

Unravelling host plant resistance in mango: Genotypic variability, weather influence, and key fruit traits affecting the infestation of oriental fruit fly, *Bactrocera dorsalis* (Hendel)

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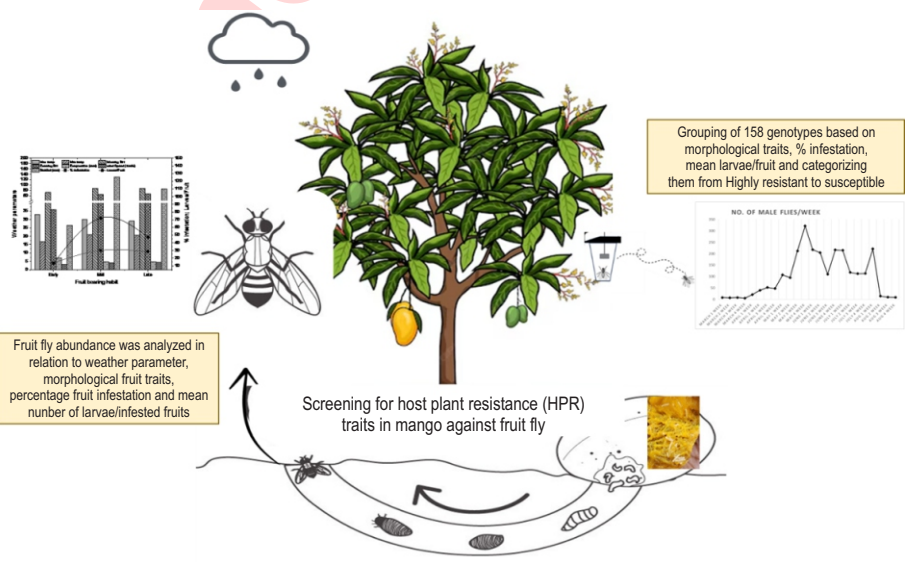
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Abstract

Aim: To understand the relationship between fruit morphological traits among different mango genotypes along with associated weather parameters interaction on infestation dynamics of the oriental fruit fly, *Bactrocera dorsalis* (Hendel).

Methodology: Screening of 158 mango genotypes was conducted during two successive fruiting years (2023 and 2024), to assess the population of fruit fly abundance in the field. Fruit fly abundance was analyzed in relation to weather parameters, morphological fruit traits, percentage fruit infestation and mean number of larvae per fruit. Based on these factors, the genotypes were categorized from resistant to susceptible.

Results: High fruit fly infestation during May to June (Mid-season) was recorded with its population density. A positive correlation was noticed between the fruit fly infestation and number of fruit fly trap catches, minimum temperature, relative humidity, morphological fruit traits, such as fruit weight, fruit length, fruit width, TSS and number of larvae per fruit. A significant negative correlation for fruit fly infestation was observed with fruit peel thickness. Among 158 genotypes, the genotypes with no fruit fly infestation grouped in the fourth cluster (Ananthabhata Apple, Appemidi, Balekoppa Appe, Dannalli Appe), which may be due to their thicker peel with low TSS and smaller fruit size.



Interpretation: The high fruit fly infestation was found mainly governed by multiple factors like fruit availability (bearing habit) coupled with prevailing weather parameters (minimum temperature and relative humidity). Some fruit morphological traits (fruit weight, fruit length, fruit width and TSS) were found to have limited role in fruit fly infestation, however peel thickness was found to significantly influence it.

Key words: Fruit fly infestation, Fruit traits, Mango genotypes, Screening, Trap catch, Weather variables

Introduction

Mango (*Mangifera indica* L.), popularly known as the “King of fruits,” is the most economically important fruit crop in tropical and subtropical regions worldwide. Global mango production exceeds 55.38 million metric tonnes annually, with India alone contributing over 40% of the total production, *i.e.* 22.42 million tonnes from 2.4 million hectares area (Kaur and Goyal, 2025). However, mango production is severely threatened by insect pests, particularly fruit flies (Diptera: Tephritidae), which infest both fallen immature and ripening fruits on the trees. Among the many pestiferous tephritid species, the Oriental fruit fly, *Bactrocera dorsalis* (Hendel), is a highly polyphagous pest, infesting over 250 host plants, including many commercially important fruits. This species alone can cause up to 80% yield loss in mango (Choudhary *et al.*, 2012) and due to its invasiveness and adaptability, it is considered as a major quarantine pest in international trade (Rashmi *et al.*, 2019). Fruit fly population dynamics in orchards are strongly influenced by seasonal factors—particularly rainfall, relative humidity, and minimum temperature—during fruit maturation (Salazar-Mendoza *et al.*, 2021; Rasolofoarivao *et al.*, 2022). Insect populations often reach their peak during the fruit harvesting period, making harvest timing a potential strategy to reduce oviposition and subsequent infestation (Grechi *et al.*, 2021).

In addition, mango genotype susceptibility to fruit flies varies depending on characteristics such as fruit maturity, texture, sap volatiles, fruit volatile cues, and peel thickness (Jayanthi and Verghese, 2008; Kamala Jayanthi *et al.*, 2020). However, the specific influence of these fruit traits on oviposition behaviour remains inadequately understood. Prokopy and Vargas (1996) suggested that peel thickness may act as a physical barrier, reducing fruit fly infestation by limiting egg penetration in thicker-peeled genotypes. Similarly, variations in peel thickness may also affect the host preference due to differences in the fly's ability to penetrate the fruit surface in *M. camptosperma* (Rattanapun *et al.*, 2010; Kamala Jayanthi *et al.*, 2020, Patel *et al.*, 2021). Therefore, host plant resistance is increasingly recognized as one of the most sustainable and cost-effective strategies for managing fruit fly infestations. Although some studies (Verghese *et al.*, 2012) have already examined fruit traits that are associated with resistance, significant knowledge gaps remain, particularly regarding morpho-physical attributes that also influence resistance to *B. dorsalis*. In view of the above, this study aimed to analyze their role and relationship with *B. dorsalis* resistance under field conditions in mango.

Materials and Methods

Study site: The study was conducted (2023 and 2024) on bearing trees at the mango Field Gene bank (8 ha) of the ICAR-IIHR, Bengaluru. A total of 158 mango genotypes including traditional varieties, popular hybrids, exotic introductions, polyembryonic types, and related *Mangifera* species were studied. All recommended agronomic practices were followed to

maintain normal plant health throughout the study period.

Monitoring fruit fly population: To monitor field populations of fruit flies, manually prepared methyl eugenol traps (20 traps ha⁻¹) were used. These traps had plywood blocks (5 × 5 × 2 cm³) soaked for 48 hr in a lure solution (6:4:1 ratio) comprising ethyl alcohol (99.9% AR), methyl eugenol, and a toxicant (spinosad 45% SC). Weekly counts of trapped male fruit flies were recorded throughout the fruiting season (March to August). Concurrently, weather data were collected from the automatic weather station at IIHR, Hesaraghatta, Bengaluru.

Screening of mango genotypes: Fruits were harvested based on their maturity indices and categorized into early, mid and late-season groups. For screening, three trees per genotype were selected during each season. At harvest, 120 fruits were randomly collected for assessment. Each fruit was individually placed in air and water-permeable paper bags and incubated at ~26°C for 20 days. After incubation, the fruits were dissected to recover fruit fly larvae. Last-instar larvae were transferred to ventilated plastic boxes containing sterile sand to facilitate pupation and adult emergence for species identification. A fruit was considered infested if at least one larva or pupa was found. The pooled data for fruit fly infestation and mean amount of larvae per fruit for two years were calculated using the standard formulae.

Assessment of fruit morphological traits: Pooled data for two years (2023 and 2024) on five randomly selected fruits per genotype were analyzed for different morphological traits, *i.e.*, fruit weight (g); fruit length (cm); fruit width (cm); total soluble solids (TSS, °Brix); peel thickness (mm) and mean number of larvae per fruit. Peel thickness was measured following the standard procedure.

Statistical analyses: The experiment was laid out in a Randomized Block Design (RBD) with three replications per genotype. Data were analyzed using SPSS v16.0 and JMP Pro v10.0 (SAS, 2012). Pearson's correlation was used to evaluate the relationship between weekly male fruit fly catches and weather parameters; associations between fruit morphological traits and infestation intensity. Stepwise regression models were developed to determine the morphological traits significantly contributing to fruit fly infestation. Significant correlation coefficients (*r*) guided model construction, with fruit fly infestation (%) as dependent variable (Y-axis) and fruit weight (x_1), fruit length (x_2), fruit width (x_3), TSS (x_4), peel thickness (x_5), and mean number of larvae per fruit (x_6) was done. The goodness-of-fit was evaluated using the coefficient of determination (R^2) and Variance Inflation Factor (VIF) was calculated to assess multicollinearity. Multivariate analyses, including Principal Component Analysis (PCA) was used along with WARD method.

Results and Discussion

The mean weekly fruit fly captures showed a steady increase from March to June. In early March, the male fruit fly

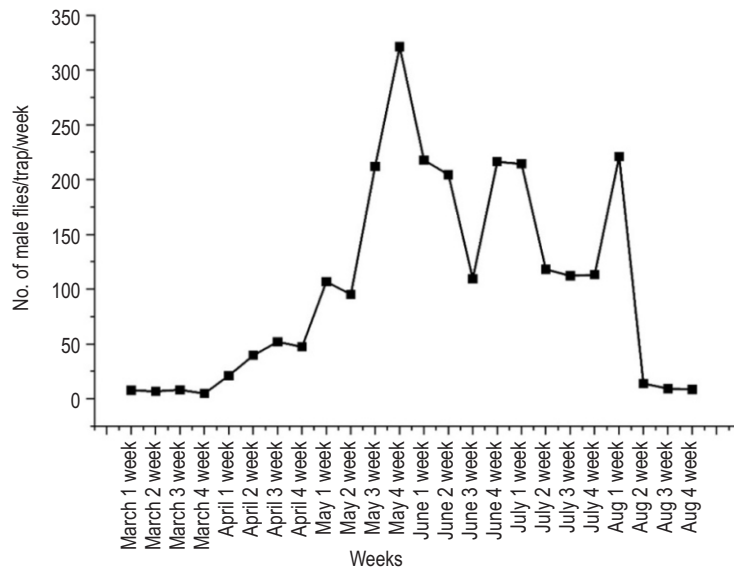


Fig. 1a: Mean population fluctuation of male fruit flies/ trap/ week in the experimental orchard (2023 & 2024).

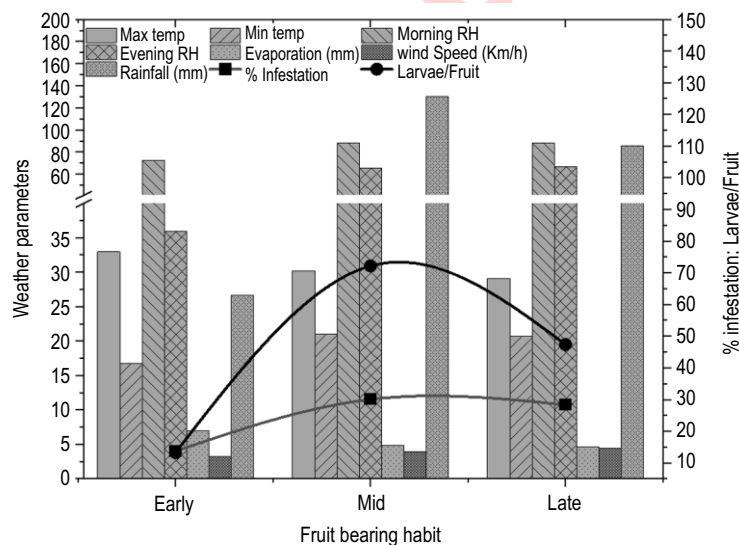


Fig. 1b: Details about fruit maturity habit, weather variables, and fruit fly infestation in mango genotypes.

captures averaged 7.9 per trap, surged from early May (212 per trap) to a peak of 321.3 per trap by late May and early June, coinciding with fruit maturation and onset of rainy season. However, the population declined from early August (14.1 per trap to 8.7 by the last week), aligning with reduced fruits availability (Fig. 1a). The mango genotypes screened were categorized based on their fruit maturity periods into early (March–April), mid (June–July) and late (by August) season bearers. The results indicated that the fruit flies primarily affected the mid- and late-season genotypes. Since fruit fly populations typically surge after

pre-monsoon or regular monsoon rains (June and July), early-season genotypes likely escape infestation. The early maturing genotypes recorded low infestation (13.71%) with low larvae/fruit (13.21). In contrast, the late-season genotypes recorded 28.3% infestation with 47.38 larvae per fruit (Fig. 1b). The fly catches were higher during May and June indicating their high population coinciding with harvest of mid and late maturing genotypes. Given the close association between abundance of fruit flies and availability of mature fruits (Jayanthi and Verghese, 2011), synchronization of peak fruit fly populations with the fruiting period

Table 1: Correlation between weather variables and the fruit fly catches in mango orchard

Parameter	Max temp	Min temp	Morning RH	Evening RH	Evaporation (mm)	Wind speed (km h ⁻¹)	Mean rainfall (mm)
Male flies Trap ⁻¹ week ⁻¹	-0.378	0.557**	0.505*	0.507*	-0.379	0.273	0.322
Max temp		-0.390	-0.884**	-0.939**	0.950**	-0.486*	-0.333
Min temp			0.613**	0.640**	-0.518**	0.169	0.373
Morning RH				0.962**	-0.924**	0.246	0.541**
Evening RH					-0.946**	0.389	0.486*
Evaporation (mm)						-0.342	-0.371
Wind speed (km h ⁻¹)							-0.311

**Correlation is significant at the 0.01 level (2-tailed), * Correlation is significant at the 0.05 level (2-tailed).

leads to heavy infestation in mid and late maturing genotypes. Correlation analysis revealed that fruit fly trap catches were significantly and positively correlated with minimum temperature ($r = 0.57$, $P \leq 0.01$) and relative humidity (morning: $r = 0.51$, $P \leq 0.01$; evening: $r = 0.51$, $P \leq 0.01$). Previous studies have shown that temperature and precipitation significantly influenced the fruit fly population dynamics (Jayanthi and Verghese, 2011; Vayssières *et al.*, 2014). Earlier studies have revealed that *B. dorsalis* population increases with rainfall and lower temperatures (Salazar-Mendoza *et al.*, 2021). The rainfall facilitates pupation by moistening the soil, creating favourable conditions for adult emergence. In general, the lower fruit fly infestation was noted in early maturing genotypes (Table. 1).

Different fruit morphological traits measured along with fruit fly infestation levels are presented in Table 2. Simple linear correlation analysis revealed a significant positive correlation between fruit weight, length, and width with fruit fly infestation ($r = 0.37^{**}$, 0.35^{**} , and 0.39^{**} , respectively; $P = 0.01$), as well as with the mean number of larvae/ fruit ($r = 0.30^{**}$, 0.29^{**} , and 0.28^{**} , respectively; $P = 0.01$). In contrast, the peel thickness showed a significant negative correlation ($r = -0.26$; $P = 0.01$) with fruit infestation (Table 2). Earlier, similar results were noted in ridge gourd (Gogi *et al.*, 2010). Kamala Jayanthi *et al.* (2020) suggested that higher peel thickness may offer physical resistance and, thus hinder oviposition as observed in *Mangifera camptosperma*.

Linear regression models developed using individual fruit morphological traits explained variability in fruit fly infestation up to 14% for fruit weight (x_1), 14% for fruit length (x_2), 17% for fruit width (x_3), 3% for TSS (x_4), 7% for peel thickness (x_5) and 66% for mean number of larvae per fruit (x_6). Step-wise regression models combining two significant fruit morphological traits explained significant fruit fly infestation variability (16 to 67%). The Variance Inflation Factor (VIF) values for these models were within the acceptable limits (<10), indicating the absence of multicollinearity (Table 3). Incorporating >two variables—selected based on significant correlation coefficients (r)—into the regression model increased the explained variability marginally (up to 71%; $Y = -6.09 - 0.004 x_1 + 0.76 x_2 + 1.77 x_3 + 0.25 x_4 - 12.68 x_5 + 0.207 x_6$, $R^2 = 0.71$, $VIF = 3.41$). A model using all fruit

morphological traits collectively explained only 24% variability in fruit fly infestation ($Y = -2.28 + 0.0015 x_1 + 1.66 x_2 + 2.65 x_3 + 0.16 x_4 - 37.27 x_5$), with a VIF value of 1.31 (Table 3). This clearly indicates the limited role of fruit morphological traits against fruit fly incidence.

The Principal Component Analysis (PCA) of fruit morphological traits and fruit fly infestation parameters revealed clear patterns of trait associations and variability among the mango genotypes (Table 4). PCA biplot (Fig. 2) showed that strongly correlated traits (percent fruit infestation/ mean larvae/ fruit and fruit length/fruit width/ fruit weight) clustered within the same quadrants, indicating shared influence or interdependence. Three principal components had Eigen values greater than 1.0 and together explained 79.94% of the total variation among 158 genotypes: PC1 accounted for 43.85% of total variability. This variability was primarily influenced by fruit weight (22.18%); fruit width (21.90%); fruit length (19.00%); fruit fly infestation (17.66%) and number of larvae per fruit (14.08%). The PC2, explained 19.67% of the variability, was influenced by peel thickness (27.67%); fruit weight (14.29%); number of larvae/ fruit (13.83%) and fruit length (12.78%). While, PC3 contributed 16.42% of the variability and was dominated by TSS (40.76%) and peel thickness (14.29%). These results indicate that fruit size (weight, width, length), infestation levels and peel thickness are the primary contributors to genotypic variability, while TSS and peel thickness heavily influence PC3, possibly reflecting fruit quality traits linked to fruit fly infestation.

PCA biplot (Fig. 2) illustrated the relationship between different traits and genotype distribution across quadrants, *i.e.*, Quadrant I (+, +) involved traits like fruit weight, fruit length and fruit width, which are closely aligned with $<10^\circ$ between their vectors, indicating strong positive correlation. This quadrant had genotypes, namely, Safed Mulgoa, Sora, Safeda Malihabad and Khudadath, which had larger fruits and higher fruit fly infestation. Likewise, Quadrant II (-, +) was associated with traits like peel thickness, TSS, and fruit fly infestation that were oriented nearly 180° apart, denoting strong negative correlations. This quadrant had genotypes like Ananthabhata Apple, Appemidi, and Dannalli Appe that had thicker peel and lower infestation, indicating peel thickness acts as a physical barrier enhancing resistance. While, Quadrant III (-, -) had genotypes with traits like smaller fruit size,

Table 2a: Mango fruit morphological traits and fruit fly infestation based on hierarchical clustering

Cluster	Genotype code	Genotype	Fruit wt. (g)	Fruit length (cm)	Fruit width (cm)	TSS (°Brix)	Peel thickness (mm)	Fruit fly infestation (%)	Mean larvae/ Infested fruit
	M1	Achar Pasand	294.60	10.16	6.98	15.37	0.12	4.33	3.52
	M2	Bappakai	144.87	8.62	6.57	13.37	0.11	25.51	23.50
	M3	Borsha	213.40	9.37	6.30	18.87	0.13	6.33	11.51
	M4	Malai Misri	249.53	9.57	7.21	15.10	0.14	11.52	87.12
	M5	Malgesh	272.73	8.77	7.66	14.63	0.17	11.50	38.52
	M6	K-O-22	167.17	9.47	6.30	18.91	0.16	15.38	54.21
	M7	Lazzat Baksh	39.00	8.27	5.21	14.07	0.16	15.51	39.50
	M8	<i>M. griffithi</i>	167.77	9.57	5.73	19.20	0.15	19.83	17.51
	M9	Clone -51	299.20	7.97	6.07	19.63	0.13	15.17	34.52
	M10	Costa	261.20	11.82	6.42	18.73	0.11	17.33	13.52
	M11	All Season	156.50	7.11	6.57	15.67	0.12	16.67	33.21
	M12	Lahara	306.83	7.77	6.27	18.61	0.15	10.44	19.12
	M13	Willard	126.23	6.70	6.71	14.91	0.13	9.52	21.11
	M14	Zardalu	169.23	6.73	7.21	17.82	0.18	10.83	5.51
	M15	Dwarf Rumani	206.80	6.91	7.17	14.52	0.12	18.22	61.51
	M16	Halsage	98.43	7.83	5.57	18.53	0.13	4.11	6.20
	M17	Heerachowki	109.07	6.72	5.67	17.91	0.11	12.17	45.01
	M18	Kurukkan	196.37	7.87	5.37	14.53	0.17	1.67	0.00
	M19	Muvandan	173.60	7.77	6.47	14.82	0.12	25.67	29.51
	M20	Hajeera	68.27	5.63	4.77	14.77	0.12	12.21	32.21
	M21	Sabre	132.53	7.87	5.37	13.81	0.13	17.11	59.22
	M22	Chandrakaran	55.43	6.27	4.23	23.17	0.21	5.01	2.11
	M23	Dattatreya Local	100.43	7.03	5.23	19.67	0.22	0.00	0.00
	M24	Pacharasi	15.10	4.13	3.27	18.40	0.12	12.33	15.5
	M25	Pachavarnam	198.20	7.27	6.67	23.12	0.15	8.12	9.50
	M26	Pusa Pratibha	252.107	6.72	6.43	21.60	0.13	8.67	9.11
	M27	Mandaviya	65.02	5.91	7.47	22.61	0.14	4.28	4.01
I	M28	Sundarshan	191.17	8.83	6.17	22.97	0.13	13.01	12.21
	M29	Agarbatti	355.03	10.27	8.17	19.70	0.11	15.17	19.21
	M30	Ashraf-us-Samar	275.8	8.51	7.82	19.47	0.11	26.02	17.01
	M31	Bombay Peda	288.07	9.37	7.47	21.13	0.12	6.23	10.52
	M32	Navneet	375.53	10.07	8.77	22.33	0.17	12.72	20.22
	M33	Mohamad Vikarabad	262.23	9.73	7.32	21.33	0.13	18.83	30.01
	M34	Kangara Matha	288.67	9.32	7.37	20.21	0.12	27.33	11.05
	M35	Muffarai	249.13	9.61	7.27	20.67	0.12	38.10	60.52
	M36	Arka Udaya	237.91	10.70	6.70	23.40	0.12	45.33	40.12
	M37	Dofasla	249.21	11.04	6.43	23.33	0.13	46.15	71.51
	M38	Rangoon Goa	321.87	11.07	7.67	21.17	0.12	26.33	32.11
	M39	Bandariya	333.67	8.34	7.02	20.53	0.11	27.12	65.52
	M40	Prabha Shankar	209.13	8.81	6.91	25.67	0.14	40.33	21.22
	M41	Sindhu	169.43	9.13	6.27	27.33	0.15	43.01	56.31
	M42	Kerala Kalapadi	372.37	8.72	7.13	19.87	0.13	31.11	128.50
	M43	Neelgoa	324.57	7.61	8.03	17.83	0.14	32.08	64.52
	M44	Pusa Arunima	268.73	8.07	6.97	18.37	0.15	37.78	82.51
	M45	Pusa Peetamber	290.27	8.37	7.07	19.53	0.16	41.67	52.52
	M46	Chitanga	183.47	7.24	6.50	19.47	0.10	38.33	31.12
	M47	Himsagar	322.60	10.2	7.37	17.97	0.13	27.21	52.50
	M48	Lal Sundari	260.92	10.07	7.13	18.23	0.15	37.04	120.11
	M49	Peach	176.71	8.21	6.87	18.03	0.16	44.67	72.52
	M50	Vattem	134.83	7.77	6.5	16.87	0.13	39.83	88.51
	M51	Khuddus	179.33	8.77	6.57	20.73	0.12	57.51	120.50
	M52	Starch	174.87	7.82	5.93	18.61	0.14	47.17	141.51
	M53	Goa Mankurd	173.23	7.23	6.10	20.67	0.21	30.50	126.50
	M54	Vhout	151.80	9.03	5.42	16.47	0.14	35.59	85.22
	M55	Hamsamamidi	154.63	7.63	5.63	21.33	0.22	42.58	25.22
	M56	Kavesana	253.32	7.57	6.12	20.17	0.21	26.54	64.52

Table continued

II	M57	Neeluddin	189.33	7.83	6.60	21.90	0.27	27.33	46.50
III	M58	Ambalavi	158.71	10.11	5.78	18.03	0.24	10.83	6.11
	M59	Dashehari	175.87	10.67	6.43	18.67	0.24	11.67	9.50
	M60	Olour	188.97	8.83	6.33	18.52	0.29	5.33	3.51
	M61	Vellaikulumban	161.63	9.53	5.62	18.91	0.22	8.33	10.52
	M62	Amrapali	228.83	9.97	5.51	23.13	0.21	17.67	9.51
	M63	Aryavardhana Rasalu	274.27	11.17	7.13	20.13	0.31	21.17	15.50
	M64	Langra	261.27	11.17	7.65	20.83	0.28	15.33	7.52
	M65	<i>M. odorata</i>	273.93	10.27	6.77	21.47	0.25	0.00	0.00
	M66	Miranda	214.3	8.36	7.30	21.67	0.35	4.33	3.11
	M67	PKM-1	237.73	9.81	6.73	19.13	0.32	22.48	23.5
	M68	Rasool	272.1	10.37	6.83	20.23	0.24	3.52	11.23
	M69	Chinnarasam	333.47	10.33	7.62	17.77	0.23	9.67	4.52
	M70	KMH-1	307.27	10.14	7.57	18.80	0.21	22.11	17.21
	M71	Puttu	277.5	9.47	7.53	19.57	0.36	3.48	6.51
	M72	Kacha Meeta	243.53	8.23	7.47	19.12	0.22	22.17	47.50
	M73	Kottur Konam	249.17	8.42	7.77	18.82	0.24	20.83	39.21
	M74	Paiyur-1	154.53	7.23	8.67	18.81	0.26	18.33	18.11
M75	Panchadara Kalasa	350.67	8.77	7.53	18.53	0.22	25.50	17.50	
M76	EC-95862	151.83	8.14	6.37	19.47	0.23	19.51	11.22	
M77	Karol	206.3	8.17	7.21	21.10	0.23	3.59	6.23	
M78	Kasturi Mamidi	223.87	8.37	7.47	18.07	0.24	2.17	1.53	
M79	Kintala Venipeta	153.4	8.17	6.20	17.93	0.23	29.33	47.12	
M80	Shendriya	228.6	7.77	7.72	19.62	0.24	9.90	27.22	
M81	Neelam	257.33	7.81	6.61	19.72	0.26	34.04	23.51	
M82	Nekkare	175.97	7.72	6.87	15.93	0.25	21.67	12.11	
M83	Padiri	187.17	10.31	6.6	17.71	0.26	25.33	16.52	
M84	Arka Neelkiran	338.6	9.73	8.22	19.21	0.23	34.21	42.53	
M85	Manipur	225.33	9.93	6.77	17.72	0.26	24.33	102.5	
M86	Prior	265.67	9.23	6.87	17.03	0.21	21.17	72.51	
M87	Kalgundikoppa Appe	430.7	9.90	8.12	20.73	0.21	30.58	17.51	
M88	Kalkand	365.67	10.83	7.71	26.63	0.23	4.28	5.52	
M89	Kerala Dwarf	435.97	9.12	9.23	13.20	0.22	26.67	64.11	
M90	Khazri	455.3	11.03	8.30	21.93	0.21	28.46	68.52	
M91	Kohinoor	275.83	9.24	7.77	21.63	0.27	30.15	36.52	
M92	H-56	422.9	9.41	9.12	20.93	0.32	29.83	82.11	
M93	Virudhanagar	226.1	9.77	7.80	22.57	0.25	25.12	24.02	
M94	Xavier	247.47	9.57	8.10	22.91	0.26	18.51	35.51	
M95	Danti Mamidi	459.57	11.23	8.38	21.67	0.22	2.67	2.23	
M96	Latif	309.73	11.23	8.17	20.97	0.34	43.12	83.23	
M97	Vanraj	447.10	10.82	9.17	19.83	0.35	32.83	53.51	
M98	Arya Samaj	281.53	10.13	6.34	14.73	0.32	28.23	59.12	
M99	Mallika	347.73	13.07	8.1	26.9	0.21	28.21	93.52	
M100	Pahilwan	459.90	13.53	8.73	18.83	0.23	12.51	6.51	
M101	Eldon	521.43	12.12	8.3	13.73	0.32	23.33	75.51	
M102	Kurd	277.77	9.14	7.4	13.27	0.25	39.50	127.23	
M103	Mylepallian	333.13	6.37	12.6	13.2	0.14	45.67	40.51	
M104	Ananthabhata Apple	9.89	4.66	2.43	3.97	0.81	0.00	0.00	
M105	Appemidi	43.10	6.32	3.42	8.1	0.62	0.00	0.00	
M106	Balekoppa Appe	52.47	6.33	4.17	3.33	0.21	0.00	0.00	
IV	M107	Dannalli Appe	25.07	6.22	2.27	2.97	0.43	0.00	0.00
	M108	Bandar Bandal	479.23	9.93	9.17	19.87	0.12	40.67	141.22
	M109	Allampur Baneshan	356.92	10.93	8.8	18.5	0.11	34.33	158.13
	M110	Chauthi	338.05	11.12	8.03	18.53	0.12	31.49	100.50
	M111	Bangalore Sindhura	323.23	13.57	7.63	17.67	0.22	52.33	191.51
	M112	Hansaraj	522.63	13.37	8.7	17.9	0.24	38.33	119.01
	M113	Navaneetham	441.67	10.81	9.2	20.47	0.12	32.83	55.11
	M114	Neeleshan	395.12	12.92	9.3	18.63	0.22	32.99	91.22
	M115	Arka Anmol	350.21	11.04	7.75	19.20	0.12	61.23	81.12
	M116	Mulgoa	363.80	9.65	8.63	20.67	0.27	43.50	171.50
	M117	Papayaraju Goa	469.52	11.71	8.77	20.72	0.24	53.23	208.52

Table continued

	M118	Totapuri	470.62	12.17	7.77	18.52	0.17	52.83	162.12
	M119	Gulabi	363.42	11.07	7.67	20.17	0.13	46.50	155.50
	M120	Neelphonso	240.07	10.43	7.62	20.27	0.16	50.67	166.51
	M121	Sensation	194.87	9.37	7.30	17.20	0.14	68.83	199.50
	M122	Banganapalli	444.07	10.70	8.61	18.93	0.12	62.67	210.22
	M123	Suvarnarekha	293.07	10.27	7.42	15.60	0.15	55.33	150.15
	M124	Tommy Atkins	451.43	11.22	9.63	16.17	0.16	65.33	216.12
	M125	Lal Khatral	356.52	13.67	6.67	18.33	0.26	45.67	36.52
	M126	Lilly	410.47	10.37	8.47	15.17	0.19	69.52	253.12
	M127	Ostin	490.47	12.47	5.63	17.67	0.14	42.32	137.51
	M128	PKM-2	352.27	13.12	7.13	14.43	0.22	35.64	30.52
	M129	Thorappadi	405.73	12.53	7.47	17.17	0.26	32.04	65.50
	M130	Alphonso	252.47	8.47	7.73	20.17	0.12	60.52	222.12
	M131	Raspuri	309.57	8.22	7.31	21.47	0.14	57.83	198.23
	M132	Sai Sugandh	474.41	15.33	7.82	19.47	0.13	43.82	80.52
V	M133	Sambalpatti Totapuri	488.37	18.20	8.57	15.63	0.22	66.17	196.51
	M134	Arka Puneet	292.12	9.73	8.32	21.01	0.13	48.33	59.52
	M135	Shakkar Gola	294.13	8.33	8.77	21.13	0.12	47.51	149.52
	M136	Yakutti	189.27	9.62	8.23	24.03	0.14	43.97	66.22
	M137	AU-Rumani	376.40	7.67	8.33	23.9	0.12	48.67	171.22
	M138	Bada Gulab	307.73	8.55	7.38	21.37	0.22	36.21	143.11
	M139	Badami Modal	187.40	8.11	5.97	17.51	0.21	24.01	139.02
	M140	Raja Pasand	177.90	7.32	6.62	20.93	0.12	57.33	209.01
	M141	Gopal Bhog	256.71	9.43	7.03	19.90	0.22	41.21	74.51
	M142	H-87	273.33	9.81	7.33	18.57	0.22	26.52	73.22
	M143	Kesar	251.97	10.13	6.73	18.07	0.31	59.22	239.21
	M144	Harsha	464.93	7.97	6.63	20.97	0.21	47.88	105.00
	M145	Keitt	485.33	8.07	6.31	20.22	0.13	52.76	204.50
	M146	Kishen Bhog	193.10	8.82	6.51	20.82	0.21	51.83	195.22
	M147	Pulihora	224.61	7.72	7.27	21.41	0.24	62.17	135.52
	M148	Amini	619.53	11.87	10.23	12.07	0.22	23.17	16.50
	M149	Hybrid 7/15	701.77	14.80	9.61	13.97	0.22	19.83	35.51
	M150	Mutwar Pasand	839.21	13.11	10.17	12.77	0.14	41.22	28.50
	M151	Arka Aruna	765.82	13.22	10.60	22.03	0.13	53.67	84.12
	M152	Kerali Goa	831.87	13.27	10.67	20.77	0.24	36.04	86.52
	M153	Khudadath	891.57	13.17	11.27	20.63	0.21	52.17	159.22
	M154	Makaram	714.31	11.27	10.07	17.93	0.27	44.59	27.50
	M155	Thambava	682.53	13.30	10.33	17.82	0.26	36.26	69.51
	M156	Safed Mulgoa	1228.41	14.67	11.13	17.81	0.25	42.83	83.21
	M157	Safeda Malihabad	956.13	12.23	10.03	21.70	0.14	16.17	56.50
IV	M158	Sora	1026.91	22.93	10.8	13.03	0.13	65.67	193.52
		Min	9.89	4.13	2.27	2.97	0.10	0.00	0.00
		Max	1228.40	22.93	12.60	27.33	0.81	69.50	253.00
		Mean	306.55	9.63	7.31	18.69	0.20	29.25	68.28
		SD	189.54	2.42	1.56	3.67	0.09	17.94	64.47
		CV(%)	61.83	25.08	21.31	19.63	45.38	61.32	94.42

thicker peels, and lower TSS. These traits likely confer reduced susceptibility to fruit flies. Likewise, Quadrant IV (+) had traits like fruit fly infestation and TSS, that positioned at $<10^\circ$ apart, indicating strong positive correlation between them. This quadrant hosted genotypes like Alphonso, Raspuri, Raja Pasand, Pulihora and Tommy Atkins that had characteristics like high sugar content and high infestation, suggesting sweetness enhancing fruit fly oviposition.

PCA highlighted critical trade-offs between fruit quality and resistance traits, *i.e.*, fruit size and sweetness were positively

associated with higher fruit fly infestation. Peel thickness emerged as a key resistance trait, inversely correlated with both infestation and TSS. These insights provide a valuable framework for selecting genotypes with natural resistance. Mango genotypes were grouped based on fruit morphological traits and fruit fly infestation and mean number of larvae per fruit using two-way hierarchical clustering with the Ward's method. The analysis revealed six major clusters (Fig. 3). Cluster I comprised of 28 genotypes, which were classified as resistant to *B. dorsalis* (infestation: 0.00- 25.50%; larvae/ fruit: 0.00 to 87.00). The genotype Dattatreya Local recorded the lowest fruit fly infestation

Table 2b: Correlation between fruit morphological traits and fruit fly infestation among mango genotypes

Trait	Fruit length	Fruit width	Total soluble sugars	Peel thickness	Fruit fly infestation	No. of larvae/ Infested fruit
Fruit weight	0.75**	0.79**	0.07	-0.07	0.36**	0.29**
Fruit length		0.60**	0.07	-0.04	0.35**	0.29**
Fruit width			0.23**	-0.18*	0.39**	0.29**
Total soluble sugars				-0.31**	0.14	0.07
Peel thickness					-0.26**	-0.19*
Fruit fly Infestation						0.80**

** , * significant @ P = 0.01 & 0.05 levels, respectively

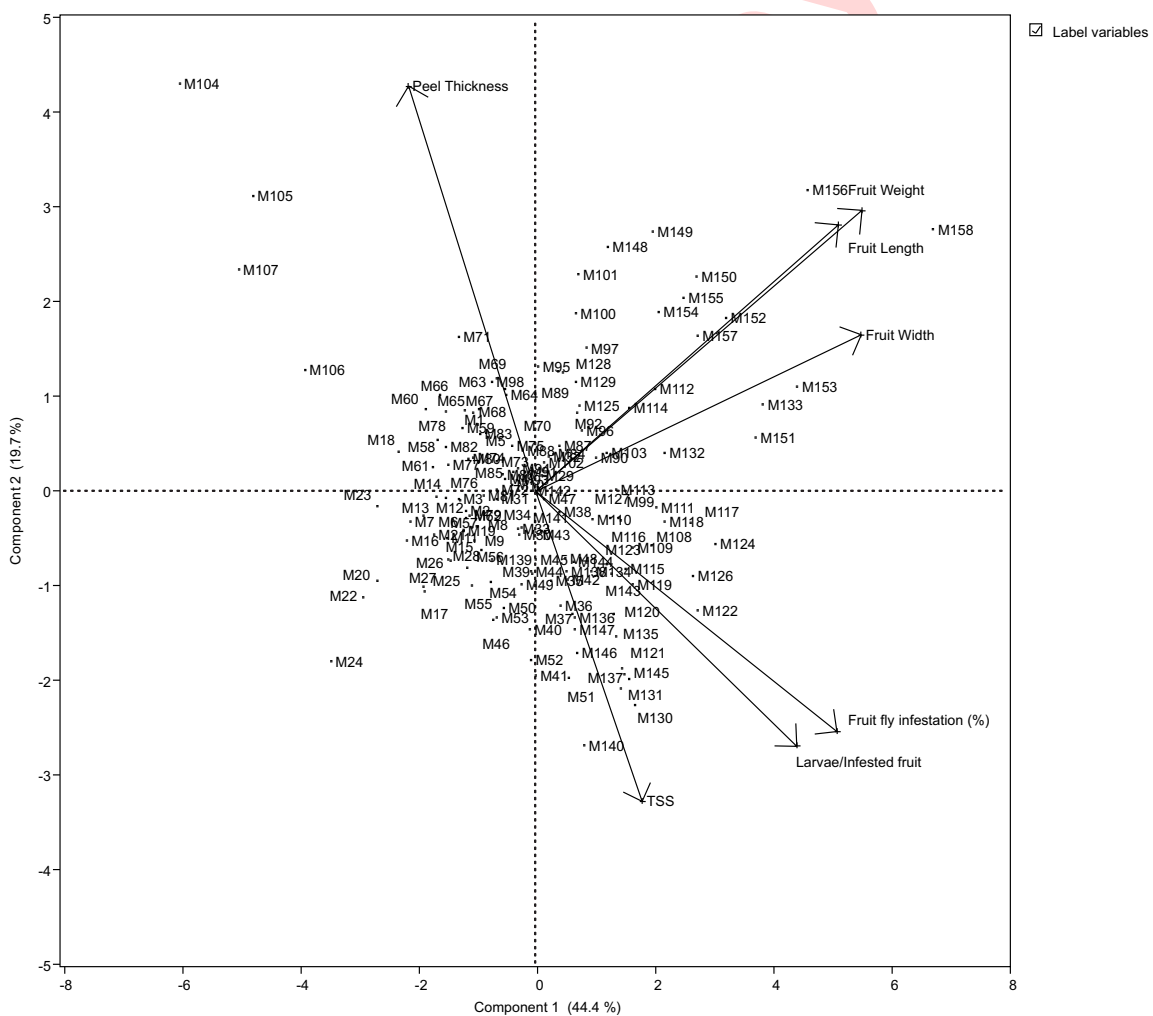


Fig. 2: Biplot of principal component analysis showing different mango genotypes and their morphological traits influencing fruit fly incidence.

(0.00%), indicating strong resistance. On the other hand, Muvandan and Bappakai recorded moderate infestation levels (25.50%). Interestingly, while Malai Misiri showed relatively low fruit fly infestation (11.50%), though recorded the highest number of larvae per fruit (87.00), which may be due to conducive

environment (volatile organic compounds and other biochemicals) that facilitated development of larvae (Kamala Jayanthi *et al.*, 2020; Verghese *et al.*, 2012). Similarly, cluster II included 29 genotypes with fruit fly infestation ranging from 6.00 to 57.50% and number. of larvae per fruit ranging from 10.5 to

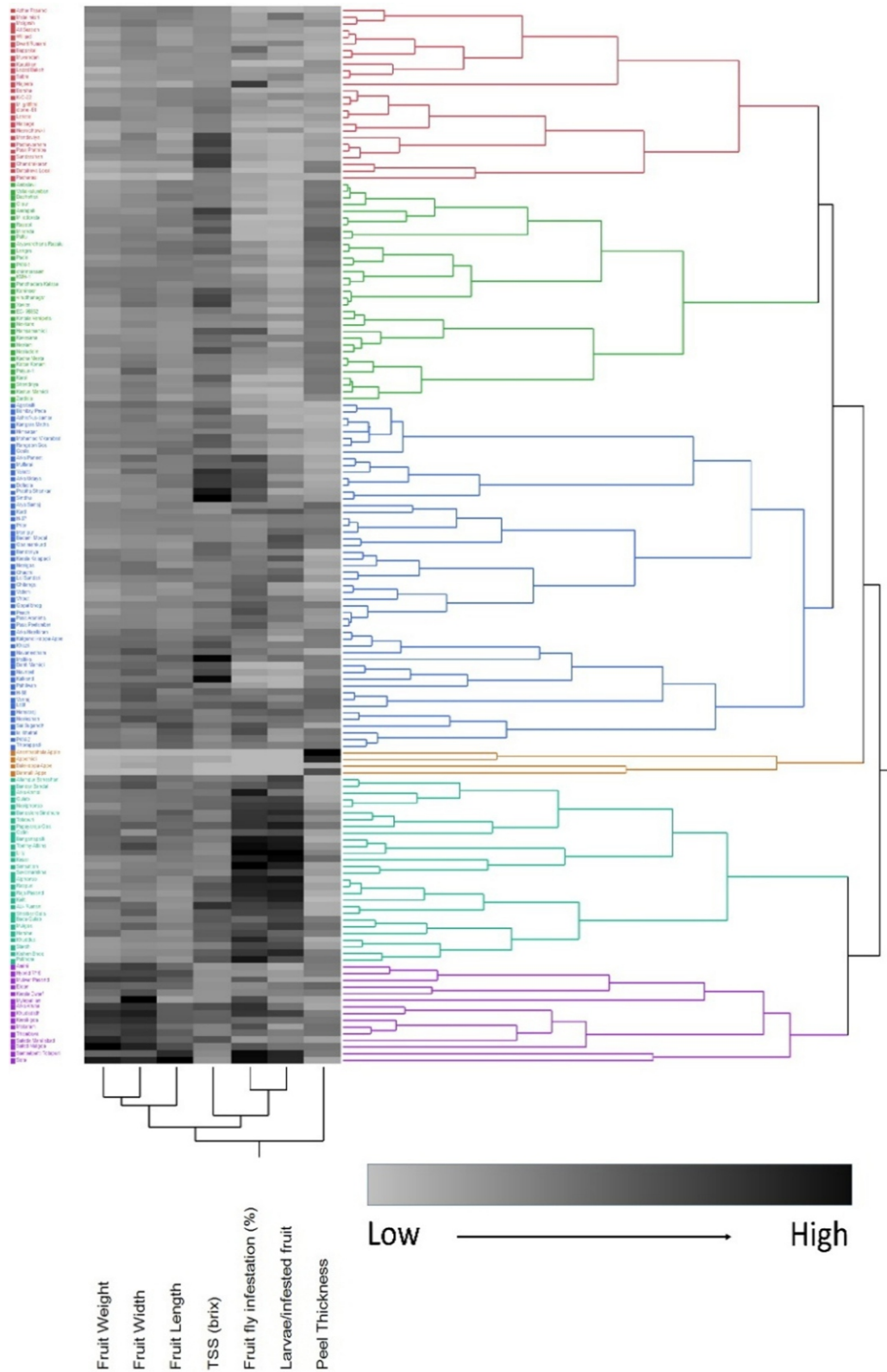


Fig. 3: Hierarchical clustering analysis (HCA) of 158 genotypes based on morphological traits, Fruit fly infestation, means number of larvae / infested fruit. The heatmap illustrates standardized values (colour scale: -2 to 2) for each parameter, with genotypes clustering into six distinct groups based on infestation.

Table 3a: Regression analyses between fruit fly infestation (%) and morphological traits of mango fruit in selected genotypes (upto two independent variables)

Traits considered	Model	R ²	VIF
x ₁	Y= 18.04+0.035x ₁	0.14	1.16
x ₂	Y= 1.99+2.79x ₂	0.14	1.17
x ₃	Y= -5.97+4.77x ₃	0.17	1.21
x ₄	Y= 14.39+0.77x ₄	0.03	1.03
x ₅	Y= 38.67-49.63 x ₅	0.06	1.07
x ₆	Y= 13.78+0.22x ₆	0.66	2.93
x ₁ + x ₂	Y= 7.16+0.02x ₁ +1.61x ₂	0.16	1.19
x ₁ + x ₃	Y= -1.19+0.01 x ₁ +3.61 x ₃	0.18	1.22
x ₁ + x ₄	Y= 6.06+0.03 x ₁ +0.65 x ₄	0.16	1.19
x ₁ + x ₅	Y= 27.26+0.03 x ₁ -44.7 x ₅	0.19	1.24
x ₁ + x ₆	Y=10.23+0.01 x ₁ +0.21 x ₆	0.68	3.12
x ₂ + x ₃	Y= -10.25+1.49 x ₂ +3.39 x ₃	0.20	1.25
x ₂ + x ₄	Y= -9.52+2.72 x ₂ +0.65 x ₄	0.16	1.19
x ₂ + x ₅	Y= 11.81+2.73 x ₂ -46.94 x ₅	0.20	1.25
x ₂ + x ₆	Y= 3.32+1.17 x ₂ +0.21 x ₆	0.68	3.14
x ₃ + x ₄	Y= -10.98+4.59 x ₃ +0.33 x ₄	0.18	1.22
x ₃ + x ₅	Y= 3.743+4.403 x ₃ -35.7 x ₅	0.20	1.26
x ₃ + x ₆	Y= -1.75+2.27 x ₃ +0.21 x ₆	0.69	3.27
x ₄ + x ₅	Y= 29.16+0.44 x ₄ -43.96 x ₅	0.07	1.07
x ₄ + x ₆	Y= 4.25+0.51 x ₄ +0.22 x ₆	0.67	3.03
x ₅ + x ₆	Y= 17.94-19.42 x ₅ +0.233 x ₆	0.67	3.00

x₁ - Fruit Weight, x₂ - Fruit Length, x₃ - Fruit Width, x₄ - TSS, x₅ - Peel Thickness, x₆ - Mean No. of larvae / infested fruit

141.5. This group was characterized as susceptible to *B. dorsalis* (TSS: 16.40 to 27.30°Brix; peel thickness: 0.10 and 0.21 mm). Overall, these genotypes exhibited relatively high TSS and thin peel traits that contributed to their susceptibility as reported by

Reddy and Vasugi (2008). Within this cluster, the genotype Khuddus recorded the highest fruit fly infestation (57.50%), with a TSS of 20.73°Brix and peel thickness of 0.12 mm. In contrast, Bombay Pedda showed the lowest infestation (6.00%) despite having a TSS of 21.13°Brix and similar peel thickness (0.12 mm). Earlier, Malo et al. (2012) reported the role of volatile olfactory cues in host plant, which repel the fruit flies.

In cluster III there were 46 mango genotypes (infestation: 0.00 to 45.60%, moderate number of larvae per fruit: 0.00 to 127.00). Within this cluster, the species *Mangifera odorata* recorded zero fruit fly infestation, with notable morphological traits such as fruit weight (273.93 g), fruit length (10.27 cm), fruit width (6.77 cm), TSS (21.47°Brix), and peel thickness (0.25 mm) suggesting it potential as a donor parent. Commercial cultivars such as Dashehari, Amrapali, and Langra recorded low fruit fly infestation (11.67, 17.67, and 15.30%) and minimal larval counts (9.50, 9.50, and 7.50). These observations are consistent with the findings of Choudhary et al. (2012). For this cluster, TSS ranged from 13.2° to 26.9°Brix, and peel thickness between 0.14 and 0.36 mm. However, the genotypes such as Vanraj and Eldon, despite having thicker peels (0.35 and 0.32 mm), showed relatively high fruit fly infestation (43.3 and 23.3%). This suggests that resistance may be influenced by volatile organic compounds, which are involved in long- and short-range pest attraction (Kamala Jayanthi et al., 2014) and some secondary metabolites (Jayanthi and Verghese, 2011; Verghese et al., 2012).

Cluster IV comprised of four genotypes (Ananthabhata Apple, Appemidi, Balekoppa Appe and Dannalli Appe) which recorded zero fruit fly infestation having higher peel thickness ranging from 0.21 to 0.81 mm and low TSS (2.97° to 4.17°Brix). Among them, Ananthabhata Apple exhibited the highest peel thickness (0.81 mm) and the lowest TSS. Given their complete

Table 3b: Regression analyses between fruit fly infestation (%) and morphological traits of mango fruit in selected genotypes (more than two independent variables)

Traits considered	Model	R ²	VIF
x ₁ + x ₂ + x ₃	Y= -11.46-0.02 x ₁ +1.57 x ₂ +3.55 x ₃	0.20	1.25
x ₁ + x ₄ + x ₅	Y= 19.79+0.003 x ₁ +0.35 x ₄ -40.24 x ₅	0.20	1.24
x ₁ + x ₅ + x ₆	Y= 14.33+0.014 x ₁ -19.03 x ₅ +0.21 x ₆	0.69	3.21
x ₂ + x ₃ + x ₄	Y= -16.46+1.55 x ₂ +3.12 x ₃ +0.407 x ₄	0.21	1.26
x ₂ + x ₅ + x ₆	Y= 7.47+1.18 x ₂ -20.02 x ₅ +0.21 x ₆	0.69	3.24
x ₃ + x ₄ + x ₅	Y= 1.91+4.36 x ₃ +0.102 x ₄ -34.55 x ₅	0.20	1.26
x ₃ + x ₅ + x ₆	Y= 2.12+2.15 x ₃ -14.49 x ₅ +0.209 x ₆	0.70	3.33
x ₄ + x ₅ + x ₆	Y= 9.18+0.41 x ₄ -14.22 x ₅ +0.22 x ₆	0.67	3.07
x ₁ + x ₂ + x ₃ + x ₄	Y= -16.45+0.001 x ₁ +1.55 x ₂ +3.12 x ₃ +0.407x ₄	0.21	1.26
x ₁ + x ₄ + x ₅ + x ₆	Y= 6.42+0.013 x ₁ +0.37 x ₄ -14.29 x ₅ +0.211 x ₆	0.69	3.26
x ₁ + x ₂ + x ₃ + x ₄ + x ₅	Y= -0.29+1.66 x ₂ +2.75 x ₃ +0.15 x ₄ -37.27 x ₅	0.24	1.31
x ₂ + x ₃ + x ₄ + x ₅	Y= -2.28+0.0015 x ₁ +1.66 x ₂ +2.65 x ₃ +0.16 x ₄ -37.27 x ₅	0.24	1.31
x ₂ + x ₄ + x ₅ + x ₆	Y= 0.029+1.15 x ₂ +0.36 x ₄ -15.4 x ₅ +0.21 x ₆	0.70	3.30
x ₃ + x ₄ + x ₅ + x ₆	Y= -2.41+2.04 x ₃ +0.25 x ₄ -11.56 x ₅ +0.21 x ₆	0.70	3.36
x ₁ + x ₂ + x ₃ + x ₄ + x ₅ + x ₆	Y= -6.09-0.004 x ₁ +0.76 x ₂ +1.77 x ₃ +0.25 x ₄ -12.68 x ₅ +0.207 x ₆	0.71	3.41

x₁ - Fruit Weight, x₂ - Fruit Length, x₃ - Fruit Width, x₄ - TSS, x₅ - Peel Thickness, x₆ - Mean No. of larvae / infested fruit

Table 4: PCA analysis of different traits evaluated in mango genotypes.

Particulars	PC1	PC2	PC3
Eigen value	3.10	1.37	1.15
Percentage of variance	44.4	19.67	16.48
Cumulative percentage of variance	44.4	64.0	80.5
Eigen vectors of variables (Partial contribution of variables)			
Fruit weight	0.47 (22.18)	0.38 (14.29)	-0.11 (1.10)
Fruit length	0.44 (19.00)	0.36 (12.78)	-0.05 (0.22)
Fruit width	0.47 (21.90)	0.22 (4.97)	-0.24 (5.67)
TSS	0.15 (2.17)	-0.36 (12.98)	-0.64 (40.76)
Peel thickness	-0.17 (3.02)	0.53 (27.67)	0.38 (14.29)
Fruit fly Infestation	0.42 (17.66)	-0.37 (13.47)	0.38 (14.09)
Mean No. of larvae/ fruit	0.38 (14.08)	-0.37 (13.83)	0.49 (23.87)

lack of fruit fly infestation, these genotypes are considered highly resistant and hold strong potential for use in fruit fly resistance breeding programmes. Earlier, Gogi *et al.* (2010) and Jayanthi and Verghese (2012) reported a positive correlation between TSS and total sugars with fruit fly infestation, whereas peel thickness showed a negative correlation.

Cluster V consisted of 40 genotypes (infestation: 24.00 to 69.00%, larvae per fruit: 30.50 to 253.00) was identified as highly susceptible. Genotypes in this cluster exhibited peel thickness between 0.10 and 0.30 mm, and TSS ranging from 14.4° to 24.03°Brix. Thin peel may be a major contributing factor to their susceptibility. Earlier, Dias *et al.* (2017) reported highest oviposition index in mango genotypes having thinner peels. Notably, several widely grown commercial varieties were included in this cluster recording higher fruit fly infestation (>60%). These included Alphonso (60.50%), Arka Anmol (61.00%), Pulihora (62.17%), Banganapalli (62.67%), Tommy Atkins (65.33%), Sambalpatti Totapuri (66.17%), Sensation (68.83%), and Lilly (69.50%). These genotypes though possess desirable commercial traits, were found to be highly susceptible as reported (Rashmi *et al.*, 2019).

Cluster VI consisted of 11 genotypes (infestation: 16.0 to 65.6%; larvae/ fruit: 16.5 to 193.5) characterized with the higher fruit weight (619.53–1228.4 g), fruit length (11.8–14.6 cm), and fruit width (10.0–11.13 cm), compared to genotypes in Cluster V. Despite having large fruit size, these genotypes exhibited moderate to high fruit fly infestation. For instance, Safed Mulgoa (1228.40 g), showed moderate fruit fly infestation (42.8%) with 83.00 larvae/ fruit. In contrast, Sora, with slightly lower fruit weight (1026.90 g), recorded the high infestation (65.60%) and highest larval count (193.50). The importance of identifying sources of resistance [antixenosis (= non-preference); antibiosis and tolerance] to target pests, followed by the characterization of physico-chemical factors influencing insect host selection for both feeding and oviposition (Rafiq *et al.*, 2008).

In the present study, a total of 158 genotypes were screened for fruit fly infestation. Understanding the fact that host

plant resistance is influenced not only by the morphological and biochemical plant traits but also environmental conditions and physiological status of the insects (Liu *et al.*, 2025), we noticed high fruit fly infestation during May to June (Mid-season) may be because of high fruit fly population that were confirmed through trap catches (upto 321.3 flies per trap). Additionally, a significant and positive correlation was observed between fruit fly infestation and number of fruit fly male trap catches indicating fruit damage levels depends on their population level too. Of several abiotic factors studied, minimum temperature and relative humidity (evening) were found to be significantly and positively correlated with fruit fly infestation and fruit fly trap catches. Earlier studies also elaborated the influence of abiotic factors on *B. dorsalis* populations (Patel *et al.*, 2021; Nataraju *et al.*, 2026).

Of several morphological traits studied, peel thickness negatively impacted the genotype susceptibility to fruit flies. Previous studies reported that the physico-chemical trait changes, fruit weight, fruit pulp:stone ratio and TSS, positively correlated with fruit fly infestation and larval density (Susanto *et al.*, 2022). Kamala Jayanthi *et al.* (2020) reported that *M. camptosperma*, a wild relative of mango exhibits ovipositional antixenosis to *B. dorsalis*. In the present study, fruit morphological traits that could influence the fruit fly infestation together can explain the variability in the fruit fly incidence to the tune of 24% indicating the limited role of these traits on genotype susceptibility or resistance. Of all 158 genotypes, the interesting genotypes like Ananthabhata Apple, Appemidi, Balekoppa Appe, and Dannalli Appe, recorded zero fruit fly infestation and exhibited true resistance were grouped in the fourth cluster had thicker peel with low TSS and smaller fruit size were significantly linked to resistance of mango against *B. dorsalis* may be used as marker traits in future breeding programmes.

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