



Plant-insect interactions in different genotypes of ber (*Ziziphus mauritiana* L) against fruit borer (*Meridarchis scyroides* Meyrick)

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Summary

Differences in genotypes of ber plant characters may affect insect-plant herbivore interactions, and variation in genotype traits is responsible for modifying the bottom-up effects. We evaluated the performance of different genotypes of *Z. mauritiana* against fruit borer, *Meridarchis scyroides* Meyrick, under field conditions in the semi-arid region of India. We found that: (i) four genotypes were resistant; 5 genotypes were moderately resistant; 7 genotypes were susceptible, and seven genotypes were highly susceptible to fruit borers infestation; (ii) per cent fruit infestation was highest in Sanur-5 (75.09 %) and lowest in Safeda (13.27 %) followed by Tikadi (14.01 %); (iii) phenols (0.96), Tannins (0.95), flavonoid (0.95) contents and pericarp thickness (0.88) had significant negative correlations with per cent fruit infestation of fruit borer, *M. scyroides*; (iv) fruit length (0.50) and pulp: stone ratio (0.77) showed significant positive correlations with per cent fruit infestation of fruit borer, *M. scyroides* and (v) flavonoid contents explained 91.40% of the total variation in fruit borer, *M. scyroides* infestation. Two principal components (PCs) were extracted, explaining the cumulative variation of 88.48 %. PC1 explained 64.34 % of the variation, while PC2 explained 24.14 %. In conclusion, growers can adopt the potential resistant genotype (Safeda) of *Z. mauritiana* with minimal financial investment to obtain higher yields.

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Keywords: *Meridarchis scyroides*, *Z. mauritiana*, genotypes, bottom-up effect, plant-insect interactions

Introduction

The ber (*Ziziphus mauritiana* Lamark) also called as desert apple, jujube, Chinese apple, Ber (Hindi), Indian plum and Permseret (Anguilla) is a tropical fruit tree species, belonging to the family Rhamnaceae (Balikai et al. 2013; Haldhar et al. 2016). In India, it is a popular fruit crop for the arid and semi-arid regions of India. Most cultivated areas are confined to Rajasthan, Haryana, Punjab, Gujarat, Maharashtra and Uttar Pradesh. The crop is gaining popularity among growers because it thrives well under adverse climatic conditions and gives good returns. Ber has been reported as an immune stimulant, anti-biotic, anti-nephritic, antiulcer, anti-diabetic, anti-inflammatory and anti-oxidant. Balikai (2009) reported 22 insect and non-insect species in Karnataka. Likewise, Kavitha and Savithri (2002) documented 23 insect species on ber from Andhra Pradesh. The fruit borer, *Meridarchis scyroides*

(Lepidoptera: Carposinidae) is a serious pest in Southern and western India (Haldhar et al. 2012; Balikai et al. 2013; Karuppaiah et al. 2015; Krishna et al. 2018; Haldhar et al. 2018a&c). The borer causes up to 70% yield loss under severe infestation (Sonawane and Dorge 1971). The moths lay eggs on fruits at the pea stage and upon hatching, the newly emerged caterpillars bore into fruits, feed on the pulp near seed, and accumulate faecal. The first and second instar larvae feed on the fruit superficially, but the third to fifth instar larvae feed internally and damage the pulp around the seed. At initial stages of fruit development, the full-grown larvae found to feed on the soft immature seeds. The occurrence of fruit borer was positively correlated with the temperature and negatively correlated with the relative humidity and wind speed (Nandihalli et al. 1996). The infestation starts in November, and the peak incidence occurs at the end of December (Gopali et al. 2003; Haldhar et al. 2013b).

Several plant characteristics affect the growth and development of arthropods (Southwood et al. 1979). The plants defend against the attack by pests by producing defensive biochemical compounds (Wimp et al. 2007) for the whole plant system (Tews et al. 2004). Plant-insect interactions are thought to be of utmost importance for understanding the dynamics of ecological communities (Sarmiento et al. 2011). Plant defence strategies against insect herbivores may involve synthesizing many biologically active compounds (allelochemicals), which are phylogenetically conserved in specific plant families

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or genera (Mithofer & Boland 2012). Plants frequently display genetic variation within and between populations for traits that influence the preference and non-preference of insects on their hosts which is resistance traits (Johnson & Agrawal 2005). It has been widely recognised that biological diversity plays a vital role in structuring community ecosystem processes (Tooker et al. 2012). The bottom-up effects in the crop plant are an economical and environment-friendly method of insect management. The attractive and beneficial feature of the bottom-up effect is that it is farmer friendly and does not need much financial investment for pest control. The nutrients and concentrations of secondary metabolites determine the identification and development of crop-specific genotypes with resistance to pests. Host plants play an essential role in determining insect populations with respect to concentrations and proportions of nutrients, which differ among species (Schoonhoven et al. 2005). Plants having antibiosis characteristics such as flavonoids, phenols, tannins etc. may cause reduced insect survival, prolonged development time, decreased size and reduced fitness of new generation adults (Gogi et al. 2010). Hence, such plant resistance mechanisms have been effectively and widely used for managing insect pests in horticultural crops (Moslem et al. 2011; War et al. 2012). Direct defences are mediated by plant characteristics that affect the herbivore's biology such as mechanical protection on the surface of the plants (e.g., hairs, trichomes, thorns, spines, and thicker leaves) that retard the development of the herbivores (Hanley et al. 2007). Cultivating resistant genotypes to fruit borer is a significant component of integrated pest management programmes; therefore, this work was taken for the studies. Developing ber genotypes resistant to *M. scyroides* had not yet been initiated owing to inadequate information on the sources of plant traits and an understanding of the bottom-up effects of crop variability. The present investigation was undertaken to identify various allelochemicals (biochemical compounds) and antixenotics (biophysical structures) traits of *Z. mauritiana* genotypes associated with resistance to *M. scyroides* infestation under field conditions.

Materials and Methods

Survey and collection of genotypes

A survey was conducted in different North Indian states namely; Gujarat, Rajasthan, Haryana, Maharashtra, Delhi, Punjab etc. and different genotypes of *Z. mauritiana* were collected. During the survey, trees were selected randomly based on tree spread, height, leaf, fruit and incidence of fruit borers. From each location three cuttings with a bud from each selected tree were collected, labelled and brought to CIAH- Central Horticultural Experiment Station (ICAR-CIAH), Godhara, Gujarat farm. The seeds of *Z. rotundifolia* were used for raising the seedlings in the nursery. The collected scion buds were used for budding on *Z. rotundifolia* seedling rootstock. Three budded seedlings of each accession were planted with a spacing of 6 by 6 m under a drip irrigation system in triplicate at the field gene bank of CIAH- Central Horticultural Experiment Station (ICAR-CIAH) farm for the establishment and all the

recommended agronomic practices (e.g., weeding, fertilization, hoeing, etc.) were followed. At the time of this study, the plants were approximately ten years old.

Screening of ber genotypes

The established twenty-three genotypes of *Z. mauritiana* at the field gene bank at the experimental farm of CIAH- Central Horticultural Experiment Station, Godhra (at 22°67'88"N 73°55'14"E and altitude of 112.46m above sea level) were used for preliminary resistance study. Twenty fruits were randomly selected from each replication, and the average incidence was recorded as per cent of fruit infested with fruit borer, *M. scyroides* during two years for incidence of fruit borers, allelochemicals (biochemical compounds) and antixenotics (biophysical structures) studies. Based on the Kaiser Normalization method, the resistance category was mentioned as immune (no damage), resistant, moderately resistant, susceptible and highly susceptible of all genotypes of Indian ber against fruit borer, *M. Scyroides* infestation.

Biochemical characters of ber genotypes

Two fresh fruits of twenty-three genotypes from each replication were selected, cut into small pieces and dried. For the estimation of biochemicals, the procedures used for each biochemical were flavonoid, phenols and tannin content and the analyses were also determined based on these procedures (Haldhar et al. 2015a). Spectrophotometric measurements were performed on an ultraviolet (UV)-1601PC UV/visible (UV-Vis) spectrophotometer (Shimadzu, Kyoto, Japan) equipped with 1 cm quartz cells.

Morphological characters of ber genotypes

Ten marketable fresh fruits of each of the twenty-three ber genotypes were used to record data on the morphological traits (Pericarp thickness, fruit length fruit diameter, pulp: stone ratio, fruit surface and pulp texture). The length of pericarp thickness, fruit diameter and fruit length were measured at five different positions of each fruit using Digital Vernier Caliper (MITU-TOYO, 300 mm, 0.01 mm reading capacity).

Statistical analysis

Transformations (angular and square root transformed values) were used to achieve normality in the data before analysis, but untransformed means were also present in all the tables. The data on percentage fruit infestation, biochemical fruit traits and principal component analysis were analyzed using SPSS 16 software (O'Connor 2000). The means of significant parameters among tested cultivars were compared using Tukey's honestly significant difference (HSD) tests for paired comparisons at a probability level of 5%. Regression and correlations between *M. scyroides* infestation with biophysical and biochemical characters were also established, using correlation analysis techniques and step-wise multiple regression analysis at a 95 and 99% significance level.

Results and Discussion

Screening of ber genotypes

The 23 ber genotypes were taken for screening against *M. scyroides* and significant differences were found in percentage fruit infestation at the experimental farm of CIAH- Central Horticultural Experiment Station, Godhra during 2015-16 and 2016-17. Based on pooled data, the

ber genotypes under study indicated a significantly low incidence of fruit borer in Safeda (13.27%) followed by Tikadi (14.01%). Significantly greater incidence of fruit borer was registered in Sanaur-5, Chhuhara and Sanaur-2 with a magnitude of 75.09, 72.90 and 71.78 %, respectively. Basis of fruit borer, *M. scyroides* incidence; Safeda, Tikadi, Darakhi and Illaichi were considered as resistant; BS-75-1, Gola, Goma Kirti, Seb and Umran were found moderately resistant; Dandan, Mahawali, Jogia, Sukavani, Narma, Reshmi and ZG-3 were found to be susceptible whereas, Banarasi Karaka, Banarasi Pawandi, Chhuhara, Kaithali, Mundia, Sanaur-2 and Sanaur-5 were highly susceptible to fruit borer (Table 1, Plate 1). The fruit infestation in 2015-16 ranged from 13.34 to 75.19% whereas, in 2016-17, it ranged from 13.20 to 75.00%. Pooled data of fruit infestation in both years (13.27-75.09%) was significantly lower in resistant and higher in susceptible genotypes (Table 1). The quality and quantity

of resources available for plants trigger plant-insect herbivore interaction, i.e., plants are affected by environmental factors, which in turn influence the performance of insect herbivores (Han et al. 2014). However, the bottom-up effects are highly variable. They may depend on both biotic and abiotic factors, such as plant genotypes (Haldhar et al. 2017), insect feeding strategy (Inbar et al. 2001), feeding specialization (Gulbrodt et al. 2011), resource type (Inbar et al. 2001) and environmental stress intensity (Mody et al. 2009). Different studies have shown that genotypes of the same species could differ significantly in their resistance to insects (Vir et al. 2015) and is influenced by plants' morphological and biochemical traits (Visschers et al. 2019, Haldhar et al. 2019 & 2022). Hosagoudar et al. (1999) reported that fruit fly infestation was high in cultivar Sanaur-2 followed by Umran and Sanaur-6 and the lowest infestation was recorded in Illaichi.

Table 1. Per-cent fruit infestation of fruit borer, *M. scyroides* on different genotypes of Indian ber, *Z. mauritiana* during final screening trials

S. No.	Genotypes	2015-16		2016-17		Pooled		Resistance category
		Fruit infestation (%)	Standard Error (SE)	Fruit infestation (%)	Standard Error (SE)	Fruit infestation (%)	Standard Error (SE)	
1.	BS-75-1	25.44 (30.27) ^{cde}	0.65	25.17 (30.09) ^{def}	0.61	25.30 (30.18) ^{def}	0.63	MR
2.	Safeda	13.34 (21.39) ^a	0.78	13.20 (21.27) ^a	0.80	13.27 (21.33) ^a	0.79	R
3.	Banarasi Karaka	57.14 (49.19) ^l	3.97	56.87 (49.03) ^l	3.93	57.01 (49.11) ^m	3.95	HS
4.	Banarasi Pawandi	64.99 (53.75) ^m	2.14	64.77 (53.62) ^m	2.14	64.88 (53.69) ⁿ	2.14	HS
5.	Chhuhara	72.96 (58.75) ⁿ	2.47	72.83 (58.67) ⁿ	2.46	72.90 (58.71) ^o	2.46	HS
6.	Dandan	30.11 (33.24) ^{ef}	1.34	29.90 (33.11) ^{fg}	1.34	30.01 (33.18) ^{fg}	1.34	S
7.	Darakhi	20.40 (26.83) ^{bc}	0.80	20.23 (26.71) ^{cd}	0.80	20.32 (26.77) ^{cd}	0.80	R
8.	Gola	26.56 (30.97) ^{de}	1.34	26.37 (30.85) ^f	1.34	26.46 (30.91) ^{ef}	1.34	MR
9.	Goma Kirti	21.31 (27.48) ^{bcd}	0.44	21.20 (27.40) ^{cde}	0.43	21.26 (27.44) ^{cde}	0.44	MR
10.	Mahawali	37.22 (37.58) ^{gh}	0.50	37.03 (37.47) ^{hi}	0.52	37.13 (37.53) ^{hi}	0.51	S
11.	Illaichi	18.15 (25.20) ^{ab}	0.66	18.00 (25.08) ^{bc}	0.67	18.08 (25.14) ^{bc}	0.66	R
12.	Jogia	47.19 (43.36) ^{ij}	3.86	47.00 (43.25) ^j	3.83	47.10 (43.30) ^{jk}	3.85	S
13.	Kaithli	54.27 (47.44) ^{kl}	1.93	54.07 (47.33) ^{kl}	1.84	54.17 (47.39) ^{lm}	1.89	HS
14.	Sukavani	41.68 (40.17) ^{hi}	1.83	41.47 (40.05) ⁱ	1.82	41.57 (40.11) ^{ij}	1.83	S
15.	Narma	34.20 (35.77) ^{fg}	0.95	34.07 (35.68) ^{gh}	0.96	34.14 (35.73) ^{gh}	0.95	S
16.	Mundia	65.53 (54.05) ^m	1.36	65.37 (53.95) ^m	1.36	65.45 (54.00) ⁿ	1.36	HS
17.	Reshmi	49.54 (44.72) ^{jk}	1.16	49.40 (44.64) ^{jk}	1.18	49.47 (44.68) ^{kl}	1.17	S
18.	Sanur-2	71.86 (58.01) ⁿ	2.06	71.70 (57.91) ⁿ	2.06	71.78 (57.96) ^o	2.06	HS

19.	Sanur-5	75.19 (60.24) ⁿ	2.53	75.00 (60.11) ⁿ	2.53	75.09 (60.18) ^o	2.53	HS
20.	Seb	26.09 (30.69) ^{de}	0.67	25.90 (30.57) ^{ef}	0.69	25.99 (30.63) ^{ef}	0.68	MR
21.	Tikadi	14.09 (21.91) ^a	1.92	13.93 (21.78) ^{ab}	1.93	14.01 (21.84) ^{ab}	1.93	R
22.	Umran	25.14 (30.06) ^{cde}	1.05	25.03 (29.99) ^{def}	1.07	25.09 (30.02) ^{def}	1.06	MR
23.	ZG-3	37.33 (37.64) ^{gh}	0.61	37.20 (37.57) ^{hi}	0.62	37.27 (37.60) ^{hi}	0.62	S
Mean± SD		40.42± 20.00		40.25 ±19.99		40.34 ±20.00		
SEm±		1.23		1.22		1.22		
LSD (P = 0.05)		3.51		3.48		3.50		

The value following different letter down the column are significantly different using Tukey's HSD test, R- resistant, MR- moderately resistant, S- susceptible and HS-highly susceptible

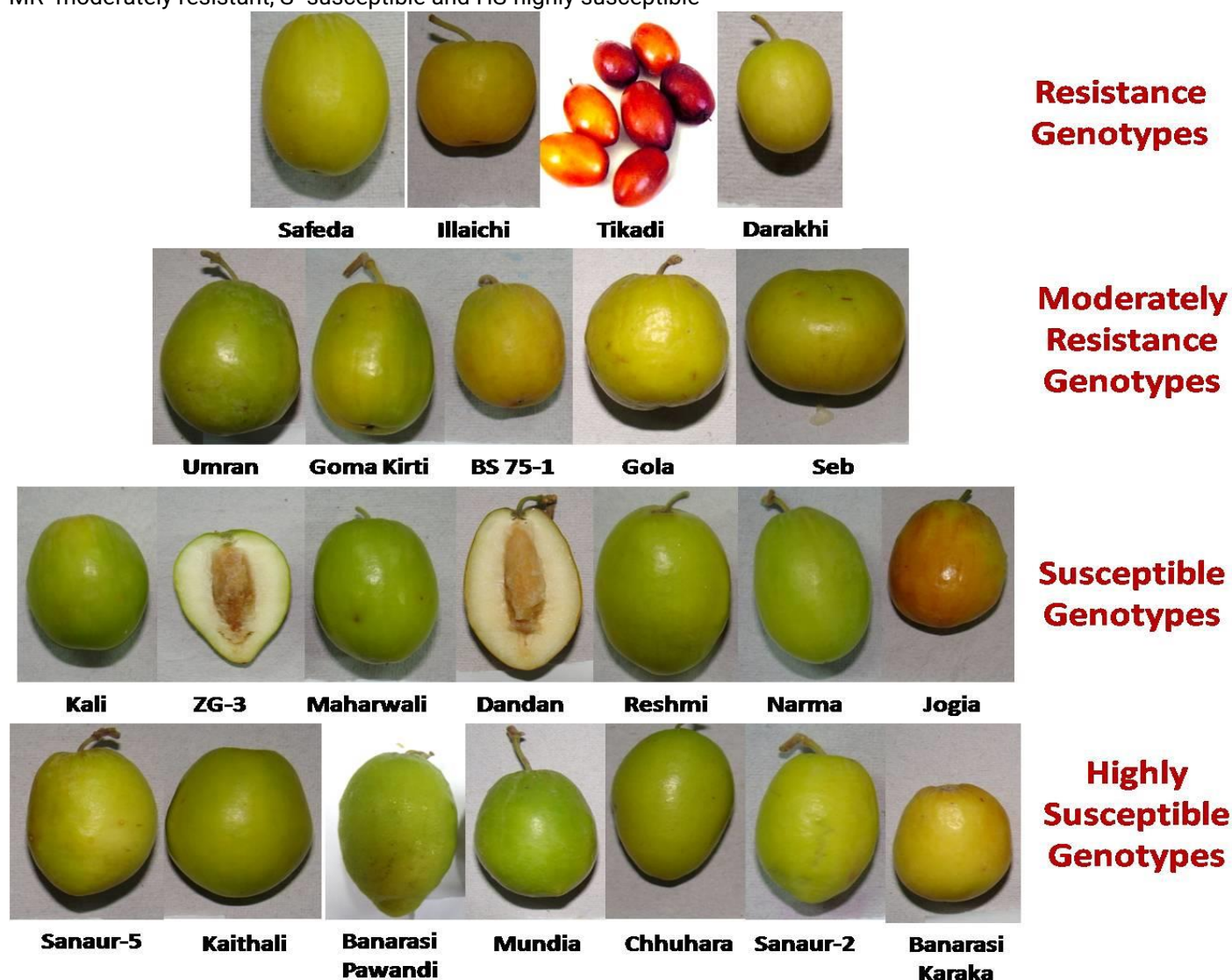


Plate 1. Different genotypes of Indian ber (*Ziziphus mauritiana*) during final screening against fruit borer, *M. scyroides*

Biochemical characters of ber genotypes

The flavonoids, tannins and phenols contents ranged from 40.68 to 187.79 mg/100g, 264.78 to 511.57 mg/100g and 119.51 to 239.01 mg/100g (on a dry weight basis), respectively with values significantly higher in resistant and lower in susceptible genotypes. The flavonoid content (187.79 mg/100g) was found to be maximum in Illaichi followed by Safeda (179.03 mg/100g) and minimum in Chhuhara (40.68 mg/100g).

The tannin content (511.57 mg/100g) was found to be the highest in Safeda followed by Tikadi (502.79 mg/100g) and the lowest in Chhuhara (264.78 mg/100g). Phenols content was highest in Safeda (239.01 mg/100g) followed by Darakhi (234.96 mg/100g) and lowest in Sanaur-5 (119.51 mg/100g) with values significantly higher in resistant and lower in susceptible genotypes (Table 2). The percentage of fruit infestation with flavonoids (-0.95), tannins (-0.95) and phenols (-

0.96) had a significant negative correlation (Table 4). The allelochemical compounds of the fruit differed significantly among the tested ber genotypes. Information is unavailable on the correlation of the biochemical traits with *M. scyroides* in ber, but little information is available for other crops. Phenolic heteropolymers play a central role in plant defence against insects and pathogens (Barakat et al. 2010; Haldhar et al. 2018b&d). Phenols also play an essential role in the cyclic reduction of reactive oxygen species such as superoxide anion and hydroxide radicals, H_2O_2 ,

and singlet oxygen, which activate a cascade of reactions leading to the activation of defensive enzymes (Maffei et al. 2007). Similar to our findings, it has been demonstrated that phenols, tannins, and flavonoids enhanced plant defences against insects and had a significant negative correlation with the percentage of fruit infestation (War et al. 2012). Tannic acid and gossypol in cotton have deleterious effects on *A. gossypii*; when concentrations increase, the mortality of cotton aphids (Ma et al. 2019).

Table 2. Biochemical (allelochemical) fruit traits of different genotypes of Indian ber, *Z. mauritiana*

S. No.	Genotypes	Flavonoid content (mg/100g)*	Tannins content (mg/100g)	Phenols content (mg/100g)
1.	BS-75-1	168.77 (13.00) ^{k**}	466.79 (21.62) ^{ijklm}	215.74 (14.61) ^{efgh}
2.	Safeda	179.03 (13.37) ^k	511.57 (22.63) ^m	239.01 (15.46) ^h
3.	Banarasi Karaka	63.84 (8.05) ^{cde}	329.63 (18.17) ^{abcd}	176.80 (13.32) ^{cd}
4.	Banarasi Pawandi	58.15 (7.69) ^{bcd}	317.69 (17.84) ^{abc}	162.90 (12.76) ^{bc}
5.	Chhuhara	40.68 (6.46) ^a	264.78 (16.29) ^a	138.13 (11.79) ^{ab}
6.	Dandan	125.14 (11.23) ^{hi}	428.73 (20.73) ^{ghijklm}	210.16 (14.52) ^{efgh}
7.	Darakhi	161.12 (12.67) ^{jk}	483.60 (22.01) ^{klm}	234.96 (15.34) ^h
8.	Gola	132.07 (11.54) ^{ij}	414.85 (20.39) ^{fghijkl}	201.38 (14.23) ^{defgh}
9.	Goma Kirti	159.57 (12.67) ^{jk}	479.27 (21.90) ^{klm}	217.68 (14.78) ^{gh}
10.	Mahawali	101.80 (10.14) ^{gh}	394.18 (19.67) ^{bcdefghi}	193.82 (13.96) ^{defg}
11.	Illaichi	187.79 (13.74) ^k	503.77 (22.45) ^m	228.70 (15.14) ^h
12.	Jogia	76.56 (8.81) ^{def}	366.76 (18.96) ^{bcdefg}	189.11 (13.74) ^{cdefg}
13.	Kaithli	70.76 (8.47) ^{cde}	344.96 (18.31) ^{bcde}	183.92 (13.60) ^{cdef}
14.	Sukavani	83.25 (9.18) ^{efg}	394.15 (19.86) ^{defghij}	189.06 (13.75) ^{cdefg}
15.	Narma	122.99 (11.14) ^{hi}	408.38 (20.20) ^{efghijk}	194.27 (13.92) ^{cdefg}
16.	Mundia	53.87 (7.41) ^{abc}	371.56 (19.20) ^{bcdefgh}	175.24 (13.27) ^{cd}
17.	Reshmi	64.83 (8.11) ^{cde}	349.61 (18.71) ^{bcdef}	180.54 (13.44) ^{cde}
18.	Sanur-2	45.17 (6.79) ^{ab}	309.90 (17.59) ^{ab}	137.26 (11.69) ^{ab}
19.	Sanur-5	46.19 (6.87) ^{ab}	310.37 (17.61) ^{abc}	119.51 (10.96) ^a
20.	Seb	137.60 (11.71) ^{ij}	447.19 (21.15) ^{hijklm}	215.59 (14.66) ^{fgh}
21.	Tikadi	176.52 (13.32) ^k	502.79 (22.37) ^{lm}	232.04 (15.24) ^h
22.	Umran	160.98 (12.57) ^{jk}	470.91 (21.72) ^{ijklm}	215.99 (14.73) ^{fgh}
23.	ZG-3	92.58 (9.67) ^{fg}	387.44 (19.69) ^{cdefghi}	187.39 (13.69) ^{cdefg}
Mean± SD		109.10±49.92	402.56±71.86	193.01±31.99
SEm±		0.41	0.69	0.41
LSD (P = 0.05)		1.17	1.98	1.17

* Analysis taken on dry weight basis of ber pulp

**Values in parenthesis are square root-transformed

Value following different letter down the column are significantly different using Turkey's HSD test

Morphological characters of ber genotypes

The fruit width, fruit length, pericarp thickness and pulp: stone ratio ranged from 12.81 to 33.4 mm, 17.18 to 43.17 mm, 0.25 to 1.16 mm and 2.12 to 27.13, respectively. The minimum fruit length (17.18mm) in Illaichi, fruit width (18.81mm) and pulp: stone ratio (2.12) in Tikadi and pericarp thickness (0.25mm) in Sanur-5 were found, but the maximum fruit length (43.17mm) in Umran, fruit width (33.4mm) in Dandan, pulp thickness (1.16mm) in Safeda and pulp: stone ratio (27.13) in Mundia genotypes, respectively (Table 3). The resistant genotypes Safeda, Tikadi and Darakhi had pulp texture (hard) and fruit surface (ridge and plain) high in resistant and low in susceptible genotypes. The pericarp thickness (-0.88) had significant negative correlations, and the

pulp: stone ratio (0.77) and fruit length (0.49) had a significant positive correlation with the percentage of fruit infestation (Table 4). Pramanick et al. (2005) indicated that the ber genotypes differed for all the physical and biochemical traits indicating divergence for them. The genotypic coefficient of variation (GCV) ranged from 65.41 to 8.43 per cent in physical and biochemical characteristics. Extreme values of genetic advance were observed for the pulp pH (0.89), and per cent, infestation on a number basis (45.78); moderate to high genetic gain was noticed for total sugars, total phenols and pulp: stone ratio, respectively. Although higher heritability values were observed for pulp pH, reducing sugars and total soluble solids (TSS); however, the genetic advance was considerably low, indicating a

minimal scope for selection in such traits. In these findings, biophysical fruit traits also significantly differ among the genotypes (Simmons et al. 2010).

Table 3. Morphological (antixenotic) fruit traits of different genotypes of Indian ber, *Z. mauritiana*

S. No.	Genotypes	Fruit length (mm)	Fruit width (mm)	Pericarp thickness (mm)	Pulp: stone ration	Pulp texture	Fruit surface
1.	BS-75-1	33.69 (5.89) ^{defg*}	23.34 (4.93) ^{efgh}	1.05 ^j	4.80 ^b	Medium	Plain
2.	Safeda	31.18 (5.67) ^{cde}	22.77 (4.88) ^{defg}	1.16 ^k	6.48 ^{bc}	Hard	Ridge
3.	Banarasi Karaka	38.45 (6.28) ^{efgh}	22.20 (4.82) ^{cdefg}	0.49 ^{cd}	20.29 ^l	Medium	Ridge
4.	Banarasi Pawandi	38.80 (6.27) ^{efgh}	22.74 (4.87) ^{defg}	0.43 ^c	15.92 ^{hi}	Soft	Ridge
5.	Chhuhara	35.43 (5.97) ^{defgh}	23.32 (4.93) ^{efgh}	0.33 ^{ab}	19.42 ^{kl}	Soft	Plain
6.	Dandan	36.13 (6.09) ^{efgh}	18.73 (4.44) ^{bcd}	0.61 ^{ef}	9.51 ^d	Soft	Plain
7.	Darakhi	25.05 (5.10) ^{bc}	17.61 (4.31) ^b	1.04 ^j	7.03 ^c	Hard	Ridge
8.	Gola	36.68 (6.10) ^{efgh}	33.40 (5.87) ^k	0.74 ^{gh}	10.13 ^{de}	Medium	Plain
9.	Goma Kirti	35.44 (6.04) ^{defgh}	26.76 (5.27) ^{ghij}	1.15 ^k	14.24 ^{gh}	Hard	Ridge
10.	Mahawali	33.42 (5.87) ^{def}	24.67 (5.07) ^{efghij}	0.72 ^g	14.62 ^{gh}	soft	Ridge
11.	Illaichi	17.18 (4.26) ^a	17.26 (4.27) ^b	0.87 ⁱ	7.56 ^c	Medium	Ridge
12.	Jogia	33.89 (5.91) ^{defgh}	20.33 (4.62) ^{bcde}	0.48 ^c	12.06 ^f	Medium	Ridge
13.	Kaithli	43.15 (6.61) ^{gh}	27.82 (5.37) ^{hij}	0.43 ^c	16.64 ^{ij}	soft	Ridge
14.	Sukavani	34.39 (5.95) ^{defgh}	24.13 (5.01) ^{efghi}	0.58 ^{de}	15.17 ^{hi}	Medium	Plain
15.	Narma	32.43 (5.78) ^{cdef}	23.75 (4.97) ^{efghi}	0.84 ^{hi}	13.39 ^{fg}	Medium	Ridge
16.	Mundia	35.17 (6.01) ^{defgh}	28.92 (5.47) ^{jk}	0.42 ^{bc}	27.13 ^m	soft	Ridge
17.	Reshmi	31.41 (5.69) ^{cde}	24.75 (5.07) ^{efghij}	0.48 ^c	11.73 ^{ef}	soft	Ridge
18.	Sanur-2	40.79 (6.43) ^{fgh}	22.29 (4.79) ^{cdef}	0.33 ^{ab}	12.91 ^{fg}	soft	Ridge & Wart
19.	Sanur-5	33.46 (5.87) ^{def}	20.95 (4.68) ^{bcde}	0.25 ^a	18.31 ^{jk}	soft	Ridge
20.	Seb	32.56 (5.79) ^{cdef}	28.83 (5.43) ^{ijk}	0.73 ^g	14.25 ^{gh}	hard	Plain
21.	Tikadi	20.06 (4.58) ^{ab}	12.81 (3.72) ^a	0.69 ^{fg}	2.12 ^a	Hard	Plain
22.	Umran	43.17 (6.62) ^h	26.51 (5.23) ^{fghij}	0.87 ⁱ	6.85 ^c	Hard	Ridge
23.	ZG-3	27.46 (5.33) ^{cd}	18.43 (4.38) ^{bc}	0.69 ^{fg}	9.77 ^d	Medium	Ridge & Wart
Mean± SD		33.45±6.35	23.14±4.53	0.67±0.27	12.62±5.70		
SEm±		0.25	0.16	0.03	0.61		
LSD (P = 0.05)		0.72	0.46	0.09	1.75		

*Values in parenthesis are square root-transformed

Value following different letter down the column are significantly different using Turkey's HSD test

Table 4. Correlation coefficient (r) between per cent fruit infestation with different allelochemical and antixenotic fruit traits of Indian *ber*, *Z. mauritiana* genotypes

	Per cent fruit borer	Phenols content (mg/100g)	Tannins content (mg/100g)	Flavonoid content (mg/100g)	Fruit length (mm)	Fruit width (mm)	Pericarp thickness (mm)
Phenols content (mg/100g)	-0.962**						
Tannins content (mg/100g)	-0.957**	0.942**					
Flavonoid content (mg/100g)	-0.956**	0.916**	0.971**				
Fruit length (mm)	0.499*	-0.460*	-0.521**	-0.502*			
Fruit width (mm)	0.183 ^{NS}	-0.143 ^{NS}	-0.189 ^{NS}	-0.193 ^{NS}	0.638**		
Pericarp thickness (mm)	-0.880**	0.854**	0.881**	0.897**	-0.346 ^{NS}	-0.027 ^{NS}	
Pulp: stone ratio	0.770**	-0.677**	-0.713**	-0.774**	0.461*	0.450*	-0.622**

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

*Significant at P = 0.05 (two-tailed)

Based on backward stepwise regression

Backward stepwise regression analysis indicated that flavonoid contents explained 91.4% followed by phenols (4.6%), and tannin (0.1%) of the total variation in fruit borer, *M. scyroides* infestation (Table 5). Haldhar et al. (2017) indicated that flavonoid and tannin contents explained more of the total variation in fruit fly infestation. The variation in fruit infestation was explained by pulp: stone ratio (0.40%) followed by pericarp thickness (0.20%) and fruit width (0.20%) (Table

5). Gogi et al. (2010) showed that the tested morphological traits (rind hardness, fruit diameter and several longitudinal ribs) explained 100% of the total variation in percentage fruit infestation. In contrast, Haldhar et al. (2017) reported that the maximum variation in fruit infestation was explained by the length of ovary pubescence followed by rind hardness and rind thickness. In contrast, the remaining biophysical fruit traits explained < 1.0% variation in the fruit infestation in kachri against fruit fly.

Table 5. Backward stepwise regression models showing the effect of different allelochemical and antixenotic fruit traits of *ber* on percentage fruit infestation

Per cent fruit infestation	R ²	Role of individual traits (%)
Y=116.22- 0.07 X ₁ - 5.60 X ₂ +0.61 X ₃ -0.32 X ₄ -0.03 X ₅ +0.18 X ₆ -0.27 X ₇	96.90	00.20
Y=117.13- 0.09 X ₁ - 6.38 X ₂ +0.48 X ₃ -0.32 X ₄ -0.02 X ₅ +0.07 X ₆	96.70	00.00
Y=120.41- 0.09 X ₁ - 5.62 X ₂ +0.49 X ₃ -0.32 X ₄ -0.03 X ₅	96.70	00.10
Y=116.54- 0.12 X ₁ - 5.39 X ₂ +0.46 X ₃ -0.34 X ₄	96.60	04.60
Y=75.67- 0.30 X ₁ - 11.44 X ₂ +0.36 X ₃	92.00	00.40
Y=83.35- 0.34 X ₁ - 8.55 X ₂	91.60	00.20
Y=82.12- 0.38 X ₁	91.40	91.40

X₁- flavonoid content (mg/100g), X₂- pericarp thickness (mm), X₃- pulp: stone ratio, X₄- phenols content (mg/100g), X₅- tannin content (mg/100g), X₆- fruit length (mm), X₇- fruit width (mm), R²- coefficient of determination

Based on the Kaiser Normalization method

Based upon the above allelochemical and morphological characters individually, grouping the entries as variables did not agree was impossible. Hence, principal component analysis was performed to achieve parsimony and reduce the dimensionality by extracting the smallest number of components that accounted for most of the variation in the original multivariate data.

Seven parameters, such as flavonoid content, tannin content, phenols content, pericarp thickness, pulp: stone ratio, fruit length and fruit width, were performed for principal component analysis (PCA). Two principal components (PCs) were extracted with eigenvalue ≥1.0, after varimax rotation with the Kaiser Normalization procedure, which converged in three iterations. The extraction communalities for all the variables tested were

≥ 0.5 , indicating that the variables were well represented by the extracted PCs, which together explained a cumulative variation of 88.48 %. PC1 explained 64.34 % of the variation, while PC2 explained 24.14 %. PC1 had the loadings for flavonoid content (0.96), tannin content (0.95), phenols content (0.95) and pericarp thickness (0.94) and pulp: stone ratio (-0.70). Fruit width (0.95) and fruit length (0.80) were loaded in PC2 (Table 6). The PC1 and PC2 were plotted, and the plot showed four discrete classes of genotypes, which could be grouped into resistant (R), moderately resistant (MR), susceptible (S), and highly susceptible (HS), as shown in Fig. 1. Haldhar

et al. (2017) indicated the two principal components were extracted explaining the cumulative variation of 88.2% in melon fruit fly infestation. PC1 explained 71.6% of the variation, while PC2 explained 16.6% of kachri melon fruit fly. Haldhar et al. (2015) found that two principal components were extracted, explaining the cumulative variation of 90% in melon fruit fly infestation and length of ovary pubescence, rind thickness, flavonoid content, ascorbic acid, free amino acid, tannins content, and phenol content was the reliable variables for characterization of resistance (Haldhar et al. 2013a; Haldhar et al. 2015b).

Table 6. Component loadings of parameters for resistance against fruit borer, *M. scyroides* in ber fruits

S. No.	Parameters	Principal components	
		1	2
1	Percent fruit borer	-0.96	0.21
2	Phenols content (mg/100g)	0.95	-0.15
3	Tannins content (mg/100g)	0.95	-0.21
4	Flavonoid content (mg/100g)	0.96	-0.22
5	Fruit length (mm)	-0.35	0.80
6	Fruit width (mm)	0.01	0.95
7	Pericarp thickness (mm)	0.94	-0.01
8	Pulp: stone ration	-0.70	0.47

Rotation Method: Principal Component Analysis with Varimax with Kaiser Normalization.

Rotation converged in 3 iterations

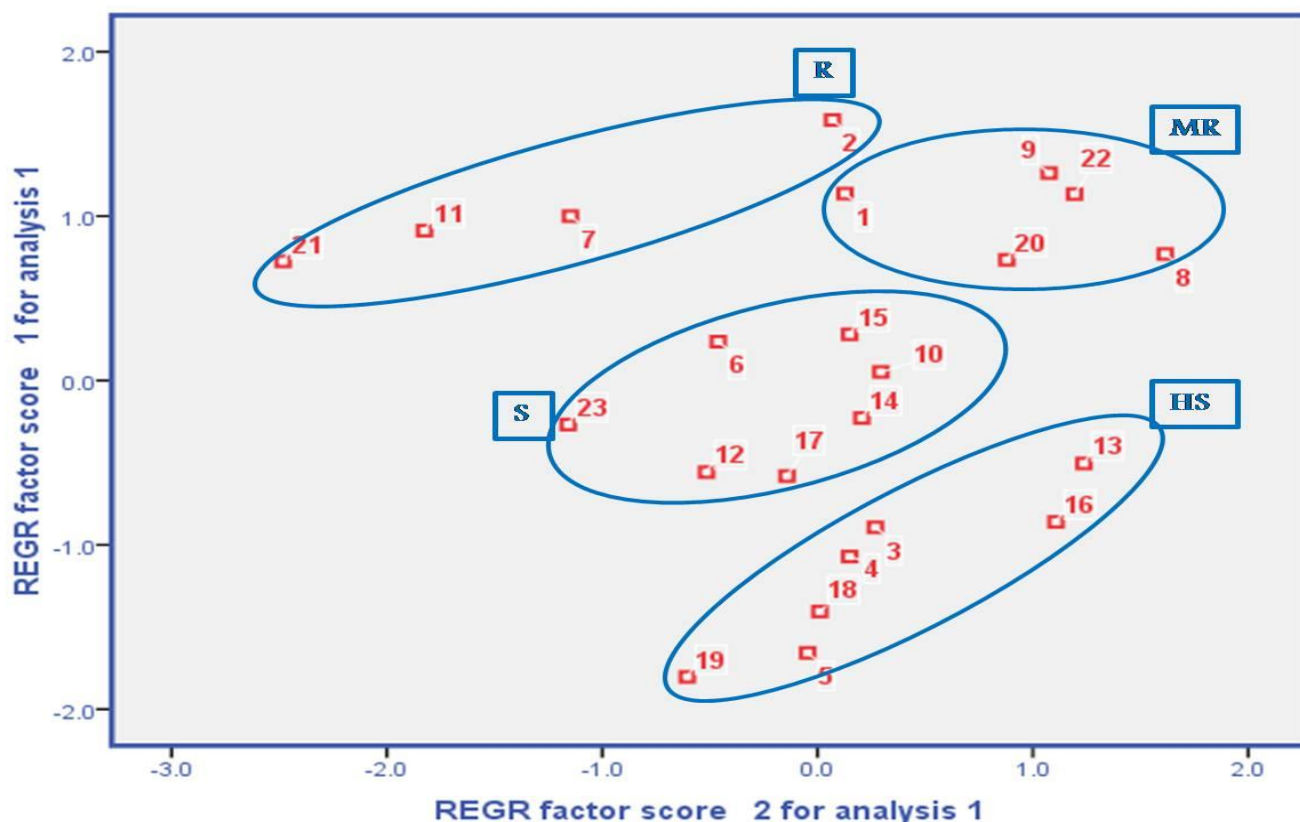


Figure 1. Plot of PC1 and PC2 showing clusters of ber genotypes showing resistance to fruit borer, *M. scyroides*

Conclusion

Thus, from the foregoing account, a reduction in ber fruit borer, *M. scyroides* infestations on resistant genotypes could be due to antibiosis (allelochemicals) and phenotypic (biophysical). Ber genotypes Safeda, Tikadi, Darakhi and Illaichi were classified as resistant and resistant to *M. scyroides* and these could be used in the future breeding program as resistant sources. Certain biochemical traits (e.g., flavonoid, tannins and phenols content) and biophysical traits (e.g., pericarp thickness, pulp: stone ratio and pulp texture) were linked to the resistance of ber against *M. scyroides* and; therefore, could be used as marker traits in plant breeding programs to select resistant genotypes

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Declaration of interests

The authors have no conflict of interest to declare.

Data sharing

All relevant data are within the manuscript.

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