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Influence of physico-chemical traits of bitter gourd, *Momordica charantia* L. on larval density and resistance to melon fruit fly, *Bactrocera cucurbitae* (Coquillett)

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Abstract: Melon fruit fly, *Bactrocera cucurbitae* (Coquillett) is one of the most important pests of bitter gourd, *Momordica charantia* L. Because of the difficulties associated with chemical control of this pest, it is important to identify the traits associated with resistance and their influence on pest multiplication. There were significant differences in test genotypes for fruit infestation and larval density/fruit. The wild accessions, IC 256185, IC 248256, IC 213311, IC 248282, IC 256110 and IC 248281 were identified as resistance sources to melon fruit fly. There was a significant and positive correlation ($r = 0.96$) between percentage fruit infestation and larval density/fruit. Percentage fruit infestation and larval density/fruit were positively correlated with depth of ribs, flesh thickness, fruit diameter and fruit length, and negatively associated with fruit toughness. Flesh thickness and fruit diameter explained 93.0% of the total variation for fruit fly infestation, and flesh thickness and fruit length explained 76.3% of the variation for larval density/fruit. Ascorbic acid, nitrogen, phosphorus, potassium, protein, reducing sugars, non-reducing sugars and total sugars were negatively correlated, while the moisture content showed a positive association with fruit fly infestation and larval density/fruit. Moisture, potassium and reducing sugar content explained 97.4% of the total variation in fruit infestation, while moisture, phosphorus, protein, reducing and total sugars explained 85.7% variation for larval density/fruit.

Key words: *Bactrocera cucurbitae*, *Momordica charantia*, bases of resistance, bitter gourd, physico-chemical traits

1 Introduction

Bitter gourd (*Momordica charantia* L.) is a popular vegetable cultivated throughout Asia, especially India, Pakistan, Sri Lanka and China. It is also grown as an ornamental crop in other parts of the world (Walters and Walters, 1988). Each and every part of this plant has nutritive or medical significance, and has a long association with human beings (Morton, 1967). Insect pests are a major constraint for increasing the production and productivity of this crop. Forty-three species have been described under the genus *Bactrocera*, which are distributed throughout the temperate, tropical and sub-tropical regions of the world, especially Asia, Africa and Australia, but India is considered as its native home (Syed, 1969; Cavalloro, 1983; Drew and Hooper, 1983; Munro, 1984; Fletcher, 1987). Amongst these, *Bactrocera cucurbitae* (Coquillett) (Dipt., Tephritidae) is a major threat to cucurbits (Shah et al., 1948). The melon fruit fly has been observed on 81 host plants, but bitter gourd is one of the most preferred hosts and has been a major limiting factor in obtaining good quality fruits and high yield (Srinivasan, 1959; Lall and Singh, 1969; Mote, 1975; Rabindranath and Pillai, 1986). The extents of losses vary between 30 and 100%, depending on the cucurbit species and the season.

It prefers young, green and tender fruits for egg laying. The females lay the eggs 2–4 mm deep in the fruit pulp and hatch in 1.0–5.1 days (Koul and Bhagat, 1994; Hollingsworth et al., 1997). The maggots feed inside the developing fruits and complete its larval development in 3–6 days (Gupta and Verma, 1995). Young larvae leave the necrotic region and move to healthy tissue, where they often introduce various pathogens and hasten fruit decomposition. The fruits attacked in early stages fail to develop properly, and drop down or rot on the plant. The full-grown maggots move to the soil from 0.5 to 15 cm deep for pupation, and pupal development is completed in 7–13 days depending on the temperature and host (Hollingsworth et al., 1997). The melon fly remains active throughout the year on one or the other host and the adult females live longer (65–249 days) than the males (27.5–133.5 days). During the severe winter months, they hide and huddle together under dried leaves of bushes and trees. During the hot and dry season, the flies take

shelter under humid and shady places and feed on honeydew of aphids infesting the fruit trees. This species actively breeds when the temperature falls below 32.2°C and the relative humidity ranges between 60 and 70%.

The vinegar fly, *Drosophila melanogaster*, has also been observed to lay eggs on the melon fly-infested fruits, and acts as a scavenger (M.K. Dhillon, unpublished data). 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 for integrated pest management of this pest (Panda and Khush, 1995). Cultivation of fruit fly-resistant bitter gourd cultivars has been limited because of lack of adequate information on the sources of resistance, traits associated with resistance and their influence on pest multiplication. Therefore, the present studies were undertaken to identify the sources of resistance, morpho-chemical traits associated with resistance and their interaction with melon fly infestation and larval density.

2 Materials and Methods

Based on the preliminary screening of 48 bitter gourd genotypes (32 accessions, eight commercial cultivars, and eight accessions belonging to the wild relative, *Momordica charantia* var. *muricata*), 17 genotypes (comprising two highly resistant, five resistant, six moderately resistant, two susceptible and two highly susceptible) were selected to study the influence of physico-chemical traits on larval density and resistance/susceptibility reaction to melon fly.

2.1 Crop

The test material was planted on raised beds (2.5 × 1.5 m), with a plant-to-plant spacing of 45 cm in July 2001 (rainy season) and March 2002 (summer season) at the Vegetable Research Farm, Chaudhary Charan Singh Haryana Agricultural University, Hisar, India. The July (rainy season)-sown crop fruited in September–October and the March-sown crop in May–June (summer season). There were three replications each with five plants in a randomized complete block design. Recommended agronomic practices (except chemical control) were followed for raising the crop.

2.2 Observations

Marketable fruits were picked at 6-day intervals and brought to the laboratory for observations on fruit fly infestation and larval density per fruit. The genotypes were grouped by following the rating system given by Nath (1966) for the fruit damage as – immune (no damage), highly resistant (1–10%), resistant (11–20%), moderately resistant (21–50%), susceptible (51–75%) and highly susceptible (76–100%). The bitter gourd fruits were infested with *B. cucurbitae* across the seasons and no other species of *Bactrocera* was observed infesting the bitter gourd fruits in that locality. The *B. cucurbitae* maggots have the peculiar habit of curving itself and springing into the air to a distance by the sudden relaxation of certain muscles. The infested fruits were cut open to count the number of *B. cucurbitae* larvae per fruit. Healthy fruits were used to observe physico-chemical traits in the test genotypes. Observations on morphological fruit characters were recorded on five randomly selected marketable size fruits in five replications. The length (cm) and diameter (cm) of the fruits were measured with the help of vernier callipers, the depth of ribs (mm) and flesh thickness (mm) were measured with a scale. Intensity of ribs was measured by counting the number of ribs in one cm^2 area. Fruit toughness (kg/cm^2) was recorded with the help of a pressure tester (Ogawa Seiki Co. Ltd, Tokyo, Japan).

The moisture content was calculated by the following formula:

$$\text{Moisture content } (\%) = \frac{\text{Fresh sample weight} - \text{dry sample weight}}{\text{Fresh sample weight}} \times 100.$$

The biochemical constituents were estimated by following the standard methods: ascorbic acid by A.O.A.C. (1960), nitrogen and protein content by Microkjeldahl's method (A.O.A.C., 1985), phosphorus (Jackson, 1973), potassium (Tewatia, 1994), and reducing, non-reducing and total sugars by A.O.A.C. (1975).

2.3 Statistical analysis

The data were subjected to analysis of variance using GENSTAT package of statistical analysis. The percentage data were transformed using angular transformation. The significance of differences between the genotypes was judged by *F*-test, and the treatment means were compared by the least significant difference at $P = 0.05$. The data on percentage fruit infestation, larval density/fruit and physico-chemical traits was also subjected to correlation, multiple linear regression and stepwise regression analysis to see the influence and association of morpho-chemical traits on resistance/susceptibility reaction to the pest and its density.

3 Results

3.1 Field evaluation

There were significant differences in percentage fruit infestation and larval density per fruit among the genotypes tested across seasons. The fruit infestation during the 2001 rainy season (September–October) ranged from 9.4 to 82.1% while, during the 2002 summer season (May–June), it ranged from 7.3 to 57.0%. Larval density per fruit ranged from 3.8 to 8.3 and 3.4 to 7.8 larvae per fruit during the 2001 rainy season and the 2002 summer season, respectively (table 1). The genotypes classified as highly resistant, resistant, moderately resistant, susceptible and highly susceptible on the basis of percentage fruit infestation in September–October (rainy season) also showed similar reaction in May–June (summer season). However, the level of fruit fly infestation was lower during the summer season when compared with the rainy season across the genotypes. Low level of infestation during the summer season also influenced the grouping of genotypes. But, there were no changes in the relative ranking of different genotypes, except Pusa Vishesh (which was susceptible during the 2001 rainy season), Arka Harit and Pusa Do Mausmi, which were highly susceptible during the 2001 rainy season, which were categorized as susceptible based on the mean values for both the seasons. The wild accessions IC 256185,

Table 1. *Effects of environment × wild and cultivated genotypes of bitter gourd on fruit fly infestation and larval density under multi-choice field conditions*

Genotypes	Fruit infestation (%)			Number of larvae per fruit			Resistance category
	Rainy 2001	Summer 2002	Mean	Rainy 2001	Summer 2002	Mean	
Momordica charantia var. *muricata* (wild genotypes)							
IC 256185	9.4 (17.8)* a†	7.3 (15.5)* a	8.3 (16.7) a	3.8 a	3.8 ab	3.8 a	HR
IC 248256	10.2 (18.6) a	8.4 (16.8) ab	9.3 (17.7) ab	4.7 abc	3.8 ab	4.2 ab	HR
IC 213311	11.7 (20.1) ab	9.0 (17.4) ab	10.4 (18.7) ab	5.9 def	4.2 abc	5.1 abcde	R
IC 248282	13.1 (21.3) cb	9.1 (17.5) ab	11.1 (19.4) ab	4.7 abc	4.9 bcde	4.8 abcd	R
IC 256110	13.5 (21.5) cb	10.7 (19.1) b	12.1 (20.3) b	5.7 cdef	3.4 a	4.6 abc	R
IC 248281	15.2 (22.9) dc	8.9 (17.3) ab	12.6 (20.1) b	4.5 abc	4.7 bcd	4.6 abc	R
Momordica charantia (cultivated genotypes)							
IC 68314-B	16.5 (24.0) d	21.3 (27.5) c	18.9 (25.7) c	4.9 abcd	4.8 bcd	4.9 abcd	R
Green long	25.7 (30.4) e	21.2 (27.3) c	23.4 (28.9) d	5.7 cdef	5.5 defg	5.6 bcde	MR
Konkan Tara	25.8 (30.5) e	23.6 (29.0) cd	24.8 (29.8) de	5.1 bcd	5.0 cdef	5.1 abcde	MR
BL 237	33.3 (35.2) f	22.0 (28.0) cd	27.6 (31.6) ef	4.0 ab	4.2 abc	4.1 ab	MR
Jaunpuri	36.1 (36.9) g	21.1 (27.3) c	28.6 (32.1) f	7.2 ghi	6.0 efgh	6.6 efg	MR
Jhalri baramasi	41.4 (40.0) h	23.7 (29.1) cd	32.5 (34.6) gh	6.8 fgh	6.4 gh	6.6 efg	MR
Hirkani	44.5 (41.8) I	24.6 (29.7) cd	34.5 (35.8) h	6.3 efg	6.1 fgh	6.2 de	MR
Pusa Vishesh	56.6 (48.8) j	29.9 (33.1) e	43.3 (41.0) I	5.9 def	6.7 hi	6.3 def	MR
IC 68255	59.2 (50.3) k	45.1 (42.1) f	52.1 (46.2) j	5.5 cde	6.2 gh	5.8 cde	S
Arka Harit	77.7 (61.9) l	53.4 (46.9) g	65.5 (54.4) k	8.3 i	7.8 i	8.0 g	S
Pusa Do Mausmi	82.1 (64.9) m	57.0 (49.0) h	69.5 (57.0) l	7.8 hi	7.8 i	7.8 fg	S

Effects	Genotypes (G)	Environment (E)	G × E	Genotypes (G)	Environment (E)	G × E	–
SE ±	0.91 (0.62)	0.31 (0.21)	1.29 (0.88)	0.37	0.13	0.53	–
LSD (P = 0.05)	2.58 (1.75)	0.88 (0.60)	3.64 (2.48)	1.05	0.36	1.49	–
CV (%)	7.9 (4.9)	7.9 (4.9)	7.9 (4.9)	16.4	16.4	16.4	–
F-probability	< 0.001	< 0.001	< 0.001	< 0.001	0.115	< 0.001	–

* Values in parenthesis are angular-transformed.
† Values following different letters are significantly different.
R, resistant; MR, moderately resistant; S, susceptible.

IC 248256, IC 213311, IC 248282, IC 256110 and IC 248281 (7.26–15.20% fruit infestation) gave resistant reaction to melon fruit fly across the seasons. The larval density per fruit increased with an increase in percentage fruit infestation (table 1) and there was a significant and positive correlation ($r = 0.96$) between percentage fruit infestation and larval density per fruit. No significant differences were observed for number of larvae per fruit during both the seasons, except IC 248256, IC 213311, IC 256110 (wild accessions), Jaunpuri and Arka Harit (cultivated genotypes), which had significantly higher number of larvae per fruit in September–October than May–June, while Pusa Vishesh and IC 68255 (cultivated genotypes) had lower number of larvae per fruit in September–October.

3.2 Influence of morphological fruit traits on larval density and resistance to melon fly

Number of ridges on the fruit surface ranged from 17.80 to 118.13 ridges/cm^2, being significantly lower in Pusa Do Mausmi and higher in the wild accession IC 213311 (table 2). The cultivated genotypes had significantly lower number of ridges when compared with wild type. In general, the number of ridges was greater in resistant and lower in the susceptible ones. Depth of ribs ranged from 1.37 to 8.61 mm, being significantly lower in wild accession IC 213311 and higher in variety Jaunpuri. Rib depth was greater in cultivated genotypes when compared with wild accessions. Flesh thickness ranged from 2.39 to 6.28 mm, being significantly lower in IC 256185 and higher in Pusa Do Mausmi. Fruit toughness was significantly lower in Jaunpuri when compared with IC 256185. Flesh thickness was positively associated with fruit infestation and mean number of larvae/fruit, while the reverse was true in case of fruit toughness. Fruit length and diameter ranged from 2.23 to 15.29 cm and 1.69 to 4.06 cm, respectively, being minimum in IC 256110 and maximum in Jaunpuri. Fruit length and fruit diameter were positively associated with fly infestation and larval density/fruit.

Fruit fly infestation was positively and significantly correlated (P = 0.01) with rib depth, flesh thickness, fruit diameter and fruit length ($r = 0.58$–0.92), and negatively correlated with fruit toughness ($r = -0.69$), and number of ribs/cm^2 ($r = -0.53$) (table 3). Multiple linear regression analysis indicated that the morphological traits explained 92.1% of the total variation in fruit fly infestation [Fruit infestation $(Y) = -4.0 - 1.97X_1 + 12.63X_2 + 8.53X_3 + 0.27X_4 + 0.04X_5 - 3.32X_6$ ($R^2 = 92.1\%$)], where X_1 is the depth of ribs, X_2, flesh thickness, X_3, fruit diameter, X_4, fruit length, X_5, number of ribs mm^{-2} and X_6 is the toughness of the fruit. Stepwise regression analysis indicated that flesh thickness (X_2) and fruit diameter (X_3) explained 93.0% of the total variation in fruit fly infestation [Fruit infestation $(Y) = -37.86 + 13.03 X_2 + 7.84 X_3$ ($R^2 = 93.0\%$)], and these can be used as marker traits to select for resistance to melon fruit

Table 2. *Morphological fruit characters associated with resistance to melon fruit fly*

Genotypes	Ridges/cm^2	Depth of ribs (mm)	Flesh thickness (mm)	Fruit length (cm)	Fruit diameter (cm)	Fruit toughness (kg/cm^2)
Momordica charantia var. *muricata* (Wild genotypes)						
IC 256185	58.80 f*	1.46 a	2.39 a	2.94 b	2.11 b	10.73 e
IC 248256	74.27 h	3.42 b	2.53 ab	2.91 b	2.01 b	10.54 e
IC 213311	118.13 i	1.37 a	2.43 a	3.49 c	1.80 a	9.85 d
IC 248282	31.07 d	3.93 c	2.45 a	7.01 e	2.69 c	9.39 d
IC 256110	64.73 g	1.43 a	2.59 abc	2.23 a	1.69 a	9.79 d
IC 248281	30.73 d	4.81 de	2.75 cd	5.86 d	2.90 d	8.63 c
Momordica charantia (Cultivated genotypes)						
IC 68314-B	24.27 c	5.23 ef	2.51 ab	7.99 f	2.83 cd	8.47 c
Green long	26.53 c	5.96 h	2.49 a	8.58 g	3.65 efg	8.47 c
Konkan Tara	30.67 d	5.83 g	2.61 abc	7.75 f	3.57 ef	7.47 ab
BL 237	26.00 c	5.37 fgh	2.72 bcd	7.69 f	3.74 gh	7.63 ab
Jaunpuri	19.07 ab	8.61 j	2.87 d	15.29 j	4.06 i	7.35 a
Jhalri baramasi	18.67 ab	6.99 i	2.69 bcd	13.68 i	3.83 h	7.60 ab
Hirkani	31.07 d	6.89 i	3.22 e	11.84 h	4.03 i	8.56 c
Pusa Vishesh	29.93 d	5.95 h	4.82 g	11.76 h	3.60 efg	8.32 c
IC 68255	34.47 e	4.70 d	4.40 f	10.31 g	3.62 efg	7.81 b
Arka Harit	21.20 b	6.06 h	4.93 g	10.21 g	3.72 fgh	7.59 ab
Pusa Do Mausmi	17.80 a	6.84 i	6.28 h	10.07 g	3.51 ef	7.53 ab
SE ± mean	1.17	0.17	0.07	0.11	0.06	0.16
LSD (P = 0.05)	3.38	0.48	0.21	0.32	0.16	0.47
CV (%)	5.3	5.8	3.9	2.4	3.1	3.3

* Values following different letters are significantly different.

Table 3. *Associations of fruit fly infestation and larval density with morphological traits of fruits of 17 bitter gourd genotypes*

Morphological traits	(%) Fruit fly infestation	Larvae/fruit	Depth of ribs	Flesh thickness	Fruit diameter	Fruit length	No. of ribs/cm^2	Toughness of the fruit
Depth of ribs	0.58*	0.67**	1.00					
Flesh thickness	0.92**	0.77**	0.38	1.00				
Fruit diameter	0.65**	0.63**	0.92**	0.41	1.00			
Fruit length	0.62**	0.73**	0.92**	0.42	0.91**	1.00		
No. of ribs/cm^2	−0.53*	−0.47	−0.81**	−0.36	−0.81**	−0.73**	1.00	
Toughness of the fruit	−0.69**	−0.66**	−0.85**	−0.47	−0.88**	−0.81**	0.76**	1.00

Correlation coefficients significant at P = 0.05* and 0.01** respectively.

fly in bitter gourd. Larval density/fruit was positively and significantly correlated (P = 0.01) with depth of ribs, flesh thickness, fruit diameter and fruit length ($r = 0.68$ –0.77), and negatively correlated with fruit toughness ($r = -0.66$) (table 3). Multiple linear regression analysis pointed that all these morphological traits explained 73.6% variation in larval density/fruit [Larval density/fruit $(Y) = 3.70 + 0.22X_1 + 0.61X_2 - 0.59X_3 + 0.19X_4 + 0.12X_5 - 0.15X_6$ $(R^2 = 73.6\%)$]. Stepwise regression analysis indicated that flesh thickness (X_2) and fruit length (X_4) explained 76.3% of the variation in fruit fly larvae [Larval density/fruit $(Y) = 2.28 + 0.60\ X_2 + 0.16\ X_4$ $(R^2 = 76.3\%)$], and these can be used as marker traits for resistance to damage by the melon fruit fly in bitter gourd.

3.3 Influence of biochemical traits on larval density and resistance to melon fly

Moisture content of the fruit ranged from 82.77 to 94.60%, being significantly lower in IC 256185 when compared with Pusa Do Mausmi (table 4). There was a significant increase in melon fly infestation and number of larvae/fruit with an increase in moisture content of the fruits. Nitrogen, phosphorus, potassium, and protein contents ranged from 1.96 to 2.98%, 0.33 to 0.67%, 1.86 to 4.93%, and 12.25 to 18.62%, respectively, being minimum in Pusa Do Mausmi and maximum in IC 256185. Nitrogen, phosphorus, potassium and protein contents were positively associated with fruit fly infestation and number of larvae/fruit. Reducing, non-reducing, and total sugars, and ascorbic acid contents ranged from 1.82 to 3.06%, 0.88–1.87%, 2.74–5.03% and 77.74–196.62 mg/100 gm, respectively.

Ascorbic acid, nitrogen, phosphorus, potassium, protein, reducing, non-reducing and total sugar contents were significantly and negatively correlated (P = 0.01) with fruit fly infestation ($r = -0.88$ to -0.97) and larval density/fruit ($r = -0.72$ to -0.87) (table 5). However, moisture content was positively associated with fruit fly infestation ($r = 0.91$) and the number of larvae/fruit ($r = 0.75$). Multiple linear regression analysis revealed that the biochemical traits explained 96.9% variation in fruit fly infestation [Fruit infestation $(Y) = 406.0 - 0.05X_1 - 2.21X_2 + 18.8X_3 - 126.0X_4 - 6.1X_5 - 9.01X_6 + 13.0X_7 - 14.8\ X_8 - 4.2X_9$ $(R^2 = 96.9\%)$] and 80.4% of the total variation in larval density [Larval density/fruit $(Y) =$

Table 4. *Biochemical constituents of different bitter gourd genotypes*

Genotypes	Moisture content (%)	Nitrogen (%)	Phosphorus (%)	Protein (%)	Non-reducing sugars (%)	Potassium (%)	Reducing sugars (%)	Total sugars (%)	Ascorbic acid (mg/100 gm)
Momordica charantia var. *muricata* (wild genotypes)									
IC 256185	82.77 a*	2.98 h	0.67 e	18.62 i	1.87 i	4.93 j	2.93 fgh	5.03 i	196.62 k
IC 248256	83.17 ab	2.96 h	0.66 e	18.50 i	1.86 hi	4.75 ij	3.06 h	4.95i	185.00 ijk
IC 213311	83.84 ab	2.97 h	0.63 e	18.56 i	1.76 gh	4.73 ij	2.96 gh	4.75 h	194.74 k
IC 248282	84.82 bc	2.89 h	0.61 e	18.06 i	1.65 f	4.69 hi	2.88 efgh	4.57 g	189.40 jk
IC 256110	85.24 c	2.83 gh	0.61 e	17.68 hi	1.66 fg	4.63 hi	2.86 efg	4.56 g	174.80 hi
IC 248281	84.46 ab	2.91 h	0.63 e	18.18 i	1.59 f	4.49 hg	2.81 defg	4.43 fg	184.00 ijk
Momordica charantia (cultivated genotypes)									
IC 68314-B	85.92 cd	2.67 fg	0.46 bd	16.70 gh	1.46 e	4.13 g	2.89 efgh	4.38 ef	178.60 hij
Green long	87.22 de	2.63 ef	0.46 bd	16.43 fg	1.27 d	3.90 f	2.79 defg	4.10 d	165.60 gh
Konkan Tara	87.68 de	2.59 ef	0.51 d	16.20 efg	1.39 e	3.51 e	2.78 defg	4.20 d	157.20 g
BL 237	90.80 g	2.59 ef	0.51 d	16.18 efg	1.43 e	3.46 de	2.76 defg	4.23 de	113.98 cd
Jaunpuri	89.48 fg	2.48 de	0.63 e	15.50 def	1.28 d	3.47 de	2.82 de	4.14 d	141.42 f
Jhalri baramasi	88.80 ef	2.45 de	0.51 d	15.31 de	1.19 cd	3.28 d	2.71 de	3.92 c	110.54bcd
Hirkani	92.04 h	2.33 cd	0.48 cd	14.56 cd	1.16 c	2.80 c	2.64 d	3.83 c	129.00 ef
Pusa Vishesh	93.80 hij	2.21 bc	0.45 cd	13.81 bc	0.99 b	2.39 b	2.23 c	3.26 b	97.60 bc
IC 68255	93.90 ij	2.13 ab	0.42 bc	13.32 abc	0.97 ab	2.54 b	2.12 bc	3.12 b	118.60 de
Arka Harit	92.30 hi	2.06 ab	0.36 ab	12.87 ab	0.90 ab	1.93 a	2.16 bc	3.11 b	103.90 bc
Pusa Do Mausmi	94.60 j	1.96 a	0.33 a	12.25 a	0.88 a	1.86 a	1.82 a	2.74 a	77.74 a
SE ± mean	0.64	0.06	0.03	0.04	0.03	0.07	0.06	0.05	4.8
LSD (P = 0.05)	1.80	0.18	0.08	1.10	0.10	0.20	0.18	0.15	13.61
CV (%)	1.6	5.4	11.6	5.4	5.5	4.3	5.4	2.8	7.3

* Values following different letters are significantly different.

Table 5. *Associations of fruit fly infestation and larval density with biochemical traits of fruits of 17 bitter gourd genotypes*

Biochemical traits	(%) Fruit fly infestation	Larvae/fruit	AA	M	NRS	N	P	K	Prot	RS
Amino acids (AA)	−0.91**	−0.77**	1.00							
Moisture content (M)	0.91**	0.75**	−0.95**	1.00						
Non-reducing sugars (NRS)	−0.93**	−0.87**	0.90**	−0.94**	1.00					
Nitrogen (N)	−0.97**	−0.86**	0.93**	−0.96**	0.98**	1.00				
Phosphorus (P)	−0.88**	−0.72**	0.79**	−0.82**	0.89**	0.88**	1.00			
Potassium (K)	0.97**	−0.85**	0.95**	−0.97**	0.97**	0.99**	0.87**	1.00		
Protein (Prot)	−0.97**	−0.86**	0.93**	−0.96**	0.98**	1.00**	0.88**	0.99**	1.00	
Reducing sugars (RS)	−0.95**	−0.77**	0.84**	−0.88**	0.88**	0.92**	0.83**	0.90**	0.92**	1.00
Total sugars (TS)	−0.97**	−0.85**	0.90**	−0.94**	0.97**	0.98**	0.89**	0.97**	0.98**	0.96**

Correlation coefficients significant at P = 0.05* and 0.01** respectively.

$69.3 - 0.004X_1 - 0.52X_2 + 1.60X_3 + 176.0X_4 + 6.06\ X_5 - 0.75X_6 - 29.0X_7 + 3.69X_8 - 4.09\ X_9$ ($R^2 = 80.4\%$)], where X_1 is amino acids, X_2, moisture content, X_3, non-reducing sugars, X_4, nitrogen, X_5, phosphorus, X_6, potassium, X_7, protein, X_8, reducing sugars, and X_9, total sugars. Stepwise regression analysis indicated that moisture (X_2), potassium (X_6) and reducing sugar (X_8) contents explained 97.4% of the variation in fruit infestation [Fruit infestation (Y) $= 306.0 - 1.73X_2 - 17.26X_6 - 23.54X_8$ ($R^2 = 97.4\%$)], while moisture (X_2), phosphorus (X_5), protein (X_7), reducing sugar (X_8) and total sugars (X_9) explained 85.7% of the variation in larval density/fruit [Larval density/fruit (Y) $= 62.4 - 0.43X_2 + 5.83X_5 - 1.05X_7 + 2.85X_8 - 3.07X_9$ ($R^2 = 85.7\%$)].

4. Discussion

Painter (1951) emphasized the need to identify sources of resistance to the target pests, followed by identification of physico-chemical factors involved in host plant selection by the insects, both for oviposition and feeding (Maxwell and Jennings, 1980). There were significant differences in genotypic susceptibility to melon fruit fly in bitter gourd. Low melon fly infestation during May–June (2002 summer season) may be because of low fruit fly population due to high temperatures (35–45°C), and low relative humidity (30–40%). High temperatures, long sunshine hours, low humidity and plantation activity have been reported to influence the population density of *B. cucurbitae* in north-eastern Taiwan (Su, 1986; Lee et al., 1992). Fruit infestation was significantly higher during September–October months than in May–June, but there was no significant variation in larval density per fruit across seasons. The bitter gourd genotypes Hisar II, Acc. 3 and Ghoti (Srinivasan, 1991), Acc. 23 and 33, C 96, NBTI 1 and BG 14 (Thakur et al., 1992, 1994, 1996), Kerala collection 1 and Faizabad collection 17 (Tewatia et al., 1997) have earlier been reported to be resistant to melon fruit fly. Inayatullah et al. (1991)

reported a positive correlation between fruit fly infestation and number of fruit fly males trapped/trap/day, and number of puparia per square foot of soil ($r = 0.92$), and a similar association between fruit infestation and larval density was observed in the present studies as well.

Plant–herbivore interactions are influenced by several morphological and biochemical plant traits, environmental conditions and physiological status of the test insects (De Ponti, 1977). Morphological factors interfere with feeding and oviposition by the insects. Shape of the fruit influences the orientation of fruit flies to a potential ovipositional site (Boller and Prokopy, 1976). Chelliah and Sambandam (1971) observed that egg lying by the melon fruit fly was 17.77% in fruits having tough rind in *Cucumis callosus* when compared with 87.33% in fruits of the susceptible variety, Delta Gold. Pal et al. (1984) also found thick and tough rind fruits of IHR 89 and IHR 213 genotypes resistant to melon fruit fly. Resistance to squash vine borer in *Cucurbita* spp. has been reported to be due to tough vascular bundles (Howe, 1949). Percentage fruit infestation increases with an increase in fruit length and diameter (Jaiswal et al., 1990; Tewatia et al., 1997). In the present studies, a positive association was observed between fruit fly infestation and larval density per fruit with flesh thickness, fruit diameter, fruit length and depth of ribs. There was a strong correlation between number of ribs and fruit toughness, and these traits can be used as markers to select for resistance to *B. cucurbitae* in bitter gourd.

Chelliah and Sambandam (1974) suggested that perception of chemical stimuli was well developed in *B. cucurbitae*. Melon fly infestation and larval density per fruit increased with an increase in moisture level; while ascorbic acid, reducing, non-reducing and total sugars, nitrogen, protein, phosphorus and potassium contents were greater in the resistant genotypes when compared with the susceptible ones. Similar findings have also been reported by Tewatia et al. (1998). Sharma and Hall (1971) reported a positive correlation between spotted cucumber beetle (*Diabrotica undecimpunctata* Howardi) feeding and total sugars of various cucurbitaceous crops. The physico-chemical traits,

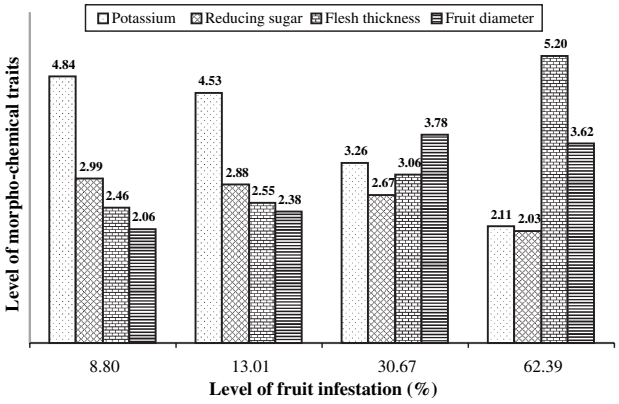

Fig. 1. *Associations of physico-chemical traits with resistance to melon fruit fly infestation under different infestation categories*

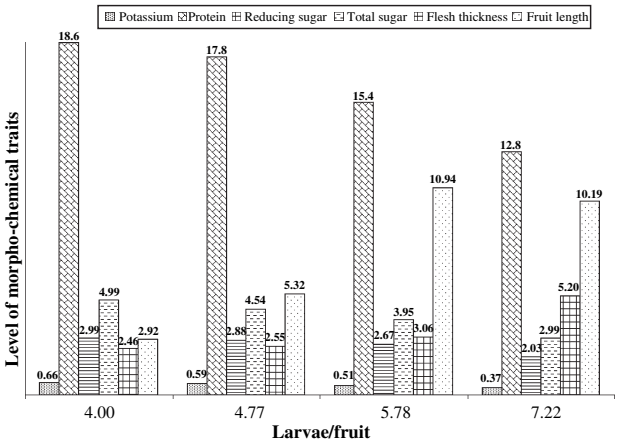

Fig. 2. *Associations of physico-chemical traits with larval density/fruit under different infestation categories*

fruit diameter, flesh thickness, potassium and reducing sugars (fig. 1), and flesh thickness, fruit length, potassium, protein, reducing sugars and total sugars (fig. 2) are the key factors influencing fruit fly infestation and larval density per fruit, and these can be used as markers (including fruit toughness and ridge density) to select lines with less susceptibility to melon fruit fly. However, it is not clear whether the components of resistance to melon fruit fly in the wild accessions of bitter gourd are different from those of the cultivated species. Further work is needed on the characterization of the mechanisms of resistance to melon fruit fly in the wild relatives, and the development of techniques for introgression of useful genes from the wild relatives into the cultivated bitter gourd to increase the levels and broaden the bases of resistance to this pest.

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