were moderately resistant; AHMM/BR-13, P. Madhuras and Arka Jeet were susceptible; whereas Arka Rajhans and GMM-3 were the highly susceptible varieties/ genotypes in both seasons (Table 2). Fruit fly infestation and larval density were higher in the rainy season than in the summer season. The larval density per fruit

Table 1 Larval density and percent fruit infestation of fruit fly on different varieties/ genotypes of muskmelon during preliminary screening trials (summer season)

Varieties/ genotypes	Larval density/ fruit	Fruit infestation (%)	Resistance category[x]
AHMM/BR-1	11.10[a]	12.61 (20.77)[z,y]	R
AHMM/BR-8	12.35[ab]	14.11 (22.05)[a]	R
RM-50	11.68[a]	14.22 (22.13)[a]	R
MHY-3	18.12[fgh]	41.32 (39.98)[ef]	MR
MHY-5	14.18[bc]	26.31 (30.82)[b]	MR
Durgapura Madhu	16.56[bcdef]	33.70 (35.46)[cd]	MR
Pusa Sarabati	18.29[fghi]	45.72 (42.52)[fg]	MR
AHMM/BR-3	14.90[bcd]	30.91 (33.73)[bc]	MR
AHMM/BR-15	15.21[bcde]	33.31 (35.22)[bcd]	MR
AHMM/BR-14	17.05[defg]	37.84 (37.94)[de]	MR
Pusa Madhuras	20.91[jkl]	49.30 (44.58)[ghi]	MR
AHMM/BR-32	17.58[efgh]	48.27 (43.99)[fgh]	MR
Hara Madhu	21.08[jkl]	52.93 (46.66)[ij]	S
Punjab Sunhari	21.44[kl]	54.99 (47.85)[jk]	S
AHMM/BR-25	18.84[fghij]	63.50 (52.83)[n]	S
AHMM/BR-35	18.16[fgh]	61.00 (51.34)[lmn]	S
AHMM/BR-7	18.48[fghi]	52.76 (46.56)[hij]	S
K. Madhu	20.51[ijkl]	71.21 (57.55)[o]	S
AHMM/BR-4	18.41[fghi]	56.43 (48.68)[jkl]	S
AHMM/BR-13	20.24[ijk]	58.20 (49.70)[klm]	S
RM-43	19.86[hijk]	61.75 (51.78)[mn]	S
Arka Jeet	19.17[ghijk]	58.12 (49.66)[klm]	S
Arka Rajhans	23.76[l]	79.49 (63.09)[q]	HS
GMM-3	22.64[l]	76.35 (60.90)[pq]	HS

[z]Values in parenthesis are angular-transformed

[y]Within columns, values followed by a common letter do not differ significantly using Tukey's HSD test

[x]R- resistant, MR- moderately resistant, S- susceptible and HS- highly susceptible

increased with an increase in percent fruit infestation and there was a significant positive correlation (r=0.971; P<0.01) between percent fruit infestation and larval density per fruit (Table 4). The larval density ranged from 11.22–24.89 and 11.06–23.71 larvae per fruit in the 2011 rainy season and 2012 summer season, respectively. Pooled data of larval density per fruit in both seasons (11.14–24.30 larvae per fruit) was significantly lower in resistant varieties/ genotypes and higher in susceptible varieties/ genotypes. The fruit infestation in the rainy season ranged from 13.33% to 86.11% whereas in the summer season it ranged from 12.63% to 79.52%. Pooled data of fruit infestation in both seasons (12.98–82.81%) was significantly lowest in resistant varieties/ genotypes and highest in susceptible varieties/ genotypes. In both seasons' pooled data, the percent fruit infestation was highest in Arka Rajhans (82.81%) and lowest in AHMM/BR-1 (12.68%) (Table 2).

Biochemical fruit traits of the re-evaluated muskmelon varieties/ genotypes Total sugar, reducing sugar and non-reducing sugar of different varieties/ genotypes fruits ranged from 309–553.27, 62.07–124.27 and 246.93–429 mg/g on a dry weight basis, respectively, with values significantly lower in resistant varieties/ genotypes and higher in susceptible varieties/ genotypes. The pH was significantly highest in Arka Rajhans (6.56) and lowest in RM-50 (5.67). Tannins, phenols, total alkaloid and flavinoid contents ranged from 0.02–0.12 mg/g, 15.27–39.13 mg/g, 0.24–1.25% and 0.40–1.05 mg/g, respectively, with values significantly higher in resistant varieties/ genotypes and lower in susceptible varieties/ genotypes (Table 3). Total sugar, reducing sugar, non-reducing sugar and pH of fruit had a significant positive correlation (P=0.01), whereas tannins, phenols, alkaloids and flavinoid contents had significant negative correlations with the percent fruit infestation and the larval density per fruit

Table 2 Larval density and percent fruit infestation of fruit fly on different varieties/ genotypes of muskmelon during final screening trials

Varieties/ genotypes	Larval density/ fruit			Fruit infestation (%)			Resistance category[x]
	Rainy season	Summer season	Pooled	Rainy season	Summer season	Pooled	
AHMM/BR-8	12.44[a; z, y]	12.42[ab]	12.43[a]	17.22 (24.47) [a;y]	14.21 (22.13)[a]	15.72 (23.34)[a]	R
RM-50	12.33[a]	11.78[a]	12.06[a]	16.67 (24.07)[a]	14.31 (22.21)[a]	15.49 (23.16)[a]	R
AHMM/BR-1	11.22[a]	11.06[a]	11.14[a]	13.33 (21.38)[a]	12.63 (20.78)[a]	12.98 (21.11)[a]	R
MHY-5	15.78[b]	14.32[bc]	15.05[b]	33.89 (35.58)[b]	26.39 (30.87)[b]	30.14 (33.28)[b]	MR
Durgapura Madhu	17.22[bc]	16.45[cd]	16.84[bc]	41.11 (39.86)[cd]	33.72 (35.48)[c]	37.41 (37.70)[c]	MR
Pusa Sarabati	18.56[cd]	18.22[de]	18.39[cd]	47.22 (43.39)[de]	45.82 (42.58)[d]	46.52 (42.99)[d]	MR
Arka Jeet	19.34[cd]	19.06[ef]	19.19[d]	62.78 (52.47)[f]	58.00 (49.59)[e]	60.39 (51.00)[e]	S
AHMM/BR-13	19.78[de]	20.40[efg]	20.09[de]	61.00 (51.36)[f]	58.08 (49.64)[e]	59.54 (50.48)[e]	S
Pusa Madhuras	21.89[e]	20.71[fg]	21.30[ef]	51.11 (45.62)[e]	49.04 (44.43)[d]	50.08 (45.02)[d]	S
Arka Rajhans	24.89[g]	23.71[h]	24.30[g]	86.11 (68.14)[g]	79.52 (63.11)[f]	82.81 (65.53)[f]	HS
GMM-3	23.44[fg]	22.78[gh]	23.11[fg]	81.11 (64.35)[g]	76.35 (60.91)[f]	78.73 (62.52)[f]	HS

[z] Values in parenthesis are angular-transformed

[y] Within each category, values followed by a common letter do not differ significantly using Tukey's HSD test

[x] R- resistant, MR- moderately resistant, S- susceptible and HS- highly susceptible

(Table 4). Backward stepwise regression analysis indicated that total alkaloid and pH contents explained 97.96% of the total variation in fruit fly infestation (Table 5). The maximum variation in fruit infestation was explained by total alkaloid contents (97%) followed by pH contents (0.96%), flavinoid (0.88%), total sugar (0.51%), phenols (0.32%), reducing sugar (0.18%), non-reducing sugar (0.10%) and tannins

Table 3 Biochemical fruit traits of different varieties/ genotypes of muskmelon

Varieties/ genotypes	Total sugar[z] (mg/g)	Reducing sugar[z] (mg/g)	Non-reducing sugar[z] (mg/g)	Tannins content[z] (mg/g)	Phenols content[z] (mg/g)	Total alkaloids[z] (%)	Flavinoid content[z] (mg/g)	pH[y]
AHMM/BR-8	336.97 (18.38)[x,w,bc]	66.60 (8.22)[ab]	270.37 (16.47)[bc]	0.12[a]	34.73[b]	1.11[b]	1.05[a]	5.87[abc]
RM-50	353.34 (18.32)[b]	72.4 (8.57)[bc]	280.87 (16.79)[bcd]	0.12[a]	38.50[a]	1.18[b]	0.97[b]	5.67[a]
AHMM/BR-1	309.00 (17.60)[a]	62.07 (7.93)[a]	246.93 (15.73)[a]	0.13[a]	39.13[a]	1.25[a]	1.01[ab]	5.77[ab]
MHY-5	357.57 (18.94)[cd]	76.27 (8.79)[cd]	281.30 (16.80)[bcd]	0.09[b]	31.17[c]	0.89[c]	0.76[d]	5.74[a]
Durgapura Madhu	361.83 (19.05)[d]	81.37 (9.08)[de]	280.47 (16.78)[bcd]	0.07[bc]	28.43[d]	0.87[c]	0.83[c]	6.01[b]
Pusa Sarabati	366.90 (19.18)[d]	86.23 (9.34)[e]	280.67 (16.78)[bcd]	0.08[b]	27.07[de]	0.74[d]	0.67[e]	6.06[c]
Arka Jeet	403.17 (20.10)[e]	105.07 (10.30)[f]	298.10 (17.29)[d]	0.06[cd]	19.77[f]	0.39[ef]	0.57[f]	6.04[c]
AHMM/BR-13	393.63 (19.87)[e]	101.93 (10.15)[f]	291.70 (17.11)[c]	0.05[d]	21.77[f]	0.44[e]	0.76[d]	6.36[d]
Pusa Madhuras	370.63 (19.28)[de]	89.93 (9.54)[e]	280.70 (16.78)[bcd]	0.08[b]	26.37[e]	0.69[d]	0.73[de]	6.03[c]
Arka Rajhans	553.27 (23.54)[g]	124.27 (11.18)[g]	429.00 (20.73)[e]	0.02[e]	15.27[g]	0.24[f]	0.40[h]	6.56[d]
GMM-3	519.27 (22.80)[f]	116.60 (10.84)[g]	402.67 (20.09)[e]	0.03[e]	16.27[g]	0.30[f]	0.48[g]	6.54[d]

[z] Analysis on dry weight (DW) basis

[y] Analysis on fresh weight (FW) basis

[x] Values in parenthesis are square root-transformed

[w] Within columns, values followed by a common letter do not differ significantly using Tukey's HSD test

Table 4 Correlation coefficient (r) between percent fruit infestation and larval density per fruit with different biochemical fruit traits of muskmelon varieties/ genotypes

	% Fruit infestation	Larval density	TS	RS	NRS	TC	PC	TAC	FC
Larval Density	0.971**								
TS	0.893**	0.835**							
RS	0.986**	0.940**	0.924**						
NRS	0.808**	0.759**	0.970**	0.838**					
TC	-0.969**	-0.928**	-0.904**	-0.970**	-0.824**				
PC	-0.987**	-0.953**	-0.861**	-0.973**	-0.775**	0.969**			
TAC	-0.985**	-0.948**	-0.847**	-0.978**	-0.751**	0.960**	0.993**		
FC	-0.951**	-0.916**	-0.877**	-0.939**	-0.794**	0.917**	0.933**	0.930**	
pH	0.855**	0.825**	0.865**	0.851**	0.831**	-0.848**	-0.839**	-0.822**	-0.700*

**Significant at $P = 0.01$ (two-tailed)

* Significant at $P = 0.05$ (two-tailed)

TS- total sugar (mg/g), RS- reducing sugar (mg/g), NRS- non-reducing sugar (mg/g), TC- tannins content (mg/g), PC- phenols content (mg/g), TAC- total alkaloid content (%), FC- flavinoid content (mg/g)

(0.01%). The total alkaloid and total sugar contents explained 92.83% of the total variation in larval density per fruit. The maximum variation in larval density per fruit was explained by total alkaloid (89.77%) followed by total sugar (3.06%), flavinoid (0.86%), pH (0.76%), phenols (0.74%) and non-reducing sugar (0.69), whereas the rest of the biochemical fruit traits explained <0.1% variation in larval density (Table 5).

Table 5 Backward stepwise regression models showing effect of different biochemical fruit traits of muskmelon on larval density per fruit and percent fruit infestation

Percent fruit infestation	R^2	Role of individual traits (%)
$Y= -122.4+ 42X_1- 69.5 X_2- 0.61X_3+ 30.4X_4- 72X_5+ 0.08X_6+ 1.2X_7- 0.264X_8$	99.96	0.51
$Y= -40.63+ 6X_1- 44X_2-0.8X_3+ 19X_4- 8X_5- 0.064X_6+ 0.44X_7$	99.45	0.18
$Y= - 9.66- 22X_1- 49X_2- 0.1X_3+ 21X_4- 62X_5- 0.037X_6$	99.27	0.10
$Y= 10.70- 28X_1- 39X_2- 0.2X_3+ 15.1X_4- 34X_5$	99.17	0.01
$Y= 7.32- 28X_1- 40X_2- 0.3X_3+ 15.8X_4$	99.16	0.96
$Y= 118.1- 20X_1- 26X_2- 1.5X_3$	98.20	0.32
$Y= 104.6- 51.5X_1- 30X_2$	97.88	0.88
$Y= 94.49- 67.8X_1$	97.00	97.00
Larval density per fruit		
$Y= -37.07+ 20X_1- 23 X_2- 0.18X_3+ 10.5X_4- 23X_5+ 0.04X_6+ 0.38X_7- 0.18X_8$	95.99	3.06
$Y= - 0.153+ 4X_1- 12X_2- 0.28X_3+ 5.4X_4- 5X_5- 0.02X_6+ 0.04X_7$	92.93	0.05
$Y= 2.92+ 1X_1- 12X_2- 0.21X_3+ 5.6X_4- 0.0X_5- 0.02X_6$	92.88	0.69
$Y= 12.54- 1X_1- 7.1X_2- 0.26X_3+ 2.9X_4- 13X_5$	92.19	0.06
$Y= 13.83- 1X_1- 6.6X_2- 0.22X_3+ 2.6X_4$	92.13	0.76
$Y= 32.05- 0.0X_1- 4.3X_2- 0.41X_3$	91.37	0.74
$Y= 28.29- 9X_1-5.4X_2$	90.63	0.86
$Y= 26.45- 12X_1$	89.77	89.77

X_1- total alkaloid content (%), X_2- flavinoid content (mg/g), X_3- phenols content (mg/g), X_4- pH, X_5- tannins content (mg/g), X_6- non-reducing sugar (mg/g), X_7- reducing sugar (mg/g), X_8- total sugar (mg/g), R^2 - coefficient of determination

Discussion

Host plant selection by insects is expressed either by the occurrence of a population of insects on the plant in nature or by feeding, oviposition or use of the plant for complete offspring development (Rafiq *et al.* 2008; Thronsteinson 1953). Selection is regulated primarily by chemoreception (Gogi *et al.* 2010b; Jeremy & Szentesi 2003). Plant varieties/ genotypes possess physiological and biochemical variations due to the environmental stress or genetic makeup, which alter the nutritional values for herbivores (Gogi *et al.* 2010b; Misirli *et al.* 2000; Rafiq *et al.* 2008). In the present study, AHMM/BR-1, RM-50 and AHMM/BR-8 were the most resistant; MHY-5, D. Madhu and P. Sarabati were moderately resistant; AHMM/BR-13, P. Madhuras and Arka Jeet were susceptible; whereas Arka Rajhans and GMM-3 were the highly susceptible varieties/ genotypes in both seasons. The percent fruit infestation and larval density were significantly lower in resistant varieties/ genotypes and higher in susceptible varieties/ genotypes of muskmelon. Numerous studies have shown that varieties/ genotypes of the same species could differ significantly in their resistance to insect pests (Dhillon *et al.* 2005a; Gogi *et al.* 2009; Sarfraz *et al.* 2006; Weems & Heppner 2001) and it is caused by biochemical traits of plants.

The allelochemical compounds of fruit were significantly different among the tested muskmelon varieties/ genotypes. Total sugar, reducing sugar, non-reducing sugar and pH were lowest in resistant and highest in susceptible varieties/ genotypes, whereas tannins, phenols, alkaloids and flavinoid contents were highest in resistant and lowest in susceptible varieties/ genotypes. To the best of our knowledge, no published literature has focused on all the biochemical traits investigated in muskmelon varieties/ genotypes against fruit fly resistance. Ismail *et al.* (2010) reported that the cantaloupe flesh extract afforded the highest yield (89.6 ± 0.3%) while the lowest yield was obtained from the seed (13.7 ± 0.5%). The leaf extract showed the highest total phenolic content (26.4 ± 0.3 mg GAE/g extract) and total flavinoid content (69.7 ± 3.37 μg RE/g extract). Similar findings showed that pH was lowest in resistant varieties/ genotypes and tannin, flavanol and phenol contents were highest in resistant varieties/ genotypes (Gogi *et al.* 2010b). Total sugar, reducing sugar, non-reducing sugar and pH of fruit had a significant positive correlation, whereas tannins, phenols, alkaloids and flavinoid contents had significant negative correlations with the percent fruit infestation and the larval density per fruit. Sharma & Hall (1971) reported a positive correlation between spotted cucumber beetle (*Diabrotica undecimpunctata*) feeding and total sugars of various cucurbitaceous crops. In the okra crop, the biochemical characters such as total sugar and crude protein were positively correlated with fruit borer infestation, whereas total phenols were negatively correlated (Ilango & Uthamasamy 1989; Jat & Pareek 2003; Sharma & Singh 2010). Similar to our

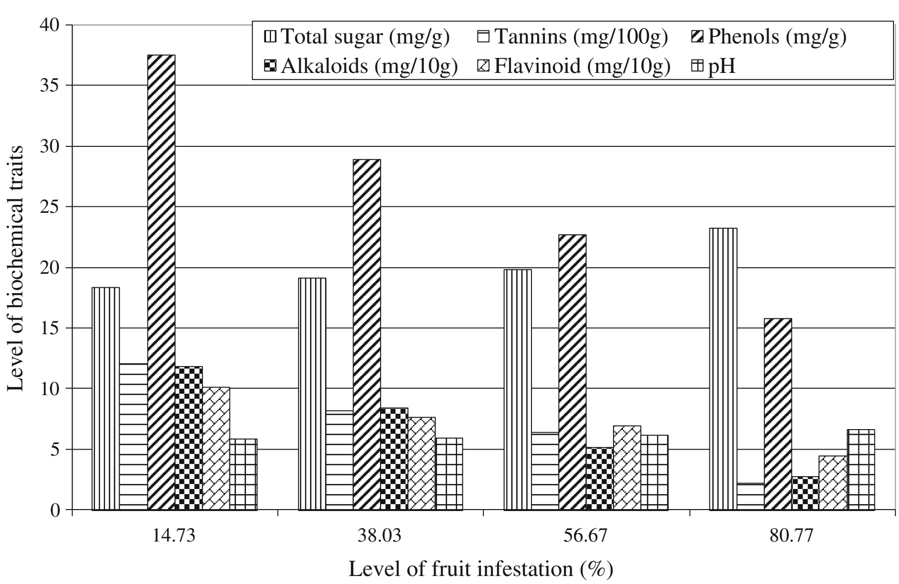

Fig. 1 Associations of biochemical traits with resistance to melon fruit fly infestation under different infestation categories

findings, phenols, tannins, and flavonoids enhanced plant defenses against insects (Gogi *et al.* 2010b; Mila & Scalbert 1994; Ryan & Robards 1998; Tomas-Barberan *et al.* 1988). In another system, rice varieties/ genotypes resistant to the brown plant hopper *Nilaparvata lugens* had higher levels of phenols than their susceptible counterparts (Grayer *et al.* 1994). Reduction of fruit fly infestations on resistant varieties/ genotypes could be due to antibiosis (allelochemicals) and our results suggest that biochemical fruit traits could contribute to these mechanisms of resistance. In summary, certain biochemical traits (*e.g.* total sugar, reducing sugar, non-reducing sugar, tannins, phenols, alkaloids, flavinoid and pH contents) (Fig. 1) were linked to resistance of muskmelon against *B. cucurbitae* and therefore can be used as marker traits in plant breeding programs to select resistant varieties/ genotypes.

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